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Constraining the Early History of Mercury and its Core Dynamo by Studying the Crustal Magnetic Field

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Abstract

We study crustal magnetic field anomalies associated with impact craters on Mercury. The sources of these anomalies likely consist of impact melt, enriched in impactor iron, that was thermoremanently magnetized in the ancient Mercury dynamo field. Results show that paleopoles are not always located near the present-day north magnetic pole, which lies near the south geographic pole. This provides further evidence that anomalies are not induced but are remanent, and represent useful constraints on the early history of Mercury and its dynamo magnetic field.

1. Introduction

Crustal magnetic field maps were obtained using low altitude MESSENGER MAG data, obtained during the last months of the mission [1, 2, 3, 4]. Though some of the anomalies are related to the Hermean topography structures, others are not. The measured crustal field can be explained through or by a combination of various sources such as thermoremanent magnetization, shock remanent magnetization or even induced fields. Distinguishing among those different sources that are contributing to a given anomaly is challenging when lacking in situ measurements. Here, we study the different anomalies that are found on Mercury that are clearly related with craters or basins. Their interior subsurfaces are thought to have cooled very slowly in a presence of a constant global magnetic field, and have been thermoremanently magnetized. The anomaly sources most probably consist of impact melt rocks that were enriched in iron from the impactor [5]. We use a unidirectional magnetization model which assumes that the melt impact rocks recorded the constant core magnetic field present when the crater was formed. The results will help to constrain the early history of Mercury, as they give insights on true polar wander event, and on the early dynamo morphology and dynamics.

2. Method

We invert for crustal magnetization by making use of a method developed by Parker for studying seamount magnetism on Earth [6], and which was recently applied to lunar crustal magnetism by [7, 8]. The only assumption that this method makes is that the magnetization within the crust is unidirectional, which is the case when the material cools below the Curie temperatures in the presence of a steady main field. As shown by Parker, a unidirectional distribution of dipoles within the crust is equivalent to unidirectional dipoles placed on the surface. Therefore, no assumptions about the source geometry are made. Many dipoles are placed within a circle over a region that encompasses the isolated anomaly, usually of the same size of the crater rim. 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 [9]. For our inversions we use the global gridded magnetic field maps at 40 km altitude from [4] based on MESSENGER magnetometer observations.

3. Results

We study five anomalies associated with craters: the two main magnetic anomalies related to the craters Rustaveli (200 km in diameter, centered at 83ºE, 52ºN), and Vyasa (300 km in diameter, centered at 275ºE, 50ºN); and three anomalies related with smaller unnamed craters centered at (289ºE, 57ºN), (295ºE, 46ºN), and (282ºE, 41ºN). For the Rustaveli anomaly, we find the best paleopole position at (269ºE, 13ºN), with a misfit value of 0.85 nT (see Figure 1).

Considering the uncertainties on the paleopole position the solution includes the South pole, where the present-day magnetic North pole is believed to be located. For the Vyasa anomaly, we find the best paleopole at (230ºE, 50ºS), with a misfit of 0.81 nT. These results, even showing an equatorial best solution, do not allow one to argue for a thermoremanent source, as the uncertainty also includes the present magnetic North pole (located near the south geographic pole).

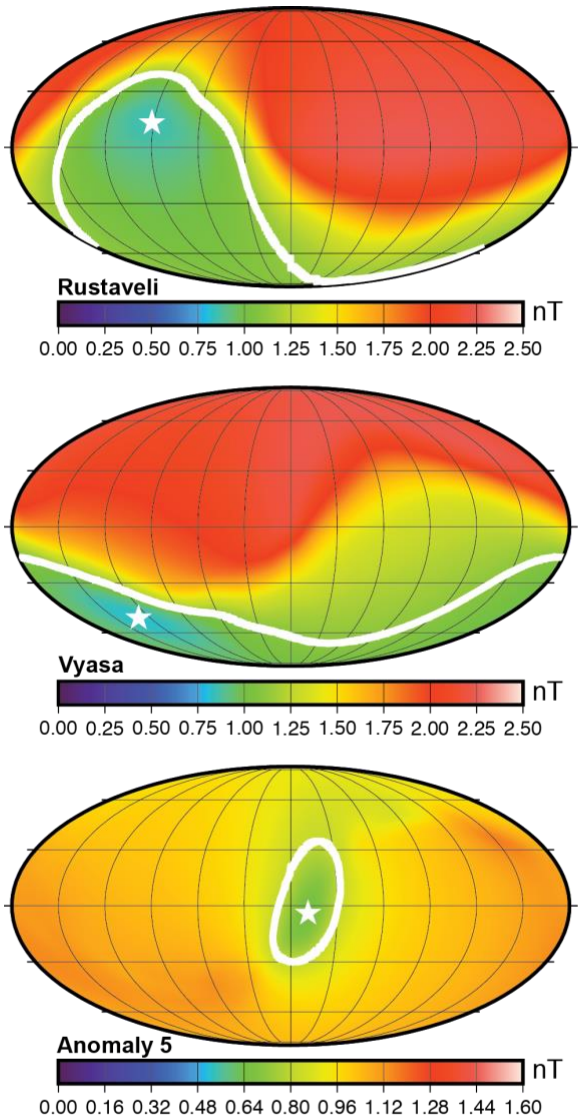

Figure 1: Misfit as a function of the paleopole position for three different magnetic anomalies associated with craters. The star symbol denotes the best fit solution and the solid white line its uncertainty.

For those cases, an induced field due to a permeability enhancement beneath the crater's interior surface process cannot be ruled out. However, anomalies with small uncertainty solutions are obtained at the equator of the planet, proving that at least some of the anomalies are thermoremanently magnetized (see Anomaly 5 from Figure 1).

4. Summary and Conclusions

Results prove that at least some of Mercury's crustal anomalies have a thermoremanent magnetization origin, implying information about the early history of Mercury's core dynamo. In particular, inferred paleomagnetic poles for some anomaly sources are not located near the south geographic pole, indicating that they are not induced in the present-day dynamo field.

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