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Constraints on the origin of the sources of lunar magnetic anomalies from orbital magnetic field data

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Introduction

Magnetic field anomalies of crustal origin are found to be heterogeneously distributed over the entire lunar surface [1]. Except for few specific cases, in general the magnetic field anomalies are not related to known geological structures. Therefore, the origin of many anomalies sources is still debated, and various possible mechanisms have been proposed. Impactors contamination that could deliver iron-rich material to the lunar surface [2], or heating associated with magmatic activity that could alter rocks into strong magnetic carriers [3], are some of the current suggestions to explain the source origin. In any case, it is accepted that the inducing field that magnetized the lunar crust was a global magnetic field generated by a core dynamo [4, 5, 6].

In order to get insights on the time evolution of the lunar dynamo, it is important to know when and how each magnetic anomaly was formed. Generally, only specific anomalies related either to swirls [3], or to impact craters [7] are used for such investigations. This is because assumptions on the source geometry are typically made to explain the observed field anomaly. In this work, we aim constrain the origin of random magnetic anomaly sources using orbital magnetic field data without making any a priori geometry assumption.

Detecting magnetized material using Parker's method

We invert for crustal magnetizaton using a unidirectional model developed by [8], to constrain the magnetization source geometry. This technique was initially applied to study the seamounts magnetization, but recently was also applied to study magnetic field anomalies in other bodies, such as the Moon, Mars and Mercury [7, 9, 10, 11]. One of the properties that this method relies on is that a 3D unidirectional magnetized body is mathematically equivalent to unidirectional dipoles placed in the boundary of the magnetized volume, transforming a 3D problem into a 2D one.

Following [9], many dipoles are placed within a circle of a given radius over a region that encompasses the isolated anomaly. For each direction of magnetization, we solve the magnetic moments of the dipoles and determine the misfit between the model and the observations using a non-negative least squares approach [12]. By doing this, we are assuming that each magnetic anomaly was formed during a period in which the ambient field was constant. The inversion yields the positions of dipoles and their magnetic moments that better explain the observations.

We note that Parker's method was designed to find the magnetization direction, and it is not self-evident that the location of the actual sources coincides with the location of the non-negative dipoles. Testing the performance of Parker's method in inferring correctly the actual source location is the aim of this work. For this, we perform a variety of synthetic tests using as sources magnetized bodies of different geometries, intended to represent the many possible magnetized source origin scenarios. For the moment three different volume configurations are considered: vertical shallow cylinder as a first approximation of a basin inner depression; vertical paralelipiped to represent dykes; and long horizontal cylinder to represent lava tubes.

We build a synthetic tests library by varying: 1) the different variables that shape the volume of the sources, 2) the depth to the top and depth to the bottom of the sources, and 3) the direction of the ambient magnetic field that magnetized the body. As a proof of concept we show a preliminary synthetic test using a vertical paralelipiped magnetized body (delimited by white solid line), in Figure 1. In Figure 1, the left panel shows the synthetic observed radial mag-

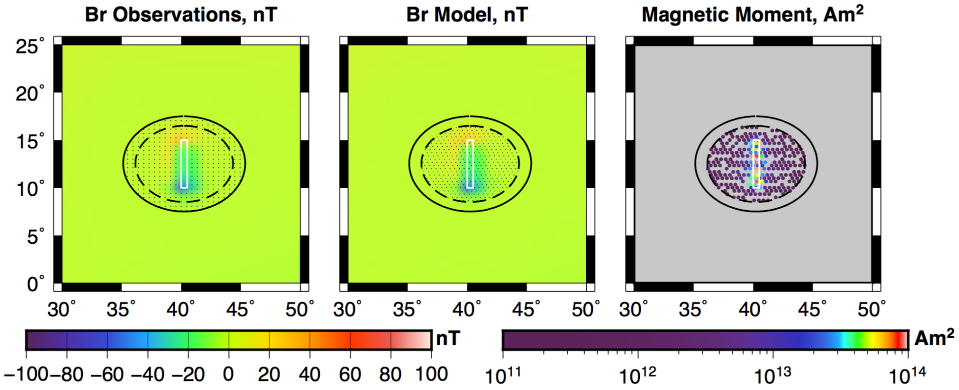

Figure 1: (From left to right) Synthetic observed radial magnetic field, the best fitting radial magnetic field model, and the magnetic moments of the retained dipoles in the inversion for a vertical paralelipiped magnetized body (denoted by a white solid line). The data points and the locations of dipoles used in the inversion are denoted by dots in the left and middle diagrams, respectively.

netic field together with the observations points delimited by a solid line circle, the middle panel shows the modeled radial magnetic field together with the a priori dipoles positions delimited by the dashed line circle, and the right panel shows the retained dipoles that better explain the observed synthetic field. The location of the dipoles having the strongest magnetic moments is found to coincide with the region where the magnetized volume is buried. Further inversion results using samples from our synthetic tests library will allow us to explore the effect of all input parameters on the correct determination of the sources location.

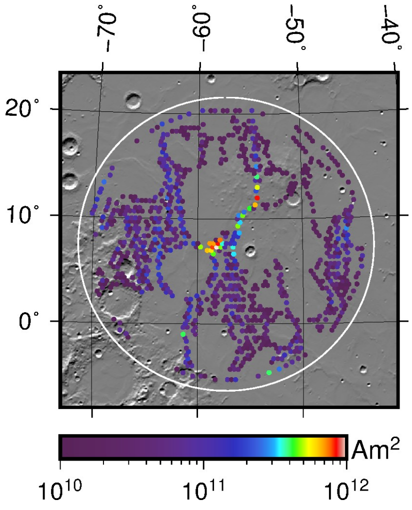

Figure 2: Magnetic moments of the retained dipoles in the inversion for the Reiner Gamma anomaly.

Constraining the origin of magnetic crustal sources by studying their geometry

If Parker's method is revealed to be successful in detecting the magnetization body geometry in general, this will allow us to place constraints on the source origin. This is true also for anomalies whose assumed origin is not related to swirls or impact craters. As an example, we show the distribution of the retained dipoles we obtain using the Parker's method for the Reiner Gamma anomaly (Figure 2). A recent study [3] points towards dykes or lava tubes as the explanation for the main source of this anomaly. This is consistent with the distribution of the dipoles with strongest magnetic moments shown in Figure 2. Analysis of many other magnetic anomalies will lead to new constraints on the origin of their sources. Some of them might be of value in constraining the evolution of the lunar dynamo.

References

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