MAGNETIC PROPRIETIES OF SHOCKED-BASALTS OF THE VARGEÃO IMPACT STRUCTURE (SOUTH BRAZIL): PRELIMINARY RESULTS

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Abstract

The impact cratering process can produce significant changes in the geophysical signatures of planetary surfaces. In this context, the study of the magnetism associated to terrestrial impact structures can be an important tool to better understand the origin of magnetic anomalies in other planets and satellites, such as Mars and the Moon. But craters on basaltic rocks, similar to those found at the surface of these planetary bodies, are rare on Earth. The 12 km wide Vargeão is a well-preserved impact structure formed on volcanic rocks from the Serra Geral Formation (~133-131 Ma). This work is focused on the study of the magnetic proprieties of shocked-basalts found in Vargeão. We conducted a detailed magnetic study that comprises: anisotropy of low-field magnetic susceptibility (AMS), remanent magnetization measurements, alternate-field demagnetization (AF) and thermomagnetic curves. Our results show that magnetization inside and outside the impact structure is dominantly carrier by magnetite. But the values of almost all magnetic parameters change in the impacted zone, and have clear trends towards to the center of the impact structure. These results may be used to assess the different hypotheses about the genesis of magnetic anomalies on the Moon and in Mars's crust, include their magnetic carriers.

Resumo

O processo de crateramento por impacto pode causar mudanças significativas nas assinaturas geofísicas da superfícies planetárias. Neste contexto, o estudo do magnetismo associado a crateras de impacto terrestres pode ser uma importante ferramenta para se entender a origem de anomalias magnéticas em outros planetas/satélites, como Marte e a Lua. Todavia, crateras formadas em rochas basálticas, similares as encontradas em outros corpos planetários, são raras na Terra. Vargeão é uma estrutura de impacto bem preservada com 12 km de diâmetro, que está alocada em rochas vulcânicas da Fm. Serra Geral (~133-131 Ma). Este trabalho é focado no estudo detalhado das propriedades magnéticas dos basaltos impactados de Vargeão e compreendeu a investigação das propriedades de: anisotropia de suscetibilidade magnética (ASM); magnetização remanescente; desmagnetização por campos alternados (AF) e curvas termomagnéticas. Nossos resultados mostram que tanto fora quanto dentro da estrutura a magnetização é dominantemente portada por magnetitas. No entanto, os valores de quase todos parâmetros magnéticos dentro da zona de impacto mostram uma clara tendência de mudança em direção ao centro. Esses resultados poderão ser usados para testar as diferentes hipóteses sobre a origem das anomalias magnéticas da Lua e de Marte, incluindo seus portadores de magnetização.

Introduction

Hypervelocity impact phenomena are of primary importance in the evolution of solid bodies of the Solar System (*e.g.* French, 2004). These phenomena can produce significant changes in the geophysical signatures of the planetary surfaces (*e.g.*, Pilkington and. Grieve, 1992; Louzada *et al.*, 2011). For example, recent data from Mars Global Surveyor suggest an important link between large impact structures and major magnetic anomalies on Mars's crust (*e.g.* Acuña *et al.* 1999; Arkani-Hamed, 2002; Mohit and Arkani-Hamed, 2004). Nevertheless, the origin of these anomalies and the mineral carriers of remanent magnetization in the Martian crust, remain a matter of debate in literature (*e.g.* Kletetschka *et al.* 2000; Rochette *et al.*, 2001, 2003, Dunlop and Arkani-Hamed, 2005).

Craters on basaltic rocks, which are the best analogs for studies about the Martian surface, are rare on Earth. Most studies to date were done on the Lonar crater, a simple crater 1.8 km in diameter, formed in the basaltic flows of the Deccan Province (India). Recently, one medium-size complex crater was identified in volcanic rocks of the Paraná basin (south Brazil) and may provide an additional analog to the impact structures of rocky planets and satellites. The 12 km wide Vargeão is a very well-preserved impact structure formed in basaltic and subordinately rhyodacitic flows of the Serra Geral Formation (about 133-131 Ma), which are locally intertrapped by eolian-sandstones of Botucatu Formation.

In an effort to shed some light onto the changes of magnetic proprieties of basalts by the impact cratering process, we conducted a detailed magnetic study on the rocks of Vargeão impact structure. Our study provides a new database of magnetic proprieties of impacted rocks that must be used in the comparative studies of Martian magnetic anomalies.

Geological setting

The Vargeão impact structure has a rim-to-rim diameter of about 12 km. It is located in the central portion of the Paraná basin, in Santa Catarina state (center at 26 º 49'S and 52 º 10'W), south Brazil. Even though there are still no radiometric ages, stratigraphic correlations show that the impact occurred after 133 Ma, which is the age of the Serra Geral Formation in this region. Stratigraphic relationships show that the impact affected dominantly the volcanic rocks of Serra Geral Formation and, less frequently, the sandstones of Pirambóia/Botucatu Formations (Kazzuo-Vieira *et al*. 2004; Crósta *et al*., 2005) (Fig. 1). Vargeão is a complex impact structure characterized by a well-preserved rim and a relative preserved central uplift (Kazzuo-Vieira *et al*. 2009). According to Kazzuo-Vieira *et al.* (2009), the rim region is characterized by concentric gravitational failures that affect flows of tholeiitic basalt (thickness up to hundreds of meters) and ryodacites (thickness of a few tens of meters). The central uplift can be divided into two domains. The first is characterized by anullar topographic elevations, consisting of blocks of eolian- sandstone of the Pirambóia/Botucatu Formations, which generally are strongly deformated. The second domain is represented by a central depression consisting of basalts and rare polymict breccia deposits. The impact features are better observed in the region of the uplift and include: impact breccias-veins, shatter cones in sandstones and basalts, and planar features of deformation on quartz (Kazzuo-Vieira *et al.*, 2009). Our petrographic results show that the impacted rocks were affected by post-impact hydrothermalism. This alteration is confined into small impact breccia-veins and consists of total or partial substitution of the melt matrix by quartz, calcite, iron oxides and clay minerals.

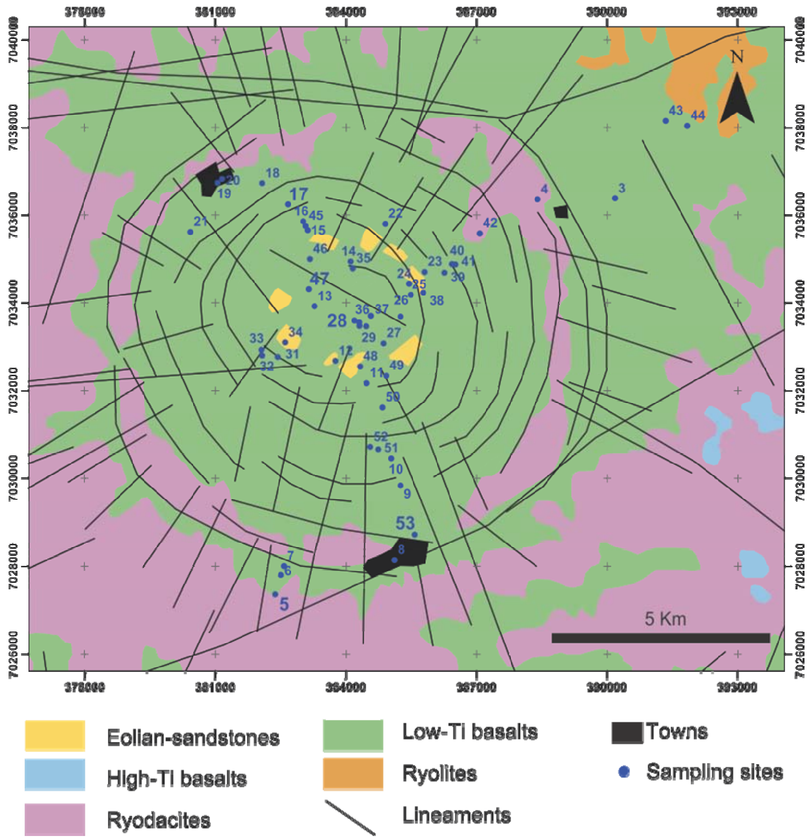

Figure 1. Simplified geological map (modified from Kazzuo-Vieira et al., 2009).

Materials and methods

We performed a mapping of the structure comprising 53 observation points (Fig. 1). The field-based description was complemented by the observation under the microscope of 60 thin sections for petrographic characterization. For the magnetic studies, we have sampled 21 sites, comprising unshocked basalts (5 sites), shocked basalts (12 sites), shocked ryodacites (2 sites) and polymict breccia (2 sites). At each site, three to six 2.5-cm-diameter oriented cores were collected with a portable rock drill and further cut into three to five specimens 2.2 cm in height, providing a total of 157 specimens for magnetic studies. The magnetic studies comprise: anisotropy of low-field magnetic susceptibility (AMS), natural remanent magnetization measurements, alternate-field demagnetization (AF) and thermomagnetic curves. AMS was determined for all samples in a KLY4S Kappabridge susceptometer (Agico Ltd.). Magnetic remanence of all samples was measured using a JR6 magnetometer (Agico Ltd.) after step-wise treatment by alternating fields (AF). AF demagnetization was carried out using an automated rotating AF-demagnetizer LDA-AMU1 (Agico Ltd.) with a maximum field of 100 mT. Thermomagnetic curves were obtained on selected samples from 8 sites after heating and cooling cycles from room temperature up to 700 ºC in a CS3 furnace coupled with a KLY4S Kappabridge susceptometer (Agico Ltd.). Experiments were done in argon atmosphere to inhibit alteration during heating.

Results

AMS scalar parameters

The mean magnetic susceptibility, $K = (K1+K2+K3)/3$, in the unshocked basalts ranges from 4 to 52 mSI (average of 22 mSI). In these rocks, the anisotropy degree P ranges from 1.00 to 1.02, and the shape parameter T ranges from -0.08 to 0.92 (average of 0.22). In shocked basalts, *K* ranges from 3 to 70 mSI (average of 26 mSI), the anisotropy degree P of these rocks ranges from 1.00 to 1.05 (average of 1.01), and the parameter T ranges from -0.76 to 0.91 (average of 0.14). The *K* in the ryodacites ranges from 7 to 15 mSI (average of 11 mSI), the anisotropy degree P ranges from 1.01 to 1.02, and the T parameter ranges from -0.75 to 0.83 (average of 0.07). In the polymict breccia, *K* ranges from 4 to 103 mSI (average of 22 mSI), P ranges from 1.00 to 1.04 (average of 1.01), and T vary from -0.40 to 0.72 (average of 0.31). Considering all lithologies, we note an increase in *K* and P values towards the center of the structure (Figs. 2A and 2B).The parameter T, which is dominantly prolate in unshocked basalts, shows a more dispersed behavior inside the impact structure (Fig. 2C)

Remanent magnetization

The natural remanent magnetization (NRM) in the unshocked basalt ranges from 0.01 to 48.95 A/m (mean of 12.66 A/m). In these rocks, the mean destructive field (MDF) vary from 1.52 to 41.55 mT (average of 17.52 mT). The NRM of shocked basalts ranges from 0.17 to 339.08 A/m (average of 29.46 A/m) and the MDF vary from 0.01 to 81.38 mT (average of 20.23 mT). For ryodacites, the NRM ranges from 2.43 to 38.22 A/m (average of 29.46 A/m) and the MDF ranges from 7.30 to 15.70 mT (average of 10.88 mT). In the polymict breccia, the NRM varies from 0.20 to 15.25 A/m (average of 3.02 A/m) and the MDF ranges from 2.24 to 19.39 mT (average of 8.12 mT). The NRM and MDF also show an increase toward the center of the structure.

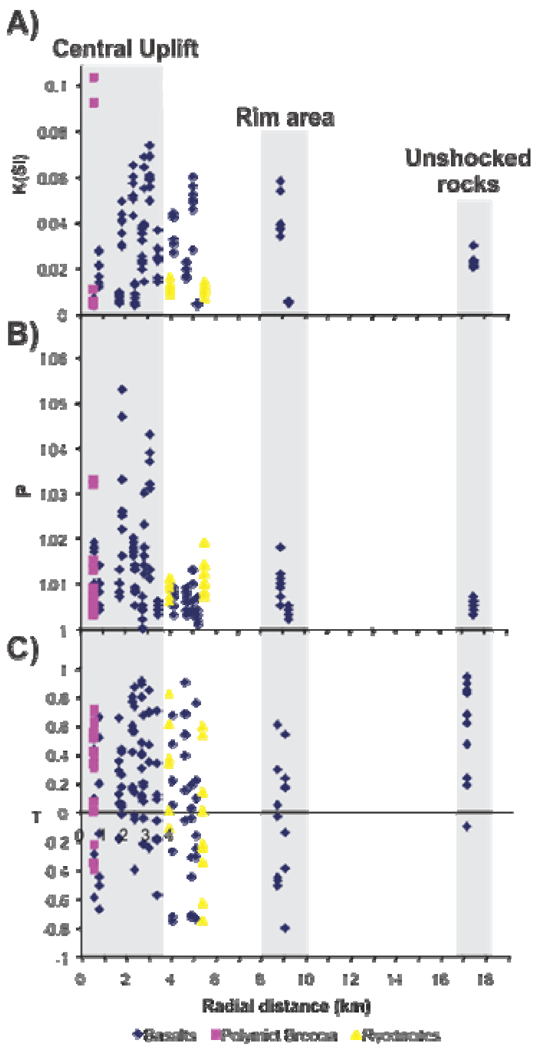

Figure 2. Magnetic parameters *vs*. Radial distance. **(A)** bulk magnetic Susceptibility K ($K=(K1+K2+K3)/3$). **(B)** Anisotropy degree P (P= $K1/K3$). **(C)** Shape parameter T ($T=[2\ln F/\ln L]-1$; and L=lineation (k_1/k_2) and F=foliation (k_2/K_3)) (Jelinek, 1981).

Thermomagnetic curves

The thermomagnetic curves have a similar behavior for all lithologies. High-temperature curves show an increase of susceptibility between 200 and 450 ºC followed by strong drop at around 580 ºC. This behavior suggests the presence of maghemite and magnetite as the main magnetic carriers in these rocks. Low-temperature curves for almost all samples exhibits a magnetic transition around -156 ºC (Verwey transition), which confirms the presence of magnetite.

Conclusions and perspectives

The origin of the magnetic anomalies and the mineral carriers of remanent magnetization associated to lager impact craters remains a matter of debate in the literature (*e.g.* Kletetschka *et al.* 2000; Rochette *et al.*, 2001, 2003, Dunlop and Arkani-Hamed, 2005; Louzada *et al.*, 2011). The demagnetization by shock, promoted by the high pressures associated to the impact of extraterrestrial bodies, is the most acceptable hypothesis about the magnetic anomalies observed on Mars (Louzada *et al.*, 2011 and references therein). Our preliminary results, obtained on the shocked-basalts of the Vargeão impact structure, show that the values of most magnetic parameters (K, P, NRM and MDF) tend to increase towards to the center of the structure and that the magnetization is dominantly carried by magnetite in these rocks. In agreement with theoretical models (*e.g.*, Gattacceca *et al.*, 2007; Louzada *et al.*, 2011), these results suggest that the changes on the magnetic proprieties of Vargeão have a direct relation with the increase in pressure during the impact cratering process, which is bigger in the centre of the impact structure (*c.f.* French, 1998). This is an ongoing study. Based on these initial results, we intend to conduct a more detailed study, including: anystheric remanent magnetization measurements (ARM); hysteresis loops, first order reverse curves (FORCs) and observations under scanning electronic microscope (SEM). Our new magnetic database will be used on a comparative study with the Martian magnetic anomalies.

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