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Magnetic Effects of Electrical Discharges on Mars

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Abstract. The magnetic field of Mars does not have a nuclear component, although many magnetic anomalies without dipolar pattern are spread mostly in the southern hemisphere of the planet with crustal magnetization values that are about 100 times greater than those observed on Earth. The distribution of martian magnetic anomalies can be explained by several magnetizing phenomena that probaly ocurred after the inner dynamo ceased (e.g.: meteorite impacts, hydrothermalism, seismicity and tectonism), nonetheless, these mechanisms can hardly explain their intensities.This work aims to reintroduce electrical discharges as a powerful magnetization mechanism and discuss the likelihood of this process as responsible for the magnetic anomalies observed in the martian surface.

Resumo. O campo magnético de Marte não possui componente nucleares, porém, muitas de suas anomalias magnéticas, sem padrão dipolar, estão espalhadas principalmente no hemisfério sul do planeta com valores de magnetização crustal que são cerca de 100 vezes mais intensos do que os observados na Terra. A distribuição das anomalias magnéticas marcianas podem ser explicadas através de diversos fenômenos que podem ter ocorrido após o cessar de um dinâmo interno (e.g.: impactos de meteoritos, hidrotermalismo, sismicidade e tectonismo), porém, esses mecanismos dificilmente explicariam suas intensidades. Esse trabalho tem como objetivo reintroduzir as descargas elétricas como um poderoso mecanismo de magnetização e discutir a possibilidade deste processo ser responsável por anomalias magnéticas observadas na superfície de Marte.

Keywords. Planets and satellites: magnetic fields – Planets and satellites: atmospheres – Magnetic fields

1. Introduction

Mars does not have a magneto-hydrodynamic field, although with Mars Global Surveyor magnetic field data and the Voorhies et al., (2002) magnetic analysis using spherical harmonics, it was estimated that Mars' magnetic sources would be restricted mainly in a 46 km radius shell, from the surface to the crust, that can be 100 times greater than the terrestrial crustal magnetism (Rochette et al. 2006). An effective way to magnetize ferromagnetic grains and rocks, increasing their remanence ratio (REM), between the Natural Remanence Magnetization (NRM) and the Saturation Isothermal Remanence Magnetization (sIRM) through the magnetic pulses of electrical discharges (Salminen et al. 2013). Although electrical discharges were never detected in the martian atmosphere, there are evidences of their incidence by the abundance of hydrogen peroxide in its soil (Atreya et al. 2006) and by the possibility of electrical activity through triboelectrical mechanism inside dust devils and their global dust storms (Farell et al. 1999; Delory et al. 2006). This work aims to describe a hypothesis that can explain how the electrical activity could be responsible for the higher magnetic anomalies observed on Mars, by the use numerical modeling to estimate the mass magnetized in different scenarios by theoretical and experimental parameters. The last must obtained by exposing pulverized rocks, analogous to martian ones, to electrical discharges. Finally, we must use inversion techniques to obtain feasible values of electrical current to support this hypothesis.

2. Implemented Models

Two magnetization models were implemented. The first was used to compare the remanent magnetization induced by lightning in same size grains of distinct ferromagnetic minerals present on Mars: magnetite, pyrrhotite and hematite (Fig. 1). The second one was used to simulate the martian dust magnetization, based on the composition of basalts from the Gusev Crater (Fig. 2) - with simulations considering 1%, 5% and 10% of magnetite present in the dust -, and aims to estimate the remanent magnetized mass by electrical discharges in an interval of time of 0.5 Ma. For both models, the Ampère Law (Eq. 1) was used to estimate the magnetization of the minerals by Eq. 2. To compare the magnetized mass a limit of 1000 $\frac{A}{m}$ was used.

$$\boldsymbol{H} = \frac{I}{2\pi r}\hat{r} \tag{1}$$

$$\boldsymbol{M} = \chi \boldsymbol{H} \tag{2}$$

3. Dissipation Model

A simulation considering the dissipated energy of the magnetic fields, when it passes through the ferromagnetic grains, was also investigated from Eq. 3, where μ is the dipole magnetic moment, μ_0 is the vacuum permeability, B is the magnetic field, n is the number of the magnetic domains inside the grain, A is the area between the domains, θ is the initial angle between the domain and the field, and x is the travelled distance in the domain rotation:

$$E_{dis} = \int_0^x \frac{n\mu.\mu_0}{2}(\boldsymbol{H} + \alpha \boldsymbol{M})(1 - \cos\theta)A dx. \tag{3}$$

α is the parameter of the molecular field, and its value, used by (Jiles & Atherton 1984), is 0.0033 for magnetite. With Eq. 3 and using the same α value, the obtained curve is compared with the curve of the magnetite dust, without dissipation, in Fig. 3, both for a 300 kA discharge.

From Eqs. 4, 1 e 2 an estimate of mass magnetized by an electrical discharge until 1000 $\frac{A}{m}$ was made for the three different minerals, calculating the mass of the grains by each mineral

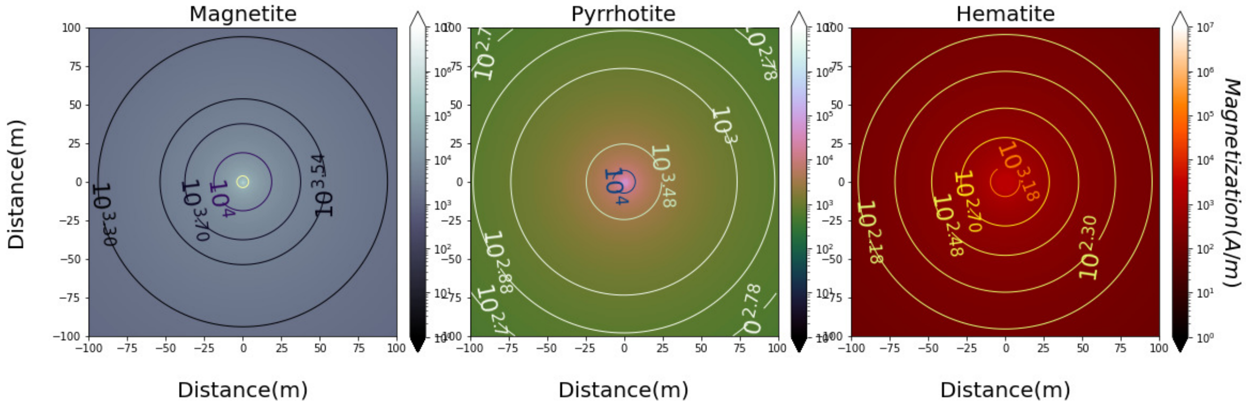

Figure 1. Maps of ferromagnetic magnetization by electrical discharges as function of the distance of propagation.

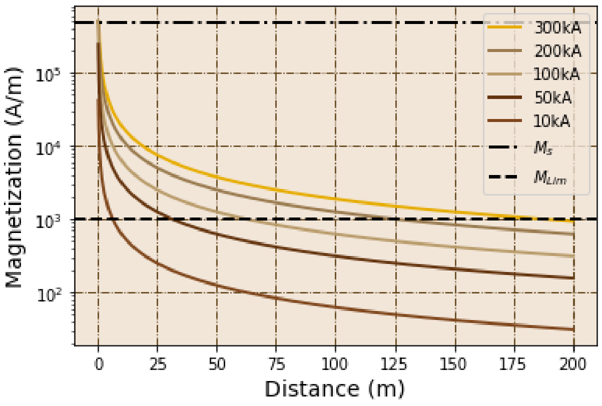

Figure 2. Magnetization considering 5% of magnetite in the composition of the grains with different values of electrical current. M_S is the magnetite saturation magnetization.

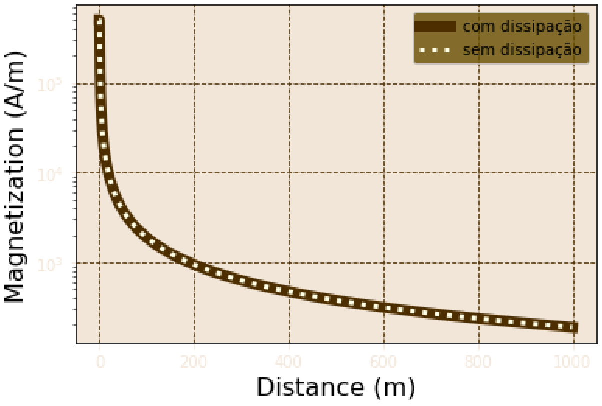

Figure 3. Magnetization by a 300 kA discharge of grains of magnetite with dissipation and without dissipation.

density e generalizing the results of the curves to a cylinder. The parameters used in the estimate are presented in Tab. 1.

$$M_{\text{TOTAL}} = m \int_0^{2\pi} d\phi \int_0^H dz. \tag{4}$$

For a 300 kA current, the magnetized mass estimated of magnetite is $5.88 \times 10^{-2}\,kg$, 4.69×10^{-3} kg of pyrrhotite and 8.81×10^{-4} kg of hematite, up to 1000 $\frac{A}{m}$.

Parameters	Description	Value
σ	grain cross section	$6.3\,\mu(m)$
δ	spacing between grains	$0.005\,(m)$
χ_M	magnetite magnetic susceptibility	3.94
χ_P	pyrrhotite magnetic susceptibility	1.54
χ_H	hematite magnetic susceptibility	0.30
ρ_M	magnetite density	$5200\,(\frac{kg}{m^3})$
ρ_P	pyrrhotite density	$4500\,(\frac{kg}{m^3})$
ρ_H	hematite density	$5200\,(\frac{kg}{m^3})$
H	extension of the electrical discharge	$9000\,(m)$

Table 1. Parameters used to estimate mass of a ferromagnetic dust magnetizated by an electrical discharges for magnetite, pyrrhotite and hematite.

4. Global Mass Estimative

Using the inhomogeneous model with dust composition holding 5% of magnetite and the Lightining Imaging Sensor Optical Transient Detector (LIS-OTD) flash rate of Sahara's, Gobi's and Patagonian desert, a remanent magnetization mass estimate was made (Eq. 5) for a planet with the same radius of Mars (≈ 3389.5 km) over 0.5 Ma in regions between 45° - 90° N and 45° - 90° S.

$$M_{Pl} = M \times \bar{N} \times \Delta t \times 4\pi R_{Pl}^2 \int_{\frac{\pi}{4}}^{\frac{\pi}{2}} \operatorname{sen} \Phi d\Phi, \tag{5}$$

where Δt is the time interval, N is the number of flashes per km^2 in a year, R is the radius of the planet, M is the mass magnetized by a single ray and Φ is the planet latitude.

For a 300 kA lightning, the total mass magnetized calculated until 1000 $\frac{A}{m}$ was 3461 ± 170 kg using Sahara's data, was found 7888 ± 394 kg for Gobi's database and 7588 ± 754 kg for Patagonian Desert flash rate.

5. Conclusions

For the first model, evaluating the induced magnetism in ferromagnetic homogeneous dust, we computed that electrical discharges with 300kA are capable to magnetize 12.53 times more magnetite mass than pyrrhotite's and 66.7 times more mass than hematite's until 1000 $\frac{A}{M}$. The mass estimate, using the inhomogeneous model, obtained that electrical discharges with maximum value of 300 kA don't magnetize more than 8000 kg of ferromagnetic grains on dust devils and dust storms in a time interval of 0.5 Ma, but the magnetization limit used was 1000 $\frac{A}{m}$, so the computational routine must be optimized with the purpose of finding the mass magnetized up to 100 $\frac{A}{m}$, the higher value found in Mars. Considering energetic dissipation of the magnetic field when it's interacting with the magnetic domains of each grain, we found that this dissipation is negligible, then the α parameter must be experimentally evaluated by the minerals hysteresis loop as others magnetic parameters, that must be analysed after rock samples, selected based in Mars crustal composition, being exposed to electrical discharges. New simulations will be made, varying the grain sizes, and then, changing their magnetic susceptibility, implying a more realistic model.

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