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Grain size dependent potential for self generation of magnetic anomalies on Mars via thermoremanent magnetic acquisition and magnetic interaction of hematite and magnetite

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Abstract

Early in the history of planetary evolution portions of Martian crust became magnetized by dynamo-generated magnetic field. A lateral distribution of the secondary magnetic field generated by crustal remanent sources containing magnetic carriers of certain grain size and mineralogy is able to produce an ambient magnetic field of larger intensity than preexisting dynamo. This ambient field is capable of magnetizing portions of deeper crust that cools through its blocking temperatures in an absence of dynamo. We consider both magnetite (Fe_3O_4) and hematite (α-Fe_2O_3) as minerals contributing to the overall magnetization. Analysis of magnetization of magnetic minerals of various grain size and concentration reveals that magnetite grains less than 0.01 mm in size, and hematite grains larger than 0.01 mm in size can become effective magnetic source capable of magnetizing magnetic minerals contained in surrounding volume. Preexisting crustal remanence (for example ∼250 A/m relates to 25% of multi-domain hematite) can trigger a self-magnetizing process that can continue in the absence of magnetic dynamo and continue strengthening and/or weakening magnetic anomalies on Mars. Thickness of the primary magnetic layer and concentration of magnetic carriers allow specification of the temperature gradient required to trigger a self-magnetization process.

Keywords: Magnetic mineralogy; Self-magnetization; Blocking temperature; Martian crust; Temperature gradient

1. Introduction

The detection of strongly magnetized ancient crust on Mars is one of the most surprising outcomes of recent Mars exploration, and provides an important

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insight about the Mars core. The iron-rich liquid core was associated with magnetic dynamo (limited in duration to several hundred million years) and probably formed during the hot accretion of Mars 4.5 billion years ago and subsequently cooled at a rate dictated by the overlying mantle (Stevenson, 2001). Presently, Mars probably has a liquid, conductive outer core and might have a solid inner core like Earth, however, no evidence of magnetic sources (Voorhies et al., 2002).

The self-magnetization of Martian crust (Arkani-Hamed, 2003) can produce a thermoremanent magnetization (TRM) of the Martian lithosphere. The process assumes that the upper part of the lithosphere acquired TRM in the early history of the planet and in the presence of the core field (the primary magnetization), whereas the lower part has been gradually magnetized by the magnetic field of the upper part as it has cooled below the Curie temperature (secondary magnetization). In Arkani-Hamed's model, the secondary magnetization from the layer that underlies the upper lithosphere magnetized by Martian dynamo is relatively weak. In this contribution we show conditions where magnetization from the deep layers can be significant, contrary to Arkani-Hamed's model. The main reason why the Arkani-Hamed's model does not generate significant contribution to the overall magnetic anomaly is because he assumed that the source layer, the upper lithosphere, is similar to that of the extrusive basalt near the oceanic ridge axes on Earth and contains constant magnetization on the order of 25 A/m. The field from the upper lithosphere, considered as a source field, allows providing ambient magnetic field for the underlying layers of contrasting magnetization factor, reflecting magnetic properties of the rocks. It is this assumption of the magnetizing layer with constant strength of 25 A/m that is different from our model where we allow this magnetization to be within 100–1000 A/m. In our model the primarily magnetized crust has high concentration (10–100%) of the magnetic material and the thermal magnetization acquisition process involves titanohematite (solid solution Fe_2O_3-$FeTiO_3$) magnetic carrier rather than titanomagnetite (solid solution Fe_3O_4-Fe_2TiO_4) as assumed for oceanic ridges on Earth.

Titanohematite rich rocks have sharply contrasting magnetic acquisition properties than titanomagnetite (Kletetschka et al., 2002; Robinson et al., 2002). Titanohematite resembles magnetic acquisition of pure hematite, which has been shown to increase with magnetic grain size (Dunlop and Kletetschka, 2001; Kletetschka et al., 2000a, 2000c), allowing massive hematite rich formation to possess magnetizations close to its saturation, exceeding 1000 A/m.

Most of the magnetic anomalies detected by MGS are located in the Southern Hemisphere within the Southern Highlands (Connerney et al., 2001). The amplitude of many of the Southern Highland anomalies (~250 nT) is over 10 times what is observed on Earth (<20 nT) at the same 400 km altitude. The presence of coherent magnetic anomalies occupying large regions indicates the past existence of magnetic dynamo in the Martian core. However, the regions where the magnetism is small or absent may be due either younger crustal masses or more complex magnetic history (Hood et al., 2003; Kletetschka et al., 2004b). Perhaps the absence/presence of magnetism is due to the underlying crust that was either formed and/or modified (igneous and/or metamorphic) after the magnetic dynamo had ceased. These events may represent remelting and/or re-heating of large portions of the crust by rock forming processes or by impact related demagnetization or physical removal of magnetized crustal material. The small or absent magnetic anomalies may also indicate magnetic minerals that are not suitable for self-magnetization of the Mars crust.

The magnetic anomaly distribution outlines two different age epochs of Mars crust. The oldest crust (>3 billion years) is associated with the significant magnetic anomalies (greater than 15–20 nT at 400 km altitude) and the younger modified crust with anomalies less than 15 nT and below the instrument detection threshold (±4 nT) (Acuna et al., 1999; Kletetschka et al., 2003b). However, if the crustal rock on Mars has self-remagnetization potential, the absence of magnetic anomalies does not necessarily indicate the crustal age but absence of conditions for self-magnetization.

2. Magnetizing mechanisms

Minerals contained within the Martian crust were magnetized, by cooling, within the ambient preexisting magnetic field. There are two distinct mechanisms that allow homogenous magnetizations of large volumes of rocks within the crust at temperatures dependent on the particular mineral—commonly around 500 °C. Mech-