The Necessary Magnetization Distribution to Explain the Observed Martian Magnetic Field

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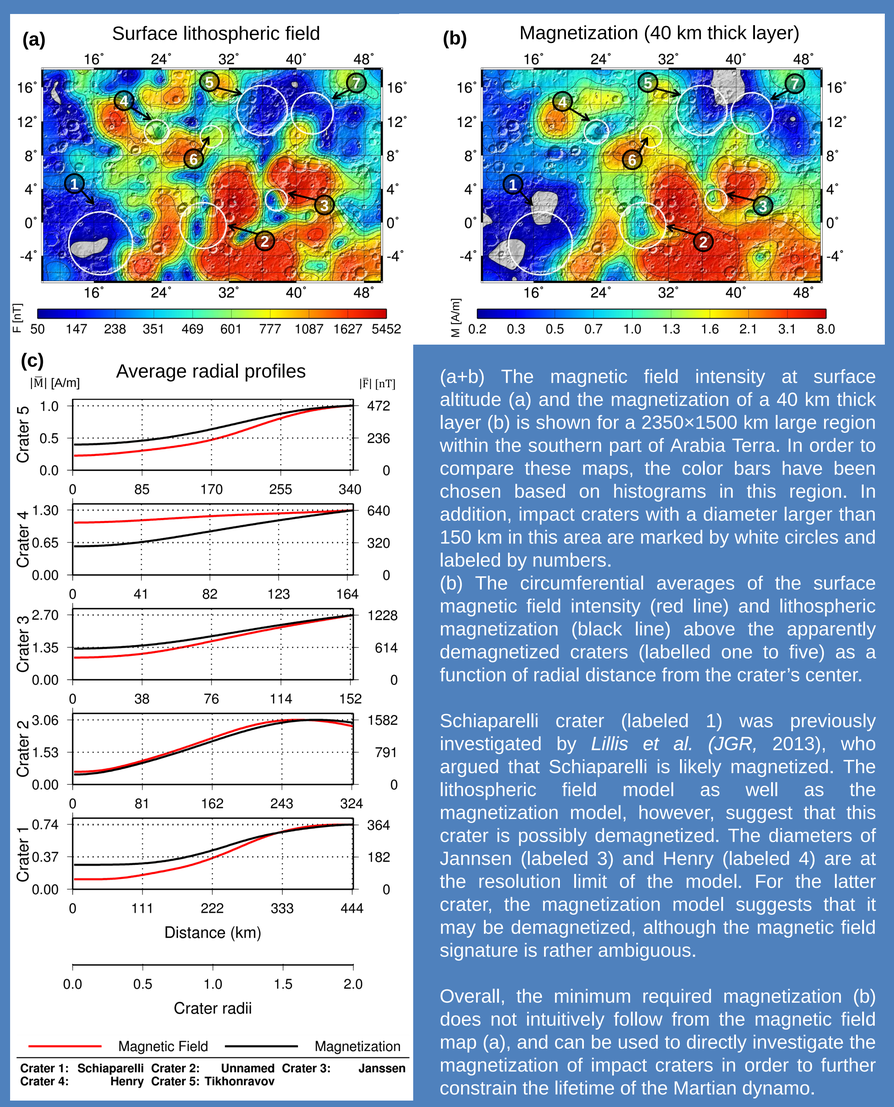
ABSTRACT We present a model of the minimum required lithospheric magnetization of Mars. This model is based on the work of Gubbins et al. (GJI, 2011), who showed that any magnetization confined to an infinitely thin spherical shell can be uniquely separated in the parts resulting in an observable magnetic field external to the shell and the respective null space. We expanded the work of Gubbins et al. (GJI, 2011) by allowing for a finite magnetic layer thickness with radially uniform magnetization. Subsequently, we derived the minimum required magnetization of Mars by assuming a 40 km thick magnetic layer (Voorhies, JGR, 2008) and using the lithospheric field model of Morschhauser et al. (JGR, 2014).

SUMMARY OF RESULTS The most intense magnetizations are obtained in Terra Cimmeria, peaking at 19.4 A/m, comparable to the extreme values of Purucker et al. (JGR,2000) and Langlais et al. (JGR, 2004), and requiring 0.3 vol.% of SD magnetite (Dunlop and Arkani-Hamed, JGR, 2005). However, most of the remaining parts of the southern hemisphere, where intense magnetic fields have been observed, require minimum magnetizations of around 2 - 8 A/m. Further, we have also identified some impact craters with signs of impact demagnetization, which may be used to further constrain the lifetime of the Martian core dynamo.

Results

Impact Craters

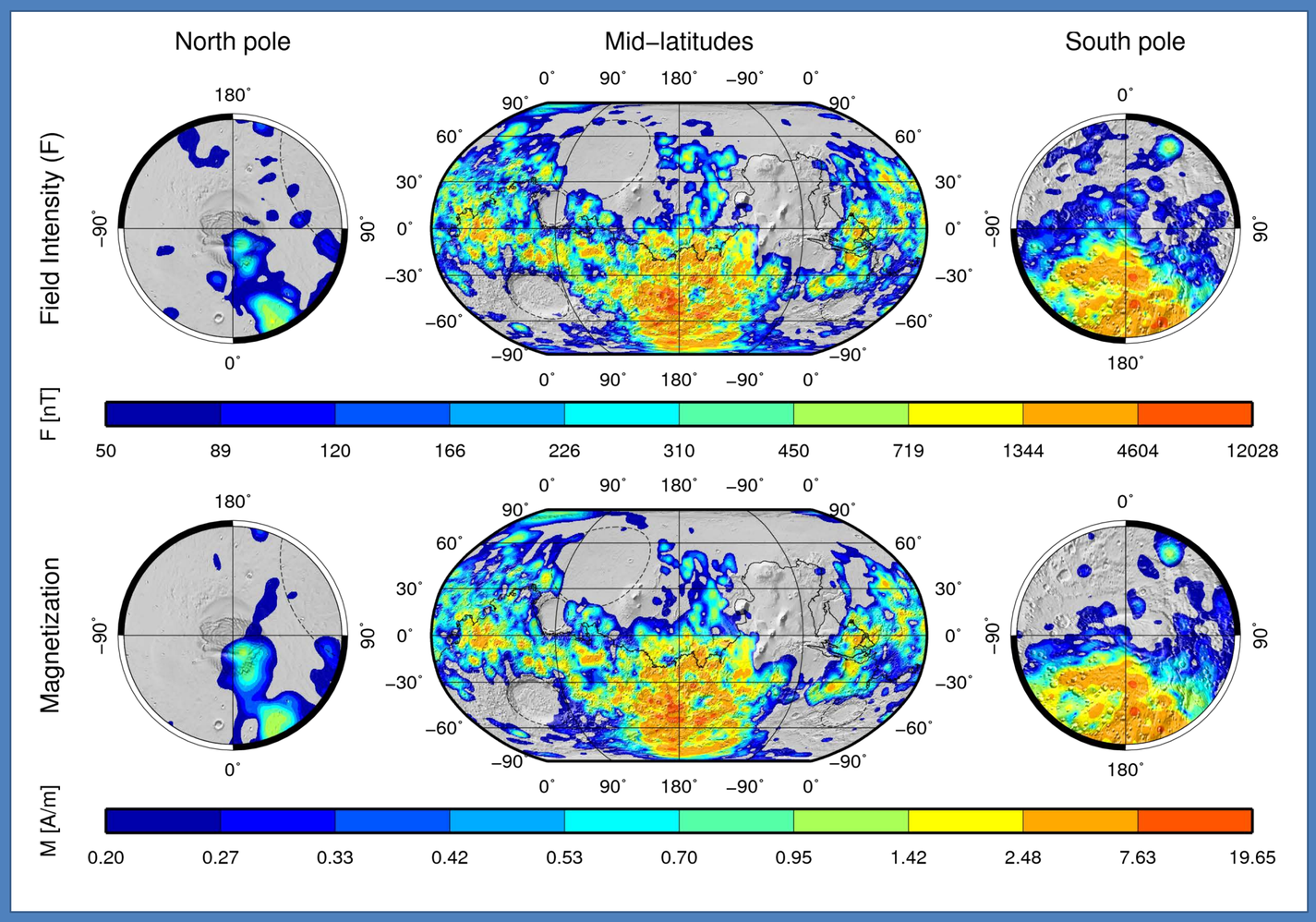


(a+b) The magnetic field intensity at surface altitude (a) and the magnetization of a 40 km thick layer (b) is shown for a 2350×1500 km large region within the southern part of Arabia Terra. In order to compare these maps, the color bars have been chosen based on histograms in this region. In addition, impact craters with a diameter larger than 150 km in this area are marked by white circles and labeled by numbers.
(b) The circumferential averages of the surface magnetic field intensity (red line) and lithospheric magnetization (black line) above the apparently demagnetized craters (labelled one to five) as a function of radial distance from the crater's center.

Schiaparelli crater (labeled 1) was previously investigated by *Lillis et al. (JGR,* 2013), who argued that Schiaparelli is likely magnetized. The lithospheric field model as well as the magnetization model, however, suggest that this crater is possibly demagnetized. The diameters of Jannsen (labeled 3) and Henry (labeled 4) are at the resolution limit of the model. For the latter crater, the magnetization model suggests that it may be demagnetized, although the magnetic field signature is rather ambiguous.

Overall, the minimum required magnetization (b) does not intuitively follow from the magnetic field map (a), and can be used to directly investigate the magnetization of impact craters in order to further constrain the lifetime of the Martian dynamo.

Magnetization of the Martian crust in a 40 km thick layer



(Top row) Magnetic field intensity at the Martian surface altitude of 3393.5 km, as predicted from the lithospheric magnetic field model of Morschhauser et al. (JGR, 2014). (Bottom row) Minimum required magnetization in a 40 km thick magnetized layer of radially uniform magnetization. The global characteristics of the magnetization and the resulting magnetic field are very similar, but differ on smaller scales.

Model description

True magnetization of Mars

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Vector spherical harmonics

Gubbins et al. (GJI, 2011)

Any magnetization can expanded in terms of orthogonal vector spherical harmonics:

$$\bar{\mathbf{M}}(r,\theta,\phi) = \sum_{l,m} E_l^m \mathbf{Y}_{l,l+1}^m(\theta,\phi) + T_l^m \mathbf{Y}_{l,l}^m(\theta,\phi) + I_l^m \mathbf{Y}_{l,l-1}^m(\theta,\phi)$$

No field external to the magnetized shell

Field external to the magnetized shell

Lithospheric fiel model

Morschhauser et al. (JGR, 2011)

- Spherical harmonic expansion
- Robust and stable when downward-continued to surface

Gubbins et. al. (GJI, 2011): The expansion coefficients of the magnetization model can uniquely be related to the expansion coefficients of the lithospheric field model. We extented this model to include a magnetized shell of finite thickness d and outer radius R:

$$\begin{Bmatrix} g_{I,l}^m \\ h_{I,l}^m \end{Bmatrix} = \frac{l+2}{\mu_0}\sqrt{\frac{2l+1}{l}}\frac{1}{\left[1-\left(1-\frac{d}{R}\right)^{l+2}\right]}\begin{Bmatrix} g_l^m \\ h_l^m \end{Bmatrix}$$

Model of Minimum Required Magnetization

Magnetization which results in an observable field external to a magnetized sphere:

$$\sum_{l,m}\left[g_{I,l}^m \mathbf{Y}_{l,l-1}^{m,c}(\theta,\phi) + h_{I,l}^m \mathbf{Y}_{l,l-1}^{m,s}(\theta,\phi)\right]$$

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