Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research 57 (2016) 477–492

Advances in Space Research
(a COSPAR publication)

www.elsevier.com/locate/asr

A comparative analysis of the magnetic field signals over impact structures on the Earth, Mars and the Moon

Anca Isac [a,*], Mioara Mandea [b], Michael Purucker [c], Benoit Langlais [d]

[a] Geological Institute of Romania, 1 Caransebes Str., RO-012271 Bucharest, Romania
[b] CNES – Centre National d'Etudes Spatiales, 2 Place Maurice Quentin 75039 Paris Cedex 01, Paris, France
[c] Goddard Space Flight Center, Greenbelt, MD 20771, USA
[d] Laboratoire de Planétologie et Géodynamique de Nantes, UMR 6112 CNRS and Université de Nantes, Nantes, France

Received 11 May 2015; received in revised form 18 November 2015; accepted 19 November 2015
Available online 27 November 2015

Abstract

An improved description of magnetic fields of terrestrial bodies has been obtained from recent space missions, leading to a better characterization of the internal fields including those of crustal origin. One of the striking differences in their crustal magnetic field is the signature of large impact craters. A comparative analysis of the magnetic characteristics of these structures can shed light on the history of their respective planetary-scale magnetic dynamos. This has motivated us to identify impact craters and basins, first by their quasi-circular features from the most recent and detailed topographic maps and then from available global magnetic field maps. We have examined the magnetic field observed above 27 complex craters on the Earth, 34 impact basins on Mars and 37 impact basins on the Moon. For the first time, systematic trends in the amplitude and frequency of the magnetic patterns, inside and outside of these structures are observed for all three bodies. The demagnetization effects due to the impact shock wave and excavation processes have been evaluated applying the Equivalent Source Dipole forward modeling approach. The main characteristics of the selected impact craters are shown. The trends in their magnetic signatures are indicated, which are related to the presence or absence of a planetary-scale dynamo at the time of their formation and to impact processes.

The low magnetic field intensity at center can be accepted as the prime characteristic of a hypervelocity impact and strongly associated with the mechanics of impact crater formation. In the presence of an active internal field, the process of demagnetization due to the shock impact is associated with post-impact remagnetization processes, generating a more complex magnetic signature.

Keywords: Terrestrial planets; Impact craters; Magnetic characteristics

1. Introduction

The most recent satellite missions carrying instrumentation to measure planetary magnetic fields have considerably increased the amount and quality of available data (Langlais et al., 2010; Mandea et al., 2007). A better description of the magnetic field of these terrestrial bodies is possible and new magnetic field models and maps have been created. Based on these achievements, the comparative analysis of the magnetic fields measured or modeled above impact craters for several terrestrial bodies becomes possible.

Usually, magnetic field anomalies are observed within impact crater rims. This can be attributed to (1) impact-induced thermal overprint of uplifted magnetic lithologies, often basement, (2) magnetized impact melt rocks or breccias, (3) shock remanent magnetization or

---

* Corresponding author.
E-mail addresses: anca.isac@igr.ro (A. Isac), mioara.mandea@cnes.fr (M. Mandea), michael.e.purucker@nasa.gov (M. Purucker), benoit.langlais@univ-nantes.fr (B. Langlais).

http://dx.doi.org/10.1016/j.asr.2015.11.019
0273-1177/© 2015 COSPAR. Published by Elsevier Ltd. All rights reserved.

demagnetization, (4) hydrothermal activity, or some combination of the above (Henkel and Reimold, 2002; Pilkington and Hildebrand, 2003). Thus, the magnetic signature of impact craters can be complex but, generally, two types of features are often apparent (Langlais and Thébault, 2011; Pilkington and Grieve, 1992; Pilkington and Hildebrand, 2003): (1) disruption of the pre-existing magnetic signature and (2) short-wavelength, relatively intense magnetic anomalies that occur near the center of the structure. It is of interest to note that the concentric magnetic trends have been used to predict the transitory diameter of impact structures even if this has led to controversy over the size estimates of some of structures (see for example the debate on the dimension of the Acraman impact structure in Hawke (2003)).

To date, there has been little work to systematically determine the petrophysical property variations that occur within different target rock types as a result of hypervelocity impacts on Earth (Cisowski and Fuller, 1978), and practically none for Mars and the Moon. Some information can however be obtained from meteorites or direct sampling. The remanent magnetization in the ALH84001 martian meteorite (Weiss et al., 2002; Weiss et al., 2010) indicates that a strong global field must have existed in the planet's history about 4 Gy before present. Hood and Zakharian (2001) correlated for the first time the shock pressure with magnetic field intensities over impact craters of Mars. Louzada et al. (2011) reviewed the impact magnetization on the martian crust, underlying that an important parameter in this processus is the nature of the magnetization carrier. It may be pyrrhotite, hematite, magnetite, all having different demagnetization pressures (Artemieva et al., 2005; Louzada et al., 2007; Louzada et al., 2010). Remagnetization processes are possible but they are also mineralogy dependent.

The absence of central magnetic anomalies over the youngest impact craters of Mars and Moon has been used to date the cessation of their dynamos at about 4 Gy ago (Frey, 2008; Halekas et al., 2002; Hood et al., 2011; Lillis et al., 2008; Purucker et al., 2012). Nevertheless, magnetic measurements show a correlation between impact craters, their demagnetization and strong magnetic fields on the diametrically opposite side of the Moon (Hood et al., 2013). These observed stronger magnetic fields may be a consequence of remagnetization of the melt ejecta in the presence of an external magnetic field.

Due to the highly variable nature of the observed magnetic responses over known craters and considerable scatter in these data, the comparison and interpretation of these morphometric features is likely to be subjective. A systematic study on the impact craters and their magnetic signals is therefore needed. In this study we focus on the very large impact craters on Earth, Mars and Moon, and analyze their topographical and magnetic features. Of the 98 craters analyzed, characteristic magnetic signatures are highlighted with significant sizes and qualitative magnetic intensities bringing some new insights on this topical issue.

The paper is organized as follows. In the next section we present the available magnetic field measurements and models which are used to study the largest impact craters on Earth, Mars, and Moon. Then, the methodology to define the main characteristics of the chosen craters and the applied method for forward modeling of the magnetic features are shown. In the fourth section the results are detailed, before concluding in the last section.

2. Data

To investigate the Earth's, Mars' and Moon's craters, two types of global, detailed data sets are used: one is based on the topographic maps and another one on lithospheric magnetic field maps. We need both sets of information to characterize the magnetic signature of impact craters. The way these maps are used and how the needed parameters are extracted are explained in the next section.

2.1. Earth

To characterize the morphological features of Earth's craters we use the map derived from the Shuttle Radar Topography Mission SRTM30 (Becker et al., 2009). It is the most complete, near-global, high-resolution map of the Earth's topography. SRTM30 is a 30 arc sec resolution global topography grid (approx. 1 km near the equator) and full-resolution data covers the globe from 60°N to 56°S latitude.

We also use the World Digital Magnetic Anomaly Map, or WDMAM (Korhonen et al., 2007) representing the total intensity magnetic field anomaly map ΔB, to characterize the crustal magnetic field above impact craters. The WDMAM digital database includes anomaly values on a 3 arc min spacing grid (about 5 km at the equator) at an altitude of 5 km above the mean sea level, on a World Geodectic System 1984 ellipsoid (WGS84). Due to the differences in coverage and quality of the magnetic anomaly information derived, different types and dates of surveys, the grid does not preserve the same spatial resolution everywhere. The coverage is especially sparse over oceans, as well as over Africa, Asia and South America. The available resolution varies from about 50 km for India, to 30 km for South America or Africa, and to 5 km for North America or Australia (Hamoudi et al., 2007). Despite the heterogeneous data used to produced the WDMAM map, it provides a qualitative view of the magnetic field of lithospheric origin at constant altitude over the studied craters.

2.2. Mars

We use the Mars Orbiter Laser Altimetry (MOLA) map to analyze the martian topography. The MOLA map is the result of one year of global mapping of Mars by Mars Orbiter Laser Altimeter (Smith et al., 1999) operated on the Mars Global Surveyor spacecraft in 1998. The MOLA topographic grid is available at 1/64° resolution in latitude