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An integrated magnetotelluric and aeromagnetic investigation of the Serra da Cangalha impact crater, Brazil

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Abstract

The research is aimed at delineating the post-impact structural characteristics across the Serra da Cangalha impact crater in Brazil using a combination of magnetotelluric (MT) and aeromagnetic data. The MT survey was carried out along three radial MT profiles trending NW–SE, ENE–WSW and NNE–SSW across the crater. For MT sites located further away from the centre of the crater, isotropic MT responses were observed, suggesting a 1D conductivity distribution in the subsurface in the frequency range of 100–10 Hz. For sites located in the vicinity of the inner ring of the crater, anisotropic responses were observed for the same frequency range. We believe that this zone probably represents the areas of structural disturbance. A 2D resistivity inversion of these data reveals a four-layer model, representing a thin resistive layer underlain by a conductive layer, a weathered basement and a resistive crystalline basement. The depth to the top of the basement is estimated to be about 1.2 km. This is in good agreement with the estimation of depth to the basement of about 1.1 km, calculated using the aeromagnetic data. However, in view of the circular geometry of the crater, we have carried out a 3D forward modeling computation to supplement the derived 2D model. The 3D resistivity forward model, fitting the MT responses by trial-by-error revealed a five-layer model, showing a significant reduction in the basement resistivity. This, perhaps, could be due to the structural disturbances that have been caused by the impact on the crater, resulting in brecciation, fracturing, alteration and shocked zone filled with weak-magnetic materials and fluids. We have calculated the effect of the impact on the overall structural deformation beneath the Serra da Cangalha crater, following the classical crater scaling relation of Holsapple and Schmidt [Holsapple, K.A., Schmidt, R.M., 1982. On the scaling of crater dimensions. II. Impact processes. J. Geophys. Res. 87, 1849–1870] and found to be about 2 km.

Keywords: Impact crater; Magnetotelluric; Aeromagnetic; Basement; 2D resistivity inversion; 3D forward modelling

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1. Introduction

Studies of meteorite impact cratering have been the subject of prime interest, as they facilitate to understand the earth's climatic and biologic evolution in a broader perspective. It is natural that meteorite impacts cause pronounced subsurface structural deformations and produce distinctive changes in the physical properties of the rocks in and around impact structures. These include: (i) changes in the electrical conductivity of the subsurface (Zhang et al., 1988; Amir et al., 2002), (ii) variations in the magnetic field (Hart et al., 1995) and (iii) mineralogical phase changes (Cisowski and Fuller, 1978), to name a few.

Zhang et al. (1988) studied the Siljan impact crater using MT and detected an anomalous upper crust having a resistivity of 1000 Ω m compared to resistivity of 10,000 Ω m found in the adjacent rocks in the region. They invoke the presence of free fluids as suggested by Shankland and Ander (1983), and existence of faults in the lower crust as the most probable source through which this anomaly developed. Mareschal and Chouteau (1990) analyzed MT data over the Charlevoix crater and delineated the existence of a deep vertical conductor and fault beneath the crater. They concluded that the meteorite impact affected the upper 20 km of the crust beneath Charlevoix region. Masero et al. (1994), using MT data, gave a 1D electrical structure of the Araguainha crater in central Brazil. Masero et al. (1995) also provided a 1D geoelectrical model of Serra da Cangalha impact crater and identified a zone of structural disturbances at a depth of 1.1 km beneath the crater, which they used in classifying the Serra da Cangalha as a shallow impact region. Unsworth et al. (2002) delineated a 2D electrical structure of Chicxulub impact crater and reported a significant reduction in the resistivity of the upper crust beneath the crater. They attributed the low resistivity to the result of hydrothermal alteration and mineralization across the ring of the crater in the upper 1–2 km of the crust.

Using magnetic method, the morphological features of various impact craters have been explained in the past. For example, Sturkell and Ormö (1998) derived a bowl-shaped structure of the Lockne crater in Sweden, which has no distinct magnetic anomaly pattern and no melt body. The absence of magnetic signature at this crater is attributed to the presence of great volume of water and wet carbonate rich sediments in the target area. Tsikalas et al. (1998) ascribed the source of the low magnitude (about 100 nT) magnetic signature observed at the Mjølnir Crater located in the Barents Sea to localized dispersed or injected impact-generated melts and/or dislocation of weakly magnetized platform sediments. Plado et al. (2000) carried out a magnetic modeling of the Bosumtwi meteorite impact structure in Ghana. They suggested that the central negative magnetic anomaly (−40 nT) was probably produced by the magnetization of the 400 m thick magnetic lens consisting of impact-melts breccias and impact-melts rocks, and that this magnetic body acquired its bulk remanent magnetization during the Lower Jaramillo normal polarity event.

In all the above studies, it can be understood that while the MT method helps to resolve deep geoelectrical structures, the magnetic method aids to delineate the crater morphology and depth to the basement. Therefore, in an attempt to characterize the Serra da Cangalha impact crater more quantitatively, we, in the present study, have analyzed both MT and aeromagnetic data sets.

2. Geological setting

The Serra da Cangalha meteorite impact crater is located at 46°52′W longitude and 8°05′S latitude in northeast Brazil within the intra-cratonic Parnaiba basin covered by Upper Silurian to Cretaceous sedimentary rocks (Fig. 1). It is the second largest impact crater of the eight known impact craters in Brazil (Crósta, 1987). Its 13 km diameter has been estimated from satellite (Dietz and French, 1973; McHone, 1979) and confirmed by aeromagnetic data sets (Adepelumi et al., 2003).

The Serra da Cangalha impact site consists of thick Palaeozoic sedimentary rocks of Poti sandstone formation. It forms the internal part of the crater and overlies the latest Famennian-Tournaisian subvertical Longá shale formation, which is uplifted by about 400 m from their regional stratigraphic level and is overlain by the Westphalian and younger Piaui sandstone formation (Melo and Loboziak, 2000). The outer edge of the impact structure consists of steep-walled plateaus and mesas, capped by undisturbed level-bedded Permian chert and silty sandstone (McHone, 1986).