

BAJADA DEL DIABLO CIRCULAR STRUCTURES (CHUBUT, ARGENTINA): GROUND GRAVITY, MAGNETIC AND ELECTROMAGNETIC SURVEYS

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ABSTRACT

Bajada del Diablo is located in the Northern Patagonian Massif, Chubut, Argentina. Circular structures have been identified on two rock types: basalts of the Quiñelaf Eruptive Complex and conglomerates of Pampa Sastre Formation. An impact origin has been proposed for these circular structures.

It is widely accepted that a key tool in the initial recognition and characterization of terrestrial impact craters is geophysics. A set of general criteria has been established, which corresponds to the geophysical signature of impact craters. These criteria can be used to evaluate the hypothesis of impact origin of circular structures.

With the aim of further investigate the proposed impact origin of the circular structures identified in Bajada del Diablo, we carried out detailed topographic, gravimetric, magnetic and electromagnetic ground surveys in two craters (8 and G) found in Pampa Sastre conglomerates and in basalts of the Quiñelaf Eruptive Complex, respectively.

We conclude that the morphological, geological and geophysical features of the studied circular structures could be satisfactorily explained assuming an extra-terrestrial projectile impact.

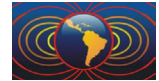
Keywords: circular structures, geophysical anomalies, impact origin, extraterrestrial projectile

RESUMEN

Bajada del Diablo está ubicado en el Macizo Norpatagónico, Provincia de Chubut, Argentina. Se han identificado estructuras circulares en dos tipos de roca: basaltos pertenecientes al Complejo Eruptivo Quiñelaf y conglomerados correspondientes a la Fm Pampa Sastre. Se ha propuesto un origen por impacto para estas estructuras circulares.

Es ampliamente aceptado que una herramienta clave en el reconocimiento inicial y caracterización de cráteres de impacto terrestres es la geofísica. Se han establecido un conjunto de criterios generales, los cuales corresponden a la señal geofísica de los cráteres de impacto. Estos criterios pueden ser utilizados para evaluar la hipótesis del origen por impacto de las estructuras circulares aquí estudiadas.

Con la finalidad de profundizar la investigación del propuesto origen por impacto de las estructuras circulares identificadas en Bajada del Diablo, se llevaron a cabo relevamientos terrestres detallados topográficos, gravimétricos, magnetométricos y electromagnéticos en dos cráteres (8 y G) identificados en los conglomerados de la Fm Pampa Sastre y en los basaltos del Complejo Eruptivo Quiñelaf, respectivamente. Concluimos que las características morfológicas, geológicas y geofísicas de las estructuras circulares



estudiadas podrían ser satisfactoriamente explicadas si se considera la ocurrencia de un impacto de un proyectil de origen extraterrestre.

Palabras Clave: estructuras circulares, anomalías geofísicas, origen por impacto, proyectil extraterrestre

Introduction

Bajada del Diablo is located in the Northern Patagonian Massif, Chubut, Argentina (fig. 1). Circular structures have been identified on two rock types: the Quiñelaf Eruptive Complex and Pampa Sastre Formation (Acevedo *et al.* 2009). Most of the rocks forming the Quiñelaf Eruptive Complex have been classified as trachytes, but other rocks are present, such as rhyolites, trachyandesites, trachybasalts, and pyroclastic rocks. Pampa Sastre Formation corresponds to conglomerate layers with basalt clasts boulder and blocks in size (up to 50 cm in diameter) in a coarse sandy matrix. The study area (fig. 1) includes at least 66 circular structures found in Miocene olivine basalts of the Quiñelaf Eruptive Complex and in the Late Pliocene/Early Pleistocene Pampa Sastre conglomerate (Acevedo *et al.* 2009). An impact origin has been proposed for these circular structures (Acevedo *et al.* 2012, Prezzi *et al.* 2012).

It is widely accepted that a key tool in the initial recognition and characterization of terrestrial impact craters is geophysics (*e.g.* Pilkington, Grieve 1992, Hawke 2004). Pilkington and Grieve (1992) established a set of general criteria that correspond to the geophysical signature of impact craters. These criteria can be used to evaluate the hypothesis of impact origin of circular structures. However, such origin can only be confirmed on the basis of geologic evidence.

With the aim of further investigate the proposed impact origin of the circular structures identified in Bajada del Diablo (Acevedo *et al.* 2009), we carried out detailed topographic, gravimetric, magnetic and electromagnetic ground surveys in two craters (8 and G) found in Pampa Sastre conglomerates and in basalts of the Quiñelaf Eruptive Complex, respectively. Both craters are simple, bowl-shaped structures with rim diameters of 300 m and maximum depths of 10 m. They have been partially filled in by debris flows from the rims and wind-blown sands (Acevedo *et al.* 2009).

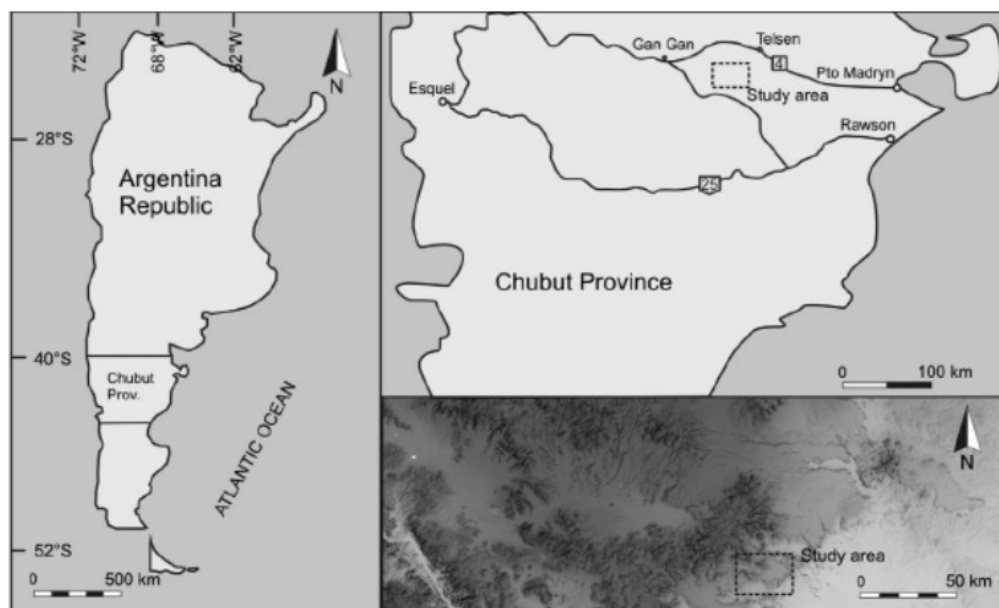
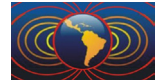


Figure 1. Location map. The inset shows a satellite image of the study area. Modified from Acevedo *et al.* (2009).



Geophysical Studies

Total magnetic field was measured at 1456 stations located in and out of craters G and 8, using a Geometrics 856 proton precession magnetometer (figs. 2 and 3). The obtained data were corrected for the diurnal variations in the Earth's magnetic field and the IGRF value was subtracted. Basalts boulders, sandy matrix and infilling sediments were collected, and the corresponding magnetic susceptibilities were measured; the intensity of the remanent magnetization of basalt boulders was also measured. 20 profiles were surveyed at crater 8 and 10 profiles were surveyed in crater G with a GEM-2 small broadband electromagnetic sensor using 5 different frequencies (figs. 4 and 5). Detailed crater topography was determined using a total station. 732 topographic points were surveyed in craters G and 8. Relative gravity measurements were made using a ZLS Burris Standard gravity meter, 39 stations were surveyed in crater 8 and 51 stations were surveyed in crater G (figs. 6 and 7), with an equidistance of 15 m and a precision of 0.01 mGal. The survey was not tied to an absolute gravity station. The geographic location of each one of the measured gravity stations was determined with a total station. Current standards for reduction of observed gravity to Bouguer anomaly established by the U.S. Geological Survey (USGS) and the North American Gravity Database Committee were applied through the use of the spreadsheet for reduction of raw data to the Bouguer anomaly developed by Holom and Oldow (2007). With the additional use of solid earth tide and terrain corrections, the complete Bouguer anomaly was calculated. This spreadsheet (Holom, Oldow 2007) calculates the corrections for instrument drift, as well as the DC shift (*i.e.*, constant value added or subtracted to observed gravity values) for multiple-day gravity surveys. To do these corrections we measured relative gravity in the same base station several times a day during the survey. The average instrument drift correction in each station was of approximately of 0.01 mGal. To calculate height and Bouguer spherical cap corrections, the height above the WGS84 reference ellipsoid for each station was measured using the total station with a precision of 0.05 m. Earth tide correction was calculated with the software TSoft version 2.1.15 and entered in the spreadsheet of Holom and Oldow (2007). Finally, terrain correction was performed using as input the topographic grid obtained from the detailed topography survey and also entered in the spreadsheet of Holom and Oldow (2007).

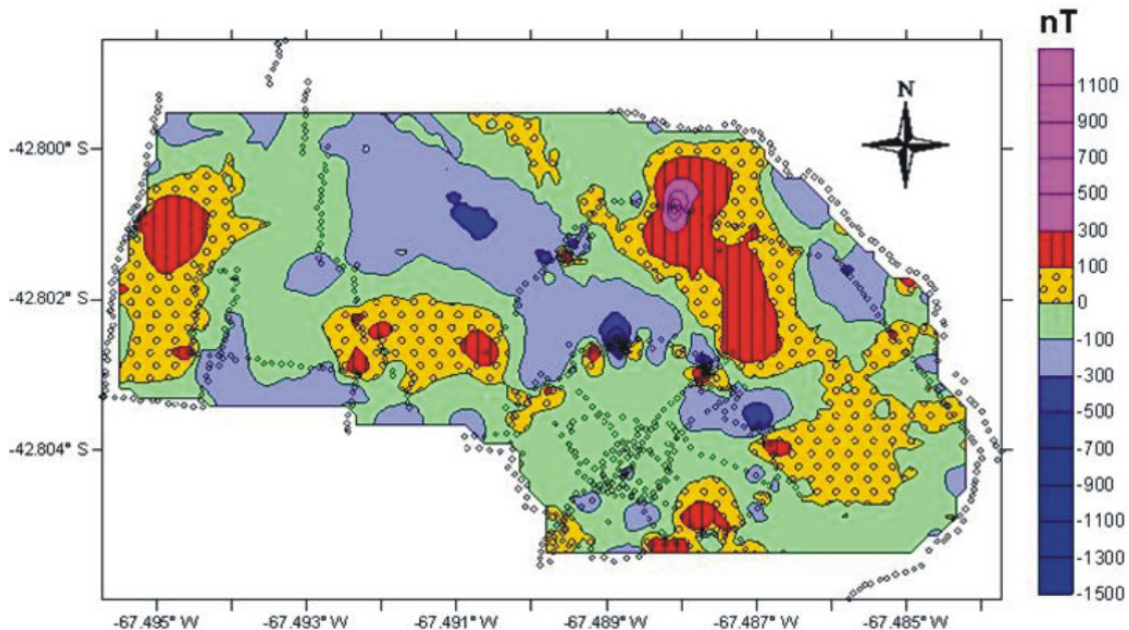


Figure 2. Magnetic anomalies detected in and out of crater 8. Diamonds: magnetic stations.

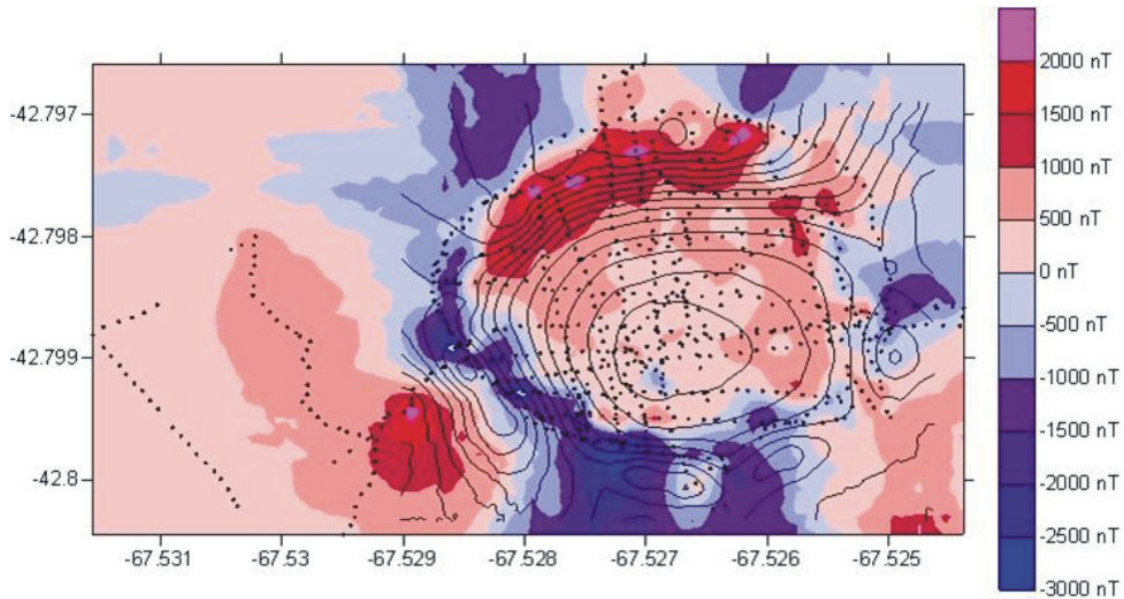
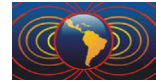


Figure 3. Magnetic anomalies detected in and out of crater G. Black dots: magnetic stations. Black lines: contour lines showing crater G’s detailed topography

Results And Discussion

The magnetic anomalies show a circular pattern with magnetic lows (-100 to 500 nT) in the crater’s floors, characteristic of impact structures. Furthermore, in the crater’s rims, high-amplitude, conspicuous and localized (short wavelength) anomalies, ranging between 2500 and -3000 nT, are observed (figs. 2 and 3). Such large amplitude and short wavelength anomalies are not detected out of the craters. Euler’s deconvolution was applied in order to estimate the depth of the sources. The first and the second vertical derivatives, the analytic signal and the curvature attributes of the residual magnetic field, were also calculated with the aim of sharpening and further analyse the detected anomalies.

For all used frequencies, the electromagnetic profiles show lower apparent electrical conductivities in the crater’s floor, while the rims present notably higher values (figs. 4 and 5).

The complete Bouguer anomaly presents a relative minimum value of ~ -1.6 mGal for crater 8 (fig. 6),

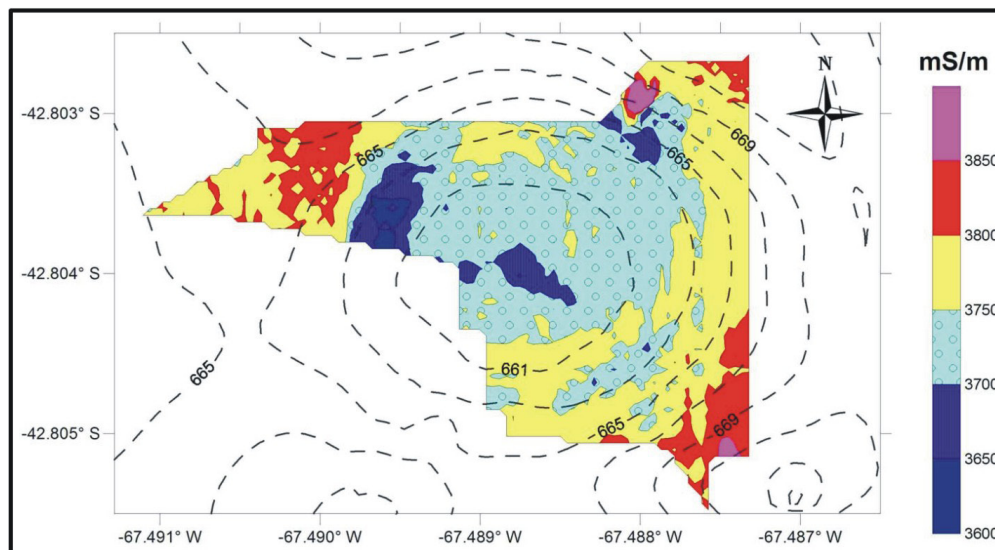


Figure 4. Apparent electrical conductivity registered in crater 8 using 3950 Hz. Black dashed lines: contour lines showing crater 8’s detailed topography.

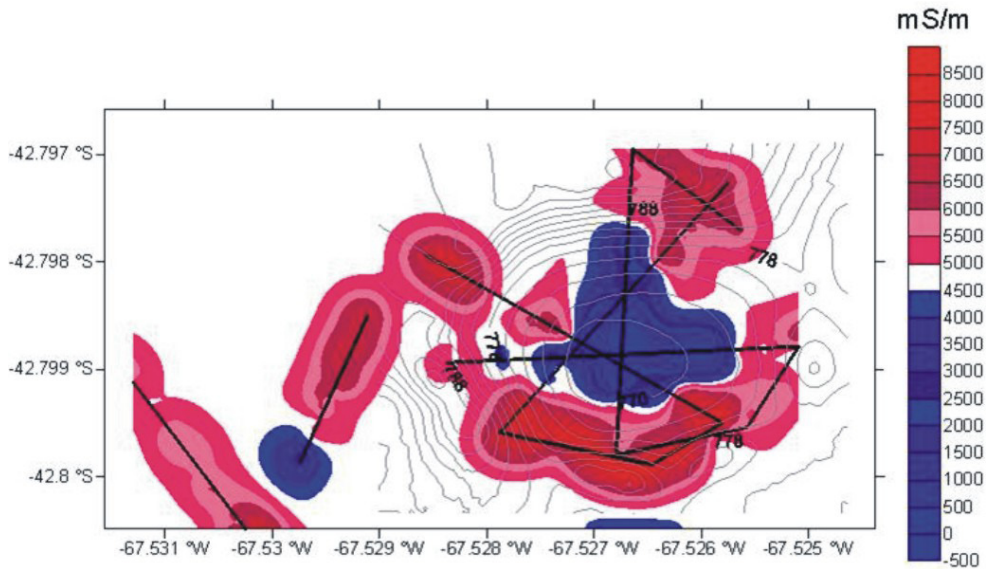


Figure 5. Apparent electrical conductivity registered in crater G using 47010 Hz. Grey lines: contour lines showing crater G’s detailed topography. Black lines: electromagnetic profiles.

which correlates perfectly with the crater’s floor (fig. 6). This negative anomaly indicates the existence of a mass deficit below the floor of crater 8. On the other hand, in the case of crater G the complete Bouguer anomaly presents a relative maximum value of ~ 1 mGal, which correlates with the crater’s floor (fig. 7). This positive anomaly indicates the existence of a mass excess below the floor of crater G.

In the case of crater 8, our results suggest that in the crater’s floor Pampa Sastre conglomerate would be absent or deeply buried. On the contrary, the crater’s rims exhibit high-amplitude, localized magnetic anomalies, higher apparent electrical conductivities and positive complete Bouguer anomalies which would be related to the anomalous accumulation of basalt boulders and blocks remanently magnetized (probably due to shock and heat effects). The fact that such high-amplitude anomalies are not present out of the surveyed crater, supports this hypothesis.

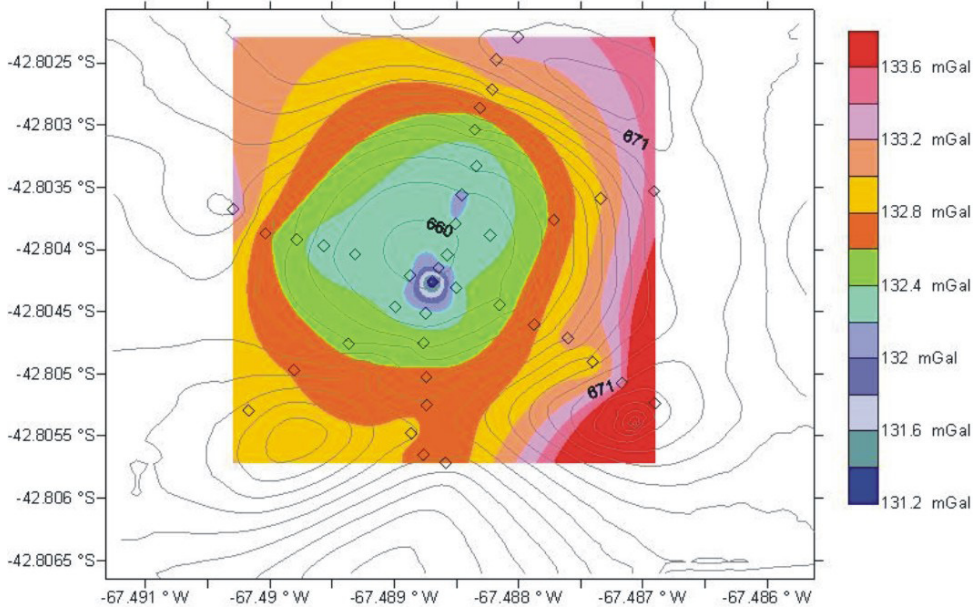
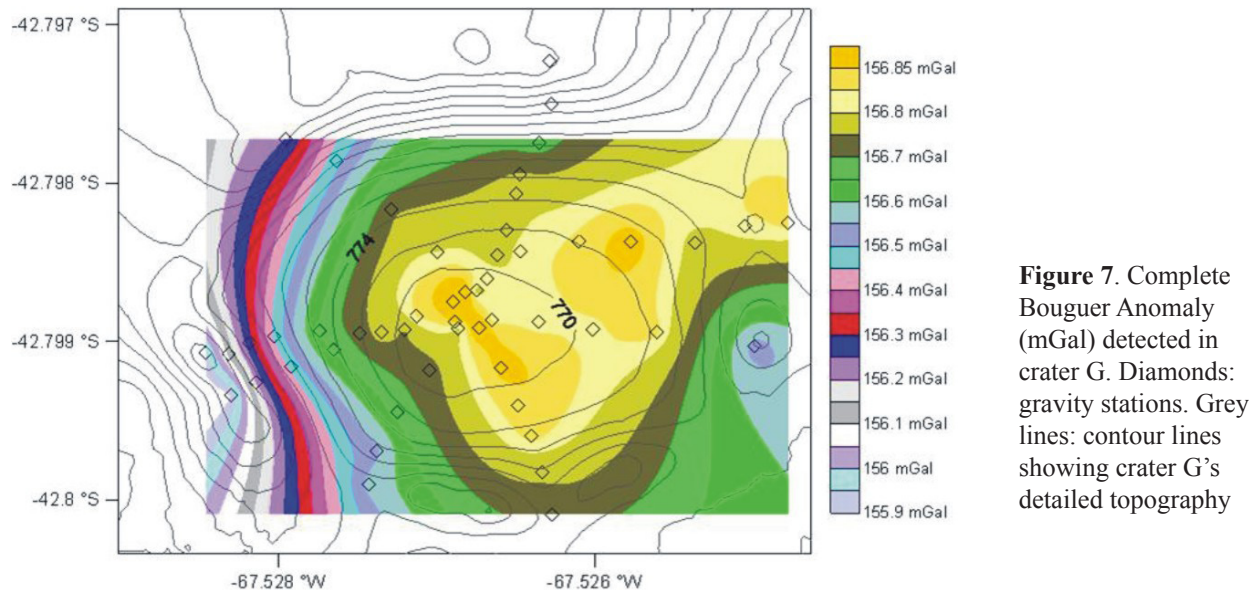
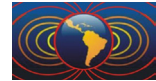


Figure 6. Complete Bouguer Anomaly (mGal) detected in crater 8. Diamonds: gravity stations. Grey lines: contour lines showing crater 8’s detailed topography



In the case of crater G, the crater's rims exhibit high-amplitude, localized magnetic anomalies, higher apparent electrical conductivities and negative complete Bouguer anomalies which would be related to the anomalous accumulation of basalt boulders and blocks. Considering that all the geological formations described in the area of crater G correspond to basaltic flows, no density contrast due to lithological differences should be expected. Therefore, the positive complete Bouguer anomaly in crater G floor could only be satisfactorily explained by means of the anomalous accumulation of blocks of basalts in the rims of the crater. Such accumulation of angular blocks leaves many empty spaces between them, which are filled with air and sand, diminishing the density of the crater's rims with respect to the crater's floors.

The morphological, geological and geophysical features of the studied circular structures could be satisfactorily explained assuming an extra-terrestrial projectile impact.

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