Unravelling the Geometry of a Holocene Continental Basin by Geoelectric Profiles and High-Resolution Magnetic Survey: Evidence from the "Sirente Crater Field" (Italy)

F. Speranza ([1]), I. Nicolosi ([1]), N. Ricchetti ([1]), M. Chiappini ([1]), F. D'Ajello Caracciolo ([1])

([1]) Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy

Summary

A scientific debate has developed in the last few years as to whether a 130 m diameter sag pond surrounded by a saddle-shaped rim and neighboring smaller sags from the Sirente Plain (Abruzzi, Italy) represent the only known Italian meteoritic crater field, a mud volcano, or an anthropogenic feature. To decipher the nature of the Sirente landforms, we carried out geophysical and geochemical investigations. Geoelectric profiles document two karstified shelf carbonate ridges lying at 10-40 m depth below calcareous lacustrine silts (and deeper more conductive sediments, likely soils/tephra) filling the Plain. The smaller sags lie just above the ridges, implying a karstic origin, whereas the main sag (also resting above a carbonate ridge) shows no roots in excess of 10-20 m depth, in contrast to the "crater" interpretation. High-resolution magnetic surveys reveal negative/positive anomaly stripes in correspondence with the buried ridges/valleys, respectively. The smaller sags, as well as the main "crater" are located in the domain of negative residuals. The positive long-wavelength magnetic signature is likely due to the strongly susceptive soils/tephra filling the buried valleys. Magnetic modelling shows that the field observed over the "crater" is incompatible with the field generated by a buried meteorite with realistic characteristics. The smaller sags are characterized by small magnetic anomaly couplets, perfectly reproducible considering the susceptibility contrast between the fill-in soil and the surrounding silts. Our data show that the "Sirente crater" and the minor depressions are simply the results of human activity and karstic processes, respectively.

Introduction

Ormö et al. (2002a) have interpreted a ca. 130 m wide sag pond (surrounded by a saddle-shaped rim) and neighboring smaller depressions from a karstic highland at the toe of the Sirente massif (Abruzzi Apennines, Italy), as the first discovered impact crater field of Italy. Yet, in subsequent years the meteoritic origin of the Sirente sags has been questioned, and the debate on their nature has become controversial. Speranza et al. (2004) proposed that the main sag pond, along with tens of similar structures from the Abruzzi Apennines, were dug by man to create a water reservoir for sheep breeding. Conversely Stoppa (2006) stated that the "Sirente crater" was a mud volcano, or a structure formed by fluid seepage. Here we report the results of new geophysical and geochemical investigations carried out in the Sirente Plain. We show that the main sag pond and the minor depressions must be the sole products of human activity and karstic processes, respectively.

Methodology

During 2006 and 2007 we performed several new geophysical investigations to unravel the setting of the sediments located below the Sirente Plain and its sags. We also carried out geochemical measurements to verify the existence of possible methane seepage. Here we provide the details on the different investigation techniques and the data elaboration methods.

Geoelectric profiles

We collected eight electrical resistivity tomography profiles across the Sirente Plain using an Iris Syscal Pro resistivity meter, applying different spacing of steel electrodes; the resistivity meter was configured to inject a square wave signal for 250 ms, with the energizing electrodes generating a potential difference of 400 Volts. For all profiles we verified a good electrical coupling between the electrodes and subsurface, with homogeneous mean resistivity contact values between adjacent electrodes of about 1 kOhm*m. All profiles were acquired using Wenner-Schlumberger and dipole-dipole arrays with 72 electrodes. Electrodes were spaced by 10, 5, and 1 meter in profiles PG6-PG9, PG1-PG3, and PG5, respectively. According to the multielectrode array geometry, the investigated pseudo-depth was of ca. 120, 60, and 15 m (respectively) below ground level. The chosen array configuration for each geoelectric profile allows a satisfactory vertical and horizontal resolution (Loke and Barker, 1995). We discarded all measurements with a repeatability error larger than 5% during acquisition.

Magnetic surveys and elaboration of magnetic anomaly data

Subsequently, we carried out four different geomagnetic surveys using a Gem System GSM 19 overhauser magnetometer, and a proton precession magnetometer as base station for monitoring and correction of geomagnetic field time variations (time reduction technique). The magnetic surveys were acquired using the magnetometer integrated differential GPS system (satellite based differential GPS system EGNOS) to locate the measured points; the area of Figure 1, about 1.2 x 0.7 km wide, was acquired by 18 NE-SW parallel profiles with mean line spacing of ca. 50 meters, with a mean station spacing along profiles of about 1.7 meters, for a total number of 7598 stations, corresponding to a global profiles length of 13,522 meters. The survey of the "Sirente crater" was acquired by 80 N-S parallel profile lines about 200 m in length, with a mean line spacing of about 3 m and a station separation along lines of about 0.5 m, corresponding to a total number of 27,900 stations. The magnetometer sensor was located about 0.4 m above the ground surface, and at water level inside the sag pond.

The two very high-resolution magnetic surveys were acquired with magnetic profile lines spacing of 1 m and a mean station distance along lines of about 0.5 m; this survey geometry guarantees a detailed sampling of the magnetic anomalies associated to the sags. The survey of sags C1-C6 was acquired by 51 NNW-SSE oriented profiles, each 100 m long. The survey of sag C17 was acquired by 50 NNE-SSW oriented profiles, each 50 m long. The positioning of the two latter surveys was obtained using single frequency Differential Global Position System (DGPS) with base and rover units, and the single point post-processing correction technique. All the acquired data were processed following standard procedures in order to isolate the local crustal contribution to the magnetic anomalies. Steps of data processing are: (1) Data quality control and spikes removal; (2) time reduction of all measurements to an unique reference time through data from the base station (elimination of the diurnal variations from the measured data); (3) elimination of the geomagnetic field components generated in the Earth's core through global reference fields (IGRF-10, International Geomagnetic Reference Field, http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html).

Conclusions

The evidence gathered so far in the Sirente Plain can be summarized as follows:

- The Plain overlies a continental sedimentary basin, hosting lacustrine calcareous silts (trenched down to 9 m depth and inferred by geoelectrics down to ca. 15 m depth) above a conductive-magnetic continental sequence (likely soils/tephra).
- The marine carbonate substratum below the continental infill lies at 10-100 m below the surface, and it is arranged in two ridges (showing karstic structures) and three valleys sub-parallel to the NW-SE long basin edges. Ridges/valleys correspond to negative/positive

(respectively) magnetic residuals, implying that the magnetic anomaly pattern is primarily controlled by the susceptive continental sequence (likely soils/tephra) accumulated at the bottom of the paleo-valleys.

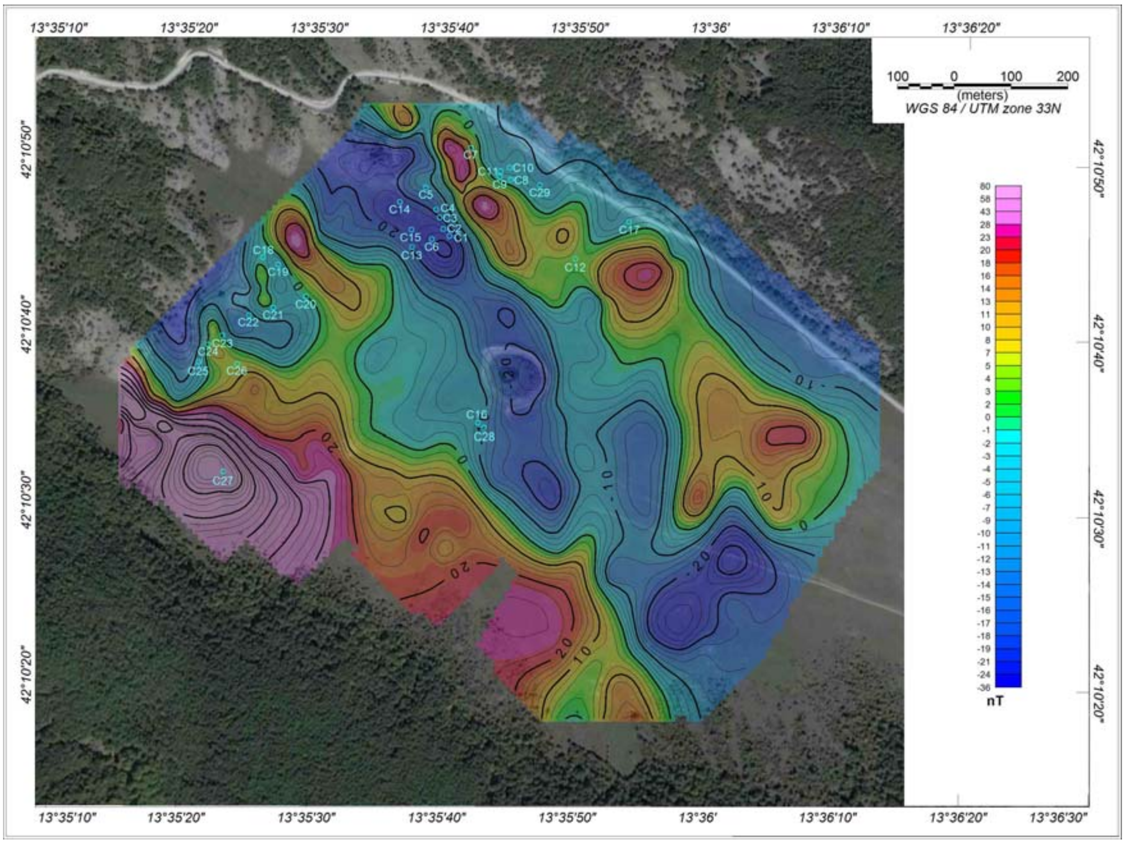

Figure 1. *Magnetic anomaly map (reduced to the magnetic pole) of the Sirente Plain, superimposed onto a satellite image from Google Earth.*

- Some thirty smaller sags without any raised rim, interpreted by Ormö et al. (2002a, 2002b, 2003, 2006, 2007) as a crater field arising from a meteoritic shower, are located exactly above the buried carbonate ridges hosting karstic cavities. Trenching of two sags by Ormö et al. (2002a, 2003) revealed that they overlie a vertical funnel-shaped body filled by soil and surrounded by lacustrine silts. It follows that the meteoritic (instead of a karstic) interpretation of their origin is untenable. Sags C18-C19 accommodated running water from snow melting in spring 2005.
- According to the impact hypothesis, an intact meteorite generating the "Sirente crater" should be located at depth. The "crater" is in fact characterized by negative magnetic residuals, while a metallic meteorite with realistic size and depth would generate a ca. 150 m wide dipolar anomaly, with a positive intensity of about 20 nT at least (such anomaly value would be significantly increased if the magnetic remanence of the buried meteorite is also considered). Therefore magnetic data and modelling exclude the occurrence of a metallic meteorite buried below the "Sirente crater". Our geoelectric/magnetic measurements show that the "crater" lies above the northern buried calcareous ridge showing karst features. Therefore it likely occupies pre-existing sags similar to the other smaller sags.

- The geoelectric profiles crossing the "crater" demonstrate that this structure has no roots in excess of 10-20 m depth. The lack of crater roots makes both the meteoritic and mud volcano hypotheses untenable.
- Our high-resolution magnetic survey of minor sags C1-C4, C6, and C17, coupled by magnetic modelling, reveals that the anomaly they yield can be matched assuming dolines below the sags filled with strongly magnetic soil. There is no need to assume "uplifted crater rims" (as suggested by Ormö et al., 2007) to faithfully reproduce the target anomalies. The volume susceptibility values required for the soil are fully consistent with mass susceptibility values measured by Speranza et al. (2004) for other Holocene Abruzzi paleosols. However, the natural soil magnetism may have been enhanced by anthropogenic iron fragments introduced in Roman-Medieval times (Stoppa, 2006), and/or in the last few decades (Mayer et al., 2007).

References

DeGroot-Hedlin, C., and Constable, S., 1990. Occam's inversion to generate smooth, two-dimensional models from magnetotelluric data. Geophysics 55, 1613-1624.

Loke, M. H., and Barker, R. D., 1995. Least-square inversion of apparent resistivity pseudosections. Geophysics 60, 1682-1690.

Loke, M. H., and Barker R. D., 1996. Rapid least-square inversion of apparent resistivity pseudosections by quasi-Newton method. Geophysical Prospecting 44, 131-152.

Mayer, W., Claudin, F., Ernstson, K., 2007. The Sirente craters (Italy): On the possible origin of geomagnetic anomalies (Ormö et al. 2007). Web site: http://www.impact-structures.com/sirente.html.

Ori, G. G., Rossi, A. P., Komatsu, G., Ormö, J., Rainone, M., Signanini, P., Torrese, P., Sammartino, P., Madonna, R., Baliva, A., Di Achille, G., 2007. Seismic data from the main crater of the proposed Sirente meteorite crater field (central Italy). Abstract. Lunar Planet. Sci. 38.

Ormö, J., Rossi A. P., Komatsu, G., 2002a. The Sirente Crater field, Italy. Meteoritics & Planetary Science 37, 1507-1521.

Ormö, J., Rossi, A. P., Komatsu, G., Marchetti, M., De Santis, A., 2002b. The discovery of a probable well-preserved impact crater field in Central Italy (abstract). Lunar Planet. Sci. 33, #1075, Lunar and Planetary Institute, Houston, Texas, USA (CD-ROM).

Ormö, J., Rossi, A. P., Komatsu, G., 2003. The Sirente Crater Field: Outline, Age, and Evidence for Heating of the Target (abstract). Large Meteorite Impacts.

Ormö, J., Koeberl, C., Rossi, A. P., Komatsu, G., 2006. Geological and geochemical data from the proposed Sirente crater field: New age dating and evidence for heating of target. Meteoritics & Planetary Science 41, 1331-1345.

Ormö, J., Gomez-Ortiz, D., McGuire, P. C., Henkel, H., Komatsu, A. P., Rossi, A. P., 2007. Magnetometer survey of the proposed Sirente meteorite crater field, central Italy: Evidence for uplifted crater rims and buried meteorites. Meteoritics & Planetary Science 42, 211-222.

Servizio Geologico d'Italia, 2006. Foglio 368 (Avezzano). Scale 1: 50 000. Agenzia per la protezione dell'ambiente e per i servizi tecnici (Italy).

Speranza, F., Sagnotti, L., Rochette, P., 2004. An anthropogenic origin of the "Sirente crater", Abruzzi, Italy. Meteoritics & Planetary Science 39 (4), 635-649.

Speranza, F., Nicolosi, I., Ricchetti, N., Etiope, G., Rochette, P., Sagnotti, L., De Ritis, R., Chiappini, M., 2009. The ''Sirente crater field,'' Italy, revisited. J. Geophys. Res. 114, B03103, doi:10.1029/2008JB005759.

Stoppa, F., 2006. The Sirente crater, Italy: Impact versus mud volcano origins. Meteoritics & Planetary Science 41, 467-477.