Preliminary Results of Magnetic and Thermal Investigation at Vulcano Island

S. Scudero[1], A. Pisciotta[2], A. D'Alessandro[1], S. Bongiovanni[3], A. Figlioli[3], R. Martorana[3], S. Speciale[1], G. Vitale[1]

[1]*Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Nazionale Terremoti, Rome, Italy*
[2]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Palermo, Palermo, Italy*
[3]*Università di Palermo, Dipartimento di Scienze della Terra e del Mare, Palermo, Italy*

Introduction

From the end of June 2021, changes in the monitored parameters (temperature, gas emission, seismicity, ground deformation) clearly indicate the beginning of a phase of unrest at Vulcano Island (Aeolian Islands, Italy). The anomalies consist of high temperatures of the fumaroles, increase of gas emissions from fumaroles and soils (both CO_2 and SO_2), ground deformation, and increased seismicity (Aiuppa et al., 2022, Inguaggiato et al., 2022). In the last decades, this volcano experienced frequent crises: 1978-1980, 1988-1991, 1996, 2004-2007, 2009-2010 (Inguaggiato et al., 2022), while the last eruption occurred in 1888-1890. For its activity, Vulcano represents the source of many potentially interconnected hazards (Selva et al., 2020).

The Vulcano island has been widely investigated to understand its volcanic evolution (Gioncada et al., 1998; Gioncada et al., 2003; De Astis; 2013; Nicotra et al., 2018), the dynamics affecting the plumbing and the hydrothermal systems (Alparone et al., 2010; Cannata et al., 2012; Totaro et al., 2022), and the structure of the active “La Fossa” cone (Barde-Cabusson et al., 2009; Revil et al., 2010). Many studies reveal a complex evolution in which the regional tectonic may play a major role. The occurrence volcanism in the southern Tyrrhenian is generally linked to large scale geodynamic processes, but, the volcanism in the southern sector of Aeolian Islands, where Volcano is located, would be also controlled by a regional-scale, lithospheric NNW–SSE trending right-lateral strike-slip fault system. Even though several evidences suggest its occurrence (Mazzuoli et al., 1995; Ventura et al., 1999, Barreca et al., 2014; Cintorrino et al., 2019), the field expression of this system is poorly constrained. Bruno and Castiello (2009) revealed some faults affecting the SW base of the active cone by means of high-resolution seismic investigations. To better understand these features and provide a possible link to the larger scale tectonic framework, a campaign of magnetic survey has been carried out in the south-western part of the cone (Fig. 1, left). Moreover, integrated magnetic and thermal surveys have been performed in the area called “Spiaggia di Levante”, well known for the activity of the fumaroles (Chiodini et al., 2005). Maps of the magnetic field and thermal images are useful to highlight features corresponding to faults, or geological discontinuity in general, at various scales.

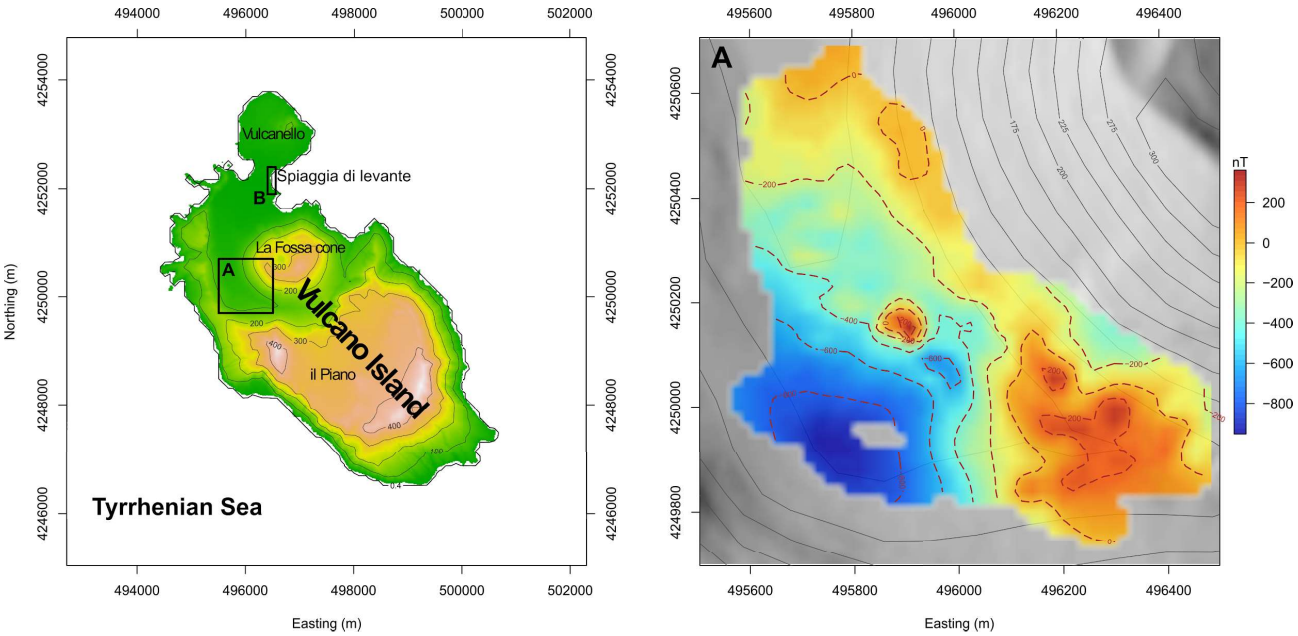

Fig. 1 – Left: relief map of Vulcano Island and location of the two surveyed areas (A and B). Right: anomaly map of the total magnetic field measured in the study area "A" located in the lower southwestern flank of the cone.

Data and method

The magnetic survey was performed with the device G-858G produced by Geometrics Inc. The magnetometer was set in gradiometric configuration with the two sensors 2.0 m apart. The magnetometer is equipped with a GPS that provides the position and the time for each magnetic measure, taken every 0.5 s. The data processing consists in the removal of spikes and in a running average over 50 samples acting as a low-pass filter. The filter attenuates the shorter wavelength component related to the shallower anomalies, enhancing the components with larger wavelength.

The areas at the southwestern base of the cone (area A) is where the seismic investigation by Bruno and Castiello (2009) revealed a velocity anomaly interpreted as a possible fault zone. In this area we performed more than 40,000 measurements in back-and-forward profiles. The average spacing between two consecutive measures is about 0.5 m. The data, reduced with respect to the International Geomagnetic Reference Field (IGRF), have been interpolated by kriging on a 20x20 m grid (Fig. 1, right).

In the area of Spiaggia di Levante (area B), we performed about 6,000 magnetic measurements in the same configuration as previously described. Moreover, a thermal survey by means of an Unmanned Aircraft System (UAS) has been performed to better investigate the fumarole field of this area. In particular, this survey consisted of a DJI Phantom 4 Pro UAS platform, equipped with FLIR Vue Pro R 640 (FLIR Systems, USA), a small sized radiometric thermal sensor designed for UAV integration and data collection. The thermal sensor was equipped with a 9 mm lens, producing images with 640X512 pixels and a spectral response in the range of 7.5-13.5 μm. The camera was mounted to the drone by a 3D-printed camera mount in a nadir view position to the ground. Infrared flights were realized before sunrise to minimize distortions like irregular surface heating

due to solar radiation, and exclusively map radiation emitted by the hydrothermal system. The flight was designed according to a classic photogrammetric criterion, with forward overlapping of 80% and side lap of 70% at 30m Above Ground Level (AGL) with a spatial resolution of the thermal images of 5 cm/pixel. The UAS image data was processed in Agisoft Metashape (Version 1.5.2.7838), a widely used commercial Structure from Motion (SfM) software package, and a thermal mosaic from infrared images has been sated out.

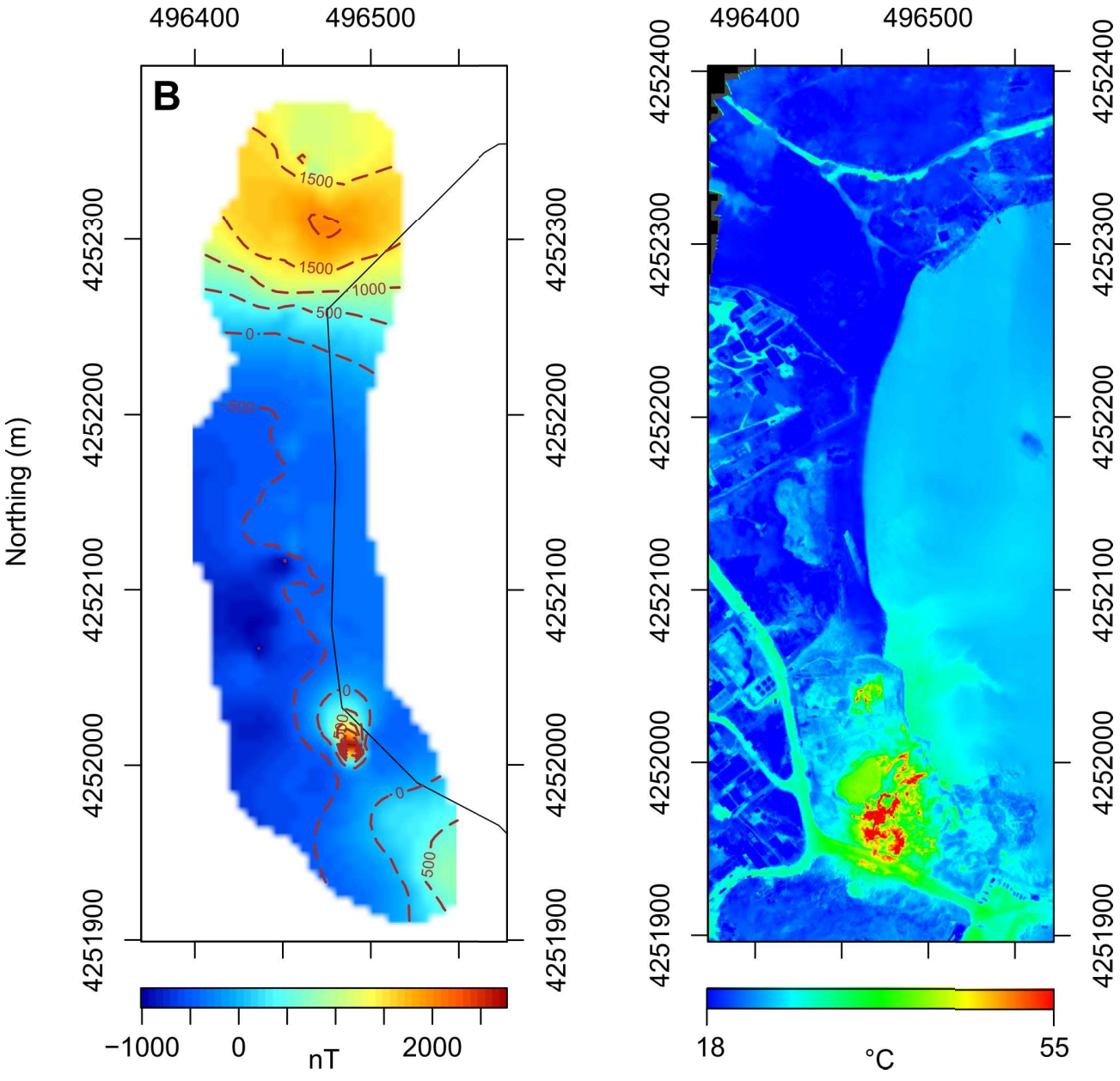

Fig. 2 – Comparison between the: anomaly of the total magnetic field (left) and the thermal UAV survey (right) for the study area “B” located in the “Spiaggia di Levante”.

Results and conclusions

The total-field magnetic anomaly map of area A is presented in Fig. 1. The total field is generally characterized by negative values. This is in agreement with the observations from other magnetic surveys (airborne, shipborne or ground-based) carried out at Vulcano Island at larger scale and at

lower resolution (Supper et al., 2004; De Ritis et al., 2005; Okuma et al., 2006; Blanco-Montenegro et al., 2007; Napoli and Currenti, 2016).

The total magnetic field shows negative values to the south-west and positive values to the north-east, outlining a large-scale anomaly extended in NW-SE direction (Fig. 2, right). This arrangement is in agreement with the position and the direction of the anomaly suggested by Bruno and Castiello (2009). Moreover, a small-scale, bipolar anomaly characterizes the central part of the surveyed area, and is ascribable to a shallower and more localized feature.

For the Spiaggia di Levante area we present both the magnetic anomaly map and the thermal map (Fig. 2). The magnetic map shows generally negative values, with a positive gradient moving northwards. This arrangement is in agreement with the other magnetic investigations and corresponds to the transition from the beach deposits to the volcanic rocks constituting the Vulcanello cone. A small-scale positive anomaly marks the southern part of the area and corresponds to the position of the thermal anomaly. This is exactly the site where is located the main part of the fumarole field.

The results coming from the magnetic technique, and also the integration with thermal imaging, provide useful information to characterize various multi-scale features of this volcanic island. The results presented are only preliminary: more accurate processing and elaboration will represent the base for the modelling of the magnetic data and therefore they will be crucial to verify the hypothesis of the fault zone running at the base of the main cone.

Acknowledgements

The authors thank Vincenzo Sapia (Istituto Nazionale di Geofisica e Vulcanologia, Sezione Roma2) who provided the magnetometer and supported the field activities.

References

Aiuppa A., Bitetto M., Calabrese S., Delle Donne D., Lages J., La Monica F. P., ... and Pistolesi M. (2022). Mafic magma feeds degassing unrest at Vulcano Island, Italy. Communications Earth & Environment, 3(1), 1-15.

Alparone S., Cannata A., Gambino S., Gresta S., Milluzzo, V. and Montalto P.; 2010: *Time-space variation of volcano-seismic events at La Fossa (Vulcano, Aeolian Islands, Italy): new insights into seismic sources in a hydrothermal system.* Bulletin of Volcanology, 72(7), pp. 803-816.

Barde-Cabusson S., Finizola A., Revil A., Ricci T., Piscitelli S., Rizzo E., Angeletti B., Balasco M., Bennati L., Byrdina S., Carzaniga N., Crespy A., Di Gangi F., Morin J., Perrone A., Rossi M., Roulleau E., Suski B. and Villeneuve N.; 2009: *New geological insights and structural control on fluid*

circulation in La Fossa cone (Vulcano, Aeolian Islands, Italy). J. Volcanol. Geotherm. Res., 185(3), pp. 231-245.

Barreca G., Bruno V., Cultrera F., Mattia M., Monaco C. and Scarfi, L.; 2014: *New insights in the geodynamics of the Lipari–Vulcano area (Aeolian Archipelago, southern Italy) from geological, geodetic and seismological data*. Journal Geodyn., 82, 150-167.

Blanco-Montenegro I., de Ritis R. and Chiappini M.; 2007: *Imaging and modelling the subsurface structure of volcanic calderaswith high-resolution aeromagnetic data at Vulcano (Aeolian Islands, Italy).* Bull. Volcanol. 69, 643–659, doi:10.1007/ s00445-006-0100-7.

Bruno P. P. G. and Castiello A.; 2009: *High-resolution onshore seismic imaging of complex volcanic structures: An example from Vulcano Island, Italy*. J. Geophys. Res., 114, B12303, doi: 10.1029/2008JB005998.

Cannata A., Diliberto I. S., Alparone S., Gambino S., Gresta S., Liotta M., Madonia P., Milluzzo V., Aliotta M. and Montalto P.; 2012: *Multiparametric approach in investigating volcano-hydrothermal systems: the case study of Vulcano (Aeolian Islands, Italy)*. Pure and applied geophysics, 169(1), pp. 167-182, doi: 10.1007/s00024-011-0297-z.

Chiodini G., Granieri D., Avino R., Caliro S., Costa A., and Werner C. (2005). Carbon dioxide diffuse degassing and estimation of heat release from volcanic and hydrothermal systems. Journal of Geophysical Research: Solid Earth, 110(B8).

Cintorrino A. A., Palano M. and Viccaro M.; 2019: *Magmatic and tectonic sources at Vulcano (Aeolian Islands, Southern Italy): A geodetic model based on two decades of GPS observations*. J. Volcanol. Geotherm. Res., 388, doi: 10.1016/j.jvolgeores.2019.10

De Astis G., Lucchi F., Dellino P., La Volpe L., Tranne C. A., Frezzotti M. L., and Peccerillo A.; 2013: *Geology, volcanic history and petrology of Vulcano (central Aeolian archipelago)*. Geological Society, London, Memoirs, 37(1), pp. 281-349.

De Ritis R., Blanco-Montenegro I., Ventura G. and Chiappini M.; 2005: *Aeromagnetic data provide new insights on the tectonics and volcanism of Vulcano island and offshore areas (southern Tyrrhenian Sea, Italy)*. Geophys. Res. Lett. 32 (L15305), doi: 10.1029/2005GL023465.

Gioncada A., Clocchiatti R., Sbrana A., Bottazzi P., Massare D. and Ottolini L.; 1998: *A study of melt inclusions at Vulcano (Aeolian Islands, Italy): insights on the primitive magmas and on the volcanic feeding system*. Bulletin of Volcanology, 60(4), pp. 286-306.

Gioncada A., Mazzuoli R., Bisson M. and Pareschi, M. T.; 2003: *Petrology of volcanic products younger than 42 ka on the Lipari–Vulcano complex (Aeolian Islands, Italy): an example of volcanism controlled by tectonics*. J. Volcanol. Geotherm. Res, 122(3-4), pp. 191-220.

Inguaggiato S., Vita F., Diliberto I. S., Mazot A., Calderone L., Mastrolia A. and Corrao M.; 2022: *The Extensive Parameters as a Tool to Monitoring the Volcanic Activity: The Case Study of Vulcano Island (Italy)*. Remote Sensing, 14(5), 1283.

Mazzuoli R., Tortorici L. and Ventura, G.; 1995: *Oblique rifting in Salina, Lipari and Vulcano islands (Aeolian islands, southern Italy).* Terra Nova, 7(4), pp. 444-452.

Napoli R. and Currenti G.; 2016: *Reconstructing the Vulcano Island evolution from 3D modeling of magnetic signatures*. J. Volcanol. Geotherm. Res, 320, pp. 40-49.

Nicotra E., Giuffrida M., Viccaro M., Donato P., D'Oriano C., Paonita A. and De Rosa R.; 2018: *Timescales of pre-eruptive magmatic processes at Vulcano (Aeolian Islands, Italy) during the last 1000 years*. Lithos, 316, pp. 347-365.

Okuma S., Nakatsuka T., Supper R. and Komazawa M; 2006: *High-resolution aeromagnetic anomaly map of the Vulcano-Lipari volcanic complex, Aeolian Islands, Italy*. Bulletins of the Geological Survey of Japan, 57, pp. 177-190.

Revil A., Johnson T. C. and Finizola A.; 2010: *Three-dimensional resistivity tomography of Vulcan's forge, Vulcano Island, southern Italy*. Geophysical Research Letters, 37(15).

Selva J., Bonadonna C., Branca S., De Astis G., Gambino S., Paonita A., Pistolesi M., Ricci T., Sulpizio R., Tibaldi A. and Ricciardi A.; 2020: *Multiple hazards and paths to eruptions: a review of the volcanic system of Vulcano (Aeolian Islands, Italy)*. Earth-Science Reviews, 207, 103186.

Supper R., De Ritis R., Motschka K. and Chiappini M.; 2004: *Aeromagnetic anomaly images of Vulcano and southern Lipari Islands (Aeolian archipelago, Italy).* Annals of Geophysics, 47(6).

Totaro C., Aloisi M., Ferlito C., Orecchio B., Presti D., and Scolaro S. (2022). New insights on the active degassing system of the Lipari–Vulcano complex (South Italy) inferred from Local Earthquake Tomography. Scientific Reports, 12(1), 1-10.

Ventura G., Vilardo G., Milano G. and Pino N. A.; 1999: *Relationships among crustal structure, volcanism and strike–slip tectonics in the Lipari–Vulcano volcanic complex (Aeolian Islands, Southern Tyrrhenian Sea, Italy).* Physics of the Earth and Planetary Interiors, 116(1-4), pp. 31-52.

Corresponding author

Salvatore Scudero: salvatore.scudero@ingv.it