Magnetotelluric survey of Ischia active volcanic island 
(Southern Italy): inference for volcano-tectonics and dynamic
Aim of the survey:

Specific- recognizing of the main volcano-tectonic structures and geothermal features associated to the resurgence of Mt. Epomeo.

General- understanding of resurgence processes that plays a central role in the evolution of calderas and associated volcanic risk (still unclear, in particular with regard to the causes and the timing of uplift).
MT survey

Magnetotellurics is an electromagnetic geophysical method for measuring the resistivity of the earth’s interior by recording the natural electric (E) and magnetic (H) fields on the surface (Vozoff, 1991).

In the present application, fluctuations of the orthogonal components of these fields were recorded at 20 measurement sites. Measurements were carried out using a Stratagem EH4 instrument, produced by Geometrics.

Once data set of field fluctuations over time had been collected, the underground resistivity complexity was obtained as a rank-2 tensor, \( \mathbf{Z} \), correlating the two orthogonal pairs \((E_x, E_y)\) and \((H_x, H_y)\) at the Earth’s surface in the frequency-domain.

This tensor is correlated with the MT apparent resistivity and phase curves, which compose the final dataset. To estimate such curves, the collected time series spectra have been estimated using a short period Fourier transform performed over the \(10^{-4} \sim 10^1\) s range. Such a period was examined to investigate the structures located across the first few kilometers of depth below ground level.
Typical configuration of the Stratagem receiver. The magnetic fields are detected with two perpendicular H-field sensors. The electric fields are detected by measuring the differential voltage between the two electrodes of the electric dipoles (between Ex0 and Ex1 for the X-direction E-field, for example)

\[
\begin{align*}
E_x &= Z_{xx}H_x + Z_{xy}H_y \\
E_y &= Z_{yx}H_x + Z_{yy}H_y
\end{align*}
\]

The ratio of electric and magnetic field intensity (E/H) termed as the impedance (Z) is a characteristic measure of the EM properties of the subsurface medium.

\[
Z = \begin{pmatrix}
Z_{xx} & Z_{xy} \\
Z_{yx} & Z_{yy}
\end{pmatrix}
\]

The resistivity of the homogeneous and isotropic half-space, is

\[
\rho = \frac{1}{\omega \mu} |Z|^2
\]

where the value of the magnetic permeability (\(\mu\)) is considered equal to the value in a vacuum (\(\mu_0\)) and \(\omega\) is the angular frequency.
MT survey

MT is one of the most used geophysical methods for geothermal exploration. Due to its characteristically deep investigation depth, it is mainly used for deep geothermal exploration and high temperature fields.

- Fluid circulation
  - Permeability
- Thermal state
  - (high/low temperature field)
- Volcano-tectonic framework
  - (soft soils/basement/magma)
MT survey

The resistivity imaging of the island of Ischia has allowed us to recognize a number of sectors, down to a depth of 2-3 km, with resistivity anomalies that are ascribable to distinctive geological features and physical conditions of the hydrothermal system below the caldera.

Variation of resistivity (main dependence) → Water content (electrolyte) → fracture and porosity permeability

Effect of various geological processes on resistivity (after Ward, 1990)

Clay alteration ↓ Dissolution ↓ Faulting ↓ Shearing ↓ Saline concentration ↓ Temperature +

Carbonate precipitation ↑ Silification ↑ Pressure +
MT survey

(IGG source)
Geological framework

Magnetotellurics survey of Ischia active volcanic island (Southern Italy)

(modified from Di Giuseppe et al., Bull Volcan, in press)
Geological framework

- Magnetotellurics survey of Ischia active volcanic island (Southern Italy)

- Resurgent block
- Donna Rachele fumaroles
- Cetara
- Panza
- Avalanche
- Maronti

GNGTS Trieste, 14-16 Novembre 2017
**Geological framework**

Average uplift $\rightarrow 2.4 \text{ cm y}^{-1}$

Mt. Epomeo (789 m asl) $\rightarrow$ uplift 800m (33ka)

(further models: Orsi et al., 1991; Tibaldi and Vezzoli, 1998; Acocella et al., 2001; Molin et al., 2003; Sbrana et al., 2009; Castaldo et al., 2017)

Rittmann (1930)
MT survey: constrains

A numbers of ambiguities in the interpretation of our data were reduced by correlating the resistivity anomalies with data provided from drilling down to depth of 1150 m (AGIP, 1987), and with previous geophysical and geochemical modeling of the island provided by Nunziata and Rapolla (1987), Chiodini et al. (2004), Paoletti et al. (2005), Di Napoli et al. (2009), Sbrana et al., (2009); Di Napoli et al., (2011), Carlino (2012), Paoletti et al., (2013), Carlino et al. (2014), Castaldo et al., 2017.

Interpretation of gravity anomalies at Ischia island (adapted from Carrara et al. 1983 and Nunziata & Rapolla 1987)
MT survey: constrains

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Interpretative model derived from 2D joint modeling of filtered potential field data along SW-NE profile, aeromagnetic data and gravimetric data (Paoletti et al., 2013).
MT survey: constrains

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Stratigraphy and temperature data of deeper wells located in the western sector of the island (from Carlino et al., 2014).
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Results and interpretation (S-N resistivity profile)

(Di Napoli et al., 2009)

Sea level

(Mt. Epomeo resurgent block)

SSW caldera boundary

(structural interpretation)

(Crystalline basement)

(Di Giuseppe et al., 2017)

(Di Napoli et al., 2009)
Results and interpretation: WSW-ENE resistivity profile

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(Di Giuseppe et al., 2017)
Magnetotellurics survey of Ischia active volcanic island (Southern Italy)

Results and interpretation

(Di Giuseppe et al., 2017)
Results and interpretation

Comparison of the shallower part of WSE-ENE resistivity profile with a geological section of the island (from Carta Geologica dell’Isola d’Ischia, CARG project).

Legend: PZE = Pizzone Tuffs (~61 ka); TFS = Frassitelli Tuffs (~62 ka); VNU = dike and tabular intrusions; TME = Mount Epomeo Green Tuff (~55 ka); PIM-FGN = Punta Imperatore ancient lavas (~117 ka); ELF = Elephant pyroclastic deposits; TCT = Citara Tuffs (~45 ka); SUN = debris and mud flow deposits; PPI = Punta Imperatore pyroclastic deposits (~18 ka); PUS = Punta Soccorso debris avalanche; a_alluvial deposits. (from CARG project)
Results and interpretation

Legend: (drill n. 4) VB = Volcanic Breccia; GT = Green Tuff; GTL = Green Tuff interlayered with trachytic lava.

(Di Giuseppe et al., 2017)
Results and interpretation

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(d) R = Reworked Tuffs and Alluvium; TYT = Trachytic Yellow Tuffs; PLD = Pyroclastic and Lava deposits; GrT = Green Tuff; TL = Trachytic lava

(Di Giuseppe et al., 2017)
Magnetotellurics survey of Ischia active volcanic island (Southern Italy)

Results and interpretation

(Di Giuseppe et al., 2017)
Rheological state of the crust

(after Carlino et al., 2014)
Conclusions

- Pure magmatic contribution to the uplift (resurgence);

- Magmatic intrusion (possibly a laccolith) at very shallow depth (with a bulge to a depth less than 1 km);

- Assuming a roughly radial symmetry of the resistivity anomaly associated with the magma intrusion (about 2 km in radius and 2 km in vertical extension), at least for the crust down to 3 km, we obtain a (minimum) magma volume of about 6 km$^3$;

- If this has been gathering since 33 ka (Tibaldi and Vezzoli, 1998), then the (minimum) accumulation rate is about 2 \cdot 10^{-4} \text{ km}^3 \text{ a}^{-1};

- A large thermal anomaly occurs in the southern and western sector of the island and is associated with a zone of heat advection and circulation of hydrothermal fluids;
Final remarks

We propose that the high resistivity body is associated with the laccolith of Ischia (Rittman, 1930; Sbrana et al., 2009; Carlino, 2012), which produced the bending, fracturing and faulting of the overlying crust, and which witnessed magma intrusion during the most recent stage of the resurgence (5 ka) (Civetta et al., 1991; Vezzoli et al., 2009).

The uplifted block has been broken up into minor blocks, with the underlying laccolith possibly developing as a complex structure. This laccolith is the engine of the robust geothermal system of the island, and -to be consistent with a high resistivity - is likely dominated by a highly crystalline mush.

The existence of such a shallow magma body is critical in terms of volcanic hazard assessment. A renewal of resurgence will be related to reactivation of the laccolith by arrival of new magma (Civetta et al., 1991). This may possibly produce a large disturbance of the geothermal system at a depth of between 1 km and 2 km. A reactivation of such a shallow magmatic system may imply imminent eruption and would pose high volcanic hazard (e.g. Cooper & Kent, 2014); certainly it would cause hydrothermal emissions to evolve towards magmatic (Vaselli et al., 2010).
Grazie per l’attenzione