IMAGING OF THE METHANA VOLCANIC COMPLEX, GREECE , WITH MAGNETOTELLURIC & AEROMAGNETIC DATA

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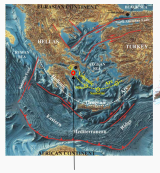
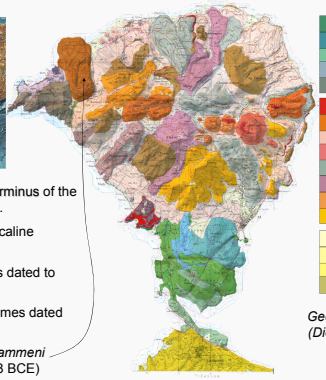
GEOLOGICAL SUMMARY

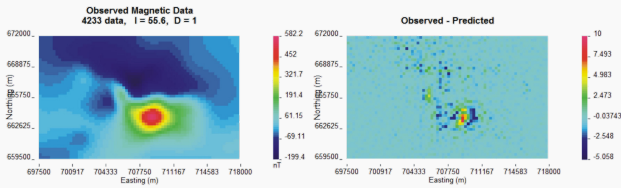




Geological map (Dietrich, 1994)

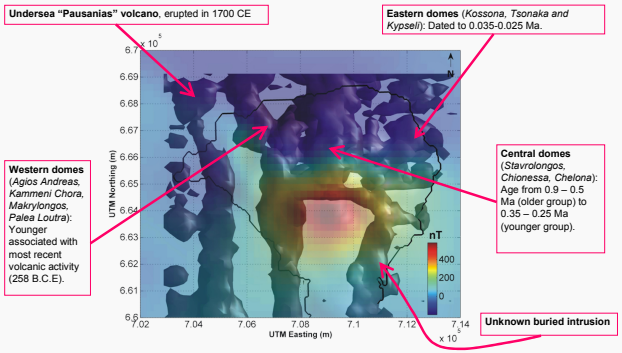
- Located at the NW terminus of the Hellenic Volcanic Arc.
- Comprises 32 calc-alcaline domes.
- Older (*central*) domes dated to 0.9 – 0.55 Ma.
- Younger (*eastern*) domes dated to 0.38 – 0.29 Ma.
- Youngest dome is *Kammeni Chora* at the NW (258 BCE)
- Last eruption: 1700 CE, "Pausanias" submarine volcano at N-NW of Kammeni Chora.
- Peninsula segmented by intense tectonic activity (*see below*).
- Thermal springs at several locations along the coast.

AEROMAGNETIC DATA



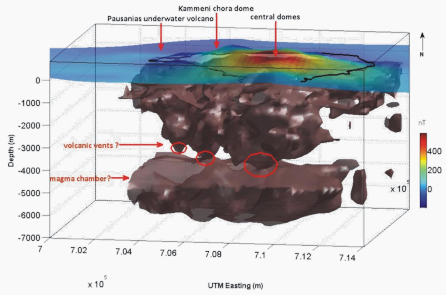
- Data extracted from the aeromagnetic map of Greece (Chailas et al., 2010, *Bull. Geol. Soc. Greece*, XLIII, No4, 1919-1929).
- 3-D inversion performed with the UBC-GIF software by Li and Oldenburg (1996, *Geophysics*, 61, 394-408).
- Inversion constrained by geological information and in situ susceptibility measurements.
- The observation is reproduced to better than 1.7%.

INTERPRETATION

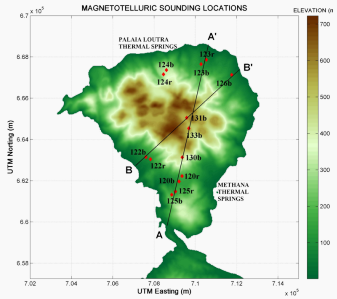


- The isometric surface encloses susceptibilities $\kappa > 0.1$ and represents the core of the main intrusive/extrusive volcanic activity.
- Apparent correspondence with the main volcanic domes observed at the surface.
- Intrusions apparently associated with N-S, W-E and NW-SE (N300° and N340°) orientations.

- Isometric surface of $\kappa = 0.025$ includes a more weakly magnetized domain at depths from 4.5 km to 7 km at least.
- Magnetization intensity and depth range comparable to expectation for magma chambers
- Red circles indicate the position of the possible volcanic vents and their relation to the main volcanic domes of the peninsula.



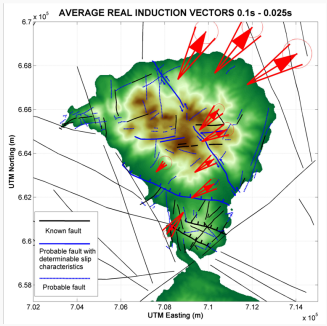
MAGNETOTELLURIC SURVEY

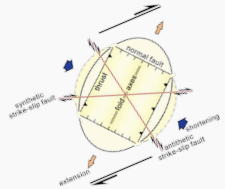


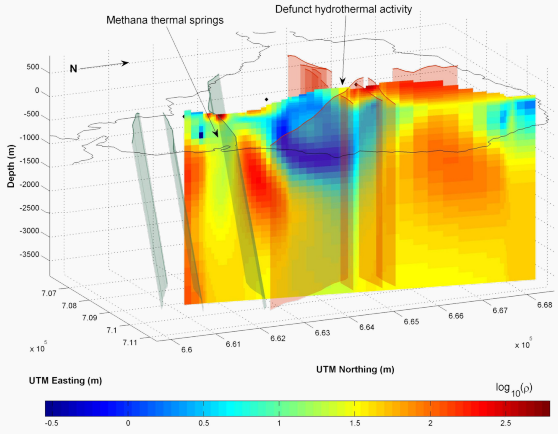
- Data collected in the frequency range 128Hz - 50s in the Magnetotelluric – Telluric mode, using a 5-component Magnetotelluric configuration at the *Base* site and a 2-component Telluric configuration at the *Remote* site.
- Measurements carried out with $Pb/PbCl_2$ electrodes and CM11 induction coils.
- 14 soundings are used in this presentation - data quality sufficient for standard processing techniques to provide satisfactory Earth response functions.
- The same data has been presented by Tzanis and Lagios (1994, *Bull. Geol. Soc. Greece*, XXX/5, 15-26); a superset of the data was analysed by Volti (1999, *Tectonophysics* 301, 111–132).

INDUCTION AND TECTONICS

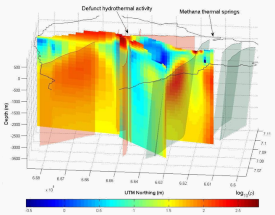
- Tectonics apparently controlled by three major normal faulting zones of direction N20°- N30°, N50°, N110° and N340°.
  - These faults form the coastline and delineate the volcanic complex.
- If the N110° faults are *normal* (as attested to by independent observations), then there's a "textbook" case of deformation by simple shear where:
  - The *local* W-E faults *interior* to the complex are interpreted as synthetic R shears.
  - The N340° faults are interpreted as antithetic R' shears
- Real Induction Vectors (RIV) in the Parkinson convention are presented as averages at periods 0.1s – 0.025s.
- RIVs indicate principal conductive direction at ~N330°-N350°
- On the premise that conductors form epiphenomenally and in association with permeability generated by faulting and fault-related structures,
  - RIVs point towards TE mode induction associated with a N330° – N350° regional azimuth.
  - The behaviour of RIVs is consistent throughout the observed bandwidth.
  - Local induction appears to be associated with fluid along R' antithetic shear faults



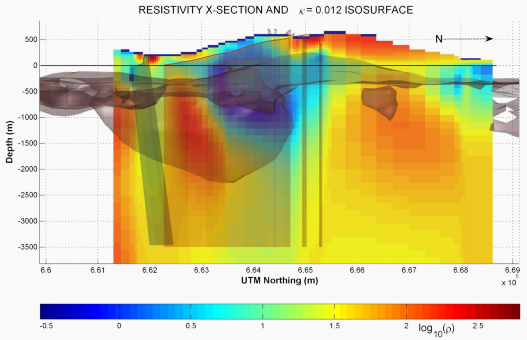




- Quantitative interpretation along profiles A-A' and B-B' performed with 2-D inversion after Rodi & Mackie (2001).
- A good conductor interpreted as geothermal reservoir is detected.
  - The "reservoir" is located within the volcanics, to the N of the Limestone – Volcanics interface.
  - The association of faulting and conductivity is clearly indicated.



JOINT INTERPRETATION



The $\kappa = 0.012$ iso-surface is a ***hull*** engulfing *lower* susceptibility values

- In volcanics, low susceptibility is epi*phenomenal* due to chemical alteration (argillization).
- Very low susceptibility (< 0.001) and resistivity of the order of sea-water indicate extensively argillized material and possibly high hydraulic permeability.
- Low-intermediate susceptibility (0.003 – 0.01) and low resistivity indicates porous material with water circulation and/or argillization.
  - The porosity of volcanics is usually secondary due to high fragmentation by cooling and tectonics.
  - The faces of the fragments may be argillized but considerable susceptibility indicates that the mother rock is not annihilated.
- The lower the susceptibility and resistivity, the higher the alteration (argillization).
- Downside: For highly altered volcanic rock, porosity is difficult to estimate due to the abundance of clay minerals.

OBSERVATIONS:

- A layer of low susceptibility and low resistivity is observed at, or just below sea level, indicating extensive lateral sea-water infiltration.
- The purported geothermal reservoir is associated with low but non-trivial susceptibility and is thus confirmed!
  - The reservoir has been considerably more voluminous at earlier geological times.
- A 2nd reservoir possibly detected in association with the "Pausanias" and "Kammeni Chora" activity of historical times.
  - The elongate southwardly low susceptibility (< 0.012) "tail" of the 2nd reservoir may be associated with fluid circulation in a fault.

RESULTS:

- High resolution images of the volcano's interior.
- Additional constraints on the tectonics
- Determination of the geothermal system and its function:
- The survey confirmed geochemical analyses by *Geotermica Italiana*, (1984) that anticipated the circulation of fluids through faulting structures at great depths.
  - Fluid transportation from the reservoir to the Methana thermal springs apparently takes place through the R' antithetic shear faults to the limestone – volcanics interface through the interface to the surface.
  - The same geochemical analyses propose that the thermal fluids might have had initial temperatures of 100-120°C, if they have remained in a carbonate rock environment. It appears that this is *not* the case.