INTERNAL STRUCTURE OF THE SANTORINI VOLCANIC COMPLEX

DETERMINED BY INTERPRETATION OF GRAVITY AND MAGNETOTELLURIC DATA

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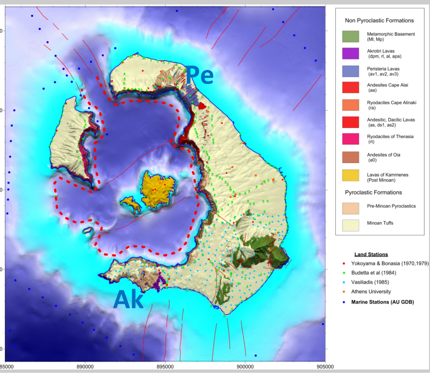


GEOLOGICAL SETTING

The present form of the Santorini Volcanic Complex (SVC) is the result of a volcanic history which lasted at least 750 *ka and,* discriminated by (Druitt, et al, 1989) in four successive periods (two of them regarded as explosive cycles). These periods were interrupted by four caldera collapses. The last collapse followed the well known Minoan eruption ~3.6 ka ago and marked the end of the third Period, leaving back the Santorini caldera (thick red broken line in the map). From that moment the volcanic activity was confined in two centers. One in the centre of the caldera, with the construction and demolition of numerous of islands (volcanic cones). And, one at about 10km NW off the northern coast of Santorini island.
The pre-volcanic metamorphic basement is still exposed in the SE quarter of the Island. The volcanic stratigraphy consist of the succession of lavas and pyroclastics (tuffs and pumice) of different horizontal extends. The older volcanic centers are Akrotiri [Ak], and Peristeria [Pe]

GRAVITY (GRV) DATA

The Gravity Anomaly Map was compiled using 550 on- and off-shore gravity measurements from different sources.
Land stations from Yokoyama & Bonasia (1970,1979), Budetta et al. (1984), Vasiliadis (1985), Athens University (1995).
Marine stations from GEODAS (2012).
Previous researchers' data were referred to IGF 1930 datum and, their adopted gravity correction procedure was not consistent to each other (considering Bouguer density and the calculation of the terrain correction).
Data homogenization was attempted by, (i) referring them to the IGSN'71 datum (ii) checking and correcting (whenever possible) for errors, (iii) applying crossover correction through common gravity bases and (iv) recalculating the terrain correction (TC) coefficients using the same topographic data sets for all gravity stations and the same procedure (TC was calculated this time in three phases, for radius up to 1500 m, a detailed 25m DTM was used, while for radius between 1500 m and 22km a 50m DTM was used, and finally for radii from 22km up to 167km a 1 km DTM was used). For both Bouguer plate correction and TC density value of 2.67 gr/cm³ was used.
The homogenized data set was enriched with data from EGM2008 satellite gravity model (Pavlis etal, 2008) for the marine area; computed and distributed by *Bureau Gravimetrique International* (values averaged over 2,5 arc-minute by 2,5 arc-minute). EGM2008 were used for coarsely filling the gaps in the marine area. The final grid for the gravity anomaly map was calculated with grid space interval 250 x 250 m.

MagnetoTelluric (MT) Survey

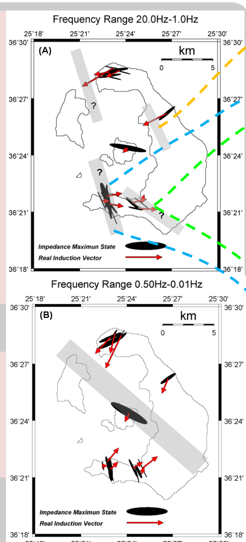
The MagnetoTelluric (MT) survey was conducted during the summer of 1993 (Lagios et al, 1996), providing a total of 34 soundings. Fairly standard observation procedures were followed, leading to the acquisition of five cartesian components of the natural EM field over the nominal frequency bandwidth 130-0.01 Hz. Robust processing methods were applied in order to obtain Earth response functions with acceptable levels of uncertainty.
The spatial analysis attempts to extract information about the configuration of the induced natural EM fields, which, in turn, depend on the geometry and configuration of lateral inhomogeneities in the geoelectric structure. The spatial analysis of the impedance tensor used herein is the Canonical Decomposition of Yee and Paulson (1986), which approaches the geoelectric structure as the equivalent of a birefringent material at low frequencies and large scales.

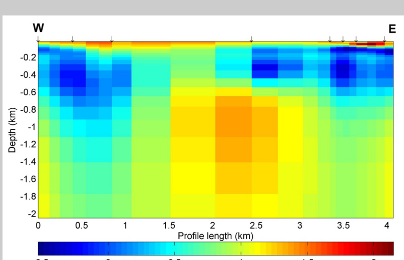
MT RESULTS

Shallow structure: Polarization ellipse of the maximum electric field and the real IV, averaged over the frequency interval 20 – 1 Hz. The configuration of the electric field indicates that the shallower part of the geoelectric structure has dominant 2-D attributes with approx. N330°-340° oriented structural trends.

- At northern Thera, the data indicate TM mode induction over the resistive part of a quasi-2D structure, the interface apparently being located at the area of the channel between Thera and Therassia.
- At Akrotiri peninsula the data show two distinct domains: Near Cape Faros the response indicates TE mode induction over the conductive side of a 2-D structure; Near Akrotiri town, TE mode is observed as well, albeit with respect to a N300°-310° oriented structure.
- The sole sounding at Nea Kammeni cannot be interpreted with confidence, as it has attributes of near-filed three-dimensionality.
- In tectonically active domains, 2-D geoelectric structures image tectonic processes due to the *epiphenomenal* development of electrical conductivity anomalies in response to faulting.

Deep structure (approx. 2 – 5 km) : Polarization ellipse of the maximum electric field and the real IV averaged over the frequency interval 0.5 – 0.01 Hz.
The deeper structure also has prevailing 2-D attributes, without being *sensu stricto* 2-D, and appears to be simpler and counter-clockwise rotated version of the shallower structure. Only one large scale structural trend with N300°-320° strike is detected and comprises a relatively broad elongate conductor centred at the Kammeni islets. This zone is delineated by the TM mode at Akrotiri peninsula and N-NW Thera and the TE mode at the Kammeni islets.

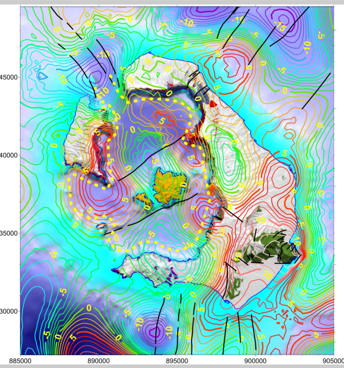




Two-dimensional inversion was carried out along a transect of approximately W-E orientation, between Faros and Akrotiri town with the algorithm of Rodi and Mackie (2001), assuming that the maximum electric field represents induction in the TE mode. The most prominent geoelectric features are two conductive zones, one near Faros at the west and one east of Akrotiri town, which appear to extend to at least 2km and are thought to be associated with the conductivity interfaces detected above. They are interpreted to be sub-vertical faults or fracture zones of high secondary permeability. Finally, it is apparent that an extensive lateral conductive formation exists at and just below sea level, which is thought to represent sea-water intrusion.

GRV High Pass Filtered Map

A high pass filtered map (Ramp: 35-30 km) was calculated in order to isolate the gravity "signal" of the SVC. Local structure is and, to further proceed to gravity modeling.



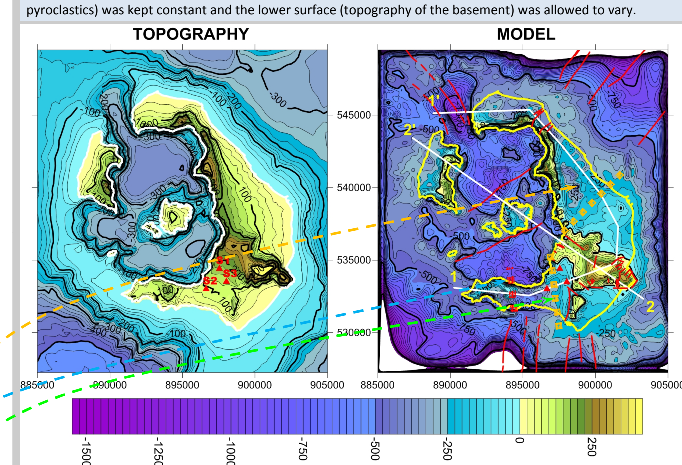
Density Measurements

Density measurements performed to rock samples
- Mp: 2.61 gr/cm³
- Ml: 2.71 gr/cm³
- Lava: 2.5 gr/cm³
- Pumice (Boyce & Gertisser, 2012):

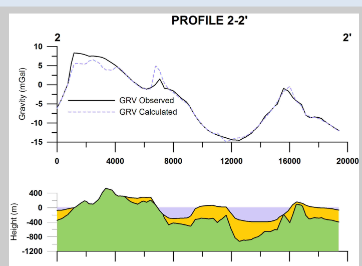
Welding grade	Distance from source (km)	Density (kg/m3)
a (*densely-welded*)	<0.25	2000–2360 (2200)
b (*slightly-welded*)	0.25–1.26	700–1510 (1200)
c (*tack-welded*)	1.26–3.7	630–1140 (760)
d (*non-welded*)	>3.7	370–900 (580)

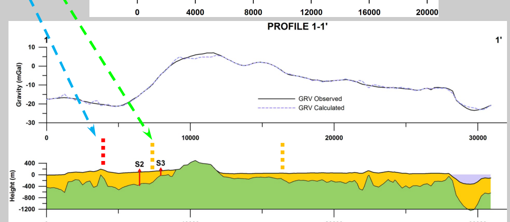
3-D GRV Inversion

The high pass filtered anomaly was inverted using an unpublished algorithm developed at the Department of Geophysics and Geothermy (S. Chailas), which is based on the theory of Radhakrishna Murthy et al. (1989, 1990). In this approach, any three-dimensional geological object can be approximated with some configuration of adjacent vertical polygonal laminae, whose gravity effect at a measurement station is calculated by line integration. The inversion procedure is iterative and uses Bott's (1960) method to readjust the thickness (or vertical extent) of the model in order to home-in to a solution.
In this implementation, the pyroclastic deposits were considered to be a single object with a density contrast of -1.7gr/cm³ against the metamorphic basement rocks. This contrast is considered plausible and reliable according to density measurements given in the Table above . The upper surface of the model (topography of the pyroclastics) was kept constant and the lower surface (topography of the basement) was allowed to vary.



In this implementation, the pyroclastic deposits were considered to be a single object with a density contrast of -1.7gr/cm³ against the metamorphic basement rocks. This contrast is plausible and reliable according to the density measurements given in the Table above . The upper surface of the model (surface topography) was kept constant and the lower surface (topography of the basement) was allowed to vary.
The results of three wells (Fytikas, 1990), drilled at the southern part of Thera, that reached the metamorphic basement, were also used to control the model (by keeping fixed the depth of the lower surface at their position).





CONCLUSIONS

The objective of Gravity Modelling was to find the thickness of the pyroclastics and low density overburden, as well as tectonic features of the deeper structure. The results have shown:
(i) Variable thickness of the pyroclastics (up to 500 m); (ii) A characteristic NNW-SSE basement indentation between Messaria and Imerovigli; (iii) Basement lineaments consistent with known offshore tectonic units (e.g. Anhydros Basin); (iv) Lineaments consistent with a NNW-SSE basement indentation of possible tectonic origin between Akrotiri Peninsula, Palea Kammeni and Therassia in the west, and the rest of SVC in the east.
MT data analysis indicates the existence of local elongate conductors collocated with the basement indentations (ii) and (iv) above, as well as a regional geoelectric direction normal to the principal axis of the Anhydros Basin. The geometry of the elongate conductors is consistent with *epiphenomenal* development of electrical conductivity anomalies in response to faulting.
The joint interpretation of gravity and MT data points toward the existence of a major structural discontinuity (possibly due to faulting) between the west and east SVC and significant influence of regional tectonics on the structure and evolution of the island.