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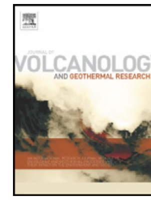

Deep structure investigations of the geothermal field of the North Euboean Gulf, Greece, using 3-D local earthquake tomography and Curie Point Depth analysis

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ABSTRACT

New findings on the deep origin of the geothermal field and volcanic centres at the North Euboean Gulf (or North Evian Gulf), Central Greece, were obtained by combining a three-dimensional traveltime inversion of microseismic data recorded by an on/offshore local seismic network with a Curie Point Depth analysis based on aeromagnetic data.

A magma chamber was detected from low seismic P-wave velocity values and high Poisson ratios at depths below 8 km also coincident with a Curie surface estimated at 7–8 km depth.

Furthermore, it was also observed that local geothermal anomalies are generated by hydrothermal flux facilitated by NW–SE and NE–SW oriented faults. Microseismic activity is also associated with these fault systems.

1. Introduction

Along the North Euboean Gulf coast (or North Evian Gulf), central Greece, several significant geothermal sites exist. Representative examples are the thermal springs of Aedipsos, Yaltra, Ilia, Kamena Vourla, Thermopylae and also the Quaternary–Pleistocene volcanoes of Lichades and Vromolimni (Fig. 1). In order to understand the origin of these thermal fields and their relation to the regional tectonics (see the map of Fig. 1) we performed a 3-D local earthquake tomography study and a Curie Point Depth analysis based on aeromagnetic data. The traveltime inversion method of microseismicity data for velocity tomography analysis has been extensively used in the past, to investigate and map volcanic structures (eg. Thurber, 1984; Lees, 1992; Laigle et al., 2000; Haslinger et al., 2001; Sherburn et al., 2003; Husen et al., 2003, 2004; Lees, 2007; Battaglia et al., 2008; Waite and Moran, 2009; Jousset et al., 2011). Also defining depth points of the Curie temperature surface from aeromagnetic data has been extensively used for studies of magmatic phenomena (eg. Tsokas et al., 1998; Ates et al., 2005; Dolmaz et al., 2005).

In the frame of the “AMPHITRITE”- project, combined onshore/offshore network consisting of 23 land-stations and 7 Ocean Bottom Seismographs (OBSes) was deployed for a 4 month period (June–October 2003) to record the microseismic activity. The instruments used for both land and OBS stations were of Geopro SEDIS IV type. This type of dataloggers provides 6-channel continuous recording with 24 bit A/D conversion and dynamic range of up to 120 dB. Papoulia et al. (2006) presented the seismicity results (Fig. 1) based on an 1D P-wave velocity model (Table 1) and the “Hypoinverse” algorithm (Klein, 2002).

More than 2000 earthquakes ranging from M_L 0.7 to 4.5 recorded by a minimum of a 6 stations per event were located. Although most of the observed seismicity was due to an earthquake swarm that occurred at the southern part of the area, there were also many events close to sites of geothermal interest like those of Kamena Vourla and Yaltra.

In the following we present how the seismic traveltime tomography detected velocity anomalies (low Vp and high Vp/Vs ratio) below the volcanic area of the North Euboean gulf that could be related with possible magmatic intrusions. The Curie Point Depth analysis based on aeromagnetic data was complementarily performed to verify that the temperature at the depths of these anomalies was very high (>580°). The methods used and the results are extensively discussed in the next chapters.

2. Geological setting — volcanism of the study area

The geographic distribution of volcanic centres in the region of central Greece is illustrated in Fig. 1. Geological and radiometric

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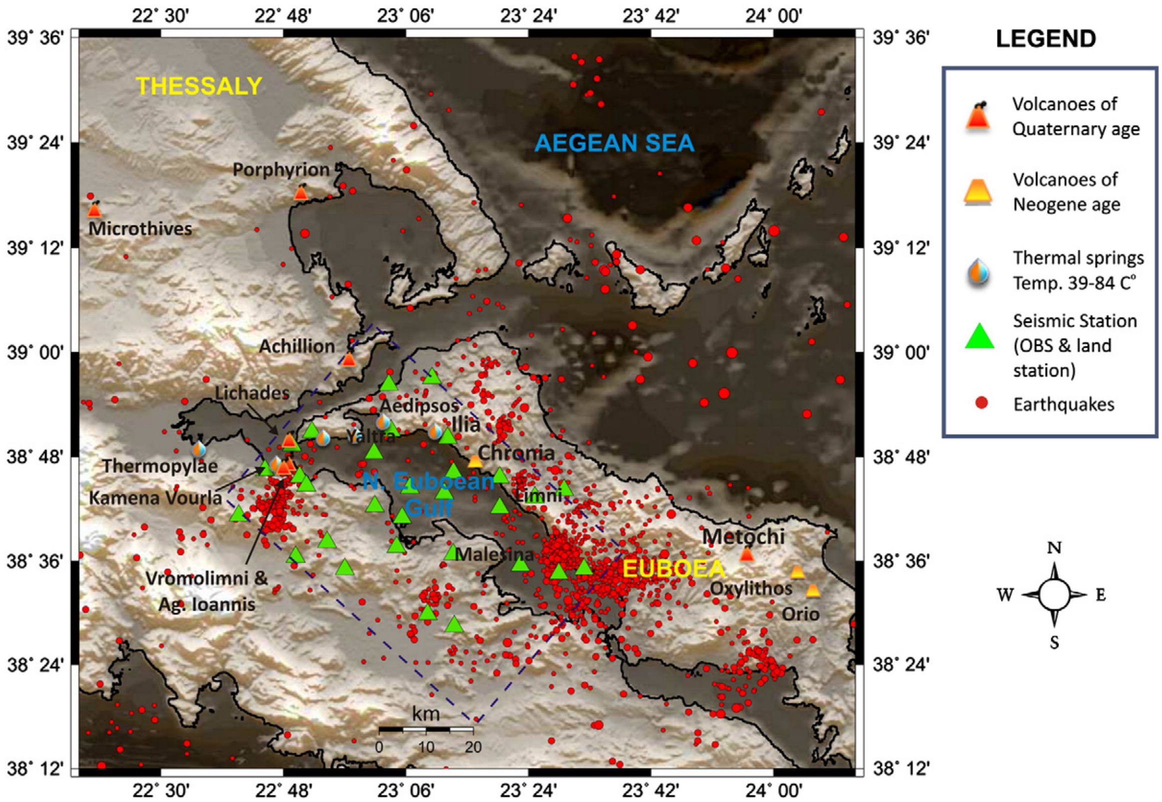

Fig. 1. Map of the central-east Greece presenting the volcanic centres and the sites of the most important thermal springs. The dashed line box indicates the study area. The seismograph stations and the initial epicentres (Papoulia et al., 2006) of the recorded seismicity are also depicted in the map.

dating have shown that the volcanism of central-east Greek mainland and North Euboea is of Miocene to Holocene age (Pe-Piper and Piper, 2002). In fact, a cluster of volcanic centres concentrated in this area and described by several authors. Most of the volcanic centres are geologically young given that at all evidence they were activated during Pliocene and Quaternary (Fytikas et al., 1976; Bellon et al., 1979; Papadopoulos, 1982, 1989; Pe-Piper and Piper, 1989, 2002). The Orio and Oxylithos volcanoes, eastern part of Euboea island, were dated to be of Lower Miocene age. Of questionable age is the volcanic centre at Chronia (Thorio) in NW Euboea. Initially it was considered to be of Neogene (Aronis, 1955) or Quaternary age (Tataris, 1960; Papastamatiou, 1961). Stratigraphic considerations however, of Papayiannopoulou (1971) suggested that this volcano is at least of Pre-Sarmatian age. Katsikatsos et al. (1980) have mapped the outcropping volcanic rocks as altered andesite of Lower Miocene age. They reported that it seems to underlie the fine-grained members of the previous Neogene system.

In addition to volcanism, various fields of hot springs with surface temperatures ranging from 39° to 83° are situated along both coasts of the North Euboean Gulf (Fig. 1): Kamena Vourla (43°), Thermopylae (41°), Yaltra (43.5°), Aedipsos (83°) and Ilia (39°) (see also Papadopoulos, 1982 and Gioni-Stavropoulou, 1983).

Table 1
Velocity model used by Papoulia et al. (2006) for the hypocentral location.

Local velocity model Velocity Vp (km/s)	Depth (km)
4.0	5
6.3	20
6.7	32
8.0	sub-Moho

In earlier studies (e.g. Fytikas et al., 1976; Bellon et al., 1979) it was suggested that the Plio-Quaternary volcanism in central-east Greek mainland and the island of Euboea belongs to the inner part of the South Aegean volcanic arc. The associated seismicity occurring at intermediate depths of around 150 km results from the subduction of the Ionian oceanic lithosphere below the Hellenic arc. The origin of this volcanism has been disputed by Papadopoulos, 1982, 1989, because the volcanism in central-east Greece has different geophysical and geochemical features from that of the South Aegean Sea. In fact, in the South Aegean volcanic arc the geochemical type of lavas is typical calc-alkaline. In the central-east Greek mainland, chemistry of the lavas ranges from calc-alkaline to weak calc-alkaline and to weak alkaline. Affinity and earthquake foci are much shallower than those of the Cretan Sea.

In the North Euboean Gulf region the Triassic–Jurassic limestones of the Sub-Pelagonian zone overlay the Permo-Triassic volcanosedimentary complex (see the geological map of Fig. 2). This, in turn, is underlain to an ophiolitic nappe tectonically emplaced over the Sub-Pelagonian sediments in the Late Jurassic to Early Cretaceous. The ophiolitic nappe is outcropping at many places of the study area with peridotite or other ultramaffic rocks (area between Limni and Mantudi, Vassilika, SW of Malesina Peninsula, Kallidromo etc.). Younger sediments of Pliocene to Quaternary age are widely extended in this region. The Plio-Pleistocene, Pliocene and Mio-Pliocene sediments consist mainly of sands, clays, marls and conglomerates. Additionally, there are few basins in the Maliakos Gulf, Atalanti and Istiea covered by Holocenic alluvial deposits. Finally, at the volcanic centres of Lichades, Kamena Vourla and Chronia there is andesitic outcropping due to the past volcanic activity.