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The April–June 2007 Trichonis Lake earthquake swarm (W. Greece): New implications toward the causative fault zone

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ABSTRACT

On 10 April 2007, three moderate earthquakes with $M_w = 4.9–5.1$ occurred in the vicinity of Trichonis Lake (W. Greece). A local network composed of 12 three-component digital seismographs was installed in the epicentral area and recorded more than 1600 events. The double-difference algorithm HYPODD, incorporating both catalog and waveform cross-correlation differential travel-time data, was applied for the successful relocation of 1490 earthquakes. The latter led to the distinction of a main NW-SE trending and NE-dipping zone, as well as of three neighboring faults; a conjugate NW-SE striking and SW-dipping marginal fault mapped along the northeastern flanks of the lake; a E-W trending and south-dipping low-angle normal fault, possibly related to the major Agrinio Fault Zone (AFZ), parallel to the northern bank of the lake; a NE-SW striking and NW-dipping normal fault, likely related to a segment of the active Evinos fault, located south of the lake. Calculation of the Coulomb stress induced by the combination of the 1975 $M_w = 6.0$ event and the three largest events of 10 April 2007 on the inferred structures, reveals that most of the seismicity lies within the "stress-loaded" region, except for the westernmost activity, which probably belongs to the deep part of the AFZ. A total of 178 reliable focal mechanisms were determined by regional and local body-wave modeling (5 largest events) and P-wave first motion polarity data. The types of the obtained focal mechanisms are predominantly normal and strike-slip, however, numerous earthquakes were found to exhibit reverse faulting. Inversion of focal mechanism data showed that the prevailing principal horizontal component σ_3 is quite homogeneous throughout the activated area with a roughly NW-SE trend, parallel to the strike of the Hellenides. On the contrary, the compressional field σ_1 appears in two patterns: NE-SW trending onshore and NW-SE trending beneath the lake. This apparent rotation of σ_1 by 90° reveals a complex system enclosed by the suggested NW-SE trending antithetic faults in depths between 7 and 9 km. The calculated stress ratios beneath the lake imply that vertical forces are close to the overburden pressure. The overall inferred stress pattern is rather linked to topographic variations, locally imposing increase or decrease of the vertical forces. The presence of the water in the lake possibly plays an additional important role, penetrating through the bedrock, reducing the friction coefficient, while the pore pressure and, consequently, the effective stress increase. Thus, shearing along mature fractures is enhanced, likely yielding the observed diversity.

1. Introduction

During April–June 2007, a seismic swarm took place in the area of Trichonis Lake, a rapidly deforming thrust and fold zone in Western Greece. The activity started on 10 April 2007, when three moderate size shallow earthquakes of $M_w = 4.9–5.1$ took place within a time interval of 7 h. Those were followed by a large number of events. The scope of the present work is to analyze in detail the seismic process's pattern, taking advantage of the waveform recordings from a dense local seismological network that was installed by our working group on 11 April 2007 and recorded the whole sequence.

Trichonis is the largest natural lake in Greece, lying between Amvrakikos gulf to the north and Patras and Corinth gulfs to the south, striking almost parallel to them (Fig. 1). Trichonis Lake, like Amvrakikos, Corinth and Patras gulfs, is a late Plio-Quaternary extensional basin, created by back-arc extensional faulting in western Greece (Clews, 1989). Most of these NW-SE structures are reverse and strike-slip faults (King et al., 1993; Hatzfeld et al., 1995; Vassilakis et al., 2011). This region plays a key role to the transition

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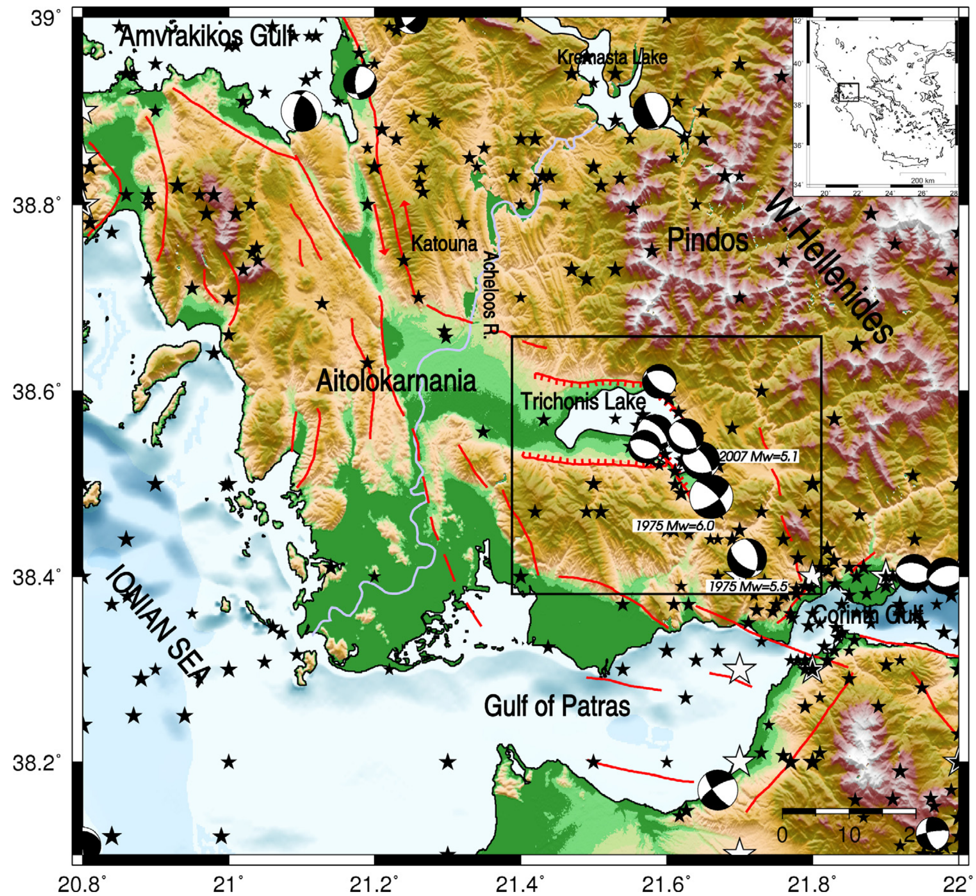

Fig. 1. Seismotectonics of the broader study area. The main tectonic features, observed (continuous lines) or inferred (dashed lines), are from Sorel (1989), Waters (1993), Doutsos et al. (1987) and Lekkas and Papanikolaou (1997). Barbed lines denote normal faults in the study area. Epicenters of historical (Papazachos and Papazachou, 2003) and instrumental earthquakes (since 1900, $M_s \geq 4.0$, Makropoulos et al., 2012) are represented with white and black-colored stars, respectively. Beachball diagrams are available lower hemisphere focal mechanisms for events with $M_w \geq 5.5$ (CMT solutions, Kiratzi et al., 2008). The study area is bounded by the black rectangle. The embedded map of Greece at the top-right corner indicates the selected area (black rectangle).

from compressional mechanics observed along the Hellenic trench (Hatzfeld et al., 1995) to extensional deformation observed in continental Greece (Armijo et al., 1992). In addition, Trichonis area constitutes the boundary of the Corinth rift propagation to the west, toward the Hellenic arc, at a rate of ~25 mm/yr (Briole et al., 2000). It is a typical pull-apart basin system, governed by two major NW-SE striking, left-lateral strike-slip faults (Vassilakis et al., 2011). Two segmented E-W trending antithetic normal faults, buried by Pleistocene deposits and thick alluvial cones, have been mapped along the margins of the lake (Doutsos et al., 1987). The major structure is a north-dipping normal fault which bounds the south shore of the lake. Although there is no direct association of this fault with large instrumental or historical earthquakes, Goldsworthy et al. (2002) have reported evidence of its relative youth in the geomorphology and the drainage system of the area.

According to both historical and instrumental seismicity (Fig. 1), the area has not suffered frequent strong earthquakes in the past (Ambraseys, 2001a,b; Papazachos and Papazachou, 2003; Makropoulos et al., 2012). The strongest known event that has occurred in the region is the 31 December 1975 (M_w = 6.0) earthquake located 3 km SE of Trichonis Lake (Delibasis and Carydis, 1977). Previous studies in the broader study area (Hatzfeld et al., 1995; Haslinger et al., 1999; Kiratzi et al., 2008; Evangelidis et al., 2008) employed data that were obtained by more sparse seismological networks, compared to the one of the present work. Thus, they were insufficient to provide detailed information concerning the complex local active structures which this study managed to delineate.

The motivation for this study was to shed light on the geodynamics of this complex area by combining both local high quality data and modern seismic analysis techniques. Earthquakes were initially located using an optimized local velocity model that provided minimum location errors and temporal residuals. Following, we performed hypocentral relocation aided by waveform cross-correlation and multiplet clustering, in order to obtain accurate estimates of the mechanical properties of the causative structures at various scales. The spatiotemporal analysis permitted the examination of possible patterns in the evolution of the seismic swarm. Focal mechanisms were calculated using P-wave first motion polarities for a large number of small events, combined with moment tensor inversion for the larger ones. Those fault plane solutions revealed a complex and diffuse configuration that involved all types of faulting. This motivated us to apply a spatial stress inversion scheme (Hardebeck and Michael, 2006) which enabled us to obtain a clearer image of the local principal stress-field components distribution. In order to evaluate the regional seismic hazard, we examined whether the initiation of the 2007 swarm was induced by static stress load. For this, we computed the Coulomb stress changes upon the resolved structures considering the most recent M_w = 6.0, 1975 earthquake (Kiratzi et al., 2008) which occurred at the south-eastern margin of the lake, in conjunction with the three largest 2007 events. The thorough investigation of the 2007 swarm presented in this work allowed for an adequate determination of the