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Static stress changes and fault interactions in Lefkada Island, Western Greece

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ABSTRACT

The complicated tectonics of the Mediterranean region, dominated by the subduction of the African plate under Eurasia, affects the whole of Greece. A significant extension rate across the Aegean sea is estimated from satellite geodetic observations, while intense seismicity is observed in parts of the Hellenic arc, manifested by strong earthquakes ($Ms > 6$) of intermediate depth that take place along it.

In Western Greece, the Ionian Islands are situated in a transitional zone (from the Hellenic subduction to the Adriatic collision), characterised by a high crustal deformation rate as revealed by the high seismicity of this zone, the highest in Greece, and the GPS velocity field estimated for the region. In this part of the Aegean plate, transcurrent fault systems dominate, one of which is the Kephalonia Transform Fault (KTF), located offshore the Kephalonia and Lefkada Islands, with a right-lateral slip of the order of 3 cm/year.

In the present work an attempt is made to assess the Coulomb stress change associated with well documented earthquake activity, from 1973 to 2003, in the Ionian Island of Lefkada. The results of this study suggest that the early 1973 event did not influence any subsequent moderate earthquakes in the area. On the other hand, the 1994 earthquake may have triggered the north segment of the 2003 event, while the 2003 earthquake ruptured two segments with the north one initiating rupture on the south segment.

1. Introduction

The Ionian region, part of the north-western termination of the Hellenic arc, exhibits large rates of continental crustal deformation accompanied by very high seismic activity, the highest in Greece as well as in Europe. Its tectonics is governed by the subduction between the African and Eurasian plates on the one hand and the motions of the Aegean and Adriatic microplates on the other. The African plate, with the Adriatic and the Aegean microplates form a triple junction in the Ionian Sea, where the right-lateral strike-slip Kephalonia Transform Fault (KTF) meets the front of the Hellenic subduction zone (Fig. 1). The region is dominated by compressional stresses (Lagios et al., 2007), while the subducting Ionian lithosphere appears to be of oceanic character (Suckale et al., 2009).

In comparison with other subduction zones worldwide, the western Hellenic convergence of the Greek landmass with the Ionian Sea basin appears unusual, as its overriding upper plate has a much faster absolute velocity toward the plate boundary than the subducting lower plate does, as is inferred from geological data and GPS measurements (Fig. 2) (Reilinger et al., 2006; Hollenstein et al., 2006; Floyd et al., 2010). The rate of the seismicity due to the convergence between these plates has been found to be small, an indication that the subduction occurs mainly aseismically. However, recent studies suggest that instead seismic coupling may take place due to the break off of the lower slab; cessation of the slab pull causes the plate above it to rebound and the upper plate to move fast (Laigle et al., 2002, 2004). It is estimated that although seismic moment release rate is moderate, it is consistent with significant seismic coupling indicated by the fast motion of the upper plate. This result is also consistent with the occurrence of major earthquakes in the region, which are known to have maximum magnitudes of ~7.2, depths of 10–15 km, and recurrence times of ~50 years (Laigle et al., 2004).

The offshore fault system (KTF), lies to the west of the island of Kephalonia, an area with a deep bathymetric trough striking at N20°E with water depths of more than 3 km (Sachpazi et al., 2000; EERI Special Earthquake Report, 2003), and forms the western termination of the Hellenic subduction zone. It consists of

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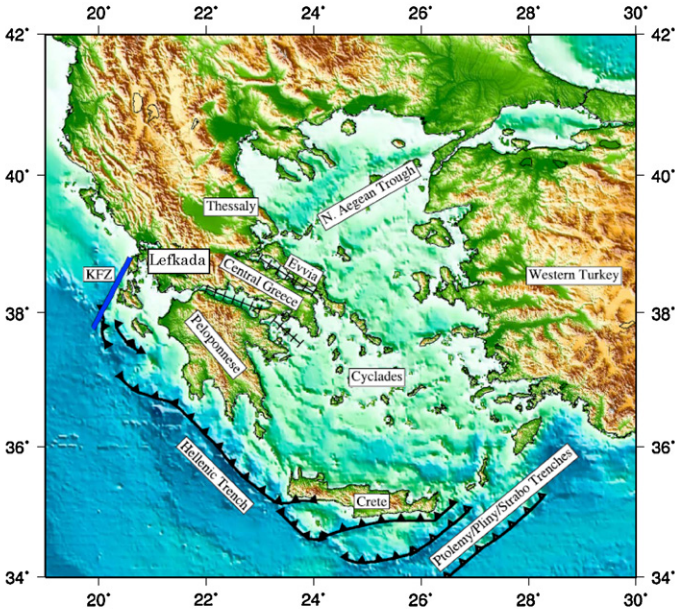

Fig. 1. Setting of the Aegean. Labels show places referred to in the text. Lines with teeth show the locations of reverse faults of the Hellenic Trench system. None of the trenches coincides with the true plate boundary. Blue line marked KFZ shows the Kefalonia right-lateral strike-slip fault zone. The major gulfs are shown by crossed lines: the Gulf of Evvia, is between Evvia and Central Greece; the Gulf of Corinth lies between the Peloponnese and central Greece. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)
After Floyd et al. (2010).

two segments with different strikes: the 90 km Kephalonia fault that strikes NE and the northern segment of 40 km long striking NNE referred as the Lefkada Fault (Scordilis et al., 1985; Louvari et al., 1999; Shaw and Jackson, 2010). Shearing between the Ionian Islands and the Southern Adriatic is accommodated along the KTF (Shaw and Jackson, 2010).

Geodesy indicates the transition to be localized in a zone about 100 km wide of NE–SW right-lateral strike-slip faulting, with the KFT fault system being the most important discontinuity. The GPS velocity field for the region has a marked SW direction and indicates a gradual increase from nearly zero to the NW of Kephalonia to about 30 mm year^{-1} to the southeast of the Patras fault, where the total Aegean–African convergence appears (Fig. 2) (Hollenstein et al., 2006; Floyd et al., 2010). Thus the faulting system here consists of several branches, in a way similar to the North Aegean trough, where the intrusion of the North Anatolian fault also displays several strands (Shaw and Jackson, 2010).

The significance of the Kephalonia Transform Fault and its role to the overall geodynamic evolution of the western subduction termination with respect to the Aegean tectonics, is also pointed by Reilinger et al. (2009) who, despite to Laigle et al. (2004), propose that the westward motion of the North Anatolian Fault (NAF) into the Northern Aegean developed the rifts of Euboea and Corinth Gulfs and the KTF-successively from east to west- and completely decoupled the southern and central Aegean and Peloponnesus from the Eurasian plate. Similar remarks are mentioned in Shaw and Jackson (2010) for the Hellenic subduction zone.

The tectonics of the region is controlled by more than one type of faults since both shear and compressional fields are active, while all recent significant earthquakes refer to offshore faults, elements adding to the ambivalence of the picture. However, the present study attempts to assess the Coulomb stress change associated with adequately documented earthquake activity in the Lefkada Island region using the Coulomb V3.0 software (Toda et al., 2007). The area has suffered several times from the occurrence of medium to high magnitude earthquakes with more recent example the

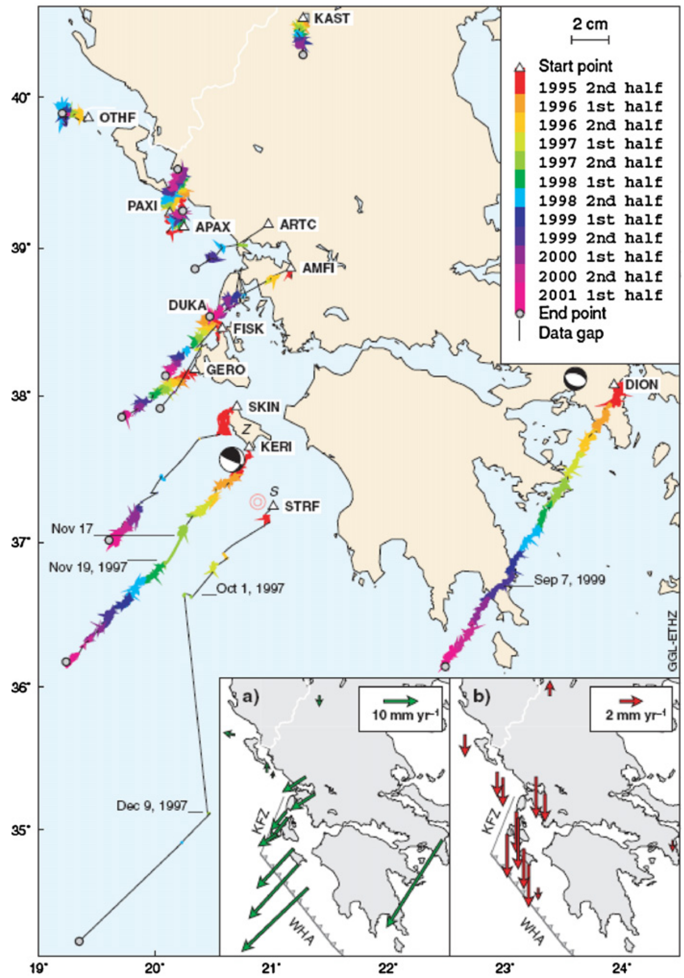

Fig. 2. GPS-trajectories of horizontal crustal motion for the time interval of 1995–2001, relative to Eurasia. The fault plane solutions represent the large earthquakes which occurred on 1997 November 18 near Strofades island (STRF station) and on 1999 September 7 in Athens, near (DION station), while the red circles mark the strong aftershocks of the Strofades earthquake. *Insets*: Horizontal (a) and vertical (b) GPS-velocities calculated by weighted linear regression of common-mode filtered coordinate time-series. For stations KERI and STRF, velocity before the Strofades earthquake is plotted. KFZ: Kephalonia Fault Zone, WHA: West Hellenic Arc, S: Strofades, Z: Zakinthos. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)
After Hollenstein et al. (2006).

August 2003 event. The implications of the 2003 earthquake on the stress conditions of the Agios Nikitas onshore fault are also discussed.

2. Static stress modelling

If stresses around an active fault, accumulated slowly, surpass the strength of the crust a fracture takes place, causing a seismic event. Part of the accumulated stress is released on this fault, while the stress field in neighbouring areas is changed. A measure of this change is the so-called Coulomb stress, which is the difference between the shear stress in the fault direction and the shear strength, assuming that the Mohr-Coulomb criterion expresses the shear strength of the faults.

Numerous studies carried out so far suggest that relatively small but sudden changes of the stress field applied on the faults may affect the rate of seismic activity in the surrounding area (King et al., 1994; Stein et al., 1994; Lin and Stein, 2004).

The Coulomb stress is calculated considering the lithosphere as a homogeneous elastic, isotropic half space, an assumption that