1. Abstract

The Mw6.4 earthquake sequence of 2015 in western Greece is analyzed using seismic data. Multiple point source modeling, nonlinear slip patch, and linear slip inversions reveal a coherent rupture image with directly toward the southwest and several moment release episodes, reflected in the complex aftershock distribution. The key feature is that the 2015 earthquake ruptured a strong asperity, which was left unbroken in between two large subevents of the Mw6.2 Lefkada doublet in 2003. This finding and the well-analyzed Cephalonia earthquake sequence of 2014 provide strong evidence of segmentation of the major dextral Cephalonia-Lefkada Transform Fault (CTF), being related to extensional duplex transform zones. We propose that the duplexes extend farther to the north and that the CTF runs parallel to the western coast of Lefkada and Cephalonia Islands, considerably closer to the inhabited islands than previously thought. Generally, this study demonstrates faulting complexity across short time scales (earthquake doublets) and long time scales (seismic gaps).

2. Historical seismicity and tectonics

The focus of this study is the 17 November 2015 earthquake (07:10:07 Greenwich Mean Time or GMT, Mw6.4), which affected the southwestern coast of Lefkada. It occurred 12 years after the 14 August 2003 Mw6.2 earthquake, which had shaken the northwestern coast of Lefkada (Fig. 1). The most prominent structure along the western coasts of the Ionian Islands is the dextral Cephalonia-Lefkada Transform Fault (CTF) zone, separating continental collision to the north with subduction to the south.

Figure 1: Seismicity along the Cephalonia Segment (CS) and the Lefkada Segment (LS) of the Cephalonia Transform Fault Zone (bold black lines). Large events are shown by gray beach balls. Red beach balls depict two major subevents of the 14 August 2003 Mw6.2 earthquake (Zahradník et al., 2005; Benetatos et al., 2007). Text above the red beach balls denotes the timing of the subevents relative to its origin time. Small red circles are aftershocks of the 2003 event, forming two well-separated clusters close to the subevents. White circles represent the seismicity after the 2003 event and before the 2015 event (seismic catalogue of the Aristotle University, doi:10.7914/SN/HT). Light blue contours denote sea bathymetry. Inset shows the position of CTF and the major tectonic elements in Greece.

3. Slip inversions

After relocation and centroid moment tensor inversion (Sokos et al., 2016), we have used three independent methods and various seismological data to analyze the rupture process of the 2015 Lefkada earthquake:

- Multiple point source (MPS) model based on iterative deconvolution using the ISOLATE code (Zahradník et al., 2005; Benetatos et al., 2007), which applied apparent source time functions (Fig. 2b) which were then inverted using the neighborhood algorithm (Sarabandi, 1999) into constant-slip elliptical patch model (Vallee and Hough, 2004).
- Near-region data (0.05-0.3 Hz) were used in combination with the empirical Green's functions method, EGF (e.g., Courboulex et al., 1993) in order apparent source time functions (Fig. 2b), which were then inverted using the neighborhood algorithm. The data were then inverted using the linear slip inversion (LSI) technique of Gallovič et al. (2015), applying (i) spatial smoothing by considering covariance function with kε decay at large wave numbers k as a prior for the slip rates and (ii) a positivity constraint on the slip rates by means of the nonnegative least squares approach (Lawsom and Hanson, 1974). The best fitting result from the LSI space-time evolution is shown in terms of slip and slip-rate snapshots in Figures 3a and 3b, respectively. Each method included a tuning of the rupture geometry to obtain the best fit with the observed data.

4. Conclusion - Relation to past events

The slip history of the previous Mw6.2 strike-slip earthquake that occurred in 2003 in Lefkada Island was analyzed by two independent groups (Zahradník et al., 2005; Benetatos et al., 2005, 2007). As shown in Figs. 4 and 5, in 2003, the initial episode of the rupture propagation stopped at the NE end of the 2003 event. After ~10 s, the second subevent of the 2003 event occurred ~20 km farther to SW, i.e., jumping over the middle fault segment, leaving it unruptured and almost free of aftershocks (Figs. 4, 5). Our study suggests that the unruptured segment remained seismically silent for 12 years and then ruptured in the 2015 earthquake. Similar complex evolution of the tectonic system has been observed elsewhere, but not commonly. For example, the 2003 and 2013 Scotia earthquakes benchmark the "coarse" pattern: the earlier earthquake is situated in between the two subevents of the latter earthquake (Ye et al., 2014). Other smaller-scale example of spatial complementarity of the slip between two earthquakes on the same fault is the 2013 Borrego, California, sequence consisting of Mw5.3 and 5.4 events separated by 1.5 h (Wei et al., 2013).

Figure 3: (a) Surface projection of the slip model obtained using the linear slip inversion (LSI) method employing strong motion waveforms from the 2003 to 2015 events separated by 1.5 h (Wei et al., 2013). The resulting model is shown by red and blue color, where the red area represents the slip that occurred in 2003, and the blue color represents the slip that occurred in 2015. The slip is shown as a rate per second. (b) Space-time evolution of the slip during the 2003 (red), 2014 (green), and 2015 (yellow) events. The gap between the two subevents comprising the 2003 event was a strong asperity that compensated its slip deficit in the 2015 earthquake. Aftershocks are marked with red stars. (c) The slip is shown as a rate per second. (d) The slip is shown as a rate per second.