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The Eastern Lower Tagus Valley Fault Zone in central Portugal: Active faulting in a low-deformation region within a major river environment

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ABSTRACT

Active faulting in the Lower Tagus Valley, Central Portugal, poses a significant seismic hazard that is not well understood. Although the area has been affected by damaging earthquakes during historical times, only recently has definitive evidence of Quaternary surface faulting been found along the western side of the Tagus River. The location, geometry and kinematics of active faults along the eastern side of the Tagus valley have not been previously studied. We present the first results of mapping and paleoseismic analysis of the eastern strand of the Lower Tagus Valley Fault Zone (LTVFZ). Geomorphological, paleoseismological, and seismic reflection studies indicate that the Eastern LTVFZ is a left-lateral strike-slip fault. The detailed mapping of geomorphic features and studies in two paleoseismic trenches show that surface fault rupture has occurred at least six times during the past 10 ka. The river offsets indicate a minimum slip rate on the order of 0.14–0.24 mm/yr for the fault zone. Fault trace mapping, geomorphic analysis, and paleoseismic studies suggest a maximum magnitude for the Eastern LTVFZ of $M_w \sim 7.3$ with a recurrence interval for surface ruptures ~1.7 ka. At least two events occurred after 1175 ± 95 cal yr BP. Single-event displacements are unlikely to be resolved in the paleoseismic trenches, thus our observations most probably represent the minimum number of events identified in the trenches.

1. Introduction

Active faulting within major river valleys poses a seismic hazard which, given the concentration of both infrastructure and population typically located in such environments, is often associated with a significant seismic risk.

The Lower Tagus Valley (LTV) is an NNE–SSE trending valley located in the southwestern region of the Iberian Peninsula. It includes part of the Lisbon Greater Area — the most developed and densely populated region of Portugal. According to the most recent studies, the LTV displays the highest levels of both seismic hazard (e.g., Vilanova and Fonseca, 2007; Giardini et al., 2014) and seismic risk (Silva et al., 2014) in Portugal.

Several destructive earthquakes have affected the valley during historical times. Some of the earthquakes that caused serious damage and many casualties along the valley have been associated with the Lower Tagus Valley Fault Zone (LTVFZ). However, both the location and the kinematics of the LTVFZ remained elusive and controversial for decades: the fault has been considered a left-lateral fault by Fonseca (1989) and Fonseca and Long (1991), a thrust fault by Cabral (1993), and a normal fault by Ribeiro et al. (1996). Recently, Besana-Ostman et al. (2012) provided the first compelling evidence of active left-lateral faulting along the western side of the Tagus River, herein called the Western LTVFZ. The current paper extends the results of Besana-Ostman et al. (2012) to the eastern side of the Tagus River and aims to shed some light into the nature of the fault zone and its characteristics.

We describe the deformational style and paleoseismic history of the newly mapped eastern fault traces, herein called the Eastern LTVFZ. This study involved 1) geomorphic mapping of active fault scarps and offset landforms; 2) paleoseismic trenching across fault scarps in order to establish the timing of past surface fault displacements; and 3) acquisition of P-wave seismic reflection data to study the fault geometry at depth. Both fault traces and data from the trenches were used to evaluate possible rupture scenarios and earthquake magnitude and recurrence. We have also analyzed offsets observed along the drainage network in order to obtain a minimum slip rate for the fault. Our study contributes new data that are essential for the evaluation of seismic hazard in the region.

2. Overview of the regional tectonic setting

The Iberian Peninsula is located within the Eurasian plate, close to its southern boundary with the African plate (Fig. 1a). While the central

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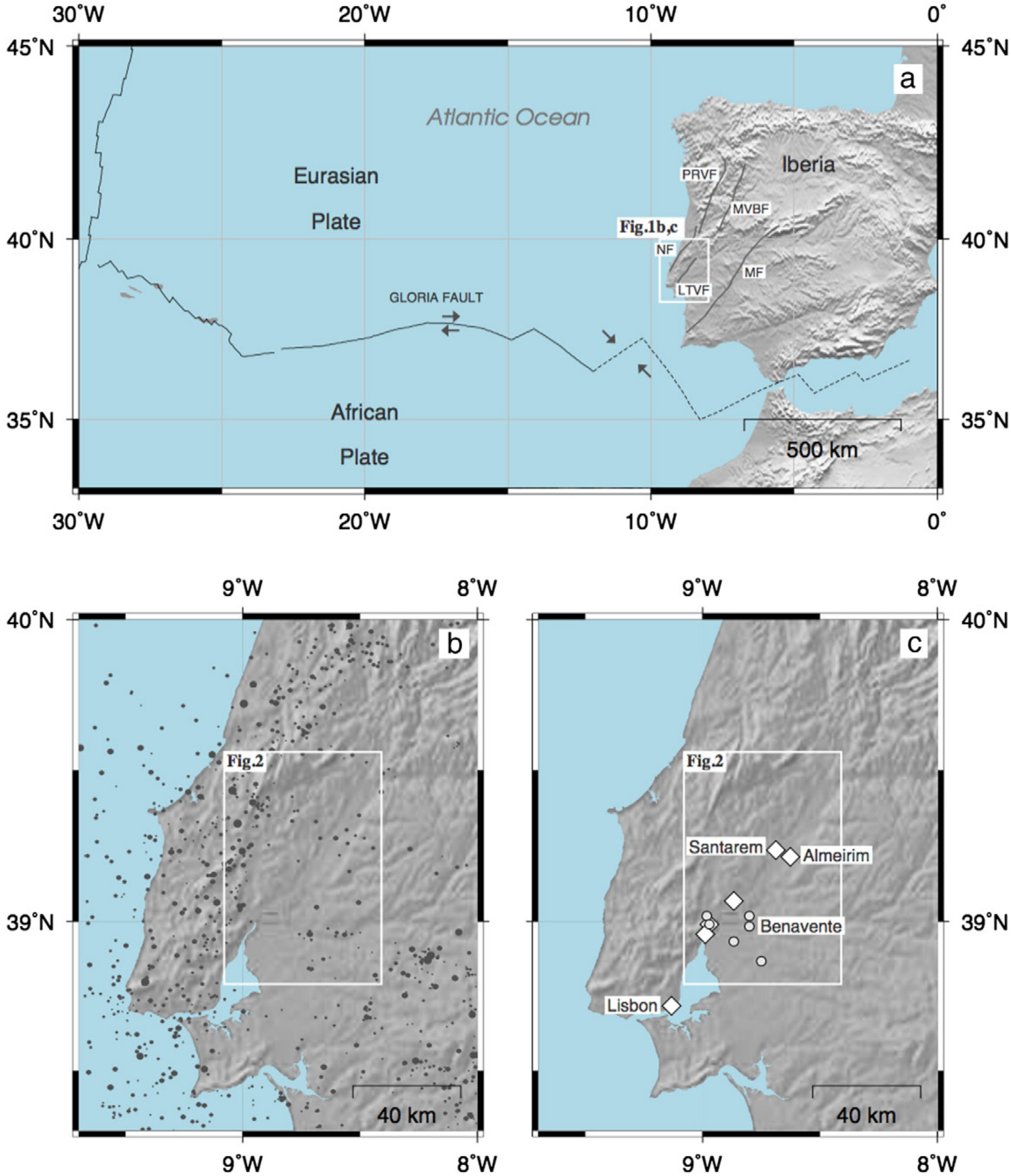

Fig. 1. a) General tectonic setting showing the location of the study area. The major intraplate faults depicted are: PRVF — Penacova–Régua–Verin Fault; MVBF — Manteigas–Vilariça–Bragança Fault; NF — Nazaré Fault; LTVF — Lower Tagus Valley Fault; MF — Messejana Fault; b) instrumental seismicity since 1960 showing magnitudes $M_L \geq 1$ according to Carrilho et al. (2004), updated up to 2013 with data from Instituto Português do Mar e Atmosfera; and c) high intensity datapoints (intensities larger than VIII–IX) for 1531 earthquake (MSK scale; diamonds) and 1909 earthquake (MM scale; circles) according to Justo and Salwa (1998) and Teves-Costa and Batlló (2011), respectively.

portion of the Azores-Gibraltar plate boundary is well defined by the Gloria dextral transform fault, west of 14°E the boundary becomes complex and diffuse and exhibits transpressional tectonics. The present-day convergence rate between the Eurasian and African plates has been estimated as 4–5 mm/yr (e.g., DeMets et al., 2010; Fernandes et al., 2003). Continuous geodetic data show that Iberia behaves as a rigid-block with respect to Eurasia, with mean-root-square misfit of site velocities of 0.85 mm/yr (Fernandes et al., 2007).

The basement of Iberia, known as the Iberian Massif, is composed of Precambrian and Paleozoic rocks, accreted together due to the Hercynian orogenic processes that took place during the Carboniferous (e.g., Ribeiro et al., 1979). A dense network of long NNE–SSW to NE–SW trending faults, formed during the Late Carboniferous, dissects the Western Iberian Massif (e.g., Arthaud and Matte, 1977). These faults have been reactivated in subsequent tectonic regimes. During the extensive tectonics associated with the Atlantic rifting event in the Mesozoic, the Hercynian faults controlled the location of the basins (e.g., Wilson, 1975; Masson and Miles, 1984). This set of basins includes the Lusitanian Basin and The Lower Tagus Basin, the latter of which comprises our study area. The Lusitanian basin was structurally inverted in the Cenozoic during compressive tectonics related to Eocene Alpine orogenic processes and again during Africa–Eurasia convergence from Late Miocene onwards (Curtis, 1993, 1999).

Some of the inherited basement faults in western Iberia are considered to be active in the current stress regime. Active tectonic studies indicate that the Manteigas–Vilariça–Bragança fault, a 250 km-long sinistral strike-slip structure located in NE Portugal (Fig. 1a) is active; using a 3-D trenching technique Rockwell et al. (2009) estimated a