Characterization of an Intraplate Seismogenic Zone Using Geophysical and Borehole Data: The Vila Franca de Xira Fault, Portugal

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Abstract

The Vila Franca de Xira (VFX) fault is a regional fault zone located about 25 km northeast of Lisbon, affecting Neogene sediments. Recent shear-wave seismic studies show that this complex fault zone is buried beneath Holocene sediments and is deforming the alluvial cover, in agreement with a previous work that proposes the fault as the source of the 1531 Lower Tagus Valley earthquake. In this work, we corroborate these results using *S*-wave, *P*-wave, geoelectric, ground-penetrating radar and borehole data, confirming that the sediments deformed by several fault branches are of Upper Pleistocene to Holocene. Accumulated fault vertical offsets of about 3 m are estimated from the integrated interpretation of geophysical and borehole data, including 2D elastic seismic modeling, with an estimated resolution of about 0.5 m. The deformations affecting the Tagus alluvial sediments probably resulted from surface or near-surface rupture of the VFX fault during M ~ 7 earthquakes, reinforcing the fault as the seismogenic source of regional historical events, as in 1531, and highlighting the need for preparedness for the next event.

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Supplemental Material

Introduction

The metropolitan area of Lisbon and the Lower Tagus Valley (LTV) region are roughly located 400 km north of the Africa–Iberia plate boundary zone (Fig. 1). In spite of a moderate seismicity (Fig. 1), the region experiences occasionally destructive earthquakes, generated at the plate boundary or at local intraplate faults. Though low slip rates have been estimated for these local, regional faults, they can generate relatively frequent moderate to large (**M** 6.5+) earthquakes, causing major damage and loss of lives (e.g., Justo and Salwa, 1998; Cabral *et al.*, 2003; Teves-Costa *et al.*, 2019). This short recurrence time may be due to the existence of multiple active faults and time clustering induced by stress changes caused by fault interaction and/or by variable rates of Coulomb stress accumulation.

One of these regional faults extends to the northeast of Lisbon, crossing the Vila Franca de Xira (VFX) city (Fig. 2) only 25 km from the densely populated Portuguese capital. This tectonic structure was generated in the Mesozoic as a large normal-fault zone and was reactivated as an oblique left-lateral reverse fault in the Cenozoic. Continued slip on the fault zone certainly postdates tilted and faulted Miocene (Tortonian) sediments that are overthrust by Jurassic rocks south of VFX, as also suggested by legacy hydrocarbon exploration seismic data (Cabral *et al.*, 2003; Carvalho *et al.*, 2006). These data show that the VFX fault is part of a fault system in the upper crust (e.g., Rasmussen *et al.*, 1998) and that it extends northeast and southwest of its known outcrops, hidden beneath the alluvial cover of the Tagus River (Fig. 2).

Based on seismic intensity distribution data, the VFX fault is thought to have generated several destructive earthquakes that damaged the city of Lisbon and neighboring localities, as in 1344 (e.g., Cabral *et al.*, 2003; Ferrão *et al.*, 2016) and 1531 (Justo and Salwa, 1998; Baptista *et al.*, 2014; Ferrão *et al.*, 2016). The 1531 (modified Mercalli intensity VIII–IX) Lisbon earthquake caused more than 1000 fatalities (Justo and Salwa, 1998; Baptista *et al.*, 2014). However, no direct evidence of post-Miocene fault

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