

Signature of fault zone deformation in near-surface soil visible in shear wave seismic reflections

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[1] Small-throw seismogenic fault segments hidden in the Holocene sediments are crucial but difficult targets in seismic exploration. We report here the detection of the deformation pattern and a concealed fault segment in the unconsolidated sediments at Vila Franca Xira, Portugal, through identification in shear wave reflection data of multiple signatures of ductile deformation associated with faulting. We find step-like changes in the stacking velocity along a shallow subsoil layer boundary, indicating synsedimentary faulting. We also recognize a consistent distortion in the moveout of the reflection events in the raw shear wave data. Synthetic modeling of seismic data helps in interpreting these observations and identifying backscattered energy from a steeply dipping shallow fault zone. Prior to this finding, there was no evidence for Holocene activity of this fault, although the fault is considered to be the most probable source for the disastrous 1531 earthquake. **Citation:** Ghose, R., J. Carvalho, and A. Loureiro (2013), Signature of fault zone deformation in near-surface soil visible in shear wave seismic reflections, *Geophys. Res. Lett.*, *40*, doi:10.1002/grl.50241.

1. Introduction

[2] Seismogenic fault segments can be present concealed in shallow subsoil. In areas where such faults are anticipated, it is important to know the location and the structure of these faults in order to perform realistic modeling of ground motion, for seismic microzonation studies, to assess the repeat times of past earthquakes, and for characterizing the hydrogeological framework of the subsurface.

[3] Faulting-related deformation in the Holocene soft sediments differs greatly from the brittle deformation in consolidated formations. Unconsolidated and partly consolidated mud generally has porosities between 40% and 80% and may thus undergo strains by loss of pore water alone [Compton, 1985]. Ductile soft-sediment deformations result in grain reorganization, disaggregation bands, intrusion of liquified sand along weak zones, water escape structures, slumping, step-like undulation of a layer boundary due to synsedimentary faulting, mixing of material in the shear zone, and wedge-like penetration of material with a different

hydromechanical property [e.g., Neuwerth *et al.*, 2006; van Loon, 2009; Fossen, 2010; Alsop and Marco, 2011].

[4] Two common approaches for investigating faults in shallow subsoil are geophysical exploration and shallow trenching. Trenching and drilling offer directly the ground truth, but being invasive and localized in nature, they cannot be carried out in urbanized or cultivated areas and are done only when the location of a shallow fault is known or strongly anticipated. Among the geophysical methods, high-resolution seismic reflection offers both good resolution and depth penetration. There are numerous earlier studies using *P* and/or *S* wave reflections, sometimes together with other geophysical methods and boring or trenching, to investigate shallow fault zones [e.g., Woolery *et al.*, 1993; Benson and Mustoe, 1995; Floyd *et al.*, 2001; Williams *et al.*, 2001; Wang *et al.*, 2004; Sugiyama *et al.*, 2003; Harris, 2009; Campbell *et al.*, 2010]. If the fault throw is significant, causing displacement of several subsurface layers, then that can be seen clearly in surface seismic reflection data. However, in the presence of high background noise in data and/or when the fault displacements are small or the shallow fault zone is steeply dipping, the detection and interpretation are difficult.

[5] At a site in the seismically active Lower Tagus Valley region, Portugal, the presence of small-throw (< 2 m) active fault segments was suspected in prior studies but could not be resolved and localized. Recently, we have found signatures of faulting-related deformation in seismic shear wave data. This finding highlights not only the possibility of detecting a small-throw fault segment buried in soil through the recognition of multiple pieces of evidence in the seismic wavefield, with essential support provided by numerical modeling, but also, for the first time, the signature of ductile soft-sediment deformation in the shear wave data and the evidence of Holocene activity of this fault. In this letter, we present these findings.

2. Study Area and Prior Investigations

[6] The western part of central Portugal has experienced large earthquakes from time to time. In many occasions, these events migrate to the inland regions, and major faulting occurs at shallow depths within the Quaternary sediments [Rockwell *et al.*, 2009]. These shallow faults, typical of intraplate low-slip-rate regions like the Iberian Peninsula and the Rhine-Graben, have generally steeply dipping fault planes [e.g., Perea *et al.*, 2003; Ferry *et al.*, 2005], and they can produce moderate to large earthquakes causing major damage and loss of lives. These faults are difficult to identify since small scarps generated by earthquakes are easily erased by surface processes during the long return period.

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