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"High resolution seismic imaging of an active fault in the eastern Guadalquivir Basin (Betic Cordillera, Southern Spain)"

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ABSTRACT

We calculated the high resolution seismic velocity, Poisson's ratio, crack density and saturation ratio structures in and around the source areas of the Torreperogil seismic series (October 2012–April 2013). This seismic series, characterized by a large number of low magnitude (below *Mw* 3.7 or *Md* 3.9) and very shallow micro-earthquakes, took place in the Guadalquivir Basin, a large flexural foreland basin with a linear ENE–WSW trending bounded to the north by the Iberian Massif and to the south by the Betic Cordillera and filled from a middle Miocene to Plio–Quaternary sedimentary sequence.

In the upper layers of the crust, strong low-velocity anomalies are extensively distributed under the central zone, which together with high Poisson's ratio and crack density values may correspond to rocks which are less likely to fracture, perhaps due to the accumulation of tectonic and seismic stress. 93% of the earthquakes occurred at depths of up to 8 km, which could indicate that the base of the seismogenic zone lies at this depth. The seismic series was concentrated in layers of strong structural heterogeneities (in the boundary area between low and high anomalies), which were likely to generate earthquakes due to differential strain accumulation beneath the region. The high velocity areas are also considered to be strong yet brittle parts of the fault zone, which may generate earthquakes (at depths of between 5 km and 9 km). By contrast, low velocity areas are less prone to fracture, allowing seismic slippage to take place (from 2 to 4 km depth).

The best estimate of the depth of the main shock (m_{bLg} 3.9) is 7.6 km, which could tend to nucleate at the base of the seismogenic zone, at the "fault end" on the boundary between a low velocity zone to the east and a high velocity zone to the west, indicating the fault plane which separates both areas laterally. Assuming that this seismic contrast is one of the main Torreperogil faults it could imply that stress has accumulated in an existing fault zone with lateral heterogeneity in velocity.

1. Introduction

If we analyze the distribution of the V_P and V_S fields for a particular site, we can also estimate its Poisson's ratio, crack density and saturation fields. Seismic wave velocity across the earth's interior depends however on many factors and it is often difficult to isolate one specific factor from the others. Poisson's ratio (σ) is directly related to V_P/V_S for the same lithology. In the shallowest layers of the crust the velocity is strongly influenced by a variety of physical factors, such as the presence of dry (Stan-Kleczek and Idziak, 2008) and saturated cracks (Berryman, 2007). Fluid-filled separate crack systems control the polarization of *S* waves (de Lorenzo and Trabace, 2011). An open, fluid-filled fracture has a stronger effect on the wavefield than the wet and dry multiple crack models, because an open fracture would have a stronger dissimilarity to the background rock (Hall and Wang, 2012). Laboratory experiments show that crack porosity significantly decreases seismic velocities even in low porosity igneous rock (Birch, 1960). If we consider a distribution of many fractures, even when the overall density of fractures is held constant, longer fractures attenuate seismic energy more than smaller ones (Hall and Wang, 2012). The development of crack damage influences changes in physical properties, such as permeability, and may be indexed relative to measureable changes in modulus or anomalously low seismic wave velocities (Vinciguerra et al., 2005; Benson et al., 2006, in Faoro et al., 2013). Permeability decreases at low differential stresses and increases at intermediate differential stresses up to a steady value at failure (Faoro et al., 2013).

Variations in the material properties of a fault zone may be responsible for variations in its seismogenic behavior (Tian and Liu, 2013),

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and these variations influence the seismic velocity that can be imaged using the seismic tomography method (Zhao et al., 2007).

In a previous study (Serrano et al., 2014) we applied the same techniques to the tomography of a wide area in the Granada Basin. In this paper we applied the methodology in a narrower area around the town of Torreperogil (province of Jaén, in Andalusia, southern Spain). This area had a high density of data due to the occurrence of a seismic tectonic series, which allowed us to create a high resolution tomographic image of the site.

2. Geological and seismotectonic setting

The study area is located (Fig. 1) in the north-easternmost part of the Neogene Guadalquivir Basin, a large flexural foreland basin (Platt et al., 2013) with a linear ENE–WSW trending bounded to the north by the Iberian Massif and to the south by the Betic Cordillera and filled from a middle Miocene, more precisely Late Langhian (Fernández et al., 1998) to Plio–Quaternary sedimentary sequence (e.g., Sierro et al., 1996). The most active sedimentary period was the Tortonian (Martínez del Olmo et al., 1984) and since then the evolution of this basin has been conditioned by the tectonics of the Betic Cordillera, such that it becomes progressively narrower and shallower towards the east. Fig. 2 shows the geological map of the area and the distribution of the 6428 events used for the tomography inversions.

Therefore, its southern border is dominated by a Burdigalian to early Serravallian synorogenic mélange unit made up above all of Triassic clays and evaporites, which marks the peak of shortening across the Betic Cordillera (Pedrera et al., 2013). The south-western Iberian Massif Variscan basement is formed by pre-Ordovician to Carboniferous rocks (Martínez Poyatos et al., 2001). The pre-Ordovician rocks include black schists, meta-greywackes, amphibolites and black quartzites, a succession of discordant volcano-debris rocks intercalated with granitoids and carbonated detrital formations from the Lower–Middle Cambrian age, with a maximum thickness of about 6000 m. These formations are covered by a lithological sequence of Ordovician to Devonian rocks with a maximum thickness of 1000 to 2000 m, alternances of quartzitic and slaty formations with very low metamorphic grade, i.e. Armorican quartzite (Floian age). The Carboniferous rocks correspond to the facies Culm of the Variscan orogeny and are about 6000 m thick. Their lithology consists of alternating slates and greywackes levels of volcanic rocks, conglomerates and limestones, intruded by granodiorites from the Los Pedroches batholith (Martínez Poyatos et al., 2001).

The Mesozoic sedimentary series are composed of Triassic detritical and evaporitic materials followed by Jurassic carbonates, mainly limestones and dolomites. The following materials from the Guadalquivir Neogene Basin appear on top of the Mesozoic sequence: a) autochthonous Upper Tortonian calcarenites, b) Messinian marls and, c) allochthonous materials from the Extensional Subbetic Complex (Rodríguez-Fernández et al., 2013).

The Neogene sedimentary sequence starts with an upper Tortonian mixed siliciclastic and bioclastic unit that consists of calcarenite/calcirudite and breccias/conglomerate layers with intercalated silts and marls towards the south. Breccias and conglomerates contain clasts of Jurassic dolomites embedded in a calcarenitic matrix. The marls thicken basinwards and alternate with bioclastic sandstone levels towards the top of the sequence (Morales et al., 2014). Recent seismic

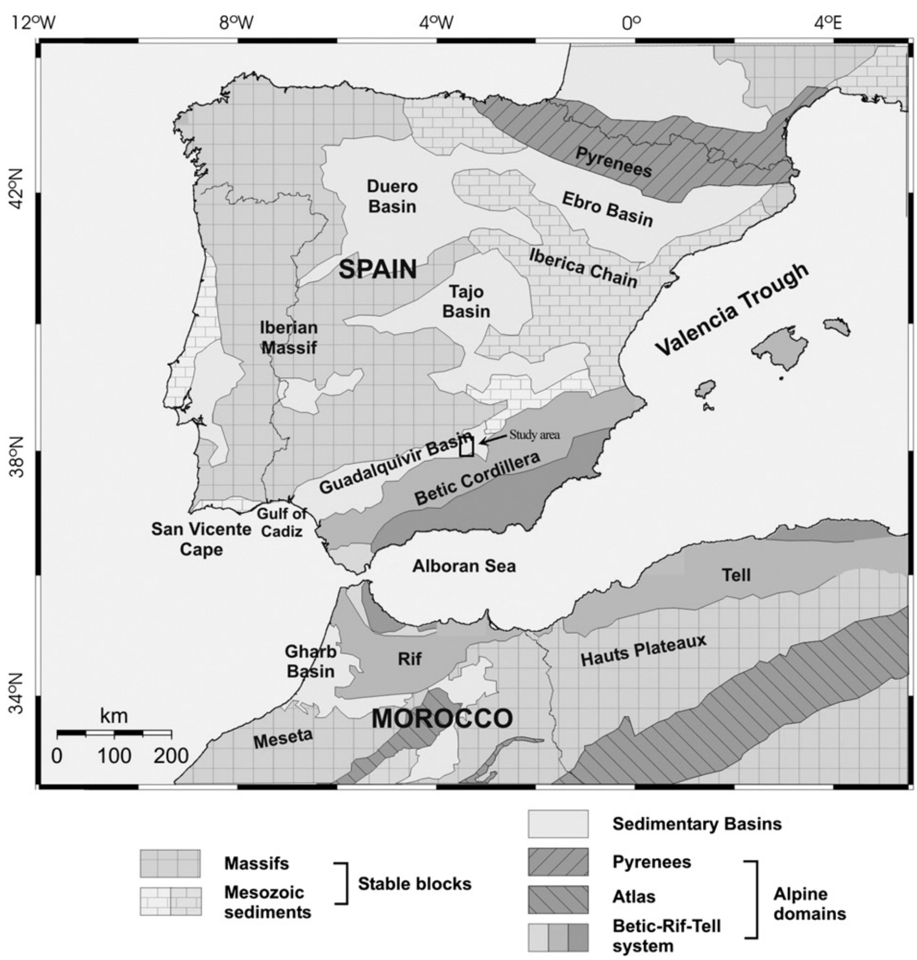

Fig. 1. Location of the study area in Spain, between the Betic Cordillera and the Guadalquivir Basin.