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Seismic velocity modelling of the Carboneras Fault Zone, SE Spain

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ABSTRACT

The Carboneras fault zone forms part of a major strike-slip fault system in SE Spain, striking NE–SW, and accommodating up to 40 km displacement. It affects basement metamorphic rocks and unconformably overlying upper Miocene sediments and volcanic rocks. High-resolution shallow seismic tomographic sections were made across the fault zone in two localities. From the same areas, fault rocks and their wallrocks were collected for laboratory seismic velocity measurements. The laboratory data were corrected for the substantial effects of near-surface crack damage. By combining these results with geological cross sections, forward velocity models for the fault zone were constructed to compare with field seismic measurements and hence to 'ground-truth' the inferences made from them. These velocity/depth relationships matched moderately well with those extracted from the in-situ tomography results. Aspects of the in-situ seismic sections matched features on the forward-modelled sections, but the comparisons showed that it is important to have some degree of foreknowledge of the geology to be able successfully to interpret seismic tomography sections as an exploration tool.

1 . Introduction

The Carboneras fault zone (CFZ) is a NE–SW trending, left-lateral strike-slip fault that forms part of a transcurrent fault system (Trans-Alborán Shear Zone) in the south-east of the Iberian peninsula (Fig. 1). Alpine metamorphic basement rocks of the Betic Cordilleras together with part of a late Miocene cover sequence are displaced by the fault system against Miocene calc-alkaline volcanic rocks outcropping to the south-east. Plio-Quaternary sediments lie with unconformity over the trace of the fault zone and show only minor effects of the fault movements (Fig. 2).

Previously, we have reported detailed studies on the structure of the fault rocks of the CFZ (Faulkner et al., 2003; Rutter et al., 1986, 2012, 2013) and laboratory measurements of gas and water permeability of the fault gouges (Faulkner and Rutter, 1998, 2000, 2003). Exposure in a semi-arid environment with very little structural overprinting on exhumed rocks makes the CFZ ideal to study as an analogue for other major strike-slip fault zones, and the results of in-situ seismic measurements can be verified by direct observations.

Nippress et al. (in preparation) report high-resolution shallow seismic tomography results from two transects across the CFZ. Such high-resolution shallow seismic and cross-hole tomography is widely employed in site investigations for engineering purposes (e.g. Kanli, 2009; Sheehan et al., 2005), often complemented by other geophysical techniques, but ground-truthing interpretations made can be a significant problem. In this paper, we report results of laboratory acoustic wave velocity measurements on rocks from the same transects along which the seismic tomography experiments were carried out. However, in-situ velocity measurements are strongly affected by crack arrays in the damaged rocks on either side of the fault zones. Forward seismic modelling, based on the outcropping geology but attempting to account for the influence of the crack arrays in the near-surface environment, was therefore carried out to make comparisons with tomographic velocity models derived from the in-situ seismic measurements.

2. Geological setting of the Carboneras Fault Zone

The CFZ forms part of a network of left-lateral strike-slip faults that extends from Alicante in the north-east, outcropping onshore as far SW as Almería and across the Alborán sea and into Morocco. The southern section of the system is shown in Fig. 1. It separates the relatively seismically active internal (metamorphic) zone of the onshore Betic Cordilleras from the seismically quiet Algero–Balearic basin to the south-west (Martıñez-Díaz et al., 2012). Rutter et al. (2012, 2013) proposed that it acts as a stretching transform fault, a velocity discontinuity forming the southern edge of an active NE–SW region of crustal stretching driven by SW-directed rollback of the subduction zone beneath the present-day Gibraltar arc (Gutscher, 2012; Gutscher et al., 2002; Lonergan and White, 1997). Rutter et al. (2012) estimate that it accommodates up to 40 km of left-lateral strike-slip offset in the vicinity of Carboneras (Fig. 1). The late Miocene crustal stretching in the Betic zone (García-Dueñas et al., 1992) is manifested through the formation of uplifted metamorphic core complexes (e.g. Sierras Nevada and Cabrera; Fig. 1) with late Miocene extensional basins lying between

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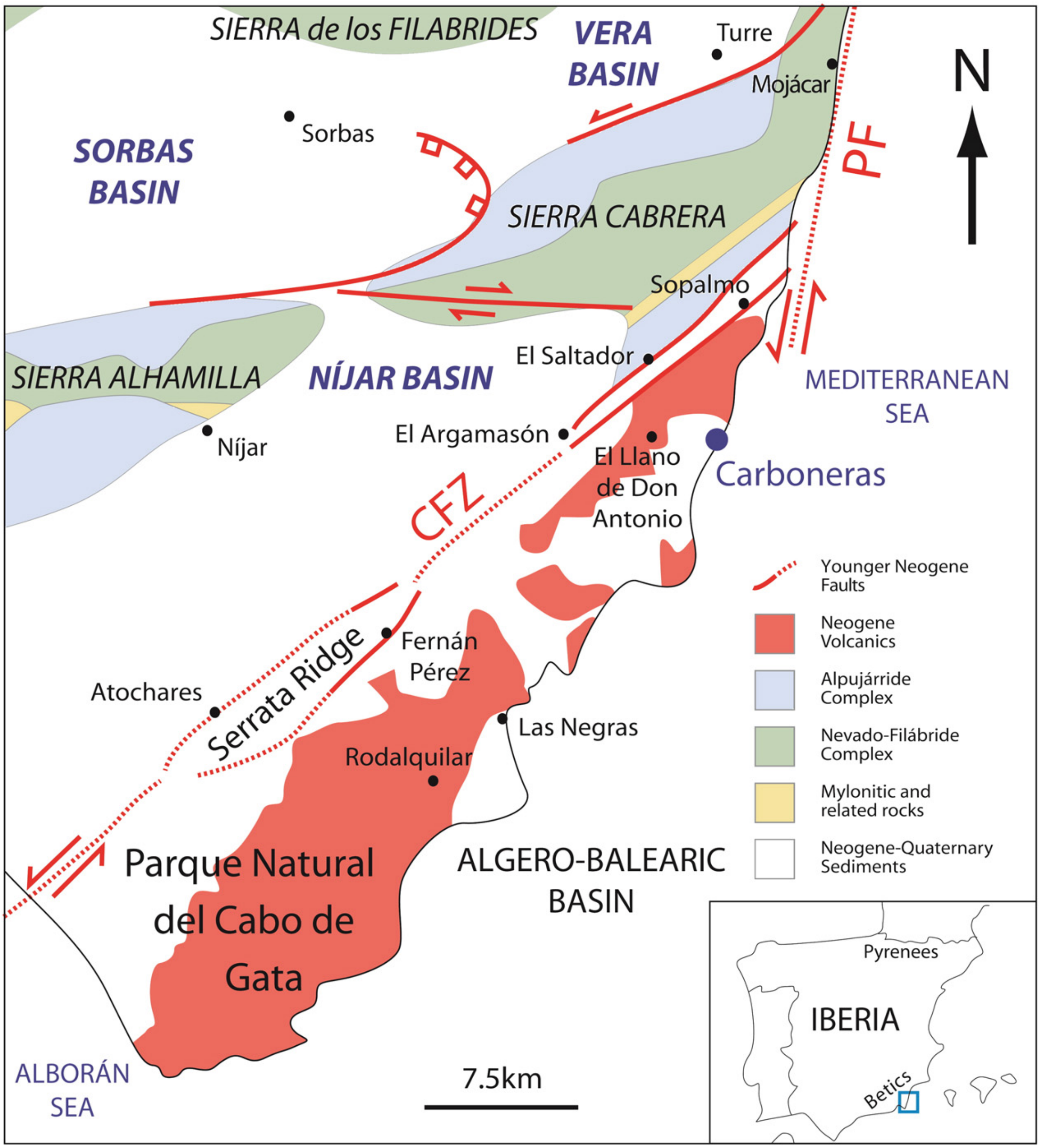

Fig. 1. The location of the Carboneras Fault Zone (CFZ) in relation to the surrounding basement uplifts (Sierras Cabrera, Alhamilla and Los Filabres), intermontane Neogene basins (Sorbas, Níjar and Vera basins), Cabo de Gata volcanic terrain to the south-east and Palomares Fault (PF) (based on Rutter et al., 2012). Box symbols on curved fault near Sorbas indicate NE–SW directed extensional faulting.

them (e.g. Alpujarras and Sorbas basins; Fig. 1). The Betic zone was also simultaneously subject to NNW–SSE directed shortening due to continued convergence between Africa and Iberia, accommodated by folding and high-angle reverse faulting in the basement and cover rocks of the Betic zone that can reorient earlier low-angle extensional faults so that they appear now as wrench faults (Giaconia et al., 2012, 2013; Vissers, 2012).

Fig. 2 shows a simplified map of the outcrop region of the Carboneras fault. The fault zone consists of four main strands, of which the southern two are longest-lived and accommodate most displacement. They cut basement rocks affected by metamorphism to varying degrees (graphitic mica schist, quartz-mica schist, andalusite-bearing schist, phyllites, quartzites, and dolomites). In the central parts of fault zones (fault 'cores') the schistose rocks are mechanically granulated and retrogressively metamorphosed with the formation of clay minerals, producing well-foliated clay-bearing fault gouge zones up to 20 m wide that can be traced for up to 15 km SW along strike from the coast to where they disappear beneath unconformably-overlying Plio-Quaternary rocks. The fault gouges often display horizontal slickenlines on the foliation surfaces and a combination of P-foliation and Riedel shears (Chester and Logan, 1987; Rutter et al., 1986) that reveal the line and sense of shear. On either side of the fault gouge zones the host schists exhibit variable degrees of crack damage extending many tens of metres away from the fault cores. In the few places where faults cut dolomites and quartzites there is intense mechanical granulation, producing weakly-cemented cataclasites.