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Intraplate stress state from finite element modelling: The southern border of the Spanish Central System

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ABSTRACT

An elastic finite element approach has been used with the dual aim of determining the most appropriate reference state of stress, namely a uniaxial strain state or a lithostatic state, and refining the understanding of the Iberian intraplate stresses. A cross-section model with an average crustal rheology and a flat topography has been analysed first in order to evaluate the influence of boundary conditions and rheological properties in the reference and tectonic stress states. The uniaxial and lithostatic states are obtained by including the overburden weight and a compressive horizontal load, which equals the uniaxial and lithostatic stress respectively, and provided that Poisson's ratio equals ~0.5 in the lithostatic state. On the other hand, a tectonic state with a $\sigma_H > \sigma_V$ regime is reproduced by adding a horizontal constant load. Subsequently, constraints on the magnitude of the predicted Cenozoic stresses along a NW–SE cross-section in the southern border of the Spanish Central System (in the Variscan granitic basement of El Berrocal) have been estimated incorporating the topographic loading, lithological variations and the most recent far tectonic stresses. The deep geological structure has been established from gravity modelling and geological data. To simulate the active strike-slip to uniaxial extension regimes in the interior of Iberian Peninsula, a lithostatic initial state has to be considered and a tectonic load in the range of 15–20 MPa has to be applied. The gradient of maximum horizontal stress originated under these conditions is in the range of 30–35 MPa km^{-1}. These results are in accordance with the estimated intraplate tectonic stress, the force along the convergent plate boundary of Eurasia–Africa, the lithospheric strength of Iberia, and the direct measurements of stresses.

1. Introduction

An important problem when estimating the stress magnitudes lies in the lack of a single reference state of stress, as the quantification of stresses, which are intimately related to tectonics, can be very different. Among others, the uniaxial strain state or the lithostatic state (according to the terms in Engelder, 1993) has been used to solve the stresses in a lithosphere assumed to be elastic (McGarr and Gay, 1978; Turcotte and Schubert, 1982; McGarr, 1988; Twiss and Moores, 1992; Engelder, 1993; Ranalli, 1995). Although the use of these reference states is sometimes justified in the scientific literature, they are usually assumed or described, without indicating which of them is the most suitable. As a result, this issue remains still a subject of controversy in the scientific community (e.g. Carminati et al., 2004). On the other hand, *in situ* measurements in deep boreholes indicate higher horizontal than vertical stresses (McGarr and Gay, 1978; Brudy et al., 1997; Reynolds et al., 2006), and both reference states represent, at best, incomplete approaches to lithospheric stresses. Several natural processes can modify the reference state, such as tectonic stresses arising from plate boundaries, topographic loading, unloading due to erosion, lithospheric bending, thermoelastic loads, and pore fluid pressure (Turcotte and Schubert, 1982; Twiss and Moores, 1992; Engelder, 1993; Caputo, 2005). Various authors have addressed the notion of the reference tectonic state in order to evaluate the relative importance of local and far field sources of stress in the intraplate lithosphere from variations of the gravitational potential energy (Zhou and Sandiford, 1992; Coblentz et al., 1994; Coblentz and Sandiford, 1994).

Intraplate stress information is essential for understanding the sources of stress responsible for lithospheric deformation. Work on recent stresses in the Iberian Peninsula are centred both on the orientation of the stress tensor, from stress inversion methods of fault-slip data and/or earthquake focal mechanism solutions (Galindo-Zaldívar et al., 1993; De Vicente et al., 1996; Ribeiro et al., 1996; Herraiz et al., 2000; Stich et al., 2006; De Vicente et al., 2008), and on its magnitude, either by means of stress relief measurements (González de Vallejo et al., 1988; Jurado and Müller, 1997; Schindler et al., 1998) or by numerical methods of stress–strain calculation (Gölke and Coblentz, 1996; Carminati et al., 1998; Andeweg et al., 1999; Cloetingh

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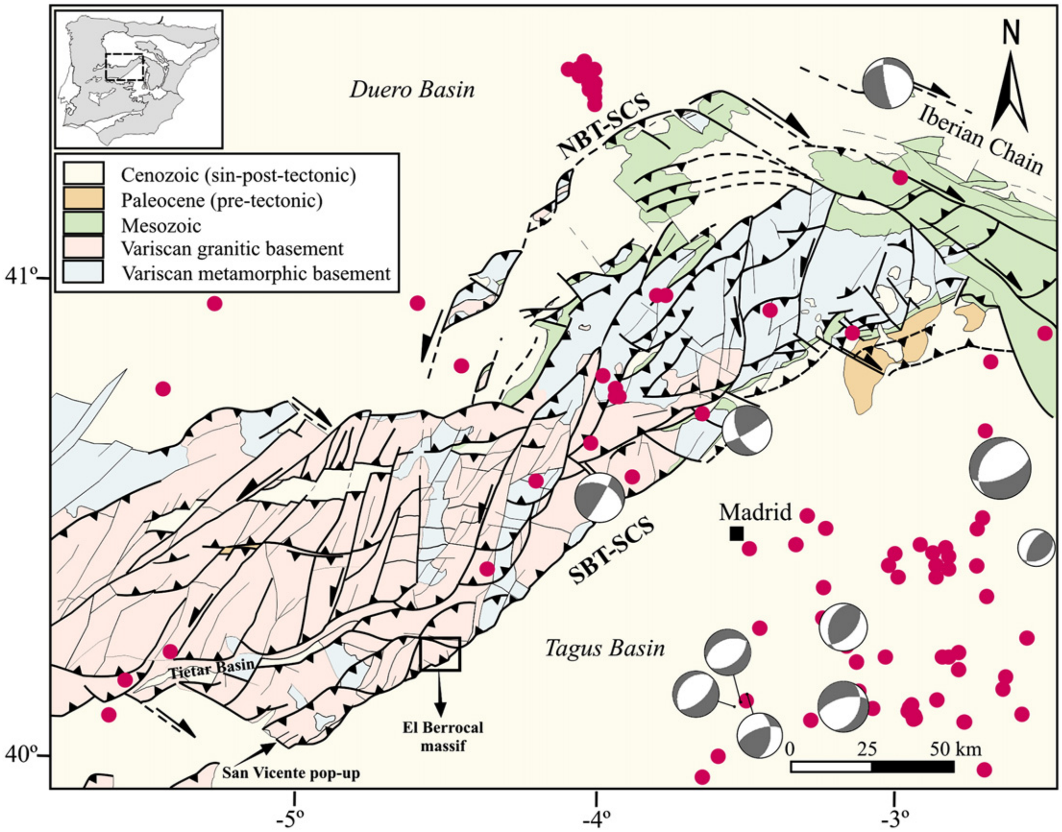

Fig. 1. Geological sketch of the Spanish Central System, with the distribution of earthquakes (dots) and focal mechanisms (for details see De Vicente et al., 2007). The El Berrocal massif (box) is located within the NE–SW sector, on the part which is closest to the E–W sector. NBT-SCS is the Northern Border Thrusts of the Spanish Central System, and SBT-SCS is the Southern Border Thrust of the Spanish Central System. Top left corner: mountainous range (grey tones) and alpine basins (white) with location of the Spanish Central System within Iberia.

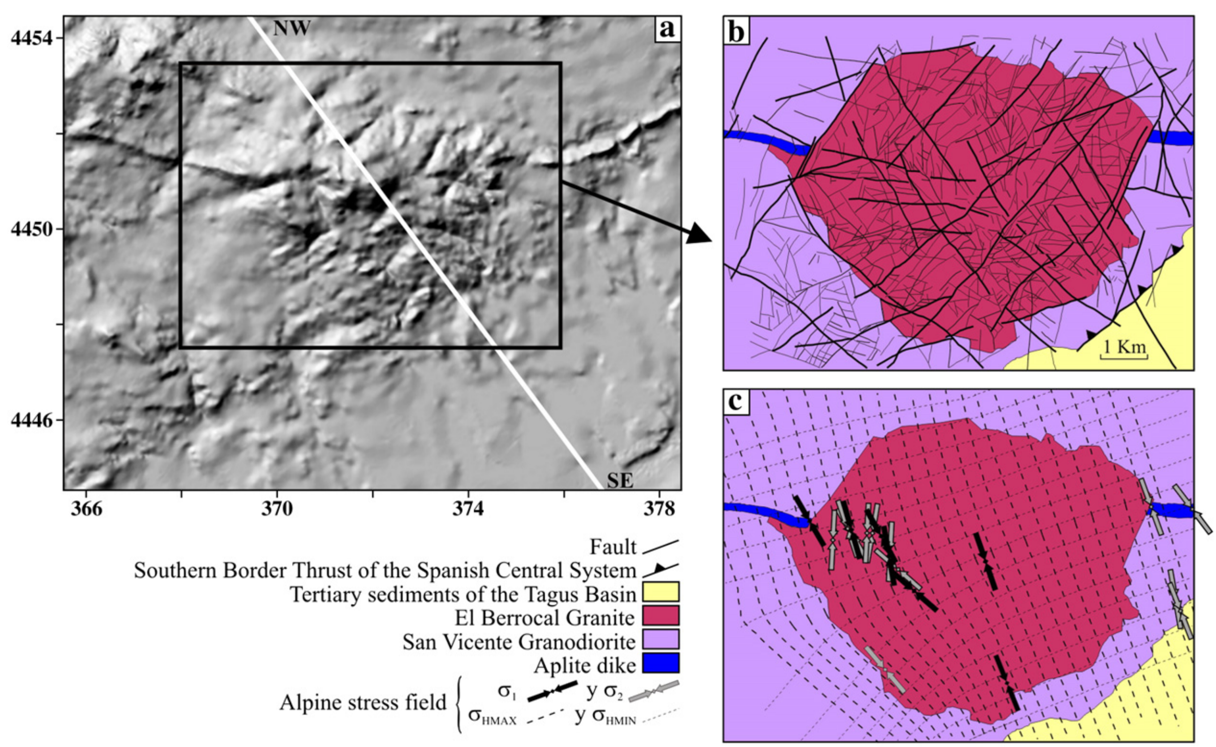

Fig. 2. a) Digital elevation model (pixel 50 × 50 m) of the El Berrocal massif used to obtain the topography of the modelled crustal section (based on the topographical maps, scale 1:50.000, Geographical Service of the Spanish Army sheets 579, 580, 602, and 603). UTM coordinates (kilometres) referred to zone 30. The NW–SE line indicates the profile orientation of the gravity and stress modelling. b) Geological map of the El Berrocal massif with the main lithological bodies and fracture network. c) Map of Alpine stress field depicting maximum horizontal stress (σ_{HMAX}) and minimum horizontal stress (σ_{HMIN}) trajectories obtained from fault population analysis. σ_1 is the horizontal projection of the maximum principal stress in strike-slip tensors. σ_2 is the horizontal projection of the intermediate principal stress in tensional tensors. Modified from CSN (2000).