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From the North-Iberian Margin to the Alboran Basin: A lithosphere geo-transect across the Iberian Plate

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ABSTRACT

A ~1000-km-long lithospheric transect running from the North-Iberian Margin to the Alboran Basin (W-Mediterranean) is investigated. The main goal is to image the changes in the crustal and upper mantle structure occurring in: i) the North-Iberian margin, whose deformation in Alpine times gave rise to the uplift of the Cantabrian Mountains related to Iberia–Eurasia incipient subduction; ii) the Spanish Meseta, characterized by the presence of Cenozoic basins on top of a Variscan basement with weak Alpine deformation in the Central System, and localized Neogene–Quaternary deep volcanism; and iii) the Betic–Alboran system related to Africa–Iberia collision and the roll-back of the Ligurian–Tethyan domain. The modeling approach, combines potential fields, elevation, thermal, seismic, and petrological data under a self-consistent scheme. The crustal structure is mainly constrained by seismic data whereas the upper mantle is constrained by tomographic models. The results highlight the lateral variations in the topography of the lithosphere–asthenosphere boundary (LAB), suggesting a strong lithospheric mantle strain below the Cantabrian and Betic mountain belts. The LAB depth ranges from 180 km beneath the Cantabrian Mountains to 135–110 km beneath Iberia Meseta deepening again to values of 160 km beneath the Betic Cordillera. The Central System, with a mean elevation of 1300 m, has a negligible signature on the LAB depth. We have considered four lithospheric mantle compositions: a predominantly average Phanerozoic in the continental mainland, two more fertile compositions in the Alboran Sea and in the Calatrava Volcanic Province, and a hydrated uppermost mantle in the North-Iberian Margin. These compositional differences allowed us to reproduce the main trends of the geophysical observables as well as the inferred P- and S-wave seismic velocities from tomography models and seismic experiments available in the study transect. The high mean topography of Iberia can be partly consistent with a low-velocity/high-temperature/low-density layer in the sublithospheric mantle.

1. Introduction

The present lithospheric structure of the Iberian Peninsula (hereinafter referred as Iberia) developed from the interplay of consecutive geodynamic processes related to: i) the Early Jurassic opening of the Betic-Rif corridor between the Central Atlantic and the Ligurian-Tethys oceans, ii) the Late Jurassic opening of the North Atlantic along the western margin of Iberia, iii) the Early Cretaceous opening of the Bay of Biscay and Pyrenean basins, and iv) the Late Cretaceous to Recent convergence of Africa and Europe, which triggered the total consumption of the Ligurian-Tethys Ocean. As a consequence of this protracted convergence phase and the acting horizontal stresses, both the north and south plate boundaries (Bay of Biscay–Pyrenees and Azores–Gibraltar, respectively) and the interior of the Iberian plate compressed resulting in orogenic belts and significant intraplate deformation (e.g., Dercourt et al., 1986; Banks and Warburton, 1991; Casas Sainz and Faccenna, 2001; Cloetingh et al., 2002; Vergés and Fernàndez, 2006; De Vicente et al., 2008).

From latest Cretaceous to Oligocene times shortening accommodated mainly along the Bay of Biscay–Pyrenees plate boundary, generating crustal-scale thrusts in the Pyrenees–Cantabrian Mountains but also in the inner part of the plate (Iberian Chain and Central System), as well as in the Betic–Rif and Atlas systems (Vergés and Fernàndez, 2006). Although deformation in the northern part of Iberia lasted until the late Oligocene–Early Miocene, from Oligocene times onward, the convergence between Africa and Eurasia was mostly accommodated along the southern and eastern Iberian margins, giving rise to the formation of the Betic–Rif orogenic system and the Valencia Trough–Balearic Promontory–Algerian Basin system, both related to subduction and further slab retreating of the Ligurian-Tethys domains (e.g., Torne et al., 1996; Gueguen et al., 1998; Vergés and Sàbat, 1999; Rosenbaum and

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Lister, 2002; Faccena et al., 2004; Spakman and Wortel, 2004; Vergés and Fernàndez, 2012).

As a result of this long history, Iberia is characterized by different geological units (Vera, 2004; Fig. 1). Western Iberia corresponds to the Variscan Iberian Massif (VIM), which is mainly made up of Precambrian to Paleozoic metasediments and granitic rocks. In turn, the eastern part of Iberia is formed by thick Mesozoic sedimentary sequences inverted during the Alpine orogeny, which may incorporate Paleozoic basement, and the associated foreland basins. The eastern and southern margins of Iberia were affected by coeval extension and compression during the Neogene, giving rise to intramontane basins and the present Iberian–Mediterranean margin. Considerable volcanic activity, with magmas characterized by calc-alkaline and alkaline affinities, developed from Early Miocene to Pliocene and Quaternary times along the Mediterranean border, affecting onshore and offshore areas (e.g., Ancochea and Nixon, 1987; Cebriá and Lopez-Ruiz, 1995; Martí et al., 1992; Torres Roldán et al., 1986; Turner et al., 1999; Villaseca et al., 2010).

The superposition of all these tectonothermal episodes resulted in large lateral variations of the crust and lithospheric mantle thickness (see Torne et al., 2015–in this volume and Mancilla and Diaz, 2015–in this volume, for recent compilations and new results). In the last decades, several studies have been conducted to unravel the lithospheric structure of Iberia and its margins using a thermal approach (e.g., Ayarza et al., 2004; Fernàndez et al., 2004; Frizon de Lamotte et al., 2004; Fullea et al., 2007; Palomeras et al., 2011; Roca et al., 2004; Tejero and Ruiz, 2002; Torne et al., 2000; Torne et al., 2015–in this volume; Zeyen and Fernandez, 1994). Recent lithospheric models incorporate a quantified thermal and petrophysical characterization of the upper mantle, down to 400 km depth, in the Betic-Rif-Atlas system (Fullea et al., 2010), across the NE Iberia and Algerian margins (Carballo et al., 2015), and across the Cantabrian Mountains and North-Iberia Margin (Pedreira et al., 2015). Up to now, however, no attempts have been made to integrate a geophysical–petrological model crossing the Iberian Peninsula from N to S and consistent with its tectonothermal evolution.

In this work, we present the crust and upper mantle structure along a 1065 km-long transect, crossing the entire Iberian plate in N–S direction, by using a modified version of the LitMod-2D code (Afonso et al., 2008). The transect starts in the Bay of Biscay and crosses the Cantabrian Mountains, the Duero Basin, the Central System, the Tagus (or Tajo) Basin, and the Betic Cordillera (hereinafter Betics), ending in the Alboran Basin (Fig. 1). The study incorporates a large amount of recently acquired seismological data from the TopoIberia Project (this volume) and is aimed to: (1) investigate lithospheric structure variations in Iberia from the Cantabrian margin in the north to the Alboran Sea in the south, combining geophysical data (elevation, gravity, geoid, heat flow, and seismic), and petrological and geochemical constraints; (2) estimate potential variations in the composition of the upper mantle, compatible with seismic data and tomography models; and (3) investigate the effects of sublithospheric mantle perturbations of thermal and/or compositional origin imaged by tomography models.

2. Geological setting

For simplicity, in this section we describe the geological characteristics of the main morphotectonic units relevant to the modeled transect, which is divided in three segments. The reader is referred to Gibbons and Moreno (2002), Vera, (2004), and Vergés and Fernàndez (2006),

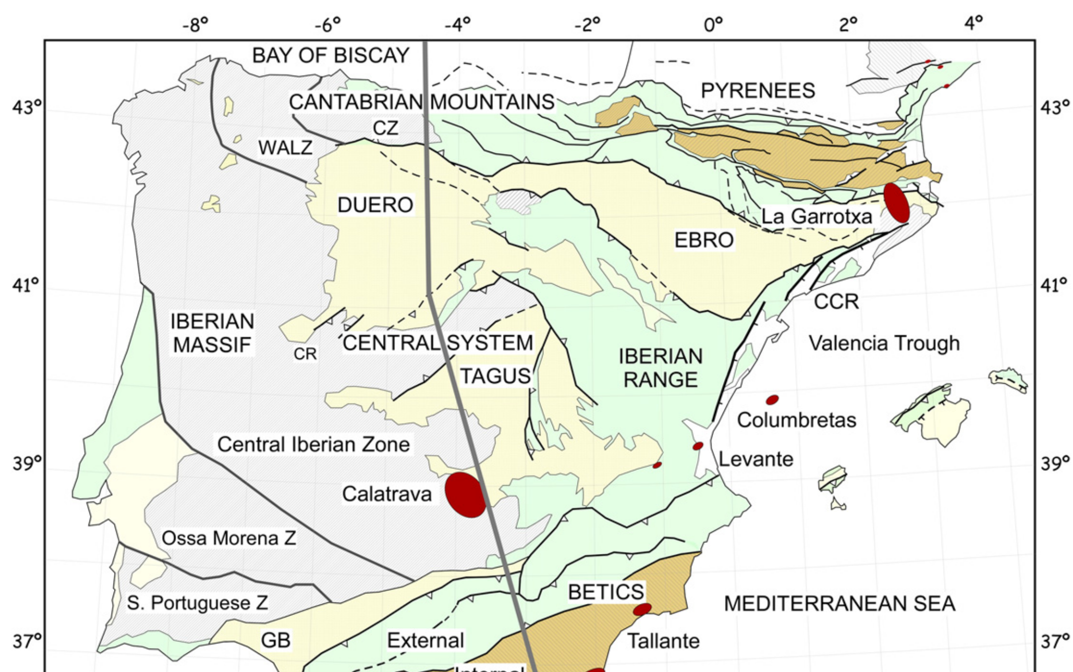

Fig. 1. Geological map of the study area showing the principal geological domains of Iberia (modified after Vergés and Fernàndez, 2006). Thick gray line locates the modeled transect. CZ, Cantabrian Zone; WALZ, West Asturian–Leonese Zone; CR, Ciudad Rodrigo Basin; CCR, Catalan Coastal Ranges; GB, Guadalquivir Basin.