Lithos 230 (2015) 46–68

Contents lists available at ScienceDirect

Lithos

journal homepage: www.elsevier.com/locate/lithos

Geophysical-petrological modeling of the lithosphere beneath the Cantabrian Mountains and the North-Iberian margin: geodynamic implications

David Pedreira [a,*], Juan Carlos Afonso [b], Javier A. Pulgar [a], Jorge Gallastegui [a], Alberto Carballo [c], Manel Fernàndez [c], Daniel Garcia-Castellanos [c], Ivone Jiménez-Munt [c], Julia Semprich [d,1], Olga García-Moreno [a]

[a] *Departamento de Geología, Universidad de Oviedo, Oviedo, Spain*
[b] *CCFS-Department of Earth and Planetary Sciences, Macquarie University, Sydney, Australia*
[c] *Institute of Earth Sciences "Jaume Almera", CSIC, Barcelona, Spain*
[d] *Physics of Geological Processes, University of Oslo, Norway*

ARTICLE INFO

Article history:
Received 19 August 2014
Accepted 23 April 2015
Available online 9 May 2015

Keywords:
Cantabrian Mountains
North-Iberian margin
Pyrenees
Geophysical-petrological modeling
Lithosphere
Mantle exhumation

ABSTRACT

Cenozoic contractional deformation in the North-Iberian continental margin (southern Bay of Biscay) led to the uplift of the Cantabrian Mountains and the northward subduction of part of the thick continental crust, down to at least ~55 km depth beneath the coastline, and perhaps even ~30–40 km deeper. In order to provide a more constrained model of this unique structure and gain insight into the factors controlling its evolution, we performed an integrated geophysical-petrological modeling of the lithosphere along a 470 km-long, N-S transect down to 400 km depth. The methodology used allows for fitting gravity anomalies, geoid undulations, surface heat flow, elevation and seismic velocities with a realistic distribution of densities and seismic velocities in the mantle and the subducting lower crust, which are dependent on chemical composition, pressure and temperature. Two models are presented, with variable maximum depth for the crustal root: 60 km (Model A) and 90 km (Model B). Results indicate that both models are feasible from the geophysical point of view, but the shallower root agrees slightly better with tomographic results. The thickness of the thermal lithosphere in Model A varies from 125–145 km south of the Cantabrian Mountains to 170 km beneath the crustal root and 135–140 km beneath the central part of the Bay of Biscay. Model B requires a thicker thermal lithosphere beneath the crustal root (205 km). Low seismic velocities beneath the Bay of Biscay Moho and in the mantle wedge above the crustal root are explained by the addition of 1–2 wt% of water. Input from dehydration reactions in the subducting lower crust is ruled out in Model A and has a very minor influence in Model B. We therefore interpret the water to have percolated from the seafloor during the formation of the margin in the Mesozoic. A later basaltic underplating was also inferred. A tentative evolutionary model (to a great extent governed by these petrological processes) is proposed, implying a minimum shortening close to 100 km from the Latest Cretaceous to the present.

1. Introduction

Passive margins and mountain belts are among the most relevant tectonic features on Earth, and are intimately related through the "Wilson cycle" of plate creation and destruction (Wilson, 1966). Rifting processes within continents may result in the formation of passive margins, which may later evolve into convergent margins creating either collisional or non-collisional orogens. Recently, significant progress was made toward the understanding of the processes governing the formation and evolution of rifted margins, including the key role of structural inheritance, thermal and rheological stratification of the lithosphere and divergence velocity, among others (eg. Huismans and Beaumont, 2007, 2011; Manatschal et al., 2015; Pérez-Gussinyé and Reston, 2001). However, much less effort has been focused on the effects that the structure and composition of passive margins have on their subsequent tectonic inversion and their control on the architecture of mountain belts (eg. Jammes et al., 2014; Tugend et al., 2014).

The North-Iberian (or Cantabrian) continental margin and the Cantabrian Mountains in northern Spain (Fig. 1) are especially interesting to study these relationships for several reasons. First, the North-

* Corresponding author at: Departamento de Geología, Universidad de Oviedo, C/J. Arias de Velasco, s/n, 33005 Oviedo, Spain.
E-mail address: david@geol.uniovi.es (D. Pedreira).
[1] Now at Department of Geology and Natural Resources, Institute of Geosciences, University of Campinas, Brazil.

http://dx.doi.org/10.1016/j.lithos.2015.04.018

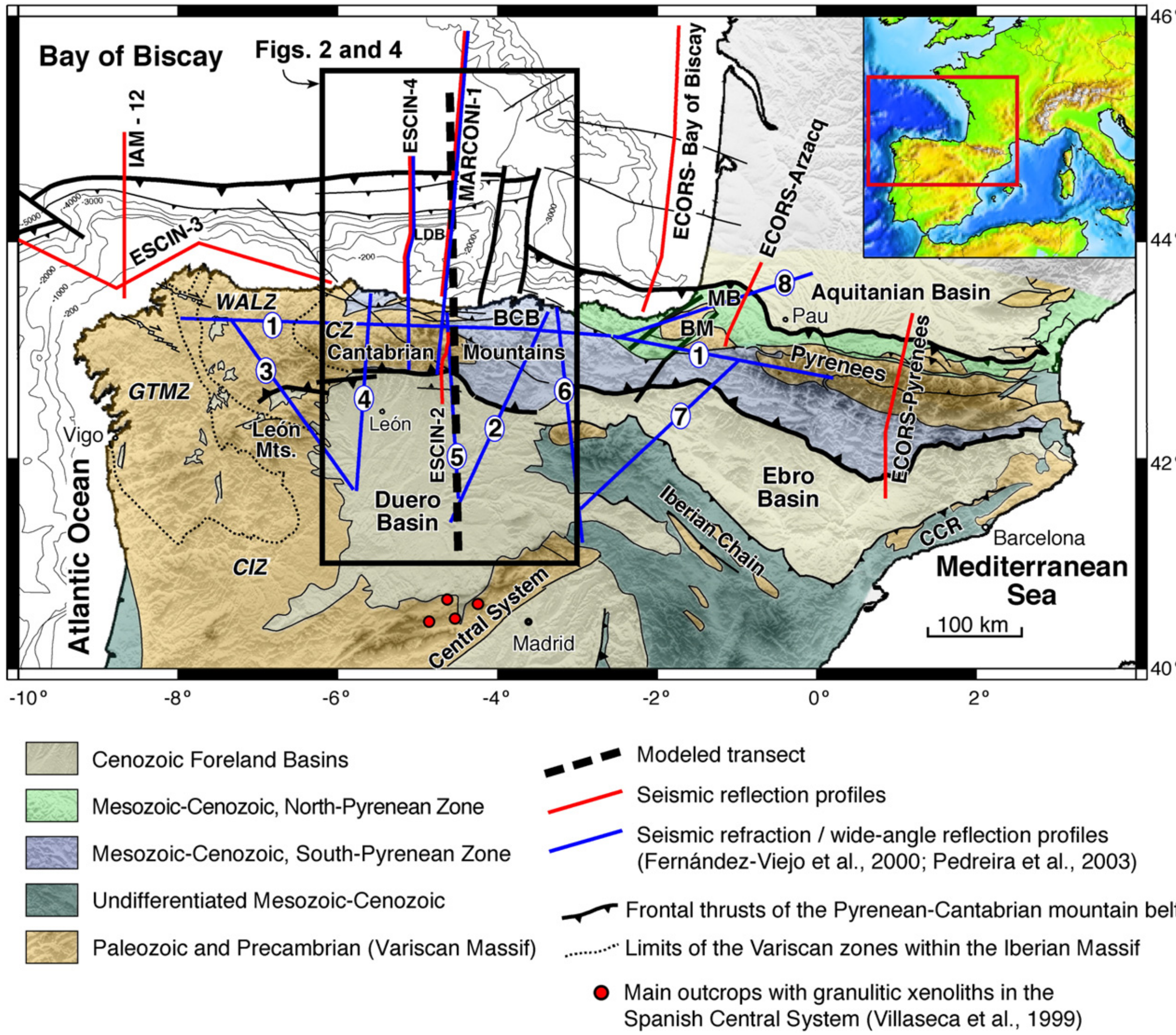

Fig. 1. Tectonic map of the Pyrenean-Cantabrian mountain belt in North-Iberia showing the location of the modeled N-S lithospheric transect and available deep seismic profiles. BCB, Basque-Cantabrian basin; BM, Basque Massifs; CCR, Catalan Costal Ranges; MB, Mauléon basin. Acronyms in italics refer to tectonometamorphic zones within the Iberian Variscan Massif: CIZ, Central Iberian Zone; CZ, Cantabrian Zone; GTMZ, Galicia – Tras os Montes Zone; WALZ, West Asturian-Leonese Zone.

Iberian margin is a rare example of a margin that evolved from passive to convergent after only ~45 my of post-rift history, being one of the shortest-lived examples of passive margins worldwide (Bradley, 2008). It formed during the opening of the Bay of Biscay in the Mesozoic, and was soon affected by the convergence between the Iberian and European plates during the latest Cretaceous-Cenozoic in the framework of the Alpine orogeny. Second, its convergent stage was also aborted at an early stage of development, so that the passive margin structure can be well constrained. This is also facilitated by a good geophysical dataset available in the area. The convergent stage is also peculiar because it led to the subduction of the thickest (inner) part of the margin toward the outer margin, at the same time as the Cantabrian Mountains were uplifted from the former continental platform. The north-directed crustal root (the same polarity as in the Pyrenees) is located approximately beneath the present-day shoreline, which adds further interest to this area from the isostatic point of view.

To understand how and to which extent the particular configuration of such a young passive margin conditioned its later evolution under a convergent setting, we need a well-constrained model of the structural, thermal, geochemical and petrophysical architecture of the crust and upper mantle.

Despite the good geological and geophysical knowledge of this area, several key issues are still poorly known. One of these issues is the nature of the basement beneath the margin. The oceanic crust with undoubtedly oceanic magnetic anomalies is present only approximately to the west of the meridian of 6°W, the remaining part of the margin being composed of thinned continental or “transitional” crust (Gallastegui et al., 2002; Roca et al., 2011; Ruiz, 2007; Sibuet et al., 2004). Seismic velocity-depth profiles in this ocean-continent transition reveal a high-velocity lower crust (~7.20–7.30 km s^{-1}) on top of a low-velocity upper mantle (~7.7–7.9 km s^{-1}) (Fernández-Viejo et al., 1998; Gallart et al., 1997; Ruiz, 2007). These velocities can be explained either by upper mantle hydration/serpentinization (eg. Roca et al., 2011) and/or by magma addition at the base of the crust by decompression melting during lithospheric thinning, but the relative importance of these processes remains enigmatic. This has important implications on the style of the tectonic inversion, because these two processes produce very different modifications in the rheological profile of the lithosphere.