Gondwana Research xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Gondwana Research

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

Thermal and petrophysical characterization of the lithospheric mantle along the northeastern Iberia geo-transect

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ARTICLE INFO

Article history:
Received 25 September 2013
Received in revised form 18 December 2013
Accepted 23 December 2013
Available online xxxx

Handling Editor: A.R.A. Aitken

Keywords:
Upper mantle composition
Iberia
Western Mediterranean
Potential fields
Thermal modeling

ABSTRACT

We present a new model on the present-day lithospheric structure along a 1100 km transect crossing the NE-Iberian Peninsula, the Western Mediterranean basin and the Algeria margin and ends at the Tell–Atlas Mountains. The modeling is based on an integrated geophysical-petrological methodology combining elevation, gravity, geoid, surface heat flow, seismic and geochemical data. Unlike previous models proposed for the region where the density of the lithospheric mantle is only temperature-dependent, the applied methodology allows inferring seismic velocities and density in the mantle down to 410 km depth from its chemical composition through self-consistent thermodynamic calculations. We have considered five lithospheric mantle compositions including predominantly average Phanerozoic and lherzolitic Proterozoic in the continental mainland, and more fertile PUM (primitive upper mantle) compositions in the Western Mediterranean basin. Mantle petrology affects the resulting density distribution and LAB (lithosphere–asthenosphere boundary) geometry and allows a direct comparison with tomography models and seismic data. Measured low Pn velocities in the Western Mediterranean basin can be explained by either serpentinization and/or seismic anisotropy and only partly by transient thermal effects. The obtained lithospheric structure is compatible with P- and S-wave tomography models.

1. Introduction

The present-day lithospheric structure of Iberia and the western Mediterranean region is the result of a complex and puzzling moving of the Iberian microplate that started in early Cretaceous times with the northward propagation of the Atlantic Ocean, and the Alpine collision of the northward moving African plate with stable Europe. The relative and complex motions of Iberia, Africa and Europe have given rise to numerous tectonic reconstructions of the Alpine–Mediterranean region (e.g., Rosenbaum and Lister, 2002; Stampfli and Borel, 2002; Handy et al., 2010; Schettino and Turco, 2010; Vissers and Meijer, 2012). According to these reconstructions, the northern convergence of Africa against Europe was accommodated by the development of two subduction zones affecting the northern and southeastern Iberian margins. The north Iberian margin evolved from the tectonic inversion of a Mesozoic rift system (Vergés and García-Senz, 2001) and resulted in the formation of the Pyrenean fold-and-thrust belt and its foreland basins, the Aquitanian and the Ebro basins (Fig. 1), which are a classic example of a continent–continent collision zone (e.g., Muñoz, 1992; Vergés et al., 2002; Sibuet et al., 2004; Vissers and Meijer, 2012) accompanied by an incipient subduction of Iberia underneath the Eurasian plate. The southeast Iberian margin evolved in a more complex subduction pattern of the Mesozoic Ligurian-Tethys ocean with either a NW-dipping subduction affecting part or the whole present-day Iberian Mediterranean margin (e.g., Gueguen et al., 1998; Faccenna et al., 2004; Rosenbaum and Lister, 2004; Spakman and Wortel, 2004), or with lateral changes in the subduction polarity dipping towards the NW in the proto-Algerian segment and towards the SE in the proto-Alboran segment (Vergés and Fernàndez, 2012). Subduction took place first along the Iberia–Eurasia plate boundary (Late Cretaceous to mid-Eocene) and later on along the Iberia–Africa plate boundary (mid-Eocene to Late Oligocene). While in north Iberia convergence was the predominant deformation mechanism, in the western Mediterranean area (Valencia Trough and Algerian Basin) coeval convergence and divergence are observed. A back-arc origin of these basins related to the combination of the northern motion of the African plate and the southeastward retreat of the Tethyan subducting slab was proposed to explain coeval extension and tectonic shortening in this region (e.g., Doglioni et al., 1997; Gueguen et al., 1998; Vergés and Sàbat, 1999; Faccenna et al., 2004). The north African margin in Algeria, presently under compression (Stich et al., 2003; Deverchere et al., 2005; Domzig et al., 2006), is formed by the piling up of metamorphic slices corresponding to the Kabylies and thrusting sheets of Mesozoic and Tertiary sediments in the Tell–Atlas region (e.g., Frizon de Lamotte et al., 2000; Mauffret, 2007).

Thereby, the present-day crustal and lithospheric mantle structure in SE-Iberia and the western Mediterranean is the result of compressional tectonics with collision/subduction in the former Eurasia–Iberia (Pyrenees) and in the Iberia–Africa (Tell–Atlas) plate boundaries, and back-arc extensional tectonics in the Neogene western Mediterranean. This complex tectonic evolution affected Paleozoic, Mesozoic and Tertiary domains with late-Hercynian plutonism in the Pyrenees

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1342-937X/$ – see front matter
http://dx.doi.org/10.1016/j.gr.2013.12.012

Please cite this article as: Carballo, A., et al., Thermal and petrophysical characterization of the lithospheric mantle along the northeastern Iberia geo-transect, Gondwana Research (2014), http://dx.doi.org/10.1016/j.gr.2013.12.012

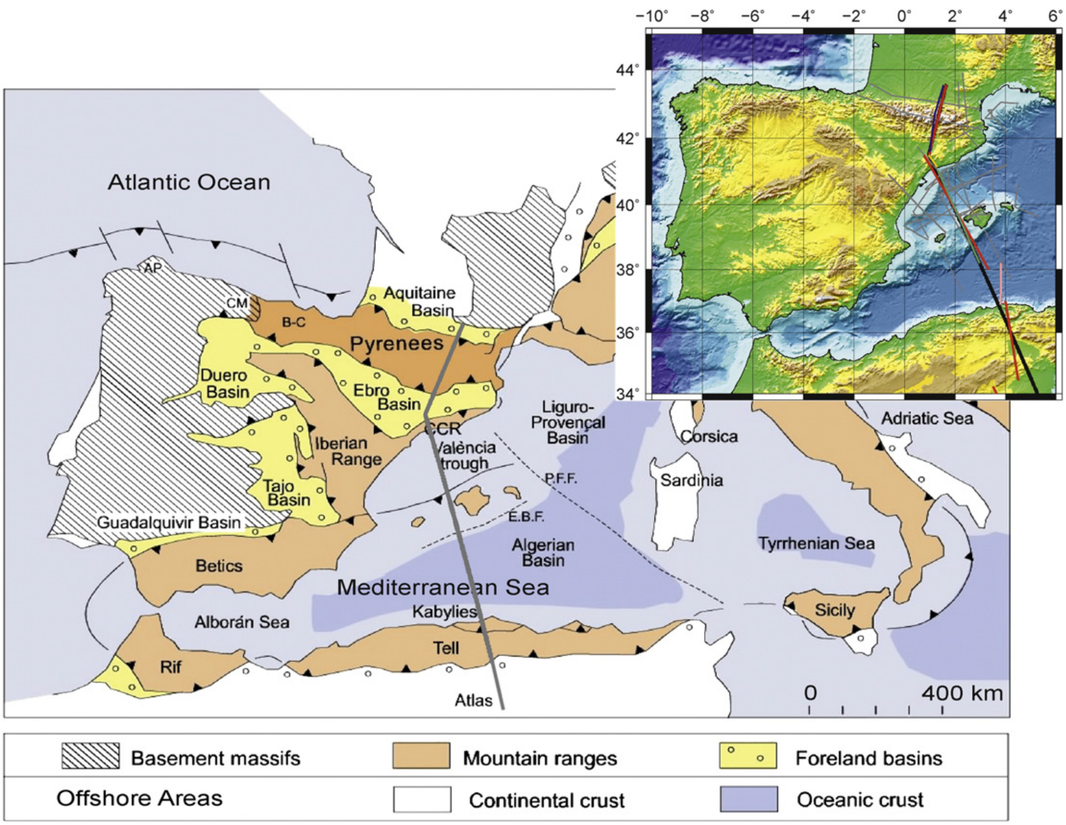

Fig. 1. Geological map of the study area showing the principal geological domains of Iberia, Western Mediterranean and North Africa. Thick gray line locates the modeled transect. Upper right inset shows the main topography and bathymetry features of the study area in which we have located from N to S: Black line-model transect; Deep blue—ECORS Pyrenees; Yellow—ESCI Catalanides; Green line—ESCI València; Pink line: ALE-4 and dark gray-other seismic experiments (Diaz et al., 201X). (see text for details). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
Modified from Vergés and Sàbat (1999).

(Michard-Vitrac et al., 1980; Fourcade and Allègre, 1981) and Neogene volcanism along the Iberian–Mediterranean margin (Martí et al., 1992; Wilson and Bianchini, 1999; Lustrino et al., 2011) and generation of oceanic crust in the Algerian Basin (Sàbat et al., 1997; Vidal et al., 1998; Booth-Rea et al., 2007). The succession of these tectonothermal events has probably modified the chemical composition of the lithospheric mantle as observed at global scale (e.g., Poudjom Djomani et al., 2001; Griffin et al., 2009) with relevant implications in the geometry of the crust–mantle and lithosphere–asthenosphere boundaries. Up to date however, a quantified thermal and petrophysical characterization of the lithospheric mantle in NE-Iberia and western Mediterranean consistent with the tectonothermal evolution of the region has not been attempted.

Unraveling the crust and lithosphere structure of the Alpine-Mediterranean region has been the subject in the last decades of numerous geological and geophysical studies that were summarized in eight regional geo-transects in the TRANSMED Atlas (Cavazza et al., 2004). Among these, the TRANSMED-II geo-transect (Roca et al., 2004) begins with a N–S trend crossing the southern part of the Aquitanian basin, the Pyrenees and the northern part of the Eastern Ebro Basin. Then it continues with a NNW–SSE direction through the southern part of the Eastern Ebro Basin, the Catalan Coastal Ranges, the Valencia Trough Basin, the Balearic Promontory, the Algeria Basin, the North African margin, the Kabylies, and ending at the Tell–Atlas mountain range (Fig. 1). Whereas the crustal structure is well defined from the numerous seismic surveys and combined seismic and gravity models (e.g., ECORS Pyrenees Team, 1988; Gallart et al., 1994; Vidal et al., 1998; Roca et al., 2004 and references therein), the depth to lithosphere–asthenosphere boundary (LAB) remains more uncertain due to the lack of direct observables and its more elusive definition (Eaton et al., 2009; Fischer et al., 2010). Existing integrated models based on the combination of elevation, gravity, geoid, heat flow and crustal seismic data show LAB depth varying from more than 130 km beneath the Pyrenees to less than 70 km beneath the western Mediterranean basins (Zeyen and Fernandez, 1994; Ayala et al., 1996, 2003; Roca et al., 2004). All these models however are based on a pure thermal approach in which the density of the lithospheric mantle is only temperature dependent and related to the density of the asthenosphere that, in turn, is considered constant everywhere (Lachenbruch and Morgan, 1990). A major caveat of this approach is the lack of full consistency with the petrophysical properties of the mantle (density and elastic parameters) and therefore, the obtained results cannot be properly compared with seismic data or tomography models. In addition, the contribution of chemical composition and phase transitions on the density and buoyancy of the lithospheric mantle and therefore, on the resulting lithospheric structure (Afonso et al., 2008; Fullea et al., 2010) are not accounted for.

A major observation in the Valencia Trough and the Algerian Basin is the low Pn-velocity values obtained in seismic experiments, which range from 7.7 to 7.95 km/s (Torne et al., 1992; Danobeitia et al., 1992; Vidal et al., 1998; Grevemeyer, pers. comm.) and the noticeable seismic anisotropy, which amounts up to 4.5% and shows almost orthogonal fast polarization directions (FPD) in both basins (Díaz et al., 2013). Low P-wave upper mantle velocities in extensional regions have been traditionally interpreted in terms of thermal relaxation, compositional crust–mantle transition, and underplating (e.g., Morgan and Ramberg, 1987; Collier et al., 1994; Thybo and Artemieva, in press) but effects of anisotropy, thermal disequilibrium and presence of water in the uppermost mantle have not been fully considered in these basins.

In this context, the aim of this work is three-fold: a) to obtain a more reliable structure of the lithosphere along the model transect incorporating, for the first time, petrophysical and geochemical constraints to

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