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Moho topography beneath the Iberian-Western Mediterranean region mapped from controlled-source and natural seismicity surveys

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ABSTRACT

The complex tectonic interaction processes between the European and African plates at the Western Mediterranean have left marked imprints in the crustal architecture of this area, particularly concerning the lateral variations in crustal thicknesses. The detailed mapping of such variations is hence of large interest, as it provides a major constraint to geophysical and geodynamic modeling at different scales. Controlled-source seismic profiling and receiver functions from natural seismicity are widely considered as major tools to constrain Moho topography. We compile here the Moho depths determined from a comprehensive number of both types of seismic surveys, to end up with a new 3D Moho depth map of the Iberian Peninsula, its continental margins and North Morocco. Since the 1970s, the lithospheric structure beneath this study area has been extensively investigated using multichannel normal incidence seismic reflection and refraction/wide-angle reflection profiling. In the last few years some high-resolution surveys at sea and inland have been acquired, the latter ones involving ~1000 land stations. On the other hand, the TopoIberia-IberArray experiment has triggered the investigations on crustal and lithospheric structure using natural seismicity, providing a homogeneous spatial resolution never achieved before. The availability of good quality results from both methodologies in a common area provides an excellent opportunity to check the consistency of the Moho depth estimations. The integration of both datasets has resulted in a new, high resolution map of the crustal thickness variations. The final grid evidences large Moho topography variations, including crustal imbrication in the Pyrenean range, a large and relatively undisturbed Variscan Massif in the center of Iberia and a probable delamination process beneath the Gibraltar Arc. The crustal thicknesses vary from ~15 km in continental margins up to values exceeding 50 km beneath the Pyrenees or the Rif Cordillera.

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1. Introduction

Well resolved knowledge on the Moho topography is an asset to the understanding of fundamental geodynamic mechanisms. Since the early 80's crustal thickness has been a key constraint to address research topics such as the tectonic evolution of orogens, basins, continental margins (e.g., Carbonell et al., 2013; Prodehl et al., 2013 and references therein). Different seismological, geophysical and geodynamic modeling methodologies at lithospheric and asthenospheric scales are grounded on an accurate knowledge of the crustal structure. As examples, P-wave tomography or 2- and 3D numerical modeling involving different variables are critically dependent on the crustal geometry, as incorrect estimations of the crustal delays may propagate through the model. Crustal models at global or continental scales are in great progression (e.g. Laske et al., 2001; Artemieva and Thybo, 2013) and provide a unique constraint to large scale studies. These, however, may often include some shortcuts or gaps when used at smaller scales, mostly arising from inhomogeneous coverage or bias in the different interpretation methods used in the compiled works.

The interpretation of deep sounding seismic (DSS) profiles and teleseismic receiver functions (RF) probably are the most suitable tools to estimate crustal thickness. In the Iberian Peninsula and North of Morocco, the availability of both large sets of wide-angle profiles, and of a dense and regular broad-band network makes it an excellent area to compare the Moho depths inferred from both methodologies.

The study area extends from the Sahara platform to the Bay of Biscay and holds a great diversity of tectonic settings including, from N to S, the crustal imbrication beneath the Pyrenean range, a large mostly undisturbed Variscan Massif in central and western Iberia, the still not completely understood geodynamic situation beneath the Betic-Gibraltar Arc and the Atlas range, resulting from the complex tectonic interaction processes between the European and African plates.

The lithospheric structure beneath the Iberian Peninsula and its continental margins has been extensively investigated since the 1970s using deep multichannel seismic reflection and refraction/wide-angle reflection profiling by different international research teams. The retrieval of the acquisition experiments and interpretation methods

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used along those decades allows to get an insight on the evolution of active seismic methodologies, from the use of a limited number of analog dataloggers providing data interpreted using 1D reflectivity methods, to the deployment of hundreds to thousands of digital equipment along a single profile inverted using ray theory. We have extended here the area covered by previous compilations (Banda, 1988; Díaz and Gallart, 2009) to northwest Africa and surrounding waters, and incorporated results from all documented surveys performed in the last years. On the other hand, the investigation of the crustal thickness using natural seismicity has boosted with the data provided by the large-scale Topo-Iberia project (Díaz et al., 2009a). The project included the deployment of the seismic IberArray, composed by 70 + BB stations and covering Iberia and Northern Morocco in 3 leg with a site-density of 60 km × 60 km. The data base holds ~300 sites, including the permanent BB networks in the area. Hence it forms a unique seismic database in Europe that allows for multiple analyses to constrain the complex geodynamics of the Western Mediterranean. Mancilla and Diaz (2015) have recently presented a Moho depth map based on the analysis of this dataset.

The aim of this contribution is to combine the Moho depth estimations coming from controlled source and natural seismicity experiments to obtain a high quality map of the region at crustal scale, hence providing a useful tool for further geophysical approaches requiring a good crustal control. As it will be discussed later on, the final grid evidences outstanding, rather sharp lateral variations in crustal thickness along several domains within the study area.

2. Geotectonic outline of the western Mediterranean region

The final objective in the knowledge of the crustal structure at regional scale is to progress in the interpretation of the present and past geodynamical processes affecting the area. Therefore, we provide hereafter a brief outline of its main tectonic domains (Fig. 1) in order to give the appropriate framework to discuss the crustal results.

The northern limit of Iberia is formed by the Cantabrian Margin, characterized by a very abrupt change in topography and resulting from the opening of the Bay of Biscay in Cretaceous times. The Pyrenean-Cantabrian range, extending from the Mediterranean Sea to the Cantabrian Mountains and uplifted during the Alpine orogenesis, marks the contact between Eurasia and the Iberian subplate. Central and western Iberia are covered by the Variscan Central Iberian Massif, one of the best exposed sections of the Variscan belt in Europe. The Central Iberian Massif was formed mainly in Precambrian/Paleozoic ages, and has remained tectonically stable for the last 300 Ma (Gibbons and Moreno, 2002). It is marked by the presence of the Meseta, an uplifted plateau with a mean altitude of around 700 m, probably the highest in Europe, which still lacks for a fully accepted explanatory model. The Central Iberian Ranges, oriented close to EW, separates two largest sedimentary basins, the Duero to the north and the Tagus to the south. Eastern Iberia is mostly formed by thick Mesozoic sedimentary basins inverted during the Alpine orogeny to form mountain belts as the Iberian Chain (Guimerà, 2004). To the East, Iberia is limited by the Valencia Trough, a basin developed during the Neogene as part of the general Cenozoic rift system of Western Europe. The western limit of Iberia is marked by the Iberian Atlantic Margin, which is a classical example of a non-volcanic passive margin. Further South, western Iberia is covered by the South-Portuguese and Ossa Morena units, both accreted to the Central Iberian Massif in Carboniferous times.

Further South, the contact between Iberia and Africa has resulted in a broad collision zone, the Gibraltar Arc System, formed by the Betic and Rif chains and by the Alboran Sea, an area with clear extensional features. A large number of tectonic models have been proposed to explain the configuration of this area (Platt et al., 2013), including lithospheric delamination (Seber et al., 1996), slab break-off (Blanco and Spakman,

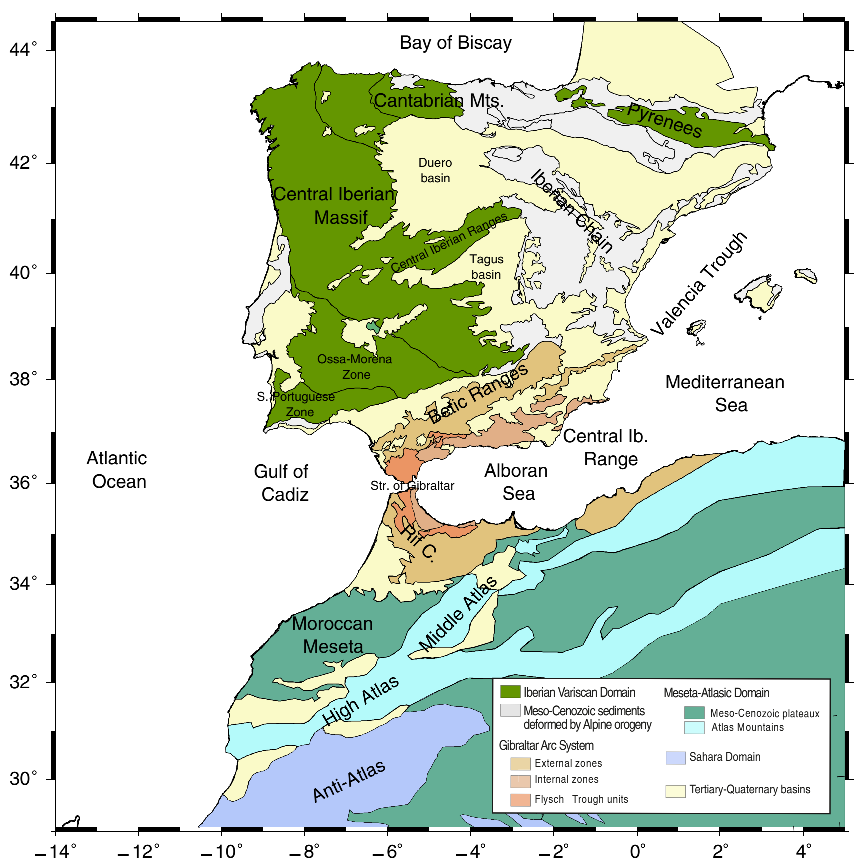

Fig. 1. Simplified map of the main tectonic domains in the Iberia-Westernmost Mediterranean region.

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