Estructura cortical del Sistema Central y sus cuencas adyacentes

Crustal structure of the Iberian Central System and adjacent basins

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Palabras clave: Sistema Central Ibérico, estructura cortical, métodos sísmicos de fuente natural

Resumen: La estructura cortical del Sistema Central Ibérico se ha estudiado mediante técnicas de sísmicas pasivas. Hemos aplicado interferometría sísmica a un conjunto de datos pasivos a través de dos técnicas para generar una corte a escala litosférica del orógeno. Las imágenes resultantes constriñen la estructura cortical de la cordillera y la de sus cuencas sedimentarias adyacentes. Ambas técnicas presentan resultados similares. Las imágenes obtenidas revelan que el límite entre la corteza y el manto es relativamente plano, con tiempos de llegada de aproximadamente de 10 s en tiempo doble, excepto bajo el Sistema Central, donde los reflectores están ubicados a 12 s en tiempo doble. Esto define un claro engrosamiento de la corteza debajo del Sistema Central, como resultado, muy probablemente, de una imbricación de la misma. El límite entre la corteza superior e inferior se encuentra a 5 s en tiempo doble y es también ligeramente más profundo debajo de la cordillera.

Abstract: The crustal structure of the Iberian Central System has been studied using passive seismic techniques. We have applied seismic interferometry to a passive dataset through two techniques to generate a lithospheric-scale cross-section of the orogen. The resulting images constrain the structure of the crust below the mountain range and that of its surrounding sedimentary basins. Both techniques provide complementary results. The resulting images reveal that the crust–mantle boundary is relatively flat, with arrival times of approximately 10 s two-way travel time except in the Central System, where reflectors are located at 12 s two-way travel time. This indicates a clear thickening of the crust below the core of the orogen, resulting, most probably, from an imbrication of the crust. The boundary between the upper and lower crust is found at 5 s two-way travel and it is also slightly deeper below the mountain range.

INTRODUCTION

The Iberian Central System (ICS) is an intraplate mountain range that divides the Iberian Inner Meseta in two sectors – the northern Duero Basin (DB) and the Tajo Basin (TB) to the south (Fig. 1). The topography of the area is highly variable, with the Tajo Basin having an average altitude of 450-500 m while the Duero Basin presents a higher average altitude of 750-800 m. The Spanish Central System extends in a NE-SW to ENE-WSW direction for over 300 km, and it has peaks above 2500 m. It is enclosed within the Iberian Massif (IB), which corresponds to one of the best-exposed Variscan outcrops in Europe. The importance of the Central Meseta in the configuration of the IB, lies in its topography. The intraplate ICS range acts as a boundary between the two basins that have a striking different elevation, being the DB around 300 m higher than the TB. This contrast may respond to the subsurface characteristics (e.g. crustal structure or rheological properties of the lithosphere). Seismic data can be used to provide new results that unravel the crustal structure of the ICS.

In this work, we present a lithospheric-scale reflectivity cross-section of the central part of the Iberian Peninsula by means of global-phase seismic interferometry (GloPSI) (Fig. 2) and ambient seismic noise interferometry (Fig. 3), acquired as part of the CIMDEF project. The array covers, from N to S, the Cenozoic Duero Basin, the Central System and the Cenozoic Tajo basins.

GEOLOGICAL SETTING

The Central Iberian Massif Deformation (CIMDEF) seismic profile is located within the Central Iberian Zone (CIZ), the most internal part of the Iberian Massif (IB). The profile crosses three main geological domains, namely the ICS, the Duero Basin (DB), and the Tajo Basin (TB). The ICS is an intraplate mountain range characterized by a thick-skin pop-up and pop-down configuration with E–W and NE–SW orientations from E to W, respectively. It was formed during the Cenozoic Alpine compression of the Iberian Peninsula and is composed by uplifted Variscan basement (Vegas et al., 1990; de Vicente et al., 1996, 2007). The current knowledge of the crustal and lithospheric structure of the Central System comes mainly from geophysical studies such as seismic data (Suriñach and Vegas, 1988; Diaz et al., 2016) and inversion and forward modelling of potential-field data (Tejero et al., 1996; de Vicente et al., 2007). These studies have found a crustal thickness in the range of 31 to 35 km, showing a thickening underneath the Central System with respect to the surrounding basins.

GEOPHYSICAL DATA AND METHODS

Data used in this study was acquired within the CIMDEF experiment by 69 short-period 2 Hz, three component stations. The stations were operational during three different time periods. The central segment (Fig. 1) of the profile was recorded between May and June of 2017 by 24 stations and covered almost 120 km. The second acquisition time was held during February and April 2018 and consisted in a deployment of 15 stations that covered the southern part of the profile. The northern and longest part, almost 170 km, was acquired between July and September 2018 and 30 new stations were installed. The data was acquired in continuous recording at 250 samples per second (sps) during a period ranging from 28 to 60 days, depending on the survey. The stations were deployed in a linear array running NW-SE with an interstation spacing of 4,8 km, covering a total length of almost 330 km (Fig. 1b). All the data was collected using the same sensors and data-loggers, and the same acquisition parameters for the three deployments. While the duration of each deployment is different, the minimum amount of data is 28 days of continuous recording.

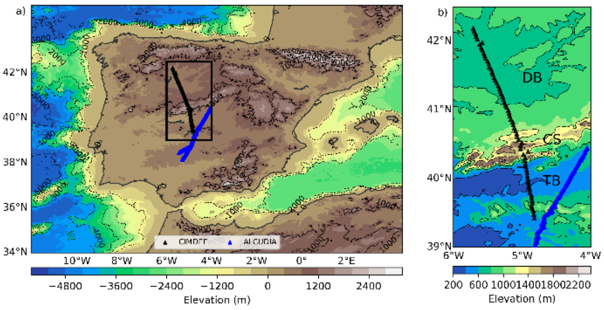

FIGURE 1. *a) Topographic map of the Iberian Peninsula showing the location of the CIMDEF profile (black triangles) with respect to the ALCUDIA-WA (blue triangles) control-source seismic transect. b) inset of the topography with the location of the main geological features crossed by the profiles.*

We have applied two different techniques to the data in order to construct a lithospheric scale cross-section of the study area. Both techniques rely on autocorrelations of the recorded signal, although the energy source is different. The first technique applied is the so-called global-phase seismic interferometry (GloPSI) (Ruigrok and Wapenaar, 2012). It uses continuous recordings of global earthquakes (> 120° epicentral distance) to extract global phases and their reverberations within the lithosphere. The processing provides an approximation of the zero-offset reflection response of a single station to a vertical source, sending (near)-vertical seismic energy, by autocorrelation and stacking the recorded earthquake phases.

The second methodology employed uses continuous recordings of ambient seismic noise, instead of earthquake recordings, to generate the zero-offset reflection response of the structure of the upper-lithosphere. The processing consists in the construction of stacked autocorrelograms of the vertical component of the ambient noise. We base our processing steps in the Phase Cross-Correlation (PCC) (Schimmel, 1999) and the time-frequency domain phase-weighted stack (tf-PWS) (Schimmel & Gallart, 2007). The PCC utilizes the instantaneous phases of the analytical signal of the data trace and produces a similarity measurement of the trace relative to a delayed version of itself. The tf-PWS is a linear stack weighted by the time-frequency-dependent instantaneous phase coherency. It enhances coherent arrivals through attenuating incoherent signals by considering the phase coherence of envelope normalized analytic signals.

RESULTS AND DISCUSSION

The images generated by both techniques highlight similar features as well as identify different characteristics that complement themselves.

The most relevant finding of the resulting images is the thickening of the ICS crust through a northward-directed imbrication of its lowermost part. In general, the crust–mantle boundary presents depths between 29 and 31 km to the N and S of the profile, while below the ICS it reaches depths of 36-38 km. The crustal thickening has a wavelength of around 100 km, and encloses the mountain range from the southern thrust, the boundary with the Tajo Basin, until the southern border of the Duero Basin. As yet, it is not clear if the imaged lower crust imbrication affects also the upper crust. In fact, the surface projection of this feature could lay on top of the southern Central System thrust or the Tiétar river fault system, thus indicating that the whole crust might be affected by this feature and further explaining the low topographies of the meseta to the S of the Central System.

The outcropping rocks of the ICS are mainly Carboniferous granites. Nonetheless, in the ambient seismic noise profile (Fig. 3), the depth continuation of the granites can be inferred. The thickness of the granitic crust below the ICS is marked by a thick package of high-amplitude/low frequency reflectors that run from the surface down to 4.5 s TWT (two-way-time) in its deepest point, shallowing to 3.5/4 s TWT towards the S and N. To the N, this characteristic signature fades out when the DB overlaps the granites, while to the S, the package is bounded by the southern thrust of the ICS, and a loss of coherency in the autocorrelations marks the end of the granites.

Some scattered reflectivity is found in the upper mantle in both profiles. In general, the reflectivity has low lateral continuity, although it is visible almost throughout the profile. It is restricted to two bands, between 40-45 km depth and around 70 km depth. The latter coincides with the reflectivity found in the ALCUDIA experiment (Ayarza, et al., 2010) and interpreted to be related with the Hales discontinuity.

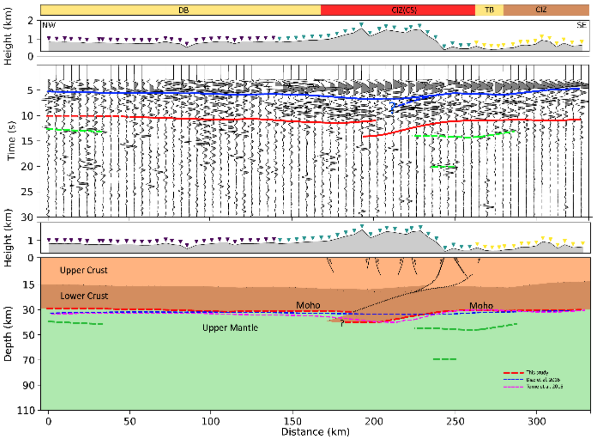

FIGURE 2. *Top, interpreted reflectivity profile retrieved by GLOPSI. Solid lines mark stable features, and dashed lines indicate possible features. The blue line marks the upper-lower crust boundary. The red line is the crust–mantle boundary. Scattered reflectivity within the upper mantle is marked by the dashed green lines. Bottom, Sketch of the proposed crustal geometry, overlapped with Moho results from gravity inversion and receiver function (RF) (Díaz et al., 2016). The proposed model portraits that the entire crust imbricates below the CS.*

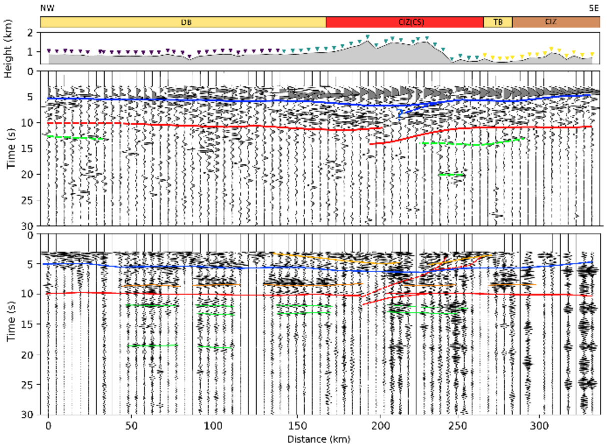

FIGURE 3. *Top, interpreted reflectivity profile retrieved by GLOPSI, as shown in Fig. 2. Bottom, interpreted reflectivity profile derived from ambient noise autocorrelations. Red line represents the Moho boundary, while the blue line represents the upper-lower crust boundary. Green lines mark reflectivity retrieved in the upper-mantle. The interpreted extension of the ICS granites is shown by the yellow line. Reflectivity within the lower crust is marked in brown lines.*

CONCLUSIONS

The results obtained from the presented lithospheric-scale profiles reveal the cortical structure below the Iberian Central System, and the Duero and Tajo basins. Our results suggest a crust divided between an upper-crust that is on average 15 km thick, and the lower crust with thickness ranging from 15 to 18 km. The boundary between both crusts is well defined throughout the profile. Within the upper-crust, the granites outcropping at the Central System have an extension of around 120 km, which covers the entire mountain range, and a maximum thickness of 10 km, thinning towards the ends of the Central System.

The most important finding of the study is the presence of an imbrication of the crust below the Central System, where the southern crust underthrusts the crust below the Central System. In general, the crust-mantle boundary is relatively flat throughout the profile, with depths ranging between 29 and 31 km, except below the mountain range. There, the imbrication deepens the crust until 36-38 km, marking a step of ~7 km with the crust-mantle boundary to the N. The crustal thickening is bounded to the S by the Tietar Basin, and the lower crustal imbrication can be projected to the surface onto the Southern Central System Thrust or the Tietar Basin fault locations. Although it is not yet clear that the imbrication affects the upper crust, our results indicate that one of those thrusts, or both, may represent crustal-scale features that could imbricate the whole crust. This structure might give insights in the topographic configuration and relation between the Central System and the Tajo and Duero basins.

Within the upper mantle, scattered reflectivity is found below the northern and central segments of the profile, in two bands enclosed in depths of 40-45 km for the top and around 70 km for the bottom. We describe the deepest of these features as the seismic image from the transition zone from spinel-lherzolite to garnet-lherzolite, known as the Hales discontinuity, and already proposed and described towards the S of the profile in other studies.

ACKNOWLEDGEMENTS

The data used for the research carried out in this contribution are stored at the DIGITAL.CSIC data repository. We would like to acknowledge the ICTJA-CSIC Seismic Laboratory (http://labsis.ictja.csic.es/, last access: 11 November 2019) for making their seismic station available for this experiment. This research has been supported by the Spanish National Research Program (grant nos. CGL2014 56548-P and CGL2016-81964-REDE), the regional government of Castilla and León (project SA065P17), and the Generalitat de Catalunya (grant no. 2017-SGR-1022); Juvenal Andrés is supported by

FPI from the Spanish Ministry of Science, Innovation and Universities (grant no. BES-2015-071683).

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