Large-scale structure of an Intraplate Fold-and-Thrust Belt: The Iberian Chain.

Estructura a gran escala de un cinturón de pliegues y cabalgamientos intraplaca: La Cadena Ibérica.

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Abstract: *The Iberian Chain is an intraplate fold-and-thrust belt developed during the late Eocene to Miocene because of the contractional inversion of the Iberian Mesozoic Basins. Its dominant trend is NW-SE, but E-W-, NE-SW- and N-S-trending structures are also present inside it. Its NE and SW boundaries are major thrusts: The North Iberian Thrust and the Serranía de Cuenca Thrust. The thrust-sheet on top of these thrusts, display two big anticlinoriums, separated by the big Almazán Synclinorium. They are interpreted as major fault-bend folds developed over the ramp and flat geometry of the two major thrusts. The level of erosion is low in most of its extent, so there is a small difference between the tectonic and the topographic reliefs. Hence, a low dip is needed for the major thrusts. A model section is presented which fits a cross-section thru the chain. A total displacement of 60km of the thrust-sheet is needed to fit the cross-section geometry, and the sole thrust is located at a depth of 10km.*

Resumen: La Cadena Ibérica es un cinturón de pliegues y cabalgamientos desarrollado durante el Eoceno Superior y el Mioceno por la inversión contractiva de las Cuencas Mesozoicas Ibéricas. Su dirección dominante es NW-SE, aunque también contiene estructuras de direcciones E-W-, NE-SW- y N-S. Sus límites NE y SW son cabalgamientos mayores: el Cabalgamiento Nord-ibérico y el Cabalgamiento de la Serranía de Cuenca. La lámina de cabalgamiento sobre estos dos cabalgamientos contiene dos grandes anticlinorios, separados por el gran Sinclinorio de Almazán, que se interpretan como grandes pliegues de acomodación a la geometría en rampas y rellanos de los cabalgamientos. El nivel de erosión es bajo en su mayor parte; por tanto, la diferencia entre los relieves tectónico y el topográfico es pequeña. De ello se deduce un buzamiento bajo para los cabalgamientos mayores. Se presenta un modelo de corte geológico que reproduce la geometría de un corte geológico a través de la cadena. Para obtener una buena coincidencia entre ambos cortes, el desplazamiento total necesario en los dos cabalgamientos es de 60 km, y el cabalgamiento basal se sitúa a 10 km de profundidad.

INTRODUCTION

The Iberian Chain (Fig. 1A) encompasses the contractional structures generated during the Cenozoic inversion of the Iberian Mesozoic basins. All these structures developed within the Iberian Plate, during the Mesozoic, in a dominant extensional regime governed by the evolution of the Tethys and the opening of the Atlantic. By the end of the Cretaceous, palustrine sediments with marine incursions were deposited (Canérot et al., 1982) indicating they were near sea-level, 200 to 300m above the present one. A thinning of the post-Variscan crust is deduced from this evolution. During the Cenozoic, the Mesozoic basins were contractively inverted because of the convergence of the Eurasian and African plates, which also generated the Pyrenean-Cantabrian Chain and the Betic-Balearic Chain at the North and South borders of the Iberian Plate.

The Iberian Chain is surrounded by the Ebro, Duero, and Tajo Cenozoic foreland basins to the North, North-West and West, the Ebro and Duero basins separating it from the Pyrenean-Cantabrian Chain and being their common foreland basins. The Iberian Chain has a length of 400km along a NW-SE direction (between the Duero Basin and the Mediterranean) and its width is between 125km and 280km in a NE-SW direction (between the Tajo and Ebro basins).

Cenozoic contractional structure

The boundaries of the chain with its surrounding foreland basins are always thrusts. Two major thrusts can be recognized (Fig. 1 A and B): i) the North-Iberian Thrust, separating the chain from the Ebro and Duero basins and ii) the Serranía de Cuenca Thrust which separates it from the Tajo Basin and the flat-lying area of La Mancha. Between these two thrusts, the thrust-system is basement involved. In most of its extension, the Serranía de Cuenca Thrust branches to the foreland to the Altomira Thrust, which involves only the Mesozoic and Cenozoic cover and includes the Loranca piggy-back basin in its overlying thrust-sheet.

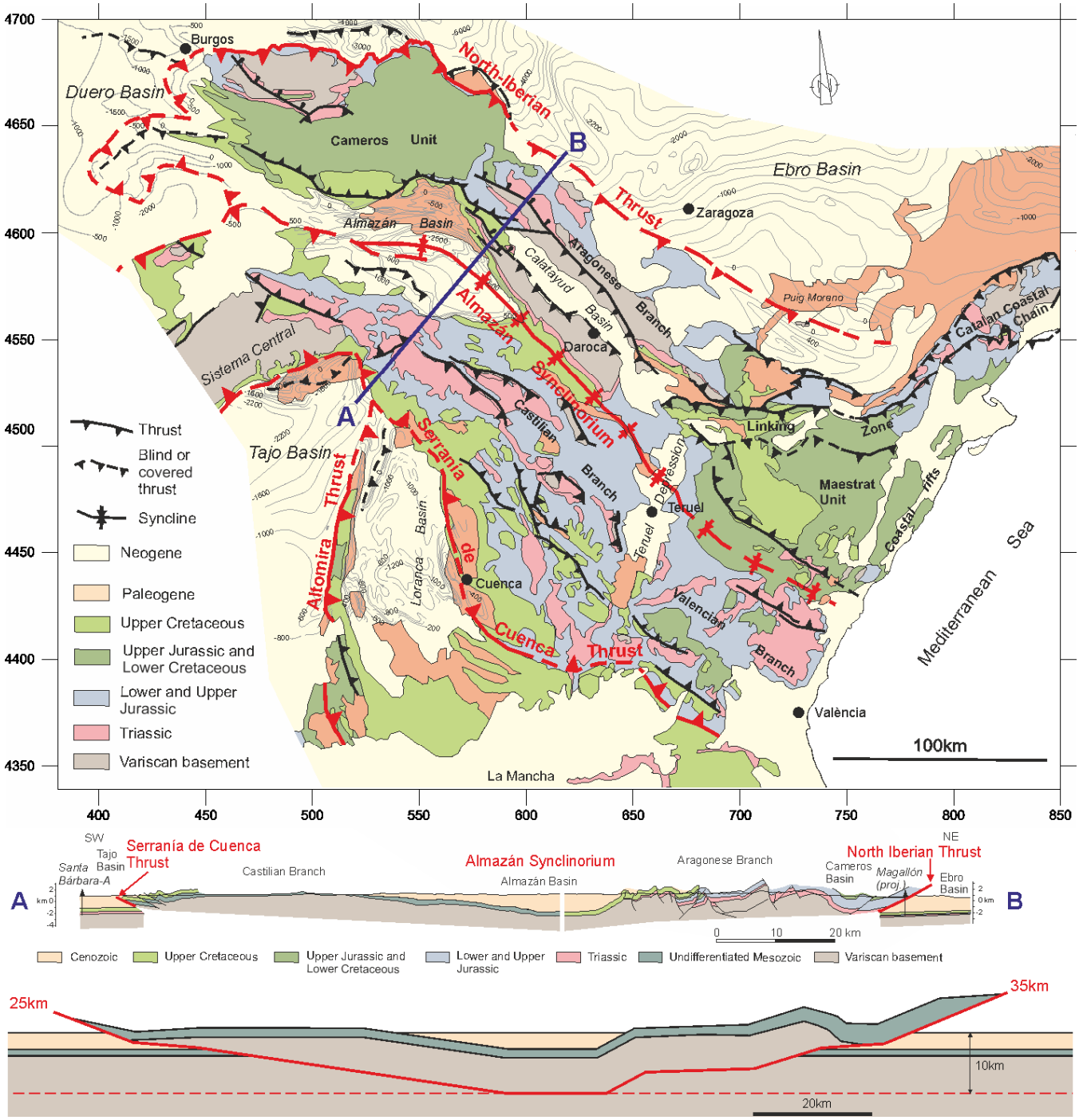

Fig 1. A) Simplified geological map of the Iberian Chain and surrounding Cenozoic basins. Contour lines of the carbonatic Upper Cretaceous top (Duero and Almazán), the Cenozoic base (Ebro) and of the base of the Upper Albian Utrillas Formation (Tajo) are shown in the syn-orogenic basins. Contour lines of the Ebro, Duero and Tajo basins are from Instituto Tecnológico Geominero de España (1990). Contour lines of the Almazán Basin are from Casas-Sainz et al. (2000). Location of the geological cross-section (B-B') and the UTM coordinates in km (30T, ED50) are also shown. B) Geological cross-section across the Iberian Chain (modified from Guimerà et al., 2004, and Guimerà, 2018). C) Model section of B-B' performed with Move®. Displacements in the northern and southern thrusts are indicated.

Reflection seismic profiles going thru the major thrusts of the chain are only found in the Cameros unit. After them, 25-30km of horizontal and up to 4 km of vertical displacements have been deduced (Casas-Sainz, 1993; Guimerà et al., 1995) for the North Iberian Thrust in that area. Isobaths of the base of the Cenozoic in the Ebro basin show how the vertical displacement of this fault is diminishing to the SE. In a section thru the Serranía de Cuenca Thrust, Muñoz-Martín and de Vicente (1998) have deduced up to 18.5km of displacement to this thrust. To these values, the internal deformation of the thrust sheets should be added.

Considering the major structures over the North-Iberian and Serranía de Cuenca thrusts, two parts can be

differentiated, which depict two anticlinoriums, separated by the Almazán Synclinorium, all of them oriented NW-SE. The northern one contains the Cameros Unit, the Aragonese Branch, and the Maestrat Unit and the southern one is constituted by the Castilian-Valencian Branch. The dominant vergence is N to NE in the northeastern part while in the southwestern part the dominant vergence is to the SW.

Level of erosion: topographic and tectonic relief.

When comparing the topography of the Iberian Chain with its structure a good match is obtained. This supports the generation of this relief as a result of the Cenozoic contraction. More than half the surface of the Iberian Chain is above 1000m, while several areas having a surface higher than several hundreds of kilometers are above 1500m.
The areas with higher relief are coincident with the two big anticlinoriums previously described. These anticlinoriums are clearly depicted by the Upper Cretaceous rocks (Fig. 1 A and B) which, being the younger rocks before the Cenozoic contraction, are good markers of the overall deformation. The Upper Cretaceous rocks are found progressively at higher elevations through the inner parts of the chain, being over 1800m at the core of the Castilian Branch and West and South of Teruel.
The preservation of Upper Cretaceous rocks, even at many of the high elevated areas, indicates a low erosion of the orogenic building of the Iberian Chain in most of its extent: in the Castilian-Valencian Branch, the SE part of the Aragonese Branch and the Maestrat Unit.
In the Cameros Unit and extensive areas of the Aragonese Branch erosion has been deeper, although Mesozoic cover have been preserved in many areas. Here there is a bigger difference between the topographic relief and the tectonic relief, although, in the areas of the Aragonese Branch lacking the Mesozoic cover, it was thin, 1500m at most.

Large-scale geometry of the contractional system

The deep geometry of the Iberian Chain thrust-system can be established after the major structures at surface. These are the North Iberian and Serranía de Cuenca thrusts and the anticlinoriums above them, separated by the Almazán Synclinorium. The last three structures are interpreted as major fold-bend folds developed inside the thrust-sheets, over the two major thrusts. The low tectonic relief in the anticlinoriums needs for a low dip of the two bounding thrusts.
A model section was performed after a cross section made from field data, oil boreholes and, in the Almazán basin, reflection seismic profiles (Fig. 1 B). This section displays the two bounding thrusts of the chain, and the Almazán Synclinorium separating the N and S anticlinoriums. A significant feature of this section is the coincidence of the depth of the Cenozoic rocks in the Ebro and the Almazán basins, while this depth is slightly less in the Tajo basin.
The section was performed using the software Move® and assuming the formation of fault-bend folds over thrusts with ramp-flat geometry (Fig. 1 C). Dips about 8º are obtained for the deep ramps, and about 20º for the frontal ramps. The sole-thrust depth obtained is 10km. No crustal thickening is generated beneath the foreland basins and the Almazán Basin. The displacement was 35km for the North-Iberian Thrust and 25km for the Serranía de Cuenca Thrust. With these parameters, a good match of the geometry of the anticlinoriums and the Almazán Synclinorium, and of the relative depth of the foreland basins and the Almazán Basin, was obtained between the cross-section and the model section. The tectonic relief generated in the model also matched that of the cross-section. The internal deformation of the thrust-sheets should be added to the 60 km of the thrusts' displacements.

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