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The formation of small- to medium-sized Cenozoic basins drained by the Tagus river (Portugal and Spain). Example of sedimentary basins formed by crustal-scale folding

Formación de cuencas cenozoicas de pequeño y mediano tamaño drenadas por el Río Tajo (Portugal y España). Ejemplo de cuencas sedimentarias formadas por plegamiento a escala cortical

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ABSTRACT

The Tagus river drains several small- to medium-sized Cenozoic sedimentary basins located along a tectonic depressed area which is flanked by two basement highs. These basins were created during the onset of the Cenozoic compressive event that underwent the interior of the Iberian Peninsula in the wake of the Africa-Eurasia convergence. They show the distinctive characteristics of compressional sedimentary basins (flanked by thrusts and reverse faults) whose mechanism of formation can be ascribed to crustal-scale folds. They constitute a good, and perhaps exceptional, example of compressional sedimentary basins formed by this type tectonic mechanism.

Key-words: *Iberian Peninsula, Tagus river, compressional sedimentary basins, crustal-scale folding*

RESUMEN

El Río Tajo drena varias cuencas sedimentarias cenozoicas de tamaños pequeño y mediano, localizadas en un área tectónicamente deprimida y flanqueada por elevaciones de basamento. Estas cuencas fueron creadas al inicio del evento compresivo cenozoico que afectó al interior de la Península Ibérica por la convergencia entre África y Eurasia. Muestran unas características distintivas de cuencas sedimentarias compresivas (flanqueadas por cabalgamientos y fallas inversas), cuyo mecanismo de formación se puede atribuir a un plegamiento a escala cortical. Constituyen un buen, y quizás excepcional, ejemplo de cuencas sedimentarias compresivas formadas por este tipo de mecanismo tectónico.

Palabras clave: *Península Ibérica, Río Tajo, cuencas sedimentarias compresivas, pliegues a escala cortical*

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Introduction

Contrary to the other major fluvial trunks in the Iberian Peninsula (Ebro, Duero and Guadalquivir), the Tagus river does not drain a unique and large basin but a series of small- to medium-sized sedimentary basins (Fig. 1). These basins are located in an ENE-WSW tectonic depressed area along which the Tagus, the main waterway in the Southern *Meseta*, flows westwards by 1007 km from its headspring in the Iberian Ranges to the Lisbon estuary in the Atlantic, draining an area of 81600 square km. This tectonic depression is flanked by two mountainous alignments. Its northern border corresponds to the different segments of the Central System and its southern one to the Toledo-Villuercas Mountains and their western extension in the San Pedro-São Mamede ranges (Fig. 1). The enclosed basins correspond to the Lower Tagus, the Idanha a Nova-Moraleja, Coria, Talaván, Campo Arañuelo, and Upper Tagus (Madrid). In a broad sense, they occupy an intermediate downfolded crustal corridor between two basement highs and ought to be necessary classified as intraplate compressional basins (Vegas., 2006; Vegas *et al*., 2015), due to the nature of their borders (largely thrusts), as well as to their formation which occurred during the Cenozoic compressive tectonic regime in the Iberian Massif.

Continental, *compressional sedimentary basins* can be divided into pull-apart (*strike-slip*), foreland (*flexural*) and formed by lithospheric folding (*buckling*), each of them with distinctive characteristics A particular case are the basins formed by crustal- scale folds as a result of a crust-mantle decoupling and the subsequent formation of folds with smaller wavelengths (50-30 km) (Fig. 2) (Cloetingh *et al.,* 2015 and references herein).

All the considerations stated before point to envisage the Cenozoic sedimentary basins of the Tagus drainage system as being formed by crustal-scale folding. Within this framework, it is possible the integration of their main morphotectonic features, sedimentary infill and geodynamic evolution in an inclusive tectonic model.

Tectonic setting

The Tagus drainage network, with the exception of the Alagón tributary, occupy an enclosed area which can be considered as a downflected crustal zone between two alignments of basement elevations. This drainage basin is compartmentalized into four tectonic depressions which exhibit a particular map-view shape, similar to a parallelogram. These tectonic depressions are named here, from west to east, as Lower Tagus, Alagón, Tiétar-Almonte and Upper Tagus (Fig. 3). The sedimentary basins of Idanha a Nova-Moraleja and Coria are situated in the Alagón depression whilst the Campo Arañuelo and Talaván basins are enclosed in the Tiétar-Almonte depression. The Upper and Lower Tagus basins correspond to their homologous depressions. It must be noted that this particular geometry is truncated in the Upper Tagus depression by the front of the Altomira Ranges, giving to this easternmost depression a triangular aspect.

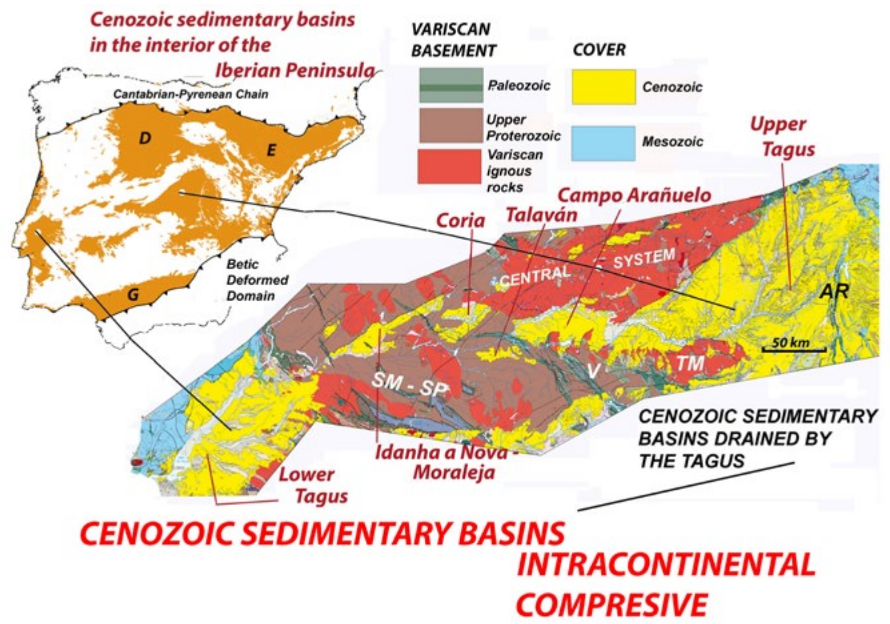

Fig. 1.- Geological context for the sedimentary basins drained by the Tagus and their location in the interior of the Iberian Peninsula. AR: Altomira Range, SM-SP: São Mamede-San Pedro ranges, V: Villuercas range, TM: Toledo Mountains. Basins: D: Duero, E: Ebro, G: Guadalquivir.

Fig. 1.- Contexto geológico de las cuencas drenadas por el Tajo y su situación en el interior de la Península Ibérica.

The formation of these depressions can be explained by the interplay of crustal-scale folding and simultaneous compressional reactivation of inherited long lines (or narrow zones) of fracture; in such a manner that the opposite sides of the parallelogram-like depressions are either up-thrusts of the flanking basement elevations or reactivated fracture zones. Both E-W thrusts and NNE-SSW reactivated fracture lines are part of the largely distributed intraplate deformation resulting in the transmission of stresses from the Cantabrian-Pyrenean border (e.g. De Vicente and Vegas, 2009).

The roughly E-W directed thrusts correspond to the brittle deformation of the anticlinal crustal folds. Nevertheless, the NNE-SSW long lines are inherited faults (in fact, narrow shear zones with discrete faults) with a complex history. They have been described as wrench faults that caused the curvature of the axial traces of the Variscan folds (Vegas, 1975) and they can also be related to tardi-Variscan shear zones that gave rise to the formation of conical folds in the late stages the of the Variscan chain. These lines of fracture correspond to the Plasencia fault, the Merida fault and its extension in the southern border of the Central System, as well as to the Ponsul fault (see Fig. 3).

The origin of these long wrench faults may be related with structures of compensation in the curvature of the Variscan Iberian Arc. It is important to note that rectilinear, hundred to thousand km long wrench faults have been recognized as rooted deep in the lithospheric mantle, long-lived and prone to be reactivated in subsequent tectonic events (Vauchez and Tomassi, 2003). In this context, the NNE-SSW transcurrent shear zones were in some way reactivated in relation with the Triassic-Jurassic transform zone situated between Africa and the Iberian Peninsula. In fact, one of them, the Plasencia fault was intruded by a dolerite dike, pointing to a limited extensional, probably transtensional, reactivation. This dike represents the only indicator for the Mesozoic reactivation of these wrench faults.

The Cenozoic reactivation appears to be mostly compressional. In this sense, it must be taken into account the minor lateral displacement of c. 3000 m along the fault-dike system of Plasencia (Rincón *et al.*, 1999). Part of the NNE-SSW long lines of fracture were reactivated as thrusts, contrasting with the Cenozoic tectonic activity in the other NNE-SSW fracture lines in the Iberian Massif, Regua and Vilariça, that, whatever their origin, are *confined* strike-slip corridors, as shown by their constrictive terminations.

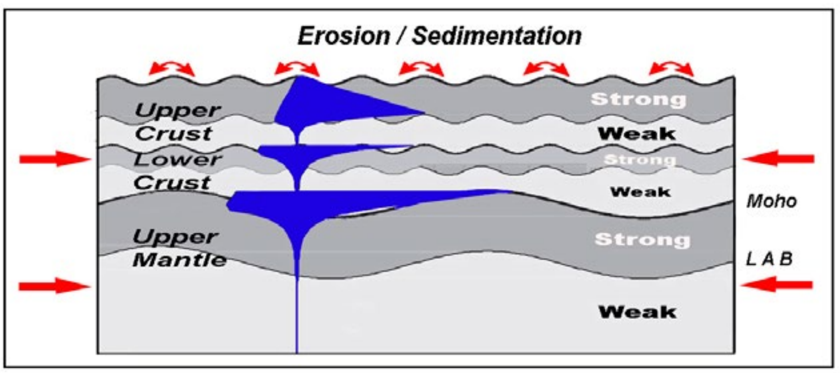

Fig. 2. Model for the formation of crustal folds in a layered and young lithosphere under compressional stresses. Decoupled crust leads to erosion and sedimentation in the small-wavelength anticlines and synclines. The strength profile is represented in blue, compression to the right, tension to the left. LAB: lithosphere-asthenosphere boundary. (modified from Cloetingh *et al*., 2015).

Fig.2.- Modelo de formación de pliegues de la corteza en una litosfera estratificada y joven bajo esfuerzos compresivos. El desacoplamiento de la corteza conlleva la erosión y la sedimentación en los anticlinales y sinclinales de longitud de onda menor El perfil de competencia está representado en azul; compresión a la derecha, tensión a la izquierda. LAB: Límite litosfera-astenosfera. (Modificado de Cloetingh et al., (2015).

Basin infill and geodynamic evolution

Once the depressions created, the processes of erosion and sedimentation started giving rise to the evolution of the basins. Cloethingh *et al.* (2015) described the pattern of subsidence for basins formed by lithospheric folding in three main stages. These can be adapted to the basins of the Tagus drainage network, taking into account their crustal dimensions and their specific tectonic setting. In this sense, it is possible to establish three tectonic-stratigraphic episodes considering the ages and nature of the

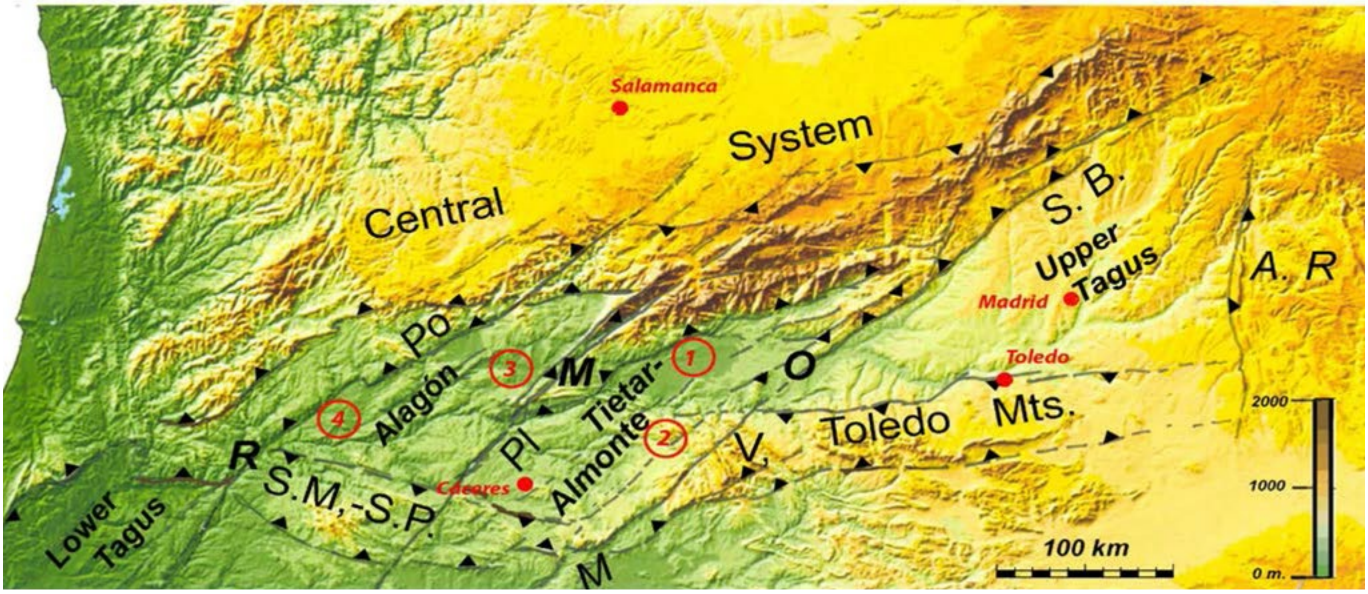

Fig. 3. DEM with the tectonic depressions containing the sedimentary basins of Fig 1. V: Villuercas Mountains, S.M.-S.P.: São Mamede-San Pedro ranges, Po: Ponsul Fault, Pl: Plasencia Fault, S.B.: Southern Border Fault, M: Merida Fault, A.R.: Altomira Range. Encircled numbers show the location of the smaller basins. 1: Campo Arañuelo, 2: Talaván, 3: Coria, 4: Idanha-a-Nova-Moraleja. Thesholds, O: Oropesa, M: Mirabel, R: Rodão.

Fig.3.- DEM mostrando las depresiones tectónicas que contienen las cuencas sedimentarias de la Fig. 1. Los números en círculos indican la posición de las cuencas sedimentarias más pequeñas. Se indica también la situación de los umbrales de Oropesa (O), Mirabel (R) y Rodão (R).

stratigraphic successions defined by Calvo *et al*. (1993) and Cunha (1996).

First tectonic-stratigraphic stage

This stage corresponds to the initiation of folding and related thrusts, as well as the compressional reactivation of the inherited faults. This tectonic activity occurred sometime after the initiation of the plate convergence at the Cantabrian-Pyrenean border and the subsequent effective stress transmission. As a result, the formation of the flanking highs occurred rapidly. Due to the time delay between the formation of the flanking highs and the effective deposition in the depressions, the initial sedimentary sequences could be restricted to the border of the basins. These basal sequences have been dated as Upper Campanian to Ypresian (Calvo *et al.,* 1993)

Second tectonic-stratigraphic stage

This stage represents the basin preservation phase with the accumulation of the most important volume of sediments, which, according with their age, have been divided traditionally into Paleogene (Lutetian to lower Chattian) and Neogene (upper Chattian to lower Tortonian); nevertheless, the tectonic significance of this division remains imprecise. In this sense, it must be taking into account that the N-S plate convergence lasted until the final suture in the Pyrenean border, which can be fixed at the time of the magnetic anomaly 6C, close the Chattian-Aquitanian limit. Since then, the plate convergence slowed, rotating progressively to NW-SE until the onset of the new Africa-Eurasia plate boundary, fixed at the age of the magnetic anomaly 5 (8,9 Ma, upper Tortonian; Mazzoli and Hellman, 1994). During this second stage the Lower and Upper Tagus depressions become filled to overfilled the latter probably with some overspill towards the SE in the eastern continuation of the Toledo Mountains. In contrast, the Alagón and Tiétar-Almonte depressions remained probably underfilled. In addition, a certain equilibrium between sediment supply and sediment deposition was reached in the final sequences composed by fluvial and lacustrine sediments.

Third tectonic-stratigraphic stage

This stage corresponds to the destruction phase which is characterized by basin captures and mass transfer out of the depressions. It comprises the upper Late Tortonian-Present time span. As stated before, during the upper Tortonian the new plate boundary changed to the south of the Iberian Peninsula with a slow NW-SE directed plate convergence, responsible of the subsequent stress transmission to the interior of the Iberian Peninsula. The reactivation of several favourable oriented thrusts occurred sometime after the onset of this new plate boundary, resulting in the development of a series of clastic deposits (*raña* and *raña-like*) along the rejuvenated scarps. Previous to and coeval with this tectonic event, the enclosed basins were converted to exorheic with the consequent processes of excavation and efficient transport of sediments out of them. This could cause the destruction of part of the basins located in the underfilled depressions (Alagón and Tiétar-Almonte) and the loss of an important amount of sediments in the overfilled ones. During this phase all the depressions became drained by a unique main fluvial trunk, the Tagus. The excavation and incision of the basins ought to be progressive by crossing the thresholds of Rodão, Mirabel and Oropesa situated in the borders of the depressions (Fig.3.). Since then, the Tagus drainage network occupies the entire downfolded area between the highs of the Central System and the Toledo Mountains and extensions.

Concluding remarks

Topographic and Cenozoic tectonic features allow to place the Tagus drainage network in a downflected crustal area bordered by two basement uplifts. This crustal area appears to be composed of four tectonic depressions which are bounded by constrictive faults and adopt a parallelogram-like shape in map view. The depressions resulted in the interplay of crustal-scale folding and simultaneous compressional reactivation of inherited long lines (or narrow zones) of fracture during the onset of the Cenozoic compressive tectonic regime that prevails up to Present in the interior of the Iberian Peninsula. This tectonic event created the sufficient available space for the formation of the sedimentary basins, becoming the depressions overfilled (High Tagus) or underfilled (Alagón, Tiétar-Almonte). In this context, the sedimentary basins drained by the Tagus experienced a common tectonic-sedimentary history.

Finally, it can be considered that the buckling model can be applied to compressional intracontinental basins of moderate size with the purpose of elucidate their origin and evolution.

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