Basement structure of the Hontomín CO_2 Geological storage facility (Burgos, Spain): integration of microgravity & 3D seismic reflection data

Estructura del basamento de la planta de almacenamiento geológico de CO_2 en Hontomín: integración de *microgravimetría y sísmica de reflexión 3D*

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Abstract: The structure of the Hontomín CO_2 geological storage research facility has been addressed combining 3D seismic reflection data, borehole information and microgravity data. The integrated interpretation constrains the basement structural setting geometry and that of the sedimentary succession. The study unravels the deep structure and topography of the basement and quantifies the thickness of the Triassic Keuper evaporites. We describe a half-graben setting filled with Keuper evaporites (up to 2000 m) forming an extensional forced fold. Three set of faults are identified with two main fault systems compartmentalizing the area into three differentiated blocks. These faults have been interpreted to be reactivated normal faults that have led to the formation of the Hontomín dome.

Key words: Microgravity, 3D seismics, basement, structural geology

Resumen: *La estructura de la planta de almacenamiento de CO_2 en Hontomín ha sido estudiada combinando sísmica de incidencia vertical 3D, datos de sondeos y microgravimetría para determinar la configuración estructural del basamento y de la cobertera sedimentaria. El estudio determina la estructura profunda del basamento y cuantifica la potencia de las evaporitas del Keuper. La zona presenta una estructura en half-graben rellenada por evaporitas del Keuper (hasta 2000 m de potencia) formando un pliegue extensional forzado. Tres sistemas de fallas han sido identificados, siendo dos principales los que compartimentan el área en tres bloques. Estas fallas han sido interpretadas como fallas normales reactivadas que han conducido a la formación del domo de Hontomín.*

Palabras clave: *Microgravimetría, sísmica 3D, basamento, geología estructural*

INTRODUCTION

Hontomín hosts the first Spanish pilot plant for geological storage of CO_2. In order to assess the suitability of the Hontomín site, a multidisciplinary study was carried out in the area including the acquisition of 3D seismic reflection and microgravity data amongst others techniques (Alcalde et al., 2013a). Here, we present a model that aims to unravel the basement configuration of the area.

GEOLOGICAL SETTING

The Hontomín structure is located within the doubly verging Pyrenean Orogen, in the southeastern part of the 'Plataforma Burgalesa' (Figure 1). The area is characterized by an ESE-dipping monocline bounded to the south by the right-lateral Ubierna Fault System (Tavani et al., 2013) and by the 'Sierra de Cantabria' Thrust to the north.

The 'Plataforma Burgalesa' was affected by three major deformation stages after the Permian period. The first stage corresponds to a Permian-Triassic extension (García-Mondejar et al., 1996), which reactivated wrench-fault systems giving rise to a set of ESE-WNW and E-W trending normal faults. The second event is related to the continental break-up and opening of the Bay of Biscay (García-Mondejar et al., 1996, Ziegler, 1988). This extensional episode triggered the formation of the Basque-Cantabrian basin and the 'Plataforma Burgalesa'. During this deformation episode, NNE-SSW faults were formed almost perpendicularly to the previous fault systems, and the Keuper rocks provided the decoupling surface that ensured different deformation styles between the sedimentary sequences above and the basement below (Tavani et al., 2013). Finally, the Pyrenean orogeny provided the compressional tectonic setting in which previous faults were reactivated with inverse and lateral offsets (Tavani et al., 2013).

The sedimentary succession of the study area lies over a Paleozoic basement, and includes a Mesozoic cover topped by Cenozoic sediments. The stratigraphic succession begins with the Triassic Keuper facies formed by evaporites and anhydrites which are followed by Lower Jurassic anhydrites and dolomites. Above this, a succession of Lower to Middle Jurassic pelagic and hemipelagic carbonate sediments is found. Following the stratigraphic succession, Purbeck facies of the Late Jurassic-Early Cretaceous formed by clays, carbonates and sandstones lay unconformably above the marine Lower to Middle Jurassic rocks. Up-sequence, a siliciclastic succession is found, comprised by the Weald facies and the Escucha and Utrillas Formations, which are interpreted as fluvial successions with sandstone infilled channels alternating with flood plain sediments. The stratigraphic succession ends up with Upper Cretaceous carbonates and lacustrine and detritic Cenozoic sediments lying unconformably above the Mesozoic series (Vera, 2004).

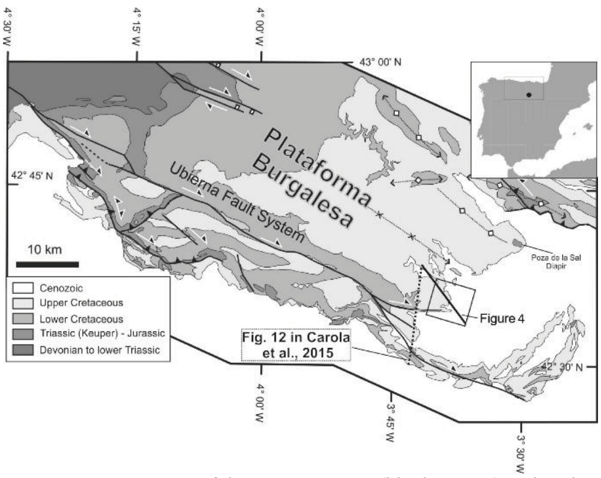

FIGURE 1. *Location of the Hontomín site (black square) within the 'Platforma Burgalesa' (after Alcalde et al. (2014)). Bold line represents the location of the section shown in Figure 4.*

GEOPHYSICAL DATA

The 3D seismic dataset was acquired in 2010 in Hontomín, across an area of 36 km^2, centered according to the target dome-shaped structure (Alcalde et al., 2013a,b). The seismic dataset was processed up to post-stack time migration. The final migrated volume provided clear images from the subsurface down to the anhydrite level. The seismic data was integrated with well-log data from four hydrocarbon exploration boreholes and three shallow groundwater sampling wells. Results indicate that the structure of the Hontomín dome include eight different sedimentary packages, from Triassic (Keuper facies) to Cenozoic and four sets of faults (Alcalde et al., 2014).

Microgravity data were acquired in 2010 with a density mesh covering an area of 4x4 km^2, with measurements taken at every 100 m which resulted in 1600 total measured points. The data (Bouguer anomaly) were processed to enhance gravity gradients in order to highlight structural features. Two 2D gravity profiles were constructed and 3D inversion of the residual dataset was undertaken.

The inversion of the microgravity data was performed integrating the information extracted from the 3D seismics. Five layers, from Cretaceous down to the anhydrites, were used to forward calculate their gravimetric signature, using a constant density for each one, and then they were subtracted from the Bouguer anomaly. In the the next step, the long wavelength component was accomplished using a first order polynomial filter to preserve the signal from the basement-Keuper interface. The residual gravity anomaly was inverted to infer the geometry of the basement. The derived geometry was used along with that of the top of the anhydrites to calculate the Keuper thickness.

RESULTS AND DISCUSSION

The Hontomín dome has been described as an extensional forced fold (Tavani et al. 2013) resulting from the extension and reactivation of Permo-Triassic normal faults affecting the basement. The presence of a detaching level represented by the Keuper Triassic salts produced the forced folding in the upper sedimentary cover by migration of these salts (Tavani et al. 2013; Carola et al. 2015). For the area of study, Carola et al. (2015) have suggested a thin-skinned configuration based on surface geology, well data and vintage seismic lines.

Our new model suggests a local thick-skinned deformation style for the area with two major faults, an E-W and a NW-SE, affecting the basement: the South and the East faults (Figure 2), already described by Alcalde et al., (2014). The model portray an area divided in three main blocks, namely "south", "centre-northwest" and "northeast" blocks. The South Fault stands out in the southern area and is interpreted as a major fault showing an offset of 150 m. Another fault parallel to the South Fault, close to the thickest interval of Keuper evaporites (Figure 3), features a normal offset of 200 m over the basement. These two faults combined create a downward displacement of the basement of about 350 m. The South Fault is thought to be a branch of the right-lateral Ubierna Fault.

The East Fault is located in the NE sector of the area and affects the basement and all the stratigraphic succession up to the Cenozoic. It shows a normal downward displacement of the SW block and a vertical offset of 400 m. In general, the South and East faults seem to have been reactivated during the Jurassic-Lower Cretaceous extension, generating a sunken basement block.

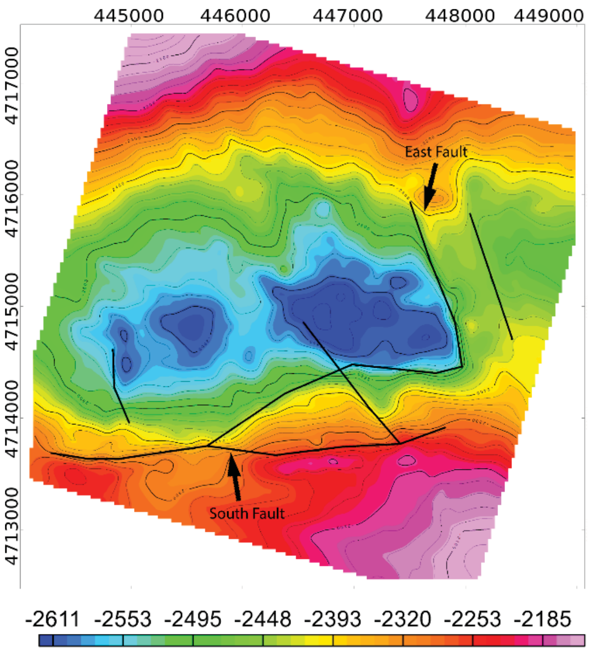

FIGURE 2. *Faults interpreted from gravity derivatives superimposed on the basement topography map resulted from gravity inversion.*

The South Fault is proposed to form a rollover anticline in the NW sector, where a basement high is identified, generated by its listric geometry (Figure 4).

A third set of faults, with NNW-SSE strike was identified. However, its gravity signature is not very significant, suggesting that the faults in this set may be affecting only the Triassic Keuper evaporites and the overlying Jurassic succession, and not the basement.

The thickness of the Triassic salt layer in the 'Plataforma Burgalesa' is very inhomogeneous from north to south (Figure 3). Exploration wells have identified different thicknesses for evaporites, ranging from 2000 m to just 300 m (Carola et al., 2015). Here, we have imaged an average thickness of 1660 m for the Keuper evaporites, with a maximum of 2020 m thick. The normal faulting affecting the basement triggered the movement of the Triassic evaporites towards the basement wall causing the dome growth.

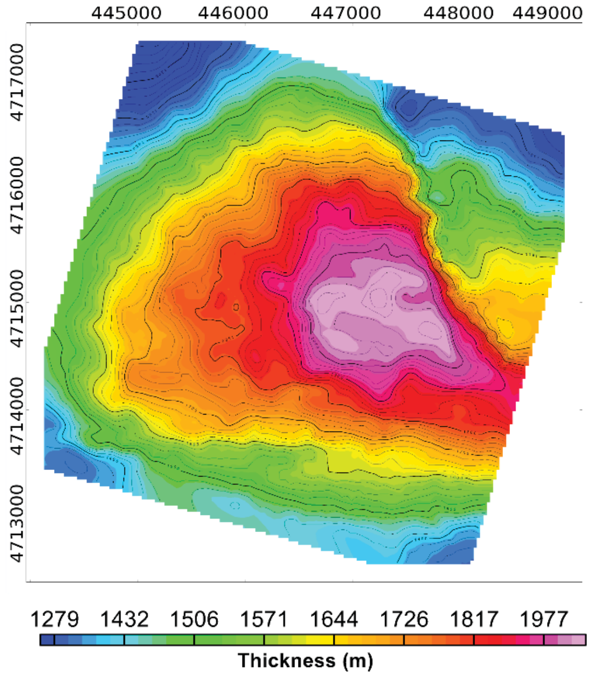

FIGURE 3. T*hickness map of the Triassic Keuper evaporites after comparing the basement topography and the bottom of the sedimentary sequence*

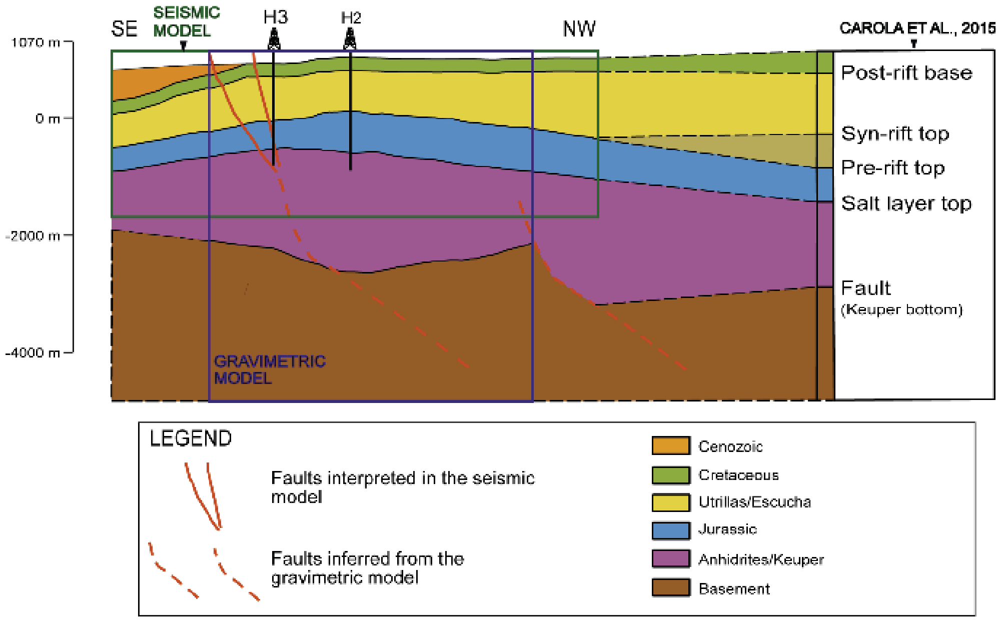

FIGURE 4. *Correlation of the joint gravity and seismic model with that presented by Carola et al. (2015). Note the thickening of the pre-rift and the salt layers to the NW. A new fault is proposed to accommodate the increased thickness.*

CONCLUSIONS

The results from the microgravity analysis of the Hontomín area reveal a thick-skinned tectonic setting configured by three sets of faults, with two of them affecting the basement. We propose a thick-skinned setting with a half-graben like structure in the South Fault, with the hanging wall filled with thick Keuper evaporites. A basement high has been identified in the NW sector, not affected by any structure. This may indicate that the South Fault has a listric fault geometry to some extent. The presence of a new fault located in the NW part, outside of the area of study, has been proposed to accommodate the thickening of the stratigraphic succession towards the NW.

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