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Structural Achitecture of the Madrid Basin from 3D Gravity Inversion

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SUMMARY

The Madrid Basin is an intraplate Cenozoic basin located in the central area of the Iberian Peninsula. Basement is characterized by a wide range of lithologies, from meta-sediments to granites. Sedimentary section is associated with a carbonatic platform in Cretaceous time and with continental environments during Tertiary. During the second half of the last century 2D seismic data was acquired and some wells were drilled by several oil & gas companies. Due to the lack of refraction seismic, the geometry of the Moho is not very well-known in the area. This study presents the results of the 3D gravity inversion performed mainly to determine the configuration of the Moho. Also, the geometry of basement has been refined after the inversion. The initial model was constrained by surface geology, 2D seismic and well data. The final 3D model shows significant density variations within the basement and the presence of an intra-basement structure in the Central Iberian System.

Introduction

The Madrid Basin is an intraplate Cenozic basin, located in the central area of the Iberian Peninsula. First documents regarding tar sands in the basin are dated in century XI. Due to the absence of a well developed source rock, structures identified during the second half of the last century as suitable for oil and gas exploration, are presently reevaluated for CO_2 and gas storages. The geothermal potential of the basin was assessed given the presence of two highly anomalous temperature systems within the basin fill.

The main purpose of the present study is to generate a 3D geological model which provides new insights on the Moho and basement configuration, and to identify lateral density variations within the Cretaceous and Tertiary sedimentary sections in the Madrid Basin. A 3D gravity inversion was performed, integrating surface geology, well-logs, 2D seismic and land gravity data.

Geological Setting

The present distribution of basins and ranges in the Iberian plate is the result of Tertiary deformation, defining an E-W structural pattern which is interpreted to correspond to lithospheric folds (Cloetingh *et al*., 2002 and De Vicente *et al*., 2007). The intermountain basins were classified by De Vicente *et al*., (2011) as Tertiary Duero-Ebro, Tagus, Guadiana and Guadalquivir depocenters developed between the uplifted basement blocks. The Madrid Basin is located in the eastern sector of the Tajo Basin (***Fig.1a and b*).**

The basement in this area is known by the numerous well-exposed outcrops. The Somosierra Fault Zone divides the Central System in two main sectors: 1) a western area exposing Variscan granites and metamorphic high-grade rocks of probable Late Precambrian age, 2) an eastern area dominated by Lower Paleozoic low-grade metamorphic rocks. The contact with Madrid Basin is a major thrust ENE-SWS trended, which clearly indicates the compressive origin of this range. This orientation is also present within the range as ENE-WSW “sierras” that limit pop-downs structures where Cretaceous and Tertiary rocks outcrop. NNE-SSW left lateral strike-slip corridors oriented act as structural boundaries.

According to Querol (1990), the thickness of the Permian-Triassic section, represented by typical Germanic facies, decreases towards the west, while Jurassic sedimentary rocks are limited to the Iberian Chain due to a pre-Cenomanian erosional event. In this area, Cretaceous sediments were deposited over Triassic rocks (Tielmes and Santa Barbara wells) or above the basement (El Pradillo well). Cretaceous rocks record coastal margin sedimentation on a carbonate platform.

Alonso-Zarza *et al*., (2004) conducted a revision of the sedimentary evolution of the Madrid Basin, showing a nearly continuous sedimentary record from Late Cretaceous to Late Miocene few short lived hiatuses. The basin fill was deposited in shallow lakes, rivers and alluvial fans. Progressive discordances edges reflect syn-tectonic depositional process of the basin infill.

3D Gravity Inversion

The 3D gravity inversion technique is a very powerful method that derives a geological model given a set of observations. A grid-based inversion was conducted in this study, which allows computing the density and the geometry of each individual surface. Once the model was created, several structural and property inversion iterations were run, minimizing the difference between observed and calculated anomaly. To adjust the Moho surface long-wavelength anomalies from the Bouguer gravity anomaly have been analyzed while for the basement and sedimentary section short-wavelengths were used. The final model is constrained by seismic horizons, well and outcrops. Thereby, a refined Moho and interpreted surfaces has been obtained.

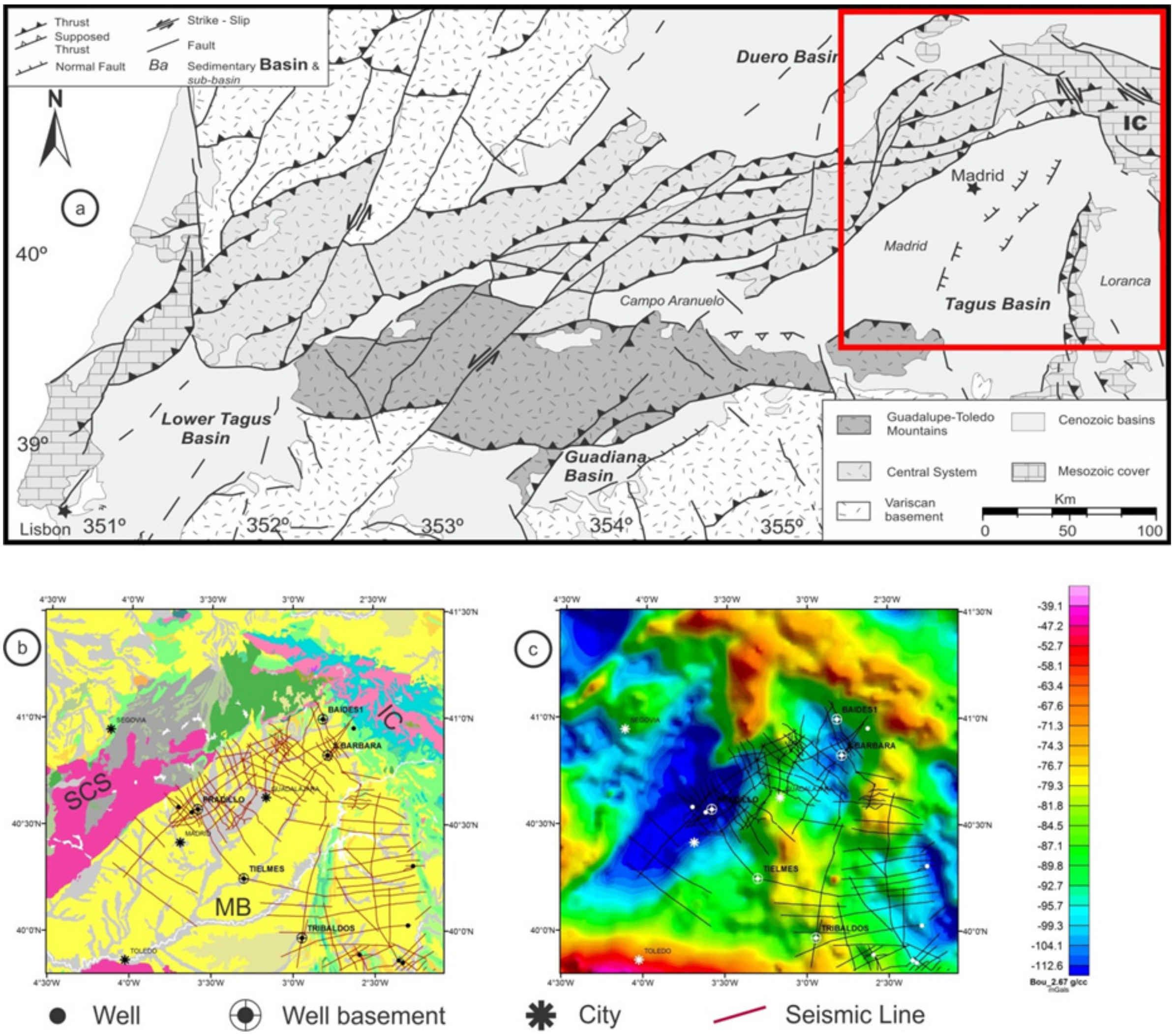

Figure 1 *(a) Tectonic map of the central area of the Iberian Peninsula (modified from De Vicente et al, 2007). (b) Location of wells and seismic lines on the geological map. (c) Bouguer anomaly map of an enlarged area: SCS: Spanish Central System, IC: Iberian Chain and MB: Madrid Basin.*

Gravity data was compiled by Álvarez (2002) from several public institutions: Instituto Geográfico Nacional (IGN), Bureau Gravimetrique International (BGI), ENRESA and Instituto Geológico y Minero de España (IGME), resulting in a 4 km cell-size grid. The most prominent feature in the Bouguer Anomaly map is the strong negative anomaly sub-parallel to the South Central System Thrust, associated with the main depocenter of the Madrid Basin (Querol, 1990) ***(Fig. 1c).***

Due to the lack of seismic refraction profiles in central Iberia area, the proposed regional depth maps of the Moho do not reflect the complexity of the Madrid Basin (Tesauro *et al*., 2008; Díaz and Gallart, 2009; Laske *et al*., 2013).

De Vicente and Muñoz- Martín (2013) re-interpreted 18 seismic lines acquired in the Madrid Basin mainly during 70´s and early 80´s (Racero, 1988 and Querol, 1990). In order to simplify the complex architecture of the basin, which is related to the structural style and drastic lateral facies changes in the Tertiary section, for the this study we used only the top of the basement, top of the Cretaceous unit and topography as input surfaces for the 3D model ***(Fig. 2a).***

Querol (1990) compiled the logs from 17 wells drilled in the basin during the exploration activity. Most of the wells reached the Tertiary and Cretaceous targets. Heterogeneous basement is confirmed by several wells, including the Santa Barbara (gneises), Baides and Tielmess (granites) and El Pradillo (black shales), while the basement penetrated by Tribaldos well is undefined.

Density data was only available in Santa Barbara and El Pradillo wells. Tertiary density values range from 2.10 to 2.35 g/cc, but higher values are observed in some carbonatic basal intervals. The Cretaceous density values varies from 2.35 to 2.60 g/cc. Lithological variations within the basement are reflected by density values between 2.50 and 2.80 g/cc. Mantle density is assumed as a constant value of 3.3 g/cc.

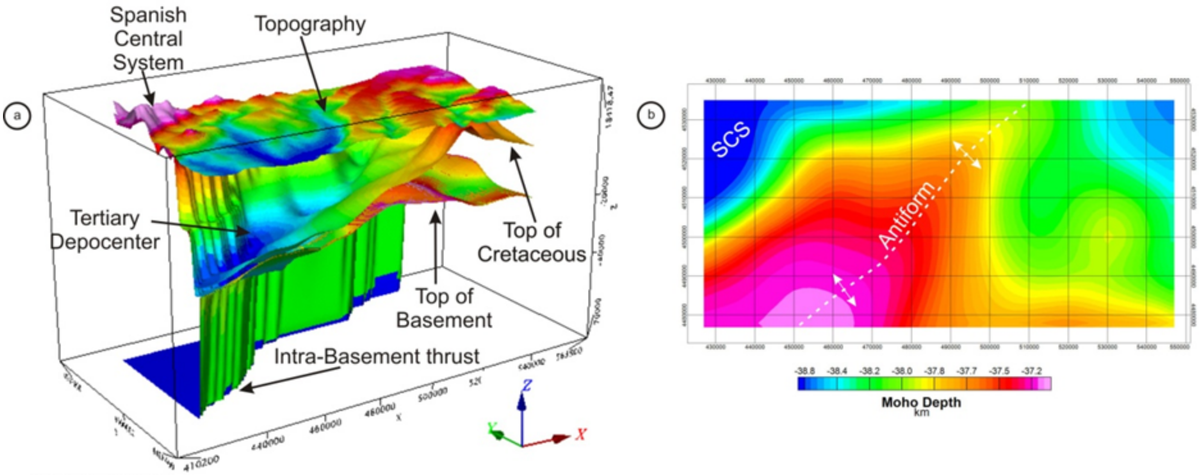

Figure 2 *(a) Geological model of the Madrid Basin with resultant horizons after 3D gravity inversion. (b) Final Moho depth map after 3D gravity inversion: (SCS: Spanish Central System).*

Results

The analysis of the deeper sources reveals that only the Moho surface derived from an isostatic approach (Álvarez, 2002) is a good starting point for the 3D gravity inversion. The results obtained in this study show a deeper Moho surface (40 km) below the Spanish Central System. In the central area of the basin the Moho is shallower.

To obtain a good fit between the observed and calculated gravity anomalies was necessary to include an intra-basement thrust, generating more realistic basement geometry. This structure is not imaged by the seismic data. These modelling results indicate significant vertical density variations within the basement.

After performing the inversion, important lateral density changes has been observed in both Cretaceous and Tertiary sections. These changes are maybe related to depositional and diagenetic changes process.

Conclusions

The 3D gravity inversion in the Madrid Basin allows an analysis of the regional structural features. The resultant geological model is constrained by 2D seismic, well and geological mapping.

A generated Moho surface is found at 40 km below the Spanish Central System. Towards the south the Moho surface defines a smooth anti-form parallel to the Central System ***(Fig. 2b),*** which seems to confirm the lithospheric folding in central Iberia. The south border fault of the Central Systems coincides with the main gradient in the Moho geometry. Towards the east this structure disappears, reflecting the inverted Iberian rift structure.

Lateral density variations within the basement are not contrasting enough to explain gravity signal. Thus, an intra-basement thrust below the Central System has been included, simulating a very homogenous hanging-wall block.

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