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New Insights on Peniche Basin (West Iberian Margin) Crustal Structure Based on Gravity Data Interpretation

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SUMMARY

A gravimetric study has been carried out over a sector of the West Iberian Margin (WIM), constrained by well and seismic data. The analytic development was made through three main stages: the processing of different gravity datasets, the production of gravity anomaly maps and 2,5D models using the processed data, and the geophysical interpretation of maps and models. The final results of the interpretation achieved, allowed the determination of crustal structure and its variation/complexity along the WIM. The main obtained results concern the pre-saline infilling and the deep structure of the margin, which vary related to the location of first-order oblique fractures.

Introduction

The West Iberian Margin (WIM) is a passive and non-volcanic margin, characterized by an extreme lithospheric stretching, which is responsible for the most of the current configuration of the margin. The structure of this region is defined by extensional faults oriented N-S, NNE-SSW, NW-SE and NNW-SSE, hence basement blocks have horst and graben configuration. The stratigraphic record starts with Triassic continental sedimentary deposits marking the rifting start, and ends on top of the Cenozoic sedimentary rocks, that are still exposed to marine water-rock interface weathering. We also find a Triassic-Jurassic salt unit and different marine sedimentary megasequences, all slightly to locally highly deformed by the Alpine Orogeny and the salt tectonics (Alves *et al*. 2006). The salt formation is the main barrier in the area to an accurate seismic imaging and interpretation.

The WIM is of double interest: from the geoscientific point of view, the margin has a complex geological history since its rifting commencement in the Triassic, through oceanic crust spreading during the Lower Cretaceous, until it reached a partial inversion during the Alpine Orogeny. Moreover, it is economically interesting as a possible analogue of its conjugate margin: the passive and prolific margin of Newfoundland, where several oil and gas fields have already been discovered.

In order to better study the present geological setting and address exploration concerns about subsalt sedimentary thickness and the nature of the margin, a new geophysical study mainly based on gravity data from different sources, was conducted. Data interpretation was aided by proprietary and public-domain seismic and wells interpretations (Alves *et al*. 2006; Dean *et al*. 2000; Whitmarsh *et al*. 1996; Péron-Pinvidic and Manatschal, 2009).

Gravity and 2D-3D seismic campaigns from TGS-Nopec (1999-2002), SCAN-Austin (2008) and CGG-Austin (2010) were used for the interpretation. Satellite derived gravity was also used to extend the recently acquired gravity data and to shade new light on the crustal nature of the Peniche Basin.

The analysis of gravity data allowed us to estimate salt and sediment thicknesses, additionally we were able to map the different crustal domains present in the margin. It also allowed the determination of crustal features parallel and perpendicular to rifting direction and enabled us to obtain a better constraint of the pre-salt sedimentary infilling.

Method

The geophysical study consisted of an initial partial re-processing of four gravity datasets, followed by qualitative interpretation, structural mapping and 2.5D gravity modelling. The results were included in a comprehensive interpretation honouring all the available data.

Gravity data were reprocessed in house in order to have one all-inclusive data set. During this phase, care was taken to avoid generating meaningless artefacts. Available data already presented some and these were removed during the re-processing.

Later we undertook the analysis of the enhanced gravity grids to understand the general structural framework. We studied the gravity patterns and compared them with known geological features. Several anomalies have a good correlation with recently studied structures, visible in seismic and wells (figure 1). This phase helped us to have a regional idea of the basin and the margin and a few hypotheses on the crustal nature were formulated.

The different hypotheses were tested against gravity data via 2.5D modelling. Modelling of gravity data is a relatively fast process that makes it possible to compare the synthetic signal response of our models with the recorded gravity data. Models can be iteratively adjusted to best fit the calculated response with the actual measured gravity. This is a fundamental step for our analysis because salt formations and basement surface have a strong gravity response and can be easily modelled. Besides, long wavelength information from gravity is directly related to deep crustal sources with a regional expression.

Two long transects across the whole margin were modelled. These lines, roughly oriented W-E, are coincident with proprietary seismic and extend further west out of the survey areas to better evaluate the regional crustal nature of the region. Satellite gravity was used to extend the line as these data contain valuable long wavelength information relevant for the crustal nature identification. Models were constrained by seismic interpretation in their very shallow part while salt and subsalt sediments were assessed based entirely on gravity, as part of this study.

In both cases, the modelling begun with the generation of an initial model based on the seismic interpretation, developed by experienced interpreters at Repsol Exploration and with a Moho surface extracted from the published database by Díaz and Gallart (2009). Then, depending on the difference or error registered between the observed and the calculated gravity curves, the initial models were modified iteratively, from deeper to shallower blocks, first solving longest wavelengths and finally the shortest.

Interpretation results discussion

Map-based interpretation

Bouguer gravity shows a general trend of increasing values towards the West (Figure 1a). That trend is related to the crustal transition that occurs from mainland, in the east end of the map, to the Iberian Abyssal Plain (IAP), which appears west of the map.

The existing E-W oriented gravity heterogeneities enabled the differentiation of three main cortical domains (Figure 1a): Continental Crust Domain, Transitional Domain or Ocean-Continent Transition (OCT) and Oceanic Crust Domain. In addition, the Transitional Crust Domain was divided in three subdomains, from East to West: Thinned Continental Crust Zone, Maximum Gravity Gradient Zone and Anomalous Oceanic Crust. One hypothesis is that this last subdomain may correspond to an area of extreme thinning leading to mantle exhumation and subsequent serpentinization (Péron-Pinvidic and Manatschal, 2009). This will be unequivocally confirmed during the modelling phase.

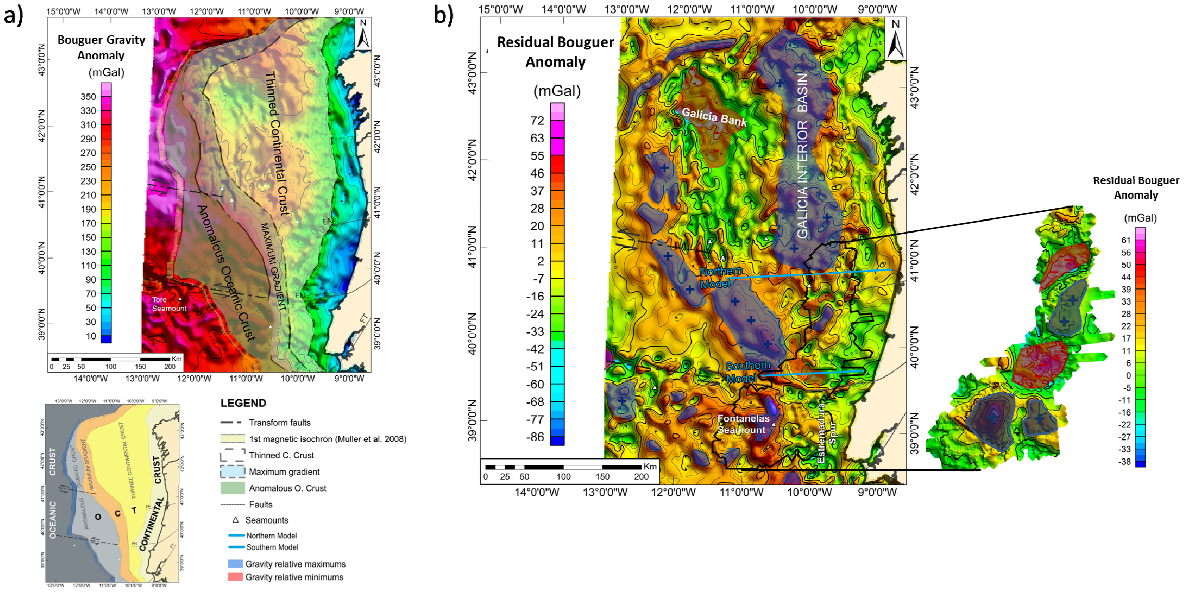

***Figure 1** Interpreted Complete Bouguer Gravity Anomaly maps. a) Crustal domains identified in the WIM. b) Residual maps of the Public domain (larger western map) and acquired/local gravity (east) joint with the delineation of the geological sources that cause the main gravity anomalies and location of the 2.5D models (blue lines).*

Once the crustal domains characterization was completed, a more detailed map-based analysis was undertaken. The residual maps calculated from the regional and local Complete Bouguer Gravity, were used to recognize shallow geological features, contained in the upper crust (Figure 1b). Thus, geological elements were mapped, such as:

- The Galicia Bank, which is visualized as a relative gravity minimum due to the continental nature and the thickness of its crust.
- The Galicia Interior Basin (GIB), represented by a relative gravity maximum because of the short depth of the Moho surface, under its location.
- The presence of a serpentinized peridotites ridge belonging to the Exhumed Mantle in the Transitional Domain, observable as relative gravimetric maximums due to the high density of their mineralogical composition.
- Two subbasins belonging to the Peniche Basin which appear surrounding the continental shelf in the SE part of the map, easier to be identified in the shipborne gravity map (eastern map on Figure 1b) because it has higher resolution.
- The volcanic complex in the south of the map, recognizable as a group of small and rounded relative gravity maximums without predominant or principal orientation.
- Two main discontinuities WNW – ESE oriented, interpreted as transform faults developed during the Mesozoic rifting.

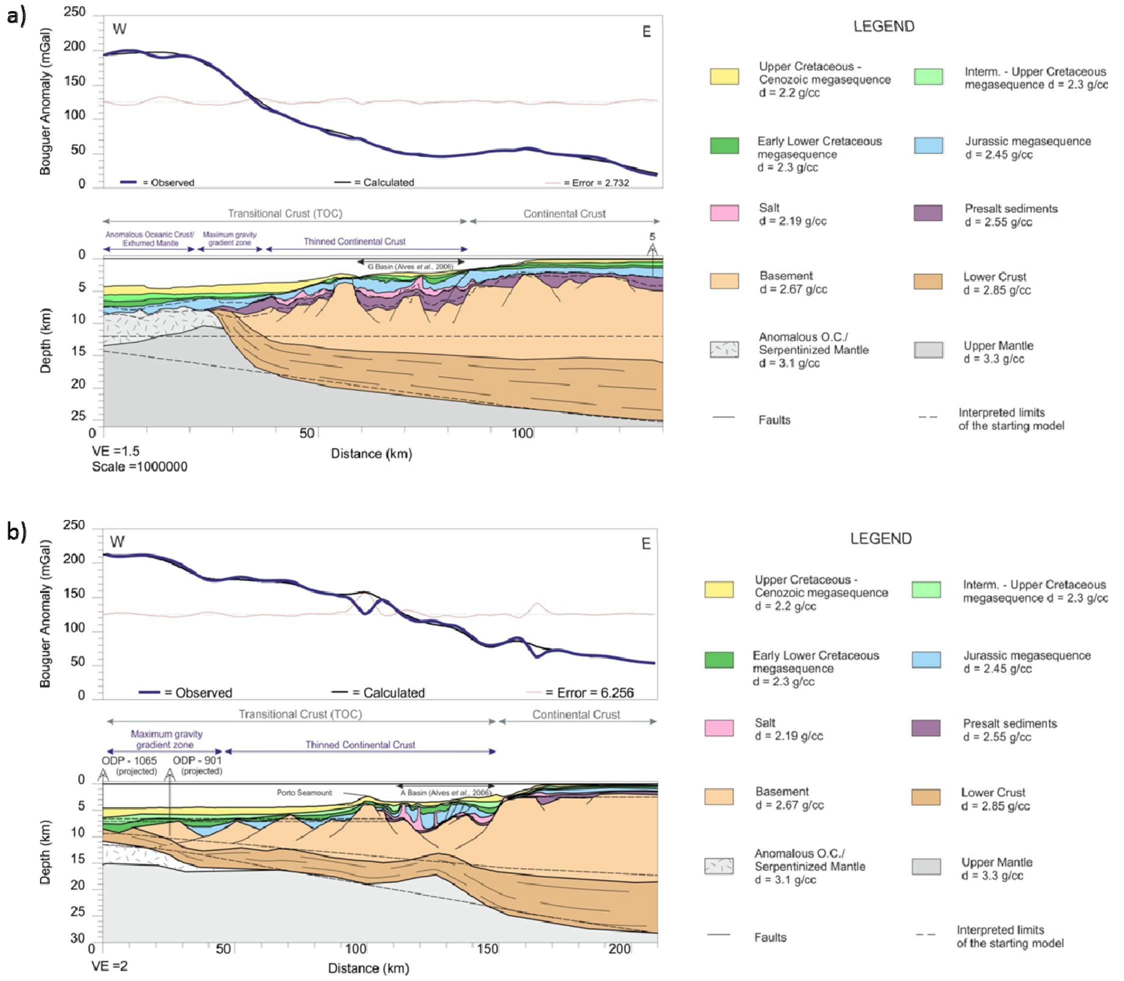

Figure 2 *Final interpreted 2.5D gravity models. (a) Peniche Basin Southern Model. (b) Peniche Basin Northern Model.*

Model-based interpretation

Both profiles show the typical gravity increasing trend of the crustal transition that takes place from mainland to the ocean (Figure 2). The initial models had a very high misfit between observed and calculated gravity, at their western end. Such large misfit required an increase in lower crust density.

To solve it completely taking into account the regional setting and the gravity magnitude of the problem, the only geologically coherent solution was to include a block of exhumed and serpentinized Mantle in the west (Figure 2). This fact fully supports the hypothesis of the existence of serpentinized peridotitic zones in the WIM, proposed in recently published studies based on seismic and wells evidences (Whitmarsh *et al*. 1996; Dean *et al*. 2000). In relation and with the aim of correcting the differences between calculated and measured gravity signals, geometry and thickness of the lower crust and the subsalt units, were modified consistently with the structural style of the margin.

The final models are constituted by a continental lower crust that gets attenuated and folded westward, leaving the space needed for the exhumed mantle. Basement appears fractured and tilted, allowing the generation of the sedimentary basins, which are filled by the upper deposits. Sedimentary layers show wedge shapes according to the movement of faults, and the salt unit evolves to diapiric structures over most of the fractures (Figure 2).

However, there are some differences between the models, which make possible to suspect the variability of the WIM from north to south. The crustal thinning looks more sharp and abrupt in the Southern Model (Figure 2a), which must be related to dynamic and composition differences in the rifting, along the margin. The thickness of the pre-salt unit is also notably higher in the Southern Model, and it may be due to a preferential area of fluvial/alluvial deposit, in the south of the margin.

Conclusions

The gravimetric interpretation has complemented and enhanced the seismic interpretation, especially for the lower lithosphere and regarding the deepest cortical units. The model-based study has given an important contribution to the estimation of the thickness and distribution of the salt unit, which is difficult to visualize and define on seismic lines and influences the exploration interest of the area. In relation, the thickness and geometry of the oldest sedimentary unit has been intensively modified compared to the initial seismic interpretation.

The gravity data reveal that the crustal transition of the WIM is complex and heterogeneous. The hypothesis of the existence of serpentinized mantle in the margin as a result of the extreme stretching, is confirmed by the gravity response of the analyzed area. There is a spatial correlation between wells where serpentinized peridotites were sampled, zones of seismic velocities layers interpreted as corresponding to an exhumed Mantle, and the zones of Anomalous Oceanic Crust defined in this gravimetric study.

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