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Structural analysis of the Serra da Boa Viagem stratigraphic series (Central Portugal): preliminary study

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Abstract: This study is based on the analysis of geological, structural and gravimetric data from the area of Serra da Boa Viagem (Cabo Mondego, Figueira da Foz, Portugal). A gravimetric survey has been made in the area to obtain more information about subsurface structures. The analysis suggests that the negative residual anomalies seem to be correlated with major tectonic faults. Reactivation of the Cretaceous Riedel transcurrent system during the Alpine deformation can explain the observed tectonic structures.

Keywords: Lusitanian Basin, Serra da Boa Viagem, gravity anomalies, structural analysis.

The aim of this study is the structural analysis of Serra da Boa Viagem (Cabo Mondego, Figueira da Foz, Portugal) stratigraphic series, based on the analysis of geological, structural and gravimetric data. The Serra da Boa Viagem stratigraphic succession is part of the Jurassic and Cretaceous sequences of the Lusitanian Basin, located along the western Iberian margin (Fig. 1). The Lusitanian Basin is an Atlantic margin rift-basin which was formed as a response to Mesozoic extension and subsequent opening of the North Atlantic Ocean. Mesozoic rifting and rotation of Iberia was followed by Cenozoic inversion movements due to Alpine collision (Rasmussen *et al.*, 1998; Jabaloy *et al.*, 2002). The reactivation of Hercynian basement faults had conditioned the structural evolution of the Lusitanian basin since the upper Triassic (Wilson *et al.*, 1989).

The stratigraphic sequence in this region starts with Lower Jurassic sediments. The base of this sequence is formed by the Coimbra formation, a dolomitic limestone dominated unit. The following series are characterised by an expressive marl-limestone accumulation, that includes Água de Madeiros, Vale das Fontes, Lemede and São Gião formations (from the Late Sinemurian to the Toarcian) (Duarte and Soares, 2002). This suggests a deposition in an epicontinental extensional basin, on a homoclinal carbonate ramp, influenced by eustatic fluctuations, local and regional tectonics (Duarte *et al.*, 2004).

The cliff section at Cabo Mondego ranges from the "Brenha facies" (Middle Jurassic) to the "paralic" bituminous facies of the Cabaços formation (Upper Jurassic). This sequence represents a regressive episode separating the Middle and Upper Jurassic, followed by siliciclastic influxes (reflecting tectonism and basement uplift) and by a transgression and climate change associated with restricted tidal activity (Azerêdo and Wright, 2004). Rifting climax occurred during Upper Jurassic and it is well represented in the Cabo Mondego stratigraphic sequence with siliciclastic deposits (Pena dos Reis *et al.*, 2000).

Erosion in the continent led to the deposition of the Figueira da Foz siliciclastic formation during the Lower Cretaceous. The Upper Cretaceous is represented by the Cenomanian-Turonian carbonate suc-

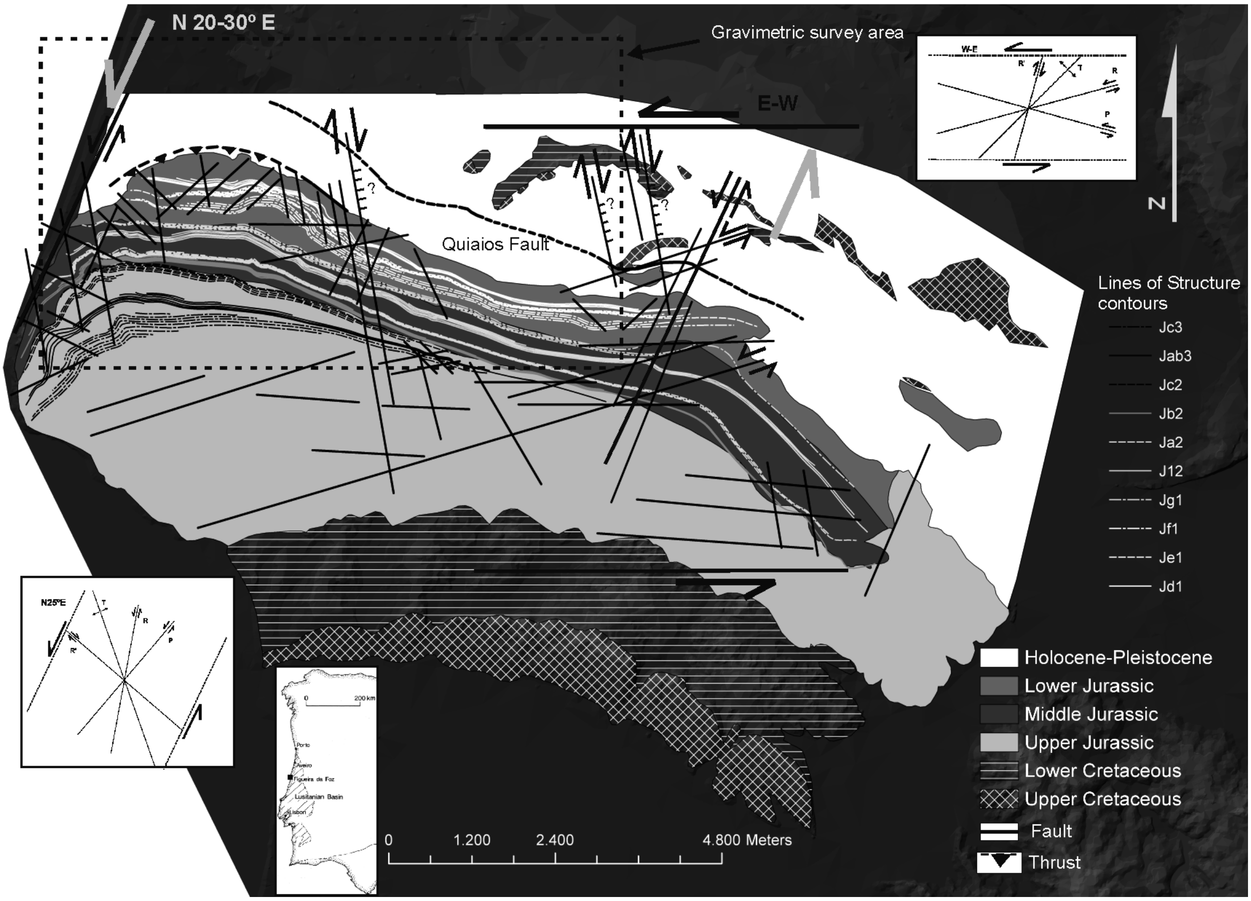

Figure 1. Geological map of the study area. Adapted from 1:50 000 geological maps (Rocha *et al.*, 1981; Barbosa *et al.*, 1988). Structural contour map showing the associated Riedel systems (contour interval: 25 m).

cessions that reflect the transgressive conditions in the basin at that time (Rey *et al.*, 2006).

The entire Mesozoic sequence dips to the south on a gentle monoclinal structure (Rocha *et al.*, 1981). The North scarp of the Serra da Boa Viagem relief, which separates the Mesozoic from the Cenozoic cover of Gândara dune system, corresponds to an inverse fault scarp striking W-E to WNW-ESE (Barbosa *et al.*, 1988; Cabral, 1995), designated by Quiaios Fault (QF) (Fig. 1).

Methods

A structural contour map was made for the study area using 1:50 000 geological maps 19A, Cantanhede (Barbosa *et al.*, 1988) and 19C, Figueira da Foz (Rocha *et al.*, 1981). A gravimetric survey was conducted in the area to obtain more information about the fracture pattern. Gravity prospecting is a useful method to study subsurface structures. The gravimetric data were collected using a LaCoste and Romberg gravimeter Model G (LaCoste and Romberg, 1991). The gravimetric field was measured at 227 points with an irregular grid that covers an area of 22.5 km^2. To locate the measurement points a GPS system was used. All the standard gravimetric corrections were applied to the data (tidal, instrumental drift, altitude, baseplate, latitude, Bouguer and topographic). These procedures limit the measured gravity to the surface of the ellipsoid (Lowrie, 1997). The *QuickTide* program was used for computing the tidal correction. The topographic correction was performed according to the Hammer grid and tables. Bouguer density values were calculated for all the data using the Parasnis method. The value used for the Bouguer density in the Bouguer and topographic corrections was 2.48 g cm^{-3}.

Results and discussion

Structural analysis

The Serra da Boa Viagem monoclinal structure seems to be associated with the Upper Cretaceous transcurrent deformation trending E-W. This event is related to the Iberia-European plate detachment and counter clockwise rotation of the Iberian plate. In this Riedel model, the Serra da Boa Viagem monoclinal is part of an anticlinal fold-faulted structure, limited by a simple E-W shear system. The transcurrent E-W deformation in the Iberian plate is contemporaneous with the opening of the Gulf of Biscay. After this, the Pyrenees formation was responsible for the reactivations of the 30ºN ± 5ºE fractures as sinistral strike-slip faults. This same episode and the alpine compression led to the tectonic inversion in the Lusitanian basin (Ribeiro *et al.*, 1990).

Compressional structures, folds and thrusts, with several orientations (E-W, NE-SW, NW-SE and N-S) are the result of the inversion of the Mesozoic basins. These structures are conditioned by pre-existent structures (Casas Sainz and Faccenna, 2001). In Serra da Boa Viagem, the E-W and NE-SW structural trends are clear (Fig. 1).

This compressive episode, which began with the collision between Iberia and Europe during the Paleogene, was followed by the collision between Iberia and Africa during the Neogene, which continues to this day (Jabaloy *et al.*, 2002). During the Pliocene, most of the thrust faults in Iberia became inactive. The active structures during the Quaternary and at the present seem to be mainly strike-slip faults and normal faults trending NNE and NNW respectively (Jabaloy *et al.*, 2002).

Gravimetric analysis

The Bouguer gravity anomaly corresponds to the algebraic sum of the measured gravity values and all the gravimetric corrections. The Bouguer anomaly values were decomposed in regional and residual anomalies. Regional anomalies are important for understanding the large-scale structures, and residual anomalies are related with local structures (Lowrie, 1997). The Bouguer anomaly map was obtained with the Surfer software, estimating the grid points by the

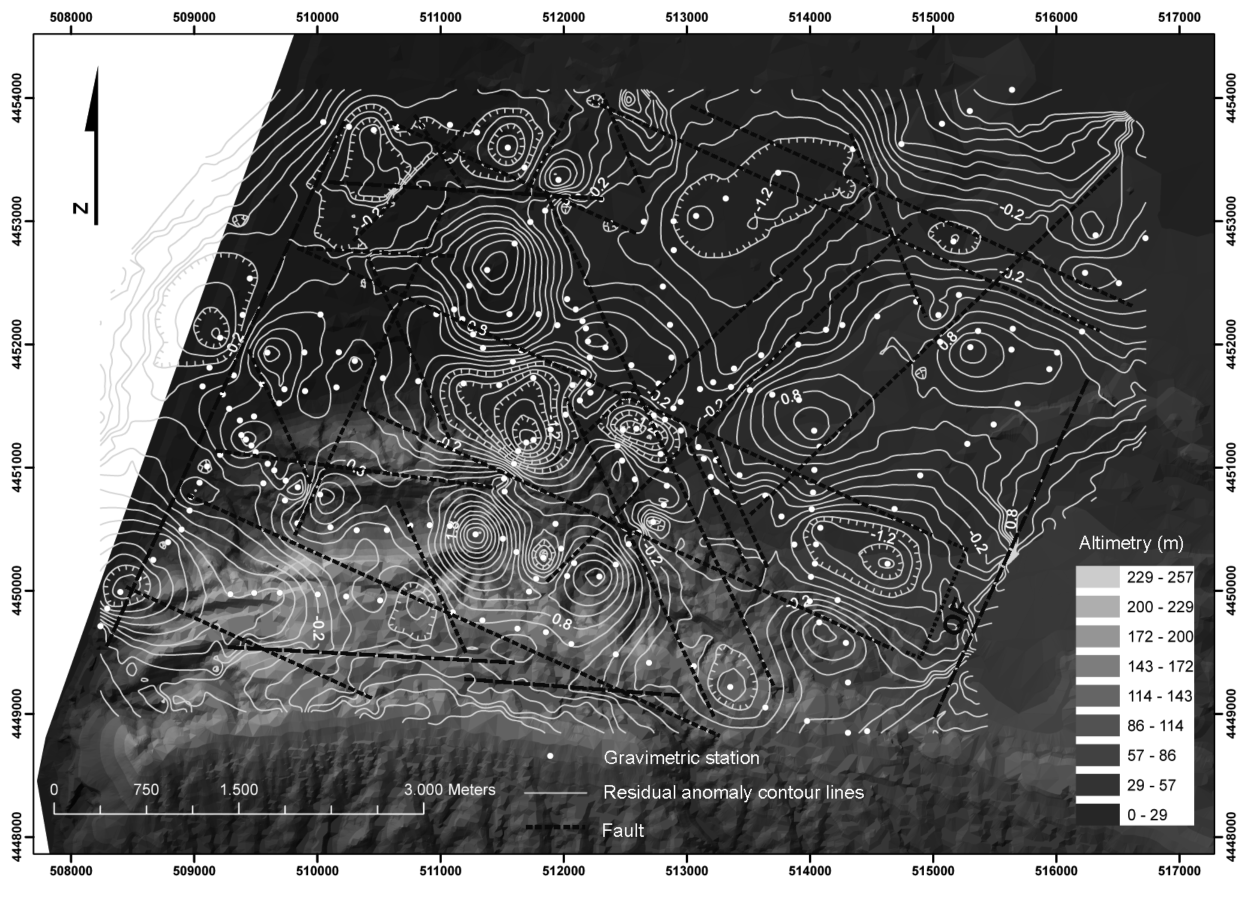

Figure 2. Residual anomaly map (contour interval: 0.2 mgal) and the fault alignments analysis (Legend: QF: Quiaios Fault alignment).

kriging interpolation method. The Regional anomalies were obtained by gridding the Bouguer anomaly data with a polynomial regression. The residual anomalies were obtained by subtracting the regional anomaly from the Bouguer anomaly data.

Data suggests that the negative residual anomalies are well correlated with the main tectonic structures that produce alternating blocks (horsts and grabens) in agreement with the Lusitanian Basin tectonic style (Figueiredo, 2001). The main tectonic faults identified strike E-W, NW-SE and NE-SW. In particular, the Quiaios fault (N60-70ºW), the major structure of the area, is well marked by a negative anomaly (Fig. 2).

Conclusions

The structural model of the study area can be explained by the cretaceous faulting, a Riedel transcurrent system striking E-W. This system led to the development of blocks separated by normal faults striking NE-SW (Pereira, 2008). This was followed by the more recent Alpine tectonics, responsible for the reactivation of previous structures (striking 30ºN ± 5ºE). This structure is nowadays concordant with a NNE-SSW-trending Riedel system with a left component slip.

The developed study is a geological and structural preliminary interpretation of gravimetric data. In the future, the gravimetric data will be modelled with suitable software in order to better constrain the proposed model.

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