Three-Dimensional Geometry of The Upper-Crust in The Mexicali Spreading Centre and Consequences on The Cerro Prieto Geothermal Area

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ABSTRACT

We interpreted the gravity data of the Laguna Salada and Mexicali Valley, obtaining the three-dimensional density model for those areas and further determined the 3D geometry of the interphase between sediments-metasediments and the upper-crust (granites). Top upper-crust geometry was determined by quadratic programming inversion constrained by hard information like a borehole and 2D seismic cross-sections. We used an algorithm that considers layers like geological formation. The inversion purpose is to find the top and bottom topography for every formation constrained by hard information.

Through our methods, we found that the sediment layer in the Mexicali Valley is as thick as 7 km, and we needed a lineal compaction function in order to agree with the seismic information. The same happens in the Laguna Salada Valley, but the compaction function was different because depth is lower that Mexicali Valley. The upper-crust top topography shows a very big depression along the Cerro Prieto faults that were reported before as the Montague basis. The basin shape runs along the Colorado River until the shoreline, which would imply that the river caused this sinking in the upper-crust. In the pull-apart basin, we see a depression in the upper-crust, meaning that sinking could be the cause for this. We also see that pull-apart basin is larger than expected. The Cerro Prieto Geothermal area is located inside the pull-apart basin. Therefore, it is important to know the geometry of this basin as this would serve towards future reservoir exploration plans.

1. INTRODUCTION

Many research works have been conducted in the Cerro Prieto area, but gravity anomaly still remains without a proper quantitative interpretation. Gravity data were collected by Pemex in the '80s, and it has been used extensively for qualitative analysis. However, few quantitative interpretations have been performed, such as Chaves et al. (2000) in 3D and Garcia-Abdeslem et al. (2001) in 2D.

The problem with the gravity method is that non-unicity is large and to find a model that agrees with the existing geology is very difficult. In this research, we introduced all the geological, 2D seismic sections and borehole information as constraints in order to guide the 3D model and reduce non-uniqueness significantly. We also found that anomaly was almost negative even that dense upper-crust granites outcrops, meaning that a large isostatic anomaly was affecting the data. We modelled the crust-mantle boundary according to the Airy-Heiskanen model. We obtained mantle depths of 35 km below the San Pedro Martir mountains and 25 km bellow Cucapa-El Mayor sierra. Mantle depths is around 20 km in areas outside mountains (Nava and Brune, 1982; Ramirez-Ramos et al., 2015). Additionally, we subtracted that isostatic anomaly to the data and obtained a residual gravity anomaly with very small positive values where mountains outcrops, meaning that anomaly only contains crustal inhomogeneities. This was the anomaly used for the 3D constrained inversion.

2. DATA AND METHODS

2.1 Data

In Figure 1, the gravity anomaly before the isostatic correction is shown. In the figure, the negative values are present almost everywhere. Anomaly was built with two databases. The one at the west is on land but interpolated, whereas, the one on the east was taken on land over secondary roads. There is an overlap with a discrepancy of 3 mGal. The inversion method is robust enough to manage this overlap.
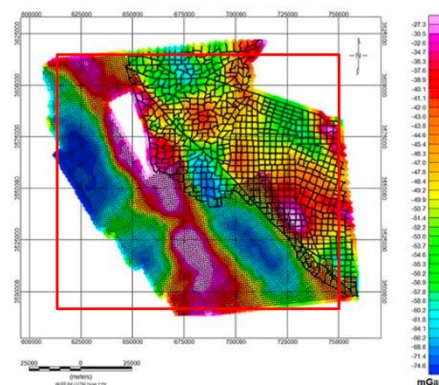

Figure 1: Gravity anomaly before the isostatic correction.

2.2 Methods

We used the algorithm from Gallardo et al. (2003) and discretised the half-space in 3D prisms. We used a layer of prisms for every geological formation. Sediments, seawater, meta-sediments, upper-crust granites, lower-crust and mantle, are represented by their respective layer of prisms. Initially, those layers are horizontal as a sandwich. Then, we proceeded to deform each layer according to the surface geology. Where there is no presence of sea-water, the thickness for those seawater prisms is set to zero. The same procedure where no-sediments are present. This way, we obligate the 3D model to agree with the surface geology. The inversion process varies the vertical thickness for every prism of every layer. We designed a Python language platform to easily colouring the surface geology, set other kinds of constraints and communicate all these data to the original 3D inversion programme in Fortran and run.

We further compute the programme with less amount of constraints and to move the density contrast for every layer. Then we add more constraints, and further tune the density contrast until misfit decrease and the model is smoothly agreeing, in our case, with the surface geology, the 2D seismic sections (Chanes et al., 2014) and boreholes.
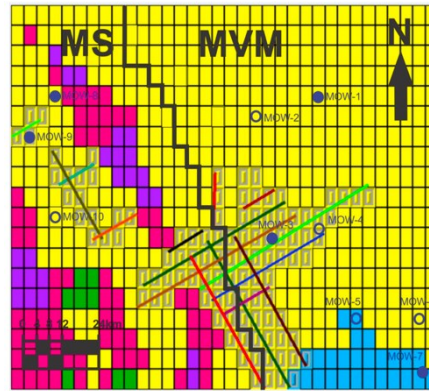

Figure 2. Grid used to simulate surface geology. Blue colour prisms correspond to seawater, yellow to sediments, red-purple to upper-crust granites. Straight lines correspond to seismic data interpreted in 2D. Dots correspond to boreholes.

3. RESULTS

We ran the programme many times and move density contrasts in small increments. This way, we found that density for sediments cannot be constant; instead, we utilize a density value that increases with depth. We also found that density for the mantle material intruding the crust where the Cerro Prieto pull-apart is located should decrease as the intrusion closes to the surface.

In Figure 3, we also found a big depression at SE, almost following the eastern edge of the Cucapa-sierra and the Colorado River. This is the Montage basin with depths as large as 8.5 km. We believe that this basin is very related with the isostatic subsidence of the Colorado River sediments, The Cerro Prieto basin in blue means that upper-crust is deeper. Sarychikhina et al. (1945) have measured subsidence around the Geothermal area related to the pull-apart movement. With this 3D model, we see that such a basin extends northeastern. Topography shows an irregular surface with highs and lows related to possible faulting producing vertical movements. Dash lines are faults suggested.
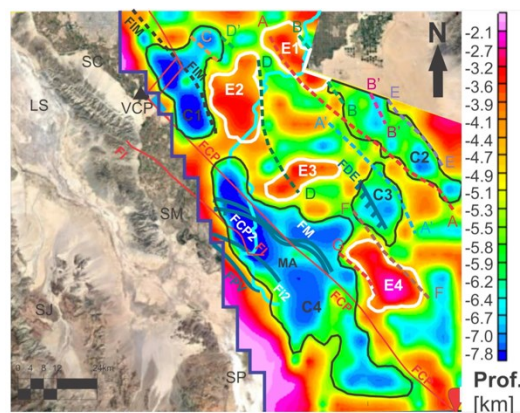
Figure 3. Top topography of the upper-crust.

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