Geophysical exploration using gravity data

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Abstract: The geometry of the northern part of the Vallès fault, between La Garriga and Cànoves i Samalús is deduced from the gravimetric survey of the region. The survey consists of the relative measurement of the vertical gravitational acceleration with a gravimeter. From the readings acquired the residual anomaly is deduced to create a two-dimensional model of the section of the fault, approximating the bodies to different polygons with a characteristic density.

I. INTRODUCTION

The study area is located in the north-eastern part of the Vallès-Penedès graben, between La Garriga and Cànoves i Samalús villages. This study is focused on the northern part of the Vallès fault which limits the Prelitoral Chain and the Valles graben [1].

In this paper, the gravimetric method is used to locate and describe the geological structure of the area in order to achieve a higher understanding of the Vallès fault. Gravimetry [2] is an indirect geophysical method which allows the characterization of densities of the subsoil by the detection of the variation in the gravitational acceleration caused by the distribution.

II. EXPERIMENTAL WORK

The gravity surveying could be done using two different methods: absolute magnitude measurements or the relative measuring of the gravity. In this case, the gravimeter allows measurements of the latest type. It measures the relative gravity of one location relative to another one. By calibration, it is converted to an absolute value, that after the required correction gives the residual anomaly, which is used to obtain a density model of the graben.

In this study, the gravimeter used is GR910 LaCoste Romberg [3]. Its operating is based on variating the force exerted by a zero-length spring with different lavers so the mass at the end of a beam is maintained at the same position. This way the effect of the variation of the gravity force in the mass is nulled by the string by applying a certain force. This force is calibrated with the lever system, so the variation of the gravity is known.

First of all, the measurement of the gravitational acceleration is taken in a known-gravity base station, in this case, at the Facultat de Física of Universitat de Barcelona. The difference between both measurements is the reading of the vertical component of the gravity at the station in milligals. Apart from the counter measurement, it is important to consider the coordinates of the station, the height of surface over which the gravimeter is positioned and the time of the measurement for the later processing of the data, especially to situate the station and calculate the corrections, applied to calculate the residual anomaly.

The process of data acquisition consists of situating the gravimeter over a metal plate, balance the instrument with the leveling screws and unblock the instrument by releasing the internal beam and measure the relative value of the vertical component of the gravity by using the nulling dial until the reading line is centered and still.

The gravity survey used a fairly irregular grid with measuring stations not equidistant to each other due to the difficulty of access to some areas. The approximate spacing is selected by the assumed dimensions and depth of the anomaly, in this case of 500 m spacing considering that the fault should reach 1.3-1.5 km depth.

There was a total of 65 stations measured. Additional data [4] has been included from previous gravimetric surveys of the region to complete the gravimetric database.

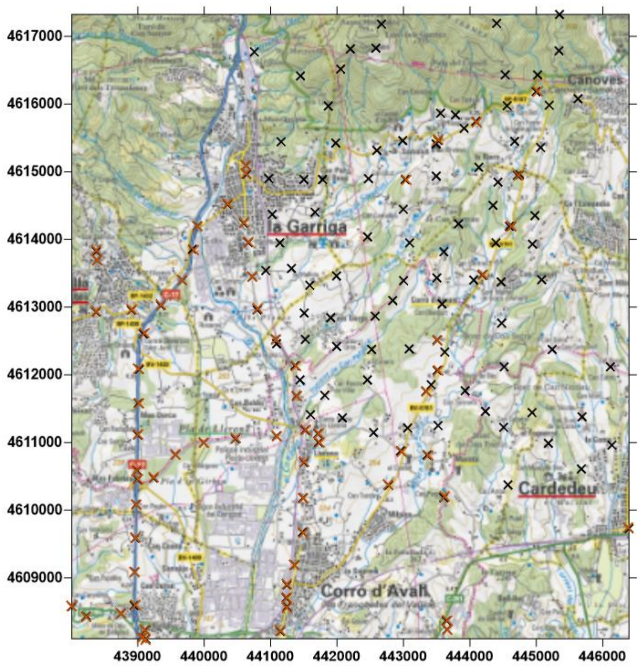

FIG. 1: Map of the gravimetric database. In orange, the acquisition stations measured. In black, the additional measurements considered.

III. DATA PROCESSING

Once the data has been acquired, it must be processed to calculate the residual anomaly, construct the grid, and choose the adequate profile orientation.

A. Corrections

First, the Bouguer anomaly [5] [6] is obtained after the application of the correction since the measurements made in the different stations of the grid are influenced by latitude, elevation, topography, and tides. It is calculated according to the expression:

$$g_{AB} = g_{obs} - (g_{Teo} - dg_{CF} + dg_{CB} - dg_{Topo}) \qquad (1)$$

Where the observed value of gravity g_{obs} is the lecture of the gravimeter corrected with the instrumental drift and the tides. The instrumental drift is the change of the null reading with the pass of the day. It is corrected by supposing that the drift is linear with time and comparing the first and last measurements at the base station. The tides are the deformation of the shape of the Earth caused by the gravitational forces, due to the Sun and the Moon. The deformation due to the tides varies with location, date and time of the day and is tabulated since its theory is well-established.

The first term subtracted, g_{Teo}, is the theoretical value of the gravity corresponding to the value of gravity on the rotating international reference ellipsoid at the latitude of the station. The ellipsoid is an approximation used to describe the shape of the Earth considering the gravitational and centrifugal potentials. This term is calculated by the expression:

$$g_n = g_e(1 + \beta_1 \sin^2 \lambda + \beta_2 \sin^2 2\lambda) \qquad (2)$$

Where λ is the latitude, g_e is the gravity at the equator of the spheroid, β_1 and β_2 are the coefficients of the Geodetic Reference System.

The free-air correction, dg_{CF}, is a correction of the gravitational acceleration variation due to the distance of the station to the ellipsoid. It ignores the type of material is in-between them. The sign of the corrections depends on whether the reading is over or under the level of the ellipsoid. It is obtained by differentiating the general law of gravitation:

$$\frac{dg_{CF}}{dR_e} = -\frac{2GM_e}{R_e^3} \approx -0{,}3085 \cdot h \ mgal \qquad (3)$$

Where G is the gravitational constant, M_e is the mass of the Earth, R_e is the radius and h is the elevation.

The Bouguer correction, dg_{CB}, compensates for the layer of rock between the reference level and the station supposing that it consists of a cylindric disk of infinite radius and uniform density. This density is assumed to be the average of 2,67 g/cm^3.

$$\frac{dg_B}{dR_e} \approx 2\pi G\rho h \approx 0{,}112 \cdot h \ mgal \qquad (4)$$

Where G is the gravitational constant, ρ is the density and h is the elevation.

The topographic correction, dg_{Topo}, is added to the station reading to represent the topography variations, the attraction created by hills or the lack of downward attraction due to valleys, for example. The usual procedure is to divide the area in comportments and compare the average elevation within each compartment with the station elevation.

After applying all the corrections, the Bouguer anomaly, g_{AB}, is mapped interpolating with the Kriging method.

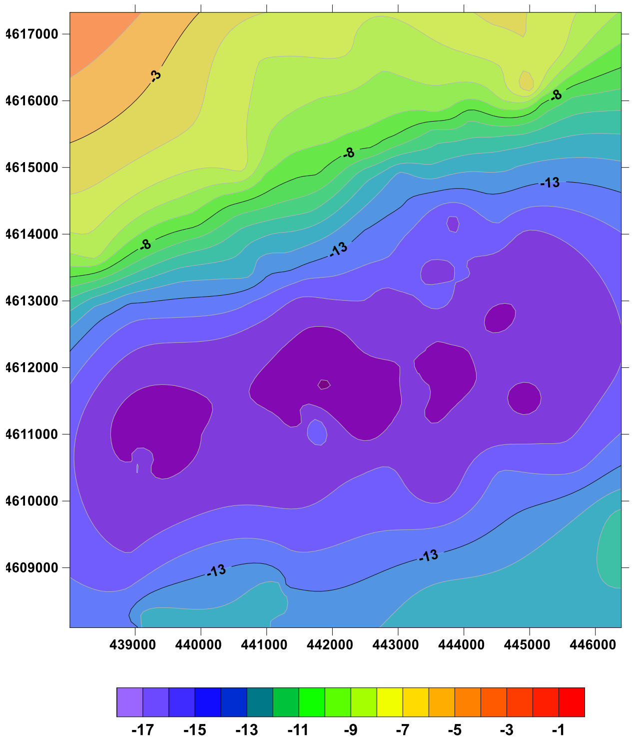

FIG. 2: Contour map of the Bouguer anomaly of the studied region in mgals.

On the other hand, the regional anomaly, g_{AR}, is the gravitational acceleration due to the deep large-scale features of the geological structure of the region. It is calculated with a polynomial regression on the gridded data. In this case, the regional anomaly is associated with an order 1 polynomial.

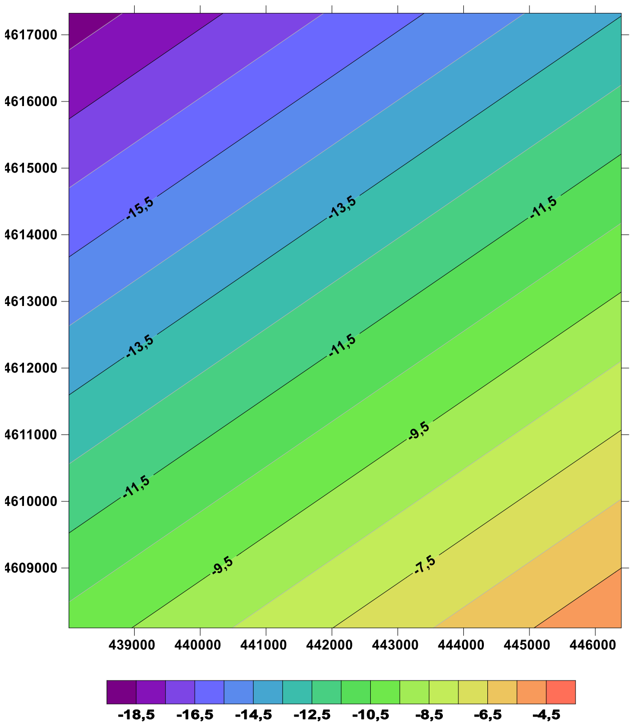

FIG. 3: Contour map of the regional anomaly values in mgals.

Finally, the residual anomaly is obtained from the subtraction of the smooth regional anomaly from the Bouguer anomaly, according to the expression:

$$g_R = g_{AB} - g_{AR} \tag{4}$$

So, subtracting the two grids, the map of the residual gravity is obtained:

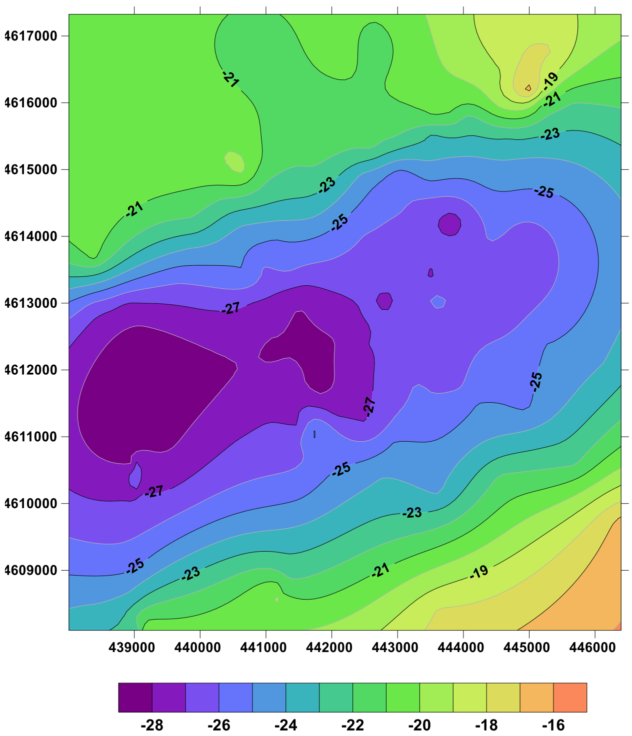

FIG. 4: Contour map of the residual anomaly values in mgals.

B. Profile

In order to get a good representation of the structure of the fault, the orientation of the profile must be chosen. The *FIG.4* is a contour representation of the studied region where it can be observed that a lower gravity anomaly is located along the NEE-SWW direction. From this, it is interpreted that the fault is oriented accordingly, separating the Prelitoral chain from the Vallès basin. This is further confirmed by the information of the basic trend of the geological mapping of the fault [7]. In order to represent both bodies, the Prelitoral chain and the Vallès basin, the profile studied would be oriented according to the NNW-SSE direction.

After selecting the profile, it is exported with the coordinates (UTM system), the altitude and the residual anomaly. The height is an important parameter, the sum of the height of the metal plate where the gravimeter is positioned and the height of the station itself. This last parameter is imported from terrain digital models obtained from the VISSIR3 [8].

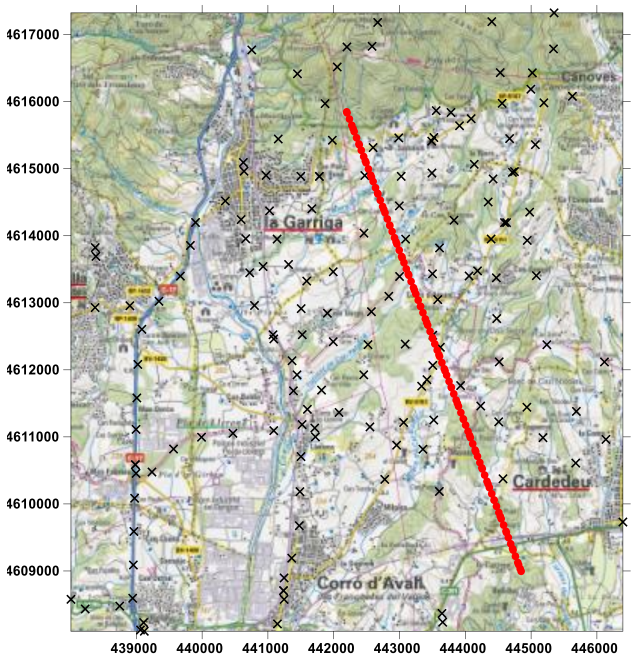

FIG. 5: In red, the profile over the map of the region. In black, the data acquisition station.

IV. MODEL

The model developed for the profile is a two-dimensional model of the density using the residual anomaly of the points of the profile selected. There are two methods of modeling; forward modeling and inverse modeling. The inverse problem [9] consists of finding the model parameters of the fault and the different densities of the structures, based on the observed data provided by the gravitational accelerations through a quantitative model.

With this model being Newton's law of gravity, the problem is linear. The error vector, the defined mismatch between the prediction and the measured data, is minimized with respect to the model parameters with methods like the least square solution or the minimum length solution using the method of Lagrange multipliers. The forward method [10] or direct problem is the fastest and easier method since it does not require as much computation power as the inversion. The operating is the opposite of the inversion, it consists on estimating the model parameters, the densities of the bodies in the subsoil, and, through the gravity theory, calculate the data predictions of the gravitational acceleration at the surface and compare them with the measured values of the gravity acceleration in the stations. To obtain the optimal model both methods are combined to polish and improve with the information that each provides. The inversion allows to find the density from the experimental field data but, being the problem underdetermined, there is more than one solution that minimizes the error. Some of these solutions does not make physical sense, having densities outside the range of the materials found in the soil or density decreasing with the depth of the upper crust. Then, the forward method can also interject to introduce probable values of the parameters, already established information of the structure.

The program used to create the model is ZondGM2D [11]. It is a 2D modeling software which allows the calculation of the inverse and the direct problem from data profiles of magnetic and gravity surveys. There are three basic methods of density modeling: layered forward mode, mesh method, and polygonal forward mode. The layered mode is used when the region has a layered structure. The mesh mode creates a regular divided grid of cells, reducing the irregular bodies of the subsoil with small blocks. The polygonal mode [12] is useful to get a more structural approach. It consists of representing a section with several closed polygons of arbitrary geometry and adjusts the position of the nodes and the density parameters to approximate the gravitational attraction created by the polygons to the observed data.

From the three modes, just the mesh method and polygonal forward mode have been used. A first inversion using the mesh mode is especially useful to get an initial inversion and a first geophysical interpretation. From these initials runs, different behavior can be perceived in the left part of the profile, corresponding to the northern region of the zone surveyed, the Prelitoral chain. While the left side has a more uniform density distribution, the other half indicates a less homogenous structure, with a different gradient of density with the depth of the subsoil. From here, it is fathomed the presence of at least three different structures. One at the left (D1) and two bodies at the right (D2 and D3). Accordingly, three polygons are created for the polygon forward mode (*FIG.6*). Then, knowing the basic geology of the region, initial densities are imposed. The Prelitoral chain is formed by igneous rocks so its density is higher than the sedimentary rocks of the Vallès basin. Introducing the standard values of these materials with the forward method, the inversion is used to refine the values and see its variation from the mean set.

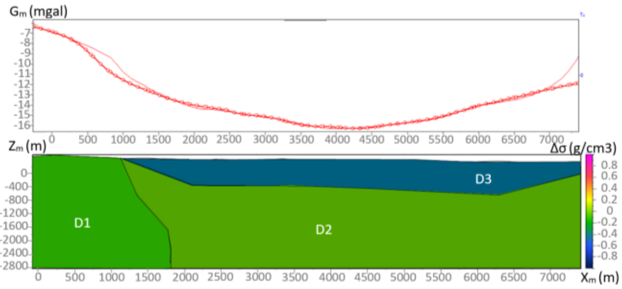

FIG. 6: On the top, with a dotted red line the measured anomaly and with a thin line the model response. On the bottom, the 2D density model.

Both, the polygon nodes and the polygons density are adjusted until the final model is obtained. A composition of the three polygons where D1 is situated at the left and D3 layered over D2 at the right. The densities are expressed as a difference from the average density of 2,57 g/cm^3. Then, the density of the polygon D1 is expected to be of 2,67 g/cm^3, for the D2 is 2,622 g/cm^3 and for the last polygon, D3 is of 2,17 g/cm^3.These model parameters found give information about the composition of the material that forms the bodies under the surface and allows to identify other of its properties. Taking into consideration the density values and the geological cartography [7] the geometry of the three polynomials have been identified. The structure D1 corresponds to granodiorites and alkali granites from Carboniferous-Permian (Palaeozoic), D2 corresponds to the basement and D3 corresponds to Vallès basin, clay and sandstones from Middle-Upper Miocene (Cenozoic).

In the upper half of the *FIG.6*, it can be appreciated a discrepancy between the profile of the residual anomaly measured and the forward calculation of the model. The difference at the far right of the model is not considered since at the limit there is not enough data and the model is underdetermined. On the other side, the mismatch at the confluence of the three polygons is attributed at the complexity of the structure at this region and the possibility that the interaction between them has caused the variation of some of the characteristics of the material.

V. CONCLUSION

The density contrast between the basement and the Vallès basin has allowed the Vallès graben characterization using the gravimetric method. This has been accomplished by reducing the different bodies to a polygon and adjust its shape and density, so the gravitational acceleration predicted conforms with the one measured. The final model obtained describes the fault with three different bodies which conform with the structure described in the geological mapping and other previous studies.

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