The gravimetric study of the Taubaté Basin and its tectonic-structural history

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Abstract

The goal of this work is to understand how geodynamic processes affected the tectonic evolution of the basin and its consequent deformation patterns, fault, fracture zones, percolation of fluids and compartmentalization of the basement, from the analysis of the land gravity data available.

Introduction

The gravity method is used to measure variations in the Earth's gravity field, allowing for the identification of gravity anomalies related to the density distribution of materials in the subsurface. The gravity study is important for several reasons: natural resources, geology, exploration geophysics and environmental monitoring.

The Taubaté Basin is an important area for geological studies located in southeastern Brazil, mainly because of its evolutionary history. In this context, gravity presents itself as a fundamental geophysical technique for understanding the geological structure of the region.

Complete Bouguer Gravity Anomaly (CBA) is an essential data reduction for several techniques interpreting gravimetric data, and yields important derivative/ maps, such as the First Vertical Derivative, Regional/Residual Separation, Tilt, Up-and-downward continuation upwards and Analytical Signal (aka Total Gradient Amplitude - TGA). These techniques allow for the identification of geological structures in the region, such as discontinuities and boundaries between rocks, which help to understand the evolution of the Taubaté Basin. Therefore, the combination between the geological and geophysical analysis of the basin is fundamental for a better understanding of the region.

The geological history of the Taubaté Basin dates back to the end of the Mesozoic during the separation of supercontinent Gondwana. At that time, the region where the basin is located was a continental environment, with a hot and humid climate and rivers that flowed towards the ocean.

In the beginning of the Cenozoic, about 65 million years ago, South America began to drift away from Africa and the Antarctic continents, and the Taubaté Basin began to form as a rift basin, i.e., an area of crustal extension with faulting and subsidence that allowed the deposition of sediments. (Riccomini et al, 2004)

During the Paleogene (between 65 and 23 million years ago), the basin continued to evolve as a rift basin, trough the deposition of continental and lacustrine sediments. During the Neogene (between 23 and 2.6 million years ago), the basin changed into a passive margin basin, with the deposition of marine and estuarine sediments. Throughout the Cenozoic, the basin was affected by tectonic events, such as the uplift of the Caçapava and Pindamonhangaba structural highs and the formation of transcurrent faults that divided the basin into different sub-basins.(Riccomini, 1989) We can see the lithological map of the Taubaté Basin in figure 1.

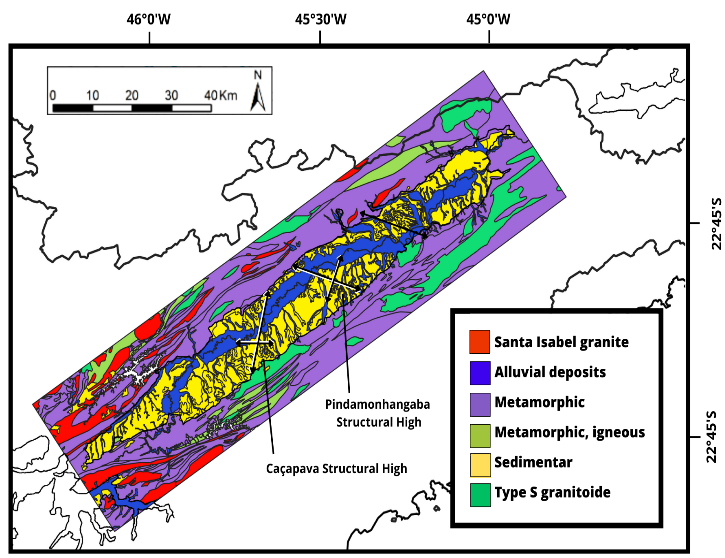

Figure 1 *- Lithological map of the Taubaté Basin.*

Currently, the Taubaté Basin is a mature sedimentary basin, with a rich and complex geological history that has been the subject of many studies and research.

Method

Departing from the (simple) Bouguer Anomaly data, we obtained the following derived maps in Oasis Montaj from Seequent:

- Complete Bouguer Anomaly
- First Vertical Derivative
- Analytical Signal
- Regional/residual separation

- Vertical and horizontal tilt
- Continuation upwards (200, 500 and 1000 meters)

The Complete Bouguer Anomaly is a data reduction that removes the effect of topography and Earth's crustal density on measured gravity data, allowing for the identification of variations in subsurface density.

The first vertical derivative is useful for delineating contacts, faults, and lineaments, while the Analytic Signal, defined below, is useful for delineating body geometry in the horizontal plane.

The analytic signal (as) of a profile is defined as (1):

$$as = \sqrt{\frac{df^2}{dh} + \frac{df^2}{dv}} \quad (1)$$

We call the horizontal derivative of the profile data along the survey path df/dh and the vertical derivative of the profile data of df/dv. (Ribeiro Filho, 2018)

The Regional/Residual separation is a technique that separates gravity anomalies into regional and residual components for the identification of local anomalies associated with geologic structures through the polynomial fitting of a surface that best fits the data.

Vertical and horizontal Tilt is used to detect and map variations in the subsurface, providing information about the geometry and orientation of geologic structures. The upward continuation simulates the value of the potential field that would be measured at different altitudes, providing the identification of geological structures at deeper depths.In summary, the use of these features at Oasis Montaj can provide important information on the structure and geology of the Taubaté Basin, helping to better understand the geological history of the region and identify possible targets for mineral exploration.

Results

We processed land gravity data available from BNDG (National Geophysical Gravity Database) in Oasis Montaj software. The data were processed and we obtained the Complete Bouguer Anomaly applying the terrain correction in the region of interest, shown in figure 2:

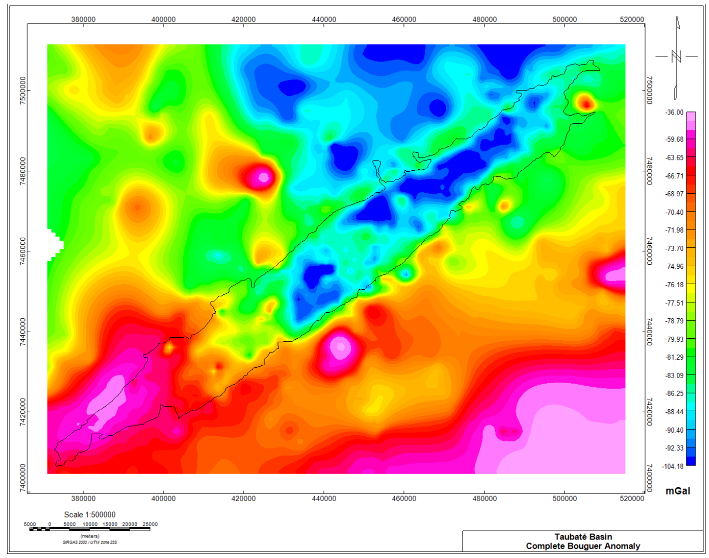

Figure 2 *- Complete Bouguer Anomaly of the Taubaté Basin.*

It is possible to observe in this image that we have the lowest values of -102 mGal in the most northeastern part of the basin, and in the Complete Bouguer Anomaly, more negative values indicate that the mass below the surface is greater than the average, that is, there is a negative density anomaly. On the other hand, more positive values indicate that the mass below the surface is less than average, i.e., there is a positive density anomaly.

These anomalies can be caused by variations in the composition of the rock or in its geological structure. For example, a negative anomaly may indicate the presence of a denser rock, such as a mineral deposit, while a positive anomaly may indicate the presence of a less dense rock, such as a sedimentary basin.

From the Complete Bouguer Anomaly channel, we generated the First Vertical Derivative using the least-curvature interpolation method, in Figure 3:

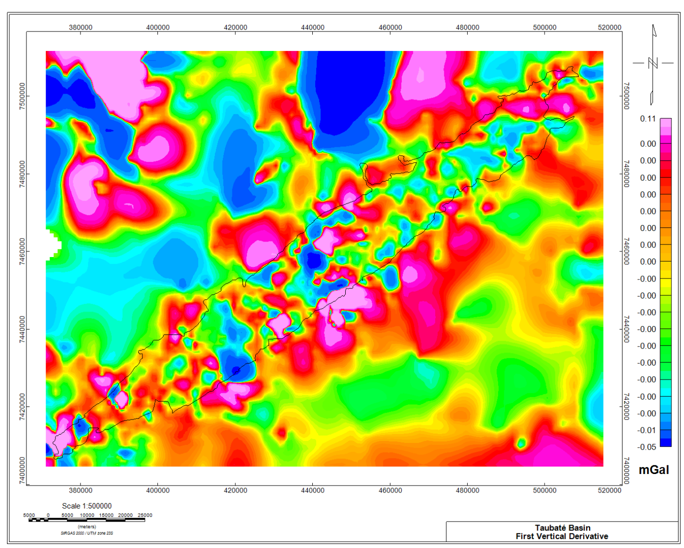

Figure 3 *- First Vertical Derivative of the Taubaté Basin.*

The vertical derivative is commonly evaluated to highlight shallow geological structures. The values in the basin range from -0.043718 to 0.08836 mGal.

In practice, negative values of the first vertical derivative indicate the presence of lower density areas in the subsurface, such as cavities, while positive values may indicate the presence of higher density areas, such as denser rock bodies or mineralized zones. We also generated the analytical signal from the Complete Bouguer Anomaly data, and its map is presented in Figure 4:

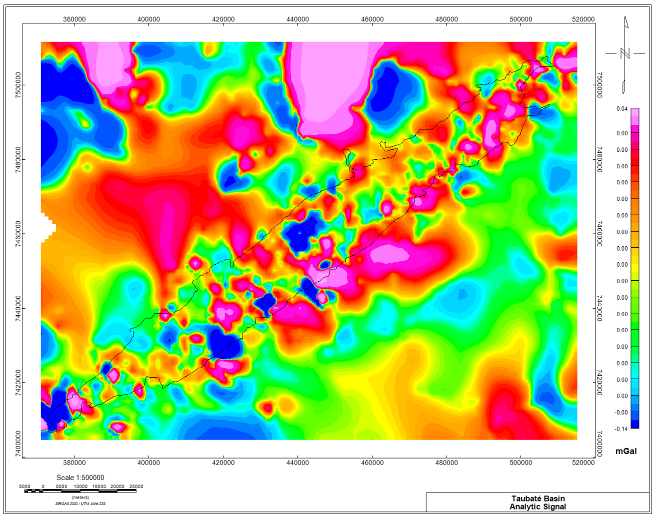

Figure 4 *- Analytical signal from the Taubaté Basin.*

Values are ranging from -0.029249 to 0.39746 mGal/m. The analytical signal is a mathematical transform of the gravity field that can be used to estimate the depth and geometry of geologic structures. Positive values of the analytic signal indicate a positive density contrast, such as a gravity anomaly caused by the presence of denser rock below the surface. Negative values of the analytical signal indicate a negative density contrast, such as an anomaly caused by the presence of a less dense rock below the surface.

The Regional/Residual Separation and Upward Continuation filters were used (200, 500 and 1000 meters) and thuis we obtained Figures 5, 6, 7, 8 and 9 respectively:

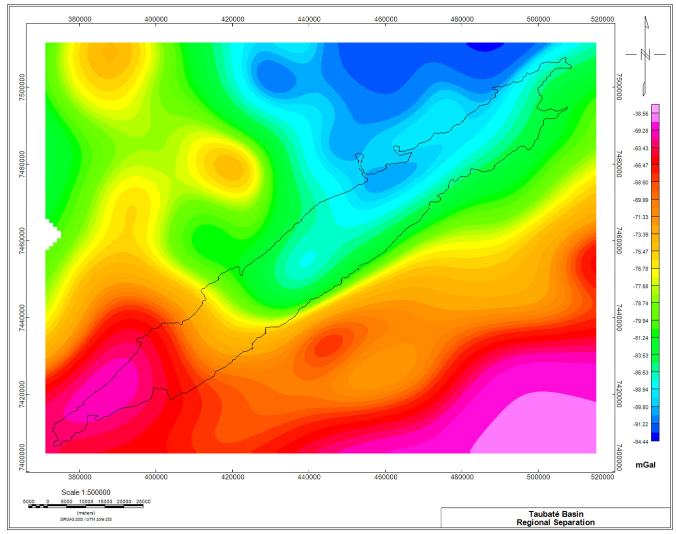

Figure 5 *- Regional separation (low pass).*

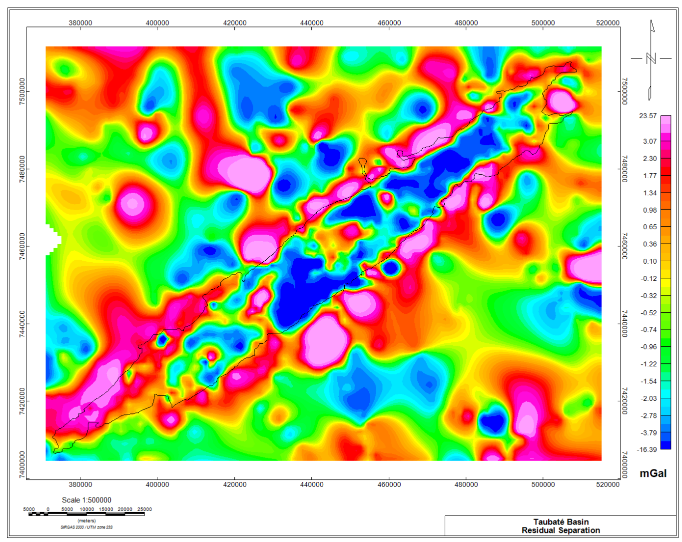

Figure 6 *- Residual separation (high pass).*

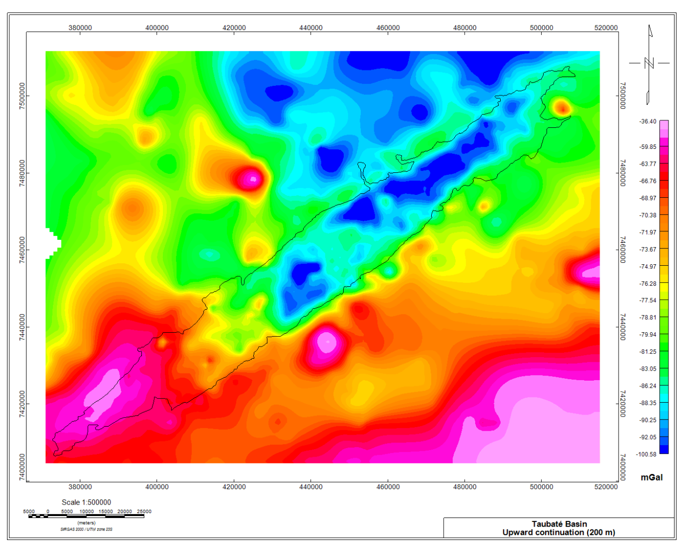

Figure 7 *- Upward continuation (200 meters).*

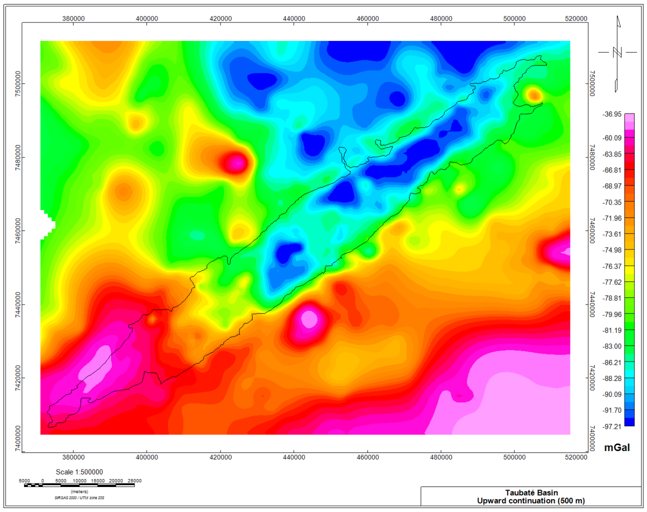

Figure 8 *- Upward continuation (500 meters).*

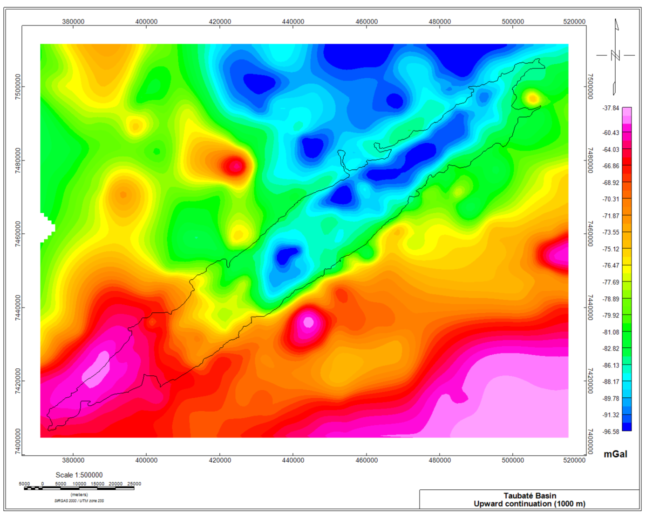

Figure 9 *- Upward continuation (1000 meters).*

In the regional separation we have values ranging from -38 to -93 mGal, presenting the density distribution of the region of interest, with the removal of the short and medium data wavelengths. This way, it is possible to observe the large geological structures of the region, such as sedimentary basins and folds, without the interference of small density variations that may be associated with smaller geological bodies. Regional separation is an important technique in the interpretation of geophysical data, because it allows for a clearer and more precise analysis of the interesting features. The residual separation values range from 23 to -15 mGal showing the local variations of the complete Bouguer anomaly, once the regional effect has been removed, which is the result of modeling the gravitational effects of large geological structures present in the region, such as mountains, sedimentary basins and folds. Thus, the residual component helps in the identification of smaller scale gravity anomalies, which may relates to smaller bodies, surface faults, folds, among others. The negative and positive values in the residual separation indicate, respectively, negative and positive gravity anomalies regarding the regional model.

Figures 10 and 11 show the vertical and horizontal tilt images respectively:

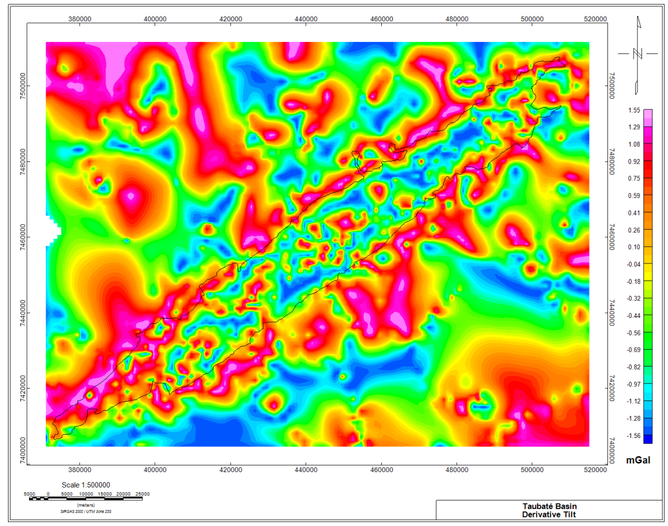

Figure 10 *- Derivative tilt of the Taubaté Basin.*

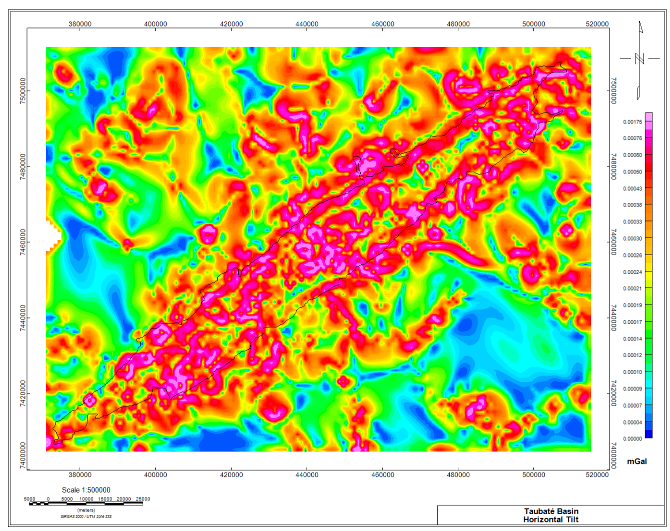

Figure 11 *- Horizontal tilt of the Taubaté Basin.*

The values for the Taubaté Basin vary between 1.56 to -1.56 in vertical tilt and most values concentrate between 0.001614 and 0.000190 in horizontal tilt. It is calculated from the relationship between the gravity differences measured at two different points, and therefore represents the vertical or horizontal inclination of the geological layers present in the study area. The total and horizontal tilt values in the Taubaté Basin suggest that there is a slight tilt of the sedimentary layers dipping towards the west, indicating a slight recent tectonic deformation. Also, the total tilt (Figure 10) may suggest some structural orientation in the NW-SE direction, perpendicular to the principal structural region direction.

Conclusions

The Taubaté Basin is an important region for geological and geophysical studies in Brazil. Gravity is a fundamental tool to understand the basin structure and geological features. The evaluation of Complete Bouguer Anomaly, and all its derivative products previously described, allow geologists and geophysicists to obtain more precise information about the basin structure. It is important to highlight that the use of these resources should be done in an integrated way with other geophysical and geological methods, allowing a better understanding of the geological history of the Taubaté Basin.

In the next future (up to the congress event) we will 3D invert this gravity data in different softwares (Oasis Montaj, SimPEG, and Fatiando) to recover a subsurface density distribution model that fits the data and hence improves on the Basin evolutionary history mode

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