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Gravity Gradient Tensor of Vargeao Impact Structure, South Brazil

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SUMMARY

The gravity gradiometry allows to study the density variation of bodies in three directions. This geophysical method represents the shorter wavelengths with higher resolution being more sensitive to small variations. In this work, we present the gravity gradient tensor of the well-preserved complex impact structure Vargeão formed on basaltic flows of the Serra Geral Formation (133-131 Ma) of the Paraná Basin. The gravity gradient tensor components were calculated using only the observed gravity data. The method is based on the solution of the Laplace equation and the Fourier transform of the original data, requiring few algebraic manipulations in the frequency domain. We demonstrate that this technique contributes significantly to the interpretation of complex structures such as Vargeão. The analysis of the results allow to determine the correct location (spatial position and limits edge) of the subsurface bodies and to estimate its center of mass. We show that this impact structure is less symmetrical on east-west direction. Moreover, our results can contribute to a better understanding of the impact crater formation which is important for understanding the planetary evolution of the Solar System.

Introduction

Impact craters are observed on the surfaces of all solid planets and satellites in our Solar System (e.g. Melosh, 1989). The impact cratering phenomena can produce significant changes in the geophysical signatures of the planetary surfaces (e.g., Pilkington and. Grieve, 1992). However, craters on basaltic rocks, which are the best analogs for studies about the planetary surface, are rare on Earth. Most studies to date were done on the Lonar crater, a simple crater 1.8 km in diameter, formed in the basaltic flows of the Deccan Province (India).

Recently, one medium-size complex crater was identified in volcanic rocks of the Paraná Basin (south Brazil) and may provide an additional analog to the impact structures of rocky planets and satellites. The Vargeão is a well-preserved complex impact structure (~12 km of diameter) formed in basaltic and subordinately rhyodacitic flows of the Serra Geral Formation (about 133-131 Ma), which are locally interttrapean by eolian-sandstones of Botucatu Formation.

In an effort to shed some light onto the changes of geophysical signature in impact craters, we conducted a gravimetric study on the Vargeão impact structure. We used the method of gravity gradient tensor (GGT) to identify subsurface bodies and to increase the knowledge about its geometry. Our study provides a new gravimetric model that might be used in the comparative studies of gravimetric planetary surface anomalies.

Gravity Gradient Tensor

The gravity gradient tensor (GGT) is mathematically defined by a 3×3 matrix (1). The nine elements present in this array are the rate of spatial variation of the gravitational field, $\vec{g} = \vec{g}(x, y, z)$, relative to the local system from the observation point.

$$\nabla\vec{g} = \begin{pmatrix} g_{xx} & g_{xy} & g_{xz} \\ g_{yx} & g_{yy} & g_{yz} \\ g_{zx} & g_{zy} & g_{zz} \end{pmatrix} \quad (1)$$

According to Laplace's equation for a field outside the distribution of mass, the sum of the diagonal component is zero, $g_{xx} + g_{yy} + g_{zz} = 0$. Furthermore, the matrix is symmetrical about the diagonal, ie, $g_{xy} = g_{yx}$, $g_{xz} = g_{zx}$ e $g_{yz} = g_{zy}$. These two facts imply that only five components of GGT are independent.

The GGT components are inversely proportional to the cube of the distance between the anomalous source and the observation point. This makes them decay faster than the acceleration of gravity. On the other hand, GGT measures the change in gravitational field in three directions, making it more sensitive to density variations in the subsurface. Thus, the GGT components contain more information of short wavelengths that may be characteristic either of the source or of the noise.

This greater sensitivity allows correlating the anomalous features with the geometry and the density distribution of the subsurface bodies (Saad, 2006). This makes gravity gradiometry to be a powerful tool, with wide applications in oil and mineral exploration.

Technological advances make it increasingly easy to acquire this type of data. In practice, the GGT components (or some of them) may be obtained by gravity gradiometers. The use of this equipment is common in airborne geophysics, and in recent years has been used even in space missions. However, the conventional gravity through the use of gravimeters still prevails, mainly because of its low cost and easy operation.

It is known many procedures to obtain the gravity gradiometer, numerically and with good approximation, from the gravity data observed in the field (Nabighian, 1984; Wang et al. 2008). Mickus and Hinojosa (2001) presented a technique to calculate the GGT using the Fourier transform

(FFT) of Laplace's equation. Through this technique, we were able to calculate the GGT of gravity anomaly of Vargeão impact structure.

Results

During the acquisition, we collect 419 points; covering approximately 177 km² (black points in the figures above). This area comprises the Vargeão impact structure and surrounding. The data points were interpolated by the Minimum Curvature method generating a 100 x 100 grid size.

The Figure 1a shows the Bouguer gravity anomaly obtained. It is possible to visualize the center of the crater. However, the regional field present in the data hinders its analysis. The right position of the crater's edge, for example, cannot be well estimated. The Figure 1b presents the regional Bouguer anomaly removed by a second degree polynomial with six coefficients. This regional field varies basically from southeast to northwest direction. Furthermore, this pattern is clearly observed in the Bouguer anomaly map. On the other hand, the residual Bouguer anomaly obtained by subtracting a regional component from the total Bouguer anomaly with its regional (Figure 1a) contributes to the knowledge of the impact structure geometry.

The central part of the crater has negative anomalies amplitude of approximately -4 mGal. However, the higher amplitude around the coordinates 26.82ºS 52.16ºW indicate its heterogeneity. Finally, the edge of the crater shows positive anomalies exceeding 4 mGal, which is more prevalent in the eastern part.

We also analyzed the Bouguer anomaly amplitude as a function of height through the upward continuation transform. This reduces the effects of noise and shallow density variations. We observe that even for an altitude of 2 km, the residual anomaly contains positive and negative amplitudes that can be associated to the center and edge of the crater. These results may help to better estimate the depth of the crater. Figure 1b shows the residual Bouguer anomaly obtained for the data upward continued to 500 m. The signal attenuation makes the central part of the crater to be represented by a more circular and smoothed anomaly (compare with Figure 1a).

The GGT was calculated using the residual Bouguer anomaly upward continued to 500 m. The GGT amplifies the shorter wavelengths of data. This allows to recover, for example, the portion of the attenuated signal after the upward continuation. Moreover, they contain information about the density distribution variation in three directions. It assists to determine the center of mass and the correct location of structures (such as the limit edge of the bodies). Here we set $x-$, $y-$, and $z-$ directions in a right-sided Cartesian coordinate system. It means x points to North, y to East and z to down.

The g_{zz} component has a direct correlation with its generator: the component g_z (Figure 2b), which makes it easier to be analyzed. For example, with g_{zz} we can identify the limits of edge easily. In addition, it amplified the signal and recovered the small heterogeneities seen in the center of the crater (near coordinates 26.82ºS 52.16ºW) of Figure 2a, not shown in Figure 2b.

The horizontal derivatives highlight those structures that are perpendicular to its direction. For example, the g_{xx} and g_{xz} components show the structure in the center of the crater discussed above, but we cannot identify it in g_{yy} and g_{yz}. This is a simple way to estimate the preferred direction and even the lateral extent of a given body. We also emphasize that neither the residual anomaly (Fig. 3a-b) nor its vertical derivative (g_{zz} Figure 3) directly allow this interpretation.

Overall, our results show that the crater is more symmetrical in north-south than east-west direction. This can be observed by comparing the main features of g_{xz} and g_{yz} at the surrounding areas of the central part. Moreover, we observed a greater variation in the southern region (below 26.84ºS) in g_{xx} and g_{xz} and an extensive variation in the eastern part of the crater (52.12ºW).

Conclusions

We have presented the gravity gradient tensor of the residual Bouguer anomaly over the Dome Vargeão area. Since the GGT is more sensitivity to density variation, it can be a useful tool to understand the crater's geology. Our results show that the center of the crater has a predominant negative density-contrast, characteristic of a region with sediments. However, the heterogeneities in this region are best observed in GGT. Furthermore, the crater is not symmetric mainly on east-west direction, suggesting that the eastern part of Vargeão' s edge is more extensive and deep.

Acknowledgements

The authors thank Bruno B. Giacomini, Marcos Vasconselos and Álvaro Crósta for the field work. We thank Douglas S. Silvestre for his comments and suggestions. The authors were supported in this research by a fellowship (HBS) from CGGVeritas-Brazil, (EPL and EBS) from CNPq and (EY) from FAPESP. Additional support for the authors was provided by the Brazilian agency and FAPESP (grant 11/08014-5).

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(a) (b)

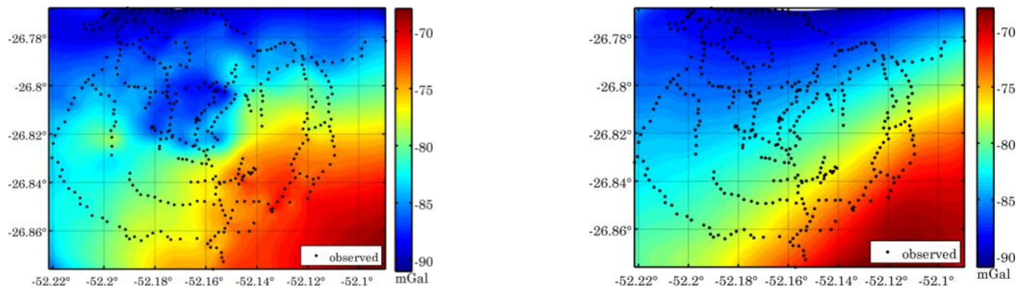

Figure 1 *Gravity anomaly of Vargeão Crater. (a) total Bouguer anomaly; (b) regional Bouguer anomaly.*

(a) (b)

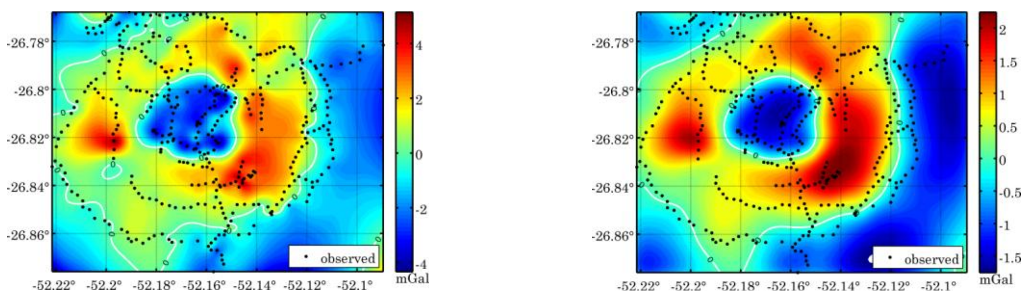

Figure 2 *Residual Bouguer anomaly. (a) at surface level; (b) upward continued to 500 m.*

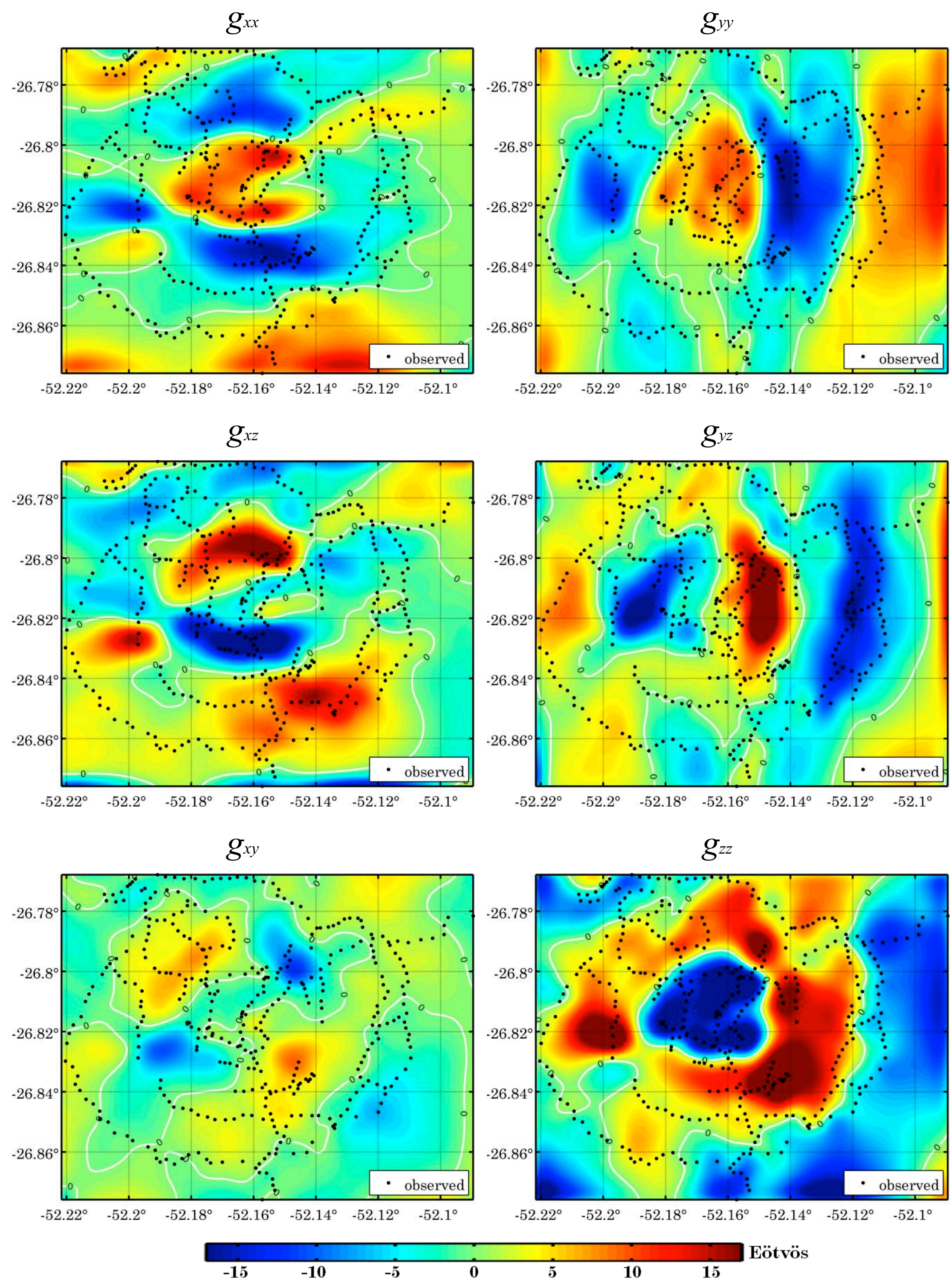

Figure 3 *Gravity gradient tensor of residual Bouguer anomaly upward continued to 500 m.*