Study of Pratinha-II magnetic anomaly: Acquisition, processing and interpretation of aeromagnetic and gravimetric data

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Abstract

Aeromagnetic and aerogammaspectrometric data indicate the presence of a deep geological structure of unknown dimensions and composition near Pratinha-MG in SE Brazil. The anomaly is located in an economically interesting area with known occurrences of ore deposits currently explored by mining companies. The magnetic data suggest that the anomaly is caused by two nearby sources, but the proximity of them and surrounding anomalies, the interference of faults in the area and the anomaly's low amplitude are challenges for the analysis. Different magnetic boundaries and depth estimating methods were applied and we were able to obtain reasonable values for the sources' parameters. Those parameters were used to constrain 3D inversions of the magnetic data. The gravimetric data is still insufficient for a quantitative analysis and for comparison with the results obtained from the magnetic data. This study is part of a more comprehensive project by the Laboratório de Geofísica da Litosfera do IAG-USP that includes several alkaline complexes in the S-SE portion of Brazil.

Introduction

Aeromagnetic surveys are often used in large unexplored areas to identify and model targets for more precise geophysical investigation. Here we study an anomaly identified in the aeromagnetic data provided by SEDE, Secretaria de Estado e Desenvolvimento de Minas Gerais through CPRM, Serviço Geológico do Brasil, acquired by CODEMIG, Compania de Desenvolvimento Econômico de Minas Gerais, during the Aerogeophysical Survey of Minas Gerais in the 2005/2006 Project. Two gravimetric campaigns were made, but the data acquired are still insufficient for more detailed analysis.

The area is located in the southern portion of the Brasilia belt, an important tectonic element of the Tocantins Province, a neoproterozoic collisional orogen developed in response to the convergence between the Amazon, São Francisco-Congo and Paraná continental blocks. The Brasilia belt is a 1100 km long complex structure of inverse faults and folds located in the eastern portion of the São Francisco-Congo block (Pimentel et al., 1999).

The geology of the area consists of mezoproterozoic milonitic and ultramilonitic chlorite-muscovite-quartz schists and subordinated mylonitic quartzites of the Canastra Group and neoproterozoic calcarenites, dolostones, ritmites, limestones, siltstones, claystones and slates of the Paraopeba subgroup.

Fig. 1 *– The area of interest is located inside the red rectangle in Minas Gerais, SE Brazil.*

The area is particularly complex for magnetics. The geomagnetic field there has relatively low amplitude (~24000 nT) and it is located in a low latitude region. The shape of the anomaly indicates two deep sources with different depths and close to each other.

Gammaspectrometric data provides a qualitative analysis of the surface lithologies. The data shows that the sources of the magnetic anomaly are deep, as no anomaly is seen in any of the U, Th, K or U-Th-K ternary maps at the location of the magnetic anomaly. A topographic map was made using SRTM data and also shows no surface geological expression in the area of interest.

Magnetic data interpretation

All the grid calculations were performed using Geosoft Oasis Montaj v. 6.4.2. For the regional field removal we used a 90 km Gaussian filter that was able to minimize the interference of other anomalies, but it is still present around the anomaly of interest. A 5 km Butterworth filter was applied to remove the effect of faults and low-wavelenght components to avoid problems with boundary detection methods and depth estimators. Figure 2 shows the result obtained using the Butterworth Filter.

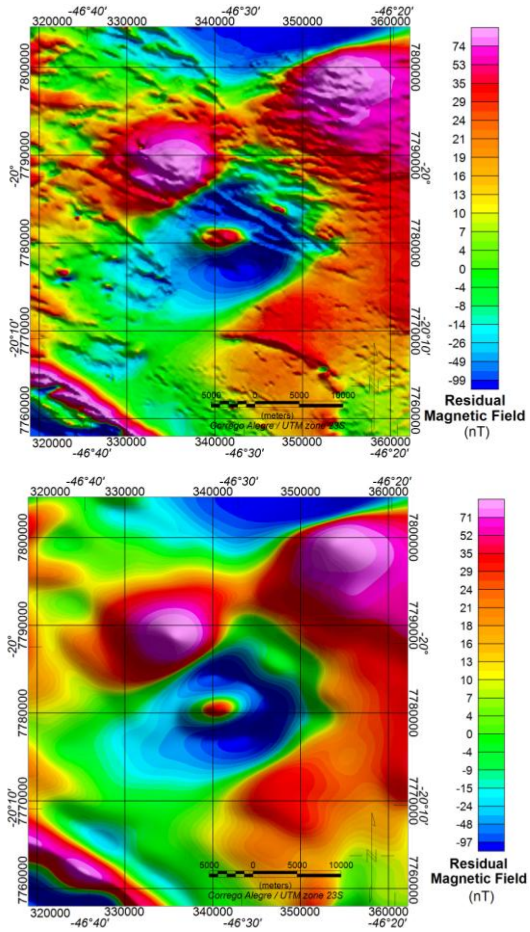

***Fig. 2** – Residual magnetic field map at the top and the same map filtered using a Butterworth filter at the bottom.*

The standard reduction to the magnetic pole (RTP) filter using IGRF values suggests a poor choice of parameters based on the grid distortion in the NW-SE direction, as figure 3 shows, so we used the method by Fedi et al. (1994).

The method consists in a distortion analysis that estimates the magnetization direction by applying a reduction to the pole filter for different couples of magnetic declinations and inclinations in order to maximize the anomaly minimum as a function of both magnetic declination and inclination. It is clear that the result of such method was still insufficient to properly reduce the anomaly to the pole, so this map must be used with caution, as it can't be considered the proper RTP map, but is the best magnetization estimative possible (for the anomaly area) as direct sampling to measure a possible remanence is discarded.

To determine the magnetic source boundaries we used the *Enhanced Horizontal Derivative (EHD)*, by Fedi & Florio (2001) and *Potential Field Tilt*, by Miller & Singh (1994). For depth to the sources we used the *Source Parameter Imaging* (*SPI),* by Thurston & Smith (1997), and *Tilt-Depth Method*, by Salem et al. (2007). Some methods such as 3D analytic signal amplitude (ASA), by Roest et al. (1992), 3D Euler Deconvolution, described by Reid et al. (1990), Horizontal gradient of the pseudo-gravity anomalies (HGAPG), as used by Cordell and Grauch (1985), and *Enhanced Analytic Signal (EAS),* by Hsu et al. (1996), were also tested, but were not successful.

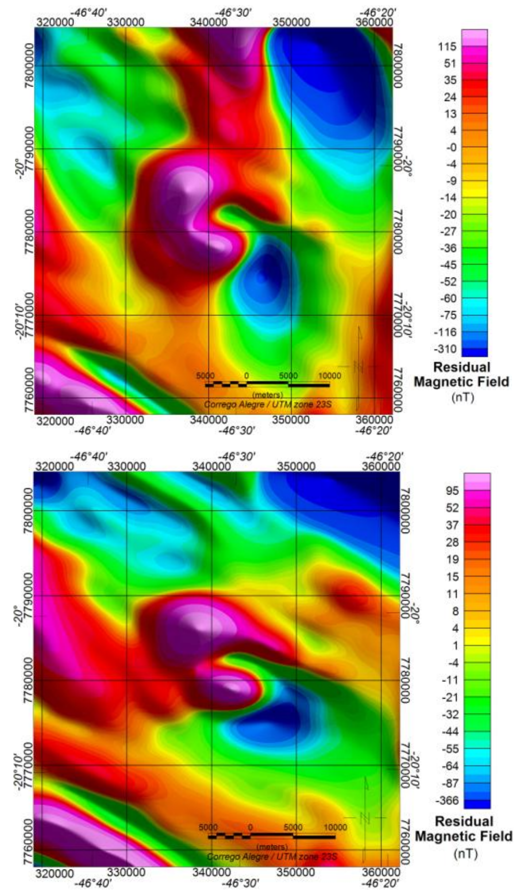

***Fig. 3** – Comparison between the standard reduction-to-the-pole operator, at the top, and the one by Fedi et al. (1994). The one at the bottom shows a better result.*

It has been shown by Roest et al. (1992) and other authors that the 3D ASA is a useful tool for the interpretation of magnetic anomalies with a remanent component, as it is independent of the magnetization parameters of the source, this is particularly useful in low latitude areas. However ASA is very sensitive to interference, because it loses resolution when magnetic anomalies are close to each other and, consequently, it wasn't useful in this case.

HGAPG is often used as an edge detector, but it was disregarded in this case due to the need of a reduction to the pole filter that couldn't be applied properly because of remanence and interference between the sources. The HGAPG shows results similar to other methods, but not as resolutive.

Euler deconvolution is based on Euler's homogeneity equation. As it doesn't need a reduction to the pole, this method is a good choice when the data cannot be pole-reduced properly, but it requires the choice of a structural index, a parameter based on the source's geology, which is unknown in this case. The deconvolution is applied in a grid using a window of size defined by the user. If the window is too big, the method loses resolution, but broad anomalies may not be represented well in smaller windows. In this case a big window size had to be used to correctly represent the anomaly, decreasing its effectiveness.

Hsu et al. (1996) developed an enhanced analytic signal technique composed of the *n*th-order vertical derivatives of two horizontal gradients and one vertical gradient. This technique shows improved resolution compared with the standard analytic signal and is a good choice when interference and remanence are significant, as RTP is required, but it requires high order derivatives, so high-frequency noise and low amplitude anomalies can be problems.

This technique also provides a depth estimation method based on the ratio of analytic signals of different orders. As the anomaly's amplitude is low, which makes the noise more significant, and the sources are too close together the method failed to determine the magnetic boundaries and provided unrealistic depth values that couldn't be trusted.

The *Potential Field Tilt* was defined by Miller & Singh (1994) in terms of the ratio between the first vertical derivative and the horizontal gradient and has the property of being positive over a source, zero over the edges and negative elsewhere. This method is useful in this case, because it is not affected by the low amplitude of the anomaly as the ratio of the two derivatives compensates the decay with depth.

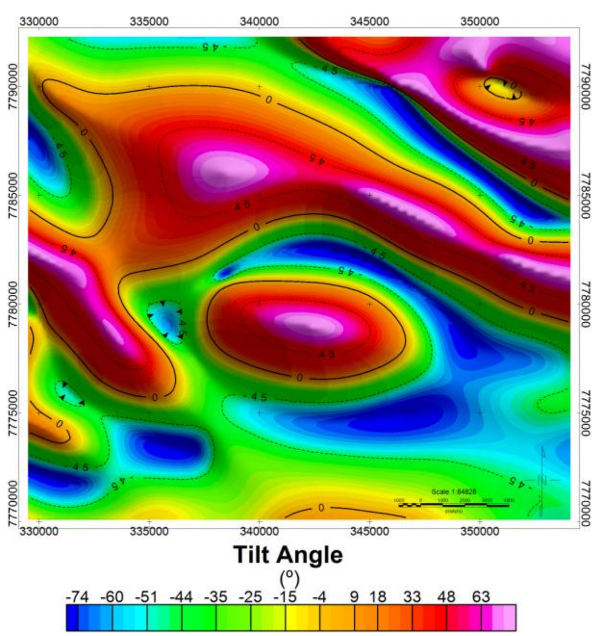

Fig. 3 *– Tilt derivative. Magnetic boundaries are defined by the zero contour curve (solid). Depth is equal to the half distance between the 45º and -45º contour curves (dashed).*

Salem et al. (2007) used the definition of *Potential Field Tilt* to create a direct and fast depth estimator based on the half distance between -45º and 45º contours on the least affected by interference areas. The depth to the top of the sources can be easily defined in the map in Fig. 3 (approximately 1000 and 700 m).

Enhanced Horizontal Derivative (EHD) was introduced by Fedi & Florio (2001) as a high-resolution potential field boundary detector. It consists in a sum of vertical derivatives of increasing orders in order to combine all the different information provided by every vertical derivative. High-order vertical derivatives maximums are usually located over the corners of the source and low-order derivatives have the greatest amplitudes that counteract the decrease in the signal-noise ratio which results in increased resolution. Maximum amplitude values are located over the edges of the source.

Fig. 4 shows that Tilt Angle and EHD had similar results. Both were able to delineate both sources' edges and surround faults that were not removed by the Butterworth filter. The derivatives in the upper source's area have lower amplitude, as the respective anomaly has higher wavelength compared to the other one, so the lower source's edges were detected with more resolution.

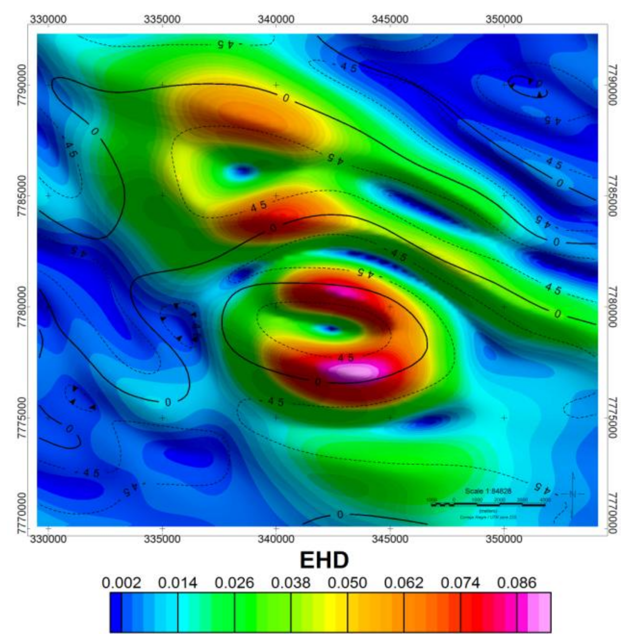

Fig. 4 *– Enhanced Horizontal Derivative. The amplitude maximums are located over the sources' edges. Tilt angle contours are shown for comparison.*

SPI™ is a method based on the local frequency, which is defined as the rate of change of the local phase of the magnetic data that estimates the edge locations, depth, dips, and susceptibility constrasts, but the last two can only be estimated when no remanence is present. As the edge detector of this method and *Potential Field Tilt* are based on the local phase the edge locations by both were equal.

The depth values shown in the map in fig. 5 were calculated using the relation between the depth and the local wavenumber as described by Thurston & Smith

(1997). The map shows some varying values over the sources' locations. This indicates that the sources are more complex than the previous methods have indicated. SPI™ failed to calculate depths for some locations over one of the sources because of small derivatives amplitudes.

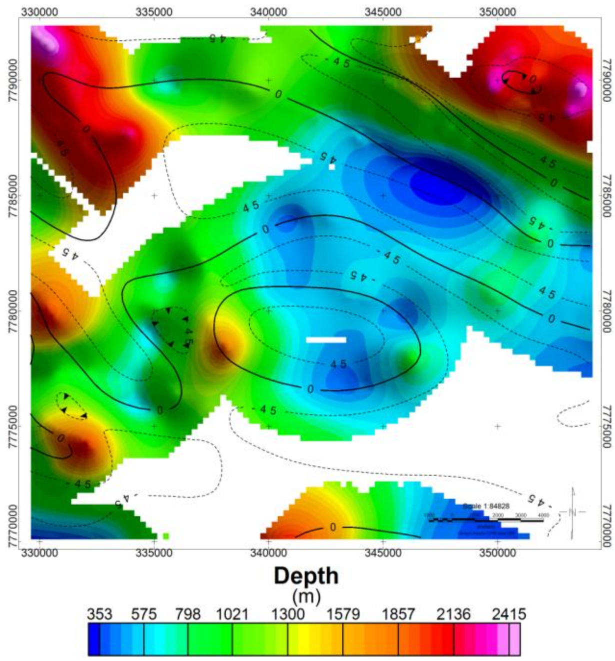

Fig. 5 – Depth values estimated by SPI™ and Tilt Angle contour. The white areas represent the locations where the depth couldn't be calculated. Tilt angle contours are shown for comparison.

Gravity method

Two gravimetric campaigns were carried out in the last six months, but the number of gravity measurements is insufficient for a good representation of a possible gravimetric anomaly.

Gravimetric data are not affected by some of the magnetic data's problems, such as remanent magnetization, so it could be used to refine the edge location, depth to the sources results already obtained and inversions results.

An additional gravimetric campaign is being planned and we will be able to complete the data set in a few months.

Inversion of magnetic data

All the inversion routines were done with MAG3D from the University of British Columbia's Geophysical Inversion Facility (UBC-GIF).

An initial model was created to constrain the inversions using the results already mentioned. It consists in two 0,5 and 1,0 km deep pipe-shaped igneous bodies with edges described by Fig. 4. We used cell sizes equal to the grid spacing (250 m) and the magnetization direction estimated using Fedi et al. (1994) method.

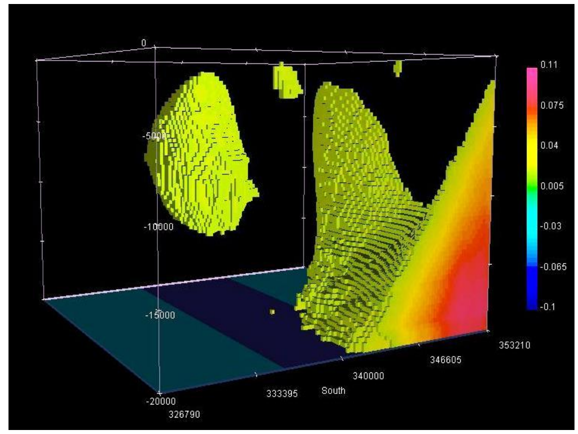

Fig. 6 – Inversion results using residual magnetic field data.

Fig. 6 shows that interference is clearly a problem in the inversion process as two sources with unrealistic shape and a third large and deep source were created. This model was obtained using residual magnetic field data.

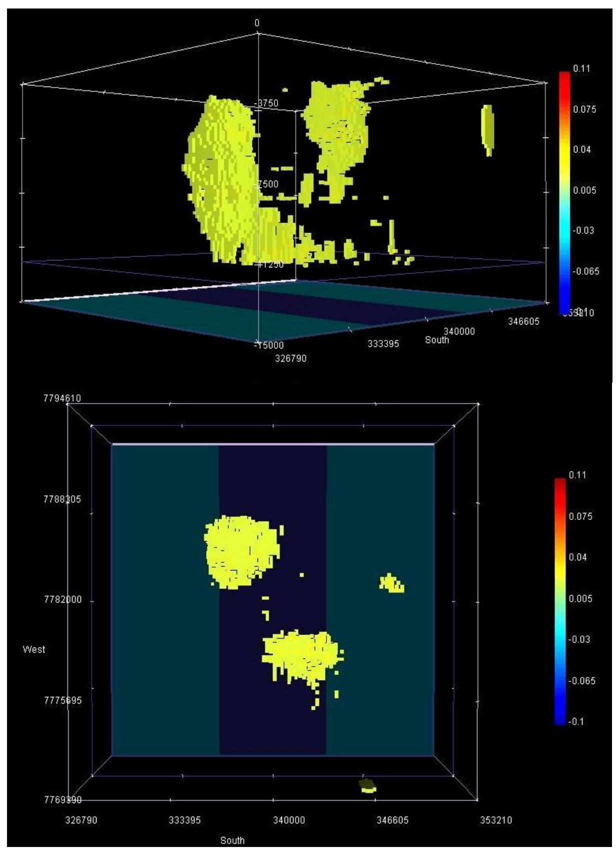

Fig. 7 – Inversion results using filtered residual magnetic data using Butterworth filters. The top figure is the model as seen by an observer in the SW, and the bottom figure is a plan view.

To solve this problem, several wavelength-based filters were applied to the data in order to remove nearby anomalies and isolate the source. Fig. 7 shows the result obtained from the residual magnetic field filtered using a 25 km, for the nearby anomalies, and a 3 km, for the faults, Butterworth filters.

The inversion process created two sources smaller than the predictions made with the boundary detection methods, but with similar depths (approximately 1,0 and 0,4 km). The magnetic susceptibility values range from 0.022 to 0.05 approximately.

The model shows two sources with a common origin. This could be interpreted as an intrusion that found two different preexistent faults as preferential ways to the surface and created two magma accumulation zones.

More tests using different methods to remove interference are going to be performed to get a more precise model.

Conclusions

The magnetic data shows some problems that require a rigorous analysis: Remanent magnetization, proximity of the sources and other anomalies, presence of faults and low amplitude. A Butterworth filter was able to remove most of the interference caused by faults without losing too much information.

The RTP indicates a poor choice of magnetization parameters and shows that the anomaly is caused by two different sources. As anomalies cannot be properly reduced to the pole when remanent magnetization is present we used an enhanced reduction-to-the-pole technique introduced by Fedi et al. (1994) to estimate the total magnetization direction.

Despite these problems, we were able to calculate reasonable values for depth and magnetic boundaries location that were used to create a reference model and constrain 3D magnetic inversions.

The parameters were estimated using *Enhanced Horizontal Derivative*, by Fedi & Florio (2001), *Potential Field Tilt*, by Miller & Singh (1994), *Tilt-depth,* by Salem et al. (2007) and SPI™, by Thurston & Smith (1997). Other techniques were tested but weren't successful.

The magnetic inversions produced a model consistent with the parameters obtained from the magnetic maps. More tests using different techniques to remove interference will be done to refine the results.

The anomaly could have been caused by two different magma accumulation zones with the same origin that created two deep intrusions. These intrusions were probably placed on weakness zones created by the faults present in the location. The nature of the intrusions is probably alkaline, as several alkaline complexes are nearby.

The gravimetric data can be a viable solution for some of the problems seen in the magnetic data, but the current amount of data is still insufficient for a quantitative analysis. A new gravimetric campaign is being planned to acquire the required data.

Acknowledgments

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