



3D Inversion of Magnetic Data at Low Magnetic Latitudes

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Abstract

Inversion is becoming a common tool for interpretation of magnetic data, but in low latitude areas the susceptibility inversion is less reliable due to the strong correlation of the inverted result with the direction of induced magnetization. By inverting for the Magnetic Vector (Ellis et al, 2012) instead of the susceptibility the contributions from both induced and remanent field components are obtained. The combination of the three vector components generated with this inversion, namely the Amplitude, Projected and Perpendicular components, allow a more effective use of the magnetic data.

In this paper we compare the results of the Magnetic Vector Inversion with the Susceptibility Inversion using airborne magnetic data from the Crixas area, Goias State, Brasil. We show the similarity of these results to the Analytic Signal (MacLeod et al., 1993) one of the most important themes used to interpret magnetic data in 2D at low latitudes, instead of the Pole Reduction widely used in other areas. Magnetic Vector Inversion allows better 3D understanding and interpretation in low latitude areas as well as in the presence of remanent magnetization.

Introduction

The interpretation of magnetic data at low latitudes has always been challenging due to the ambiguous results generated by the application of the Pole Reduction to those areas. The use of the Analytic Signal Amplitude brought a significant contribution to the interpretation of magnetic data, especially at low latitude locations and has been incorporated as one of the main 2D themes used in geophysical interpretation in those geographical areas (MacLeod et al., 1993).

With the advance of computational power, the implementation of algorithms to invert magnetic data generating 3D voxels has become more accessible and widely incorporated in the workflow of magnetic data interpretation. The most common implementation of magnetic data inversion generates a susceptibility voxel, but this result shows a strong correlation with the induced field which limits its use in the case of remanence, demagnetization and at low magnetic latitudes.

The development of the Magnetic Vector Inversion (MVI; Ellis et al., 2012), that generates three field components, brings a new light in the interpretation of magnetic data. The application and comparison of the Magnetic Vector

and Susceptibility inversion results in the Crixas Greenstone belt, located in Goias state, central Brazil, is an example of the contribution to the interpretation that this method can bring.

The example also shows the strong correlation of the MVI results with the Amplitude of the Analytic Signal, supporting the use of the method in low latitude areas and in the presence of remanent or demagnetized sources.

The results presented include constrained inversions, particularly the iterative reweighting inversion that uses the non-constrained output as a constraint to get more focused results. Mineral exploration targets tend to be at relatively shallow depths compared to deeper targets such as the basement. Using the residual magnetic field instead of using the total magnetic field as input emphasizes the shallower anomalies and the inversion obtains better resolution for mineral exploration targets.

Method

Measuring the magnetic field B in a series of locations r gives the forward equation for the Magnetic Vector (Ellis et al, 2012):

$$B_{\beta}(\mathbf{r}_j) = \sum_{k,\alpha}^{N,3} m_{k,\alpha} \int_{v_k} \partial_{\alpha} \partial_{\beta} \frac{1}{|\mathbf{r} - \mathbf{r}_j|} d\mathbf{r}^3 \quad (1)$$

Discretization of equation (1) gives the equation for the direct problem

$$\mathbf{B}(\mathbf{r}) = \nabla \int_V \mathbf{M}(\mathbf{r}') \cdot \nabla' \frac{1}{|\mathbf{r} - \mathbf{r}'|} d\mathbf{r}'^3 \quad (2)$$

That can be simply represented as:

$$\mathbf{B} = \mathbf{G} \mathbf{m} \quad (3)$$

The Magnetic Vector Inversion problem is to solve for \mathbf{m} , given \mathbf{B} . To be able to resolve this inverse problem, it is necessary to subject B to regularization conditions. The implementation that has been used in this work applied the Tikhonov minimum gradient regularizer (Zhdanov, 2002) to solve the inverse magnetic problem for the magnetic vector by minimizing the difference of the calculated and measured field.

Examples

The geology of the the Crixas beltstone area has been well studied and there are several published papers describing it (e.g. Jost and Scalandora, 2010; Blum et al., 2001; Kuyumjian and Costa, 1999, Thomson and Fyfe, 1990).

The hosting Crixas greenstone belt is underlain by a typical Archcan metamorphosed volcanic-sedimentary sequence and is surrounded by granite-granite gneiss terrane. Some of the Crixas gold deposits are located at the contact of the metavolcanic and metasedimentary sequences while others are in the metasedimentary rock. The style of deformation within those deposits are typical of a high-strain environment. The majority of the deposits in this area are related to the Brasiliano cycle event.

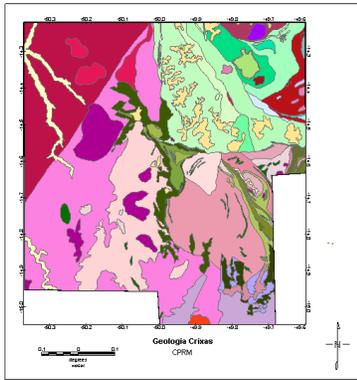


Figure 1: Geological map and legend for the Crixas greenstone belt area, published by CPRM

Airborne Total Magnetic Intensity (TMI) for the Crixas area in Goiás state, was supplied by the Industry and Commerce Secretary of Goiás State through its Geology and Mining Superintendence.

The Crixas greenstone belt was covered by three different individual surveys (Fig.2), namely Areas 2, 3 and 5. The survey was conducted by LASA in the years 2004-2006 with N-S lines, 500 m line spacing and 100 m height draped survey. The mean magnetic inclination for the studied area is -18° and the mean declination is -19.2°

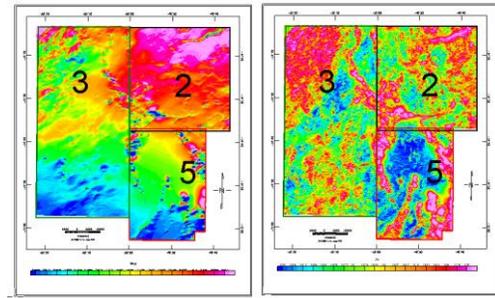


Figure 2: Merged TMI (right) and Analytic Signal (left) with the survey outlines for Areas 2,3 and 5.

In order to have more reliable results, the inversion was conducted for each area separately based directly on the database containing the measured data in order to avoid the creation of mathematical artifacts due to merging and/or gridding. The results were then presented on a single 3D map.

Results

Unconstrained susceptibility and magnetic vector inversions were ran for all areas. The susceptibility results show strong North-South tendencies as well as anomalies aligned with the declination direction that are not present in the MVI results.

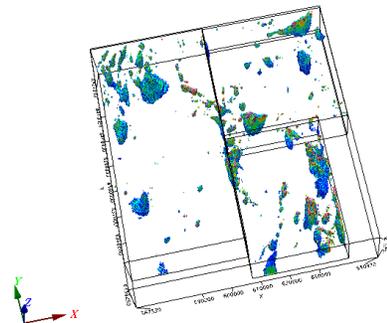


Figure 3: Susceptibility inversion for the Crixas area. Vertical exaggeration 2, cell size x=190 m; y=190 m and initial value for z= 25 m. Results clipped to 0.005 SI units.

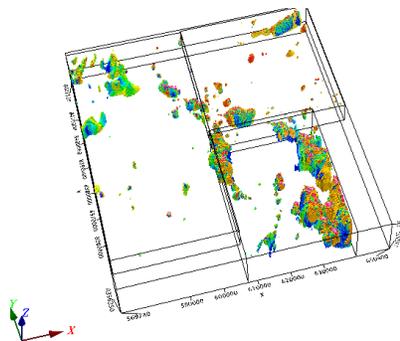


Figure 4: MVI for the Crixas area. Vertical exaggeration 2, cell size x=190 m; y=190 m and initial value for z= 25 m. Results clipped to Amplitude = 0.003.

The MVI generates three voxels that forms the Magnetic Vector results with the projected, perpendicular and amplitude components. The amplitude component is used to filter the perpendicular and projected components that are jointly displayed.

Interpretation

For mineral exploration sources below 2000m are of little interest so the use of the residual field as input in the inversion brings an output that highlights the shallower sources of interest.

We have inverted data for the Crixas greenstone belt comprehended in area 2 and 3 using the residual field component, by applying a high pass filter with wavelength cutoff set at 8500 m and have found an anti-correlation between the MVI results with the existing Gold mine locations (obtained from DNPM) (Fig.4). The gold occurrences in Crixas are located in nonmagnetic sedimentary environment and the identification of the surrounding structures is an important enabler for the interpreter to locate the potential targets for further investigation as shown in Figures 4 and 5.

and delineation of the magnetic sources. In Figure 6, they are presented together for better comparison.

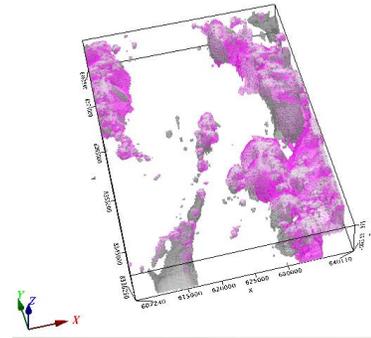


Figure 6: Susceptibility and Magnetic Vector Inversion for the Crixas area 5.No vertical exaggeration, cell size x=190 m; y=190 m and z initial = 25 m. Susceptibility in gray clipped to 0.04 and projected and perpendicular components of the magnetic vector in magenta filtered using the amplitude component.

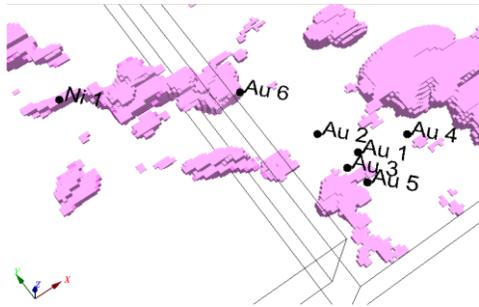


Figure 5: Voxel result from MVI inversion for the Crixas area 2 and 3.Projected and Perpendicular components combined with location and identification of the mine locations as provided by DNPM.

The mine legend is the following:

LEGEND OF MINES

ID	MINE
Au 1	MSG - Jazida Mina III
Au 2	MSG - Jazida Mina Nova
Au 3	MSG - Depósito Mina IV
Au 4	CLEVELAND - Depósito Meia Pataca
Au 5	MSG - Jazida Palmeiras
Au 6	CLEVELAND - Depósito da Mina Inglesa
Ni 1	VM - Ocorrência Fazenda Boa Vista

Considering the target being gold exploration, as the flight line spacing of the survey was 500 m, this was far from ideal, but it still shows clearly the areas to be followed up with more detailed surveys.

We also applied Magnetic Vector and Susceptibility inversions for Crixas Area 5 and the results have corroborated the superiority of MVI in the identification

The projected and perpendicular components of the Magnetic Vector should be analyzed together and can be combined in different ways to provide a better interpretation of the results. They can also be displayed using the same color table as in Figure 6 or using a single color table for each component as in Figure 7 and also as vectors as in Figure 8.

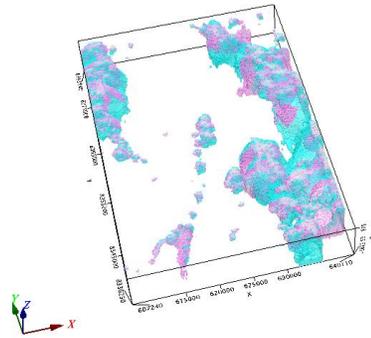


Figure 7: Results of the Magnetic Vector Inversion for Crixas area 5. No vertical exaggeration, cell size x=190 m; y=190 m and initial z = 25. Projected component in magenta and perpendicular component in cyan.

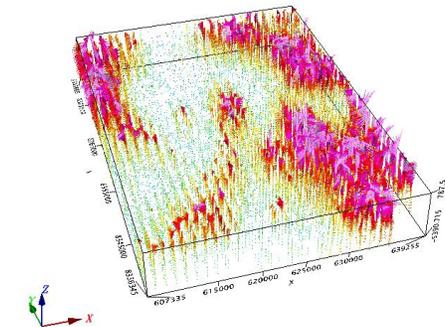


Figure 8: Same results from Figure 7 displayed as Vectors.

The 3D visualization of the combined components of the MVI results together with the amplitude of the analytic signal shown as a relief surface, confirms the similarity of the presented themes, despite of the fact that we are comparing scalar and vector results.

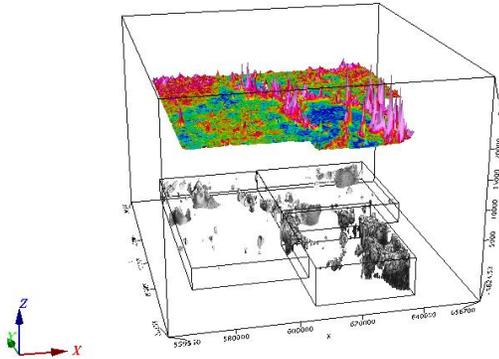


Figure 9: Amplitude of the Analytic signal with color and relief in 3D over results of Magnetic Vector Inversion in gray for the Crixas areas 2, 3 and 5. Projected and perpendicular components

The results of the Magnetic Vector Inversion can be further refined, using a constrained inversion, by inputting the initial amplitude result as the voxel constraint obtaining a more focused output. This technique was applied to Crixas area 5 and Figure 9 presents the comparison of the unconstrained results with the constrained ones using one reweighting iteration.

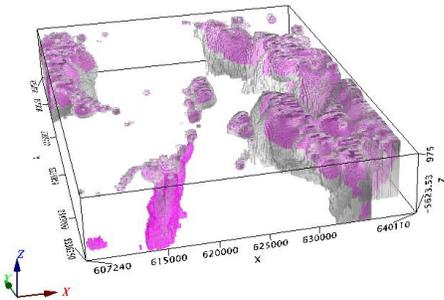


Figure 10: Results of the Magnetic Vector Inversion for Crixas area 5. Comparison of MVI non-constrained results in gray with one reweighting iteration in magenta.

By using the residual magnetic field, obtained with the application of a high pass filter with 8500 m wavelength as cutoff, the result emphasizes the shallower sources that are the targets for mineral exploration purposes. In Figure 10 we present the comparison of the Magnetic Vector Inversion of the total magnetic field with the results of the Magnetic Vector Inversion of the residual magnetic field applied to Crixas area 5.

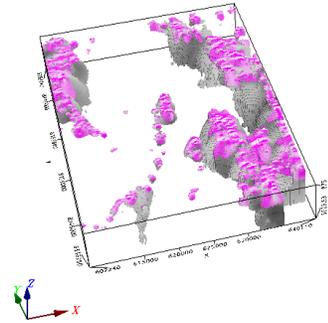


Figure 11: Results of the Magnetic Vector Inversion for Crixas area 5. Comparison of MVI total magnetic field inversion results in gray with MVI residual magnetic inversion in magenta.

Conclusions

The increase of computational power has enabled the incorporation of the results of magnetic data inversion for interpretation projects. The susceptibility inversion is the most common available implementation of this solution. The Magnetic Vector Inversion improves the obtained results especially in low latitude areas and in the presence of remanent and/or demagnetized sources.

The good results obtained with the use of MVI in the Crixas area, central Brazil, confirmed in alignment with the published mineral occurrences, encourages the application of this technique in other low latitude areas, where historically the Analytic Signal filtered results have been used as the main 2D interpretation theme for source location due to the instability of the reduction to the pole technique.

This study has also indicated a number of good practices to apply in order to obtain better results that include using the database containing the original measured results instead of the interpolated surface (grids), to invert the residual field for mineral exploration target selection and to perform the iterative reweighting inversion to get more focused outputs.

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