The use of magnetics in the detection of magnetite destruction zones and its implications for iron exploration at the Quadrilátero Ferrífero, Minas Gerais,Brazil.

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Abstract

This paper reviews the magnetic response of some iron ore deposits over the Moeda Syncline at the Quadrilátero Ferrífero, Minas Gerais, Brazil and traces a correlation between iron ore bodies and the magnetic image of the analytic signal. The majority of the iron mine pits are related to analytic signal lows near or inside analytic signal highs. It is possible due to the magnetite martitisation process that destroyed the magnetite by oxidation and enriched the proto-ore banded iron formations in hematite. Consequently, when exploration iron at the Quarrilátero Ferrífero, airborne magnetic images should be used to target areas where the magnetite destruction occurred more intensely.

Introduction

Geophysics was first used for mineral exploration in the early seventeenth century and the first mineral commodity that was target of geophysical surveys was iron (Flis, 2008). Magnetite is the most common and most potent magnetic mineral and it is a major component of banded iron formations (BIF), which are normally composed of hematite, magnetite and quartz. Thus, the early use of geophysics in the search of iron is not a surprise.

In the past airborne magnetic surveys were used basically to determine if a magnetic iron body existed. After the long development of better acquisition systems, high resolution airborne surveys can now map minor changes in magnetite in rocks and iron formations.

In the early of the twenty one century, the iron industry suffered intense change due to the high iron ore demand from China. The necessity of high ore grade dropped enormously. Iron ore deposits with lower grades turned to be economically viable. BIF with considerable amounts of magnetite became also ore.

In addition, as stated by Orberger *at ali* (2013), the understanding of the hematitisation of magnetite grains is important as it changes ore quality in iron ore deposits, and impacts exploration, mineralurgical and metallurgical processing.

Modern magnetic surveys can contributed in the understanding of hematitisation process that a specific area has suffered. The aim of this paper is to discuss this capability in an important iron production district as the Quadrilátero Ferrífero, located at the Minas Gerais state in Brazil.

Study area

The figure 1 shows the study area location. This area is related to the Moeda Syncline which is defined by the rocks of the Cauê formation of the Paleoproterozoic Minas Supergroup.

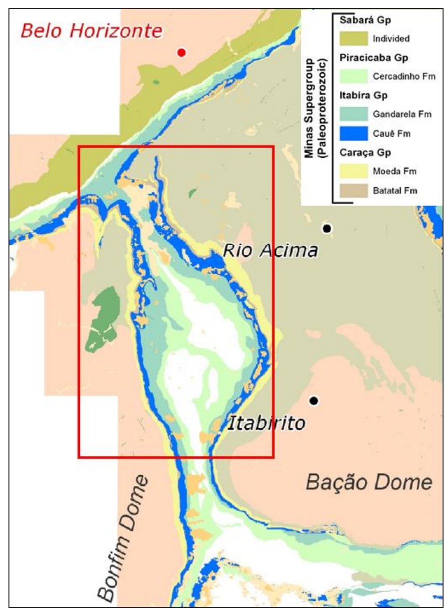

Figure 1 Regional geological map (modified after Carlos *et ali.* 2014). This map also shows the location of the study area (red polygon) on regard the cities of Belo Horizonte, Rio Acima and Itabirito.

The Moeda Syncline was chosen as the study area due to the availability of a governmental high resolution airborne mag-gamma survey over well-known banded iron formations related to the Cauê Group that hosts important iron mines such as the VALE-MBR mines.

Hematitisation process

The hematitisation process is the oxidation of the magnetite (Fe3O4) that is transformed into martite, an octahedral or dodecahedra hematite (Fe2O3). This process can be related to hydrothermal or supergene alteration and is in many cases is incomplete. The relict magnetite influences directly the magnetic property of the martite. The figure 2 shows a photomicrograph a martite from the study area.

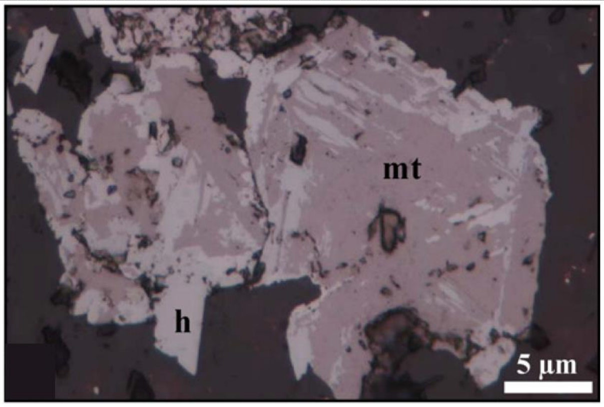

Figure 2 Photomicrograph of an itabirite from the Moeda Syncline area. Detail of a martite (mt) crystal showing relicts of magnetites reflected light (modified from Spier *et ali.*, 2007).

Accessed data

The accessed airborne data was from a survey conducted in 2001 over lines 250 metres apart. The flight direction was 30º and height was 100 metres. The survey was contracted by CODEMIG – Companhia de Desenvolvimento Econômico de Minas Gerais. The survey covered an area much larger than the study area that has dimensions of 15 km (east-west) by 30 km (north-south). The figure 3 shows the final image of the total magnetic intensity (TMI) windowed just over the study area.

The mine pits were extracted from 2014 CNES / Astrium high resolution images available at google earth. A total of 31 pits were localized. Figure 3 shows the image right over the study area overlaid by the iron mine pits.

Magnetic data interpretation

Two aspects are directly interpreted over the satellite image. Firstly, the Moeda Syncline is mapped by topographic highs that were preserved due to the silica in BIF units. Secondly, the majority of the iron mines are located in the east flank of the syncline.

The local geomagnetic field when the survey was conducted had an inclination of -30º, a declination of -21º and mean strength of 25307 nT. In a normal situation, these characteristics make the application of magnetics a challenge mainly due to the low inclination of the field.

However, the local geology makes the application even more challenge due to the north-south direction of the syncline structure, almost over the declination direction and the presence of BIF units that are frequently associated to strong remanent magnetization, due to self-demagnetization as well.

The complexity can be addressed in TMI image display in figure 3 and in other transformed images such as the magnetic derivatives and the Tilt image.

Flis (2008) presented an interesting example of magnetite destruction mapping by the use of the analytic signal filter over the Pic De Fon at Simandou, Guinea. This example is reproduced in figure 5. As can be seen the high-grade iron mineralizations are in non-magnetized areas that are spatially related to magnetic zones.

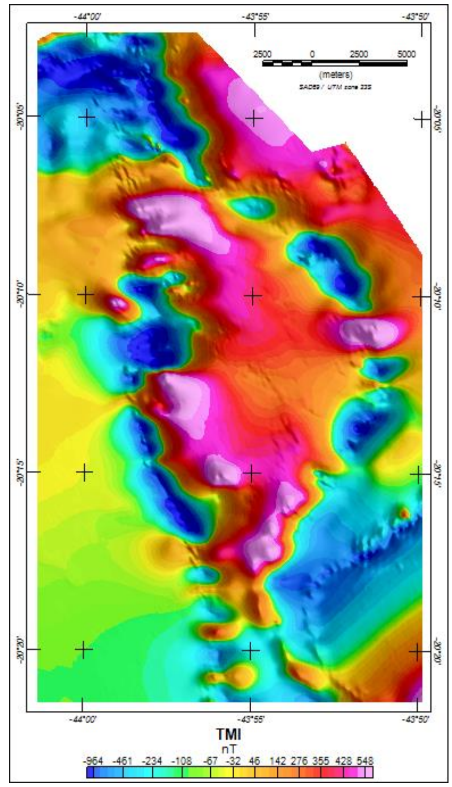

Figure 3 Total magnetic intensity image of the study area.

Figure 4 Image where the iron mine pits were extracted, the shown image displays a detail right over the Mina do Pico pits.

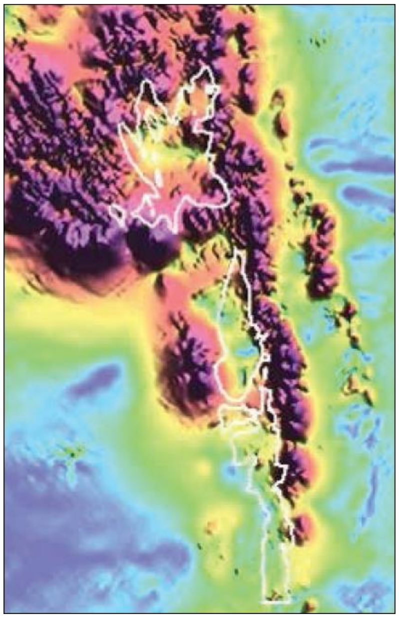

Figure 5 Analytic signal of the total magnetic intensity derived from an aeromagnetic survey over the Pic De Fon, Simandou, Guiana, from Flis (2008). The white polygons outline the limits of the high-grade iron mineralization.

The analytic signal transformer was applied on the magnetic data of the study area, aiming to check if similar results as Flis(2008) would be observed. The figure 6 shows the analytic signal image of the Moeda syncline.

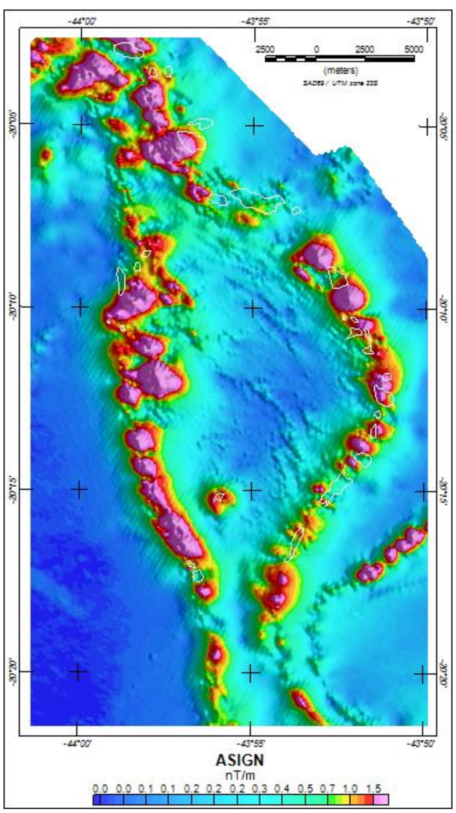

Figure 6 Analytic signal of the total magnetic intensity derived from an aeromagnetic survey over the Moeda Syncline.

The analytic signal filter was able to define the BIF units better than any other transformer of the magnetic field. Mainly due to the way that it handles the remanent magnetization.

However to map areas where the magnetite was transformed partially to hematite it is fundamental a careful equalization of the image color distribution. The hot colors should reflect only very magnetized zones as shown in figure 6.

Using the correct color scheme, geological knowledge can be directly extracted from the figure 6 image. Fact that is impossible when using the pure TMI image (figure 3) and its derivatives.

The analytic signal image (figure 6) suggests that the west flank of the Moeda syncline has more magnetite rich BIF units than the east flank. Perhaps this explains the fact that there are more iron mines on the east flank when compared with the west flank.

The majority of the mine pits are not related to analytic signal highs. However the pits are spatially related to the highs, as Flis (2008) observed at Simandou.

The figure 7 shows the correlation of the analytic signal and the Mina do Pico and Sapecado mines. Both are important iron mines owned by VALE S/A. The Mina do Pico is between two analytic signal highs. The two pits are separated by magnetic area. The southwest limit of the Sapecado lays right over an analytic signal high.

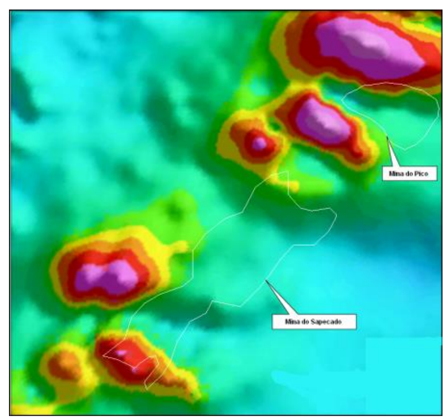

Figure 7 Analytic signal image overlaid by the Mina do Pico and Sapecado mine pits.

Another interesting analytic signal local low and a mine pit correlation is observed at Várzea do Lopes iron mine owned by GERDAU S/A. Figure 8 shows that the Várzea do Lopes pits lays over two local lows that are surrounded by very magnetized units. The image suggests that the mine area is related to a zone where the magnetite was transformed to hematite.

Iron exploration regional targeting

The airborne magnetic data is an important exploration tool to define magnetic targets related to BIF units. However, by the use of high-resolution surveys, it is possible to escape from selection only magnetic rich BIFs areas. By the use of high-resolution data, it is now possible to define areas where the magnetite was transformed to hematite.

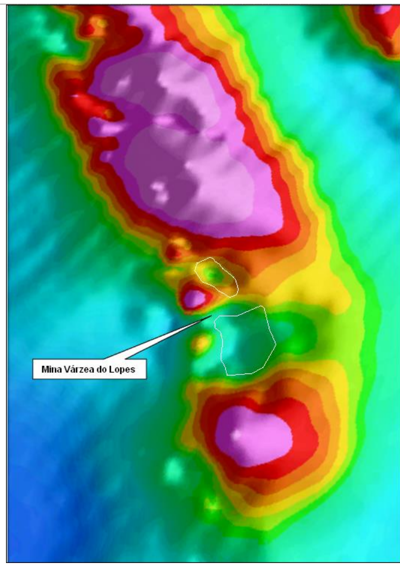

Figure 8 Analytic signal image overlaid by the Mina Várzea do Lopes pits.

The analytic signal transformer should be used as a primary tool to define areas that could be related to hematite rich BIFs to ground follow.

Aiming to assure that a specific target is related to more hematite-rich BIF than magnetite rich BIF, other methodologies should be used. In this aspect, the gravity methodology should be applied as argued by Carlos *et ali* (2014) and Braga *et ali* (2010) that presented interesting case studies on the use of gravity methodology at the Quadrilátero Ferrífero.

It is important to keep in mind that gravity surveys are always more expensive than magnetic surveys. Thus, the correct use of high resolution airborne magnetic data reduces the areas where the gravity methodology should be applied, reducing the exploration costs.

Conclusions

The technical development in airborne magnetics shifted from a simple magnetic source finder tool to a methodology that can map different contents of magnetite in an iron formation.

The analysis of a high resolution airborne survey over the Moeda Syncline at the Quadrilátero Ferrífero showed that the analytic signal image can qualitatively map magnetite-hematite transformation in the local banded iron formations. Magnetic images were overlaid by the iron mine pits. The majority of the mines are related to analytic signal lows inside or beside analytic signal highs.

Therefore, aiming to reduce exploration costs, high resolution airborne magnetic airborne surveys should be used to generate regional targets that could be related to iron formations with more hematite than magnetite. Only after that, other technologies, such as gravity, should be used to help the mapping of hematite-rich iron formations.

Acknowledgments

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