Self-Organizing Maps applied to Magnetization Vector Inversion

Aisengart, T., Geosoft Latinoamérica; Pereira, J.G., Geosoft Latinoamérica; Rech, M., Geosoft Latinoamérica; Barbosa, R.D., Geosoft Latinoamérica; Porto, C., Geosoft Latinoamérica; Ando, J. L. Geosoft Latinoamérica.

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Abstract

The Magnetization vector inversion (MVI), although having only recently entered the available toolset to process and interpret data from magnetic surveys, has already proved to bring high value, especially in environments where there is remanence, in low latitude areas, demagnetization or susceptibility anisotropy in general. The Self Organizing Map (SOM) technique have also been used successfully helping the target selection for further investigation.

In this work, we present the results of application of both techniques to three different areas, i.e. we have applied the SOM technique to the Magnetization Vectors models resulting from the unconstrained inversion applied to the Pontes e Lacerda and Goiás Alkaline Province airborne surveys in Brazil and to the magnetic grid resulting from the compilation of several surveys in the Ngamiland area in Botswana.

The results are very encouraging and enabled both the automatic identification of the principal magnetic domains and the differentiation of the magnetic anomalies.

Introduction

Recently we have developed and published some case studies showing the results of unconstrained MVI applied to regional airborne magnetic data such as the 1:250.000 Pontes e Lacerda map sheet (Aisengart et al, 2016b); the Ngamiland magnetic compilation (Burns, 2016) and the Alkaline Province of Goiás (Aisengart et al, 2016c). For some of them (Aisengart et al, 2016b and 2016c) we also applied the SOM technique generating very interesting and encouraging results.

With the constantly growing availability of public data including regional airborne geophysical data, such as the Botswana Ngamiland geophysical compilation and the Goiás airborne survey used in this work, allied to the ability to run inversions, makes the application of automatic interpretation techniques to generate initial targets very important. The other example used in this work was the Pontes e Lacerda aeromagnetic survey that was kindly provided by CPRM.

In this study, we have applied the SOM technique to separate the anomalies from the background and then applied it again only to the anomalies to classify them in different classes. We have used the Cartesian components of the vectors results of the MVI (Vx, Vy, Vz) in conjunction with the Cartesian coordinates (X, Y, Z) as the input to generate an unsupervised classification using an implementation of the SOM technique in three dimensions.

Method

The Magnetization Vector Inversion - MVI (Ellis *et al*, 2012) is an inversion technique that it has been used very frequently, because it give us a much more reliable model and better representation of the geological environment, when we have complex areas respect to its magnetic properties.

Until quite recently, the physical property used to describe magnetic materials in the earth, particularly for inversion, was the susceptibility that is related to Magnetization:

$$\vec{M} = k\vec{H}e \qquad (1)$$

Therefore, the Magnetization Vector target equivalent to the Susceptibility target is a collection of magnetic dipole sources and the assumption to use susceptibility is that the magnetization vector is aligned with the inducing field direction that is the Earth's field direction.

Considering the complex nature of rocks, we need a more close approach that considers also the anisotropic magnetization and remanent magnetization that is applied using VOXI-MVI:

$$\vec{M} = (\vec{k} + \vec{k}_R)H_e = \vec{k}_{MVI} H_e \qquad (2)$$

This equation shows how the MVI susceptibility relates to magnetization vector and is based on $\vec{k}_{MVI}$ the effective susceptibility (anisotropic + remanent) and through it, we can estimate inclination and declination of this effective magnetic susceptibility for a magnetic source (Aisengart, 2015), providing us a good perspective of structural parameters to map the geology in subsurface.

Self-Organizing Maps (SOM) (Carneiro *et al*, 2012; Cracknell & Reading, 2014) is an unsupervised classification technique used to analyze and visualize high-dimensional data, based on principles of measures of vector quantization. It is an ideal tool to analyze a dataset consisted of disparate geophysical input parameters when you are looking for relationships and trends.

In this paper, our approach is to use SOM to classify the magnetization domains applied to the results of VOXI MVI from different areas. We have used the GX developed in Python by Ian McLeod, which differs from the ones normally found in the literature (Carneiro *et al*., 2012; Cracknell & Reading, 2014) as it is based on the 3D topological space.

Using the MVI VOXI results for each area, we created an initial SOM classification with a total of 8 classes, which allowed us to separate the magnetic anomalies from their background, considering that 2% of the data is anomalous. Analyzing the results, we have noticed that the background classes are also useful as they give an indication of the main magnetic domains and structural directions. The second step was to filter and remove the background and then use 18 classes to classify the anomalies. Although in some cases 18 classes can be too much and some of them can be joined, when applying the technique to regional datasets, it seems an appropriate setting and the results are very encouraging, as they seem to reflect appropriately the diversity encountered in nature.

Examples

Rocks and mineral deposits have physical and mineralogical characteristics related to their composition and origin that differentiates them from the hosting environment, resulting in magnetic anomalies coming from the contrast of their physical properties of magnetization exemplified in the three areas studied in this work.

Area 1- Pontes e Lacerda

Pontes e Lacerda city has been in evidence since the gold discovery in the region. The area, located in Southwestern of Mato Grosso state, close to the Bolivian border, corresponds to the Sheet SD.21-Y-C, 1:250.000, Pontes e Lacerda (Figure1).

Geologically, it is located in Southwestern Amazonic Craton; this is being formed by the junction of Paleo-Mesoproterozoic lands (1.8 to 1.4 Ga). The Jauru (eastern and central parts) and Rio Alegre Tectonic Domains (western part) dominate the area (Fernandes et al., 2005) (Figure2). In the eastern portion of Jauru Domain occur the Águas Claras Granodiorite e metavulcanic-sedimentary rocks. The Santa Helena Intrusive Suite is located in its central portion and, in the west, the Jauru Domain is bounded by the Rio Alegre and Paragua Domains. The contact with the Rio Alegre Terrain created a normal ductile shear zone. In the region also occur the Fortuna Formation metaconglomerate, where the gold occurrences are located, as well as the metamorphic rocks of the Pontes e Lacerda Group (Ruiz, 2005). In the border with the Paragua Terrain, extreme southwestern, Holocenic sediments cover the region. The same occurs in the northern and southern limits of the Rio Alegre Domain, named as Rio Alegre Terrain and Rio Alegre Orogen (Saes, 1999).

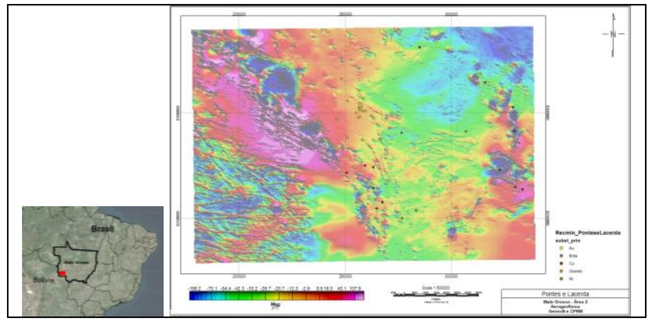

Figure 1 – On the left, location of the study area in red; on the right, the area in detail showing the grid of the Total Magnetic Intensity.

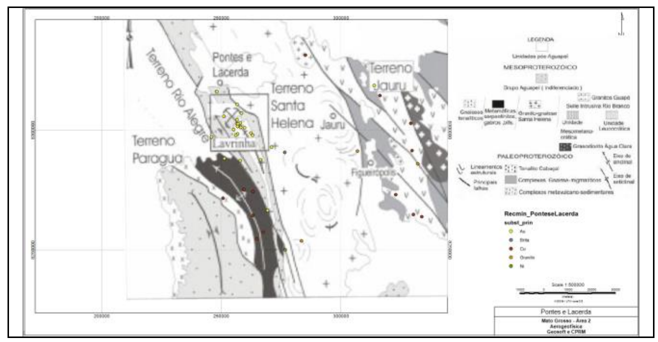

Figure 2 – Geological and Tectonical map (modified from Fernandes et al., 2005).

The access to a higher computational power has allowed us to invert the whole area (160Km x 110Km) in high resolution (with a 150x150x75m cell) creating a final output with 1083x750x44 cells (Figure3) (Aisengart, 2016a, Aisengart et al, 2016b). The MVI result allowed the identification of the main geological and structural features in surface, besides possible sources in depth. Bordering the Rio Alegre Terrain the model has shown magnetic anomalies aligned according to the NW-SE direction and in West area a strong magnetic response in depth, indicating a possible identification of the basement.

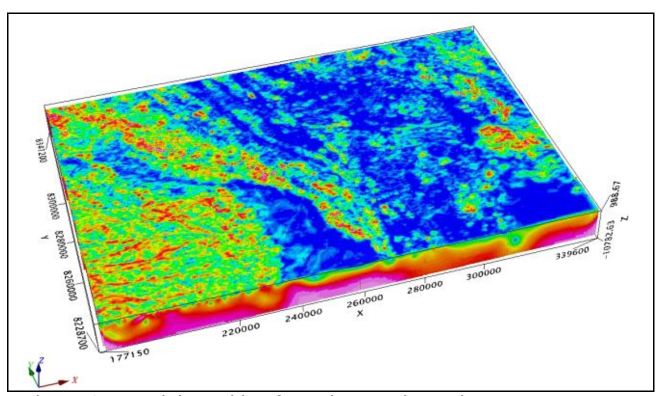

Figure 3 – Model resulting from the MVI inversion.

Area 2- Goiás Alkaline Province (GAP)

The GAP, at the Northern border of the Parana Basin, in the Goiás State, Brazil (Figure4), is located along the Brasilia Belt with some of the main alkaline complexes concentrated in the South of the Goiás Magmatic Arch. Its intrusions are characterized by having several alkaline complexes, dykes and local volcanic products (Rocha, 2013). In the GAP area, systems of long sub-vertical faults also occur hosting alkaline intrusions and sometimes are recognized as rifts or en echelon systems. The crossing of faults system, where structural NW-SE directions predominates, could have influenced the site of the intrusions (Dutra, 2011).

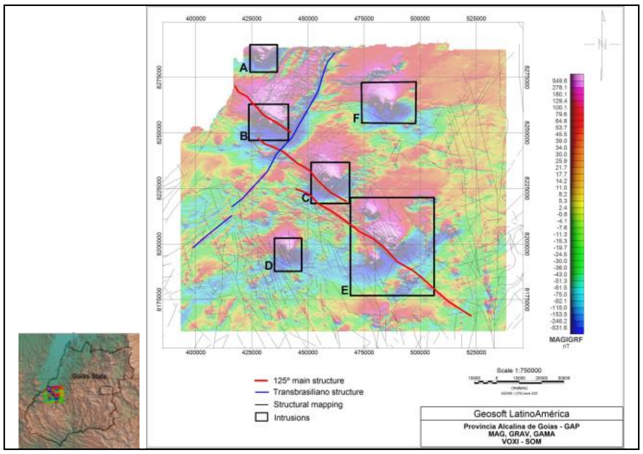

Figure 4 – On the left, location of the study area in red; on the right, the area in detail with TMI grid, main structures and Intrusive bodies: (A) Morro do Engenho, (B) Araguaia, (C) Montes Claros, (D) Arenópolis, (E) Iporá, and (F) Santa Fé.

The MVI was the method applied to invert the whole area and each intrusion named above. In the inversion of the total area (145x130 km) the model cell size was 300x300x150 meters (Figure5). The integration of existing geological and geophysical data enabled us to characterize and individualize the main alkaline occurrences (Figure4) in the GAP area.

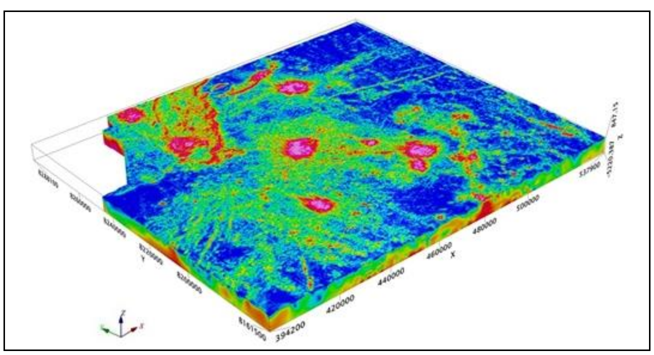

Figure 5 – MVI model result for the GAP area.

Area 3- Ngamiland, NW of Botswana

In order to attract foreign investments, the Botswana government decided to allow public access to their geoscientific data and established a partnership with Geosoft to provide this access. In the Botswana Portal (http://geoscienceportal.geosoft.com/Botswana/search) it is available, amongst other data, a compilation of magnetic airborne surveys that was used as the input for a very big MVI (944 x 832 x 45 cells) with the results also published in the portal and available for download (Burns, 2016).

Ngamiland, Northwest distict of Botswana (Figure6), is part of the Kalahari Desert and occupies a key position within southern Africa for linking the Damara and Zambezi-Lufilian orogens. The Okavango Rift System, also located in the NW of Botswana, is a branch of the East African Rift system and have deep structural features that are masked at the surface by sedimentation from Karoo Supergroup and Kalahari Group.

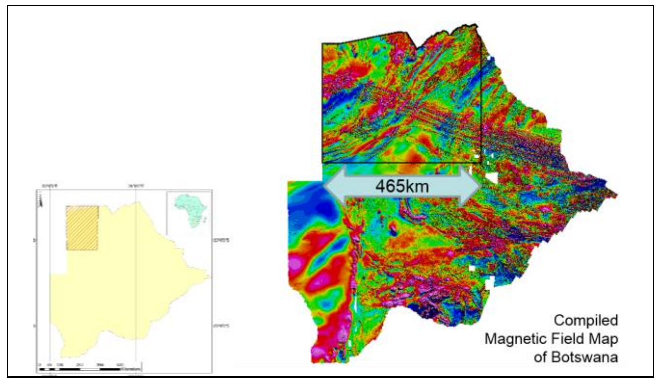

Figure 6 – Study area delimited by the black rectangle above the grid of the Total Magnetic Intensity (Botswana Portal, 2016).

The area lies within the Rehoboth subprovince and comprises the Paleoproterozoic Rehoboth Subprovince, the Mesoproterozoic Sinclair Supergroup and the Neoproterozoic Damara Supergroup. The Damarides in Botswana occupy the western section of the Damaran/Katangan rift basin, bounded by the Archaean to Palaeoproterozoic basement rocks of the Kalahari and Congo cratons to the SE and NW respectively. The Damara Belt shows high-angle convergence and lacks evidence of oblique or transcurrent movements (IGS Xplore, 2016) (Figure7).

The Ghanzi-Chobe Zone of volcanosedimentary rocks deformed into NE-SW trending and SE-verging open to tight folds forms a 500km long and 100km wide portion of the Kalahari Copperbelt in Botswana. The belt represents a rift basin fill on the NW margin of the Kalahari Craton that was deformed during the Late Neoproterozoic-Early Paleozoic Pan-African orogeny (Jacobs et al., 2008). The Okavango Zone in NW Botswana consists of the Roibok and Koanaka Groups and the Kwando Complex which display NW-verging folds – opposite transport direction to Ghanzo-Chobe zone. Ngamiland area also incorporates a small synclinal infold of Mamuno Formation overlies the Kwando Complex.

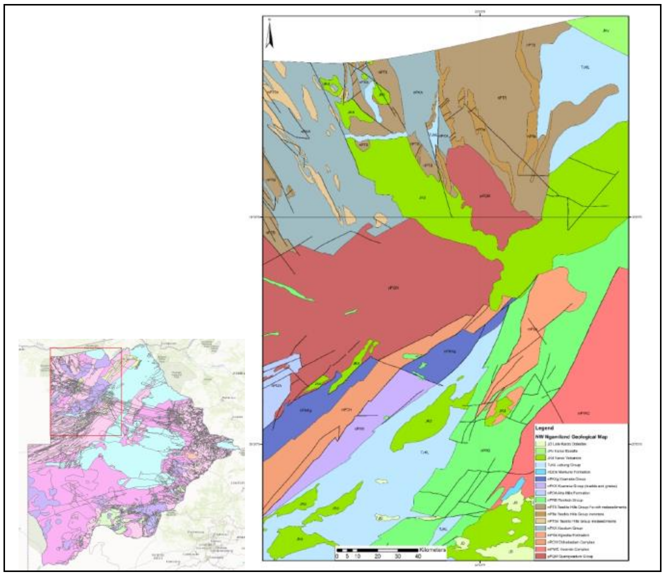

Figure 7 – Botswana Geological map and a geological detail of Ngamiland area (Botswana Portal, 2016 and IGS Xplore, 2016).

The MVI results add clear 3D images of the shallow crust beneath the Okavango delta region, one of the world's largest inland deltas. Often referred to as the 'jewel' of the Kalahari and Africa's last Eden, the 22,000 square-kilometer Okavango delta itself is an alluvial fan contained within a seismically active graben structure at the south-western extremity of the East African Rift system.(Burns, 2016).

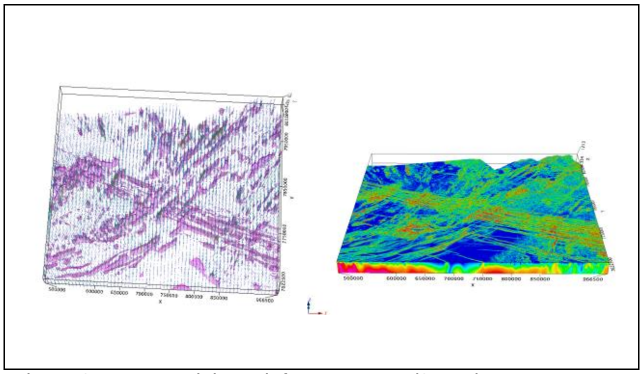

Figure 8 – MVI model result for Botswana (3x VE).

Results

Area 1- Pontes e Lacerda

To apply the SOM analysis, we have exported the MVI results to a database and selected the Cartesian components of the Magnetization vector, allied to the Cartesian coordinates to classify the data, creating initially 8 classes, considering 2% of the data as anomalous. The results can be seen in Figure 9.

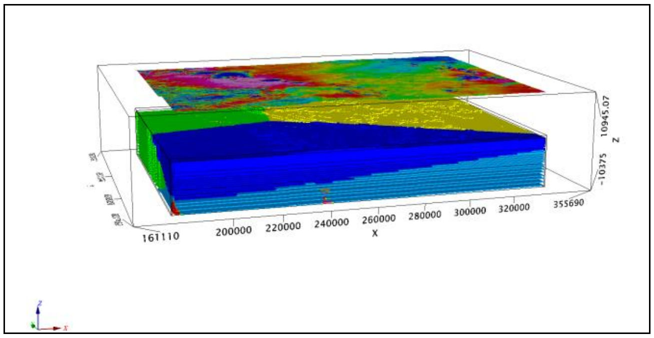

Figure 9 – Background classes – Main Magnetic domains.

When analyzing the background classes, we noticed that even those give us useful information as it seems to indicate the main magnetic domains. After removing the background, the anomalous classes are further classified in 18 classes (Figure10), in this case considering 5% as anomalous providing an automatic interpretation to be validated using existing additional information or through further exploration.

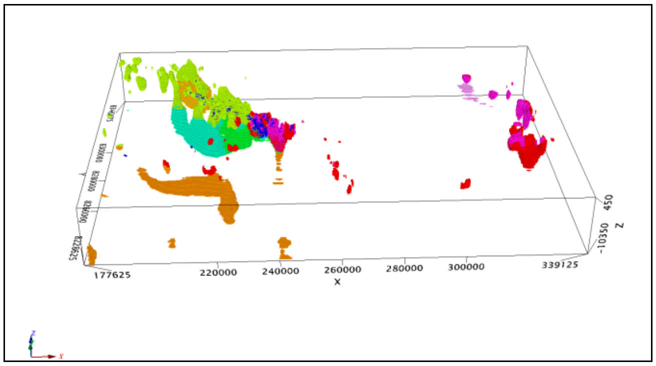

Figure 10 – Anomalous classes – Classification of anomalies in 18 classes.

Area 2- Goiás Alkaline Province (GAP)

The same workflow and parameters were applied to the GAP area resulting in the identification of the main magnetic domains in the first pass of the SOM process (Figure11) and the anomalous features presented in Figure 12.

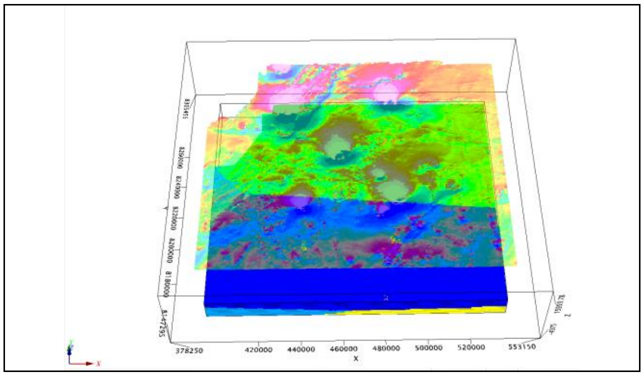

Figure 11 – Background classes – Main Magnetic domains.

As the magnetic response of the GAP is stronger due to the geological setting and also the area is better known and studied, the anomalies were better characterized (Figure12) and we were able to identify the possibility of the existence of three distinct mineral systems forming the alkaline intrusions

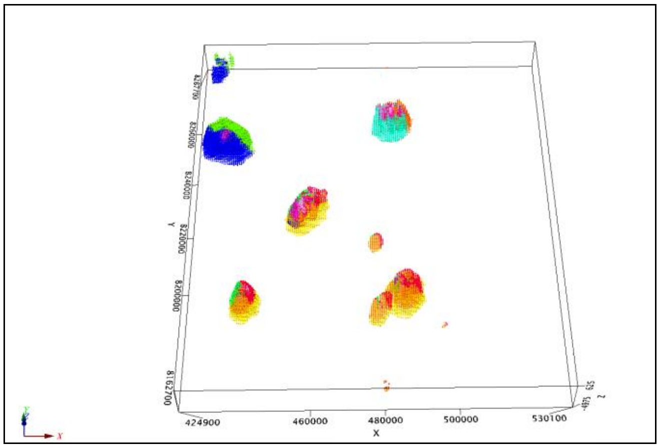

Figure 12 – Anomalous classes – Classification of anomalies in 18 classes.

Area 3- Ngamiland, NW of Botswana

As some of us have participated in the creation of the extra-large model of Botswana, we have applied the same workflow and parameters were applied to the MVI result enabling the identification of the main magnetic domains in the first pass of the SOM process (Figure13) and the anomalous features presented in Figure 14.

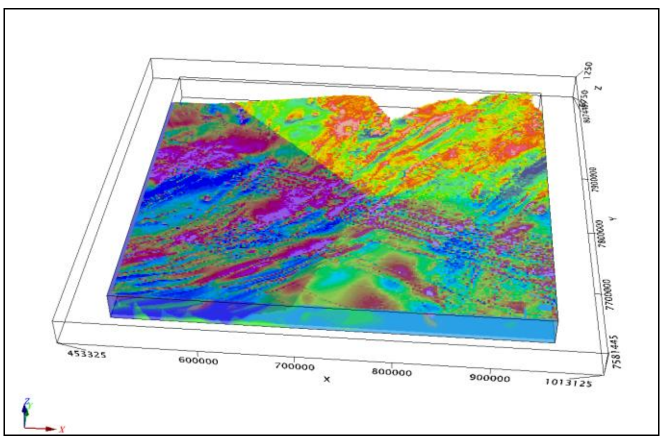

Figure 13 – Background classes – Main Magnetic domains.

This area also has very good magnetic response both from the geological and structural features. As can be seen in Figure 14, the 18 classes used for the SOM analysis distinguish geological lithologies and structures, besides indicating shallow and deep features.

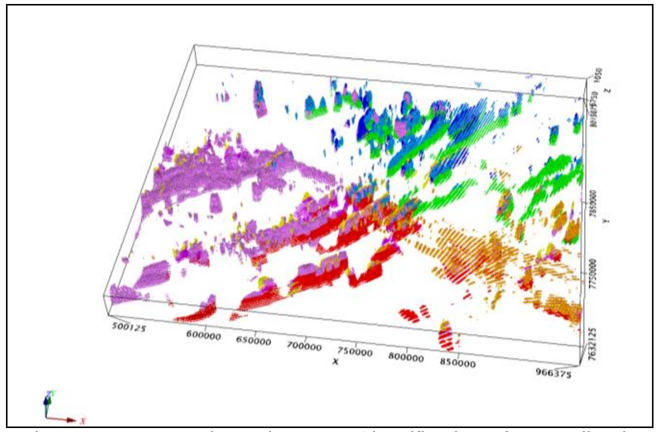

Figure 14 – Anomalous classes – Classification of anomalies in 18 classes.

Conclusions

SOM has already been applied in a successful way for automatic geophysical interpretation in 2D using magnetic and radiometric data (Carneiro, 2012), in classification of seismic attributes (Klose, 2006) and in this work we have showed that the 3D implementation of the SOM technique can provide a very useful automatic interpretation using as input regional or local MVI unconstrained models.

As this technique reduces the dimensionality of the inputs it is important to incorporate in the future additional 3D data such as density models generated from Gravity data and/or drillhole geological and geochemical information to create more supported automatic interpretations.

Area 1- Pontes e Lacerda

The SOM technique identified 18 distinct classes demonstrating lithologies and/or geochemical and mineralogical distinct areas with magnetic anomalies, including the N-NW areas where there is an extensive holocenic coverage.

As this is a frontier area with only a few published studies, we were not able to validate the results and look forward to have access to more information that can corroborate our findings.

Area 2- Goiás Alkaline Province (GAP)

Differently from the previous area, GAP is very well studied and the application of the SOM technique suggested the existence of three distinct mineral systems forming the alkaline intrusions (Figures 4 and 12): (i) one system englobing the Morro do Engenho and Araguaia anomalies, (ii) one englobing Montes Claros, Arenópolis and Iporá and a (iii) third system with Santa Fé anomaly.

Analyzing the structural map, we observe that the Transbrasiliano structure (Az. 40º) is the one that divides system (i) from systems (ii) and (iii) two magnetic domains and also, 125º Lineament divides systems (ii) and (iii). This result is aligned with published studies from the area (Rocha, 2013).

Area 3- Ngamiland, NW of Botswana

The SOM result demonstrate very well the lithologies and structures surface mapped corresponding to the Ghanzi-Chobe Zone of volcano-sedimentary rocks deformed into NE-SW trending and the Okavango Zone which display NW-verging folds (opposite transport direction to Ghanzo-Chobe zone). It also distinguishes well the shallow and deep structure that have different directions related to the tectonical occurrences.

We hope that this work collaborate to a deeper understanding of this important and complex area.

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