Processing and Integration of airborne magnetometry data for the assessment of geotectonic context of the central portion of Az 125° Lineament

Loiane Gomes de Moraes Rocha* - loianemoraes@hotmail.com
Augusto César Bittencourt Pires, Adriana Chatack Carmelo, and José Oswaldo de Araújo Filho
Universidade de Brasília - Instituto de Geociências

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This paper was prepared for presentation during the 12th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, August 15-18, 2011.

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Abstract

The Az 125° Lineament is the main structural featur e in Brazil presenting the most important kimberlite provinces and carbonatite complexes. The study area comprises the central portion of the lineament and covers parts of Tocantins Province, São Francisco Craton and Paraná Basin. The relationships involved in the geotectonic evolution of Az 125° Lineament provided, along its length, mineralizations with significant economic importance. Magnetometry is an essential geophysical method for tectonic studies. The processing and integration of aeromagnetic survey data comprising the study area allowed the generation of a magnetometric model. This model will enable a better understanding of the geotectonic development of the Az 125° Lineament, a nd its relation to intrusive procedures that led to these important provinces.

Introduction

In Brazil, alkaline-carbonatite complexes and kimberlitic provinces occur in arched and faulted areas in the edge of the Paraná, Paranaíba (Almeida, 1986), and Amazonas basins (Biondi, 2003), along three major structural lineaments (Gonzaga & Tompkins, 1991). The most important of them presents a 125° azimuthal direction, and it is denominated as Az 125° Lineame nt (Bardet, 1977). In the region of Triângulo Mineiro, this is known as Alto Paranaíba Lineament (Schobbenhaus, 1975).

The Az 125° Lineament occurs from the state of Rondônia to the coast of Rio de Janeiro, intermittently outcropping in the states of Mato Grosso, Goiás, and Minas Gerais (Fig. 1). Pereira *et al*. (2008) display the Az 125° Lineament as one of the most significant metal lotect to the intrusion of kimberlitos diatremes in Brazil. It represents an important set of faults that worked as a conduit for the ascent of kimberlitic magma. The associated rock types are: i) in the state of Rio de Janeiro: syenitic rocks and phonolites; ii) in Triângulo Mineiro: carbonatites and kimberlitos; and iii) in the state of Goiás: alkaline ultrabasic rocks and lamprophyres. Mineralized kimberlitos are directly related to the Az 125° Lineament in the Paranatinga and Aripuanã provinces, as well as other sterile bodies in Pimenta Bueno Graben, in Rondônia state (Gonzaga & Tompkins, 1991).

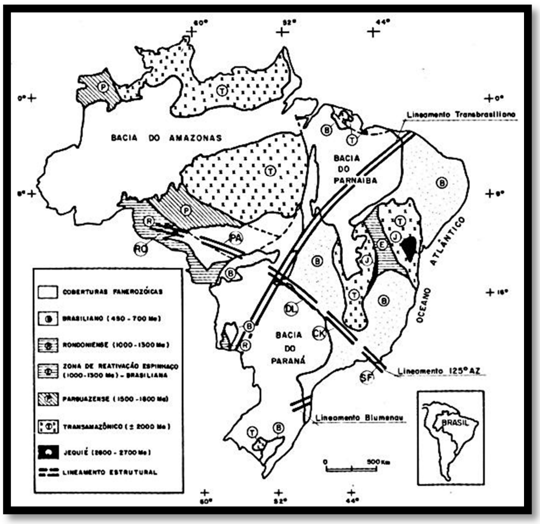

Figure 1 – Map of Brazil displaying the Az 125° Lin eament (Gonzaga & Tompkins, 1991).

The characteristics of the carbonatite complexes express the geological and tectonic regime of their formation separated into two types according to the morphology (Lapin *et al*., 1999): i) Central Type: intrusive complexes characterized by a rounded or oval shape; ii) Linear Zones of Carbonatites and Fenites: associated to deep faults, and can be intrusives or extrusives (Lapin & Ploshko, 1988). In the area of study are founded the carbonatite complexes of Central Type. They occur in orthoplatforms, both in its central and marginal parts, and the carbonatites are displayed as dikes and annular or bearing veins, stocks, and plugs, associated to ultrabasic, alkaline ultrabasic, alkaline basic, and alkaline rocks (Lapin *et al*., 1999).

The location of a kimberlite intrusion, in a regional scale, is controlled by deep structures, and on large scales this intrusions tend to be positioned along faults. Many kimberlitos have been associated to diabase dikes, regional faults, and geological contacts, indicating that the regional scale structures play an important role in the selection of magnetic targets. These structures and their intersections generate weak zones in the crust, providing conduits of least resistance to kimberlite intrusions. In many cases, these regional structures can be easily identified from the magnetic signature pattern, since that kimberlites are ultramafic rocks with susceptibilities ranging from 1 to 80 x 10^{-3} SI (Power *et al*., 2004). The success of the use of magnetometry in discriminating and delineating kimberlitic bodies is based on the susceptibility contrast of them and the rocks they are surrounded by (Smith & Fountain, 1999).

Geophysical methods are important tools for acquiring information that will aid the understanding of geology and add a tridimensional view of the area of study (Moraes Rocha, 2007).For convenience and clarity, methods derived from the measurement of fields produced by natural sources and that can be measured from airborne platforms are used, such as the airborne magnetometry which presents itself as an essential method in tectonic studies.

The geotectonic relationships involved in the Az 125° Lineament evolution provided, along its length, the presence of mineralizations which assigned a significant economic importance. Understanding, by a magnetometric model, the geotectonic behavior of Az 125° Lineament and its relationship to the intrusiv e processes that led to these important provinces are the main goal of this work.

Study Area

The study area comprises the central segment of Az 125° Lineament, involving the states of Goiás and Minas Gerais. The geophysical data are provided from the following airborne magnetometric surveys: Areas 1 and 4 of Goiás and Areas 1, 7, and 9 of Minas Gerais, resulting in an area of almost 198.000 km² (Fig. 2). The region comprises three geological units: the Tocantins Province, the São Francisco Craton, and the Paraná Basin (Fig. 3).

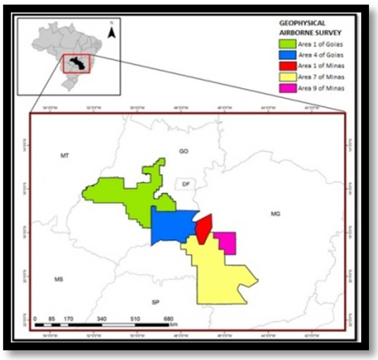

Figure 2 – Location map of airborne magnetometric surveys areas.

The Tocantins Province consists an orogen system, characterized by fold and fault belts called Brasília, Paraguay, and Araguaia Belts, resulting from the convergence and collision of three continental blocks (Delgado *et al*., 2003):.Amazonas Craton (west); São Francisco Craton (east), and Paranapanema Craton (southwest).

The São Francisco Craton is defined and delimited as a component of South American Platform not involved in the neoproterozoic brasiliana tectogenesis. Its substrate consists of an arquean block that was partially spared from the proterozoic orogenesis. Their coverages are divided into two major morphotectonic features: i) São Francisco Basin, that occupies almost the entire segment of meridian direction of the cráton; and ii) Paramirim Aulacogen, that characterizes a morphotectonic feature of the northern portion of the craton (Alkmim, 2004).

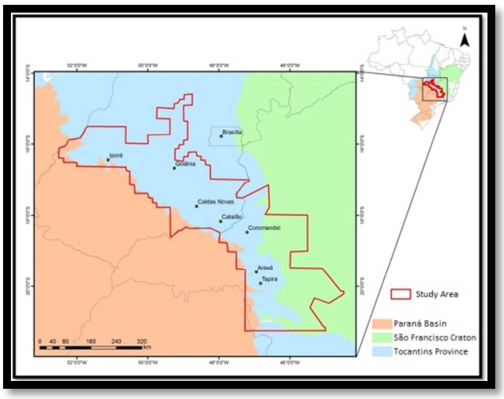

Figure 3 – Map of geologic units of the study area.

The Paraná Basin consists in an extensive sedimentary region of South America, comprising within its limits, a Late Ordovician to Late Cretaceous magmatic-sedimentary succession (Milani, 2004). From Late Ordovician until the Late Mesozoic, the Paraná Basin was an autonomous subsidence and sedimentation-magmatism unit, being interrupted by movements of "Waldeana" Reactivation and opening of South Atlantic(Almeida, 1969).

Gonzaga & Tompkins divided the Az 125° Lineament in five segments (Fig. 1): i) Brasiliano Segment (SF); ii) Brasiliano Segment (CK); iii) Brasiliano Segment (DL); iv) Parguazense Segment (PA); and v) Rondoniense Segment (RO). The study area is inserted in CK Segment, where no significant mineralizations of diamonds in kimberlites occur. This characteristic is consistent with general ideas about mineralized kimberlites, where it is shown that all significant mineralization in kimberlites, as well as in lamproites, are in bodies located in areas of the world where the last thermotectonic event occurred more than 1,500 Ma ago (Gonzaga & Tompkins, 1991).
Gonzaga & Tompkins (1991) present the CK Segment (Fig. 4), between the cities of Bambuí and Catalão, as the most important feature in number of bodies associated to carbonatites and kimberlites (Upper Cretaceous). In this segment occurred some of the biggest Brazilian diamonds, although it is not a tectonic zone conducive to primary diamond sources, since the last thermotectonic event occurred during Brasiliano (750-450 Ma).

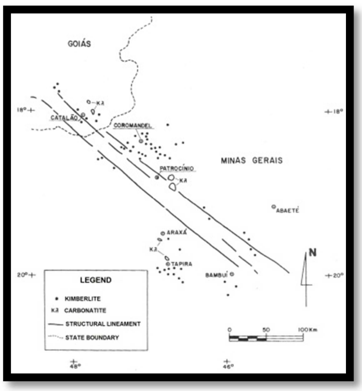

Figure 4 – Map of CK Segment, presenting kimberlites and main carbonatite complexes of Alto Paranaíba Kimberlitic Province, in Minas Gerais and Goiás (Gonzaga & Tompkins, 1991).

Method

The following geophysical data were used: Goiás – Arco Magmático de Arenópolis – Sequência Juscelândia Project (Area 1 – GO), Faixa Brasília Sul Project (Area 4 – GO), Unaí – Paracatu – Vazante – Coromandel Project (Area 1 – MG), Patos de Minas – Araxá – Divinópolis Project (Area 7 – MG), and João Pinheiro – Presidente Olegário – Tiros Project (Area 9 – MG). The airborne geophysical surveys of all areas were conducted by Lasa Engenharia e Prospecções S.A. In 1 and 4 areas of Goiás the survey was carried by a contract of SGMTM/MME/SIC/SGM/FUNMINERAL. The Area 1 of Goiás survey was flown in 2004, with flight height of 100 m, flight lines with in N-S direction and line spacing of 500 m, and tie lines in E-W direction and line spacing of 5,000 m. The Area 4 of Goiás survey was acquired in 2005 and followed the same parameters of Area 1.The Area1of Minas Gerais was elaborated by Secretaria de Estado de Minas e Energia do Governo de Minas Gerais (SEME) in 2000. The area was divided into two blocks: north and south. In this study we used only the southern block, with flight lines direction of N30W spaced in 250 m, tie lines with N60E direction and line spacing of 2,500 m, and flight height of 100 m. The 7 and 9 Areas of Minas Gerais had surveys organized by an agreement of SEDE, CODEMIG, MME, and CPRM, in the years of 2006 and 2007, respectively. Both surveys had flight lines spaced at 400 m, oriented in N-S direction, and tie lines spaced at 8,000 m in E-W direction, with flight height of 100 m. The magnetic data were recorded in nanotesla (nT) and were processed by Oasis Montaj^{TM}, version 7.1.1 (Geosoft, 2009).

The evaluation of the data was conducted by the investigation of the presence of inconsistences and the spatial distribution of flight lines (Blum *et al*., 2001) to eliminate defects of data positioning related to the position of flight lines and data spikes referred to the noise during the acquisition of them (Maas et al., 2003). After this initial phase, the channel MAGIGRF was interpolated into a regular grid by using the bidirectional method (implemented in Oasis Montaj software as bi-grid), allowing the generation of the Anomalous Magnetic Field (Fig. 5). The bidirectional method is designed for data interpolation of geophysical surveys conducted in parallel lines, since they tend to enhance the features perpendicular to the flight lines (Parro, 1998). The choice of bidirectional method was also motivated by the fact that it better preserve high frequencies. This procedure was performed separately for the databases of the five areas, whose grids were attached by using the gridknit method (Geosoft, 2009).

From the Anomalous Magnetic Field grid, there were obtained its horizontal (Dx and Dy) and vertical (Dz – Fig. 6) derivatives that allowed the generation of Analytical Signal Amplitude (Fig. 7), Total Horizontal Gradient Amplitude (Fig. 8), and Analytical Signal Inclination (Fig. 9). Euler solutions maps were also generated (Figs. 10 to 13).

The process of data visualization and interpretation was developed in Geographic Information System (GIS) using ArcGis 9.3 software, (ESRI, 2008).

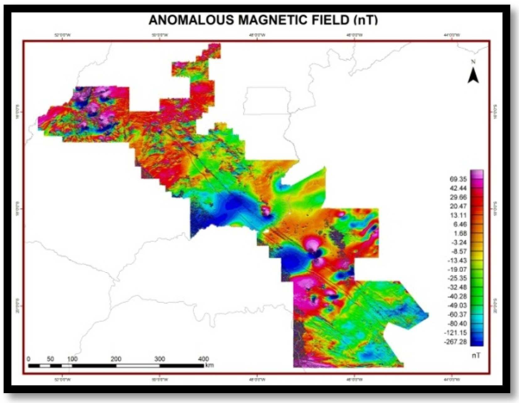

Figure 5 – Anomalous magnetic field image.

Results

The Anomalous Magnetic Field image (Fig. 5) shows a very active magnetic relief. Linear anomalies elongated according a NW-SE direction are present along this axis comprising all over the area. Bipolar anomalies signatures, with positive lobe to the north and negative to the south (characteristics at low latitudes), occur in northwest and central portions of the study. The following linear transformations supported the analysis of the anomalous magnetic field:

1) Vertical Derivative (Fig. 6): this product enhances high frequency signatures, allowing the interpretation of shallow structures. In this image stand out anomalies already observed in the image of the anomalous magnetic field, especially the NW-SE lineament, and allows the interpretation that these anomalies are from shallow magnetic sources.

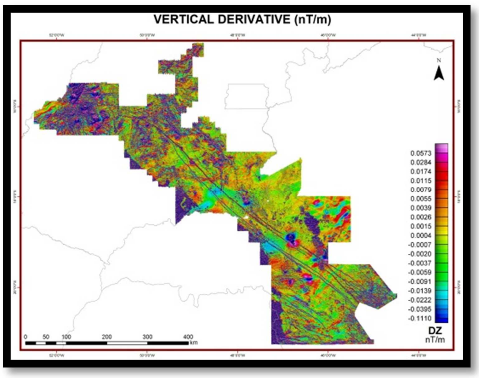

Figure 6 – Vertical derivative image.

2) Analytical Signal Amplitude (Fig. 7): this product has a very interesting function in the context of magnetic interpretation, since it represents the amount of magnetization independent of the direction of bodies magnetization and the direction of Earth's magnetic field (Gunn, 1997). It consists of an efficient technique for the determination of geometric parameters such as location of geological and structural boundaries (Blum, 1999). It enables, by the delimitation of the bodies borders, the definition of the position of magnetic sources. It enhances the linear anomalies oriented along the NW-SE axis, which spatially correspond to the Az 125° Lineament. Also magnetic signatures stand out in circular and oval

shapes in northwest and central parts of the area, which are associated with intrusive bodies (carbonatites and kimberlites) already mapped.

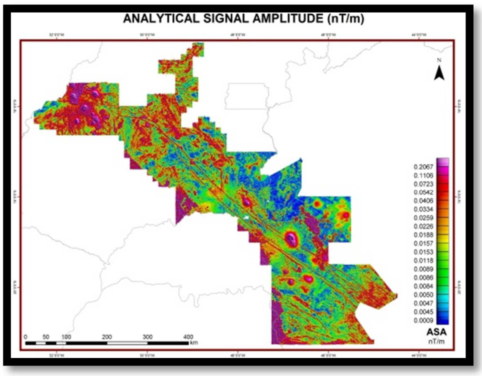

Figure 7 – Analytical signal amplitude image.

3) Total Horizontal Gradient Amplitude (Fig. 8): this transformation allows the verification of large lateral variations (Zacchi *et al*., 2007). In this image, lineaments with NW-SE axis and the circular anomalies are also enhanced, and their lateral limits are better detailed.

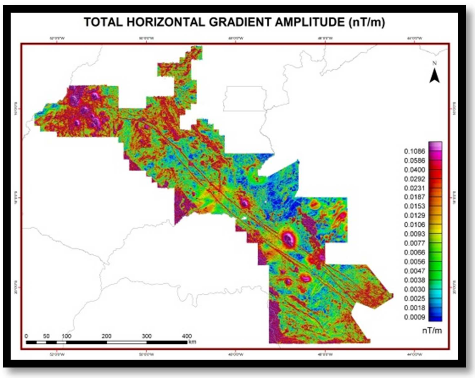

Figure 8 – Total horizontal gradient amplitude image.

4) Analytical Signal Inclination (Fig. 9): this product has a textural pattern that helps the characterization of linear features (Teixeira *et al*., 2006). It allows a refined study of plot and texture of the magnetic field. In the image, linear signatures are more expressive and facilitate the demarcation of associated magnetic units and structures.

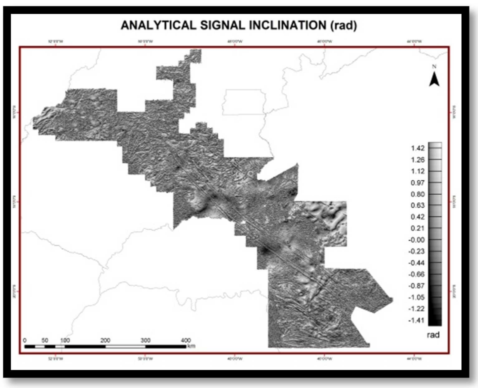

Figure 9 – Analytical signal inclination image.

Euler solutions maps for index 1 (dykes and sills) and 2 (pipes – Geosoft, 2009) were generated from the anomalous magnetic field with the aim of enhancing anomalies with those formats and estimating depths of magnetic sources. The best response to bot solutions index, 1 and 2, was with window size 7 and tolerance of 10%. The higher tolerance and lower the window, the greater the number of calculated occurrences (Teixeira *et al*., 2006). In maps of structural index 1, linear features were enhanced. The greatest depths calculated for this index were around 4,200 m. As seen in Figure 10a, linear magnetic features mainly correspond to the colors orange and yellow, whose depths are ranging up to about 850 m. From these estimates, it was generated a map using only solutions whose depths were estimated between 2 and 850 m (Fig. 10b). The map of structural index 2 is mostly recommended for the analysis of cylindrical signatures, as is the case of intrusive bodies occurring in the area. The results were well satisfactory, not only for these structures, but also for linear signatures. The greatest depths founded for this index were around 6,300 m (Fig. 11a). In the areas where intrusive bodies signatures were enhanced, the estimated depth was between 46 and 1,600 m (Fig. 11b).

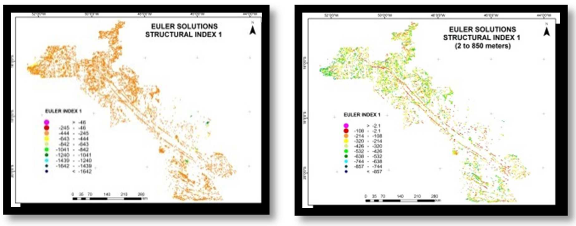

Figure 10a – Map of Euler solution (index 1). Figure 10b – Map of Euler solutions (index 1) for depths around 850 m.

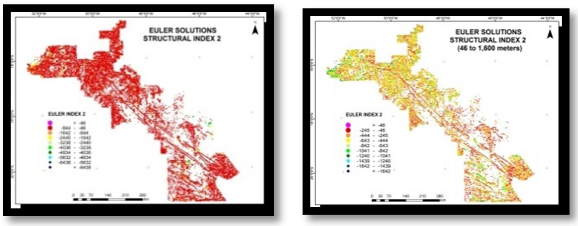

Figure 11a – Map of Euler solution (index 2). Figure 11b – Map of Euler solutions (index 2) for depths around 1,600 m.

The radially averaged power spectrum (Fig. 12) reinforces the information given by the Euler solutions. The significant signals continue until approximately the critical wavelength 0.9 km^{-1}, being dominated by noises for wavelength larger than this. This represents the highest spatial frequency valid for the sampling. The Nyquist wave number of the sampling is about 1.8 km^{-1}, which corresponds to a wavelength of 0.5 km. Therefore, only the anomalies with signatures with dimensions greater than this value are significant. The spectrum shows that there are, at least, three main magnetic sources families related to the depths in which they can be found. The representative group of deeper sources has depths around 9 km. The intermediate group is located in a zone of medium depths about 4 km and the shallower magnetic sources group is in order of 1 km.

The integration and analysis of magnetic images enabled the interpretation of regional magnetic lineaments in the study area (Fig. 13). These lineaments are almost straight and have a NW-SE trend.

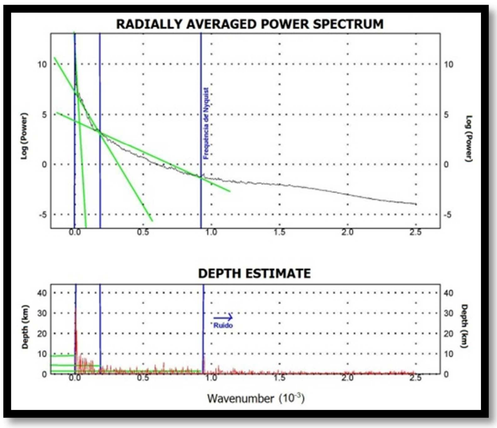

Figure 12 – Radially averaged power spectrum.

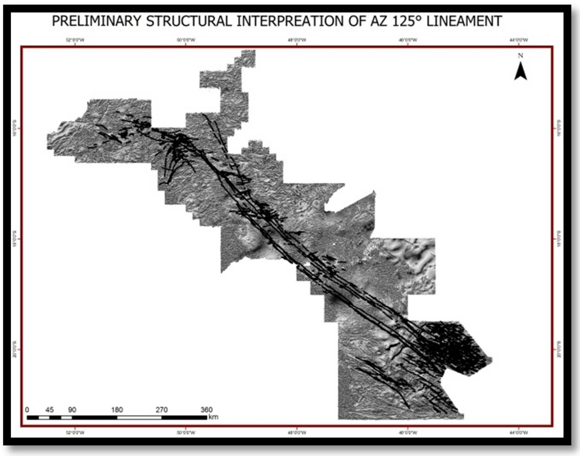

Figure 13 – Preliminary structural interpretation of Az 125° Lineament.

Magnetic lineaments were preliminarily interpreted in the region of Araxá and Tapira plutonic complexes (carbonatites – Fig. 14). It is possible to interpret that the lineaments that surround the carbonatite bodies usually have a radial pattern. Many other directions are observed, however, the lineaments are strongly enhanced in NW-SE direction.

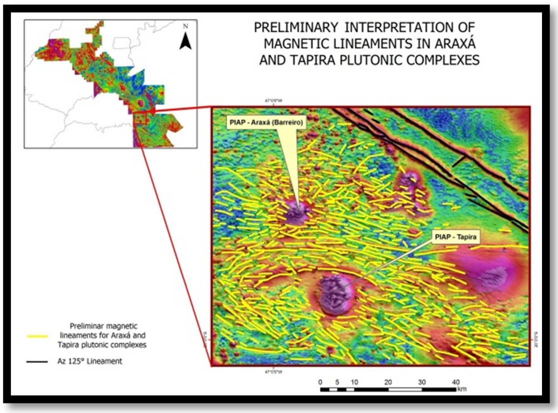

Figure 14 – Preliminary interpretation of magnetic lineaments in Araxá and Tapira plutonic complexes region.

Discussion

There is a strong correlation between plumes tracks and occurrence of kimberlites and carbonatites (Bell, 2001). This seems to be what occurs along the Az 125° Lineament in Brazil. The Az 125° Lineament may be the result of a hot spot track with rectilinear local elevation sequenced by mantle rocks generally contaminated type EMI (Enriched Mantle I). A more detailed correlation with a hot spot track, considered the Trindade hot spot, which began about 120 My (Crough *et al*., 1980) is mister. Magnetic method proposed applied to the study of the central segment of Az 125° Lineament, which crosses distinct geotectonic regions – Tocantins Province, São Francisco Craton, and Transbrasiliano Lineaments (Araújo Filho *et al*., 2010) – will certainly give new ideas to this ongoing research.

Conclusions

The processing of magnetic airborne data provided to generate several geophysical products. The integration and analysis of them in the form of images allowed the study and interpretation of geotectonic context of the area, permitting the creation of a magnetic model.

Regionally, magnetic lineaments almost rectilinear in NW-SE direction were drawn, which spatially correspond to Az 125° Lineament. Magnetic signatures with circular and oval shapes are observed along these lineaments and are associated with intrusive bodies already mapped in the region.

The radially averaged power spectrum and Euler solutions data provided significant information, and showed that the deepest magnetic sources families are about 9 km deep.

Acknowledgments

The authors thank SIC/SGM-GO, CPRM, and SEME/CODEMIG by assignment of the airborne geophysical data. The first author especially thank CAPES – Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, for the Ph.D. scholarship.

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