Revista Brasileira de Geofísica
RBGf
Brazilian Journal of Geophysics

Revista Brasileira de Geofísica (2012) 30(4): 445-458

ISSN 0102-261X
www.scielo.br/rbg

MAGNETOMETRIC AND GAMMA SPECTROMETRIC EXPRESSION OF SOUTHWESTERN SÃO FRANCISCO BASIN, SERRA SELADA QUADRANGLE (1:100.000), MINAS GERAIS STATE

Humberto Luis Siqueira Reis[1,2,3], Maria Sílvia Carvalho Barbosa[1], Fernando Flecha de Alkmim[1] and Antonio Carlos Pedrosa Soares[3]

Recebido em 19 janeiro, 2011 / Aceito em 6 dezembro, 2011
Received on January 19, 2011 / Accepted on December 6, 2011

ABSTRACT. Located in the southwestern portion of São Francisco Basin, the region covered by the Serra Selada quadrangle (1:100.000) contains deformed rocks of the Neoproterozoic Bambuí Group, unconformably overlain by Cretaceous sedimentary and volcaniclastic rocks of the Areado and Mata da Corda groups, respectively. The aerogeophysical data shows two main magnetometric domains. A low frequency anomalies domain is apparently related to deep structures of Precambrian basement. High frequency anomalies represent the volcaniclastic/epiclastic deposits of Mata da Corda Group. The Bambuí Group exhibits intermediate-to-high K and Th contents (1 to 3% and 10 to 16 ppm, respectively), while U-levels are around 2.5 ppm. Significant changes in these values are caused by the distribution of rock types, tectonic features and hydrocarbon exudations. Areado Group sediments show low K (<1 %), low Th (<10 ppm) and low U (<2 ppm). Mata da Corda Group successions and associated covers exhibit very low K (sub-traces), and high Th and U concentrations (>20 ppm and >3 ppm, respectively). These values seem to be strikingly influenced by weathering processes. The performed analyses confirm the applicability of aerogeophysical data in geological mapping, and represents an important tool for the study of both the tectonic scenario and hydrocarbon accumulations in southwestern São Francisco Basin.

Keywords: magnetometry, gamma-ray spectrometry, Serra Selada Quadrangle, São Francisco Basin.

RESUMO. Localizada na porção sudoeste da Bacia do São Francisco, a área abrangida pela Folha Serra Selada (1:100.000) contém rochas sedimentares deformadas do Grupo Bambuí (Neoproterozoico), localmente recobertas, em pronunciada discordância, pelos sedimentos e depósitos vulcanoclásticos/epiclásticos cretáceos dos grupos Areado e Mata da Corda, respectivamente. Os dados aerogeofísicos mostram dois domínios magnetométricos principais. Um deles é caracterizado por anomalias de baixa frequência (ABF), aparentemente relacionadas a estruturas do embasamento pré-cambriano local. O outro é marcado por anomalias de alta frequência (AAF), representando os depósitos vulconoclásticos/epiclásticos do Grupo Mata da Corda. O Grupo Bambuí exibe teores de K e Th intermediários a altos (1 a 3% e 10 a 16 ppm, respectivamente), enquanto os teores de U giram em torno de 2,5 ppm. Esse dados mostram algumas variações, geralmente influenciadas pela distribuição dos diferentes litotipos, feições estruturais e ocorrência de emanações de hidrocarbonetos. Os sedimentos do Grupo Areado, por sua vez, mostram baixos conteúdos de K, Th e U (<1%, <10 ppm e <2 ppm, respectivamente). As rochas do Grupo Mata da Corda e coberturas associadas têm teores muito baixos de K (subtraços) e altas concentrações de Th e U (>20 ppm e >3 ppm, respectivamente). Estes valores parecem sofrer grande influência dos processos de intemperismo. As análises realizadas confirmam a grande aplicabilidade dos levantamentos aerogeofísicos no mapeamento geológico e constituem excelentes ferramentas no entendimento do cenário tectônico e dos depósitos de hidrocarbonetos da região sudoeste da Bacia do São Francisco.

Palavras-chave: magnetometria, gamaespectrometria, Folha Serra Selada, Bacia do São Francisco.

[1]Departamento de Geologia, Escola de Minas, Universidade Federal de Ouro Preto (UFOP), Secretaria de Pós-graduação, Campus Morro do Cruzeiro, 35400-000 Ouro Preto, MG, Brasil. Phone: +55(31) 3559-1602 – E-mails: humbertosiqueira@gmail.com; mscbarbosa@gmail.com; ffalkmim@gmail.com

[2]Petra Energia S/A, Alameda Oscar Niemeyer, 119 (15° andar), Vila da Serra, 34000-000 Nova Lima, MG, Brazil. Phone/Fax: +55(31) 3323-8888 – E-mail: hr@petraenergia.com.br

[3]Centro de Pesquisas Professor Manoel Teixeira da Costa (CPMTC), Universidade Federal de Minas Gerais (UFMG), Avenida Presidente Antonio Carlos, 6627, Pampulha, 31270-901 Belo Horizonte, MG, Brasil. Phone: +55(31) 3409-4450; Fax: +55(31) 3409-4440 – E-mail: pedrosasoares@gmail.com

INTRODUCTION

São Francisco Basin practically occupies the entire meridional oriented portion of the homonymous craton, comprising an area around 400.000 km^2 in the states of Minas Gerais, Goiás and Bahia (Alkmim & Martins-Neto, 2001) (Fig. 1). Its west, northwest and east limits coincide with the craton limits, whereas its south limit has an erosive nature. The northeastern limit, along Setentrional Serra do Espinhaço, borders the Paramirim Corridor, that corresponds to an intracratonic deformation zone (Alkmim et al., 1993). Located in the southwest portion of the basin, in Minas Gerais, Serra Selada Quadrangle (1:100.000) is delimited by the geographical coordinates 45°30'-46°00'W and 18°30'-19°00'S, and covers an area of approximately 3.000 km^2. The quadrangle comprises part of Patos de Minas, Três Marias and Paracatu micro-regions, and it can be accessed from Belo Horizonte by BR262 highway (300 km) as well as BR040 highway (250 km) (Fig. 1).

The first detailed studies in the Serra Selada quadrangle were carried out by PETROBRAS and METAMIG (included today in CODEMIG), between the 60s and 80s decades, mainly focusing the prospecting of gaseous hydrocarbons (Fugita & Clark F, 2001; Araújo, 1988 *apud* Pinto et al., 2001). The achieved discoveries subsequently aroused the development of regional recognition works, including geophysical and geochemical surveys. In parallel, also in the 70s decade, geologic mapping campaigns were developed at a scale of 1:250.000. They covered the entire region of Três Marias (Menezes-Filho et al., 1977). In 2003 again, surface geological surveys at scales of 1:250.000 and 1:100.000 were performed in a large part of São Francisco Basin (e.g.: Signorelli et al., 2003). Recently, the area was covered by the mapping survey of Alto Paranaíba Project (Pedrosa-Soares et al., 2011), and corresponds to one of the exploratory blocks conceded by the Brazilian National Petroleum Agency (ANP) to the ORTENG / CODEMIG / IMETAME / CEMIG / Sipet / Agropastoril consortium. Important subsuperficial accumulations of gaseous hydrocarbons have already been found in this region.

The identification of the geophysical patterns and their correlation with geological field data are routine tools to understand the local tectonic-stratigraphic context. In this way, the interpretation of radiometric and potential field information seems to be very useful for both geologic mapping support and identification of targets for mineral and hydrocarbon exploration (e.g.: Menezes et al., 2006; Carneiro & Barbosa, 2008; Matolin et al., 2008).

In this work, aeromagnetometric and aerogammaespectrometric data of Serra Selada Quadrangle region are analyzed, and once integrated, allow the delimiting of different lithological packages, as well as the recognition of structures and magnetic bodies, either cropping out or buried. Since they show a good correlation with the geological data obtained on surface, these surveys are important to individualize units and discover new geological features.

GEOLOGIC CONTEXT

São Francisco Basin (Fig. 1) covers the meridional sector of the homonymous craton (Almeida, 1977). Stratigraphically, contains records successive basinal cycles younger than 1,8 Ga (Alkmim & Martins-Neto, 2001), which include Precambrian deposits, partially deformed and metamorphosed, to undeformed, Permocarboniferous and Cretaceous sequences and associated covers (e.g.: Dardenne, 1981; Campos & Dardenne, 1997a; 1997b).

The Precambrian deposits are distributed along four distinct structural compartments in São Francisco Basin (Alkmim et al., 1993). Three of them are deformed and show structures with centripetal vergency. They occupy the east, west and northwest boundaries of the basin, and they represent the intracratonic expression of the Araçuaí, Brasília and Riacho do Pontal belts, respectively. On the other hand, along the central sector, such sediments are little-deformed to non-deformed.

SERRA SELADA QUADRANGLE GEOLOGY

In this area there are Neoproterozoic deposits of the Bambuí Group, sediments of the Areado Group and volcanic rocks of the Mata da Corda Group, both Cretaceous in age, and Cenozoic covers (Reis, 2011).

Bambuí Group

The Bambuí Group presents a maximum outcropping thickness of ca. 1200 m, represented at the surface by Lagoa do Jacaré, Serra da Saudade and Três Marias formations (Fig. 2).

Lagoa do Jacaré formation is characterized by a succession of grayish carbonates with some contribution of marls and terrigenous fractions. Laminated/stratified calcilutites and fine-grained calcarenites are the main lithologies, with local contributions of rudites and siltstones. The formation occurs in the western area, showing N-S oriented bodies tectonically inverted over the sediments of Serra da Saudade Formation.

Serra da Saudade Formation, which mostly occurs in Serra Selada Quadrangle, is mainly composed by grey to greenish siltstones/sandstones and claystones (the green ones known as *verdetes*), with plane-parallel lamination/stratification. Marls and calcarenites, sometimes containing oolitic fractions and through

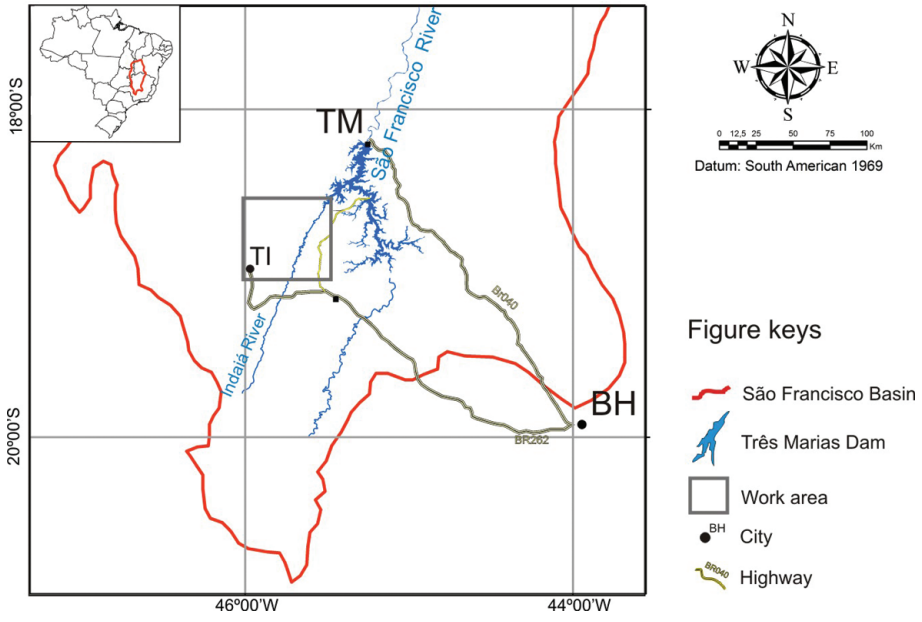

Figure 1 – Location map of Serra Selada Quadrangle (1:100.000) in the São Francisco Basin, showing the main highway access from Belo Horizonte, as well as the main local cities (BH: Belo Horizonte, TM: Três Marias and TI: Tiros).

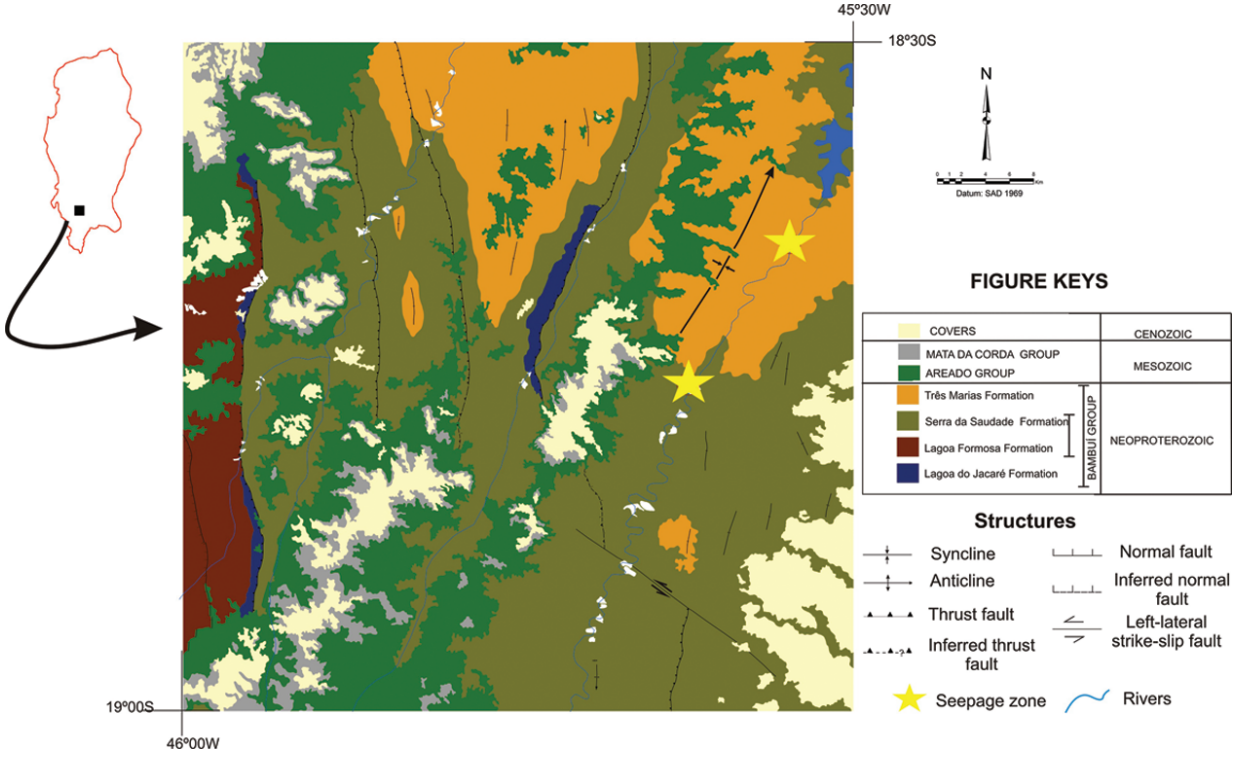

Figure 2 – Simplified geological map of Serra Selada Quadrangle (1:100.000), modified after Reis (2010).

cross-bedding structures, are also described. Towards the top, the psamitic contribution increases significantly, with common intercalations of metric quartz-sandstone beds or centimetric sandy lenses with hummocky cross-bedding structures.

Lagoa Formosa Formation, in turn, is composed by laminated siltstones and claystones associated, to the west, with mono to polymitic diamictites. Apparently, these deposits are correlated to Serra da Saudade Formation units.

Três Marias Formation lays gradationally over Serra da Saudade Formation sediments. It is composed by micaceous fine-grained sandstones, arcosean sandstones, arkoses and claystones. It presents plane-parallel strata, planar cross-stratifications, hummocky structures, ripple marks, load structures wave cross-bedding.

Sub-surface and field survey data indicates two structural domains for Neoproterozoic Bambuí rocks in the area of Serra Selada Quadrangle: to the west, a sector where the rocks are deformed; to the east, a compartment where the deposits were not affected by compressional deformation. In the first, the Bambuí lithotypes are involved in a fold-and-thrust belt with a general N-S direction. Synclinoria and anticlinoria with hinges pending to N and NNE are delimited by large inverse faults, like the Galena and Rio Borrachudo faults, besides others with smaller throw (Fig. 2). Such faults coupled to a large detachment zone located in the base of Bambuí Group (Coelho et al., 2005; Coelho, 2007). In the undeformed domain, northeast sector (and extreme E) of the area, deposits from Upper Bambuí Group are horizontal, with scarce gentle to open folds, as well as isolated kink bands.

Areado and Mata da Corda Groups

Overlaying the Precambrian sediments, above a prominent angular and erosive unconformity, there are Cretaceous deposits of the Areado Group (Campos & Dardenne, 1997a; Sgarbi et al., 2001; Sgarbi, 2011a). In the domains of Serra Selada Quadrangle, the Areado Group consists mainly of aeolian sandstones, associated to fluvio-deltaic (?) (clast-supported conglomerates and poorly sorted sandstones) and lacustrine (mudstone and lithic sandstones with carbonate matrix) deposits.

The volcanoclastic and sedimentary rocks of Mata da Corda Group lays over the Areado Group. They are represented by cineritic tuffs, lapilli tuffs, agglomerates, volcanic breccia (locally), and also conglomerates and epiclastic sandstones. Its basal contact with Areado Group has an angular and erosive nature, directly related to the beginning of an important alkaline magmatic event that affected a large part of Central Brazil in Upper Cretaceous and constitutes the Minas-Goiás Alkaline Province (Sgarbi & Gaspar, 2001 *apud* Sgarbi et al., 2001).

Both Cretaceous units are regionally undeformed, exhibiting, however, local diastrophic structures. In a basin sense, they constitute the Barremian-Maastrichtian fill of the Sanfranciscana Basin, as defined by Campos & Dardenne (1997a; 1997b).

METHODOLOGY

The geophysical data used in this work were provided by Companhia de Desenvolvimento de Minas Gerais (CODEMIG) and are part of Minas Gerais State Aerogeophysics Survey Program – 2005/2006. Serra Selada Quadrangle is included in Area 9 of this survey (João Pinheiro-Presidente Olegário-Tiros), which comprises Biquinhas, Carmo do Paranaíba, Cedro do Abaeté, João Pinheiro, Lagoa Formosa, Morada Nova de Minas, Paineiras, Patos de Minas, Presidente Olegário, São Gonçalo do Abaeté, Tiros and Varjão de Minas counties (Fig. 3).

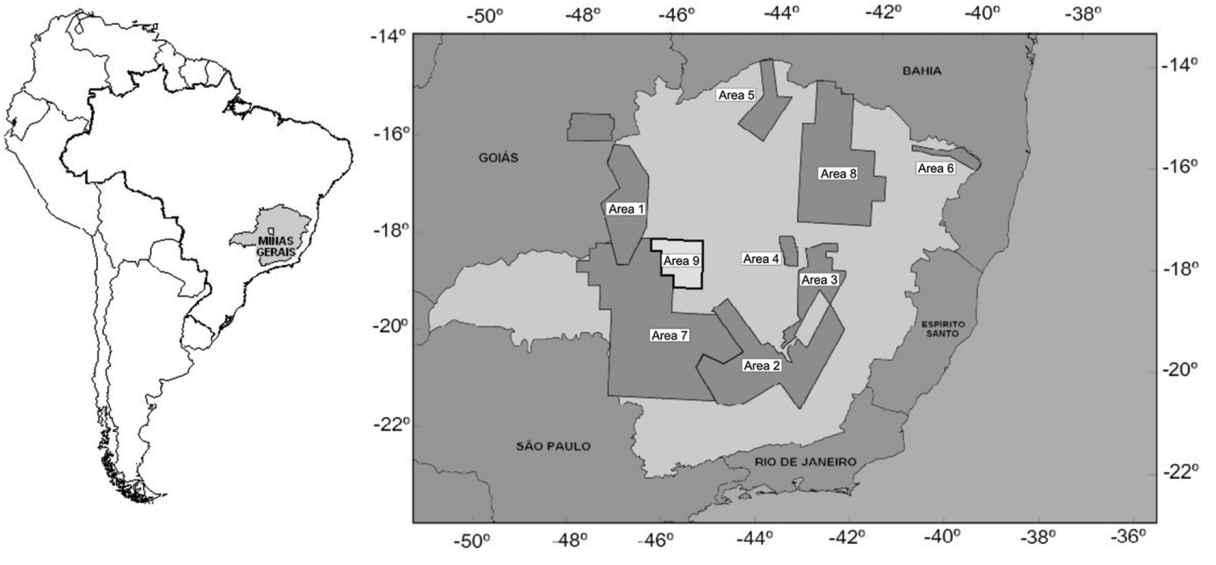

Figure 3 – Area 9 location, Aerogeophysical Survey Program of Minas Gerais State (2005/2006). Source: Lasa (2007).

The main parameters of data acquisition were (Lasa, 2007):

- Flight line direction: N-S;
- Flight line spacing: 0.4 km;
- Control line direction: E-W;
- Control line spacing: 8.0 km;
- Interval between the consecutive geophysical measurements: 0.10s (magnetometer) and 1.0s (gamma-ray spectrometer);
- Average flight height: 100 m;
- Approximate flight speed: 270 km/h.

The Anomalous Magnetic Field Map, Vertical Gradient (first-order) of the Anomalous Field Map, Residual Field Map and Analytical Signal Amplitude Map, as well as the gamma-ray spectrometry maps in K, Th and K channels and ternary image mage were generated, using the Oasis montaj® software (GEOSOFT) (Fig. 4).

RESULTS

Magnetometry

From the Anomalous Magnetic Field Map (IGRF – International Geomagnetic Reference Field-removed), it is possible to distinguish two domains, one that is composed by high frequency anomalies (HFA) and another one that is characterized by low frequency anomalies (LFA; Fig. 5). Considering the frequency/depth relation of the magnetic anomalies, it can be inferred that they are shallow and deep anomalies, respectively. The deeper anomalies should correspond to the response of the basement and constitute the local magnetometric background.

In both domains, magnetometric lineaments are observed oriented preferentially in the NE direction, but in the high frequency domain, a larger contribution of ENE lineaments is observed locally (Fig. 5). It is important to note that in the center-southern part of the quadrangle, as well as in its NNE part, there are marked anomalies with ENE to E-W direction, respectively, in the LFA Domain. Due to the different polarization, it can be deduced that the magnetization occurred in distinct moments for each domain. Also in Figure 5, it is possible to identify a NW-trending and well-marked lineament in the NE and SE quadrants. Apparently, this lineament is younger than the LFA Domain anomalies and older than the HFA Domain anomalies.

As the high frequency anomalies were highlighted in Vertical Gradient (first-order) and Residual of the Anomalous Magnetic Field maps (Figs. 6 and 7), they are likely related to shallow bodies. On the other hand, the low frequency anomalies corre-

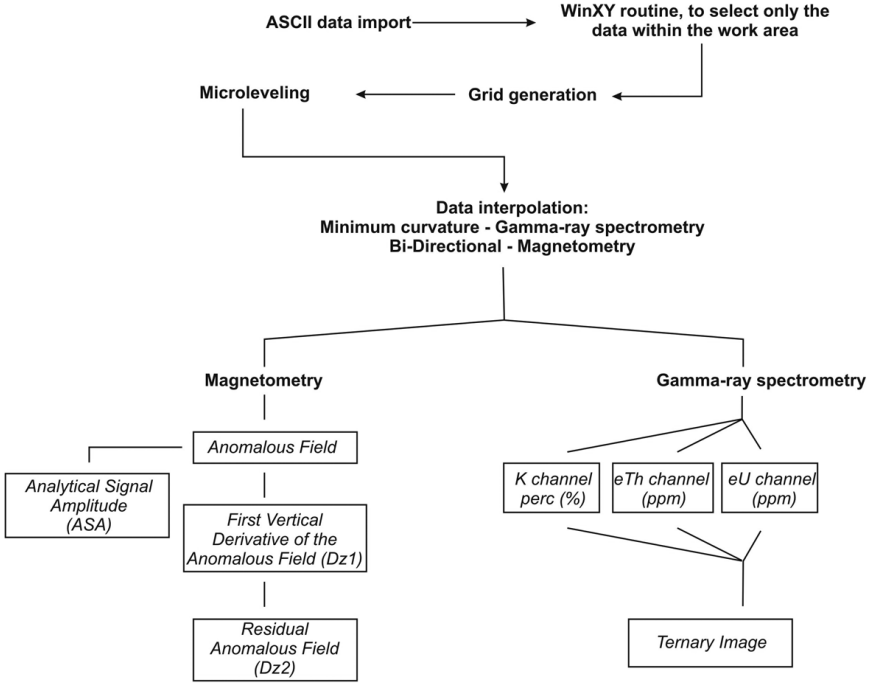

Figure 4 – Flowchart of the aeromagnetometric and aerogamma-ray spectrometry data processing in the creation of geophysical maps of Serra Selada Quadrangle (1:100.000).

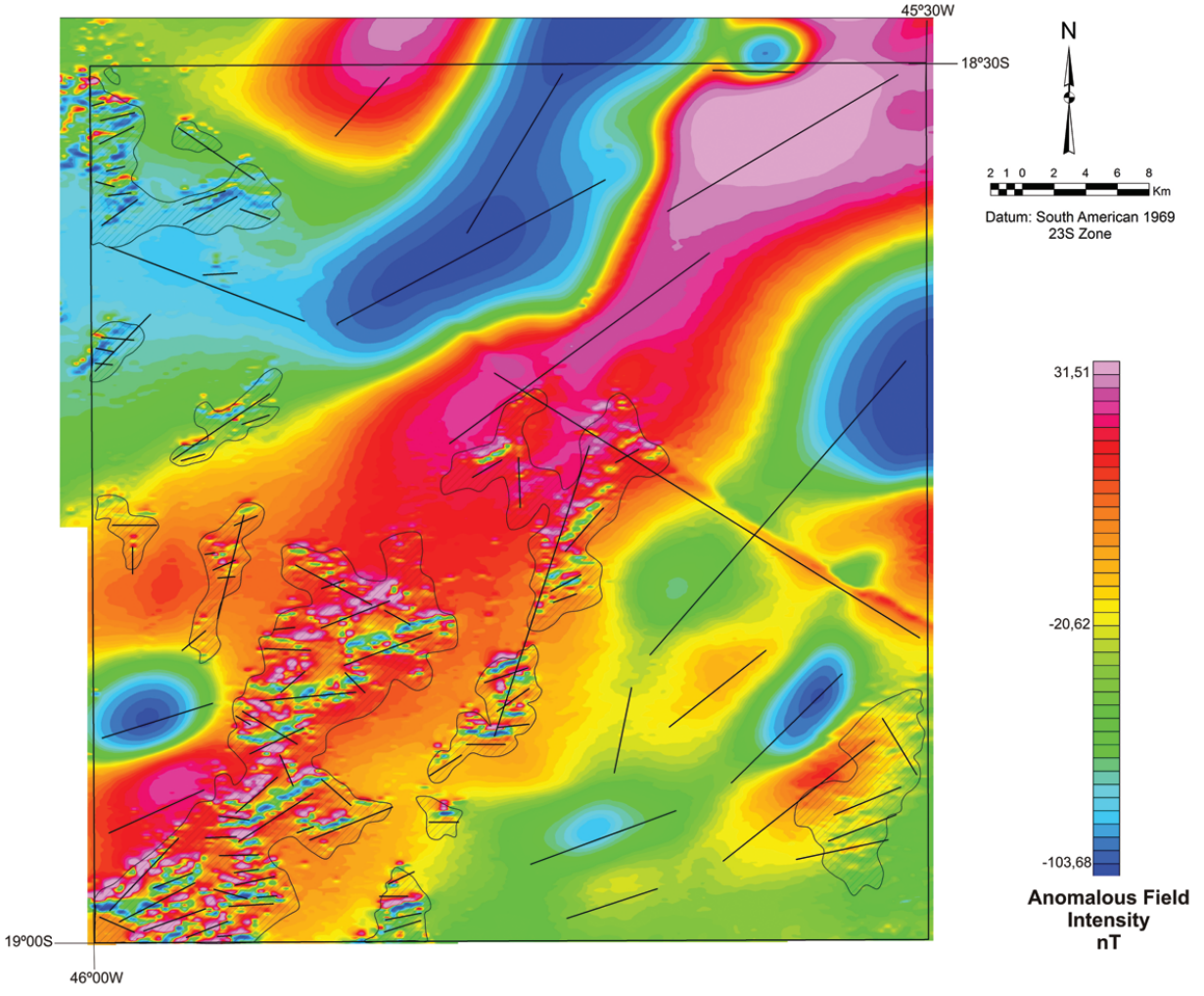

Figure 5 – Anomalous Magnetic Field Map (IGRF removed) of Serra Selada Quadrangle (1:100.000). The hachured areas correspond to high frequency anomalies; the other areas correspond to domains of low frequency anomalies (magnetometric background). The black traces correspond to interpreted magnetic lineaments.

spond to deeper bodies, and were suppressed in the data filtering. In the Residual Magnetic Field Map (Fig. 7), it is also possible to observe anomalies oriented according to the main drainages that intersect the mapped area, as well as the low relative depth of the NW-trending anomalous source. It is important to remember that filters applied in vertical gradient magnetometric maps are appropriate to highlight shallow sources, without necessarily altering the polarity of the magnetic anomalies (Carneiro & Barbosa, 2008).

In field, the high frequency domain (HFA) is related to the volcanic/volcanoclastic and epiclastic units of Mata da Corda Group, which exhibit considerable quantities of Ti-magnetite (Sgarbi, 2011b), thus explaining its geophysical behavior. The subtler high frequency anomalies in the SE region of the quadrangle correspond to a lateritic cover, associated to Neoproterozoic fine-grained rocks.

The low frequency domain (LFA), however, seems to reflect, in large part, the basement behavior, since the Bambuí Group sediments as well as the Areado Group deposits do not present significant quantities of ferromagnetic minerals. Thus, the large dipoles NE oriented in the northeast and center-north portions of the quadrangle would represent basement highs and lows, respectively. Such hypothesis is in accordance with interpreted seismic sections and structures observed on surface (Reis et al., 2010).

The NW oriented anomaly, persistent in large part of the quadrangle, may represent unexposed mafic dike. Similar dikes

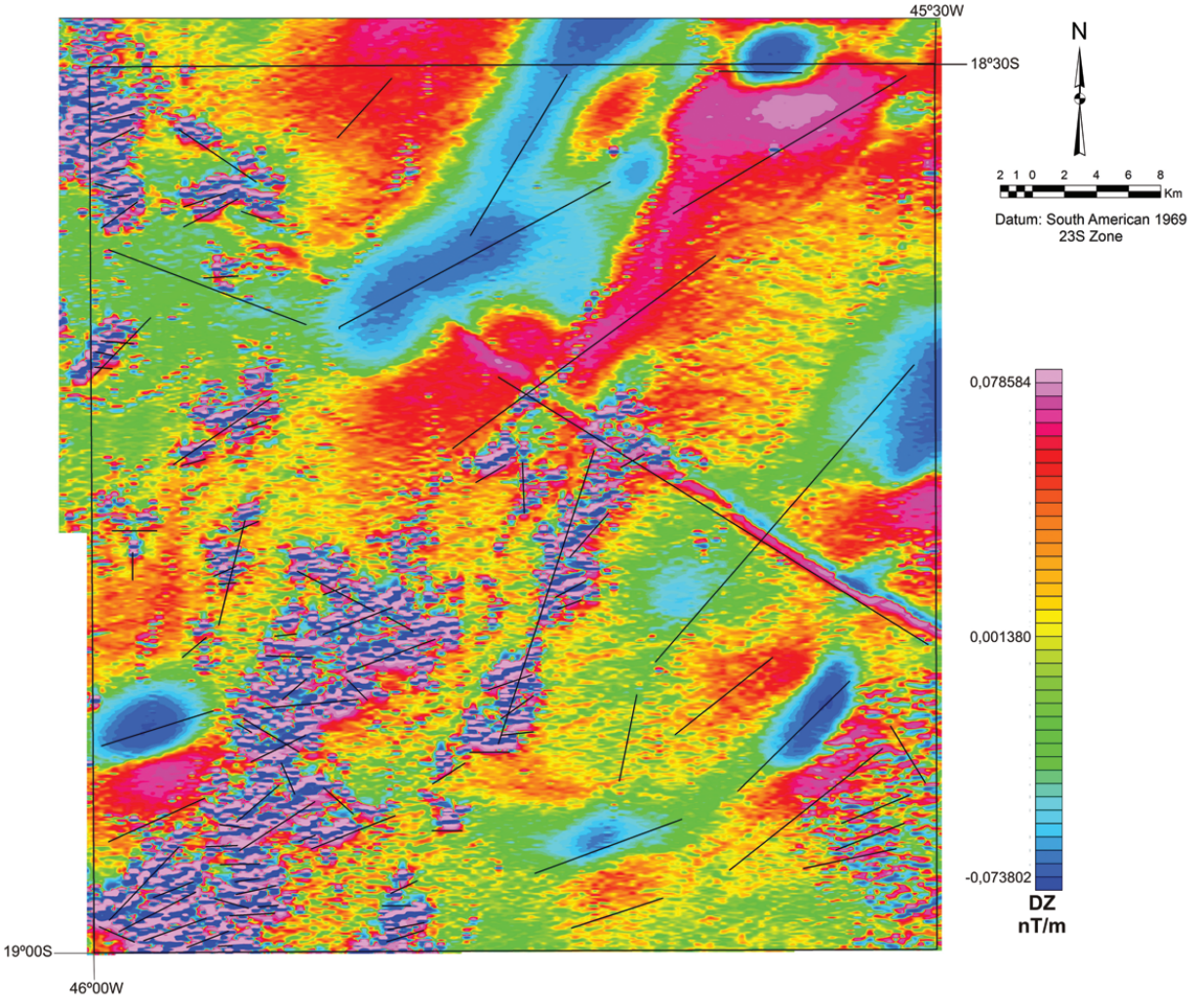

Figure 6 – First Vertical Derivative of the Anomalous Field Map, Serra Selada Quadrangle (1:100.000). The black traces correspond to interpreted magnetic lineaments.

were described along the meridional portion of São Francisco Basin and belong to families of NW-trending magnetic lineaments. Carneiro & Oliveira (2005 in Carneiro & Barbosa, 2008) obtained $^{39}Ar/^{40}Ar$ ages equal to 1,7 Ga for such magmatism, suggesting a relation with the Estaterian rifting events described in the adjacent belts of the São Francisco Craton (e.g.: Knauer, 2007; Valeriano et al., 2004).

Thus, considering the Analytical Signal Amplitude Map (Fig. 8) it is possible to delimit the main outcropping magnetic bodies of Mata da Corda Group and associated eluvial covers, as well as demarcate the main lateritic-detritic covers distributed in the SE and E regions of the quadrangle. On the other hand, the Residual Field Map may indicate superficial concentrations of ferromagnetic minerals along the main drainage axes (Fig. 7). Considering the occurrence of diamantiferous placers along the Abaeté, Borrachudo and Indaiá rivers, some of these ferromagnetic minerals would constitute important indicators for the diamond prospecting.

Gamma-ray spectrometry

The gamma-ray spectrometry data exhibit, in general, three large domain, which are directly related to the three main outcropping geological units: Bambuí, Areado and Mata da Corda groups (and respective Cenozoic covers) (Fig. 9). For this reason, the domains will be described here according to the units they represent and will be analyzed using a relative scale (from low to high) of values recorded in the limits of the work area.

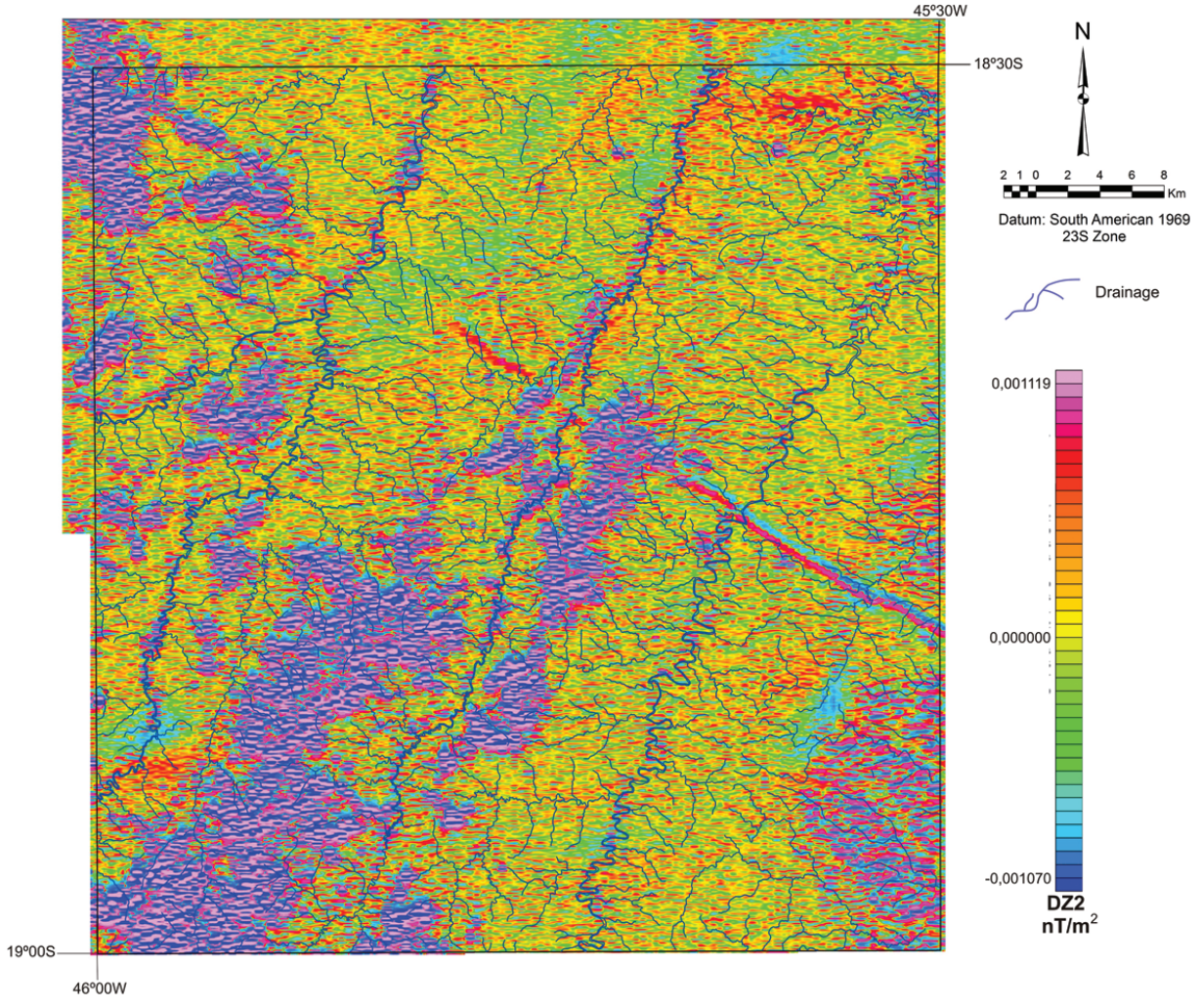

Figure 7 – Anomalous Residual Field Map, Serra Selada Quadrangle (1:100.000). Superficial anomalous bodies are distributed in topographically elevated regions, in the W and central portions of the quadrangle, as well as along the main drainage axes. These propably correspond to magnetic mineral concentrations in alluvial sediments.

Bambuí Group

It presents intermediate to high K contents (between 1 and 3%). Based on field data, it is concluded that the highs are mainly related to the lithotypes of Três Marias Formation (specially arkose and arcosean sandstone) and to the mudstones of the Lagoa Formosa and Serra da Saudade formations. Such concentration can be explained by the presence of feldspar in the arcosean packages, as well as potassium adsorption capacity of potassium by clay minerals. The green mudstones and fine-grained sandstones (*verdetes*) of Serra da Saudade Formation represent important potassium sources, as they are rich in glauconite minerals (Lima et al., 2007). Therefore, they correspond to remarkable features on gamma-ray spectrometry map – K Channel (Fig. 9).

The Bambuí Group exhibits, in Serra Selada Quadrangle, medium to high Th contents, which vary from 10 to 16 ppm. Its units exhibit higher concentrations in the center-north, east and northeast regions of the quadrangle, where they are related to arcosean sandstones and arkoses of Três Marias Formation. More elevated contents, located in the center-south portion of the quadrangle, can be related to the upper sandstones of Serra da Saudade Formation (Fig. 9). The largest concentrations in the SE and E regions (around 20 ppm) are directly associated to the lateritic covers, commonly related to the undeformed fine-grained deposits of Bambuí Group. In this case, its relative concentration could be explained by the extreme immobility of thorium during weathering processes. Once associated to heavy minerals like monazite and zircon, the high relative values of Th the psamitic

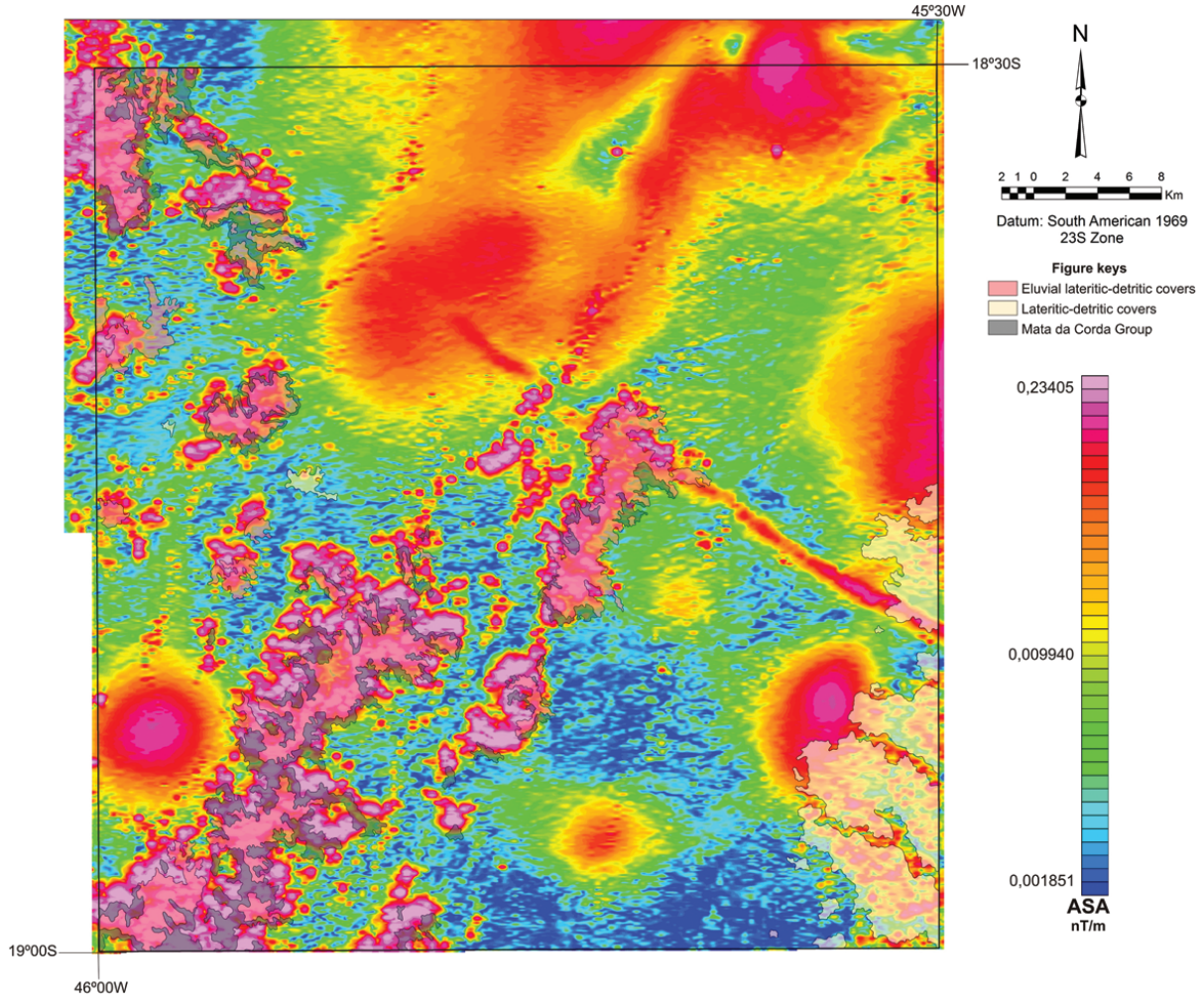

Figure 8 – Superimposition of the Analytical Signal Amplitude Map and the main outcropping magnetic units (compiled from field data), Serra Selada Quadrangle (1:100.000).

fractions may be directly related to a larger concentration of these minerals in sandstones.

On U-Channel, the Neoproterozoic deposits show intermediate values (around 2,5 ppm), with greater contents (>3,5 ppm) associated to the lateritic covers of southeast and east portions of quadrangle. Similarly to Th, the uranium is relatively immobile during weathering processes, which explains its higher concentration on these deposits.

In general, carbonate rocks exhibit lower K and Th contents.

Important NNE to NNW trending lineaments can be delineated by the K and Th channels. They correspond to remarkable structures on Geocover-Landsat image and trend parallel to metric/decametric fold hinges and other associated fracture systems, which are typical of the western deformed compartment. Extensive K and Th highs along the Rio Borrachudo valley and in the west part of quadrangle represent important thrust faults that only affect the Neoproterozoic deposits. Apparently, this elevated concentration can be the result of hydrothermal fluid percolation and the consequent illitization of clays along the faults and respective damage surfaces. In a similar way, the elevated thorium and potassium content, denoting NE oriented lineament in the eastern sector (Fig. 9), may correspond to the surface expression of the Traçadal Fault, which is not mapped in the Serra Selada Quadrangle limits.

It is also necessary to highlight the existence of elevated K contents in the extreme northeast of the quadrangle (around 3%, Três Marias Dam region). Taking into account the occurrence of important natural gas seeps and subsuperficial accumulations in the region, as well as in other areas, these "anomalous" concentrations may be related to the potassium leaching

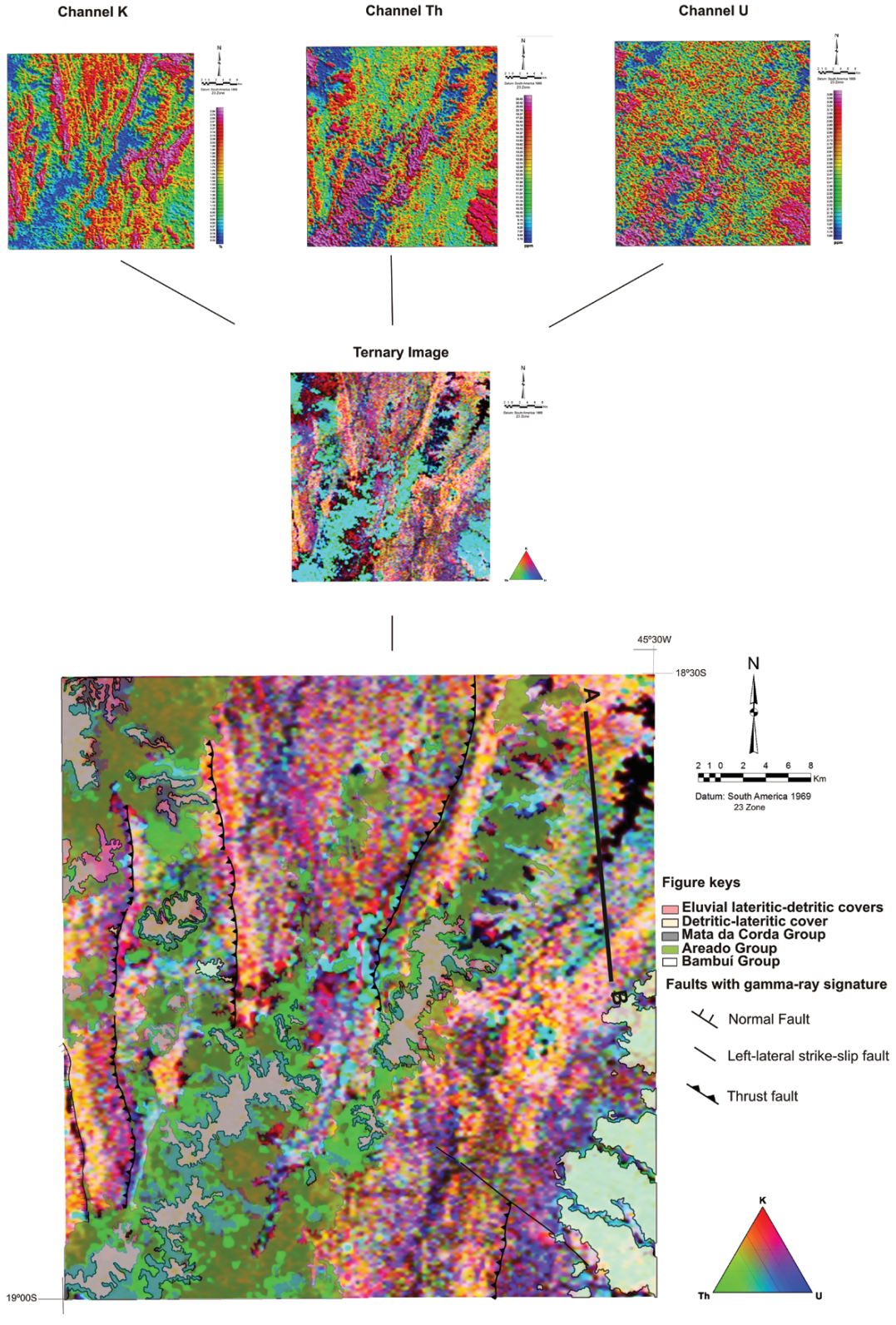

Figure 9 – Aerogamma-ray spectrometry in K, Th and U channels in Serra Selada Quadrangle area (1.100.000). The traces of the main mapped faults and lithostratigraphic units (Bambuí, Areado and Mata da Corda groups) were placed over the ternary image. Expressive potassium highs, locally, set the limits of the verdete bodies that mainly occur in the southeast portion of the quadrangle.

and reconcentration (Fig. 10). The meteoric water acidification, promoted by compounds like carbon dioxide that are present in hydrocarbon systems, would be one of the main agents responsible for the element transport (Matolin et al., 2008). Potassium ions are extremely mobile and seem to be highly soluble at pH lower than 7.

Table 1 summarizes the main outcropping rocks of Bambuí Group and their aerogamma-ray spectromety responses.

Areado Group

In general, the outcropping rocks and the associated covers of this group exhibit low content of potassium (<1%), low Th (<10 ppm) and low U (<2 ppm). These low values can be explained by the leaching of soluble elements during the weathering (like the case of K), as well as by the original low contents of the sediments. For the first case, it is important to note that these units occur in topographically elevated regions, where intense weathering processes occur.

Mata da Corda Group

The lithotypes and covers related to this unit exhibit a low potassium content (near zero) and high thorium and uranium relative contents (higher than 20 and 3 ppm, respectively). Although being related to magmatic rocks of potassic/ultrapotassic affinity in other points of the basin (Campos & Dardenne, 1997a; Sgarbi, 2011b), the lack of significant quantities of potassium can be directly related to intense weathering and leaching on the top of the plateaus. On the other hand, the elevated contents of thorium and uranium can be explained by the higher natural concentration of these elements in volcanic and/or volcanoclastic units, as well as by their low mobility in relation to the weathering processes.

DISCUSSION AND CONCLUSIONS

In Serra Selada Quadrangle (1:100.000), the Neoproterozoic rocks of Bambuí Group are the main units, being locally covered by sedimentary and volcanoclastic/epiclastic rocks of the Cretaceous Areado and Mata da Corda groups. These lithotypes exhibit distinct magnetometric and gamma-ray spectrometry characteristics, locally strongly influenced by tectonic processes.

The Bambuí Group is marked by low magnetic values. Huge low frequency anomalies (LFA) are related to the substrate and are expressed as NE oriented dipoles in the northeast and center-north sectors of the quadrangle. Subsurface data suggest that these magnetic anomalies correspond to highs and lows of the basement (Reis et al., 2010). Lagoa do Jacaré, Serra da Saudade/Lagoa Formosa and Três Marias Formations rocks exhibit distinct gamma-ray spectrometry patterns (Table 1), of which K and Th concentrations underwent significant redistributions along Neoproterozoic thrust faults. Apparently, the potassium contents seem to show intensive influence of the natural gas accumulations in the NE sector of the quadrangle (Fig. 10). In this way, the redistribution would have been influenced by the action of acids related to hydrocarbon accumulations.

Areado Group sediments exhibit low magnetization and low radionuclide contents. These values result from the rocks composition as well as from the weathering processes acting in more elevated regions, where they occur.

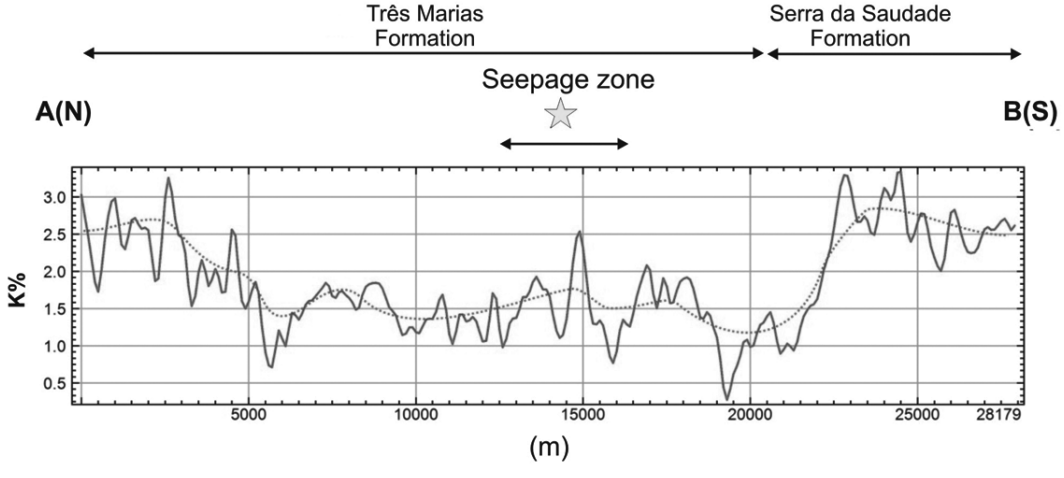

Figure 10 – Potassium contents (K%) along a section (A-B) N-S oriented that intersects the seepage zone of Northeastern Serra Selada Quadrangle. The potassium contents were obtained from the Gamma-ray spectrometry Map – K channel, presented in Figure 9. Locations of the emanation zones and respective sections are in Figures 2 and 9, respectively.

Table 1 – Gamma-ray spectrometry response of the main Bambuí Group lithologies in the area comprised by Serra Selada Quadrangle (1:100.000).

Lithotype	Arkoses, arcosean sandstones	Claystones and Siltstones	Verdetes	Carbonates
Stratigraphic unit	Três Marias and Serra da Saudade	Serra da Saudade, Lagoa Formosa and Três Marias	Serra da Saudade	Lagoa do Jacaré
Response in K channel	High	Intermediate to High	High	Low
Response in Th channel	Intermediate/High	Intermediate	Intermediate	Intermediate/Low
Response in U channel	Intermediate	Intermediate	Intermediate	Intermediate/Low

Mata da Corda Group rocks present relatively elevated magnetometric values due to their high concentration in magnetic minerals. Besides, they exhibit elevated Th and U concentrations (>20 and 3 ppm, respectively), apparently influenced by the relative concentration of these elements during the weathering. Weathering would also be the responsible for the low K concentration on the tops of the plateaus.

The different Cenozoic covers can be easily delimited in Analytical Signal Amplitude maps (lateritic covers; southeast sector of the quadrangle), as well as due to their elevated U and Th concentration (imobile elements during the weathering processes).

The obtained results show the extensive applicability of the magnetometric and aerogamma-ray spetrometry methods to individualize the different lithological units and tectonic structures. In the Serra Selada Quadrangle (1:100.000), the comparison with geological field data (Fig. 2) constituted an important step to understand the tectonic-stratigraphic arrangement of the transition sector between the Western Deformed Domain of São Francisco Basin and the Central Undeformed Domain (sensu Alkmim et al., 1993). Considering the prospective potentiality of the region, such data configure the first steps to delimit the potential accumulation/migration zones of gaseous hydrocarbons. It is important to note that, due to lower cost and recurring success in applying these techniques, the analysis of potential and radiometric geophysical data has been increasingly used for hydrocarbon exploration (e.g.: Nabighian et al., 2005).

ACKNOWLEDGMENTS

The authors would like to thank Companhia de Desenvolvimento Econômico de Minas Gerais (CODEMIG) for financing the field researches and providing the aerogeophysical data, and also Centro de Pesquisa Manoel Teixeira da Costa (CPMTC) for the logistic support and infrastructure. The first author would like to thank Conselho Nacional de Desenvolvimento da Pesquisa (CNPq) for providing the master degree scholarship. F.F. Alkmim and A.C. Pedrosa-Soares would like to thank CNPq for providing the research productivity grant.

REFERENCES

ALKMIM FF, BRITO NEVES BB & CASTRO ALVES JA. 1993. Arcabouço tectônico do Cráton do São Francisco – Uma revisão. In: DOMINGUEZ JML & MISI A (Eds.). O Cráton do São Francisco. Salvador, SBG – Núcleo BA/SE, p. 45–62.

ALKMIM FF & MARINS-NETO MA. 2001. A Bacia Intracratônica do São Francisco: Arcabouço estrutural e cenários evolutivos. In: PINTO CP & MARTINS-NETO MA (Eds.) Bacia do São Francisco: Geologia e Recursos Naturais. SBG/MG, p. 9–30.

Almeida FFM de. 1977. O Cráton do São Francisco. Revista Brasileira de Geociências, 7(4): 349–364.

CAMPOS JEG & DARDENNE MA. 1997a. Estratigrafia e sedimentação da Bacia Sanfranciscana: Uma revisão. Revista Brasileira de Geociências, 21(3): 269–282.

CAMPOS JEG & DARDENNE MA. 1997B. Origem e Evolução da Bacia Sanfranciscana. Revista Brasileira de Geociências, 27(3): 283–294.

CARNEIRO MA & BARBOSA MSC. 2008. Implicações geológicas e tectônicas da interpretação magnetométrica da região de Oliveira, Minas Gerais. Revista Brasileira de Geofísica, 26(1): 87–98.

COELHO JCC, MARTINS-NETO MA & MARINHO MS. 2005. Delimitação da província alóctone da fase thin skinned de deformação na borda oeste da Bacia do São Francisco. In: SBG, III Simpósio Sobre o Cráton do São Francisco, Anais, p. 208–210.

COELHO JCC. 2007. Estilos estruturais e evolução tectônica da borda oeste da Bacia do São Francisco, com base na integração de dados de superfície, sub-superfície, litogeoquímica e isótopos. Master dissertation, DEGEO/Escola de Minas, UFOP, 112 p.

DARDENNE MA. 1981. Os grupos Paranoá e Bambuí na Faixa Dobrada Brasília. In: SBG, Simpósio do Cráton do São Francisco. Salvador, Anais, p. 140–157.

FUGITA AM & CLARK F JG. 2001. Recursos Energéticos da Bacia do São Francisco: Hidrocarbonetos líquidos e gasosos. In: PINTO CP & MARTINS-NETO MA (Eds.) Bacia do São Francisco: Geologia e Recursos Naturais. SBG/MG, p. 265–284.

KNAUER LG. 2007. Supergrupo Espinhaço em Minas Gerais: Considerações sobre sua estratigrafia e seu arranjo estrutural. Geonomos, 15(1): 81–90.

LASA ENGENHARIA E PROSPECÇÕES S.A. 2007. Relatório Final do Levantamento e Processamento dos Dados Magnetométricos e Gama-espectrométricos. Área 9 – João Pinheiro-Presidente Olegário-Tiros. Levantamento Aerogeofísico de Minas Gerais. Secretaria de Estado de Desenvolvimento Econômico de Minas Gerais (SEDE). 121 p.

LIMA ONB, UHLEIN A & BRITTO W. 2007. Estratigrafia do Grupo Bambuí na Serra da Saudade e geologia do depósito fosfático de Cedro do Abaeté, Minas Gerais. Revista Brasileira de Geociências, 37(4-suplemento): 204–215.

MATOLIN M, ABRAHAM M, HANAK J, KASPAREC I & STRANIK Z. 2008. Geochemical and geophysical anomalies at the Zdanice Oil-and Gas Field, SE Czech Republic. Journal of Petroleum Geology, 3(1): 97–108.

MENEZES-FILHO MR, MATTOS GMM & FERRARI PG. 1977. Projeto Três Marias. Relatório final. DNPM/CPRM, 6 vol.

MENEZES P de TL, ROIG HL, SILVA GB & MANE MA. 2006. Prospecção mineral do Grupo Paranoá. Reprocessamento de dados aerogamaespectrométricos e interpretação integrada a imagens TM-LANDSAT 5. Revista Brasileira de Geofísica, 24(3): 343–355.

NABIGHIAN MN, GRAUCH VJS, HANSEN RO, LAFEHR TR, LI Y, PEIRCE JW, PHILLIPS JD & RUDER ME. 2005. 75th Anniversary: The historical development of the magnetic method in exploration. Geophysics, 70(6): 33ND–61ND.

PEDROSA-SOARES AC, NOCE CM, VOLL E, KUCHENBECKER M, REIS HLS & FRAGOSO DGC. 2011. Projeto Alto Paranaíba, Belo Horizonte, CODEMIG, 873 p.

PINTO CP, PINHO JMM & SOUSA HA DE. 2001. Recursos minerais e energéticos da Bacia do São Francisco em Minas Gerais: Uma abordagem regional. In: PINTO CP & MARTINS-NETO MA (Eds.) Bacia do São Francisco: Geologia e Recursos Naturais. SBG/MG, p. 139–160.

REIS HLS. 2011. Folha Serra Selada, SE.23-Y-B-V, escala 1:100.000. In: PEDROSA-SOARES AC, NOCE CM, VOLL E, KUCHENBECKER M, REIS HLS & FRAGOSO DGC (Eds.), Projeto Alto Paranaíba. Belo Horizonte, CODEMIG, p. 736–782.

REIS HLS, ALKMIM FF, PEDROSA-SOARES AC & BARBOSA MSC. 2010. Tectono-stratigraphic context and geophysical expression of hydrocarbon seepage at Três Marias Dam region, São Francisco Basin, Brazil. In: ADIMB, IV Simpósio Brasileiro de Exploração Mineral.

SGARBI GNC. 2011a. Sedimentação do Cretáceo Inferior na Bacia Sanfranciscana: O Grupo Areado. In: PEDROSA-SOARES AC, NOCE CM, VOLL E, KUCHENBECKER M, REIS HLS & FRAGOSO DGC (Eds), Projeto Alto Paranaíba. Belo Horizonte, CODEMIG, p. 68–146.

SGARBI GNC, SGARBI PB DE A, CAMPOS JEG, DARDENNE MA & PENHA UC. 2001. Bacia Sanfranciscana: O registro Fanerozóico da Bacia do São Francisco. In: PINTO CP & MARTINS-NETO MA (Eds.) Bacia do São Francisco: Geologia e Recursos Naturais. SBG/MG, p. 93–138.

SGARBI PBA. 2011b. Magmatismo do Cretáceo na Região Sudoeste da Bacia Sanfranciscana: O Grupo Mata da Corda. In: PEDROSA-SOARES AC, NOCE CM, VOLL E, KUCHENBECKER M, REIS HLS & FRAGOSO DGC (Eds.), Projeto Alto Paranaíba. Belo Horizonte, CODEMIG, p. 147–227.

SIGNORELLI N, TULER MP, SILVA PCS & JUSTO LJEC. 2003. Carta geológica da Folha Três Marias, escala 1:250.000 – SE23Y-B. Projeto São Francisco. CPRM/CODEMIG.

VALERIANO C de M, DARDENNE MA, FONSECA MA, SIMÕES LSA & SEER HJ. 2004. A evolução tectônica da Faixa Brasília. In: MANTESSO-NETO V, BARTORELLI A, CARNEIRO CDR & BRITO-NEVES BB DE (Org.) Geologia do Continente Sul Americano: Evolução da obra de Fernando Flávio Marques de Almeida. Beca, p. 575–592.

NOTES ABOUT THE AUTHORS

Humberto Luis Siqueira Reis. Undergraduate in Geology at Universidade Federal de Minas Gerais (2008) and Master degree in Stratigraphy and Tectonics in Neoproterozoic hydrocarbon systems at Universidade Federal de Ouro Preto (2011). In the last years, has been carrying out works in regional geology/tectonics and geologic mapping. Presently, is member of the post-graduate program in Crustal Evolution and Natural Resources at Universidade Federal de Ouro Preto in partnership with Royal Holloway University of London; Doctorate degree in Structural Geology and Basin Tectonics. Member of the hydrocarbon exploration staff of Petra Energia S/A on the São Francisco Basin and external collaborator of Centro de Pesquisas Professor Manoel Teixeira da Costa (CPMTC-UFMG).

Maria Sílvia Carvalho Barbosa. Undergraduate in Geological Engineering at Universidade Federal de Ouro Preto (1987), Master degree in Crustal Evolution and Natural Resources at Universidade Federal de Ouro Preto (1990), and Doctorate degree in Geophysics at Universidade de São Paulo (1999). Presently is a geophysicist of Fundação Gorceix and associated professor at Universidade Federal de Ouro Preto. Experience in Geoscience, with emphasis in Mathematical Modelling. Main research subjects are: geophysics, geophysical prospecting, potential methods, mathematical modelling and applied geophysics.

Fernando Flecha de Alkmim. Undergraduate in Geological Engineering at Universidade Federal de Ouro Preto (1978); Doctorate degree in Natural Sciences at Clausthal TU, German (1985). Presently is an associate professor of Field Geology, Historical Geology and Geotectonics at Universidade Federal de Ouro Preto. The research area is Structural Geology/Tectonics, dedicated to the study of anatomy and evolution of orogenetic belts.

Antonio Carlos Pedrosa Soares. Undergraduate in Geology at Universidade Federal de Minas Gerais (1979), Master degree in Geology at Universidade de Brasília (1984), and Doctorate degree in Geology at Universidade de Brasília with laboratory internship at Université de Paris VI (1995). Presently is an associate professor of Geology in the undergraduate and post-graduate courses of Instituto de Geociências of Universidade Federal de Minas Gerais. Experience in Geotectonics, Regional Geological Cartography and Economic Geology, acting mainly in Araçuaí Belt/Orogen (correlations and non-metallic mineral deposits), as well as in the geotectonics of Precambrian orogens.