Magnetic-structural framework and gamma-ray spectrometry of Brusque region, Santa Catarina State, Southern Brazil

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This paper was prepared for presentation during the 15th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, 31 July to 3 August, 2017.

Abstract

Gamma-ray spectrometric and magnetic maps – including a structural-magnetic framework - were generated with the purpose of verify its implications for Precambrian geology of Brusque region, eastern Santa Catarina State, south of Brazil. The study area is predominantly comprised by metavolcanic-sedimentary and clastic sequences from Brusque Group – Rio do Oliveira and Botuverá Formations – in addition of intrusive granitoids associated to the complex (*e.g*. Northern and Southern Valsungana Granitic Suites). The processed and interpreted aerogeophysical data were acquired along north-south lines spaced at 500 m, with a mean terrain clearance of 100 m. The structural-magnetic framework revealed structures, primarily in northwest-southeast strike direction, possibly related to dikes which were not previously mapped. Furthermore, magnetic lineaments showed a good correlation with the main geological units and granted new features to study area. The estimates depths of magnetic sources oscillated between 200 and 600 m. The Southern Valsungana Suite showed maximum values (greater than 600 m) and the highest gamma-ray anomalies. The F-parameter showed low values in southern batholith and high values in the northern one, indicating that hydrothermal alteration processes did not occur (or in small scale) on the southern massif, in contrast to its northern counterpart. Five gamma-ray spectrometric domains were characterized through the radionuclides K, eU and eTh. These domains were linked to the local geology. Therefore, the structural-magnetic framework and gamma-ray spectrometric maps showed that geophysical methods comprised a valid mechanism to geological mapping displaying the feasibility of magnetics and radiometrics in order to geological complementation and confirmation, especially in areas with difficult access, outcrops scarcity and/or dense vegetation cover.

Introduction

Aerogeophysical data are often applied in geological cartography and to mineral and hydrocarbon prospecting by government and private companies (Isles & Rankin 2013). In this decade, the Geological Survey of Brazil - CPRM, has been conducting airborne geophysical (magnetic and radiometric) surveys over the Brazilian crystalline basement. In this background, we use the data acquired from CPRM (2011) to delineate a magnetic-structural framework and characterize the gamma-ray spectrometric of Brusque region, Southern Brazil, in addition to their correlation with the geology of area. The area is comprised by metavolcanosedimentary sequences and igneous batholiths. We aim to increase the cartography and geological knowledge of an area known for its mineral occurrences such as gold, tungsten and other, and which displayed difficulties to mapping, like scarcity of outcrops and weathering mantle.

Research area and geological setting

The study area is located on the eastern portion of Santa Catarina State, Southern Brazil, bounded by coordinates 48º45' – 49º west longitude and 27º - 27º15' south latitude, amounting to approximately 690 km^2 (Fig. 1).

Units of Brusque Group (or Brusque Metamorphic Complex) and associated granitoids, such as the Northern and Southern Valsungana granitic suites, compose the study area. These units are inserted in the setentrional Dom Feliciano Belt, part of Mantiqueira Province (Heilbron *et al*. 2004). This belt was divided by three tectonic domains: north, central and south, limited by Itajaí-Perimbó and Major Gercino shear zones (Fig. 1).

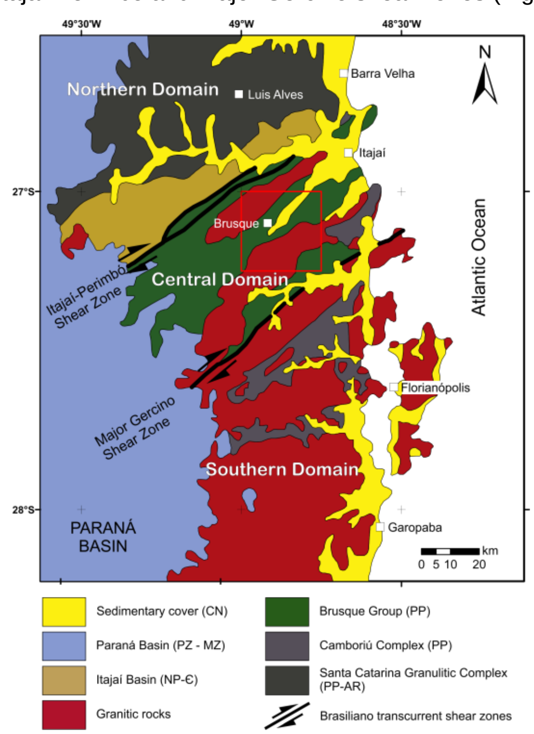

***Figure 1** – Geological background of study area (red square), eastern Santa Catarina state (adapted from Chemale et al. 2012).*

The study area is located exclusively on the central domain embracing the Brusque Group and its related igneous intrusions, like the Valsungana Batholith. The Brusque Group comprises Neoproterozoic metavolcanosedimentary sequences representing the upper crust southern segment of Dom Feliciano Belt (Basei *et al.* 2011, Chemale *et al*. 2012). The origin and evolution of Brusque Group are objects of controversy in literature. It is related to a peri-cratonic basin setting, which went through deformation and metamorphic events when it collided with Florianópolis Batholith (Basei *et al*. 2011) or it is linked to a regional metamorphism with sedimentation associated to a rifts system which advanced to continental margin (Philipp *et al*. 2004).

We used a 1:100,000 geological map from Basei *et al*. (2014) for analysis in GIS environment with geophysical data (Fig. 2). The units were divided in Brusque Group, intrusive granitoids in Brusque Group (*e.g.* Valsungana Batholiths and Nova Trento Suite), Camboriú Complex, Mesozoic dikes and Cenozoic cover.

The Brusque Group is composed of a lower metavolcanosedimentary sequence (Rio do Oliveira Formation) in tectonic contact with a top clastic sequence (Botuverá Formation). The ages established for this group date the Cryogenian period.

The Rio do Oliveira Formation comprises low to medium grade metamorphic units. It encompasses metabasalts, amphibole-biotite schists and calc-silicate rocks intercalated with bands rich in carbonate (metabasic and calc-silicate unit); tourmalinites bearing pyrite and cherts (tourmalinitic unit); biotite-muscovite-quartz schists with chloritoid or garnet porphyroblasts (metapelite-psammitic unit).

The Botuverá Formation includes low to medium grade metamorphic clastic units. The low to medium grade metamorphic units consist of: muscovite-quartz schists, garnet-mica-quartz schists and quartzites (metapsammitic unit); schists intercalated with quartzites (metarhythmitic unit); hornblende carbonatic schists, quartz-muscovite carbonatic schists and marbles (metacarbonatic unit); muscovite schists, garnet-biotite schists, calc-silicate rocks (metapelitic unit). The low grade metamorphic units include isotropic to foliated orthoquartzites (quartzitic unit); micaceous quartzites and sericite-biotite schists (metapsammite rhythmitic unit); gray chlorite-biotite-sericite schists (metapelitic unit).

Two Ediacaran units comprise the Camboriú Complex, Morros do Boi Migmatites and Ponta do Cabeço Granite. The first corresponds isotropic to low banded migmatites and, the latter includes diatexitic granitoids of tonalitic to granodioritic compositions.

Neoproterozoic intrusive granitoids in Brusque Group include biotite monzo- to sienogranites bearing alkali feldspar megacrysts (Valsungana Suite) and isotropic biotite monzogranites (Nova Trento Suite). Acessory minerals for these suites are zircon, apatite, allanite, titanite, opaque minerals and subordinate tourmaline (Basei *et al.* 2011).

Equigranular to porphyritic with plagioclase phenocrysts diabase dikes comprise the Mesozoic units of study area.

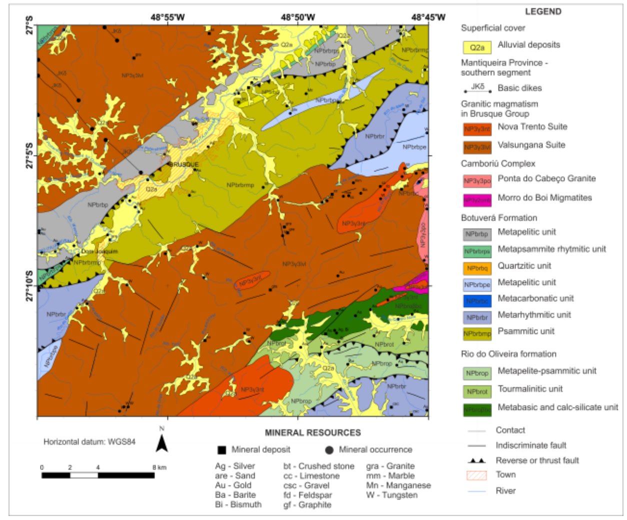

Figure 2 – *1:100,000 geological map of study area (modified from Basei et al. 2014).*

Cenozoic covers embrace alluvial deposits constituted by terrigenous clastic sediments.

Method

In this present research, magnetic and gamma-ray spectrometric (K, eU, eTh) data from Aerogeophysical Paraná-Santa Catarina Project (CPRM 2011) were processed and interpreted. The survey is characterized by north-south flight lines, with a mean terrain clearance of 100 m. Grids were created using bi-directional interpolation method with 100 m of unit cells, which are 1/5 of the spacing between flight lines. Tie-lines had 10 km of spacing.

Aeromagnetic processing

The magnetic method detects magnetism differences on rocks by measuring variations in the Earth's magnetic field (Dentith & Mudge 2014).

The flowchart on Figure 3 shows all the processed steps for magnetic characterization. We generate a radially averaged power spectrum (Fig. 5) (Spector & Grant 1970) of Total Magnetic Intensity (TMI) to separate the components of depth of sources as breaks on the spectral function. This helps on application of filters for depths of interest.

We reduced the TMI data to pole using magnetic inclination of -37.28º and declination of -18.34º, which correspond to the magnetic field at the time of the airborne survey in the study area. Subsequently, aiming for reducing the noise and aid on delineation of deep structures, it was applied the upward continuation filter to 500 m. The tilt angle of the total horizontal derivative (TAHG) transform (Ferreira *et al.* 2013) were used to delineate the structural-magnetic framework (Fig. 6). This transform is an edge detection method, being less sensitive to variations in the depth of the sources (Ferreira *et al.* 2013).

Euler deconvolution solutions (Thompson 1982) were utilized to show the location of magnetic sources (Fig. 6).

The structural index chosen was zero (contact model), spatial window size of 1,000 m and maximum error tolerance of 10 %. Both parameters were chosen by trial and error, analyzing the results that better fitted for interpretation.

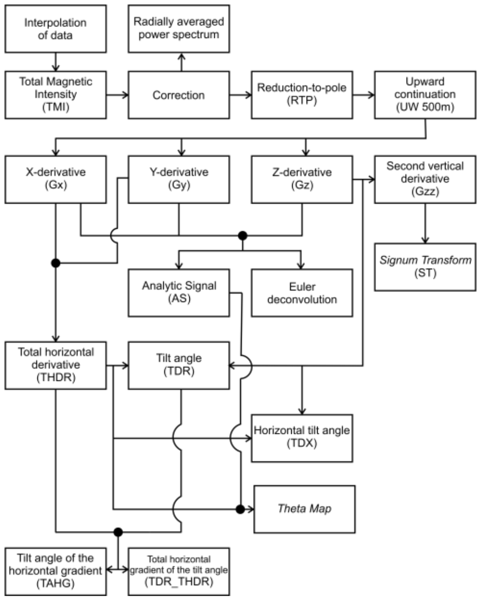

Figure 3 – *Aeromagnetic processing flowchart.*

Aerial gamma-ray spectrometry processing

Gamma-ray spectrometry method involves the physical measure of radiation from gamma rays naturally emanated from the upper 30-45 cm Earth's surface, showing the concentration of K, eU and eTh (Dickson & Scott 1997, Dentith & Mudge 2014).

Basic (K, eU, eTh), transform (eU/eTh, eU/K, eTh/K), F-parameter, normalized (Kd, Ud), and ternary (RGB) maps were generated. The steps of gamma-ray spectrometry processing were displayed on Figure 4. The correction done on grids is due to negative concentrations identified on all channels (K, eU, eTh) that could mask the ratios (eU/eTh, eU/eTh, eTh/K), F-parameter and normalized (Kd, Ud) maps. According to Ferreira *et al.* (2009), a minimum value should be assigned by adding constants on the basic grids, such as 0.01 for K, eU and eTh.

The F-parameter or K*eU/eTh parameter (Gnojek & Prichystal 1985) among other ratios (eU/eTh, eU/eTh, eTh/K) could reveal areas with strong hydrothermal potassic e/or sericitic alteration. Hydrothermal alteration may result in ore mineralization, such as cooper, lead, gold, silver (Ferreira *et al*. 2009, Ribeiro *et al*. 2013). High values of F-parameter may lead to hydrothermal alteration and low ones tend to represent mantle weathering.

Five gamma-ray spectrometric domains were delineated (Figure 9) according to proportional concentrations of channels (K, eU, eTh) on ternary (RGB) map, which enhances areas with different radioelements counts that may not seen on basic maps (Ribeiro *et al.* 2013).

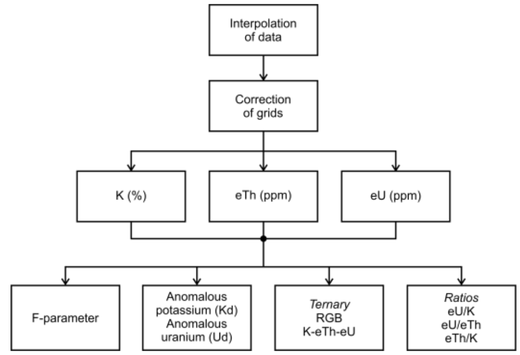

Figure 4 – *Gamma-ray spectrometric processing flowchart.*

Results and Discussion

The radially averaged power spectrum was divided in three components (Fig. 5). The deep sources showed wavelength up to 2.5 km and depths above 500 m, whilst intermediate sources displayed wavelength between 2.5 and 0.5 km and depths down to 500 m. It was not possible to discriminate the shallow sources and noises by depth estimate. Nevertheless, these sources were separated by wavelength, amounting values below 0.5 km.

The structural-magnetic framework obtained from TAHG map (Fig. 6) displayed a greater concentration of magnetic lineaments on central and southeast areas. Preferential strike of lineaments is NE, parallel to regional trend (Chemale *et al*. 2012). In spite of a lack of some compatibility between geological contacts and magnetic lineaments, some correlations were detected, as the boundaries of Northern Valsungana massif (Fig. 6 and 7). We detected large lineaments with NW strike direction on central portion that were not previously mapped by Basei *et al.* (2014). These features were detected in all magnetic maps generated according to the flowchart of Figure 3 and we suggest that they are an extension of

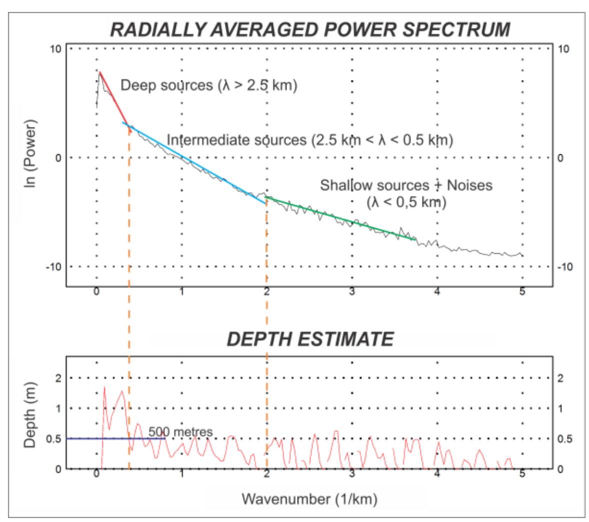

Figure 5 – *Radially averaged power spectrum of TMI with interpretation of the wavelength intervals (1/λ) and estimation of depth to top of magnetic sources.*

dikes mapped on the northwestern portion of study area (Fig. 7) or even new dikes. These hypotheses are supplied by dikes swarms with NW strike direction, which were reported in Botuverá region, the adjacent sector of study area, by Campos *et al.* (2012).

Euler deconvolution solutions map (Fig. 6) displayed estimate depths ranged from 200 m to 600 m in general, while depths over 600 m were represented almost exclusively on Valsungana Suite batholiths. Considering the high rates of depth and taking into account the radially averaged power spectrum data (Fig. 5), both Southern and Northern Valsungana massifs, the latter with the highest values of depth, could be inserted on the deep sources of spectrum function.

The F-parameter (Fig. 8) displayed high values in northwestern area (above 1 %), referred to Northern Granite Valsungana and some portions of Botuverá Formation. In contrast, the southern massif and Rio do Oliveira Formation showed low values. It was proposed that hydrothermal alteration processes were more able to occur on Northern Valsungana batholith instead of the southern one. Moreover, F-parameter comprised a useful method to analyze potassium abundance to the eTh/eU ratio and the uranium abundance to the eTh/K ratio (Gnojek & Prichystal 1985).

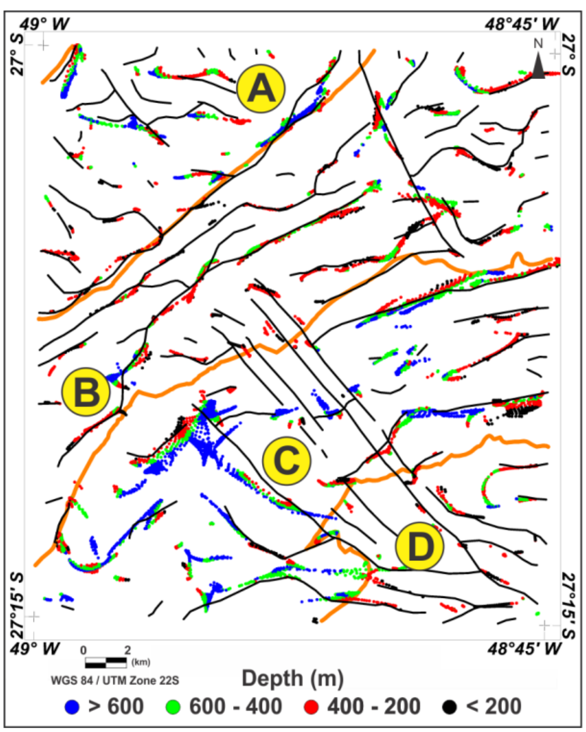

***Figure 6 –** Magnetic lineaments (black lines) interpreted from TAHG map overlapping Euler deconvolution solutions (colored circles, SI = 0). Main geological units: A – Northern Valsungana Suite, B – Botuverá Formation, C – Southern Valsungana Suite and D – Rio do Oliveira Formation.*

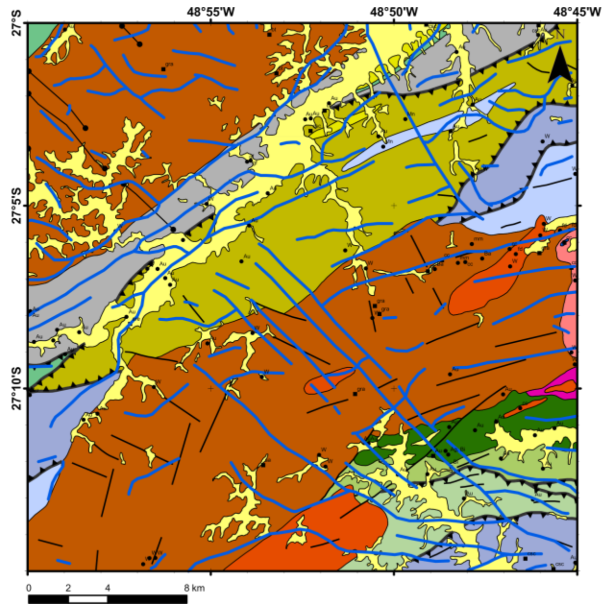

***Figure 7 –** Geological map from Basei et al. (2014) and magnetic-structural framework (blue) for study area. Note the extensive magnetic lineaments in central portion without geological equivalents. It was suggested these features are dikes.*

Five gamma-ray spectrometric domains were characterized for study area (Fig. 9):

- A domain displayed the highest concentrations for K, eU and eTh. K concentration could be explained by Southern Valsungana massif K-feldspar megacrysts and micas. Ulbrich *et al.* (2009) report that accessory minerals on granitic bodies, such as allanite, apatite, epidote, titanite and zircon, contained significant quantities of eU and eTh to show a geophysical response. All these minerals, except for epidote, were reported on the southern batholith. They were suggested for the high rates of eU and eTh. This domain showed the highest radioelement concentrations.

- B domain was characterized by medium counts of K and eTh, and low of eU. Rio do Oliveira Formation were correlated to this domain. The schists present on this formation represent the K concentration, whilst eU and eTh counts were typical of metabasic rocks, according to Dickson & Scott (1997). It should be noted that Rio do Oliveira Formation is covered by superficial cover and geophysical responses may be misleading.

- High counts of K and medium of eU and eTh represent the C domain, which was associated with Botuverá Formation. Values of K were represented by presence of feldspars and micas from schists and micaceous orthoquartzites. Concentrations of eU were suggested as remobilization of part of the eU from Northern Valsungana Suite to this region due to pedogenic processes. It should note that the effect of metamorphism on the distribution of K, eU and eTh is somewhat uncertain (Dentith & Mudge 2014).

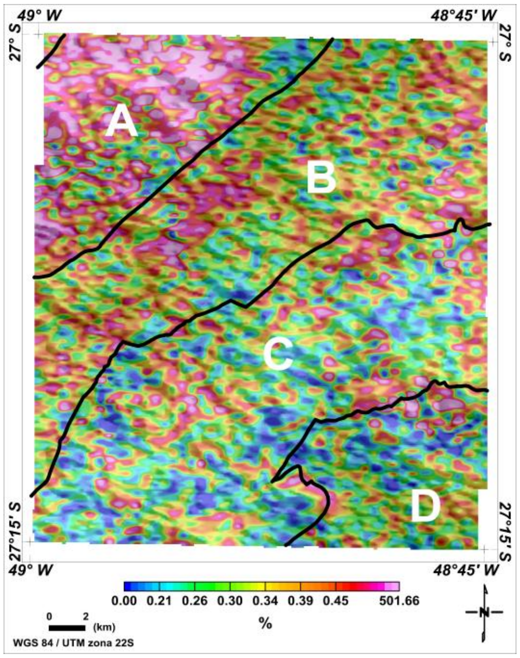

Figure 8 – *F-parameter map showing high rates for Northern Valsungana granite and low values for the southern one. This may represent hydrothermal alteration processes on northern batholith. Main geological units: A – Northern Valsungana Suite, B – Botuverá Formation, C – Southern Valsungana Suite and D – Rio do Oliveira Formation.*

- D domain (high K and eTh concentrations, and average of eU) was related to superficial cover along the Itajaí-Mirim river.

- High counts of K, medium of eU and low of eTh characterized the E domain. It was associated with Northern Valsungana. The distribution of K and eU in this suite is similar to the southern massif. For the low eTh values, we proposed that organic compounds or acid solutions could solubilized thorium or it may also be transported adsorbed on colloidal clays, according to Dickson & Scott (1997).

Conclusions

The structural-magnetic framework showed a significant number of magnetic structures without equivalence to geological features mapped. Nevertheless, some contact relationships could be confirmed, such as the Northern Valsungana Batholith boundaries. The incompatibility may be attributed to the low contrast of magnetic susceptibility between of study area rocks and its high structural complexity.

Enhancement magnetic methods confirmed geological features in study area and suggested new ones, such as broad magnetic lineaments with northwest-southeast strike direction, probably related as an extension of diabase dikes mapped or even new dikes. We suggest reconnaissance surveys or field tests in the area to corroborate this hypothesis.

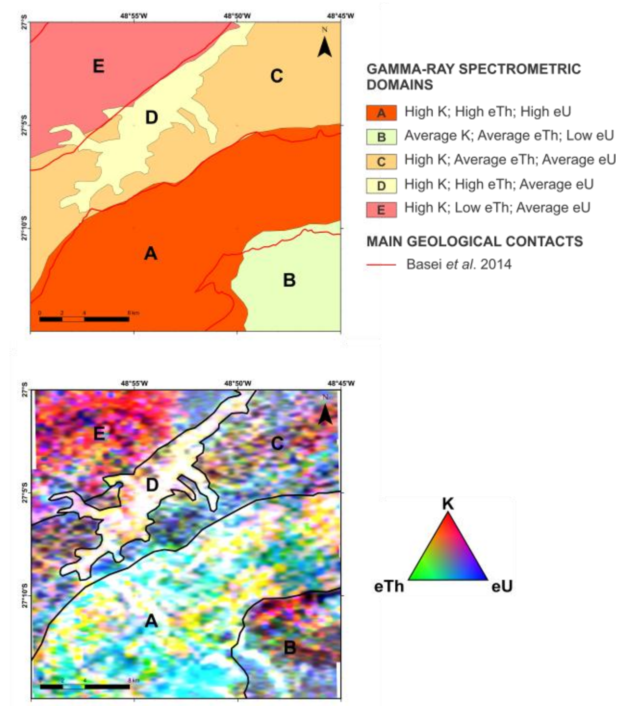

Figure 9 – *Gamma-ray spectrometric domains of study area (above). Gamma-ray spectrometric domains traced (black lines) on ternary RGB map (below).*

Depth estimates through Euler deconvolution technique ranged from 200 m to 600 m, while subordinated areas showed values over 600 m and were associated with the boundaries of Valsungana massifs. The Southern Valsungana Suite comprised the main portion of deep sources in the radially averaged power spectrum (sources above 500 m of depth).

The low penetrability of gamma-ray spectrometry allowed relate the main geologic units with the geophysics patterns. Five gamma-ray spectrometry were established, showing the highest values of potassium, thorium and uranium, for granitic suites (mainly for Southern Valsungana) in study area.

The low rates of F-parameter in Southern Valsungana Suite, in contrast to its northern counterpart, may suggest that hydrothermal alteration processes occurred in the northern massif whereas the southern one showed a lack of them.

Acknowledgments

We would like to thank the Companhia de Pesquisa de Recursos Minerais (CPRM, Geological Survey of Brazil) for permission to use the airborne geophysical data in Brusque area. F.J.F. Ferreira was supported in this research by a fellowship from National Council for Scientific and Technological Development (CNPq, Brazil), under contract 306978/2015-16.

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