Use of gammaspectrometric airborne data as tool in regional geologic mapping in the Parana State – Brazil

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Abstract

This paper presents results of the processing of gammaspectrometric data (TC, K, eU, and eTh) from a 300 km^2 area to the North of Curitiba, PR. Samples are separated 67 m from each other along 1,000 m spaced, 120 m high flight lines. After transformed to regular 250 x 250 m grids, the maps were superimposed to the geological map of the area, which corresponds to Paleoproterozoic gneisses and mylonite-gneisses (Atuba Complex), deformed Mesoproterozoic syenogranites (Agua Comprida Granitic Suit), Mesoproterozoic schists and quartzites (Santana Sequence), dolomitic marbles, metasiltstones, phyllites (Capirú Formation), sericite-phyllites and orthoamphibolites (Votuverava Formation), the latter two pertaining to the Açungui Group (Neoproterozoic). The entire area is cut by diabase dykes swarms of the Serra Geral Formation (Mesozoic). The results obtained from geological-geophysical integration allowed gammaspectrometric responses to be correlated to the local stratigraphic units, which rendered a more detailed geological cartography of the area. Internal geophysical variations in geological units reflect lithologic contrasts observed at fieldwork.

Introduction

The present study was based on airborne gamma-spectrometric data from the approximately 300 km^2 region in North-Northeastern Paraná, Brazil, delimited by 25º04'08" – 25º17'16" S and 49º04'01" – 49º14'32" W (Córrego Alegre horizontal datum).

The objectives of the present study are (1) to compare radiometric responses of lithotypes described by undergraduate geology students of the Universidade Federal do Paraná in 2003, and (2) to assess the suitability of the method as a regional geological mapping tool for use in intensely weathered areas.

Geologic Context

The area of interest comprises Paleoproterozoic gneisses and mylonite-gneisses of the Atuba Complex (Figure 2), deformed Mesoproterozoic syenogranite terms of the Água Comprida Granitic Suit, identified based on lithology and structures (Toczeck *et al.* 2003), and shales and quartzites of the Santana Sequence (Setuva Complex). The Neoproterozoic is represented by metabasic and metasedimentary rocks of the Capirú and Votuverava formations (Açungui Group). Capirú Formation comprises dolomitic marble, metasiltstone, quartz-sericite-phyllite, graphyte-phyllite, magnetite-phyllite, metasandstone, quartzite and shale bodies. Votuverava Formation is composed of quartzite, sericite-quartz-phyllite, and orthoanphibolite with reliquiar foliated structures (Sofia *et al.* 2003). Mesozoic basic dykes of the Serra Geral Formation (São Bento Group) associated with important NW-SE lineaments are also present. Unconsolidated Quaternary sediments occur disconformably. The term Água Comprida Granitic Suit is used to designate deformed syenogranites pertaining to the Setuva Antiform nucleus, formerly referred to as gneisses and paragneisses of the Pré-Setuva Complex (Ebert 1971). The shales and quartzites surrounding the Setuva Antiform's nucleus are referred to as the Santana Sequence.

In the area of interest, four deformation events are observed, namely D_1, D_2, D_3, and D_4. D_1 represents the thrust tectonics responsible for an S_n foliation. D_2 represents the folding event responsible for the Setuva Anticline, the S_{n+1} foliation and also folding at varied scales. D_3 represents a sinistral N55-60E faulting related to the Lancinha Transcurrent System. D4 relates to the evolution of the Ponta Grossa Arch, with dextral and sinistral movements to which microgabbro, diorite and diabase dykes present in the area are associated (Toczeck *et al.* 2003).

The same geological nomenclature was adopted by all geological mapping students in 2003.

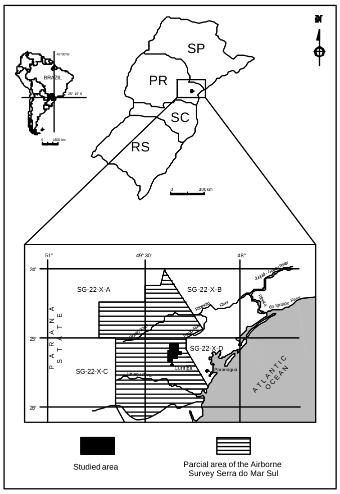

Figure 1 – Location of the area on the Serra do Mar Sul airborne survey (modified from Silva 1999).

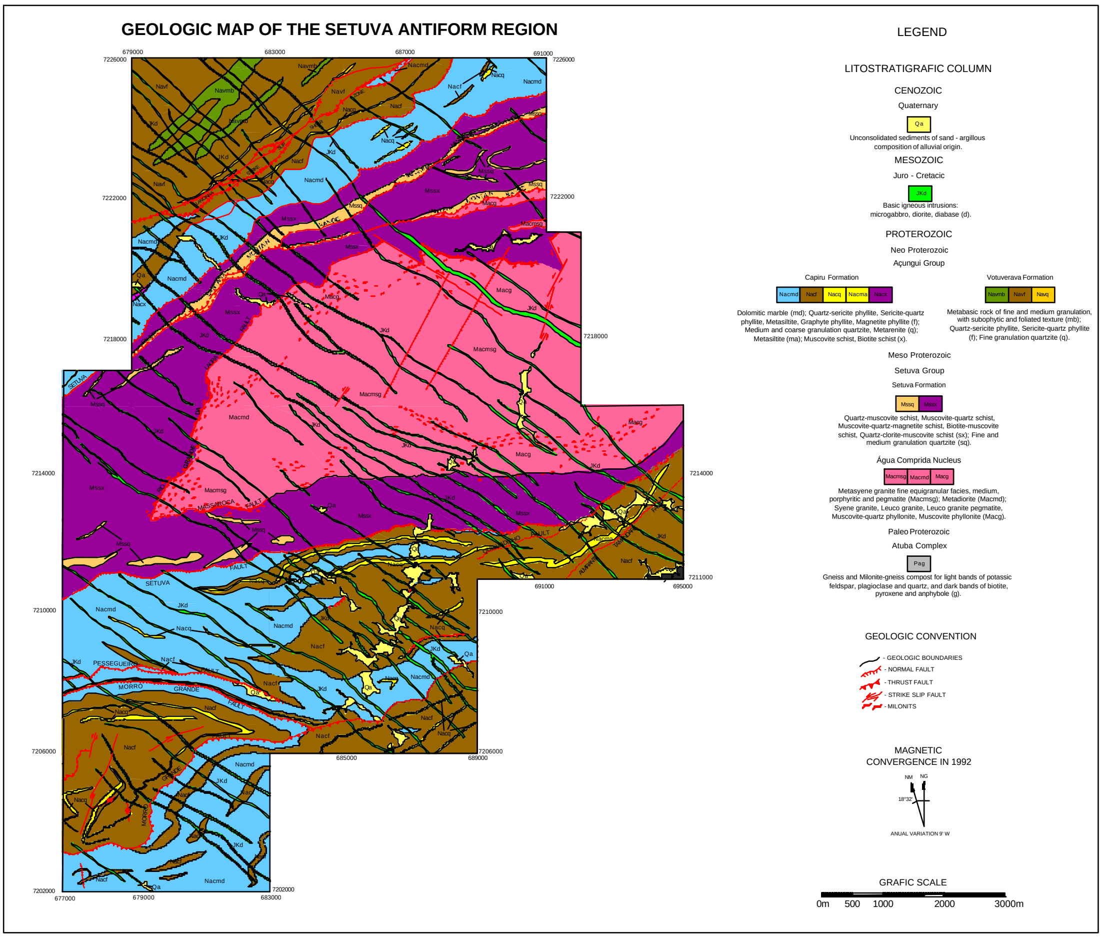

Figure 2 – Geological map of the Setuva Antiform region by the undergraduate UFPR geology students in 2003.

Parameters of the Airborne Survey

The aerogeophysical data used (Serra do Mar Sul Project) were sampled by CPRM (1978) in counts per second and later transformed to TC (μR/h), K (%), eTh and eU (ppm) by BARMP (1997). The average flight height was of 120 m, samples being spaced 67 m along flight lines, which in the area of interest are separated approximately 1,000 m from each other and oriented preferentially to N30W. The total surveyed extension inside the area of interest was of linear 290 km, with a total of 4,323 points sampled.

Methodology

The original xyz data were imported to *Geosoft's Oasis Montaj^{TM} v.5.1,* delimited for the area of interest, and transformed into a regular 250 x 250 m grid using the minimum curvature (MC) interpolation method (Briggs 1974). Other interpolation methods were tested, namely bidirectional, kriging, and tinning, but MC was the method that presented best results. This allowed to generate 1:150,000 scale total count (μR/h), K (%), eU, eTh (ppm) and ternary R (K) - G (eTh) - B (eU) contours. K, eTh, and eU statistics were calculated from the geosoft database to analyse the population's distribution, and also to calculate minimum, maximum, mean, and standard deviation values for their respective channels.

A digital elevation model was constructed from a regular 90 x 90 m SRTM (Shuttle Radar Topography Mission) grid to evaluate the radionuclides' mobility in the terrain by superimposing it to their respective gamma-ray values.

A CAD (DXF) frame with geologic contacts of the main lithostratigraphic units was superimposed to the geophysical maps.

Results

Total Count Channel (TC)

As it can be observed from the total count map (Figure 3), a clear division exists in the nucleus of the Setuva Antiform, with high count values as compared to other parts of the nucleus, which indicates that part of the deformed syenogranites is richer in alkalis. This zone corresponds to the band of phyllonites mapped at fieldwork. The same is noticed for the nucleus' edge, where high total count values (in red) are observed, which is not observed to the south of the antiform, probably due to migration of radionuclides across the landscape.

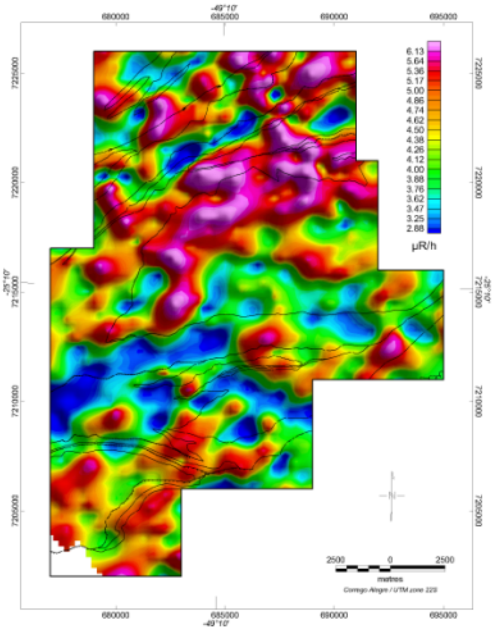

Figure 3 – Total count map (μR/h) of all the area, pseudoiluminated to N45E.

To the North of the anticline, and especially in the Northeast extremity of the area, dolomitic marbles of the Capiru Formation show higher values as compared with the southern portion of the structure. In the South extremity, values for marbles and the phyllites are similar. Some higher values are related to the Almirante Tamandare Fault (to the East). The same occurs along the Lancinha Transcurrent Shear Zone (LTSZ) and in the southern portion of the Morro Grande Fault. For phyllites of the Capiru Formation, no typical gammaspectrometric pattern is observed showing variation in the percentage of plyllosilicate minerals (high and low local values, in blue). The metabasic rocks present low values.

In figure 4, the total count variation for all of the area can be seen, for Água Comprida Granitic Suit (ACGS) and for the external parts of the antiform. The large contribution of the syenogranites to the radioelements total counts is evident.

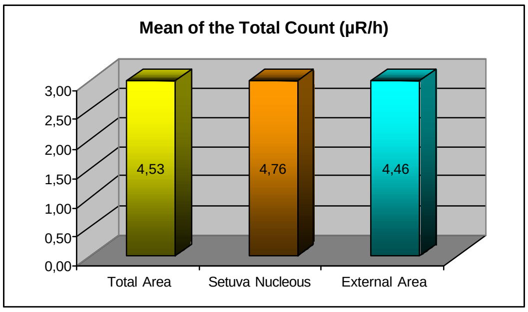

Figure 4 – Total count (μR/h) with mean values for the total area, the Setuva nucleus, and the area external to the nucleus.

Potassium Channel (K)

In Figure 5, areas of high values (1,8%) due to mineralogy and/or better exposition of rocks can be observed for shales to the North of the anticline.

In the nucleus of the anticline, a homogeneous gammaspectrometric pattern (~1,15%) is noticed, except for some phyllonites to the North of the structure.The metabasic rocks present low K values due to their basic composition. In Figure 5, the responses for phyllites of the Capiru and Votuverava formations are similar near LTSZ. The NE-SW band of Capiru marble (Northern portion) shows higher values in its Northeast extremity and to the North of Morro Grande Fault, possibly related to the phyllite lenses mapped. These plyllosilicate-rich lenses would raise values. High values can also be observed in the alignment of the Almirante Tamandaré Fault. The low value segments inside the Setuva Antiform are interpreted as being related to altered rock, which is indicative of loss of potassium due to weathering. High K values are observed along the LTSZ alignment and along an alignment in the Southeast, probably related to the Atuba Fault.

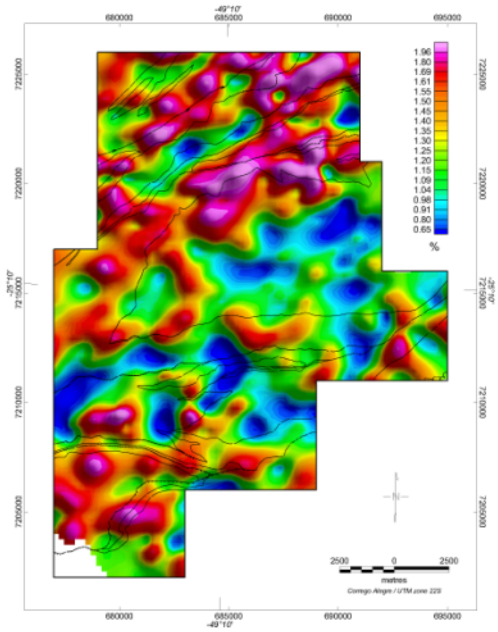

Figure 5 – K (%) over all the area, pseudoiluminated to N45E.

Figure 6 reveals the average K value differences over the whole area, in the ACGS and its externals. It is possible to visualize that grades in the entire area of interest and in those areas other than The ACGS are close (~1,35%), while K grades in the nucleus of the antiform are lower than in the rest of the area (1,21%). This may result from depletion of this radioelement.

Apparently, ACGS does not contribute K percentages to other litostratigraphic units. The K grades for this granitic suite reflect the mineralogical composition of the rock, composed mainly of potassic feldspar (microcline). In the rest of the area, K is found in mica, a mineral form commonly present in shales and phyllites, as depicted on the geological map.

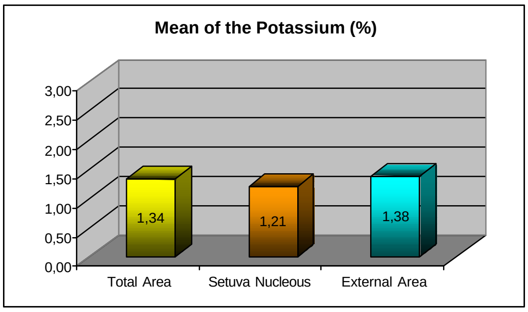

Figure 6 – Mean K (%) values for the entire area, the Setuva nucleus and its surroundings.

Uranium Channel (eU)

Areas in the northern portion of the ACGS, including the band of shales at the edge of the anticline, present U grades higher than the clark of this element in Earth's crust i.e., 3 ppm. Inside ACGS, anomalies occur with values equal or superior to the clark (Fig. 7).

The uranium commonly present in nature, which is in the oxidated form (U_{+6}), has its mobility modified by absorption of hydrated iron oxide, clay minerals, and colloids, and also by precipitation under reducing conditions. That would explain the grades of uranium above of the clark in the nucleus, which is due to intense intemperism. In the marbles to the south of the ACGS, low uranium values reflect the rock type. However, the same rock presents higher values to the North of ACGS i.e., above 3 ppm, which indicates areas sufficiently affected by intemperism. Uranium and thorium are concentrated in clays and iron oxides.

Areas of intermediate uranium values can be observed in phyllites of the Southeastern part of the area of interest. Enrichment zones can be related to deformation processes in which uranium-rich fluids are mobilized. The map in Figure 7 shows great variability of uranium grades in ACGS, probably because of pedogenetic phenomena, or concentration in ruptil structures (see Figure 2) or alluviums. Concentration of uranium can be associated to alluviums of the Capivari River (to the Southeast), to metaritmites of the Capiru Formation (to the East), and to the LTSZ alignment.

Figure 8 shows the variation in uranium grades in the whole area of interest, in ACGS and its externals. Notice that the equivalence in grades of this radioelement in the whole area of interest and in the area external to the nucleus of the Setuva is perceived (~2,72%). The highest grades (2,80%) occur in the ACGS, and are related to mineral traces this litotype (e.g., zircon) or even to the retention of U_{+6} in clays and iron oxides due to intemperism.

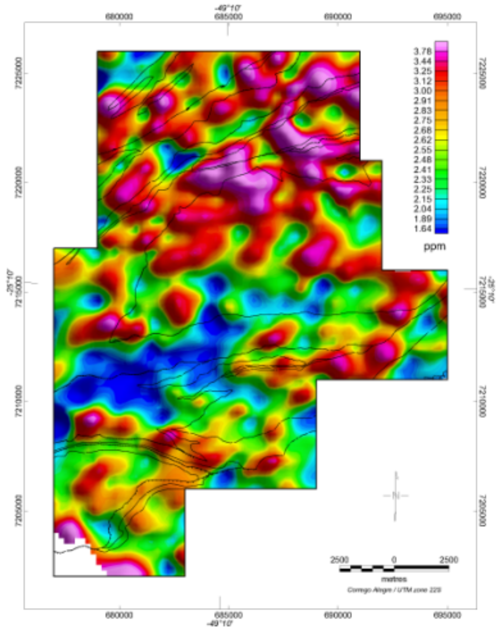

Figure 7 – Uranium map (ppm) of the entire area of interest, pseudoiluminated to N45E.

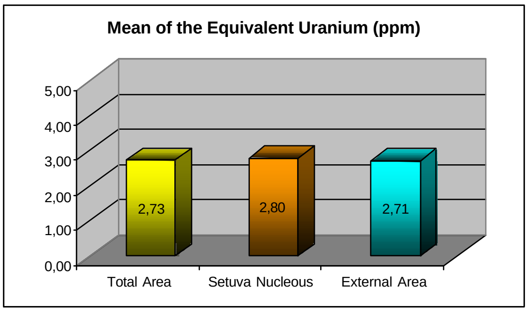

Figure 8 – Uranium (ppm) with mean values for the entire area, the Setuva nucleus and its surroundings.

Thorium Channel (eTh)

It can be noticed in Figure 9 that responses in ACGS are clearly higher (13 ppm and above), especially where phyllonites occur.

The contact between ACGS and shales of the North edge of the anticline is clear. Intermediate values are observed for dolomitic marbles in the Southern, Southeastern and Northeastern portions of the area of interest. The portion corresponding to metabasic rocks presents low values. As well the uranium map for the entire area of interest, the thorium map defines the alignment of the LTSZ clearly. A band of intermediate values defines the contact between the Açungui Group and the Setuva Complex in the Central-Southern portion of the area. Anomalous high grades can be related to normal faulting in the ACGS. High values of thorium in the Southern portion of the area relate to dolomitic marbles of the Capiru Formation, with thick lenses of phyllites. Thorium tends to be restricted to clays, colloids and iron oxides, forming anomalous concentrations without any geologic correlation.

Anomalies can be associated to regions of strong relief due to mobilization of this radioelement in the landscape.

Figure 10 reveals a predominance of thorium in the ACGS (13,36%) in relation to grades for the total area (11,39%) and for the area external to ACGS (10,75%), with little participation of this element in the grades of the entire area of interest.

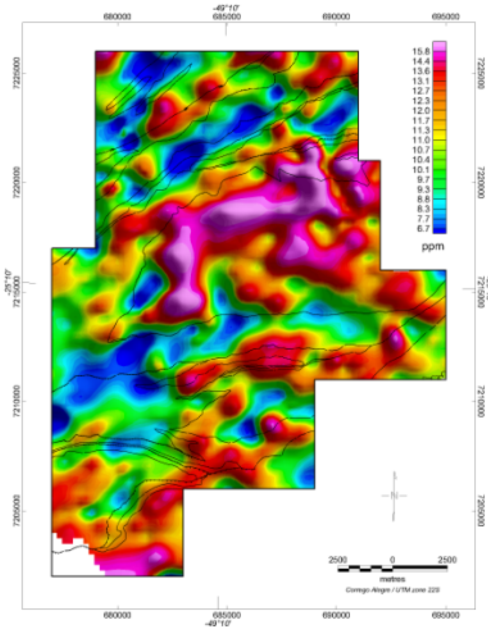

Figure 9 – Thorium values (ppm) for all the area of interest, pseudoiluminated to N45E.

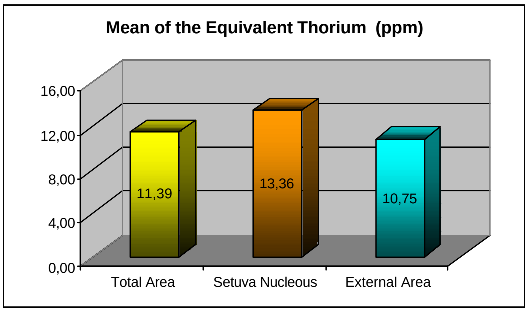

Figure 10 – Thorium (ppm) with mean values for the entire area, the Setuva nucleus and its externals.

Ternary Composition

The ternary map of the K-eTh-eU parameters (Figure 11) shows interaction of the three radionuclides in the definition of the contacts of the ACGS and the borders of the nucleus. Green indicates predominance of thorium over the two other radioelements. White in the Northeast edge of the nucleus indicates, simultaneously, high grades of the three radionuclides. The South contact of the nucleus with the Santana Sequence shows the influence of K on the other elements, whereas in the neighborhoods of the LTSZ it shows contribution of uranium and potassium.

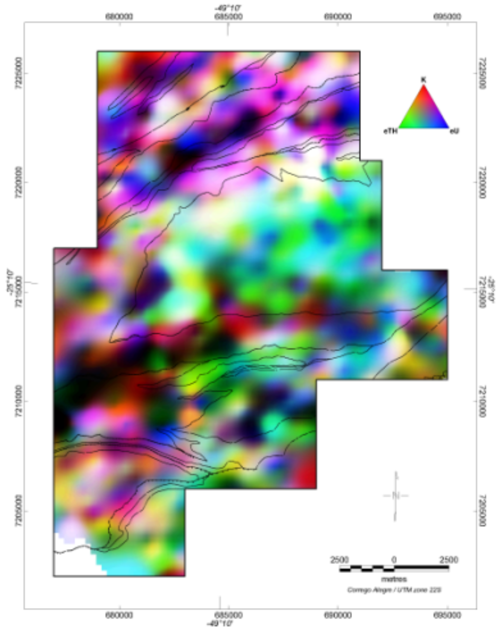

Figure 11 – Ternary R (K) - G (eTh) - B (eU) map composition for the entire area.

3D View

A common problem in interpreting geophysical data is the mobility of radionuclides in the terrain, mainly in areas of strong relief, and in subtropical regions. As an aid to interpretation of geophysical maps, a SRTM grid was superimposed to grids of potassium, uranium and thorium. In order to enhance main anomalies, histograms being equalized to 50% (Fig. 12).

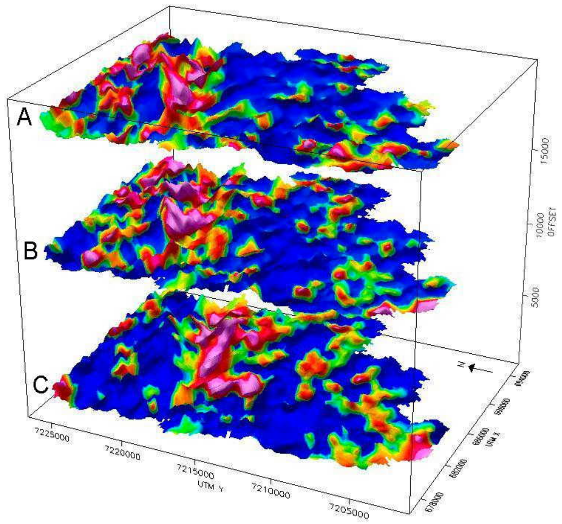

Figure 12 – 3D view of the potassium (A), uranium (B) and thorium (C) maps. The maps present histograms equalized to 50% and are superimposed to a digital elevation model. Vertical exaggeration of 5x.

Conclusions

The integration of geologic information with airborne gammaspectrometric data shows to be a very important tool in the characterization of litostratigraphic units and geologic structures, especially for syenogranites of the Setuva Antiform.

Some parameters such as the equivalent uranium (eU) and equivalent thorium (eTh) reveal wheatered portions in the interior ACGS, which can be related to lithologic facies or ruptil structures. Also, it was possible to analyze the spatial distribution of radionuclides in the terrain and to verify lithologic contrasts inside a single unit.

The use of the technique clearly marked the contact between the granite in the nucleus of the Setuva Antiform (ACGS) and its shale and quartzite hosts of the Santana Sequence, which corroborates the contacts raised in field.

The high eU and eTh grades and the depletion of K in the ACGS can be related to weathering as these elements are easily adsorbed by iron oxides and clays.

The small difference in values of K, eU and eTh in the entire area and where ACGS is absent indicates that the suite does not supply radioelements to the surrounding rocks, thus no significant grade variation is noticed.

Acknowledgments

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