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MAPSAR Simulation Campaign: Evaluation of the SIVAM/SIPAM SAR System for Geologic Mapping in Carajás Mineral Province

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Abstract. The Carajás Mineral Province is located in the eastern portion of the Amazon craton, state of Pará and contains a significant number of mineral deposits, most of them exhibiting structural and lithological controls, such as sets of dilation faults. This paper presents the results of the interpretation of simulated MAPSAR (Multi-Application Purpose SAR) data, integrated with aerogeophysical data, over a portion of the Province. The integrated SAR-geophysical data were assessed as auxiliary tools for geological and structural mapping, using data fusion techniques for generating imagery for geological interpretation. SAR images were produced by the SIPAM R99-B system and the airborne geophysical data by the Brazil-Canada Geophysical Project. Prior to fusion, SAR and geophysical data were individually processed for enhancing geological information. The results allowed establishing the relationship between the features extracted from fused images and the main lithologic and geomorphologic domains known in the area. These results demonstrate the potential of these data and methods for the geological analysis of areas of high metallogenetic potential in the Amazon, in support to regional mineral exploration programs.

Keywords: remote sensing, aerogeophysics, image processing, MapSAR, Carajás Mineral Province.

1. Introduction

Remote sensing and airborne geophysics are regularly used for geological mapping, particularly in areas such as the Amazon, with little geological knowledge and high mineral potential. However, data generated by these methods are often interpreted separately and not in an integrated way. Data fusion techniques using digital image processing techniques, when applied to geophysical and remote sensing data, can enhance lithological and structural contents which otherwise would not be perceived on individual data sets. Consequently, images produced by fusing multi-source data can be very useful for geological mapping (Henderson e Lewis 1998, Rencz 1999, Drury 2001).

Airborne geophycal surveys usually take gammaspectrometric measurements simultaneously with magnetometric measurements. In the context of geological mapping, the data usually used for data fusion, particularly in vegetated terrain such as the in the Amazon, are gammaspectrometry and remote sensing, both in the optical and in the microwave spectrum (Dias e Paradella 1997, Paradella et al. 1997, Paradella et al. 2000a, Santos et al. 1997, Teruya 2002, Madrucci et al. 2003). Gammaspectrometric methods are based on element disintegration, particle emission and electromagnetic radiation which can be detected by sensors (Luiz e Silva 1995, Dickson e Scott 1997, Blum 1999). The objective is to sample gamma radiation windows corresponding to natural emission due to radioactive isotopes of potassium, uranium and thorium, or elements resulting from their decay, coming from the Earth's surface or from maximum depths of up to 30cm (Dickson e Scott 1997). The resulting data are therefore an important source of information about the lithologic composition of the terrain.

Aeromagnetometric and remote sensing data fusion is less frequently used for geologic mapping, albeit with a few examples in the literature (Texeira 2003, Texeira et al. 2003, Carneiro 2005). Combining these data sets require some prior methodological and interpretative considerations, mainly due to the fact that information of totally different nature, and coming from different crustal levels, are being fused and interpreted as a single image.

Differently from the information contained in remote sensing images acquired in the optical portion of the electromagnetic spectrum, which represents chemical composition of surface materials, in the microwave portion of the spectrum, used by radar sensors (SAR – *synthetic aperture radar*), the information is related to the physical and electric properties of the terrain. Aeromagnetometric data, on the other hand, register the magnetic gradients from the Earth's crust coming from different depths (up to a few kilometers). Furthermore, the magnetic field in regions of low latitude is represented by di-polar anomalies. In this context, in order to correctly position magnetic anomalies over the causing source, it is necessary to process the data using filters such as reduction to the pole or to the equator, or even amplitude of analytical signal (Luiz e Silva 1995, Blum 1999, Nabighian et al. 2005).

The Carajás Mineral Province, located in the domains of the Amazonia rain forest, comprises several mineral deposits, of a diversified variety. One of the main obstacles for mineral exploration activities is the lack of direct access to rock outcrops, necessary to collect data and to define potential targets for mineralization. This is due to the presence of dense vegetation and thick weathering cover, typical of the Amazon, constraining the use of traditional exploration methods. Several of the mineral deposits known in Carajás exhibit relationship with magnetic gradients and are controlled by geological structures (mainly faulting). The latter are usually expressed as conspicuous textural patterns on terrain morphology. The combined use of SAR and aerogeophysical images can therefore help to surmount the constraints usually found in the Amazon for mineral exploration, providing the basic information for defining the areas of higher potencial and even for target generation.

The present study used SAR data acquired by an airborne MAPSAR simulator integrated with low-resolution aerogeophysical data, in order to assess the potential of the future joint spaceborne mission being set up by INPE (Brazil) and DLR (Germany) for geological applications in rainforest areas with mineral potential, such as the Carajás Mineral Province.

2. Objectives

This work aimed to assess simulated MAPSAR data, in conjunction with aerogeophysical data, in a portion of the Carajás Mineral Province, for geological interpretation in the context of mineral exploration applications. The focus of the assessment was on fused MAPSAR-aerogeophysical data for providing basic geological information for exploration programs in the Amazon, an area known for its high mineral potential and lack of geological information. To achieve this objective, R99-B SAR data simulation MAPSAR characteristics was employed together with magnetometric data acquired by the Brasil-Canada Aerogeophysical Survey (PGBC-1020), integrated through the use of digital fusion techniques.

3. Main Characteristics of the Test-site

The Carajás Mineral Province is divided into two main geotectonic units: the northern Itacaiúnas Belt (Araújo 1988; Araújo e Maia 1991) and the southern Rio Maria Granite-Greenstone Terrain (Dall´Agnol 1986, 1987; Althoff 1996). Both units are bounded to the east by the Araguaia Fold Belt and to the west by the Southern Pará Proterozoic Province. The northern limit of the Province is transitionally covered by Tertiary and Quaternary sediments. In the Águas Claras region the following lithologic units occur: (i) tonalitic gneisses, with trondjemites, granodiorites, granites and amphibolites of the Xingu Complex (Silva et al. 1974; Hirata *et al.* 1982); (ii) amphibolitic gneisses, granites, granodiorites, stratoid granites and syn-tectonic deformed granites of the Igarapé Gelado Formation; (iii) meta-basic and meta-sedimentary rocks with banded-iron formations (BIFs) of the Grão Pará Group (Araújo e Maia 1991; Wirth *et al.* 1986); (iv) sedimentary sequence of the Águas Claras Formation (Nogueira *et al.* 1995; Pinheiro 1997); (v) granites and anorogenic dykes cutting the Xingu Complex, Grão Pará Group and Águas Claras Formation (DOCEGEO 1988).

4. Methodology

4.1. MAPSAR Data Characteristics and Processing

MAPSAR data were simulated by the R-99B SAR system operating with the same specifications to be used by the future satellite system: L-frequency (23,9cm, 1.27 GHz), multi-polarization (HH, VV and HV), 10m spatial resolution and incidence angle in the range 45^o through 53^o. The methodology employed for processing SAR data in order to simulate the MAPSAR system is described by Mura *et al.* (2005).

4.2. Aerogeophysical Data Processing

Aerogeophysical data were acquired through an agreement between the National Department of Mineral Researh (DNPM), Brazilian Ministery of Mines and Energy, and the Canadian International Development Agency (CIDA). The data are part of the Brazil-Canada Aerogeophysical Survey (PGBC-1020), conducted between 1975 and 1976 (DNPM 1981). The total area of PGBC-1020 encompasses part of the states of Goiás, Tocantins, Mato Grosso, Pará and Maranhão, covering 375.000 km^2, with sampling intervals of 1 second along flight lines. Production lines are oriented N-S and spaced of 2 km in a first, reconnaissance survey. In a second survey, flight lines were spaced 1 km, allowing gathering more detailed information. Control lines were carried out along E-W, spaced of 14 km.

Prior to data fusion with the simulated MAPSAR data, aerogeophysical data were processed according the methods described next.

The first step was to examine the data for artifacts which could affect subsequent processing, such as noise in the original digital records. The methods “Fourth Difference” and “P parameter” were employed for this purpose, allowing identifying records with values outside the standard-deviation from the total record population (Blum 1999). Both types of data, magnetometric and gammaspectrometric, contained such artifacts, which were then identified and eliminated from the data set.

The next step was to remove from the data base the contributions of the IGRF/DGRF (*International/Definitive Geomagnetic Reference Field*). Magnetic anomalous field and gamma data were then used for generating regular grids with cells spaced of 500m, by interpolating the original data points, thus producing a first set of grids. The next step was to apply a micro-leveling technique for correcting small artifacts, proposed by Minty (1991). Magnetic anomalous field was then used to produce an image of the amplitude of the analytical signal (AS). This image depicts the depth of magnetic sources and is useful for positioning magnetic anomalies in relation to their deep sources.

After applying these correction techniques, the data were submitted to interpretation in order to define geological boundaries, structural features, depths of magnetic bodies and other geological features.

4.3. Image Fusion in the Spatial Domain

Schowengerdt (1997) described image fusion in the spatial domain as a technique for transferring high-frequency information, contained in images with higher spatial resolution, to images with lower spatial resolution but higher spectral resolution.

This method was applied for fusing simulated MAPSAR data, representing the higher spatial resolution image (10m), with gammaspectrometric and magnetometric data, representing the lower spatial resolution (500m), "spectral" data. The results are shown in **Figure 1A** (MAPSAR+Mag/AAS), **Figure 1B** (MAPSAR+Gamma/CT), in **Figures 3A**, **3B**, **3C**, **3D** and **3E** (MAPSAR+individual K, U, Th channels and a color composite of K, Th, U in RGB –, respectively).

The fused images allowed the analysis of the spatial variation of AAS values, represented by different colors produced with the use of the pseudo-coloring (or color slicing) technique applied on the original black-and-white image, depicting at the same time textural elements due to topographic relief from SAR images as intensity attributes.

The assessment also included a comparison between SAR-geophysical fused images using two different SAR systems: simulated MAPSAR and RADARSAT-1. **Figure 3** shows the same images as in **Figure 1**, but replacing simulated 10m MAPSAR (L band, HV pol.) with 8.5m RADARSAT-1 (Fine mode, C band, HH pol.) in the fused image products.

5. Results

Fused SAR+geophysics image products clearly display the boundaries of the main lithogeophysical domains known in the study area. Most of these boundaries coincide with conspicuous topographic features, revealing a clear relationship between different lithologies and relief patterns.

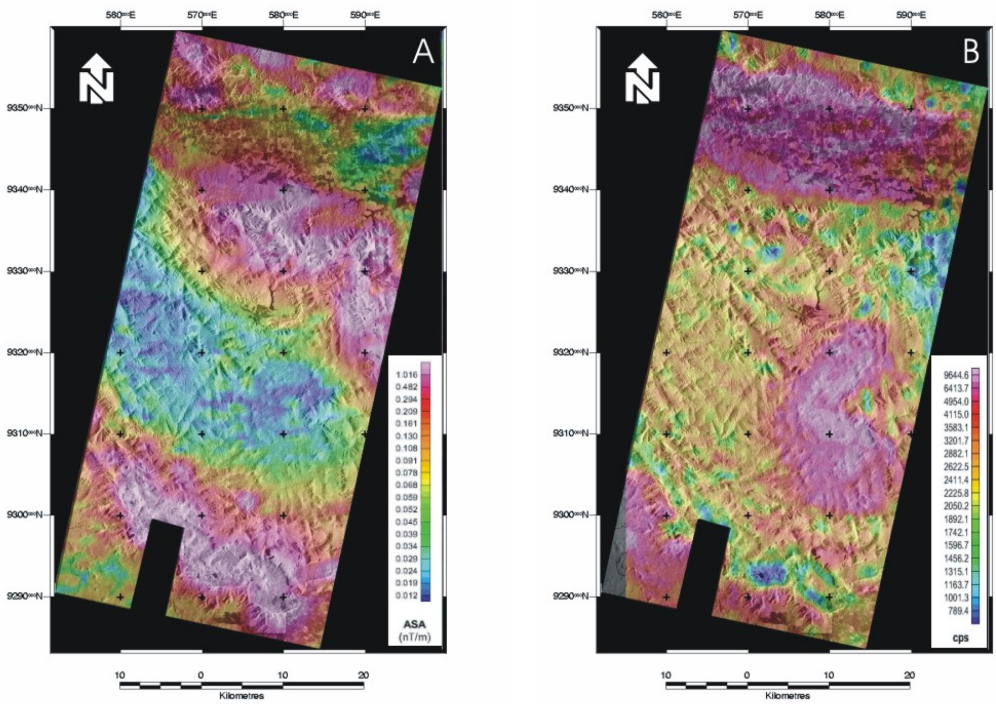

Figure 1 – Image fusion of simulated MAPSAR and aerogeophysical images: (A) MAPSAR fused with magnetometric image (amplitude of analytical signal); (B) MAPSAR fused with gammaespectrometric image (total count channel).

Geophysical filtering techniques, such as AAS, are quite effective for enhancing magnetic anomalies in low latitude areas, as in the case of the Carajás Mineral Province. In the MAPSAR+Mag/AAS fused image these anomalies can be readily related to surface (relief) patterns.

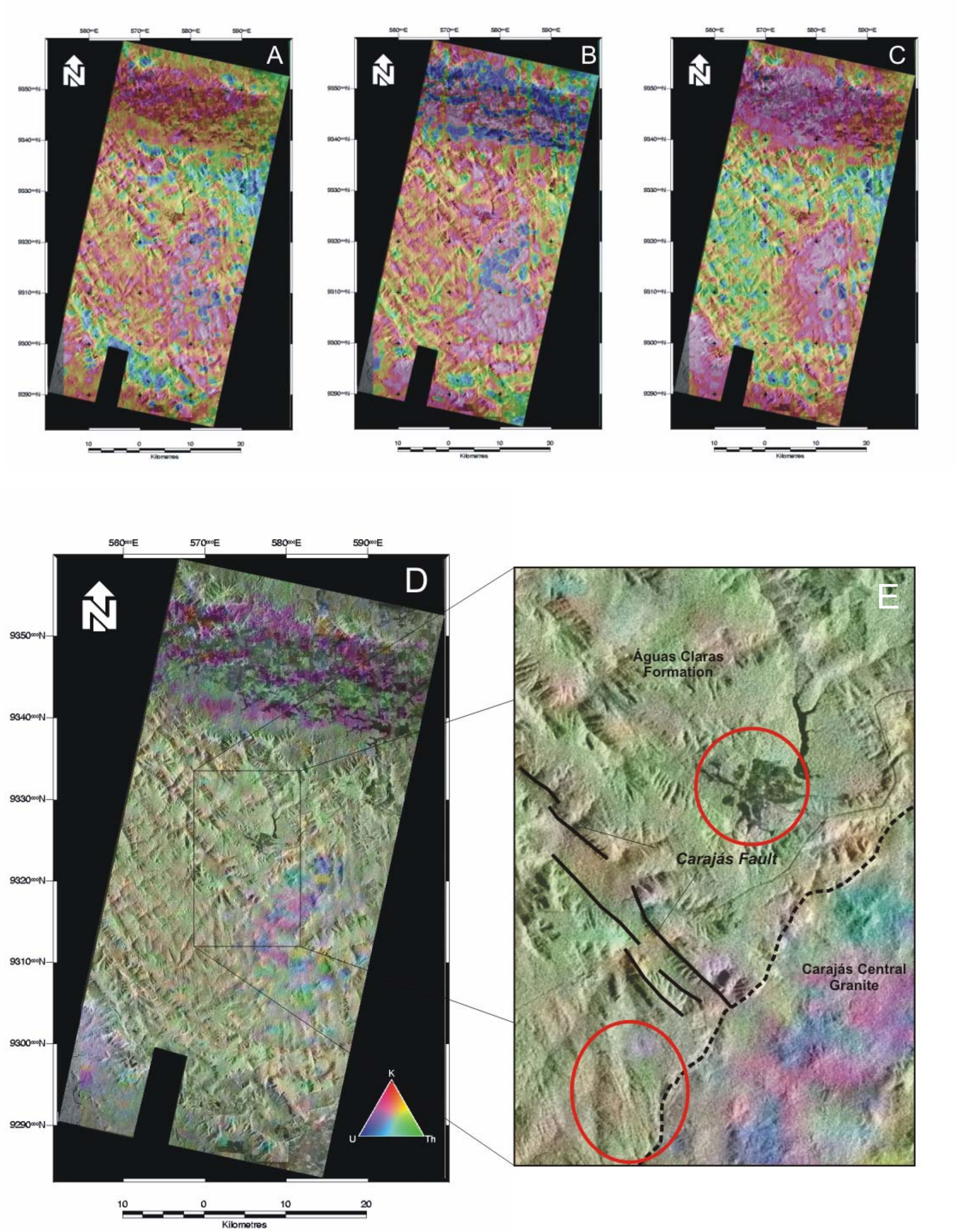

Figure 2 – Image fusion using simulated MAPSAR and airborne gammaspectrometric images: (A) K channel; (B) Th channel; (C) U channel; (D) color composite of K-Th-U in RGB. (E) Detail of figure 2D for comparison with simulated RADARSAT data (see also Figure 4E).

Variations in the lithologic composition, as well as sharp changes in relief texture caused by different geologic units, can be readily interpreted from the fused SAR+gamma image product, such as those shown in **Figure 1**. The recognition of the major domains, based on a combination of relief patterns and mag/gamma patterns, allowed establishing the boundaries between different litho-stratigraphic units.

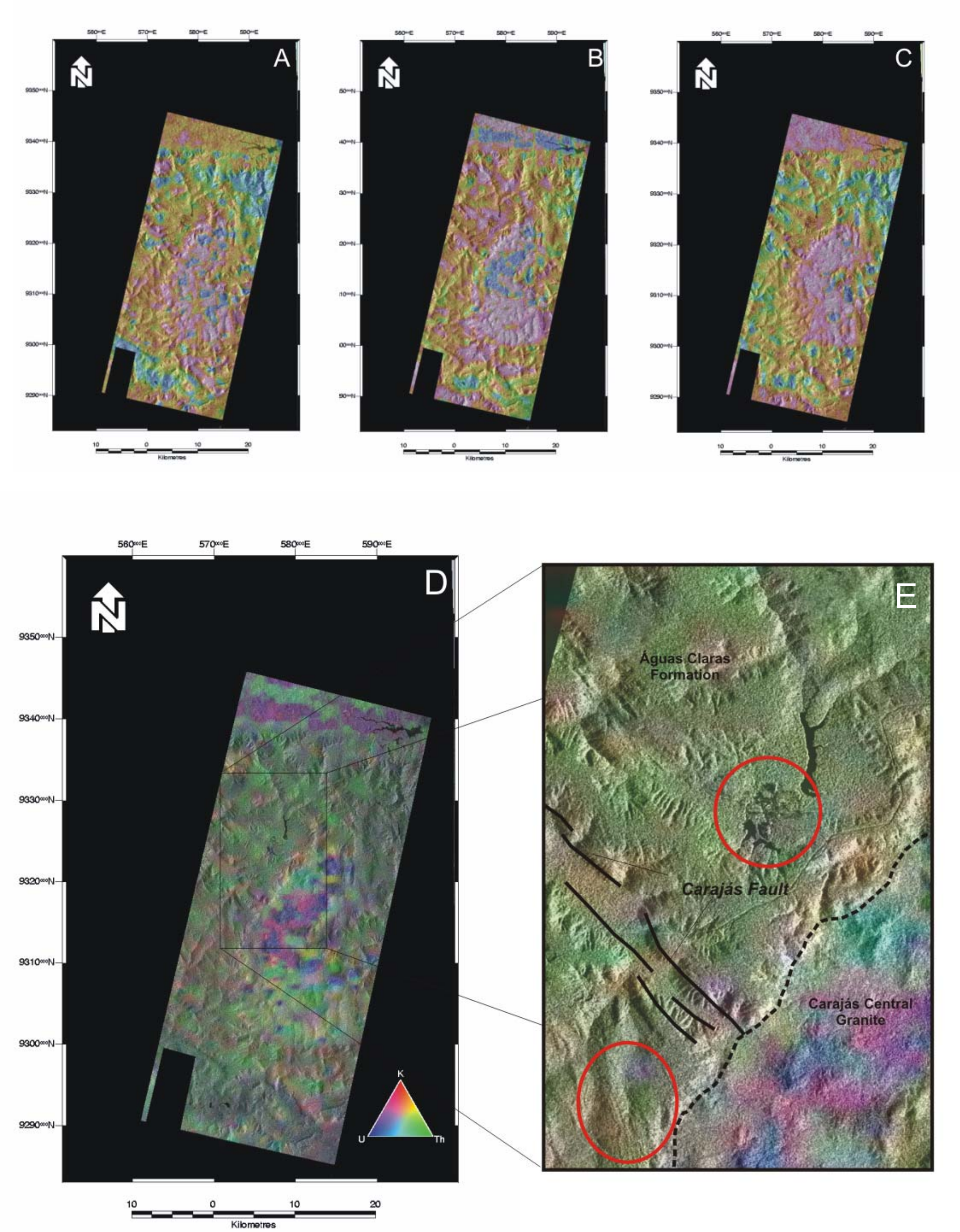

Figure 3 – Image fusion using RADARSAT (C-Band - Fine mode) and airborne gammaspectrometric images: (A) K channel; (B) Th channel; (C) U channel; (D) color composite of K-Th-U in RGB. (E) Detail of figure 4D for comparison with simulated MAPSAR data (see also Figure 3E).

The comparison between the results obtained by SAR+geophysics image fusion shows that MAPSAR data was able to enhance textural and tonal attributes which were not clearly depicted in higher spatial resolution RADARSAT-1 data (**Figure 2D**). Some areas which exemplify this result are marked with red circles in **Figures 2E** and **3E**.

6. Conclusions

Results achieved through this investigation show that the integrated analysis of fused MAPSAR+geophysics images are especially useful for geologic mapping. This is due to the fact that these integrated images enhance lithological, compositional and structural attributes, which in turn provide fundamental information about the unexposed geology typical of the Amazon region.

The combined use of MAPSAR and airborne geophysical data (even from pre-existing, low resolution surveys acquired in the 1970´s and 1980´s) therefore represent an effective and low-cost alternative in the initial phases of geologic mapping and regional mineral exploration campaigns in the Amazon, where thick vegetation and deep soil coverage do no allow direct access to the bedrock.

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