Geological and Geophysical Study of Nova Era and São Domingos do Prata Domains – Minas Gerais, Brazil.

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Abstract

The main objective of this study consisted on the identification of potential areas for emeraldiferous deposits located in the mesoregion of Itabira, Minas Gerais. The delimitation of the areas of interest was based on the application of the integrated geological and geophysical mapping method and intuitive graphical technique for the recognition of possible target areas of gemstones deposits in an area of 35 km^2 approximately located in the Itabira and Nova era Emerald Province, northwest of the Iron Quadrangle. In order to perform this work, aerial magnetic and radiometric data referring to area 2 of CODEMIG, published in 2001, were used. Furthermore, the geological data presented in the mapping campaign of Folha Coronel Fabriciano inserted in Projeto Leste, published in 2000 were also used as a source of data. Therefore, the following steps were performed: a bibliographic review, data processing through Oasis Montaj software Geosoft 7.01, ArcGis 9.3, OpenStereo 0.1.2 and Euler 1.0, geological-geophysical integration, field activity to confirm the integrated interpretations performed and the development of a final report. Thus, from knowledge of the emerald´ genesis and its occurrence at the region added to integrated analysis between the thematic maps generated (geological and geophysical data), was possible to identify primary and secondary potential areas for prospecting of emeralds.

Introduction

The study area is located in the region of Itabira and Nova Era, southeast center portion of Minas Gerais state. It is known worldwide for its mineral richness and positioned within the limits of the Emerald Province of Minas Gerais State, inserted in the Guanhães Complex domains, northwest of the Iron Quadrangle, in between the North of Rio Casca and the south of Guanhães (Delgado, 2007; César-Mendes e Svisero, 1989) (Figure 1).

In this context, the research consisted on the application of geological-geophysical mapping techniques in a selected field of 35m^2 in between the municipalities of Nova Era and São Domingos do Prata, MG (Figure 2). Due to confidential agreements, the precisely location of the investigated area will not be published.

Thus, the main aims were to determine areas of interest for possible mineral deposits, with potential for emerald through the application of the geological and geophysical mapping method and intuitive graphical technique in the Nova Era and São Domingos do Prata region, in Minas Gerais, Brazil. The research was developed between the months of July and November 2016.

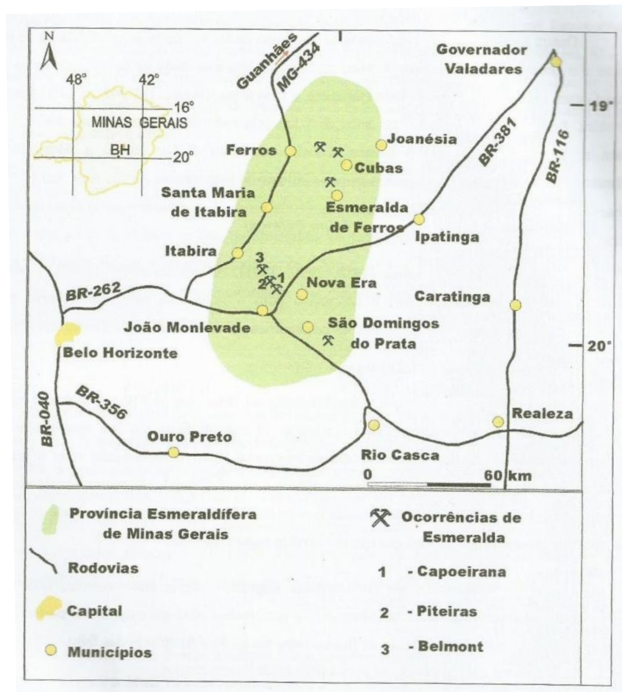

Figure 1 - *Emerald Province of Minas Gerais State, modified from César-Mendes, 2000.*

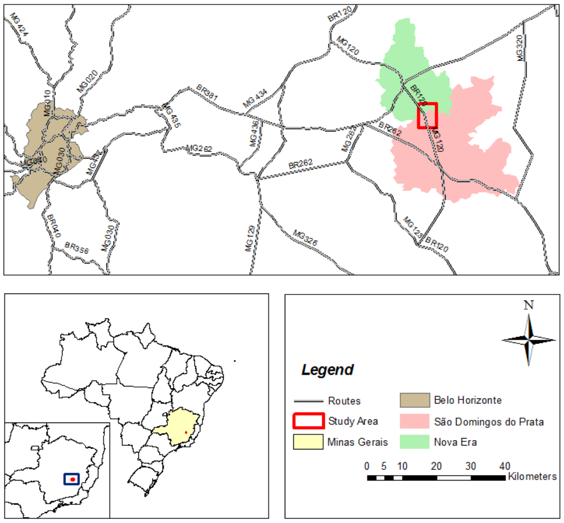

***Figure 1** - Location map and access routes to the study area.*

Method

The present study started with the bibliographical review to obtain geological data on the regional and tectonic structural aspects dominant in the region, besides emphasizing the main mineral genesis of interest in the area investigated, associated to the emeraldiferous deposits.

The geophysical data base used was: aviation geophysical survey of Codemig, scale 1: 25,000, denominated Area 2, conducted in 2001 through DNPM and CPRM. These data were provided by the CPRM, which, in turn, joined the techniques of processing, filtering and interpretation of geophysical data: magnetometric and radiometric. Folha Coronel Fabriciano's regional mapping on the 1: 100,000 scale, carried out by CPRM in the context of the Eastern Project, published in 2000, was also used as a source of information.

In this context, a qualitative analysis was performed in which the MAG_2E and RAD_2E files were imported into the Oasis Montaj Geosoft 7.01 for ".gbd" file generation and, through the "WINXY" routine and files in the ".xyz" format, data were processed for interpretation and correlation with the geology of the studied area.

The database was interpolated according to a constant 300m mesh for making magnetometric thematic maps: total magnetic field, anomalous magnetic field, analytic signal amplitude (ASA), derived from analytical signal amplitude (DASA), first anomalous magnetic field vertical derivative (Dz), first horizontal derivate, (Dx) and (Dy). In addition to the generation of radiometric maps (potassium channels in % (K), uranium channels in ppm (U), thorium channels in ppm (Th), total counting (CT), ratios between eU/Th, eU/K, eTh/K; F Parameter map and ternary radioactive element map.

Using the ArcGis 9.3 the thematic maps generated were integrated for a qualitative interpretation of the data. From the radiometric maps (CT, F parameter and ternary radioactive element map) and magnetometric maps (ASA, Dx, Dy), marked lineages were delineated in the investigated area. In this same context, the observed lineaments were plotted in steronets for interpretation from the OpenStereo program. Magnetophases were also established based on the amplitude map and analytic signal amplitude (ASA), as well as the radiophases were determined from the ternary image.

Continuing in the process of qualitative analysis, the magnetic anomalies present allow to identify, in the majority, the structural directions of a given region. Similarly, the ternary radioactive element map is widely applied in the geological characterization exercise, since the joint arrangement of the radioelement distribution in a single image contributes to the delimitation of the compositions of the geological units present in a given area (Kearey *et al.*, 2009). Therefore, the maps of ASA, Dx, Dy and Ternary Image were the most revelant maps used in this phase of the research.

Through the free version of the Euler 1.0 software, the Euler deconvolution (3D) was applied from 6 profiles distributed 1000m equidistant in the interested area. Combined with the previously studied geological data, it has allowed the quantitative analysis of the subsurface geological structures by the 3D visualization of its structures and its estimated depth.

In the sequence, information included from the analyzed bibliography added to the data generated, integrated and interpreted together, were essential to evaluate the aspects that control the regions interpreted as the areas of interest and possible mineral deposits. Thus, the target regions were arranged in probabilistic maps based on the genesis of emeralds and their occurrence in the region studied.

Thus, a field trip was concluded in order to confirm the interpretations, previously performed and to validate the resulting target regions based on the integration of the analysis accomplished. Consequently, the areas classified as target regions were then arranged in concordant final probabilistic maps based on controlling factors of the genesis of emeralds, its occurrence in the region and the resulted data from the field.

Examples

According to Silva (2000), the area studied belongs to the Araçuaí Belt of the Brasiliano Cycle, which is located in the northern portion of the Mantiqueira Geotectonic Structural Province (Almeida & Litwinski 1984, Almeida & Hashui 1984, Padilha *et al*., 1991). Archaean rocks belonging to the Mantiqueira Complex, locally intercalated with the Rio das Velhas Supergroup, were mapped in these domains. Furthermore, lithologies from the São Sebastião do Soberbo Metamorphic Suite and from the Borrachudos Suite, metasediments of the São Tomé Formation, Rio Doce Group were also characterized in the region. In addition, newer units that cut these rocky bodies, such as dikes and sills of metagabbros and metadiabases and Quaternary units also compose the stratigraphy of the area (Figure 3).

Most of the emerald mineralization in the region is lithologically controlled by the presence of vulcanosedimentary sequence (metapelitic schists, metaultramafic schists, amphibolites, quartz veins and pegmatoid vein) in contact with granitic gneisses(Souza *et al.*, 1987). In other words, it is necessary the combined occurence between mafic rocks rich in Cr, V, Mg with felsic rocks rich in alkalis and Be (Frantz et al., 1996).

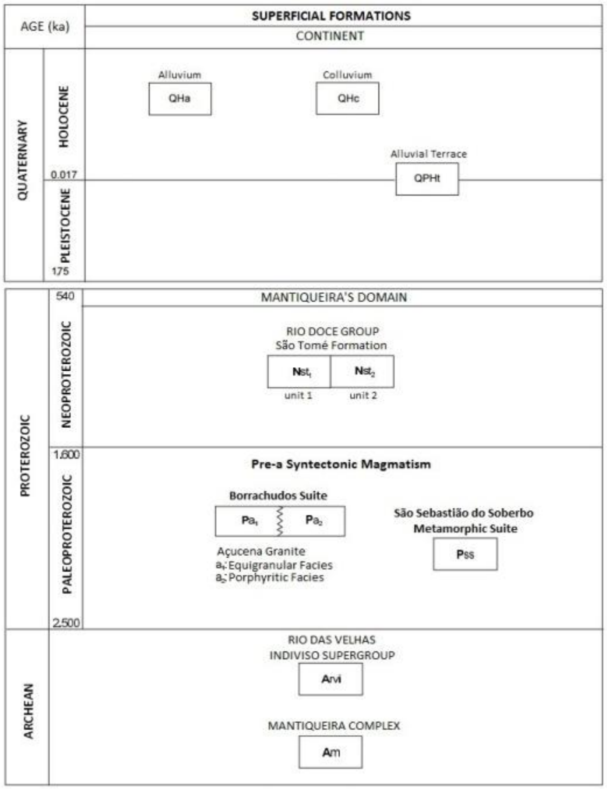

Figure 2 - *Litostatigraphy column of Coronel Fabriciano's regional mapping project, modified from Silva, 2000.*

Furthermore, the structural control plays a role in the formation of emerald deposits through the occurrence of faults, shear zones, fractures and foliations. It allows a better interaction between the essential elements for their crystallization as well as provide a channel for the percolation of residual solutions of the crystallization of pegmatites or hydrothermal veins, normally rich in K, Be, Ti, Si, and H_2O (Souza 1988, D'el Rey Silva & Giuliani 1988, Frantz et al. Al. 1997, Machado 1998).

For that reason, the radiometric and magnetometric thematic maps created were interpreted based on the lithological and structural controls of the mineralization of the emeralds. Consequently, the study of the lineaments and the integration between the geological and geophysical data and correlation between the lithologies, mineralization controls and geophysical interpretations were carried out to pre determine potential areas to be analyzed and visited in the field trip concluded.

Therefore, lineaments and magnetofacies interpretation (Figure 4) were interpreted through the derivative maps (Dx and Dy) as well as the ASA map. Were identified 50 main lineaments, which have shown in the rose diagram (through the Open Stereo software 0.1.2) a preferred direction for NW (346.6º).

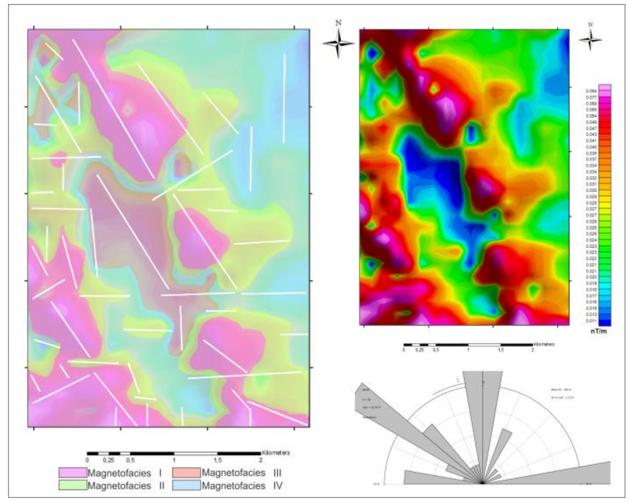

Figure 3 - *Lineaments analisys and magnetofacies characterization based on the ASA map. Roseta with preferential of lineaments and original ASA map.*

On the other hand, the qualitative analysis of the radiometric maps was mainly concluded using the CMY ternary image, due to its great lithological affinity and conformity with the regional mapping of the area. Thus, combined with the other thematic maps generated, 61 lineaments were drawn, most of them with preferential direction for NW (332.9º) (Figure 5).

The combined analysis using the geological information and the geophysical analysis are exemplified by the Figure 6 and Figure 7, based on the radiometric and magnetometric data, respectively.

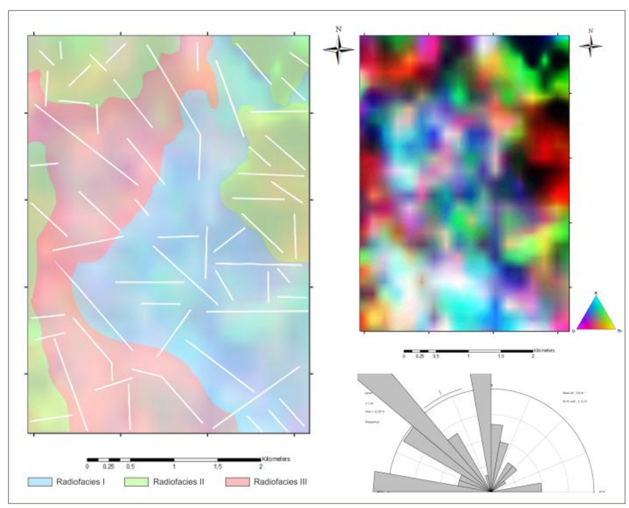

Figure 4 - *Lineaments and radiofacies characterization through CMY ternary radioactive element map and the analysis by OpenStereo 0.1.2.*

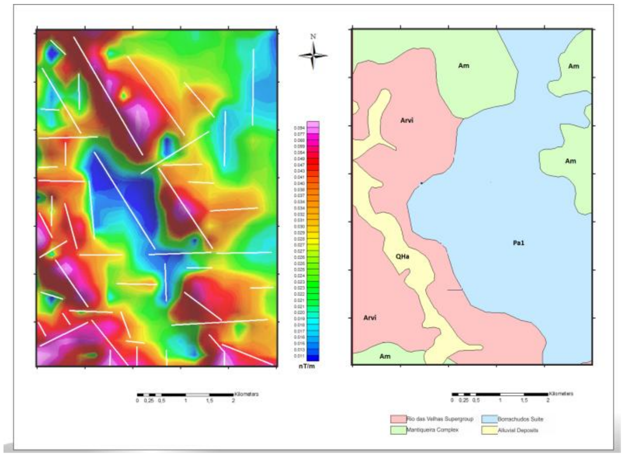

__Figure 5 -__ Geophysical and geological integration based on geophysical analysis and regional geological map from the Coronel Fabriciano's Mapping Project published in 2000 (See figure 3 for lithotype label especification).

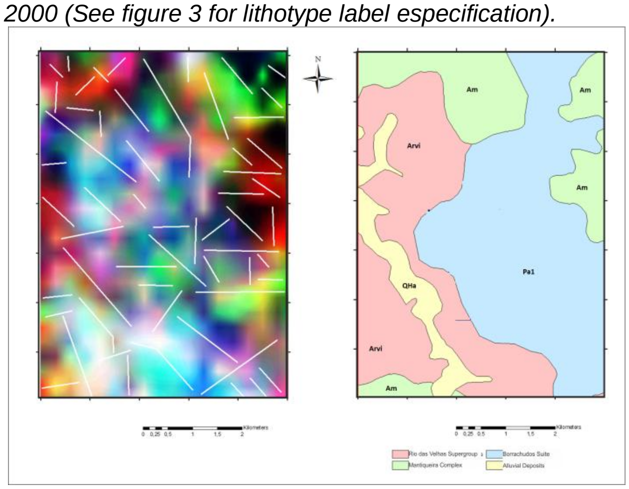

__Figure 6 -__ Interpreted lineaments overlayed on the CMY ternary radioactive element map and geological information from Coronel Fabriciano's Mapping Project, published by CPRM in 2000 (See figure 3 for lithotype label especification).

Results

The quantitative analysis was performed by 6 Euler deconvolution profiles traced in the ASA map. The inversion process was accomplished under the following predefined parameters: structural index = 1 and maximum depth of 925 meters.

As can be observed in Figure 8, the Euler deconvolution profiles show structures that vary between 200 and 500 meters deep, and can reach up to 800 meters approximately. These structures are associated with folds and, mainly, faults, as the indicative arrows show in Figure 8. In general, it is observed that the main structures of the studied region do not have very expressive depths, which indicates that the magnetometric anomalies are unlikely related to a specific lithological type, but rather associated to the remobilization of fluids rich in ferromagnetic materials structurally controlled, for example, through failures and folds.

As shown in Profile 3 exemplified below, the most superficial structures reach up to approximately 300 meters in depth are related to very intense magnetic responses represented by the high and low magnetic answers at the ASA map. The deeper structures can reach approximately 700 meters. They are also related to magnetic anomalies, but in this case with very well marked structuration (preferential direction - NW-SE) with great extension in the studied area.

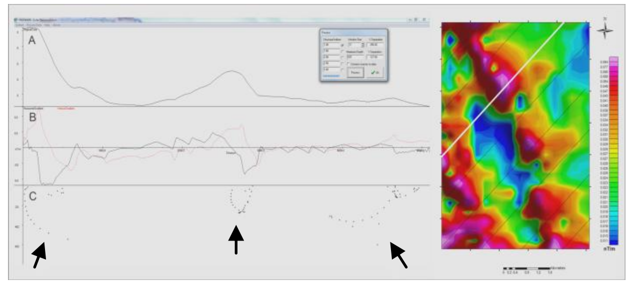

__Figure 7 -__ Profile 3 of Euler deconvolution realized through software Euler 1.0 from the ASA map. The profile shows: __A.__ generated data; __B.__ horizontal gradients (in black) and vertical gradients (in red); __C.__ depth estimation of the anomalies.

Further, after the deconvolution of all 6 profiles, the data obtained were compiled using a kriging method in the ArcScene 9.3 software in order to generate the 3D model (Figure 9). So, it was possible to visualize the anomalies and lineaments present in depth. Furthermore, it enabled the differentiation of those structures the ones observed in 2D.

In general, the structural analysis performed in both, qualitative and quantitative analysis, showed that there is a strong association between magnetometric structures, such as lineaments, geological contacts, and interpretations from radiometric analysis. Majority in the western portion of the area, the lithological contacts are also directed to the lineaments interpreted from the geophysical data. For instance, the deconvolution profile shows its correlation with the main lineaments that control the study area.

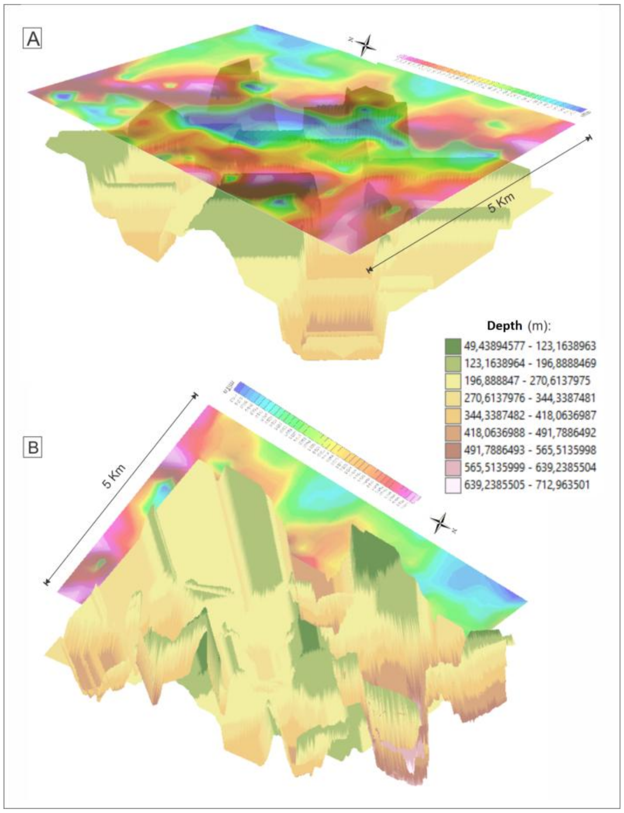

Figure 8 - *View of the 3D model generated from the kriging technique in the ArcScene 9.3.* ***A.*** *Top view of the model* ***B.*** *Lower view of the 3D model shown in A.*

Followed by the processing data stage of this study, a field trip were concluded in order to verify the results from the laboratory analysis. In this context, the thematic maps created from the data and the integration analysis based on the geological, geophysical, structural and genesis control factor and the results from the quantitative analysis enable, all together, the elaboration of two probabilistic maps. The first one superficial and the other sub superficial, from the radiometric and magnetic information, respectively (Figure 10).

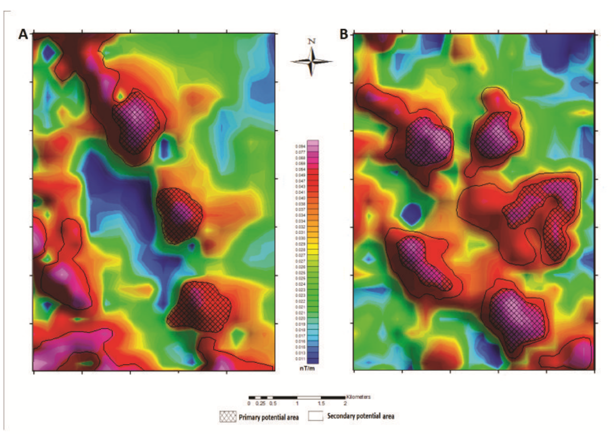

Figure 9 - *Probabilistic thematic maps.* ***A.*** *Magnetometric Probabilistic Map.* ***B.*** *Radiometric Probabilist Map.*

The first thematic map showing the arrangement of magnetometric anomalies may be associated with shear zones, areas of alteration, mafic-ultramafic rocks in depth as well as possible mineralizations. On the other hand, the probabilist map based on the radiometric analyzes, correlate superficial aspects and the emerald genesis characteristics in the region to elucidate possible potential areas for emerald prospecting.

Then, in order to better investigate the potential areas delimited in these two maps, the superficial probabilistic map was used to determine the points to be visited. In fact, the field activity proved the effectiveness of the geological characterization from the interpretation of the radiometric thematic maps. Subsequently, an old dig was found in the point 3 (Figure 11) and an active artisanal emerald mining located in the fourth pointed visited in a predetermined area prospective potential (Figure 12).

Figure 10 - *Old dig found in the field trip at the study area.*

Figure 11 - *Active artesanal emerald´ mining found during the field trip. View of the mining dump*.

The presence of this small scale underground mine in the previously delimited area as a target area was an important found, since it proved the quality and effectiveness of the model used. In addition, in the artisanal mining boundary was observed the occurrence of tectonic contact between the ultramafic rocks and the granites of the Borrachudos Suite as well as its association to the mineralization of the emeralds in the region.

Thus, based on the information obtained in the field, a final probabilistic map was created (Figure 13). It suggests that the positive radiometric anomaly inserting points 4, is the first primary target area to be better studied among the regions of interest. Among the target areas delimited and visited in the field, it stands out for its proximity to the contact between rocks of the Rio das Velhas Supergroup and the Borrachudos Suite. It is important to point out that the occurrence of the mining is surrounds that area. Similarly, the positive anomaly placed in the investigated points 8 and 9 should be highly considered as they still lithologically and sctructurally correlated to the point where was confirmed the emerald occurrence. In both anomalies the lineaments interpreted and the magnetometric analyzes also show their strong potential.

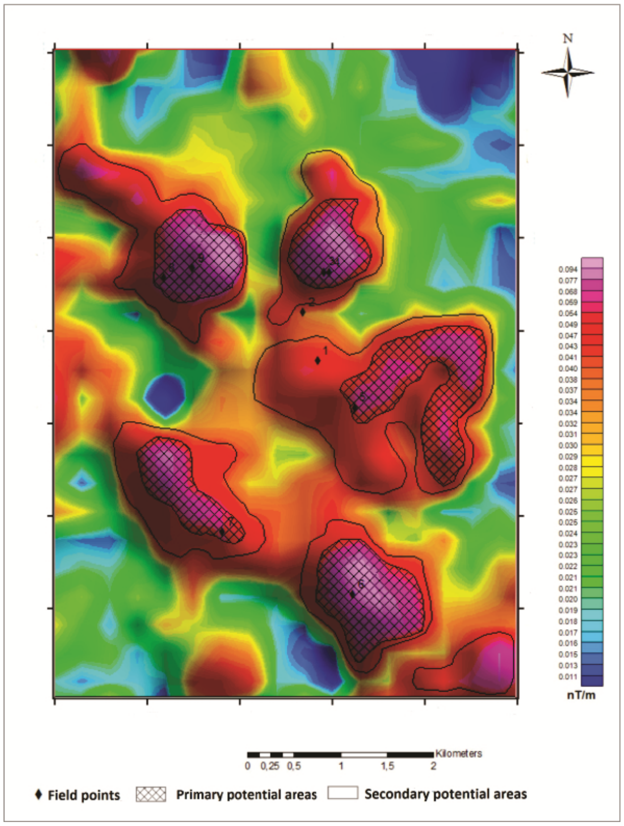

Figure 12 - *Final probabilistic map of the target areas for emerald deposits based on superficial information.*

Conclusions

The applied methods were essential for the analysis of the controlling factors of the emerald mineralization in the studied region in order to identify the potential areas. Therefore, the applied techniques were successfully accomplished in the identification of lithotypes, delimitation of geological contacts and possible hydrothermal zones associated to the shear zones, which allow the interaction between the fluids from the Borrachudos´ granites, rich in Be, with the fluids from ultramafic rocks rich in Chromophores. Thus, the possible occurrence of the emerald was confirmed if, in this case, there is associated hydrothermalism.

Similarly, the in-depth structural study through Euler deconvolution method was crucial for the visualization of 3D anomalies. It has contributed to the interpretation of the structural aspects, possible shear zones and failures possibly associated with mineralization. The obtained data and the results were consistent with the field observations, which confirmed the efficiency of the model applied. In addition, it has verified the potential of the study area through the identification of the most favorable regions for the occurrence of the emerald deposits.

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