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Gold ore identification in Santa Catarina Gabbro using electrical resistivity tomography (ERT) and visualization of mineralization in three dimensions, São Sepé, Rio Grande do Sul, Brazil

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Abstract

This work presents the geological-geophysical characterization of a probable occurrence of gold in Santa Catarina Gabbro, in São Sepé region, Rio Grande do Sul state, southern Brazil. Previous works have indicated the presence of gold in the region in current sediments geochemical prospecting campaigns and suggests that the source area would be the Santa Catarina Gabbro. To investigate over this probable occurrence of gold, geological and structural surveys were conducted, followed by the acquisition of geophysical information using the DC-resistivity and IP methods, with the dipole-dipole array. The geophysical data were processed in 2D inversion and then interpolated to allow the three-dimensional visualization of possible mineralization. Interpretations based on the compilation of geological and geophysical data, in association with the regional structural context, suggest that the probable mineralization were originated from the intrusion of the São Sepé Granite, whose hydrothermal fluids were hosted in fractures during the tectonic events that occurred in the region. The results obtained in this work allow to outline a feasible deposit architecture with the geological context of the region and to assist a future drilling strategy aimed at the identified probable targets.

Key words: Mineral research, Resistivity Chargeability, Electrical tomography, Gold.

Resumen

Este trabajo presenta la caracterización geológica-geofísica de una probable ocurrencia de oro en el Gabro Santa Catarina, en la región de São Sepé, estado de Rio Grande do Sul, sur de Brasil. Trabajos anteriores han indicado la presencia de oro en la región en las actuales campañas de prospección geoquímica de sedimentos y sugieren que el área de origen sería el Gabro Santa Catarina. Para investigar sobre esta probable ocurrencia de oro, se realizaron estudios geológicos y estructurales, seguidos de la adquisición de información geofísica utilizando los métodos de resistividad DC e IP, con el arreglo dipolo-dipolo. De estos datos se obtuvieron inversiones 2D las cuales luego fueron interpolados para permitir la visualización tridimensional de la posible mineralización. Interpretaciones basadas en la recopilación de datos geológicos y geofísicos, en asociación con el contexto estructural regional, sugieren que la probable mineralización se originó a partir de la intrusión del Granito São Sepé, cuyos fluidos hidrotermales se alojaron en fracturas durante los eventos tectónicos ocurridos en la región. Los resultados obtenidos en este trabajo permiten delinear una arquitectura de yacimiento factible con el contexto geológico de la región y ayudar a una futura estrategia de perforación dirigida a los objetivos probables identificados.

Palabras clave: Investigación mineral, Resistividad, Cargabilidad, Tomografía eléctrica, Oro.

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1. Introduction

The world demand for mineral resources has increased significantly in recent years and, on the other hand, the number of discoveries of new economically viable mineral deposits has decreased. The discovery of new mineral deposits means ensuring the provider of metallic and non-metallic goods to supply the current demand (Marjoribanks, 2010; Mostafaei & Ramazi, 2018). Giant mineral deposits have already been discovered over the course of the 20th century and new probable deposits are far from economic consumer centers, in places whose complex climatic and geological conditions require technology and large financial investments to detect or even exploit them.

The geophysical methods applied in prospecting and mineral research use the contrast of physical properties between the host rock and a potentially mineralized target and assist in the determination of new mineral deposits. DC resistivity (DC) and induced polarization (IP) are important survey techniques for mineral prospecting and enable fast and low cost surveys in mineral deposit studies (Chapman & Mortensen, 2016; Deng & Wang, 2016; Dentith & Mudge, 2014; Marjoribanks, 2010; Moon *et al.*, 2006; Zonge *et al.*, 2005). The use of automated geoelectric data acquisition systems, due to its versatility, has been widely disseminated to solve environmental, hydrological, geotechnical, and especially mineral research, in which a greater detail of the subsoil is sought. The low cost, high speed and wide area of data acquisition and good response in complex and heterogeneous geological environments has driven the use of this technique by several authors in the last decades and has been successful in determining targets (Amidu & Olayinka, 2006; Côrtes *et al.*, 2016; Dahlin & Loke, 1997; Gouet *et al.*, 2016; Griffiths & Barker, 1993).

Gold has high mobility in soils, especially in tropical regions, as is the case in the study area. The formation of some deposits depends on the mobility, transport, and precipitation of gold in regions of strong weathering. The acquisition of geochemical data is also very important, since the high mobility of gold can lead to the concentration and generation of rich deposits (Biondi, 2015; Mann, 1984; Vasconcelos & Kyle, 1991). The association of geochemical and structural methods can direct the geoelectrical studies in the detection or detailing of targets and achieve the success in the investigation.

The southern center of Rio Grande do Sul state was an important mining province in the early 20th century. The mineralization of the São Sepé region, where the present study area is located, is associated with milky quartz lodes intruded in basic and metabasic rocks. The main deposits of gold were recognized in the mines of Bossoroca, Cerrito do Ouro, Passo da Juliana, Guardinha, Lavrinha, Viúva Guerra Durval and Estuque (Bettencourt, 1972; CPRM, 1995, 2014).

The presence of gold in the Santa Catarina Gabbro was indicated geochemical exploration in current sediments in recent fluvial sedimentary deposits conducted in previous geological and metalogenetic surveys (CPRM, 1995). Similar DC (> 5,000 Ω.m) and IP (> 10mV/V) values for this type of mineralization have been described in geophysical surveys carried out in the region by some authors and served as a basis for correlation in this work, and this shows that, in fact, the use of electrical methods are reliable for metals prospecting (Côrtes *et al.*, 2016; Moreira *et al.*, 2012, 2016; Moreira & Ilha, 2011).

2. Materials and Methods

Investigations in the study area started with detailed geological mapping and collection of structural data. Then, the acquisition of geophysical information was carried out. The equipment used in the geophysical survey was the Terrameter LS resistivity meter, manufactured by ABEM Instruments (Sweden), with a resolution of 1μV (ABEM, 2012). This equipment is calibrated for resistivity measurements by periodic

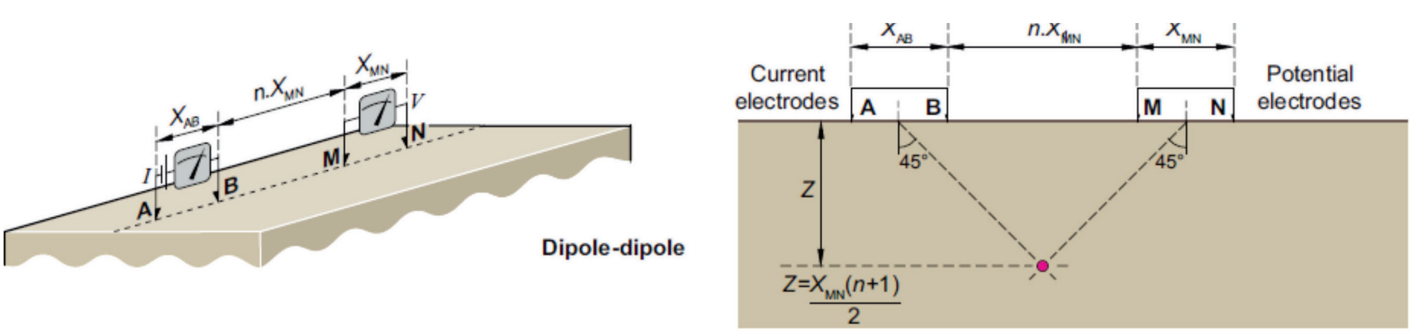

Figure 1. Scketch of the dipole-dople array used in this study that was adapted from dipole-dipole array. Adapted from Keary (2009).

cycles of alternating and low frequency electrical current. This procedure allows the noise filtering of the acquired signal. Data was obtained by using the dipole-dipole arrangement and the methods of Electroresistivity and Induced Polarization (Dentith & Mudge, 2014). The dipole-dipole array presents good lateral resolution and good results in the identification of vertical structures, as it is the geological context of the study area (Moreira *et al.*, 2016; 2018; 2020; Cortês *et al.*, 2019). For the studied targets the dipole-dipole arrangement, associated with the geological and structural surveys carried out in the field, returned promising results with the geological reality of the mineralized bodies.

The dipole-dipole array is the most widespread among the several existing for the realization of electrical imaging. It consists of an arrangement widely used in mining, underground water prospecting, environmental studies and engineering geology (Telford *et al.*, 1990). In the dipole-dipole array the electrodes are arranged in lines and the spacing between the pairs of current and potential electrodes remains fixed during data acquisition. The data acquisition consists in obtaining several measurements, with fixed and equal spacing of the emission dipole (AB) and of the reception dipole (MN) (Figure 1).

During the acquisition of geophysical data, both resistivity and chargeability the arrangement is displaced "n" times the distance equal to the dipoles spacing. The measured value is then represented at a point on the surface located at the intersection of the lines that depart 45° from the center of the dipoles, positioned at the midpoint between them. Higher depths of investigation are achieved as the distance between the dipoles increases but limited by an acceptable value where that corresponds to the potential readings higher than the noise level present at the investigated site. By repeating this procedure, a pseudosection of apparent electrical resistivity is generated along the survey line (Coggon, 1973).

The geophysical data collected were processed using the software Res2Dinv (Geotomo, 2003). This software is able to analyze large data sets and to determine, based on inversion method, a two-dimensional model of resistivity and chargeability for the subsurface (Griffiths & Barker, 1993).

In the inversion process the pseudo section generated by the acquired data is represented by a mesh of rectangular equal area, each with its own resistivity (Milsom & Eriksen, 2011). The smoothing inversion method, used in this work, is based on the mathematical method of least squares, which aims to minimize the sum of the squares of errors between the model response and the observations. The RMS values are high, possibly due to the large contrast of values in each section. During the data acquisition period, which took place towards the end of the rainy season, the contact resistance values were low consequently. Information regarding the topography and azimuth along each line were obtained by compass and a digital elevation model. The distance between the lines were determined using a measuring tape. In this way, the data processing considered the topographic adjustment and the inversion model.

The difference between the apparent resistivity values, measured in the field and calculated by the resistivity adjustment of the block model is expressed by the RMS error. The final data are presented in the form of sections of resistivity and chargeability in terms of distance versus depth, with a logarithmic graph scale and interpolation intervals of color values (Loke & Barker, 1996).

After the 2D inversion at each line, the generated data were collected in a single file, later used as a database for the generation of quasi 3D models and depth maps, using Oasis Montaj software (Geosoft, 2010).

The interpolation of the data for 3D visualization was performed using the kriging method, followed by the application of the statistical method of minimum curvature for smoothing the central values in relation to the extremities. The least curvature statistical method was used to solve the kriging border effect.

The ERT lines were set perpendicular to the main structures of the selected targets, allowing a greater contrast between the hosting rock and the structures like fractures and quartz veins, with emphasis on the mineralized zones. The main foliation of the rock is millimetric, penetrative and occurs in several directions, but there is a predominance for NW and NE, which are the main trends for the region, according to the literature (Biondi, 2015; CPRM, 1995; Jackson *et al.*, 1973).

3. Results and Discussion

3.1. Geologic and metalogenetic context

The Santa Catarina Gabbro is located at Sul-rio-grandense Shield (SRGS), which is a geotectonic unit located in the southern portion of the Mantiqueira Province, with predominance of metamorphic and sedimentary igneous rocks, in the south center of the state of Rio Grande do Sul, southernmost Brazil (Almeida *et al.*, 1981; Hasui *et al.*, 1975).

During the Neoproterozoic (~ 900-550 Ma) the SRGS was an important area of crustal accretion and reworking. The geochronological information indicates three main orogenic events: (i) crustal accretion phase with juvenile magmatism

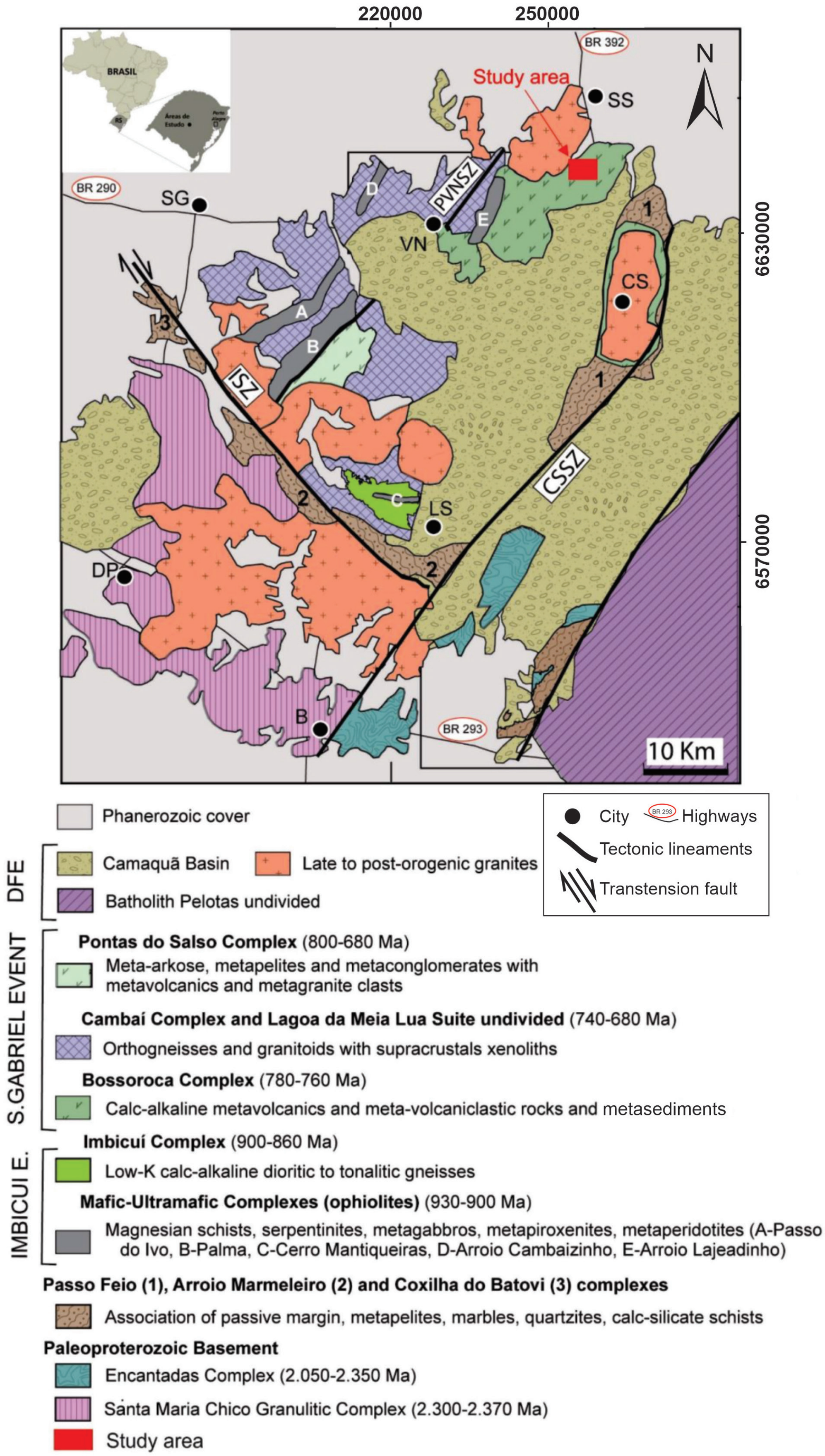

Figure 2. Regional geologic map. B: Bagé, CS: Caçapava do Sul, DP: Dom Pedrito, LS: Lavras do Sul, SG: São Gabriel, SS: São Sepé. Shear zones: SZPVN-Shear Zone Passinho/Vila Nova; SZI-Shear Zone Ibaré; SZCS-Shear Zone Caçapava do Sul (Philipp *et al.*, 2016).

between ca. 890 and 860 Ma; (ii) continental arc magmatism and accretion between ca. 770 and 680 Ma; (iii) collisional metamorphism between 650 and 620 and main magmatic phase between ca 650-550 Ma with a strong crustal anatexis caused by injection of magmas (Fragoso Cesar, 1991; Philipp *et al.*, 2016). The SRGS is limited by regional NE-SW lineaments and is divided in the terrains Taquarembó, São Gabriel (where the study area is located), Tijucas, Santana da Boa Vista and Pelotas (Andriotti, 1999; Fragoso Cesar, 1980; Fragoso Cesar *et al.*, 1982; Goñi *et al.*, 1962; Hartmann *et al.*, 2000; Pertille *et al.*, 2015; Philipp *et al.*, 2016).

The tectonic evolution in the SRGS indicates the closure of ancient oceans and the metamorphism of a sedimentary sequence (Bossoroca Metamorphic Complex) and marine bottom magmatism (Basic Metamorphic Ultrabasic Complex). The rocks of the Ultrabasic-Basic Metamorphic Complex show evidence of a genesis related to the sea bottom magmatism, possibly related to ophiolite sequences and reaction between basaltic magmas and peridotite rocks (Biondi, 2015; Philipp *et al.*, 2016).

Mineralized zones are not random geological accidents and devoid of connection with geological processes forming the earth's crust. The gold occurrences of Santa Catarina Gabbro probably were hosted in different portions and depths of that body by a specific post-magmatic event that produced heat in sufficient quantity to cause the mineralized solutions to flow to the host rock, the gabbro (Hartmann *et al.*, 2000; Koppe, 1990; Skinner, 1997).

The Basic-Ultrabasic Stratigraphic Complex is composed of ultrabasic portions of serpentinized peridotites, pyroxenites, in variable proportions; and another basic portion that includes gabbros, leucogabbros and anortosites, related to intrusive and tectonic events dating from the Lower Proterozoic (Rêgo, 1981).

This unit is divided into two plutonic bodies: the Pedras Pretas Massif and the Santa Catarina Gabbro. Pedras Pretas Massif has its geological, petrological and geochemical details characterized in previous works (CPRM, 1995; Rêgo, 1981). Santa Catarina Gabbro was originally described by early authors and will be detailed below (Rodrigues *et al.*, 1982).

The contact relation between the Vacacaí Complex and the rocks of the Basic-Ultrabasic Stratigraphic Complex is controversial, since authors discuss whether the bodies are related to the evolution of the basic-ultrabasic metamorphites (Issler *et al.*, 1973; Koppe *et al.*, 1985) or if they are considered as belonging to the transamazonic base exposed in nuclei of dipole structures (Soliani Jr., 1986). For the Santa Catarina Gabbro, which has a considerable extension in depth according to the magnetometric profiles of the Camaquã Aerogeophysical Project (Jackson *et al.*, 1973), there is no evidence

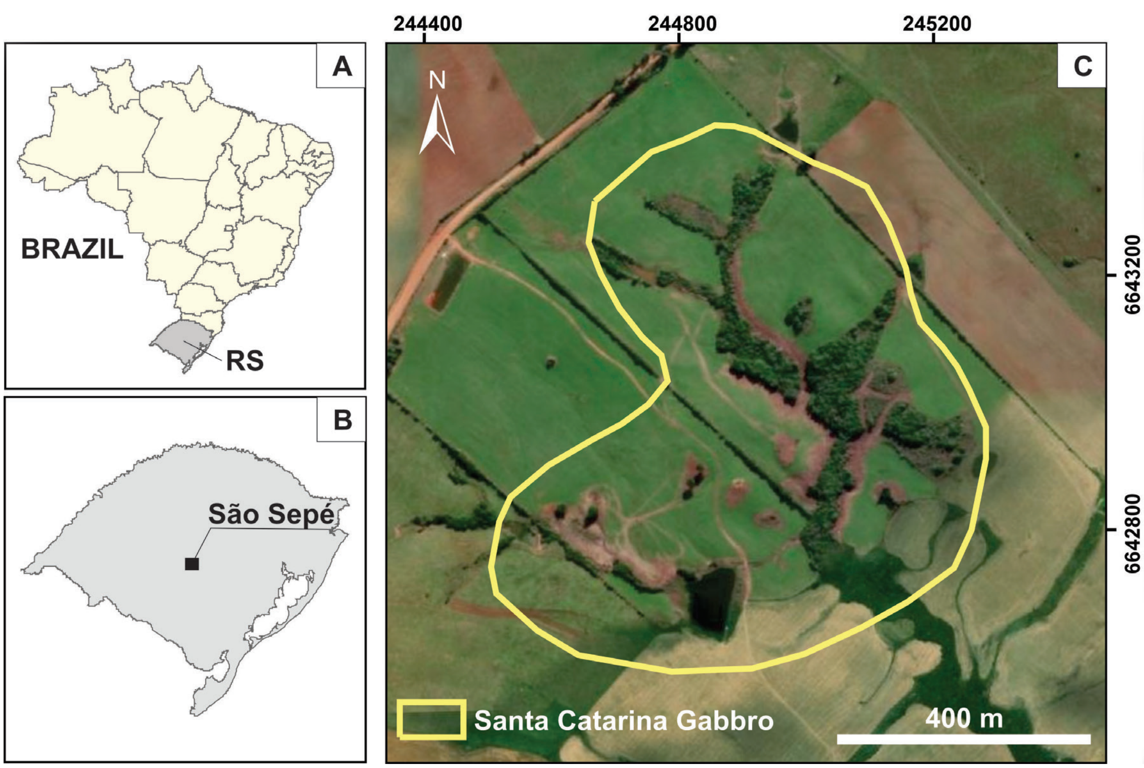

Figure 3. Localization of the study area.

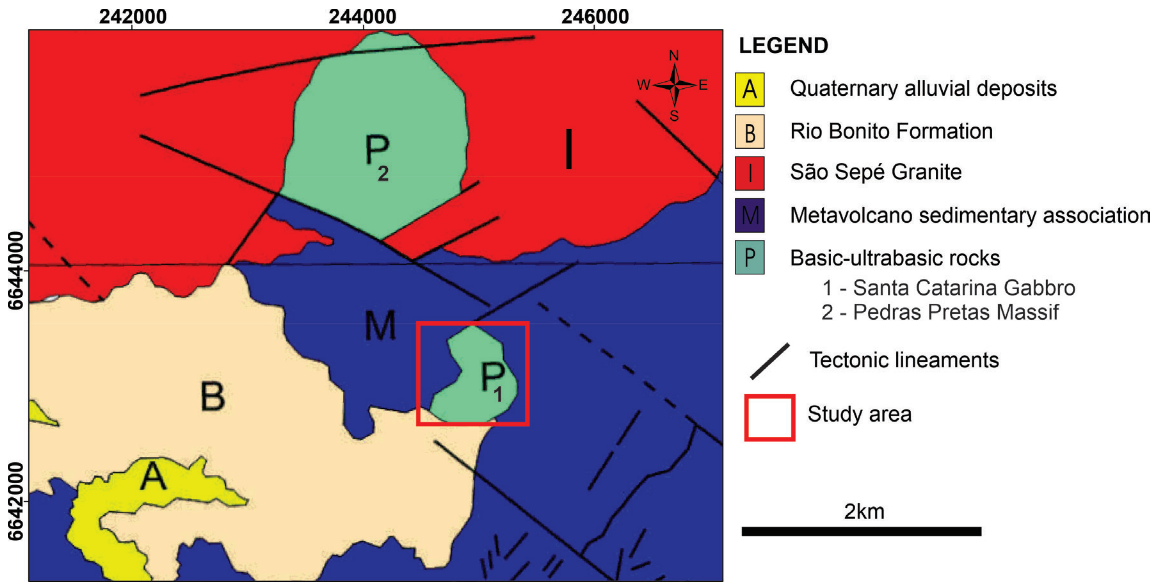

Figure 4. Local geologic map. Adapted from Andriotti (1999).

that it has been affected by the tangential deformation phases imposed on the rocks of the Vacacaí Complex.

Previous works correlate the Santa Catarina Gabbro with the Mata Grande Gabbro, whose adopted age is 2.2 Ga (CPRM, 1995; Rodrigues *et al.*, 1982). The relation of contact with the Pedras Pretas Massif is not clear, mainly due to the fact that these rocks are exposed in the form of blocks. However, in the ultrabasic nucleus in the southeastern portion of the Pedras Pretas Massif an intense fracturing is observed, which is the tectonic contact with Santa Catarina Gabbro. The Santa Catarina Gabbro exposed area covers 0.8 km^2 with outcrops of rounded boulders scattered across the field, whose dimensions reach up to one meter in diameter, and in slabs in drainage beds (Figure 4).

Due to the outcrop characteristics of this unit, it is difficult to visualize primary magmatic structures, although a fine irregular and discontinuous banding is observed, represented by the concentration of mafic minerals in levels of millimeter thickness. In the outcrops surveyed it was observed that the gabbro is quite fractured, whose directions predominate in the NNW direction.

Santa Catarina Gabbro mineralogy consists of plagioclase (45 to 80%), pyroxene (5%), opaque minerals (5%), apatite (2%), quartz (7%) and traces of alkali feldspar and zircon. The secondary mineralogy is composed of amphibole (30 to 50%), epidote (5%), chlorite (10%), sericite, carbonates, and secondary opaque (Rêgo, 1981; Rodrigues *et al.*, 1982).

The most common texture is the cumulate, with differentiated terms and unequigranular texture optic to subophic. The structure of the rock is massive, equigranular of fine granulation to medium and dark coloration. Therefore, the above authors classify this unit as gabbros, diorites and quartz diorites (subordinates).

Although the Santa Catarina Gabbro is inserted in a context of a metamorphic belt, the mineralogical composition does not indicate that the rock has been affected by regional metamorphism and can be classified as a gabbro. The absence of deformations suggests that Santa Catarina Gabbro is an autochthonous body, of Transamazonian age (Sartori, 1978). By means of these data Santa Catarina Gabbro is nowadays understood as a tectonic window of an older basement, on which were lodged rocks of the Metavolcanic Sedimentary Belt.

The gold mineralizations of the São Sepé region are associated with milky quartz veins deposits and are intruded in basic and metabasic rocks that may correspond to tectonic imbrications of the Basic-Ultrabasic Metamorphic Complex. These deposits are recognized in the mines of Bossoroca, Cerrito do Ouro, Passo da Juliana, Guardinha, Lavrinha, Viúva Guerra Durval and Estuque (CPRM, 1995). It is suggested that the metalogenesis of the Bossoroca, Cerrito do Ouro and Passo da Juliana mines are classified as depth source orogenic hydrothermal deposits (Groves *et al.*, 1998; Remus, 1999).

The orogenic model was originally applied strictly to the syntectonic deposits formed in compressional or transpressional systems, that is, syn-orogenic deposits. However, the term has been progressively expanded to include deposits that are post-orogenic in relation to processes at their crustal depth of formation. The orogenic hydrothermal deposits occur in all grades of metamorphic rocks, associated with accretion and collisional orogenic ages ranging from the Archaean to the Cenozoic. The hydrothermal source is derived from the juvenile crust at about 700 Ma during the dynamothermal regional metamorphism and TTG magmatism of the volcanic arc region, associated with extensional veins, from E-W to NW-SE directions, connected to the shear zone (Groves *et al.*, 1998).

The petrographic analysis of the Santa Catarina Gabbro shows that gold (Au) is not present in its mineralogical composition, however the geological and geochemical data show a potential area for Au ± sulfides (Rêgo, 1981; Rodrigues *et al.*, 1982). Therefore, the gold may have been leached from the Vacacaí Metamorphic Complex, during the regional metamorphism phase, with reconcentration along the low angle shear zones, in the form of fractions and hydrothermal lodes.

There are no specific studies on the origin of the hydrothermal fluid and source of metals that originated the auriferous mineralizations in the gabbro, however, evidence of metamorphism in green shale facies above amphibolite as contact metamorphism (hornblende facies) generated by the intrusion of the São Sepé Granite, evidences that this was the source of heat responsible for the concentration of ore in the gabbro fractures (D'Ávila *et al.*, 1985).

Previous work on geochemical prospecting in current sediments identified the occurrence of 48 gold pints in a drainage that flows from Santa Catarina Gabbro (CPRM, 1995). After the publication of the results of that work, there was no further mineral research to delimit the probable occurrence of gold in the study site. The work of geological mapping and acquisition of geophysical survey was carried out to test the hypothesis that Santa Catarina Gabbro is the source rock and that there is a probable mineral deposit there (Figure 5).

3.2. Geological mapping and structural survey

Geological mapping and structural survey data indicated that Santa Catarina Gabbro has a massive structure with the presence of fractures (Figure 6). To evaluate the local structural pattern, 130 fracture measurements were taken. The fractures are arranged in different directions, but with families of fractures arranged according to the NNW direction. Then, it was possible to obtain a reliable statistic of the structural measures and to plot this information in the stereogram, using OpenStereo software (Grohmann & Campanha, 2010) (Figure 7). These fractures may be related to a crustal relaxation phase

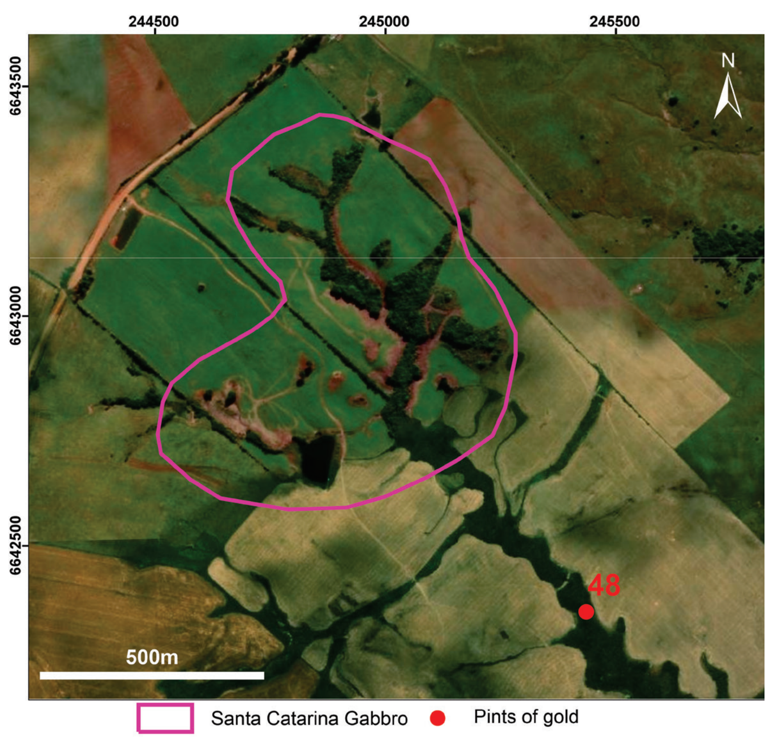

Figure 5. The numbered points are the places where gold pints were found in geochemistry of current sediments and pan concentrate. The number indicates the amount of gold pints found in each location (CPRM, 1995).

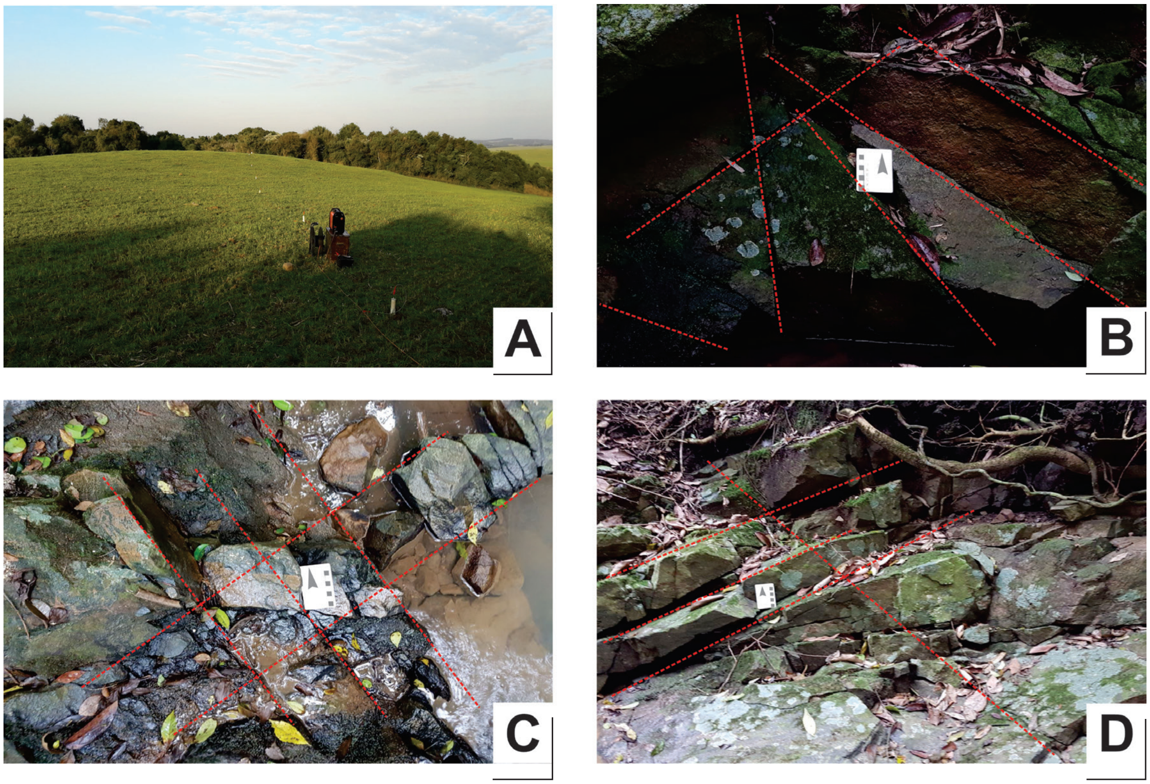

Figure 6. A: predominant land cover in the study area (pastures); b, c and d: Santa Catarina Gabbro outcrops with presence of fractures, with predominance of the NE-SW and NW-SE directions (the arrow direction of the card in the photo is to the north).

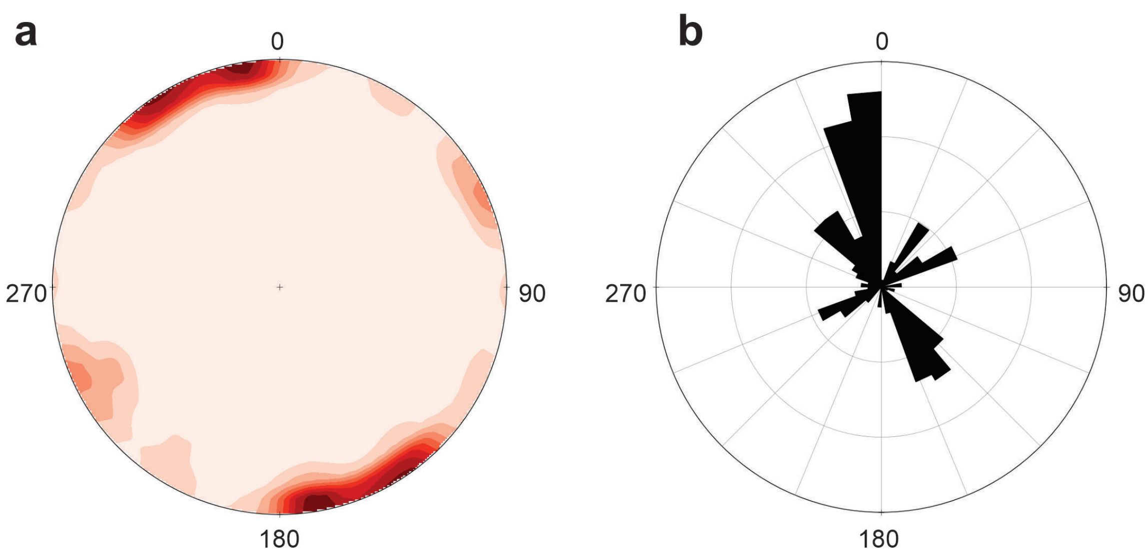

Figure 7. Stereogram of the main directions of the Santa Catarina Gabbro fractures.

after the intrusion of the Caçapava and São Sepé granites and probably acted as preferred paths for metasomatic liquids of the probable mineralization. The study of the structural arrangement for ore prospecting is fundamental for planning the distribution of electrical tomography lines, since previous works show that the gold mineralizations in the region are associated with fractures (Moreira *et al.*, 2012). From this information, the electrical tomography lines were distributed in a E-W direction.

3.3. Geophysical survey

The geophysical survey consisted of 5 parallel lines of electrical tomography each with 400 meters of length spaced 100 meters and with 10 meters electrode spacing heading N90, and 10 levels readings of electrical resistivity and chargeability (Figure 8).

Petrography works did not detect primary gold in the original chemical composition of the Santa Catarina Gabbro, therefore, the anomalies can be attributed to the strong polarization of structures and can be interpreted as high concentrations of metallic minerals probably distributed in fractures (D'Ávila *et al.*, 1985; Rodrigues *et al.*, 1982).

The analysis of the resistivity models allows to discriminate areas of low resistivity (<35 Ω.m) in the central domain of the sections, possibly associated with percolation of water in preferred flow paths. The resistivity is inversely proportional to the salinity of water, as the dissolved salts act as a pathway for electric current flow. In the field was recognized a high angle foliation in the central band of electrical tomography lines, besides fracturing in several points. Such structures can serve as preferential percolation zones of meteoric waters, whose interaction with amphiboles and pyroxenes results in hydration and generation of clay minerals. This process results in water saturated alteration zones which justifies the characteristic of low resistivity observed in practically all sections (Delgado-Rodríguez *et al.*, 2014).

The 2D inversion models show that the spatial distribution of the contrast values for the explored levels is not uniform, with zones of low resistivity and high chargeability in the form of rounded or elliptical pockets throughout the sections and at various levels of depth. Specific ranges of resistivity values (between 0.5 Ω.m and 10,000 Ω.m) and chargeability (between 0.01 mV/V and 20.0 mV/V) were selected for

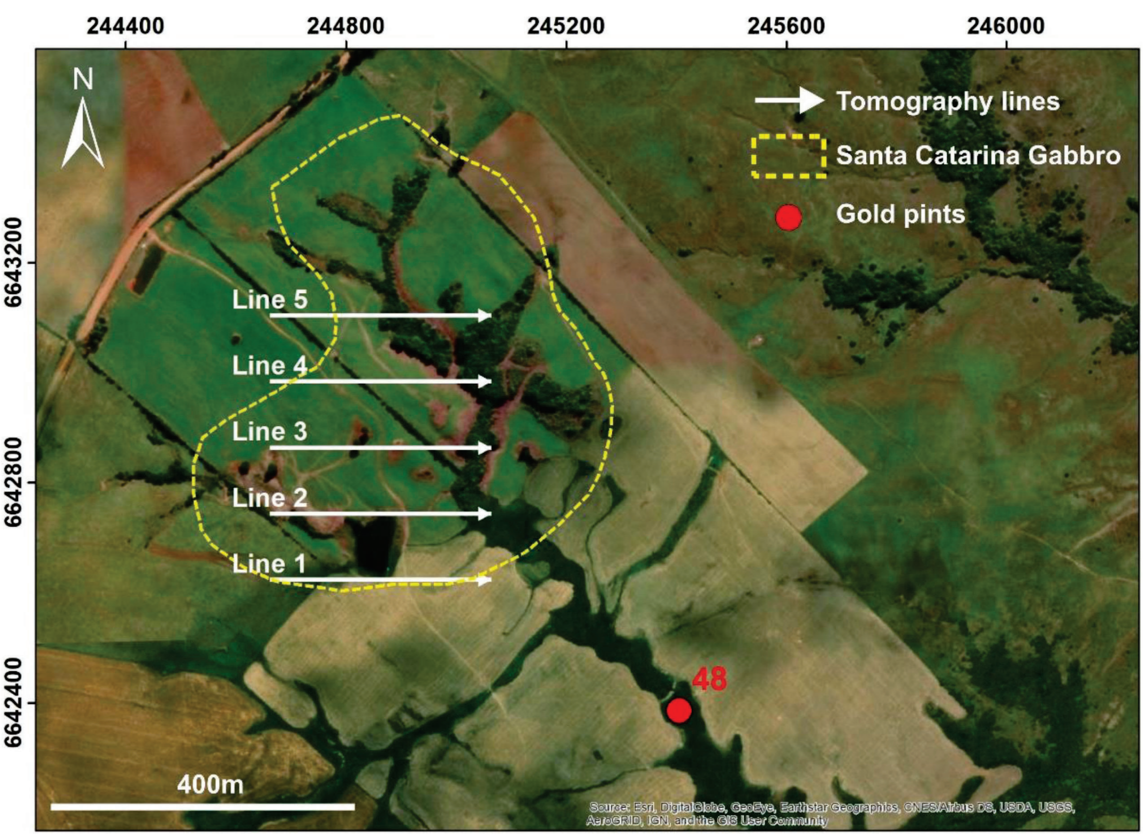

Figure 8. Location of the electric tomography with the direction N90°E.

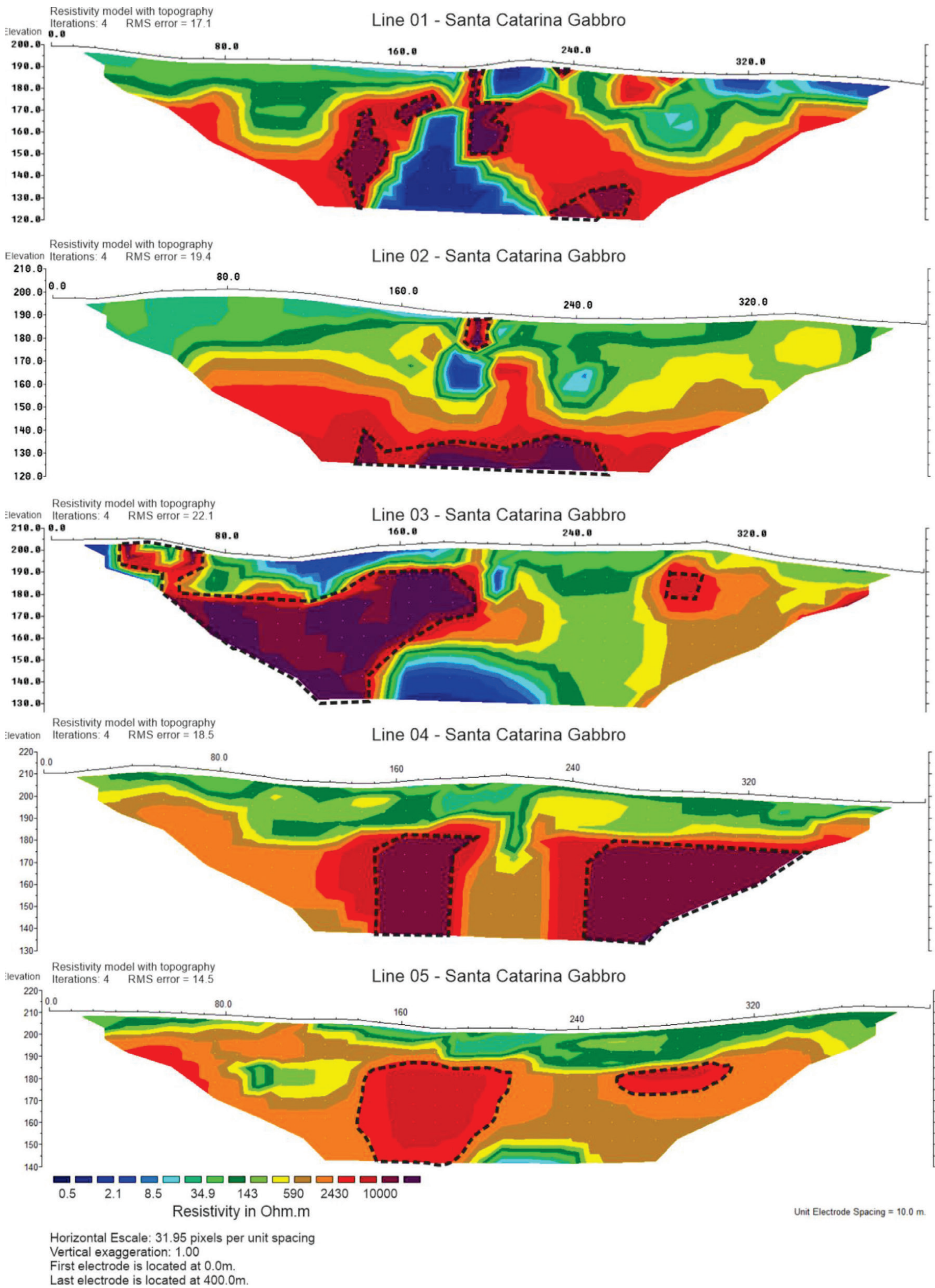

Figure 9. Inversion models for resistivity (ER).

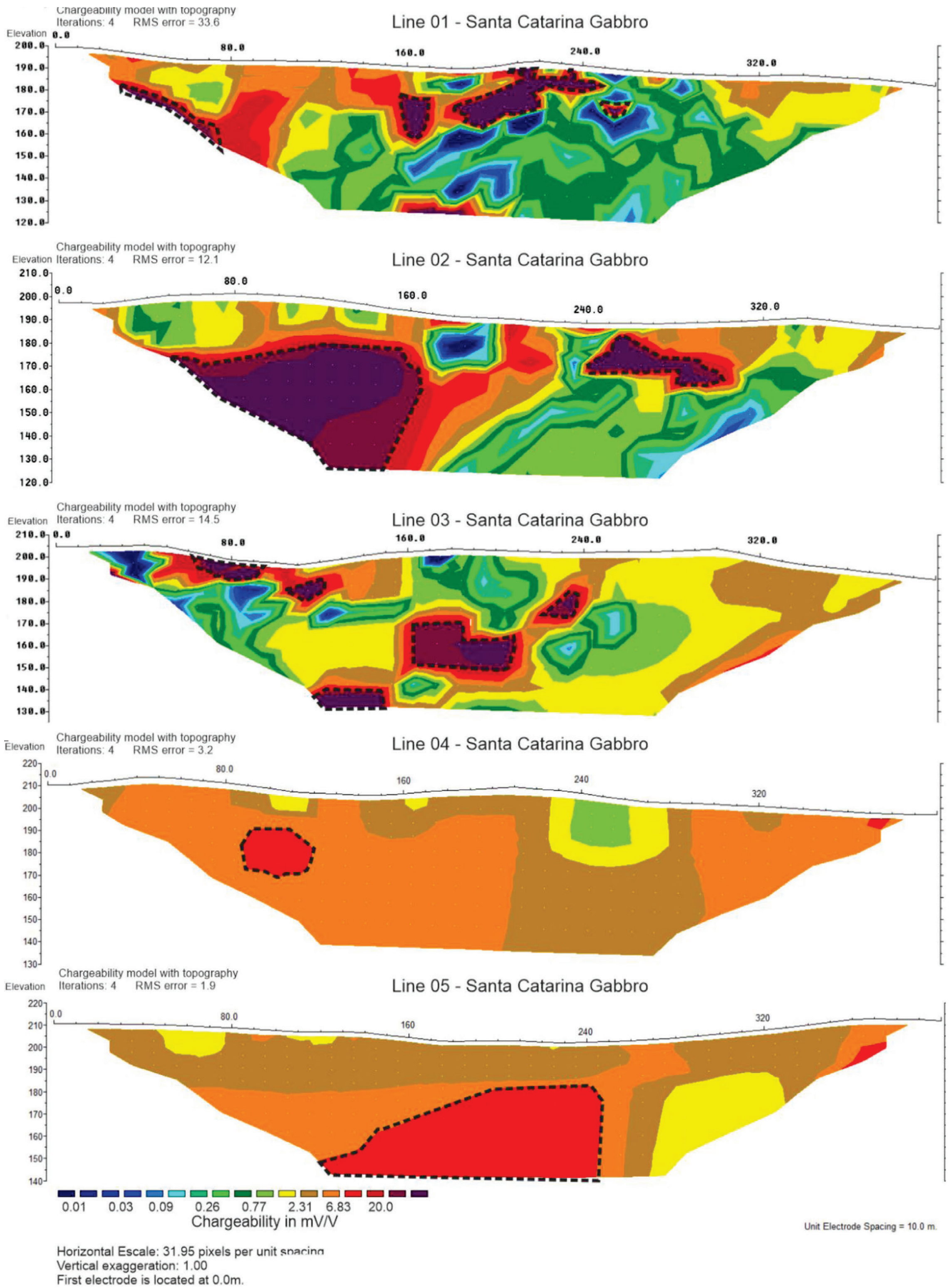

Figure 10. Inversion models for chargeability (ER) High chargeability values are marked.

modeling in the form of 3D visualization model surfaces, to evaluate the forms of zones of resistivity and chargeability anomalies (Figures 9 and 10).

The analysis of the 2D inversion models also indicate zones of high resistivity (> 10.000 Ω.m), both in deep and outcrop positions. In the field, gabbro boulders were observed, which justifies the high resistivity and, therefore, the regions of high resistivity located in depth should then be analogous and represent the rocky massif (probably with some degree of silicification and some late quartz veins). Likewise, the inversion models for chargeability show gradients that represent a possible mineralized structure, with areas of high chargeability disposed in most extension of the sections, with gradients higher than 20 mV/V, not necessarily coincident with areas of low resistivity.

The mineralization was hosted in the gabbro through several tectonic events, and the difference of chargeability between these and the host rock were detected in the inversion models. Similar values were acquired for this scenario and served as a basis for correlation in this work (Moreira *et al.*, 2012).

Several evidence support the concept that Au is mobile as dissolved or colloidal complexes in surficial environments. Several studies have found elevated dissolved Au concentrations in the vicinity of Au mineralization (Hamilton *et al.*, 1983; Xie *et al.*, 1987). Therefore, according to the authors above mentioned, near-surface chargeability anomalies may refer to gold mineralization, which, although deep-hosted associated with quartz veins, migrated to shallower levels given the mobility properties of the metal.

However, these anomalies correlates with earlier works where the authors describe the occurrence of gold pints (between 7 and 48 pints), magnetite (80% by volume of concentrate) and pyrite(CPRM, 1995). Similar IP values for this type of mineralization were described in another geophysical survey carried out in the region by some authors and served as a basis for correlation in this work (Moreira & Ilha, 2011).

The distorted form of field propagation of the dipole-dipole array is effective in the detection in verticalized structures. The size and shape analysis of the potentially mineralized zones and the 2D inversion models were combined in 3D visualization models, in association with the structural data collected in the field. From the blocks with interpolated resistivity surfaces, isovalues surfaces were modeled for each block, representative of the acquisition array, which may reveal structures and the possible mineralization architecture (Figures 11 and 12).

After the discrimination of regions of high chargeability and low resistivity, obtained from the interpolation of those acquired in the pseudo-sections, the information was correlated to stablish locations with overlapping of these values, which may indicate the occurrence of a mineralized zone (Figure 12).

The humid tropical climate of Brazil favors the chemical weathering of rocks and the consequent formation of residual soil. This weathering can reach depths of a few tens of meters and act on the mineralized zone, as is the case of the study area. The natural evolution of the relief, associated with the humid climate, the formation of soil by the breakdown of rock and mineralized zone can favor the incorporation of gold nuggets in the soil. Erosion and surface water runoff acting in this location can condition the transport of gold particles to the following region's drainages.

The information on the localization of possible gold mineralization from the three-dimensional visualization model, allows to indicate on map probable occurrences on a map that could be useful in the stage of establishing strategies for a future drilling campaign. The following mineralization localization map integrate geoelectric, geological and structural information for Santa Catarina Gabbro, described along this work and it can lead to the localization of the main occurrences of gold in the region. (Figure 13).

Conclusions

Previous work on geochemical prospecting in stream sediments found an attractive amount of gold pints, which lead to suggest that Santa Catarina Gabbro could be the source rock for gold mineralization (Rodrigues *et al.*, 1982). This work gathered geological, structural, and geophysical information that aimed to test this hypothesis.

Geological reconnaissance in the Santa Catarina Gabbro area allowed the description of a basic rock whose structure is relatively simple, composed of fractures in some preferred directions. The gabbro petrography analyses indicated the absence of gold in its composition; therefore, the ore possibly is hosted in fractures, or possible quartz veins that are further introduced in the rock.

The geophysical information associated to the data collected in the geological reconnaissance, allowed the imaging of structures contrasting with the physical parameters, closely related to the tectonic elements of a deposit. It also allowed the delimitation of a possible sulphide mineralization in depth and marginal silicification zones, characterized by low resistivity and high chargeability anomalies. These results are consistent with those described in works reported in the academic journals.

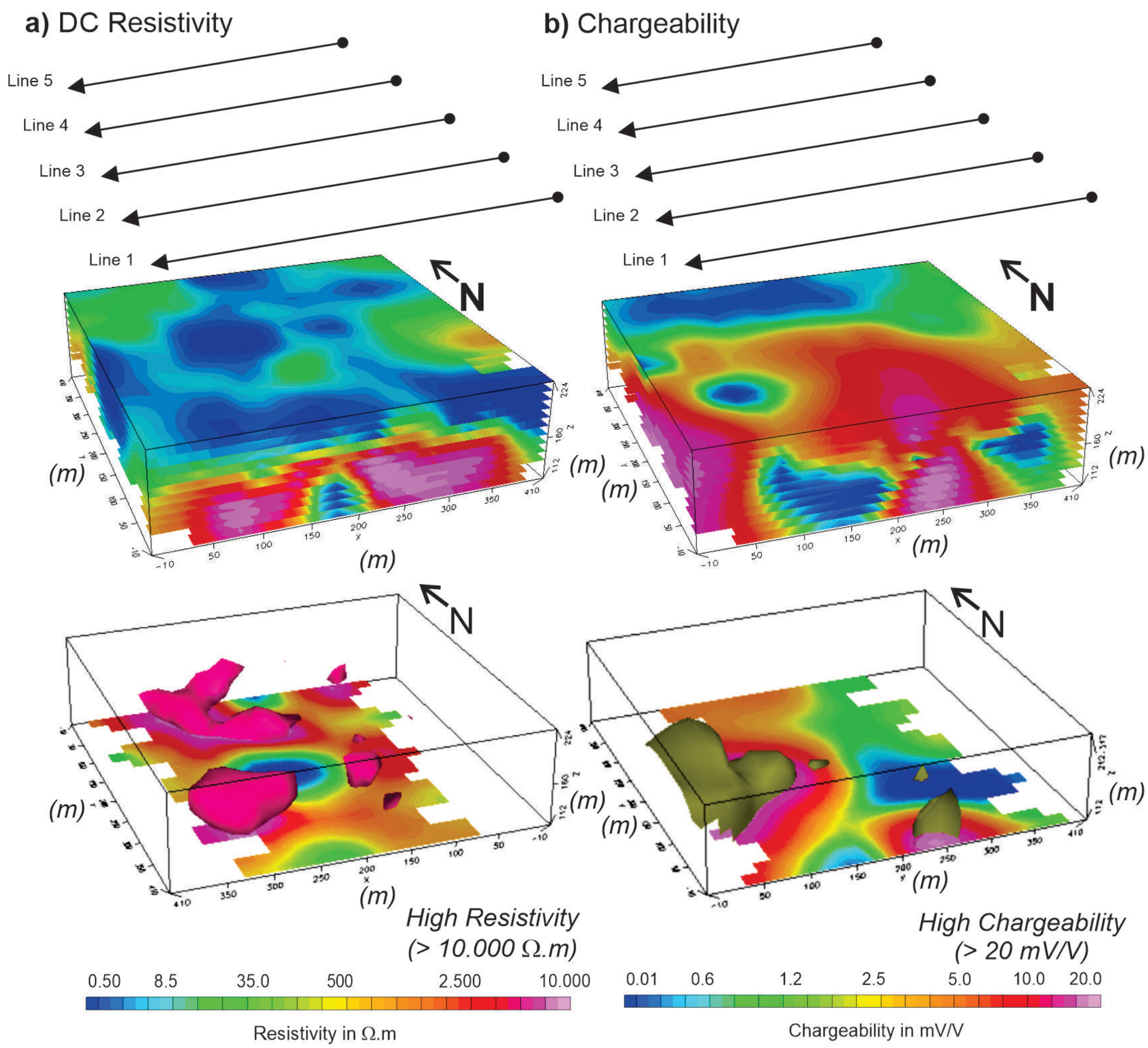

Figure 11. a) 3D visualization (upper panel of resistivity distribution), and bodies with resistivities > 10,000 Ohm.m. b) Chargeability distribution (upper panel), and isosurface with a chargeability of 29 mV/V (lower panel).

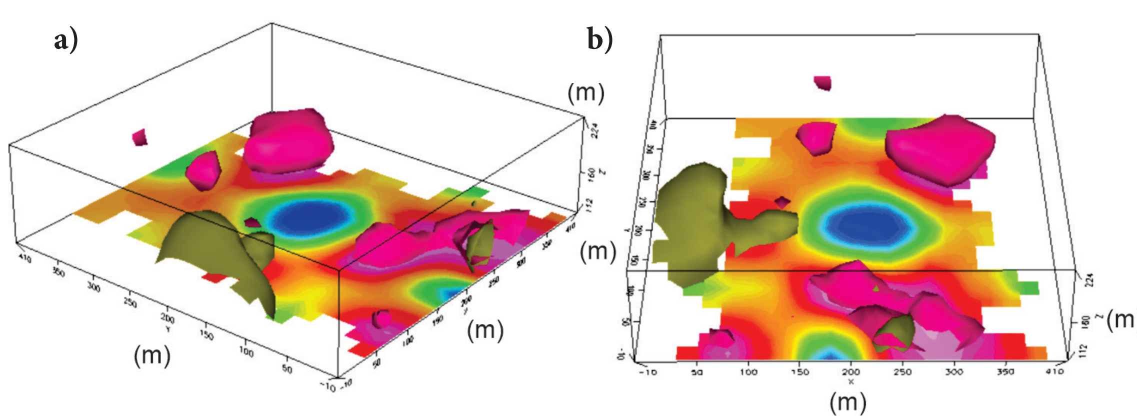

Figure 12. a) 3D view where high resitivity (> 10,000 Ohm.m) and high chargeability (>20 mV/V), b) Rotated 3D view shown in a).

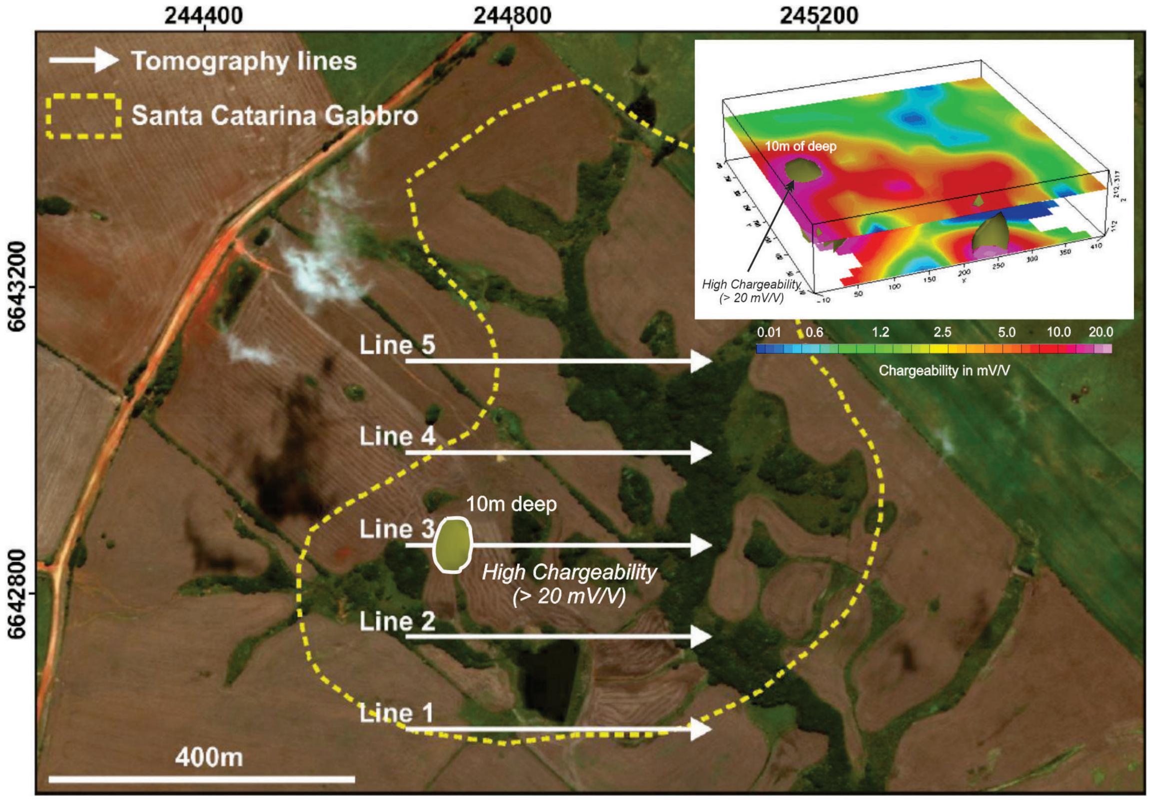

Figure 13. Position of the shallow high chargeability area (10m deep) in the study area.

The humid tropical climate of Brazil favors the chemical weathering of rocks and the consequent formation of residual soil. This weathering can reach depths of a few tens of meters and act on the mineralized zone, as is the case of the study area. The natural evolution of the relief, associated with the humid climate, the formation of soil by the breakdown of rock and mineralized zone can favor the incorporation of gold nuggets in the soil. Erosion and surface water runoff acting in this location can condition the carriage of gold particles to the region's drainages.

The analysis and interpretation of the results were based on the regional geological evolution, structural context and metalogenesis of the deposits, which resemble the occurrences of Bossoroca and Cerrito do Ouro, which are deactivated mines, but which explored deposits of hydrothermal origin. The occurrence of sulfide mineralization with associated gold comes from hydrothermal fluids from the intrusion of the São Sepé Granite. This regional metallogenetic context gave rise to small volume bodies, but with great potential for high levels of gold.

From the analysis and interpretation of 2D inversion models and 3D visualization acquired in the geophysical survey, it is understood that the dipole-dipole arrangement is suitable for this study, as it presents good resolution of rock structures, such as fractures.

The results allowed the three-dimensional determination of the morphology of the possible sulphide mineralizations, through the integration of geoelectric and structural data. However, the confirmation of the targets requires research work with the use of direct investigation methods, such as, for example, drilling campaigns and collection of samples and further geochemical analysis. The information obtained in this work reveals that the probable mineralizations present a structural control, whose disposition in depth is conditioned by fractures attitudes.

These results make possible to outline a strategy for a drilling campaign directed at the targets identified, with reduction of uncertainties, which is decisive in terms of an adequate quantification of reserves and economic feasibility of mineral occurrences and are incentives for the use of geoelectrical methods.

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Conflicts of Interest

"The authors declare no conflict of interest."

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