Geosciences
Geociências

# Geophysical prospection in tin mineral occurrence associated to greisen in granite São Sepé (RS)

http://dx.doi.org/10.1590/0370-44672017710098

**Marly Aparecida Silva**
Mestranda em Geociências
Universidade Estadual Paulista - UNESP
Departamento de Geologia Aplicada
Rio Claro - São Paulo - Brasil
marliy.silva@yahoo.com

**Cesar Augusto Moreira**
http://orcid.org/0000-0002-6949-6679
Professor Adjunto
Universidade Estadual Paulista - UNESP
Departamento de Geologia Aplicada
Rio Claro - São Paulo - Brasil
moreirac@rc.unesp.br

**Karolliny Borssatto**
Mestranda em Geociências
Universidade Estadual Paulista Júlio de Mesquita Filho
São Paulo- São Paulo - Brasil
karol-borssatto@hotmail.com

**Lenon Melo Ilha**
Técnico em Laboratório
Universidade Federal do Pampa
Caçapava do Sul - Rio Grande do Sul - Brasil
lmgeofisik@hotmail.com

**Shaiely Fernandes Santos**
Mestranda em Geociências
Universidade Estadual Paulista Júlio de Mesquita Filho
Rio Claro - São Paulo - Brasil
fer.shay@gmail.com

## Abstract

The discovery of new mineral resources involves various research techniques through direct and indirect studies. The geophysical methods are important tools in the detection of deep deposits because they use the contrast between the physical properties of the hosting rocks and the mineralized zone. In this sense, electrical geophysical methods are widely used in the prospecting of sulfide deposits. This work presents and discusses the results of the application of the Induced Polarization geophysical method in the investigation of a tin mineral occurrence associated with greisen, located on the western border of São Sepé Granite. The study area is located in the central portion of the Rio Grande do Sul State, in the municipality of São Sepé (RS), housed in the metavolcano-sedimentary rocks of the Vacacaí Metamorphic Complex. Six lines of electrical tomography were parallel arranged in the N30W direction. The 2D inversion models allowed to identify areas of high chargeability (above 5.0 mV/V), possibly attributed to areas with sulfide accumulation. The areas with low values (below 1.9 mV/V) area associated with soil and rocks absent of mineralization. Through the 3D visualization models, it was possible to identify that the mineralized zone apparently has continuity for more than 36 m. These models also allowed identifying the morphology and the lateral continuity of the sulfide zone. Thus, the results of this work demonstrate the possibility of using Induced Polarization in the research of cassiterite deposits with associated sulfides due to the contrast of physical properties obtained from the high polarizability of the sulfides.

**Keywords:** mineral exploration, induced polarization, cassiterite, sulfides.

## 1. Introduction

Mineral exploration is the first stage in the discovery of new mineral resources and the re-evaluation of mineral occurrences already known. In this phase, several techniques of geological investigations are applied with the purpose of detailing the geological conditioning agents of a mineral deposit.

Remote sensing analysis and geochemical studies through the sampling of water, soil, rock and water flow sediment are the most commonly used direct methods in mineral exploration. However, these investigative techniques are limited to outcropping deposits and are little effective in identifying these deposits hosted at great depths (Licht, 1998).

Thus, geophysical methods are effective in locating sub-outcropping deposits, since they depend basically on the contrast between the physical properties of the deposit and the surrounding environment. The physical properties of a deposit, in turn, are directly related to the physical properties of the minerals that make up their volume (Milsom, 2003; Moon *et al.*, 2006).

The location of subsurface mineral deposits via geophysical methods can be direct; that is, when the response comes from the mineral good being prospected or indirect, when the deposit has insufficient amounts of the mineral sought. In this case, the deposit can only be detected if the mineral good being searched is associated with other minerals with contrasting physical properties and with considerable volume or even with some geological structure (Dentith and Mudge, 2014).

Some characteristics, such as low cost and quick data acquisition, make the use of geophysical methods advantageous

in mineral exploration. Among the various terrestrial geophysical methods available, the most used in the prospecting of sulfide deposits are the electrical methods. These methods allow the characterization of the deposits through anomalous zones with physical parameters of chargeability and resistivity.

The Polarization Induced method is effective and frequently used in the prospection and detailing of mineral occurrences, as shown by the studies done by Irvine and Smith (1990), Moreira and Ilha (2011), Pereira *et al.* (2015), Côrtes *et al.* (2016), Moreira *et al.* (2016) and Vieira *et al.* 2016. However, there are no scientific studies that use geophysical methods in the research of cassiterite associated with *greisen*, although the works cited above prove the effectiveness of the electrical methods in the detection of sulfide bodies.

Thus, this work presents and discusses the results of Induced Polarization (IP) applied in the prospection of a tin deposit associated with greisen and quartz veins, located on the western border of São Sepé Granite (RS). The probable mineralization occurs inserted in the metasedimentary rocks of the Vacacaí Metamorphic Complex, identified through geochemical studies of the sieving concentrate performed by the Mineral Resources Research Company (Companhia de Pesquisa de Recursos Minerais) (CPRM, 1995).

## 2. Area of studies

The area of studies is located in the southwest portion of the municipality of São Sepé (RS), distant approximately 270 km from the capital Porto Alegre, with access through BR 290 to the intersection with BR 392. From the interchange, access is made by BR 392 to Rincão da Juliana road, São Sepé municipality, from which it is possible to access the occurrence of tin, after traveling 26 km by dirt road (Figure 1a).

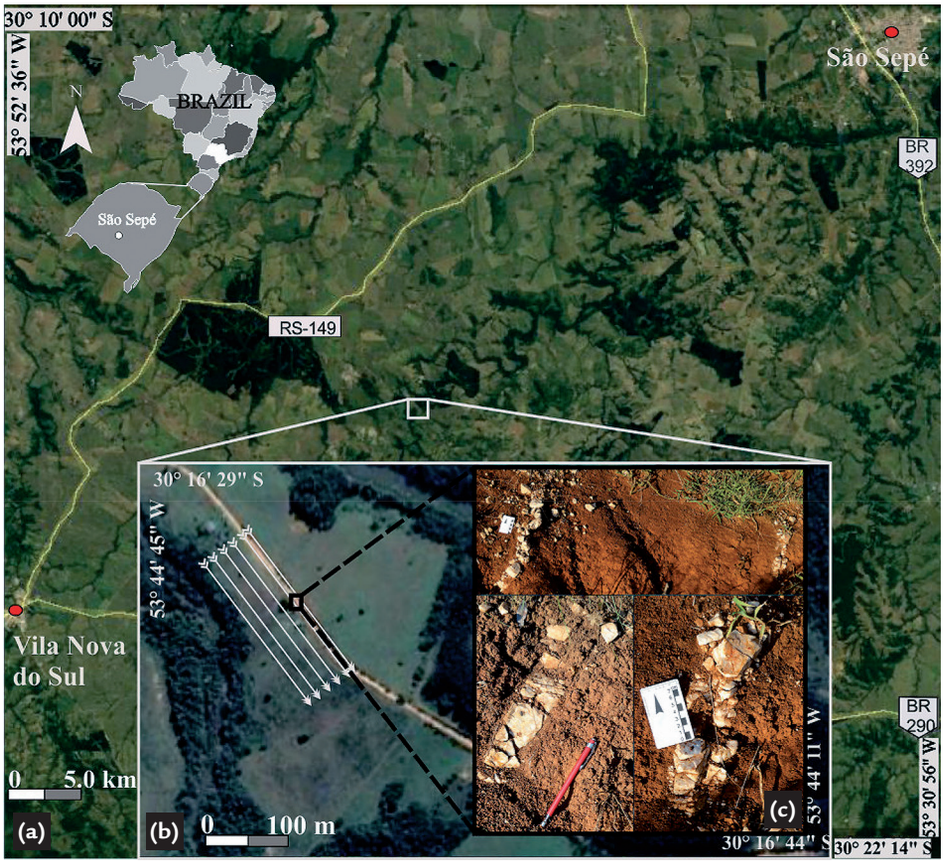


Figure 1
a) Location of the area of studies.
b) Detail map of the study area with the profiles of the electrical resistivity tomography (Modified from the Google Earth).
c) Outcrops of quartz veins in road section.

In the region where this work was performed, known as Passo da Juliana, several gold mineralizations were described, such as the mines of Bossoroca, Cerrito do Ouro, Estuque and Juliana, all inserted in the rocks of the Vacacaí Metamorphic Complex and associated with intrusions of the São Sepé, Lavras and Caçapava do Sul Granites (CPRM, 1995).

The tin mineralizations occurring in the Passo da Juliana region, the object of study of this work, were identified through geochemical studies in flow sediments carried out by the Mineral Resources Research Company (CPRM) in the 1980s. Subsequently, works on geological mapping and chemical analyzes of soil and rock were performed to detail this occurrence in an area of 12Km$^2$, which allowed to determine that the study area is the source of the dispersion halo of the elements (Sn, Au, Mo, As) found in current sediments (CPRM, 1995).

The evidences of these mineralizations occur in the peripheral zone of the São Sepé Granite, mainly in the east and west edges, hosted by the cornubianitic shales of the Vacacaí Metamorphic Complex. In the region of studies, more than 80 occurrences in quartzite filon minerals were identified, occurring isolated, forming filonean zones or alignments, to which gold, tin and sulfide are associated (CPRM, 1995).

Tin mineralizations are related to greisen, which in flow sediments are accompanied by pyrite, arsenopyrite and fluorite. Geochemical anomalies in stream sediments were also identified for Mo (5ppm) and As (13ppm). In this way, the mineralization indexes and the geological context of the

area are compatible with Sn (± Mo ± Bi) mineralization models in greisens filonean bodies restricted to large subcropping greisenized domes (CPRM, 1995).

The region study is located in the central region of Rio Grande do Sul State, consisting of igneous, metamorphic and sedimentary lands generated mainly during the Transamazonian (2,26-2,00 Ga) and Brazilian tectonic cycle (900-535 Ma) (Hartmann *et al*., 2007). It is compartmentalized in the Taquarembó, Tijucas, São Gabriel and Batolito Pelotas Terrains, limited by large regional failures heading NE-SW (Paim *et al*., 2000). The São Sepé granite consists of texturally isotropic granites, with amphibole-biotite monzonites in the center and biotite sienites in the border. The contact between them is abrupt, oriented in the N-S direction, and close to the internal contact both granites (monzonites and sienites) are sectioned by dykes of aplites and microgranites (Gastal and Ferreira, 2013).

The area is inserted in the Vacacaí Metamorphic Complex, which encompasses several associations of deformed and metamorphic volcano-sedimentary rocks in the shale-green facies to lower amphibolite (Chemale Jr, 2000).

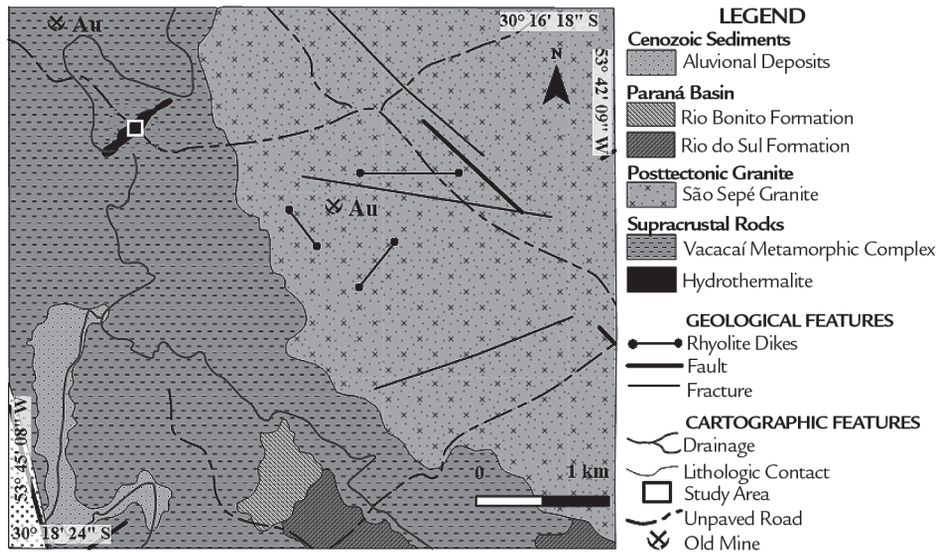


Figure 2
Geological map of the study area (Adapted from CPRM, 1995).

## 3. Materials and methods

The geophysical survey consisted of the application of the Induced Polarization method, selected due to the history of applications in deposits with disseminated sulfides and the contrast between the physical properties of the nesting rock and the sulfide zone. This method consists in the application of an artificial current in the ground through two electrodes and the measurement of the potential generated in two other electrodes close to the current flow (Telford, 1990).

The equipment used was the Terrameter LS resistivity meter manufactured by ABEM Instrument (Sweden), belonging to the Geophysics Laboratory of the São Paulo State University (UNESP). The calibration of the equipment was made using 1 s of current input, being the minimum current of 200 mA and maximum of 500 mA, with 2 windows of fixed and consecutive readings of 0.1 s and beginning of the window of reading after the cut of current (delay time) of 0.2 s.

Non-polarizable ceramic electrodes filled with aqueous solution supersaturated in $CuSO_4$ were used. These electrodes are composed of a porous base and a copper rod; a configuration that allows solution traffic and infiltration in the soil, in order to reduce the resistance of the contact and to minimize the generation of parasitic currents generated by the use of metallic electrodes

Six electric dipole lines were performed in a dipole-dipole arrangement, each 210 m long, positioned in the N30W direction, based in quartz veins recognized in field surveys (Figure 1c). Lines 1 and 2 were spaced 6 m apart from each other and the others 12 m apart (Figure 1b). The spacing between the electrodes was 5 m, established based on the estimated dimensions of the greisen and the desired depth of investigation.

The data were stored in the machine's internal memory in a .dat extension, which can be opened and edited through a text editor. The modeling of the data to obtain the inversion 2D models, with the estimated depths realized using the program Res2dinv, developed by Geotomo Software. Before the inversion procedure, the topographic data of each line for adjustment of the topographic surface in the models were inserted.

Subsequently, the data were modeled in the Res2dinv program, based on the inversion parameters suggested by the program for the modeling of sulfide bodies. The result of this modeling is presented in the form of sections of chargeability, with real depth estimated and adjusted with the terrain topography.

The 2D inversion models were exported from Res2dinv and imported into Oasis Montaj software developed by Geosoft aiming to create a 3D visualization model with adjustment of topographic data. These 3D visualization models facilitate the understanding of complex geological structures associated to the modeling of mineral deposits and to hydrological problems, such as flow of contaminants (Zanchi *et al*., 2009; Aizebeokhai *et al*., 2011; Moreira *et al*., 2012, Moreira *et al*, 2016, Camarero and Moreira, 2017).

## 4. Results

Previous geological reconnaissance and structural surveys in the area enabled the recognition of quartz veins in the N70E direction (Figure 1c). Based on this structural configuration, acquisition in the orthogonal direction to the

veins and in parallel between the lines was proposed. The orientation of the electric tomography lines, orthogonal to the direction of the quartz veins, also cross the contact between the metasediments of the Vacacaí Metamorphic Complex and the São Sepé Granite, a boundary characterized by fracturing associated with intrusion and magmatic cooling. This structural context is described in detail by Gastal and Ferreira (2013), characterized by a radial pattern around the intrusive and orthogonal to the set of quartz veins described in the field, which at the site studied, the general orientation is N30W.

Apparently, the set of N70E quartz veins was formed due to the metasomatic processes during the final stages of intrusive expansion in the region. The second set of fractures and veins is possibly associated with the cooling phase, with retraction of the magma chamber and establishment of radial fractures, concomitantly filled by hydrothermal liquids from the final phases of magmatic crystallization. The migration of hydrothermal fluids into magmatic systems consists of the percolation of gaseous solutions rich in silica dissolved in water and a set of chemical elements with an ionic radius incompatible with the main minerals forming granitic rocks such as feldspars and micas.

The migration of these fluids to lower pressure zones, often positioned in zones bordering the magma chambers, provides adequate temperature and pressure conditions for the combination of these chemical elements and formation of a varied set of mineral deposits. For the case under study, the mineral assemblies related to the mineral accumulations are cassiterite, gold and sulfides.

Cassiterite is the main mineral of tin ore, whose pattern of dissemination in quartz veins and its set of physical properties, makes it impossible to recognize mineral accumulations by conventional geophysical methods. However, its association with gold and sulfide diffusion allows its indirect recognition from geophysical studies using the Induced Polarization method.

Overall, in the 2D inversion models, the geophysical results of chargeability showed intermediate to high values, above 1.5 mV/V. Lines 1, 2, 4 and 5 present the highest chargeability contrasts, characterized by the presence of areas of high chargeability, above 5.0 mV/V, located between the 100 m and 170 m positions (Figure 3).

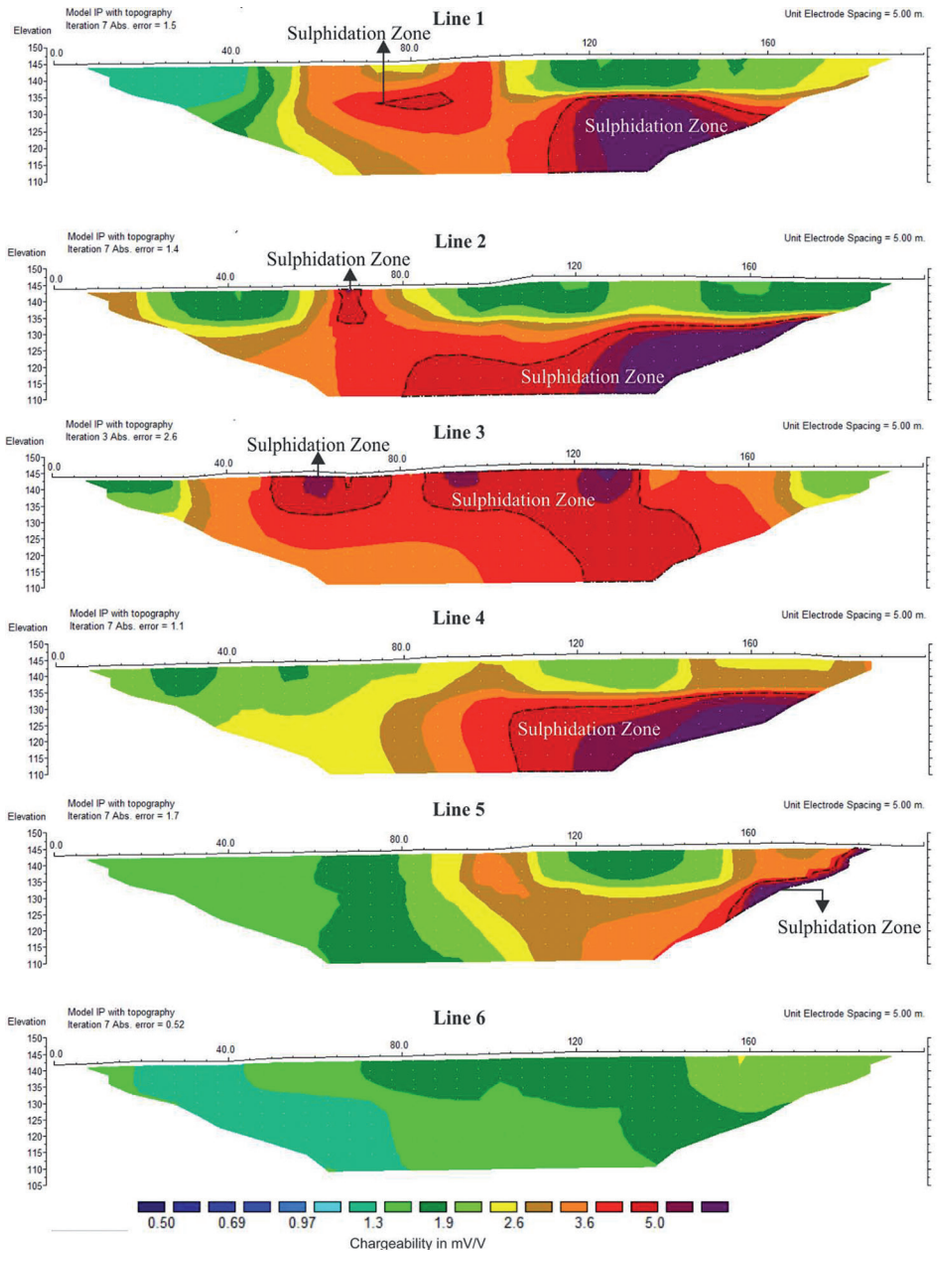


Figure 3
Inversion model for chargeability.

These zones of high chargeability represent, possibly, the preferred migration path of the hydrothermal liquids coming from the final stages of crystallization of São Sepé Granite. The top of these lines up to the depths of 15m is generally characterized by areas with chargeability values below 2.6 mV/V and probably represent the altered nesting rock or soil.

In line 3, subsurface circular anomalies of high chargeability are found, around 5.0 mV/V, located in the center of the section between the positions of 50m and 130m. These described anomalies occur from the top to the bottom of the section with high values of chargeability and are possibly associated with zones of sulfides and cassiterite accumulation.

Line 6 presents the lowest values of chargeability throughout the section, lower than 2.6 mV/V, from the surface to the base of the section. These zones with moderate to low values of chargeability are probably related to quartz-schists of the Vacacaí Metamorphic Complex.

The integration of the lines into 3D visualization models allows the identification of subsurface sulfide zones, possibly associated with the occurrence of cassiterite, which coincide with the geochemical anomalies identified by CPRM (1995) through chemical analyzes made in rock collected in the study area. Thus, the model confirms the existence of two elongated zones in the direction N30W with a probable accumulation of sulfides, located between positions 120 and 198 m (Figure 4). The models also show the existence of three small circular bodies, coincident with the small anomalies highlighted in the 2D inversion models (Figure 3).

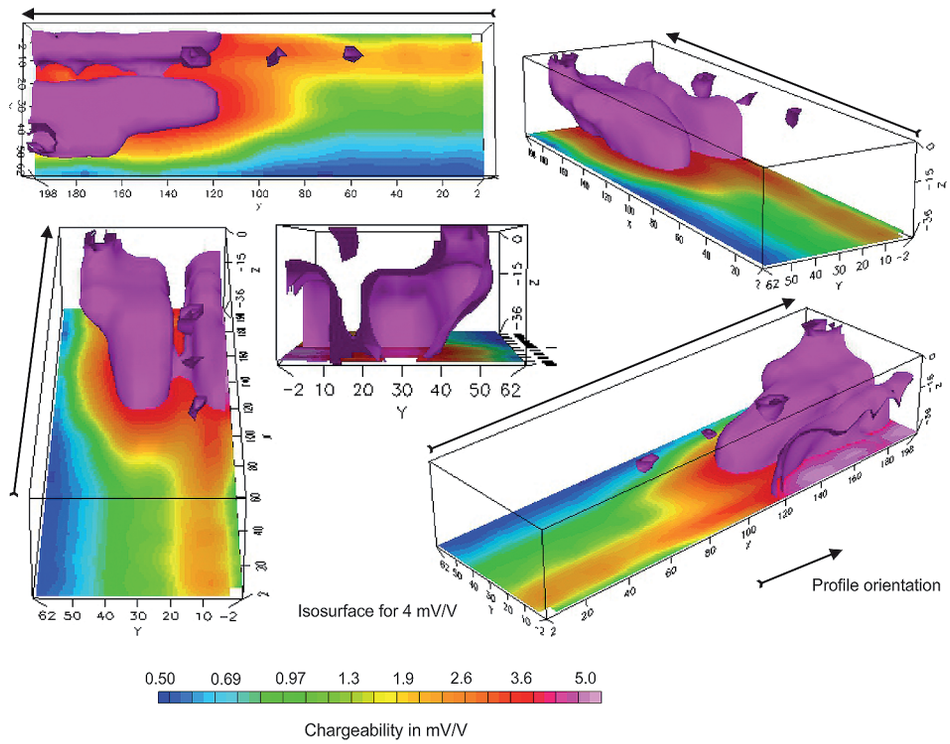


Figure 4
3D chargeability models of high chargeability zones (probable mineralization).

## 5. Conclusions

The results presented in this work are based on indirect data and on genetic models of tin mineralization the greisen type in quartz veins. In the study area, two sets of quartz veins occur with directions N70E and N30W, related, respectively, to the expansion of the magma chamber and the final phases of intrusive crystallization. The geophysical data showed that the sulfide occurs in the quartz veins with direction N30W, whose genesis is associated to the migration of aqueous solutions rich in silica and chemical elements such as Sn, As and Mo, responsible for mineralization of sulfide, gold and cassiterite.

In the 2D inversion models, it was possible to identify zones with high and low chargeability. Areas with low values (less than 1.9 mV/V) possibly indicate the presence of quartz-schists, nesting rocks to the intrusive granite, described in the field. Zones with values greater than 5.0 mV/V recognized in the sections, possibly indicate accumulations of sulfides and cassiterite.

The geophysical data revels a mineralization zone comparatively little in relation to the mapped mineralized zone. The data allowed defining two bodies up to 36 m depth, maximum limit of investigation, but with an indication of continuity. Apparently, these bodies have continuity towards the acquisition lines, that is, into the granite.

Therefore, the results were satisfactory in the morphological definition of the occurrence of tin, due to the contrasts between the physical properties of the nesting rock and the occurrence of sulfides associated with cassiterite. In the context of the studied mineralization, the mineral paragenesis associated with cassiterite is composed of metallic sulfides (pyrite, arsenopyrite, galena, among others) that polarize. In this sense, these minerals (metallic sulfides) are responsible for the contrast of chargeability between the nesting rock and the mineralized zone. Thus, the Induced Polarization method also allowed relating the 3D modeling results in depth, to the probable continuity and the morphology of the mineralization.

Based on the relationship between the chargeability standards and common genetic models for tin mineralization, it is recommended to open trenches and drill holes for sampling and direct rock analysis in order to evaluate the distribution of the contents in the area investigated.

## Acknowledgements

The authors wish to thank the National Council for Scientific and Technological Development, (CNPq) by the financial support referring to the Edital Universal 470821/2013, and the Coordination for the Improvement of Higher Education Personnel (CAPES) for the scholarships granted. They also thank the Laboratory of Geophysics of São Paulo State University (UNESP) for providing the resistive meter and to the colleague Livia Portes Innocenti Helene for contribution.

## References

AIZEBEOKHAI, A. P., OLAYINKA, A. I., SINGH V. S., UHUEGBU, C. C. Effectiveness of 3D geoelectrical resistivity imaging using parallel 2D profiles. ***International Journal of the Physical Sciences,*** v. 6, n. 24, p. 5623-5647, 2011.

CAMARERO, P. L., MOREIRA, C. A. Geophysical investigation of Earth dam using the electrical tomography resistivity technique. ***REM-Revista Escola de Minas,*** Ouro Preto, v. 70, n. 1, p. 47-52, 2017.

CHEMALE Jr, F. Evolução geológica do Escudo Sul-Riograndense. In: HOLZ, M., DE ROS, L. F. (Eds.). ***Geologia do Rio Grande do Sul.*** Porto Alegre: Universidade Federal do Rio Grande do Sul, 2000. p.13-52.

CÔRTES, A. R. P., MOREIRA, C. A., VELOSO D. I. K., VIEIRA L. B., BERGONZONI, F. A. Geoelectrical prospecting for a copper-sulfide mineralization in the Camaquã sedimentary basin, Southern Brazil. ***Geofísica Internacional,*** v. 55, n. 3, p. 165-174, 2016.

COMPANHIA DE PESQUISA DE RECURSOS MINERAIS (CPRM). Programa Levantamentos Geológicos Básicos do Brasil: Passo do Salsinho, Folha SH-22-Y-AI-4, Estado do Rio Grande do Sul, Brasília, 1995. 372p.

DENTITH, M., MUDGE, S. T. ***Geophysics for the mineral exploration geoscientist.*** Cambridge: Cambridge University Press, 2014. 516p.

GASTAL, M. C., FERREIRA, F. J. F. Discussão dos processos de construção do complexo granítico São Sepé, RS: feições geológicas e petrográficas. ***Pesquisas em Geociências,*** Porto Alegre, v. 40, n.3, p. 233-258, 2013.

HARTMANN, L. A., CHEMALE JR., F., PHILIPP, R. P. Evolução Geotectônica do Rio Grande do Sul no Pré-Cambriano. In: IANNUZZI, R. e FRANTZ, J.C. (2 Ed.). ***50 Anos de Geologia.*** Porto Alegre: Instituto de Geociências, 2007. 396p. (Cap. 7, p. 97-123.)

IRVINE, R.J., SMITH, M.J. Geophysical exploration for Epitermal deposits. ***Journal of Geochemical Exploration,*** v. 36, n. 1, p. 375-412, 1990.

LICHT, O. A. B. ***Prospecção geoquímica: princípios, técnicas e métodos.*** Companhia de Recursos Minerais-CPRM, 1998. 236p.

MILSOM, J. ***Field Geophysics.*** Chichester: John Wiley & Sons. Malden: 2003. 249p.

MOON C.J. et alii. Introduction of mineral exploration. (2ª ed.). Blackwell Publishing, 2006. 499p.

MOREIRA, C. A, ILHA, L. M. Prospecção geofísica em ocorrência de cobre localizada na bacia sedimentar do Camaquã (RS). ***REM-Revista Escola de Minas,*** Ouro Preto, v. 64, n. 3, p. 305-311, 2011.

MOREIRA C. A., LOPES S. M., SCHWEIG C., SEIXAS A. R. Geoelectrical prospection of disseminated sulfide mineral occurrences in Camaquã Sedimentary Basin, Rio Grande do Sul State, Brazil. ***Revista Brasileira de Geofísica,*** v. 30, n. 2, p. 169-179. 2012

MOREIRA, C. A., BORSSATTO, K., ILHA, L. M., SANTOS, S. F., ROSA, F. T. G. Geophysical modeling in gold deposit through DC Resistivity and Induced Polarization methods. ***REM-Revista Escola de Minas,*** Ouro Preto, v. 69, n. 3, p. 293-299, 2016.

PAIM, P., CHEMALE Jr., F., LOPES, R.C. A bacia do Camaquã. In: HOLZ, M., DE ROS, L.F. (Eds.) ***Geologia do Rio Grande do Sul.*** Porto Alegre: UFRGS, 2000. p. 231-274.

PEREIRA, A. M., MOREIRA, C. A., BORTONIN, J. R. M., LOPES, S. M., NARDY, A. J. R. Magnetometric exploration in intrusive basic with evidence of gold in northern region of the Camaquã Sedimentary Basin (RS). ***REM-Revista Escola de Minas,*** Ouro Preto, v. 68, n. 2, p. 163-169, 2015.

TELFORD, W. M., GELDART, L. P., SHERIFF, L. E. ***Applied Geophysics.*** Cambridge: Cambridge University Press, 1990. 770p.

VIEIRA, L. B., MOREIRA, C. A., CÔRTES A. R. P., LUVIZOTTO, G. L. Geophysical modeling of the manganese deposit for induced polarization method in Itapira (Brazil). ***Geofísica Internacional,*** v. 55, n. 2, p. 107-117, 2016.

ZANCHI, A., SALVI F., SANCHETTA S., STERLACCHINI, S., GUERRA, G. 3D reconstruction of complex geological bodies: examples from the Alps. ***Computers & Geosciences,*** v. 35, n. 1, p. 49-69, 2009.

Received: 30 June 2017 – Accepted: 21 December 2017.