

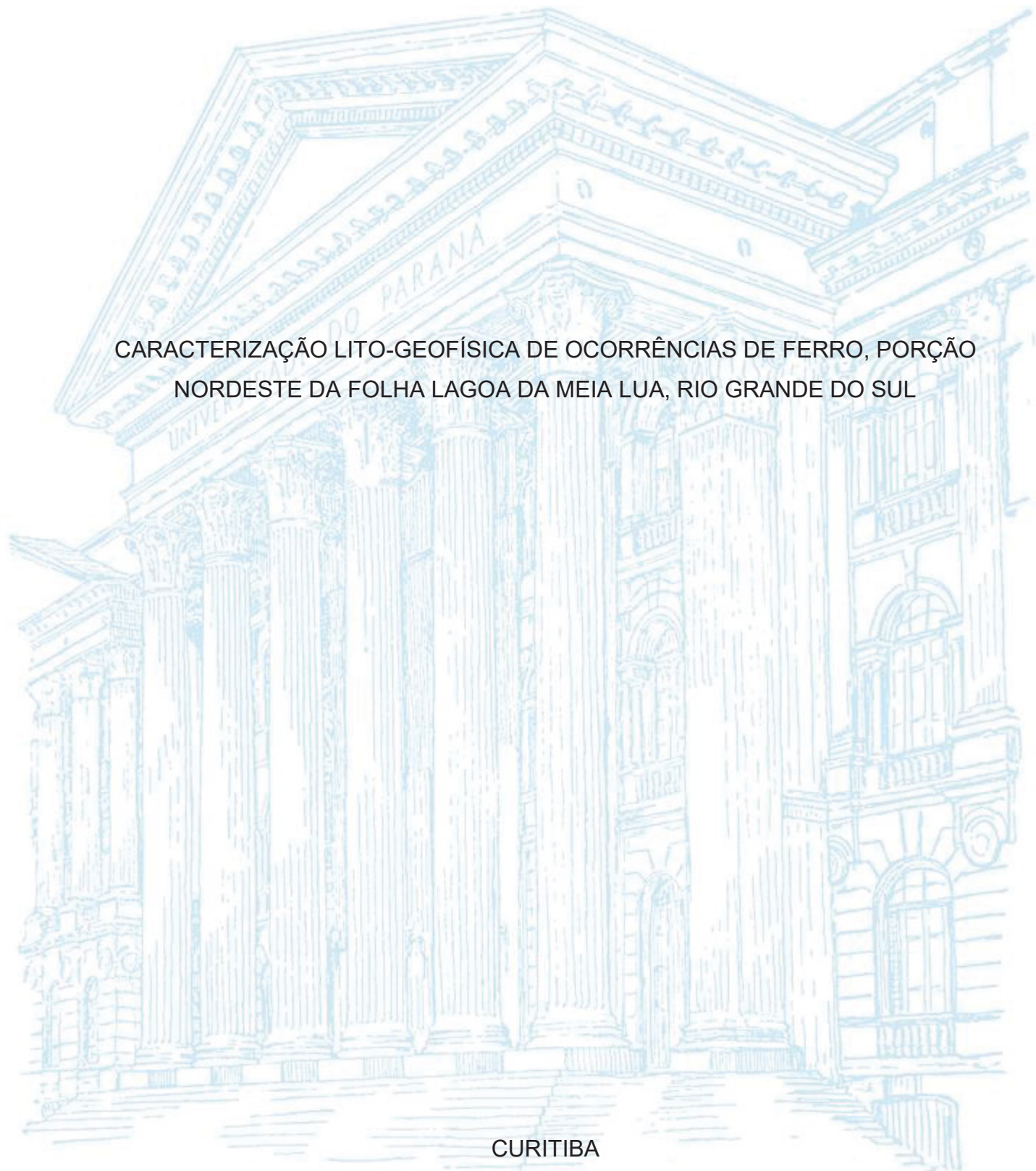
UNIVERSIDADE FEDERAL DO PARANÁ

FABIANO GARCIA MADRID

CARACTERIZAÇÃO LITO-GEOFÍSICA DE OCORRÊNCIAS DE FERRO, PORÇÃO
NORDESTE DA FOLHA LAGOA DA MEIA LUA, RIO GRANDE DO SUL

CURITIBA

2023



FABIANO GARCIA MADRID

CARACTERIZAÇÃO LITO-GEOFÍSICA DE OCORRÊNCIAS DE FERRO, PORÇÃO
NORDESTE DA FOLHA LAGOA DA MEIA LUA, RIO GRANDE DO SUL

Dissertação apresentada ao curso de Pós-Graduação em Geologia Exploratória, Setor de Ciências da Terra, Universidade Federal do Paraná, como requisito parcial à obtenção do título de Mestre em Geologia

Orientador: Prof. Dr. Maximilian Fries

CURITIBA

2023

DADOS INTERNACIONAIS DE CATALOGAÇÃO NA PUBLICAÇÃO (CIP)
UNIVERSIDADE FEDERAL DO PARANÁ
SISTEMA DE BIBLIOTECAS – BIBLIOTECA CIÊNCIA E TECNOLOGIA

Madrid, Fabiano Garcia

Caracterização lito-geofísica de ocorrências de ferro, porção nordeste da folha Lagoa da Meia Lua, Rio Grande do Sul / Fabiano Garcia Madrid. – Curitiba, 2023.

1 recurso on-line : PDF.

Dissertação (Mestrado) - Universidade Federal do Paraná, Setor de Ciências da Terra, Programa de Pós-Graduação em Geologia.

Orientador: Prof. Dr. . Maximilian Fries.

1. Prospecção mineral. 2. Processamento de dados. I. Fries, Maximilian. II. Universidade Federal do Paraná. Programa de Pós-Graduação em Geologia. III. Título.

Bibliotecária: Roseny Rivelini Morciani CRB-9/1585

TERMO DE APROVAÇÃO

Os membros da Banca Examinadora designada pelo Colegiado do Programa de Pós-Graduação GEOLOGIA da Universidade Federal do Paraná foram convocados para realizar a arguição da Dissertação de Mestrado de **FABIANO GARCIA MADRID** intitulada: **CARACTERIZAÇÃO LITO-GEOFÍSICA DE OCORRÊNCIAS DE FERRO, PORÇÃO NORDESTE DA CARTA LAGOA DA MEIA LUA, RIO GRANDE DO SUL**, sob orientação do Prof. Dr. MAXIMILIAN FRIES, que após terem inquirido o aluno e realizada a avaliação do trabalho, são de parecer pela sua APROVAÇÃO no rito de defesa.

A outorga do título de mestre está sujeita à homologação pelo colegiado, ao atendimento de todas as indicações e correções solicitadas pela banca e ao pleno atendimento das demandas regimentais do Programa de Pós-Graduação.

CURITIBA, 15 de Dezembro de 2022.

Assinatura Eletrônica

19/12/2022 16:14:19.0

MAXIMILIAN FRIES

Presidente da Banca Examinadora

Assinatura Eletrônica

16/12/2022 09:28:55.0

LUÍS GUSTAVO DE CASTRO

Avaliador Interno (UNIVERSIDADE FEDERAL DO PARANÁ)

Assinatura Eletrônica

16/12/2022 14:55:56.0

MATHEUS SILVA SIMÕES

Avaliador Externo (UNIVERSIDADE FEDERAL DO PAMPA)

DECLARAÇÃO

Declaramos para os devidos fins que **FABIANO GARCIA MADRID** realizou sua defesa de dissertação intitulada “**CARACTERIZAÇÃO LITO-GEOFÍSICA DE OCORRÊNCIAS DE FERRO, PORÇÃO NORDESTE DA CARTA LAGOA DA MEIA LUA, RIO GRANDE DO SUL**” em 15 de dezembro de 2022, no Programa de Pós-Graduação em Geologia da Universidade Federal do Paraná, área Geologia Exploratória, nível Mestrado, e que por sugestão da banca examinadora, o título foi alterado para “**CARACTERIZAÇÃO LITO-GEOFÍSICA DE OCORRÊNCIAS DE FERRO, PORÇÃO NORDESTE DA FOLHA LAGOA DA MEIA LUA, RIO GRANDE DO SUL**”.

Curitiba, 17 de abril de 2023.



Prof. Dr. Leonardo Fadel Cury

Coord. Programa de Pós-Graduação em Geologia
Setor de Ciências da Terra
Universidade Federal do Paraná

AGRADECIMENTOS

Aos meus pais Afonso e Isabel, por serem exemplo de vida, apoiando minha decisão de enfrentar este desafio e nunca medindo esforços para que eu conseguisse sempre seguir nesta busca por conhecimento.

A geóloga Beatriz Matias, namorada, companheira, colega de profissão e exemplo de determinação. Presenciou de perto esta trajetória, participando ativamente no êxito do estudo, contribuindo com seu conhecimento nas discussões geológicas e fonte de força incondicional em todos os momentos.

Ao professor Dr. Maximilian Fries, quem me acompanhou desde à graduação na busca por ocorrências minerais e foi presente, sempre de maneira primorosa, clara e calcado em seu amplo conhecimento e experiência, contribuindo para o enriquecimento deste estudo, seja auxiliando remotamente no processamento e interpretação dos dados ou enfrentado temperaturas próximas a 40°C no pampa gaúcho durante as etapas de campo.

Ao geólogo Hamilton Luiz, amigo de longa data, disposto a encarar a campanha exploratória, a qual foi incansável e obstinado em executá-la da melhor forma, contribuindo diretamente na aquisição dos dados que permitiram a elaboração deste estudo.

...quem não sabe pra onde vai, não vai à lugar nenhum...

(JAYME CAETANO BRAUM, 1993)

RESUMO

A área nordeste da folha Lagoa da Meia Lua, sul do Brasil, é amplamente conhecida por seus recursos minerais e potencial prospectivo, e essas ocorrências estão correlacionadas aos complexos metamórficos de Palma e Passo do Ivo. Considerando que as principais informações geológicas (mapeamento) nesta área possuem uma escala regional de 1:100.000 e a cobertura aerogeofísica fornece apenas dados de baixa resolução para definição de alvos, há uma falta de avaliação precisa e análise detalhada na exploração de minérios. Diante dessas características, a principal proposta deste estudo é aprimorar e avaliar as ocorrências conhecidas de minério de ferro e seus limites propondo mais levantamentos (planejamento geofísico e sondagem). Em relação a esses aspectos, foi realizado o reconhecimento preliminar (semi-detulhe) aplicando aerogamaspectrometria, aeromagnetometria e imagens de satélite integradas a um MDT (em SIG). Além disso, como aprimoramento da resolução e parametrização direta das áreas potenciais, foram mapeados afloramentos de rochas, coletadas amostras de mão, descrições, medidas estruturais e de susceptibilidade (*in situ* e laboratório). Dados indiretos, como análise MDT, processamento e filtragem de dados magnetométricos, permitiram a detecção de padrões de topografia (estruturas do relevo) e detecção de altos valores/domínios magnéticos, relacionados ao contexto do arcaibouço estrutural e a áreas potenciais. Os altos valores magnetométricos estão relacionados à ocorrência de Fe localizada ao longo da Unidade de Pelito-Calcissilicática, provavelmente causada por BIFs, que, nas medidas de susceptibilidade, durante etapa de campo, atingiram mais de 240×10^{-3} SI. O processamento e a análise de dados aerogamaspectrométricos indicaram uma baixa concentração de minerais radioativos especialmente coincidentes com o Complexo Ofiolítico Palma, permitindo inferir os seus limites relacionáveis as BIFs. A análise e integração desses produtos revelaram áreas/limites de interesse para detalhamento e novos levantamentos. Como abordagem quantitativa e eficaz, sugere-se modelagem geológica como subsídio de estimativa de recursos e geofísica de detalhe (IP/resistividade, magnetometria e gravimetria) como assistência para modelos de inversões 3D para suporte à definição de alvos mais detalhados, realizando por fim geoquímica e campanhas de sondagem.

Palavras Chave: Ocorrência Mineral, Processamento de Dados, Prospecção.

ABSTRACT

The northeast area of the Lagoa da Meia Lua sheet, Rio Grande do Sul State, Brazil has been widely known for its mineral resources and prospective potential, and these occurrences are correlated to the Palma and Passo do Ivo metamorphic complexes. Considering that the main geological information (mapping) in this area has a regional scale of 1:100,000, and the aerogeophysical coverage provides only low-resolution data for target definition there is a lack for an accurate evaluation and detailed analysis in ore exploration. Given these characteristics, this study's main proposal is to enhance and assess known occurrences of iron ore, its limits, and evaluate its probable concentrations proposing further surveys (geophysics and drilling planning). Concerning these aspects, we performed a preliminary reconnaissance (semi-detail) applying aerogamaspectrometry, aeromagnetometry, and satellite imagery integrated to a GIS (DEM). Further, as a resolution enhancement and direct parameterization for potential areas, exposed rocks (outcrops) were mapped on the field, collected, described followed by structural measurements, and susceptibility (*in situ* and laboratory). Indirect data such as GIS analysis (DEM), magnetometry data processing and filtering allowed the detection of the patterns due to the topography (relief structures) related to the structural framework context and detected high magnetic values/domains linked to potential areas. The high magnetometric values are related to the Fe occurrence located along the Pelitic calc-silicate Unit, probably caused by banded iron formations, which hand samples susceptibility measurements in the field survey, can reach over 240×10^{-3} SI. Airborne gamma-ray processing and analysis indicated a low concentration of radioactive minerals spatially coincident with the ophiolitic complex Palma enabling defines the BIF's limits. The analysis and integration of these products revealed interesting follow-up areas/limits for enhancement and further surveys. As a quantitative and effective approach such as geological modeling as subsidy for resources estimation we suggest detailed geophysics (IP/resistivity, magnetometry, and gravimetry) as assistance for 3D inversions and modeling to support a definition of narrower targets to plan geochemistry and drill hole campaigns.

Keywords: Mineral Occurrence, Data Processing, Prospective.

LISTA DE FIGURAS

FIGURA 1 - Mapa de localização da área de estudo.	13
FIGURA 2 - Geologia do Terreno São Gabriel.	16
FIGURA 3 - Mapa Geológico e principais ocorrências minerais descritas na área de estudo.	17

SUMÁRIO

1	INTRODUÇÃO	11
1.1	ESTRUTURA DO TRABALHO	12
1.2	ÁREA DE INTERESSE.....	12
1.3	OBJETIVO GERAL.....	13
1.4	OBJETIVO ESPECÍFICO	14
1.5	CONTEXTO GEOLÓGICO	14
1.6	MATERIAIS	18
1.7	MÉTODOS.....	18
2	RESULTADOS	20
3	CONCLUSÃO E FECHAMENTO	47
	REFERÊNCIAS.....	48

1 INTRODUÇÃO

A constante evolução tecnológica causa um significativo impacto na sociedade de forma geral e, também, nas geociências. Constantes aperfeiçoamentos e descobertas de técnicas aplicadas ao geoprocessamento de dados tem agregado substancial valor na elaboração e qualidade dos trabalhos, economizando tempo e custo. Atualmente, uma ampla gama de *software* e dados estão disponíveis para acesso imediato, tanto de forma paga quanto gratuita, possibilitando ao usuário diferentes abordagens e processamentos integrados em ambientes de informação geográfica (SIG).

Uma importante base de dados em estudos exploratórios indiretos consiste nos levantamentos aerogeofísicos magnetométricos e gamaespectrométricos realizados pelo Serviço Geológico do Brasil – CPRM. Estes, recobrem áreas de interesse prospectivo em diferentes regiões e são de domínio público. Através da magnetometria e respectivas anomalias no campo magnético terrestre (resultante das propriedades magnéticas das rochas e materiais em subsuperfície), descontinuidades (estruturas) e importantes variações litológicas, são detectáveis. A rápida operação, associada ao baixo custo por km² dos levantamentos aerotransportados, torna a aeromagnetometria atraente no auxílio a exploração de depósitos minerais que contenham minerais magnéticos (Kearey et al., 2009).

A gamaespectrometria constitui uma importante ferramenta em diferentes estudos como no monitoramento ambiental, na distribuição de contaminantes radioativos e exploração mineral, por meio do auxílio ao mapeamento de alteração hidrotermal, caracterização de intrusões indiferenciadas, pontos de afloramento de intrusões ígneas entre outros (Ribeiro et al., 2014; Hoff et al., 2004).

Outro método indireto reconhecido e amplamente utilizado atualmente consiste no sensoriamento remoto realizado por satélites. Informações da superfície são captadas a partir de sensores ativos e passivos ao longo de todo o espectro eletromagnético, possibilitando o imageamento superficial, modelagem de relevo entre outras características de uma região alvo, que através do processamento destes dados permitem diversas interpretações. Robustas bases de dados são ofertadas sem custo por diferentes agências e institutos de pesquisa como por exemplo a *National Aeronautics and Space Administration* (NASA) e a *European Space Agency* (ESA). Estes dados e respectivas informações são de ampla aplicação em inúmeras áreas

de pesquisa, como por exemplo na área ambiental, geologia econômica, pedologia, cobertura de solo (Antunes et al., 2017), identificação de feições estruturais, geomorfologia entre outros (Pour e Hashim, 2015).

A integração de geofísica e sensoriamento remoto é vista em diversos trabalhos publicados, entre eles a caracterização de alvos prospectivos de ouro em veios de quartzo sulfetados em alterações hidrotermais (Menezes et al. 2006), reconhecimento de áreas alvo para elementos terras raras (nióbio) em complexos carbonáticos na Groenlândia (Bedini e Rasmussen, 2018). Essa integração associada a informações diretas como mapas geológico/estruturais tradicionais, podem oferecer importantes resultados que ajudam a detalhar o conhecimento de uma região alvo, como apresentado por Grochowski et al. (2019).

1.1 ESTRUTURA DO TRABALHO

Este trabalho está segmentado em três capítulos onde:

O primeiro busca contextualizar o tema da dissertação, discorrendo a área de estudo, os objetivos, o contexto geológicos, materiais e métodos utilizados durante a pesquisa;

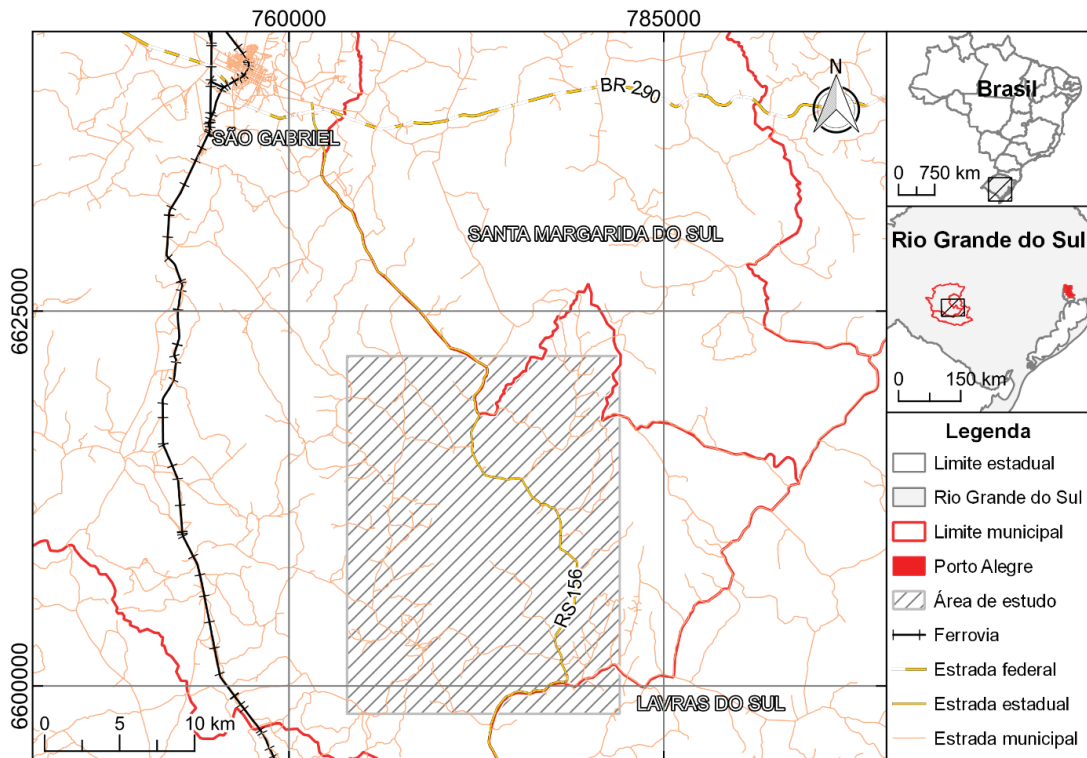
O segundo, apresenta como resultado o artigo completo intitulado **“EXPLORATION AND ASSESSMENT OF IRON OCCURRENCES - A CASE STUDY APPLYING AIRBORNE GEOPHYSICS AND GIS ALLIED TO FIELD MAGNETIC SUSCEPTIBILITY MEASUREMENTS”**, submetido a revista *“Journal of Applied Geophysics”*;

O capítulo final, corresponde as considerações a respeito da pesquisa seguido pelas referências bibliográficas utilizadas.

1.2 ÁREA DE INTERESSE

A área de estudo está situada no município de São Gabriel, próximo à divisa com as cidades de Santa Margarida do Sul e Lavras do Sul, estado do Rio Grande do Sul. Ocupa uma área de 434 Km² a nordeste da denominada carta Lagoa da Meia Lua (folha SH 21-Z-B-VI-2 MI-2994/2). O principal acesso dá-se por meio da BR 290 sentido São Gabriel - Porto Alegre (5 km) com entrada a sul para a BR 473 (15km) (FIGURA 1).

FIGURA 1 - Mapa de localização da área de estudo.



A região é majoritariamente drenada pela bacia hidrográfica do Rio Vacacaí Mirim pertencente a região hidrográfica do Rio Uruguai, as bacias hidrográficas dos rios Santa Maria e Camaquã ocupam porções muito pequenas nos extremos sudoeste e sudeste respectivamente. Os principais corpos d'água que cortam a região são o Rio Vacacaí, Arroio Palma, Arroio do Ingá e Arroio do Salso.

A geomorfologia segundo a classificação do Instituto Brasileiro de Geografia e Estatística (IBGE, 2003) é marcada majoritariamente por planaltos rebaixados sul rio-grandenses com depressões ao longo do Rio Jacuí e ao sul por planaltos residuais sul rio-grandenses.

Os principais solos da região são chernossolos argilúvicos, argissolos vermelho-amarelo e luvisso solo háplico.

1.3 OBJETIVO GERAL

De modo geral, este trabalho tem como proposta integrar informações geofísicas, geológicas e geomorfológicas no auxílio a detecção e delimitação de alvos potenciais para ocorrências minerais de ferro.

1.4 OBJETIVO ESPECÍFICO

Especificamente, pretende-se contribuir no detalhamento lito/geofísico da região e identificação de ocorrências minerais no Complexo Metamórfico Palma e zonas mineralizadas associadas em escala de semidetalhe, delimitando alvos prospectivos para subsidiar pesquisas minerais mais robustas. Destacam-se os seguintes objetivos específicos necessários para a produção deste estudo:

- Compilação e processamento de dados aerogeofísicos de magnetometria e gamaespectrometria do Projeto Aerogeofísico Escudo Sul-Riograndense - CPRM (2010) para a área de estudo.
- Análise geomorfológica de relevo através dos modelos digitais de elevação de dados Alos Palsar (12,5 metros de resolução) da *Alaska Satellite Facility (ASF DAAC 2014; Includes Material © JAXA/METI 2011;)*
- Identificação e delimitação de estruturas em escala de semidetalhe (1:25.000) para litologias nas áreas adjacentes às ocorrências minerais da região nordeste da carta Lagoa da Meia Lua;
- Parametrização dos dados indiretos/diretos a partir da integração geológica (petrografia) e medidas de susceptibilidade magnética (*in situ*) em afloramentos e amostras de mão.
- Delimitação de zonas com maior interesse prospectivo para avanço em técnicas de investigação de detalhe, como geoquímica e sondagens.

1.5 CONTEXTO GEOLÓGICO

A região de estudo encontra-se geologicamente situada no embasamento cristalino do denominado Escudo Sul-Riograndense. Esta região é pertencente ao Cinturão Dom Feliciano, que é a porção sul da grande Província da Mantiqueira. Localmente a área é constituída pelos litotipos do Terreno São Gabriel. Estas classificações aqui apresentadas, com exceção do Escudo Sul-Riograndense, são denominações geotectônicas complexas e que frequentemente são redefinidas.

A Província da Mantiqueira foi inicialmente descrita por Almeida et al. (1977), conhecida como uma região de grandes altitudes com frequente presença de porções montanhosas, se estende desde Montevideú (Uruguai) até o estado da Bahia (Brasil),

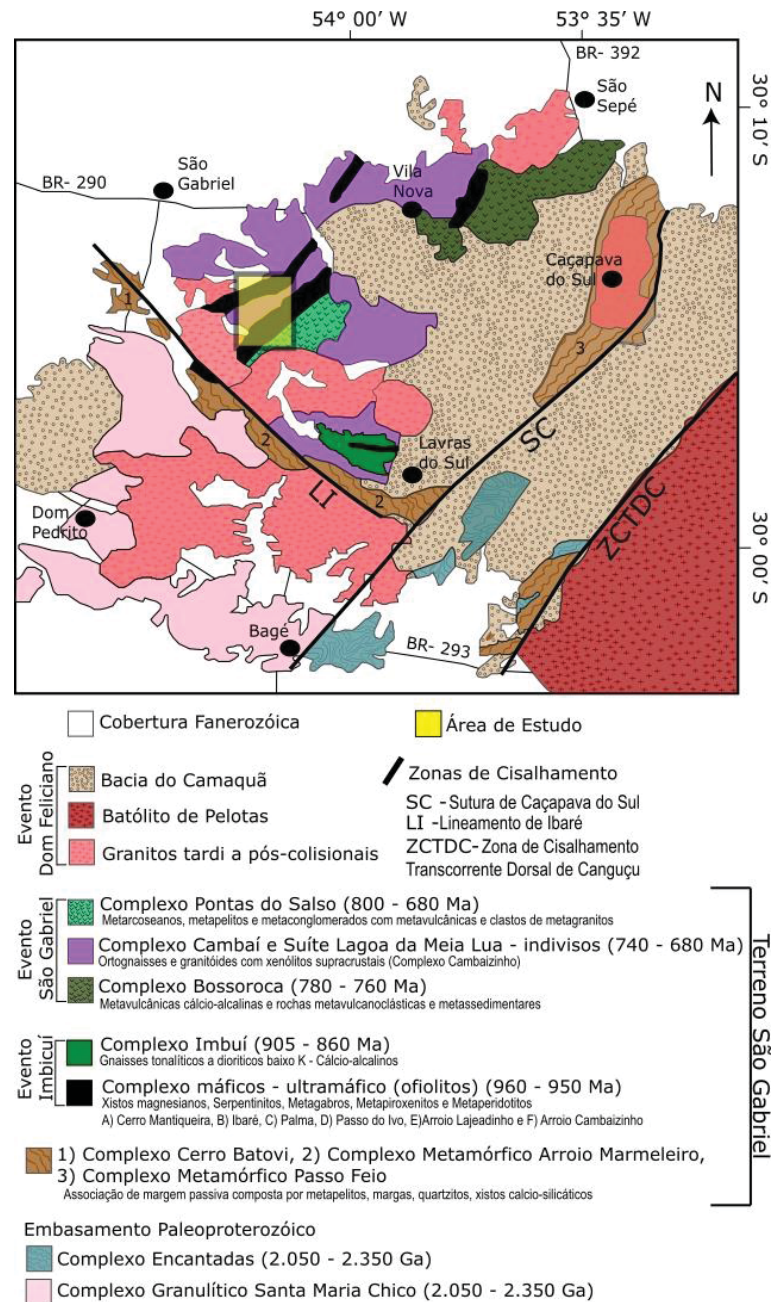
por cerca de 3000 km ao longo da costa leste do Brasil. Segundo Bizzi et al. (2003) e Laux (2017), esta província detém o registro da evolução neoproterozóica da América do Sul entre cerca de 900 à 520 milhões de anos, com a preservação de unidades paleotectônicas arqueanas, paleoproterozóicas e mesoproterozóicas.

Ainda de acordo com Bizzi et al. (2003) suas grandes unidades geotectônicas são integradas por uma sucessão de cinturões de empurrão e dobramentos e a maioria desses cinturões corresponde a orógenos colisionais, que ocorreram durante a colagem neoproterozóica/cambriana e apenas no domínio central e no extremo sudoeste da Província da Mantiqueira é que foram descritos orógenos controlados por subducção, nos orógenos do Terreno São Gabriel e Rio Negro.

O segmento mais ao sul da Província da Mantiqueira é chamado de Cinturão Dom Feliciano, este vai desde próximo a Montevideu (Uruguai) até o estado de Santa Catarina (Brasil). Conforme Phillip et al. (2016) o Cinturão Dom Feliciano foi formado por uma longa evolução que durou cerca de 450 milhões de anos, com seu início marcado pela abertura do Oceano Charrua (950 a 900 milhões de anos) e final correlato ao seu fechamento em paralelo com a colisão de arcos magmáticos entre 770 e 680 milhões de anos. Este é subdividido em a) Terreno São Gabriel, b) Terreno Tijucas, c) Batólitos Aiguá, Pelotas e Florianópolis e d) Terrenos Punta de Leste e Rocha.

Na porção oeste do Cinturão Dom Feliciano, a área de interesse está delimitada por sobre rochas de domínio do Terreno São Gabriel (FIGURA 2), que é constituído por rochas remanescentes de complexos ofiolíticos e três arcos magmáticos neoproterozoicos (Phillip et al., 2016). As unidades encontradas ao longo do Terreno São Gabriel são geralmente orientadas para NE/SW devido as zonas de cisalhamento no sentido N30-40°E. As diferentes litologias podem ser principalmente agrupadas em três associações petrotectônicas, a) Prisma acrescionário Palma, b) Associações de arcos relacionados e c) associação vulcano-sedimentar e plutônica do Seival.

FIGURA 2 - Geologia do Terreno São Gabriel.



FONTE: Modificado de Phillip et al. (2016)

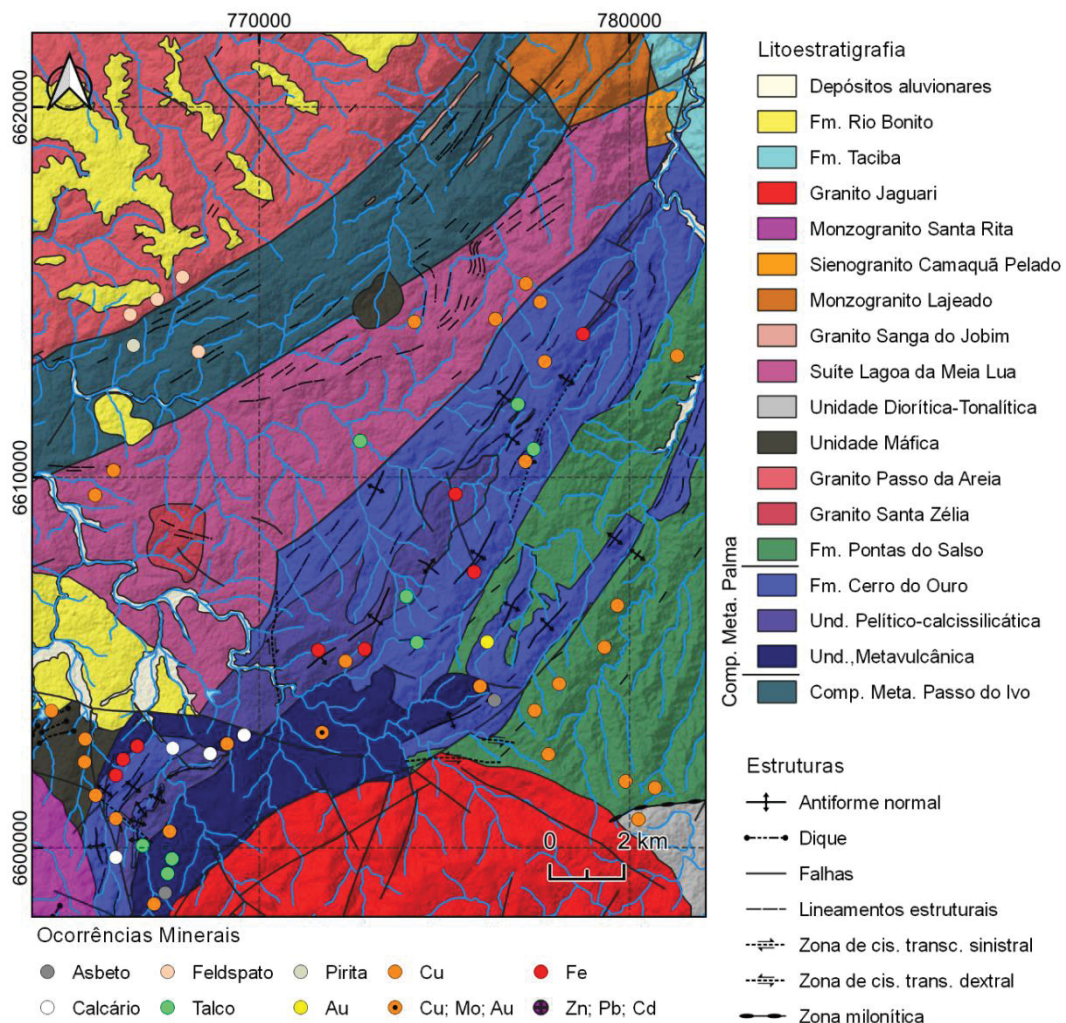
As rochas de interesse neste estudo compreendem os limites definidos segundo Phillip et al. (2016) como a porção do Prisma Acrescionário Palma, constituído por placas tectônicas de complexos ofiolíticos,

O Complexo Metamórfico Palma, objeto desta dissertação, é limitado ao sul pelo Granito Jaguari, a leste pela Formação Pontas do Salso, no extremo sudeste da área pelo Monzogranito Santa Rita, a noroeste pela Suíte Lagoa da Meia Lua e

nordeste pela Formação Taciba. Segundo Laux (2017) tal complexo é composto por serpentinitos, anfibolitos de granulação fina, metagabros, metacherts e BIFs.

Este complexo pode ainda ser subdivido litologicamente em três unidades menores: a) Unidade Máfica-ultramáfica ou Formação Cerro do Ouro, predominantemente formada por rochas meta-ultramáficas como xisto magnesiano nas bordas, serpentinitos principalmente no centro e metabasitos, b) Unidade Pelítico-calcissilicática, composta por rochas sedimentares como quartzitos, intercalados com metaultramáficas podendo ocorrer localmente formações ferríferas (BIF) e c) Unidade Metavulcânica representada por basaltos, basalto-antedesitos, andesitos, metadacito e metandesito, conforme apresentado no mapa geológico da área de interesse da FIGURA 3.

FIGURA 3 - Mapa Geológico e principais ocorrências minerais descritas na área de estudo.



FONTE: Modificado de Laux (2017).

1.6 MATERIAIS

Durante o desenvolvimento do estudo foram utilizados os seguintes dados públicos:

- a) Base cartográfica em SIG de Hasenack e Weber, 2010;
- b) Geologia regional de proposta por Laux (2017);
- c) Dados aerogeofísicos regionais (magnetometria e gamaespectrometria) do Serviço geológico do Brasil - CPRM, 2010;
- d) Sensoriamento remoto (modelos digitais de elevação e imagens de satélite) (ASF e NASA).

A etapa de aquisição de dados de campo foi realizada com auxílio de:

- a) Susceptibilímetro KT-10 da Terraplus Inc. para dados de susceptibilidade magnética e;
- b) Bússola geológica do tipo Clar para medição das atitudes das principais estruturas e descontinuidades.

1.7 MÉTODOS

O processamento e análise dos dados geofísicos foi realizado com auxílio do *software* OASIS Montaj. O processamento dos dados de sensoriamento remoto, a compilação de todas as informações em ambiente SIG e respectivas análises foram executadas através do *software* QGIS sendo, desta forma, permitindo a visualização e correlação espacial de maneira simultânea entre diferentes bases de dados.

O processamento dos dados geofísicos consistiu na geração de mapas das anomalias geofísicas magnetométricas e gamaespectrométricas. Complementarmente, o modelo digital de terreno foi interpretado a partir a técnica de relevo sombreado com exagero vertical de 5 vezes e azimute de iluminação de 315° e 45° o que evidenciou as direções principais das macroestruturas geomorfológicas. Ambas as bases de dados foram interpretadas em conjunto e com o mapeamento geológico regional de Laux (2017).

A análise e interpretação das bases de dados orientou na definição de áreas alvo para coleta de dados em campo, ou seja, direcionando a execução das medições da susceptibilidade magnética em afloramentos, seccionando as principais litologias bem como a coleta de amostras de mão para estudo petrográfico.

Realizadas as integrações e interpretações do banco de dados gerado, indicase zonas de alto potencial para a uma realização de campanha prospectiva de maior detalhe, onde através da caracterização lito-geofísica das áreas de interesse, pertence-se delimitar zonas anômalas para as ocorrências de ferro.

2 RESULTADOS

EXPLORATION AND ASSESSMENT OF IRON OCCURRENCES - A CASE STUDY APPLYING AIRBORNE GEOPHYSICS AND GIS ALLIED TO FIELD MAGNETIC SUSCEPTIBILITY MEASUREMENTS

*Fabiano Garcia Madrid¹; Maximilian Fries^{2,3}

¹ Post-Graduate Student in Geology at the Federal University of Paraná.

² Associate Professor at Unipampa, Caçapava do Sul Campus, Laboratory of Applied Geophysics (LGA).

³ Professor of the Post-Graduate Program in Geology at the Universidade Federal do Paraná.

*Correspondent author email: fabianomadrid.rs@gmail.com

ABSTRACT

The northeast area of the Lagoa da Meia Lua sheet, Rio Grande do Sul State, Brazil has been widely known for its mineral resources and prospective potential, and these occurrences are correlated to the Palma and Passo do Ivo metamorphic complexes. Considering that the main geological information (mapping) in this area has a regional scale of 1:100,000, and the aerogeophysical coverage provides only low-resolution data for target definition there is a lack for an accurate evaluation and detailed analysis in ore exploration. Given these characteristics, this study's main proposal is to enhance and assess known occurrences of iron ore, its limits, and evaluate its probable concentrations proposing further surveys (geophysics and drilling planning). Concerning these aspects, we performed a preliminary reconnaissance (semi-detail) applying aerogamaspectrometry, aeromagnetometry, and satellite imagery integrated to a GIS (DEM). Further, as a resolution enhancement and direct parameterization for potential areas, exposed rocks (outcrops) were mapped on the field, collected, described followed by structural measurements, and susceptibility (*in situ* and laboratory).

Indirect data such as GIS analysis (DEM), magnetometry data processing and filtering allowed the detection of the patterns due to the topography (relief structures) related to the structural framework context and detected high magnetic values/domains linked to potential areas. The high magnetometric values are related to the Fe occurrence located along the Pelitic calc-silicate Unit, probably caused by banded iron formations, which hand samples susceptibility measurements in the field survey, can reach over 240×10^{-3} SI. Airborne gamma-ray processing and analysis indicated a low concentration of radioactive minerals spatially coincident with the ophiolitic complex Palma enabling defines the BIF's limits. The analysis and integration of these products revealed interesting follow-up areas/limits for enhancement and further surveys. As a quantitative and effective approach such as geological modeling as subsidy for resources estimation we suggest detailed geophysics (IP/resistivity, magnetometry, and gravimetry) as assistance for 3D inversions and modeling to support a definition of narrower targets to plan geochemistry and drill hole campaigns.

Mineral Occurrence, Data Processing, Prospective.

1 INTRODUCTION AND OBJECTIVES

The region of Lagoa da Meia Lua has a significant mineral history with described mineral occurrences. Toniolo and Kirchner (2001), for example, describe occurrences of gold correlated with the Palmas Metamorphic Complex and the Passo do Ivo Metamorphic Complex. These potential gold deposits occur indiscriminately associated with metavolcano-sedimentary sequences, alkaline acidic intrusive rocks, and sedimentary sequences. According to Laux (2017), this is one of the regions with the greatest mineral potential in the state of Rio Grande do Sul, with real or potential resources for noble, ferrous, and non-ferrous metals. They represent inputs for agriculture, as well as industrial minerals and rocks for use in civil construction.

An effective exploratory approach, combined with geology, is geophysics, which, through its diverse techniques, allows for the indirect recognition, characterization, and delineation of the structural and lithological behavior of target areas. In the context of iron mineral occurrences associated with banded iron formations, magnetometry and gamma spectrometry are recognized methods with broad application.

Based on relevant information about the area, the main geological mapping is found in Laux (2017), which has a regional scale (1:100,000) and aerogeophysical data from the *Projeto Aerogeofísico Escudo do Rio Grande do Sul - CPRM* (2010) with regional coverage, and a lateral spacing between flight lines about 500 meters. Therefore, the mapping scale and anomalous values observed in this data has a regional scale and an improvement can be supplied by local investigation.

Considering these elements, the principal focus of this study is to apply an effective exploratory routine focused on an area with mineral occurrences. Specifically, a compilation of pre-existing information, processing and analysis of aerogeophysical data, and lithological description of rocks on site were carried out. Additionally, direct measurements of susceptibility in outcrops and hand samples, providing support for a litho-geophysical correlation and identification of potential zones/targets in the Palma Metamorphic Complex.

2 GEOLOGICAL CONTEXT

The study area is situated in the crystalline basement of the so-called South-Riograndense Shield, southeast of the Mantiqueira Province. This region is tectonically located in the Dom Feliciano Belt, which is the southern portion of the large Mantiqueira Province. Locally, the study area comprises rocks belonging to the São Gabriel Terrain (SGT), more specifically the portion called the Palma Accretionary Prism (Phillipp et al, 2016).

Phillipp et al. (2016) describes the Palma Accretionary Prism as five large ophiolitic complexes with elongated bodies parallel to regional structures in the NE/SW direction. These complexes are Palma, Passo do Ivo, Cerro da Mantiqueira, Cambaizinho, and Arroio Lajeado.

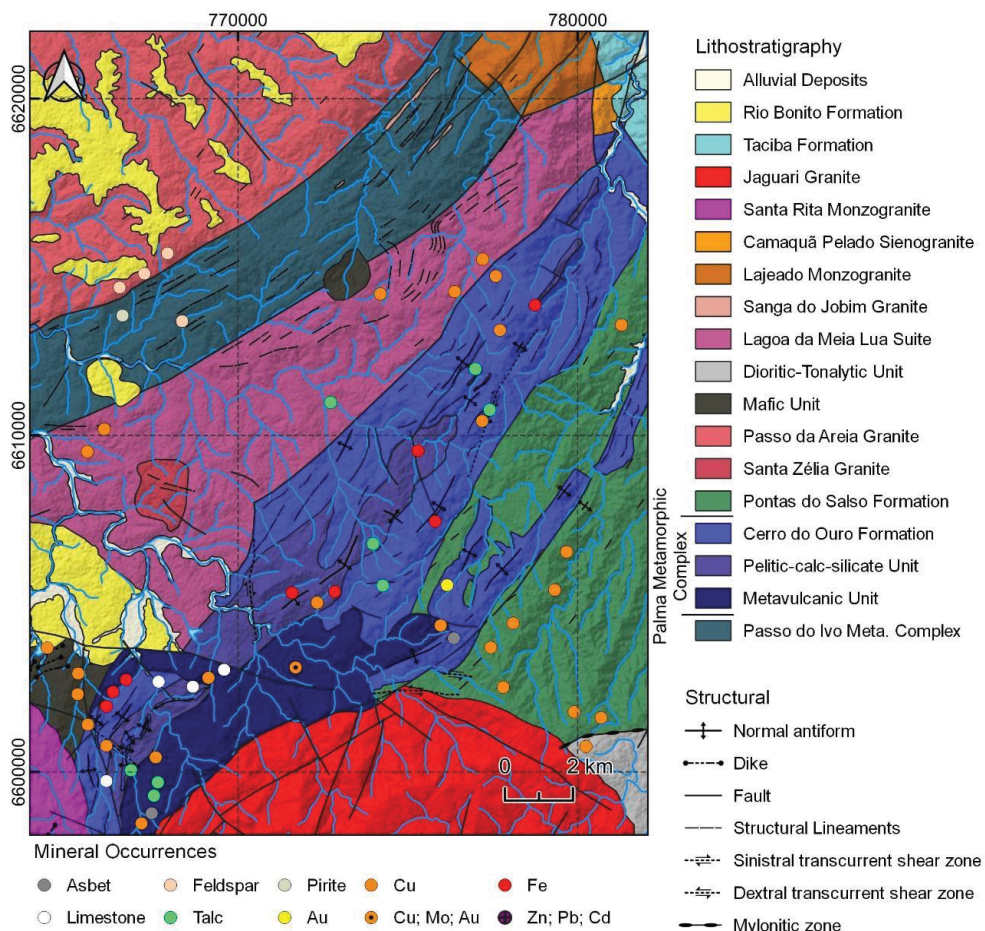
The Palma Metamorphic Complex, the subject of this study, is bounded to the south by the Jaguari Granite, to the east by the Pontas do Salso Formation, to the extreme southeast of the area by the Santa Rita Monzogranite, to the northwest by the Lagoa da Meia Lua Suite, and to the northeast by the Taciba Formation. According to Laux (2017), this complex is composed of serpentinites, fine-grained amphibolites, metagabbros, metacherts, and banded iron formations (BIF). Its units are preferably arranged as elongated bodies with a NE-SW preferred direction, which is the result of

movement influenced by the Caçapava do Sul shear zone, as indicated by Phillipp et al. (2016).

This complex can still be lithologically subdivided into three smaller units, which are: a) Mafic-ultramafic Unit or Cerro do Ouro Formation, predominantly formed by meta-ultramafic rocks such as magnesian schist on the edges, serpentinites mainly in the center, and metabasites, b) Pelitic-calc-silicate Unit, composed of metasedimentary rocks such as quartzites, schists, intercalated with meta-ultramafic rocks, and locally occurring banded iron formations (BIFs), and c) Metavolcanic Unit represented by basalts, basalt-andesites, andesites, metadacite, and metandesite (Laux, 2017).

The object of this study is the rocks belonging to the Palma Metamorphic Complex, locally known as the Pelitic-calc-silicate Unit represented in Figure 1, where a large number of occurrences of various metallic minerals along the bodies belonging to this complex are also notable.

Figure 1 - Geological and mineral occurrence map of the study area.

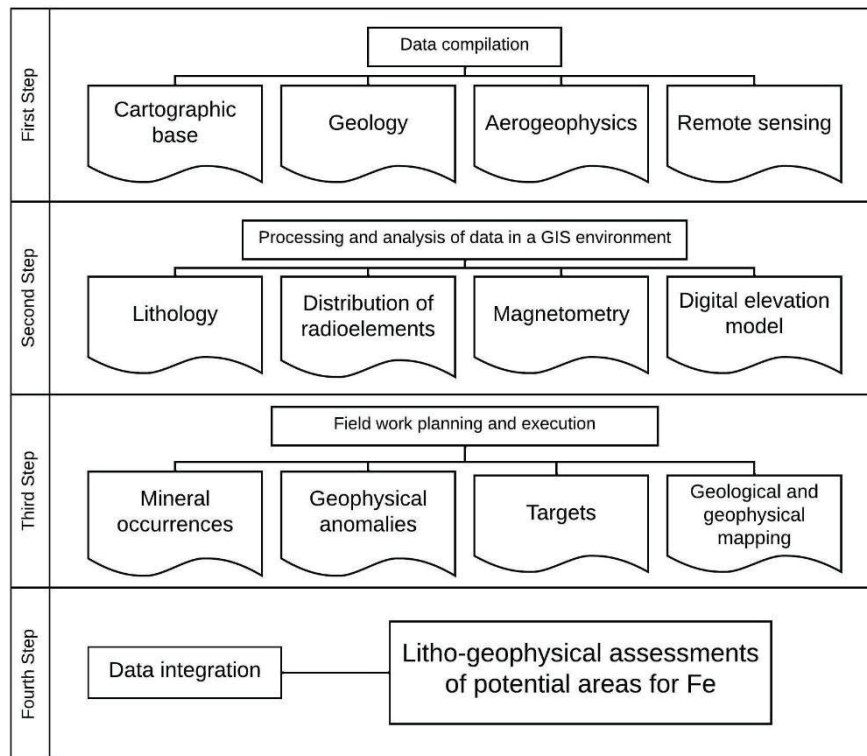


From: Laux et al. (2017).

3 MATERIAL AND METHODS

The study was conducted in four stages: i) compilation of available data in literature and public databases, ii) processing and interpretation of different GIS databases, iii) planning and execution of field research, and iv) integration and interpretation of results with emphasis on areas of greater prospective interest (Figure 2).

Figure 2 - Activity flowchart.



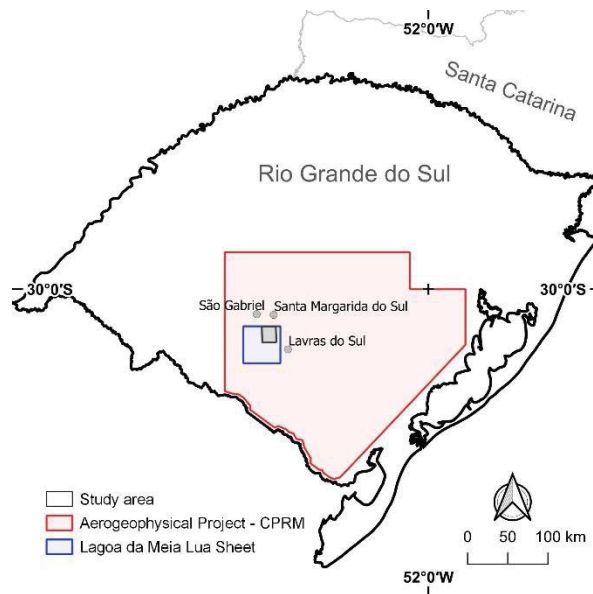
3.1 Data base

Composed through the compilation and organization of public geophysical data (aeromagnetic and gamma-ray spectrometry data), this dataset is based on the *Projeto Aerogeofísico Escudo do Rio Grande do Sul* conducted by the *CPRM - Serviço Geológico do Brasil*, in 2010, with the assistance of *LASA Engenharia e Prospecções S.A.* The magnetometric anomalies are necessary for correlation with direct measurements of rock's magnetic susceptibility. Anomalies observed through gamma-ray spectrometry offer variations of radioelements throughout the area like an indirect geochemistry.

The geological information, mineral occurrences, and cartographic base are derived from the Lagoa da Meia Lua Sheet (Laux, 2017).

As a support product for indirect analyses, a digital elevation model was provided by the Alos Palsar in Alaska Satellite Facility - ASF/NASA. Figure 3 contains the area boundaries and the respective databases used.

Figure 3 - Map presenting the location of the principal database and the study area.



3.2 Processing and analysis in GIS environment

The information was compiled in a GIS environment using QGIS 3.16 software, allowing for the visualization and integration of different information, as well as the simultaneous correlation of all spatial elements and characteristics, highlighting relevant correlations in prospective analysis.

For compiling, processing, and generation of raster data from the geophysical database, the OASIS Montaj software was used.

3.2.1 Geology

The geological map (Laux, 2017) provides not only lithological descriptions but also information about regional structures and mineral occurrences in the area. It allows identification of correlations between possible mineralized zones and associated lithologies. Such elements are essential for the correlation with other sources of direct and indirect information.

3.2.2 Aeromagnetometry

Aeromagnetic data was selected for the study area. The values of the total anomalous field were corrected to the IGRF of the region. Interpolation was performed using the bi-directional line gridding method of kriging. The option of pre-classification of data was used to remove backtracks, following manual quality recommendations of the software.

To generate the grid, a cell size of 100 x 100 meters was defined, following the premise of applying 1/4 of the sampling distance (Nyquist number). The generated maps were a) total magnetic induced "TMI" and b) reduced-to-pole "RTP".

The use of the RTP filter based on TMI anomalies aims to relocate magnetic maxima to the center of causative sources, transforming dipolar anomalies into monopolar ones (Telford et al., 1990). The following correction parameters were used for the region:

- a) Magnetic inclination = -36.84° .
- b) Magnetic declination = -13.34° .
- c) Tilt amplitude = -53.16° .

As of July 1st, 2010, the average acquisition date for obtaining these values.

For large areas with highly magnetized rocks, the upward continuation technique helps to reduce high-frequency noise and can be interpreted to indicate larger or deeper causative sources according to Hansen and Miyazki (1984). Following this premise, an upward continuation of 400 meters was estimated for the RTP data, generating the c) "RTP-UW400m".

Using the RTP-UW400m product, the Amplitude of the Analytic Signal was calculated and the map d) "ASA (UW400RTP)" was generated. This enhancement technique, initially introduced by Nabighian (1972, 1974), indicates that the maximum values coincide with the edges of the magnetic body when they are extensive, or its center when they are narrow.

Finally, based on RTP-UW400m, the Tilt Angle of the Horizontal Gradient was also generated with the map e) TAHG(UW400RTP) presented by Ferreira et al. (2010). This is another method that induces the delineation of the boundary of magnetized bodies, regardless of their depth.

It is important to consider that the values of the magnetic data have been normalized to the mean, that is, the value of the mean data has been added so that the central value of the data scale is approximately zero, without compromising the mathematical relationship between the anomalies.

3.2.3 Aerogammaspectrometry

The aerogammaspectrometric data and their respective flight lines were selected for the study area. Prior to interpolation, it was observed that the database contained concentrations with negative values. Therefore, following the methodology proposed by Ferreira et al. (2014), the values were normalized to 0.01 when below zero or equal to zero for division purposes (see Table 1).

Table 1 - Minimum gross and adjusted values for the average.

Channel	Original data	Normalized
T.C.	-0,558356404	0
K	-0,128961116	0,01
eTh	-1,50700867	0,01
eU	-0,847098112	0,01

The interpolation, performed using the Minimum Curvature method (Briggs, 1974), was applied to the normalized data of each element, following a formula of 1/5 of the sample distance. As the average spacing between flight lines is 500 meters, a cell size of 100 X 100 meters was adopted.

The maps with their respective observed anomalies are as follows:

- a) Total count, "TC" of radioactive elements.
- b) Potassium channel "K".
- c) Equivalent thorium channel "eTh".
- d) Equivalent uranium channel "eU."

3.2.4 Remote sensing

The application and analysis of data from digital terrain models, based on remote sensing, allow for the representation of the geomorphology of a particular area. This is an important tool for studying and characterizing the geological evolution of

different materials (soils and rocks) over millions of years. This dynamic offers the detection of features and discontinuities that contribute to the delimitation of lithologies and also support structural analysis.

The delimitation of lineaments may indicate faults or subsurface structures (lithological contacts, intrusions), representing important elements for understanding the tectonic and structural context, according to Andrades Filho and Fonseca (2009). Soares and Fiori (1976) describe positive lineaments as prominent features in the relief, arranged in a straight or slightly curved manner, parallel and forming symmetrical or slightly asymmetrical ridges, while O'Leary et al. (1976) describe negative lineaments as straight stretches of valleys or channels with the presence of drainage.

3.3 Geological descriptions and geophysical measurements

The field work in the area of interest consisted of local description and cataloging of the main lithotypes observed. Two exploratory campaigns were employed, one geological and one geophysical (magnetic susceptibility measurements). The local geological reconnaissance consisted of characterizing outcrops in terms of rock type, structural data measurements (fractures/joints, discontinuities, and mineral lineaments), and collecting hand samples for simple macroscopic analysis and classification.

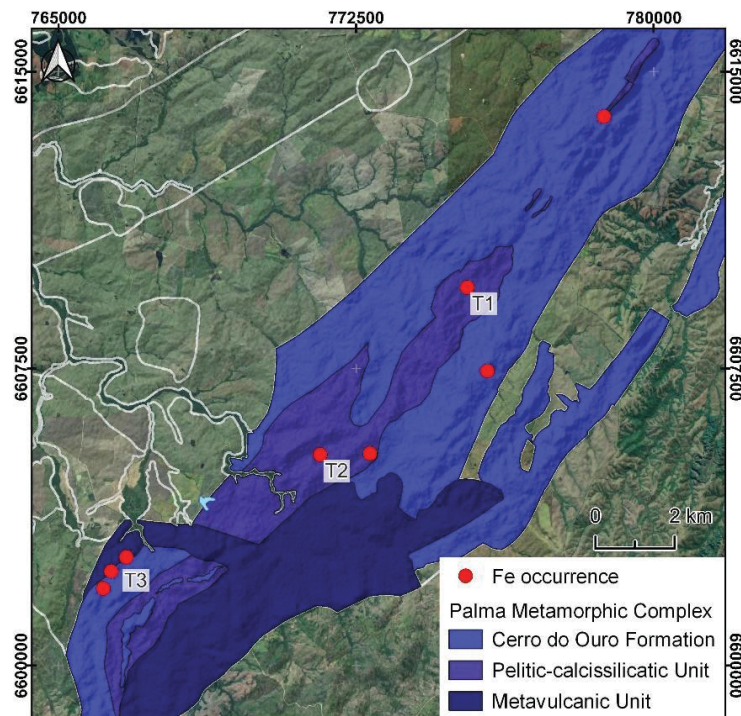
The geophysical investigation comprised measurements of magnetic susceptibility carried out with a portable Kappameter susceptibilimeter, model KT-10. The equipment belongs to the Federal University of Pampa, Caçapava do Sul campus. The measurements performed followed the approach proposed in Dentith and Mudge (2014). This consists of averaging 10 (ten) measurements per rock/outcrop. In this way, a relevant estimate of the magnetic minerals present (or not) in a particular rock is obtained, thus constituting an indirect geochemistry. Such a procedure is widely used in exploratory studies involving occurrences of metallic minerals. Rocks and/or samples that are highly oxidized or weathered are discarded. The unit of measurement used in this study is 10^{-3}SI (International System of Units).

4 RESULTS AND DISCUSSIONS

4.1 Geological context

In Laux (2017), at least 8 occurrences of Fe are identified along the Palma Metamorphic Complex. Of these occurrences, two stand out as potential prospects in the center of the area. These are called Target 1 and Target 2 and are located in a strip with significant coverage of the Pelitic-calcissilicatic Unit of the Palma Metamorphic Complex, where there are also reports of bodies of banded iron formations (BIF). In addition to these, along the contact between the Metavolcanic Unit and the Cerro do Ouro Formation, also of the Palma Metamorphic Complex, in the southwest of the area, three occurrences of Fe are delimited along a profile of just under 1 km. This site was called Target 3 (Figure 4).

Figure 4 - Study area detail map, presenting targets 4, 2 and the lithologies.



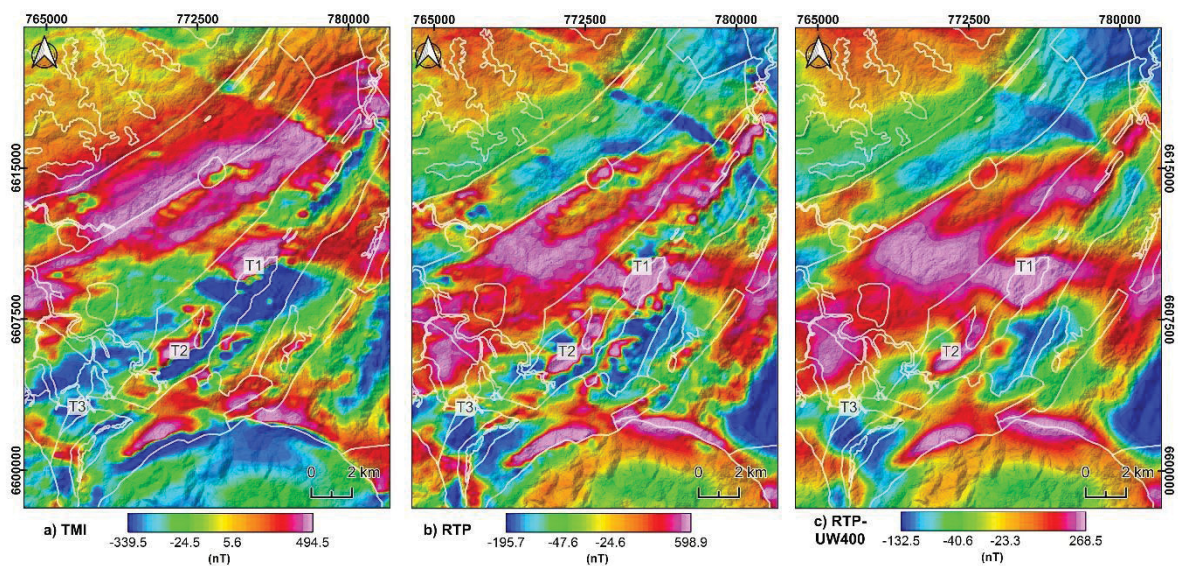
4.2 Aeromagnetometry

The aeromagnetometric anomaly maps presenting the TMI anomalies (Figure 5A) highlight a region in the area with high observed positive anomalous values ranging from 100 nT to 500 nT, with lower amplitudes/wave frequencies towards the north of the area. Another region with significantly negative anomalous values ranging from -350 nT to -50 nT is observed, exhibiting higher amplitudes/wave frequencies in

the southern area. Generally, it is observed that dipolar contrasts are oriented in the NE-SW direction, except for a NW-SE oriented structure located in the northeastern portion and an E-W granite intrusion in the southernmost point.

For RTP filter applied to the aeromagneto metric anomaly maps (Figure 5B), the effect of the filter is observed by the centered anomalies over the causative sources. Thus, it offers a more direct and reliable association with the lithological and structural features detected. As TMI data tends to present high-frequency noise for regional analysis (ambient noise) due the presence of magnetized small bodies or shallower causative sources (surface), we applied the upward continuation filter at 400 m (RTP-UW400). This procedure attenuates these noisy features as shown in Figure 5C. There is a significant decrease in noise, especially along the central portion of the map, corresponding to the Palma Metamorphic Complex.

Figure 5 - Aeromagneto metric maps with blank geological boundaries shown in a) TMI, b) RTP and c) RTP-UW400.



Applying the Analytical Signal Amplitude (ASA) from Figure 6A, it is possible to notice the presence of high values ranging from 0.45 to 0.60 nT/m in the form of anomalous magnetic highs observed along the Pelitic-Calcissilicatic Unit (Targets 1 and 2).

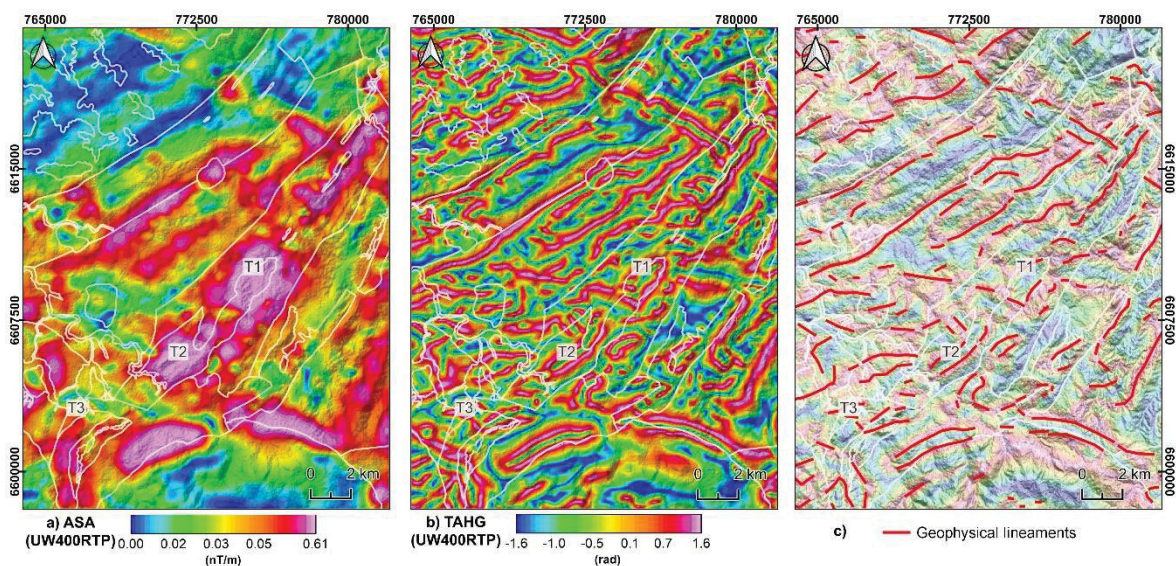
The TAHG, as shown in Figure 6B, enables and enhances the detection of geophysical lineaments that can be correlated to structural conditioning at the edges of causative sources. It is worth noting that there is a strong correlation with the regional geology and a suggestion of the presence of structural conditioning, such as

contacts, faults, or fractures, as well as probable elongated smaller bodies in the NE-SW.

Extracting the main magnetic lineaments enhanced and observed by the TAHG method (Figure 6C), a NE-SW direction trend becomes evident throughout the area, as well as the pre-established geological boundaries.

Contrary to geological observations, an NW-SE anomaly is observed to the northeast without correlation with surface lithology and mineral occurrences. It hypothesizes here that this anomaly is caused by a deeper source, such as the intrusion of a dike or posterior structure. To the south, a well-defined contact of Jaguari Granite with the near lithologies is well evidenced.

Figure 6 - Aeromagnetometric maps with geological contacts showing in a) amplitude of the analytical signal, b) inclination of the analytical signal of the total horizontal gradient and c) geophysical lineaments extracted from b).



In general, there is a strong correlation with the observed magnetic anomalies for the defined Targets 1 and 2. These are located in the region of a high amplitude dipole for TMI values, positive anomalous values for RTP and ASA, and with boundaries indicated by TAHG.

For Target 3, a distinct behavior of the observed anomalies is notable. It is important to mention that in this location, there is an indication of contact between the magnesian schists, serpentinites, and metabasites of the Cerro do Ouro Formation with the metadacites and metandesites of the Metavolcanic Unit. This may indicate the influence of hydrothermal fluid percolation that can cause the reduction or even

eliminate the magnetism present in the magnetic minerals that make up the rocks' framework.

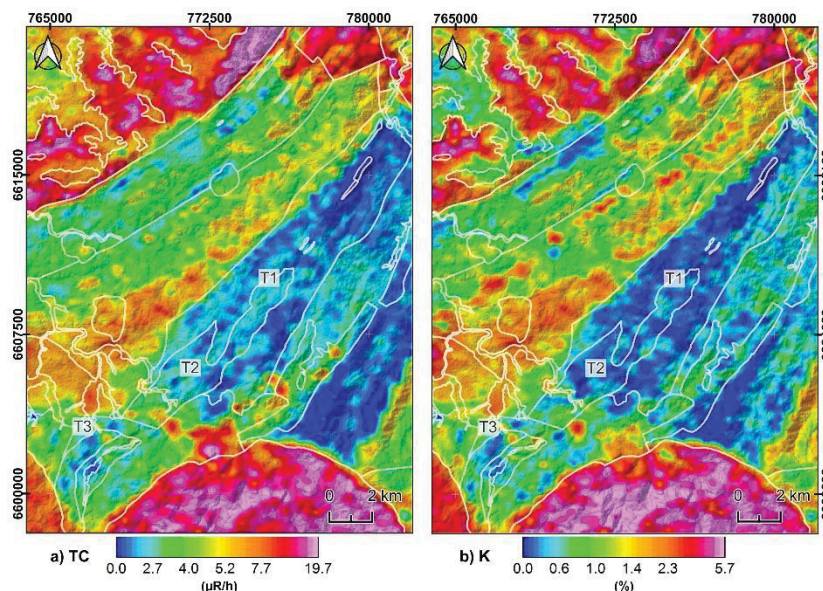
4.3 Airborne gamma spectrometry

In this study, the distribution of radioactive elements was analyzed and interpreted through the generation of respective maps, including a) total count (TC $\mu\text{R/h}$), b) potassium (K %), c) thorium (eTh ppm), and d) uranium (eU ppm).

The total count of radioactive elements (TC) shown in Figure 7A allows the observation and identification of significant concentrations above the average of 5.8 $\mu\text{R/h}$, which are well-defined for the granitoids in the northern and southern portions. The Palma Metamorphic Complex is characterized by median to very low concentrations of radioactive elements (with variations ranging from 0.2 $\mu\text{R/h}$ to 12 $\mu\text{R/h}$ and an average of 2.9 $\mu\text{R/h}$).

The potassium channel (K) in Figure 7B has an average concentration of 1.7% in the area, and the concentrations are distributed similarly to what occurs for TC. Concentrations relatively lower and closer to zero are found locally along the Palma Metamorphic Complex.

Figure 7 - Gamma Spectrometric maps and geological boundaries, where a) total count of radioactive elements (TC) and b) potassium channel (K).

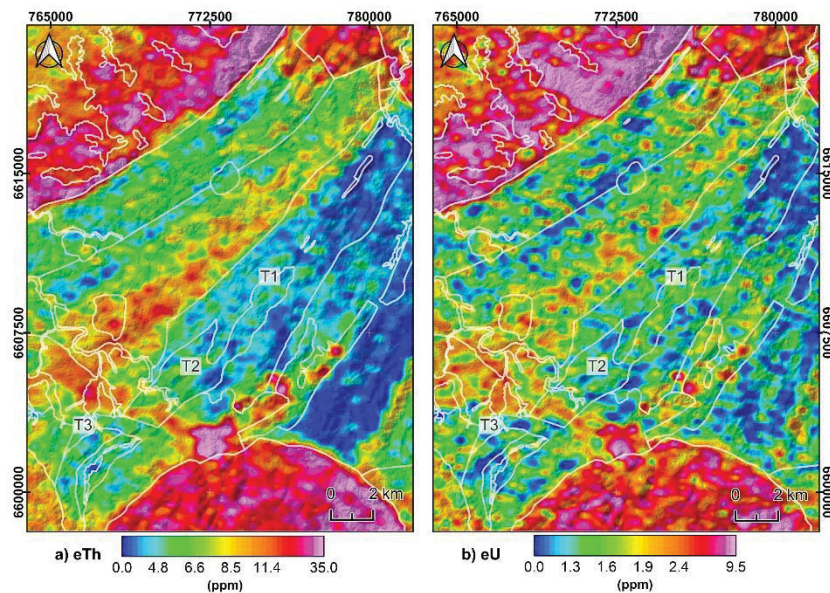


For the equivalent thorium channel (eTh), Figure 8A, the average concentration in the region is 9.1 ppm, reaching values of 35 ppm in the northern and southern

regions. Intermediate values are observed in the central-northern portion and minimum values in the central-southern portion. Concentrations below 5 ppm are found in areas near Fe occurrences.

In the channel of equivalent uranium concentration (eU), Figure 8B, the average found is 2 ppm. Following the channels displayed previously, the extreme northern and southern areas concentrate the highest values of the element, reaching up to 9.5 ppm. However, in the central region, the values are close to and below the average. Nevertheless, unlike the other channels, the distribution appears more varied and diffuse, even close to mineral occurrences.

Figure 8 - Gamma Spectrometric maps, and geologic boundaries of a) thorium equivalent (eTh) and b) uranium equivalent (eU) channels.



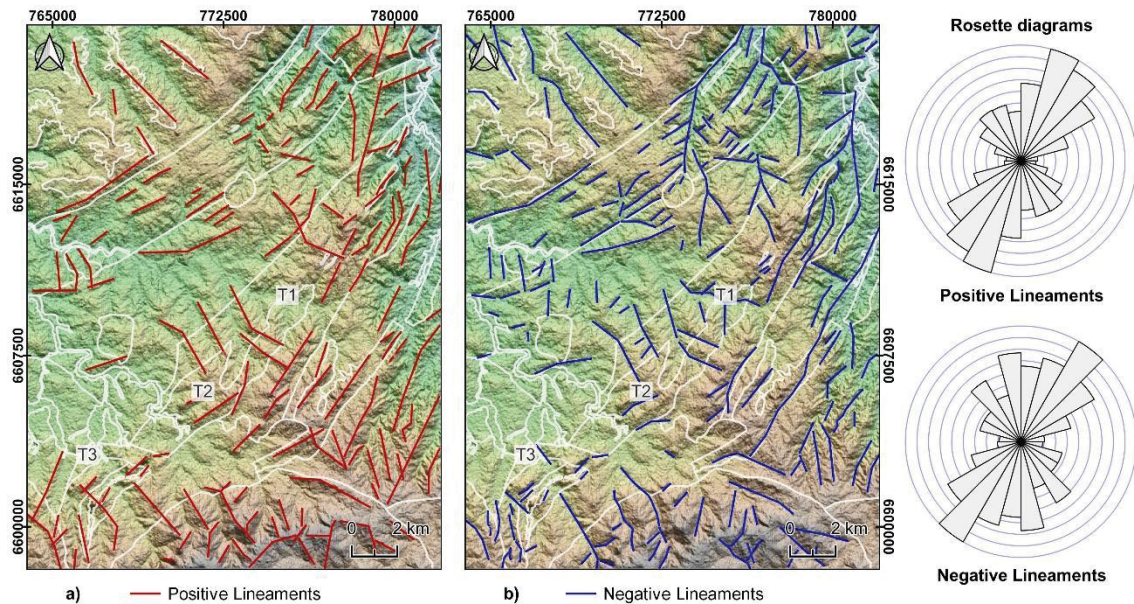
For Targets 1 and 2, low to median concentrations are observed in correlation to Target 3, which is also characterized by higher concentrations of radioactive elements in its proximity.

4.4 Remote Sensing

The digital terrain model (DEM) provided significant assistance in understanding and visualizing regional geomorphology and the area of interest. Features detected and surface relief structures can often be related to subsurface structures. Thus, positive lineaments are delimited in Figure 9A, and negative lineaments are delimited in Figure 9B.

Additionally, to the right of Figure 9, rosette diagrams with the main orientations of regional lineaments are displayed. For both positive and negative lineaments, the preferred direction indicated is between 015° and 045° for NE-SW.

Figure 9 - Maps of relief lineaments in a) positive, b) negative and with respective rosette diagrams on the right.

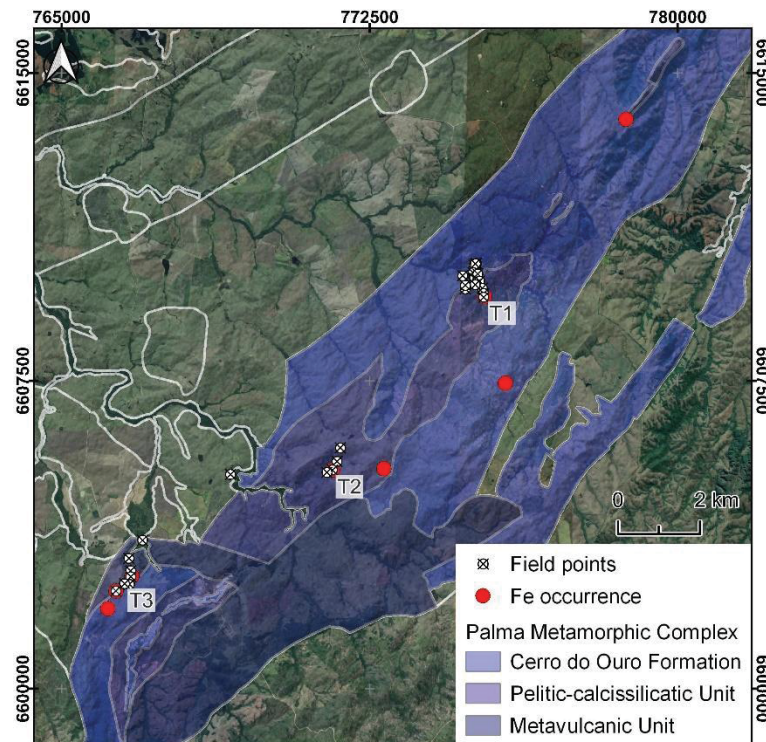


The targets 1, 2, and 3 are related to negative lineaments, that is, they are in valleys or channels. Regionally, the three areas of interest are arranged in the same NE-SW direction, following the regional structural pattern, and following the geophysical data indications.

4.5 Geological/Geophysical mapping

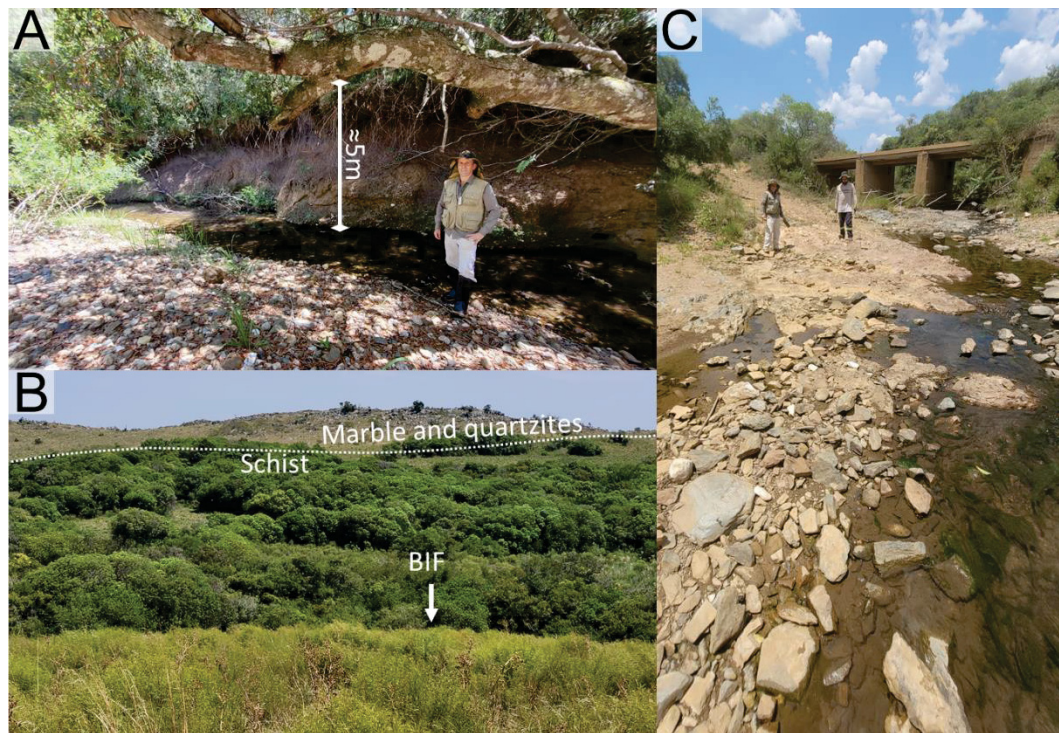
The previously presented results (shown in 4.1 to 4.4) served as support to follow up a geological/geophysical mapping in the area. Therefore, the emphasis is on detailing the targets indicated as potential sources of iron. A geological and macro petrographic characterization, and additionally outcrops and hand samples susceptibility measurements (variations) are presented as products (Figure 10).

Figure 10 - Map with the field measurement points (white dots), Fe occurrences (red dots), and main lithologies.



In a general context, rocky outcrops are found in the highest portions of the area. Specifically, lithologies composed of marble intercalated with quartzite and quartz veins are present. In negative reliefs, associated with drainage channels, schists predominantly outcrop (in the regions of Targets 1 and 2) and metabasic and metandesite rocks (in the vicinity of Target 3). In other portions, there is a significant coverage of soil and colluvial material, which makes it difficult to define contacts between lithologies in the field. Such coverings, in some places, are up to 5 meters thick (Figure 11).

Figure 11 - General view of the geological context of the area. In a) drainage channel showing a thick layer of soil, target 1, b) ridges with quartzite outcrops (possible metacherts), target 2 and c) drainage channel with contact between metabasic and metasites, target 3.



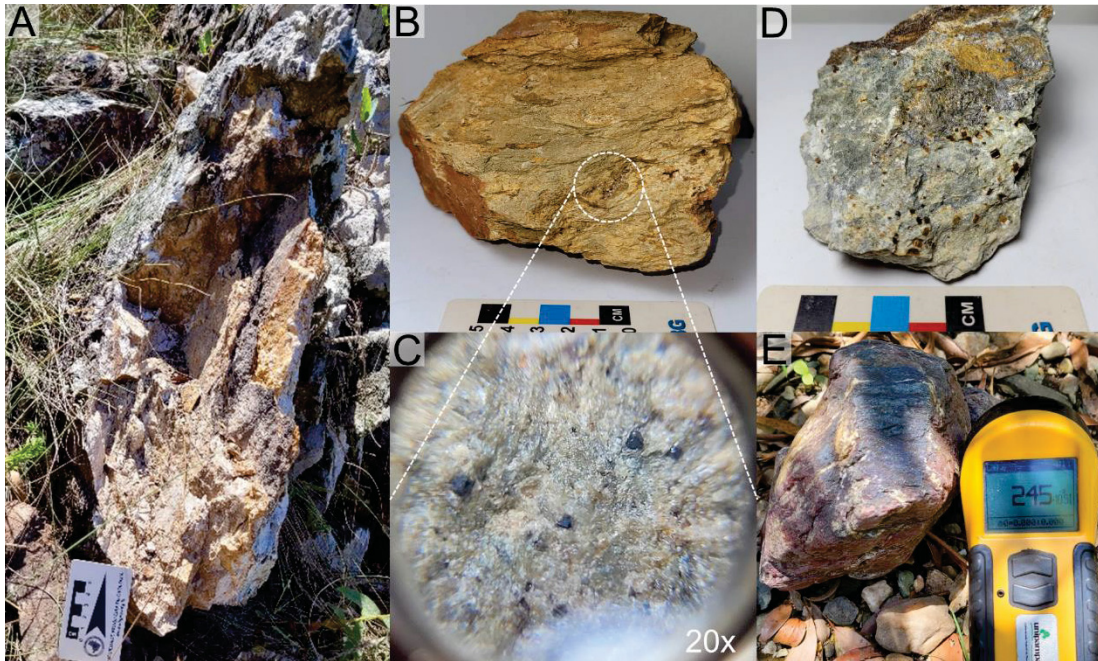
4.5.1 Target 1

Near Target 1, in a northwest-southeast profile, stratigraphic blocks of metamorphic rocks were identified from bottom to top. These include marble blocks, quartzite outcrops, magnetite-rich schist with fine-grained magnetite disseminated, talc-schist with some millimetric crystals of magnetite occurring pointedly, and finally, along the course of the drainage, blocks of banded iron formations (BIF).

These lithologies are oriented in the NE-SW direction with foliation and schistosity in the same direction, at $135/65^\circ$ dip direction.

The magnetic susceptibility average values of the lithologies are $0.03 \times 10^{-3} \text{SI}$ for the marbles, $3.3 \times 10^{-3} \text{SI}$ for the magnetite-rich schists, $0.5 \times 10^{-3} \text{SI}$ for the other outcrops of talc schists, and up to $245 \times 10^{-3} \text{SI}$ for the BIFs (Figure 12). The maximum registered value is $384 \times 10^{-3} \text{SI}$.

Figure 12 - a) Quartzite with NE-SW orientation, b) schist with magnetite crystals magnified 20x in c), d) talc-schist with some magnetite and e) banded iron formation.



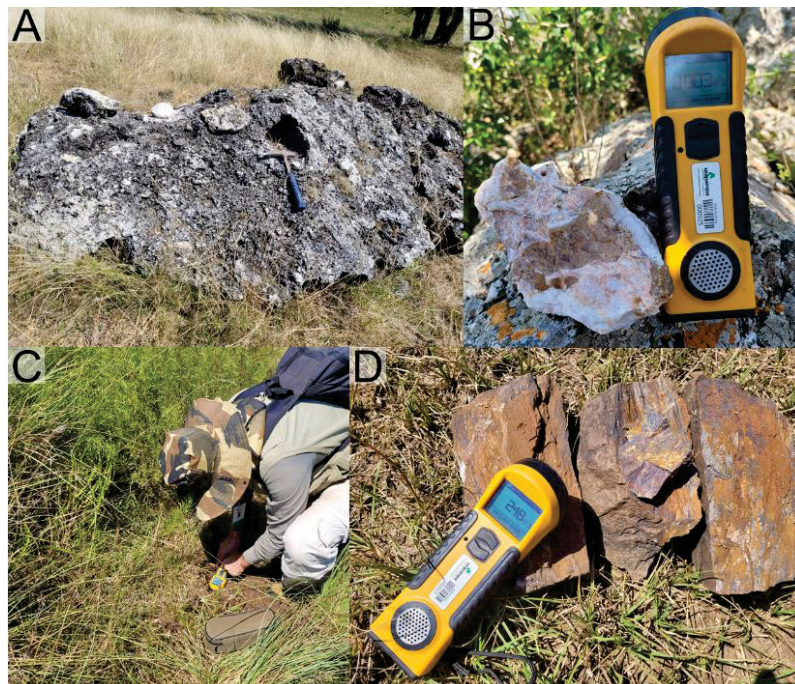
4.5.2 Target 2

In a NW to SE direction profile along the lithologies, metamorphic sedimentary rocks such as marble are identifiable in a restricted outcrop with breccia characteristics, followed by an extensive wall of quartzite (likely metachert also described by Laux, 2017). Next, strongly weathered talc schists and rolled blocks of BIFs deposited along the SE of the others were observed in sequence.

The spatial arrangement and orientation of lithologies in this portion correspond stratigraphically to what is observed in Target 1, with fracture orientation and schistosity at 130/70° dip direction.

The magnetic susceptibility readings indicated average values of $0.074 \times 10^{-3} \text{SI}$ for the marbles (breccia), $0.079 \times 10^{-3} \text{SI}$ for the quartzites (metachert), and $0.41 \times 10^{-3} \text{SI}$ for the altered schists, with values reaching up to $248.10 \times 10^{-3} \text{SI}$ for the BIF samples, which were strongly distinct from the others. At the exact coordinates of the regional target, the soil readings at a depth of 15 cm (control points) averaged $1.325 \times 10^{-3} \text{SI}$ (Figure 13).

Figure 13 - a) Marble with breccia texture, b) quartzite (probably metachert), in the highest portion, c) readings taken in soil and d) BIF samples found in thalweg.



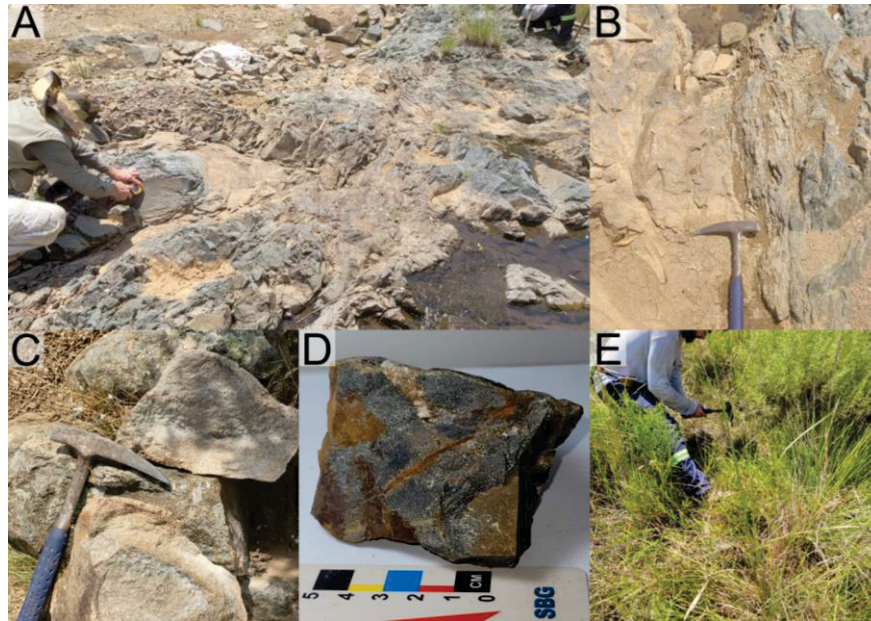
4.5.3 Target 3

To the southwest, near Target 3, the terrain generally has lower slope compared to other locations. At the intersection point between Palma River and an access road, the contact between the Meta-volcanic and Cerro do Ouro units was observed, where the former exhibits pinkish metandesites and the latter exhibits dark gray metabasites.

The contact observed in the drainage (Figure 14B) occurs abruptly and follows the regional orientation of this point, which is NE-SW. No outcrops were observed in the rest of the area; only large boulders from metandesite and metabasite, as well as small rolled blocks with an incipient schistosity and reddish coloration resulting from the presence of iron oxides, were present.

The magnetic susceptibility of the metandesites was around $0.853 \times 10^{-3} \text{SI}$ for the massive metabasites, $3.98 \times 10^{-3} \text{SI}$ for the samples with slight mineral orientation and presence of oxidation, and $45.343 \times 10^{-3} \text{SI}$. No outcrops were found at the exact coordinates of the occurrences, and readings taken at a depth of 15 cm in the soil indicated an average of $0.883 \times 10^{-3} \text{SI}$ for Target 3 (Figure 14).

Figure 14 - a) Metabasite susceptibility reading, b) metandesite contact, c) metandesite boulders d) oxidized sample with high susceptibility values, and e) site of occurrence with no evidence of outcrop.



4.6 Magnetic susceptibility of the rocks in the studied area - results and analysis for the described lithotypes

Table 2 presents a statistical summary and an integration of all the average values of magnetic susceptibility measured and their associated lithologies. This overall chart represents an important source for analysis and interpretation in understanding the selected targets and also establishing a relationship with the previous airborne data.

In summary, high magnetic susceptibility BIF samples were found in Targets 1 and 2. In Target 3, no BIFs were identified, but metabasic samples with indications of mineral orientation and incipient schistosity were found, which present anomalous values compared to nearby host rocks, albeit with less intensity than in the other targets.

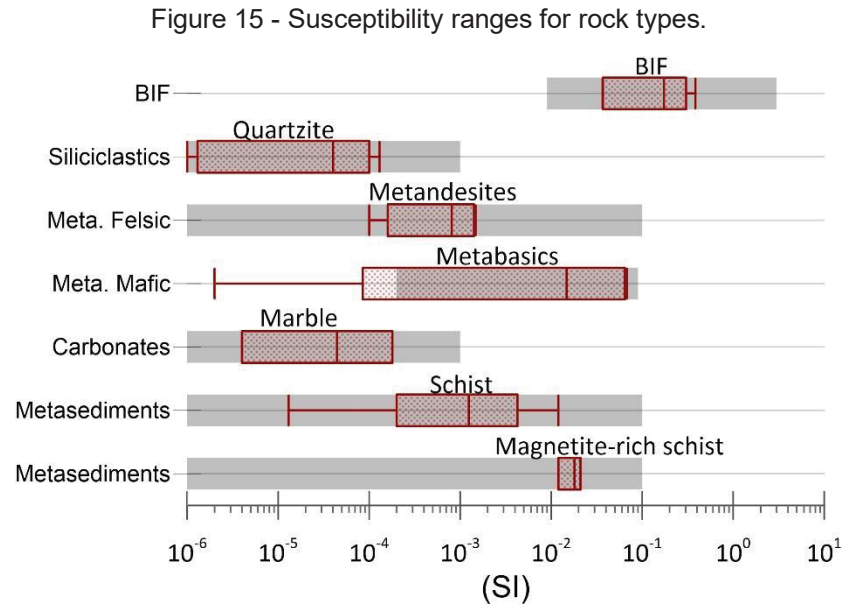
Table 2 - Statistical summary of susceptibility readings in 10^{-3}SI .

	BIF	Quartzite	Metandesite	Metabasic	Marble	Schist	Magnetite schist
Min.	36,7	0,001	0,10	0,002	0,004	0,013	12,0
Max.	384	0,130	1,48	67,80	0,180	12,00	21,0
Mean	173,7	0,037	0,81	14,759	0,044	1,241	18,0
Median	177,0	0,016	0,90	1,840	0,007	0,445	18,5

The complexity of magnetic mineralogy and limitations of this sampling method can present difficulties in accurately assigning a "medium" susceptibility value to a lithological unit. On the other hand, selecting a range that encompasses the majority of data is generally the best approach in exploration surveys (Dentith and Mudge, 2014). Thus, the objective here was to identify susceptibility ranges for probable individual units and where significant contrasts may occur in order to enhance potential domains/areas to follow up (geochemistry, soil/rock sampling, etc).

Figure 15 contains the ranges of magnetic susceptibility (SI) values indicated for the major rock groups (in gray) initially proposed by Clark (1997) and modified by Dentith and Mudge (2014). Considering that SI data can often be asymmetric it is suggested a graphical presentation and analysis using logarithmic frequency distribution offering more symmetry to the representation.

In the red boxes, the limits of the sample interval between the 10% and 90% quartiles are presented. This result highlights the distribution of values with adherence between the collected data and the ranges indicated by the literature. The outer dashes indicate the maximum and minimum values, and the inner line indicates the mean.



Modified from Dentith and Mudge (2014)

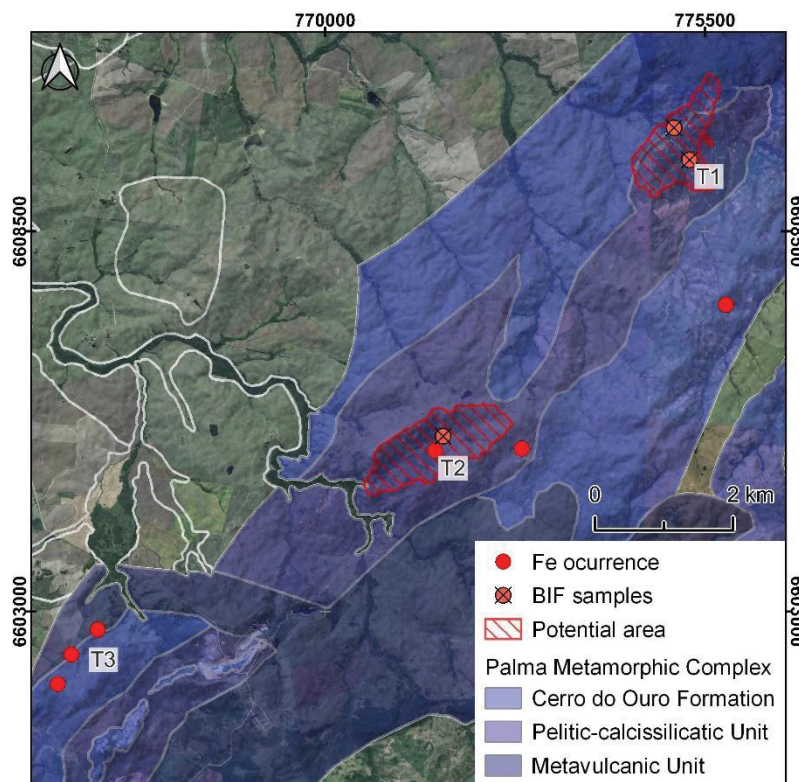
4.7 Detailing and location of prospective potential targets

The results of the field prospecting described, allowed for an indication of a correlation between geology and geophysics with the occurrence of iron resources.

Through the location of BIF blocks with high relative magnetic susceptibility values, associated with the configuration of reliefs and their respective limits (ridges), which suggest possible changes in lithology, as well as movements of surface material, new potential areas to investigate were defined and delineated.

Figure 16 presents the contribution basins delimited based on the DEM, indicating the area with the highest potential for the origin of mineralized samples corresponding to the BIF lithology.

Figure 16 - Map showing the indication of potential Fe areas for investigation (red dashes) for occurrences of BIFs based on the analysis carried out.



According to Figure 17, Targets 1 and 2 stand out as potential sectors for further exploration. This continuity is relevant in order to obtain greater detail on mineralizations and the delimitation of the mineralized body. Additionally, it is suggested that further geophysical details be carried out using methods such as electrical resistivity, induced polarization (IP), magnetometry, and gravimetry, to provide a more precise definition of the targets and to support the planning of geochemical and drilling campaigns, which are important for defining the geometry and subsurface limits of banded iron formations.

As an example, it is suggested to perform geophysical surveys of electrical resistivity and IP profiles in the NW-SE direction, intersecting the lithological contacts

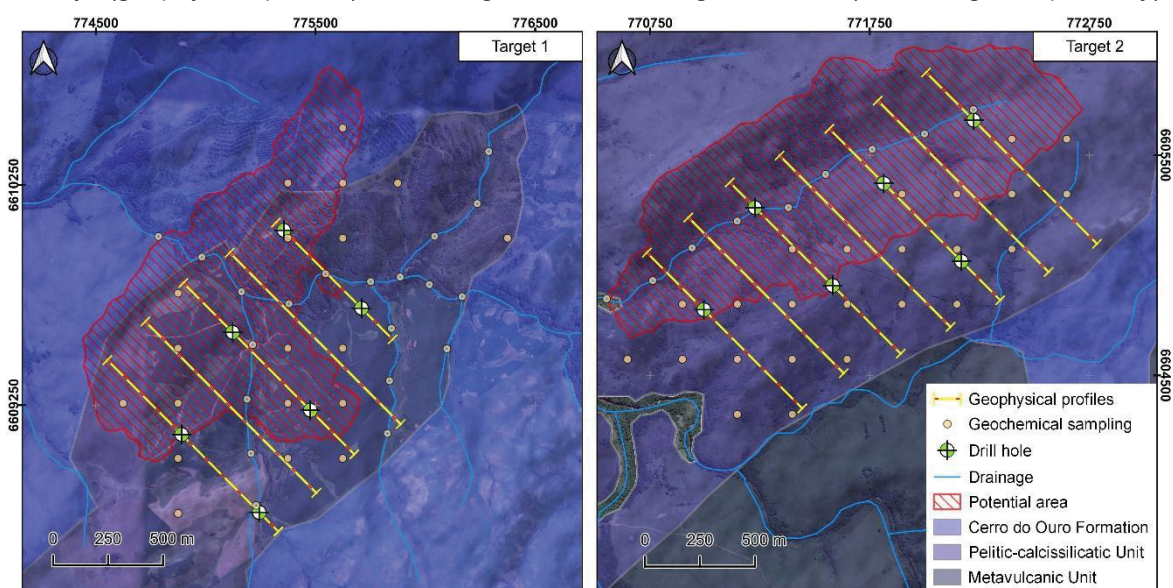
orthogonally. Following the same alignment and allowing for data correlation, additional acquisitions of magnetometry and gravimetry are proposed.

Due to the thick soil found in the area, data on chemical elements are fundamental and constitute important resources for identifying primary and secondary zones, as well as determining the probable surface concentration of the metal (source areas). To achieve this, a geochemical campaign is suggested, following the main drainage systems that cut through the target areas, complemented by a regular grid initially indicated with a spacing of 250m x 250m, with further refinement in the potential areas indicated by more detailed geophysical methods.

Additionally, it is proposed to carry out sampling of boreholes in the southeast sectors of targets 1 and 2 of the area, considering the structural and geophysical information previously obtained. This will allow the construction of stratigraphic profiles that are also oriented orthogonally to regional structures, namely in the NW-SE direction with an inclination of approximately 30° to NW. The description of the borehole represents relevant data in the results, specifically for the geological characterization at subsurface level. This, in correlation with geophysics, allows for a more assertive interpretation of the lithological behavior at depth.

Figure 17 contains the suggested limits/areas for detailing exploratory campaigns indicated for targets 1 and 2.

Figure 17 - Map showing potential Fe areas for investigation (red dashed) and indications for future surveys (geophysical profiles) and drilling locations for Targets 1 and 2 (left and right respectively).



5 CONCLUSIONS

The definition of an economically viable mineral resource requires a long and complex study from the prospecting phase (greenfield) to the opening of a mine. The primary stage corresponds to the exploration and prospecting of the area, which is a step where there are no guarantees of success and the investment is considerable. Therefore, considering that it is essential to optimize time and resources, an effective alternative arises with the use of publicly available data that can support more assertive and robust prospecting campaigns without additional acquisition costs.

Considering the implementation of a mineral exploration routine/strategy for base metal (Fe), guided by a public database, these data allowed the localization, delimitation, and integration:

a) Occurrences of iron, which were mapped by Laux (2017) along the Palma Metamorphic Complex, specifically in the Pelitic-Calcissilicate Unit, are associated with BIFs.

b) Anomalies in total magnetic field anomalous maps, with observable high values through enhancement applied techniques such as ASA and TAHG.

c) Indirect geochemical characterization by gamma spectrometry revealing that average and low concentrations of radioactive elements are present in metabasic rocks, schists, and BIFs within the area's context;

d) Structural framework which NE-SW trend direction is determined from the MDE and outlining the main geomorphological lineaments of the region of interest.

The analysis, integration, and interpretation of this data culminated in the planning and execution of a mineral exploration in the field of three main targets. Occurrences of lithologies with economic interest for iron were evidenced, as well as magnetic susceptibility signatures consistent and compatible with technical literature for mineralized samples in two out of the three targets.

The presented study offered low-cost and effective approaches and techniques for mineral research in these regions, confirming the existence of iron mineralization associated with banded iron formations lithology. Individualized analyses of the targets allowed for the refinement of potential areas, indicating the acquisition of data through new complementary exploratory campaigns aimed at defining the limits on the surface and behavior in the subsurface of the mineralized body.

REFERENCES

- ALMEIDA, F. F. M. de; HASUY Y.; NEVES, B. B. de B.; FUCK, R. A.; O Cráton do São Francisco. **Revista Brasileira de Geociências**, Campina Grade, v. 7, n. 4, p.349-364, 1977.
- ANDRADES FILHO, C.O.; FONSECA L.M.G. Lineamentos estruturais a partir de imagem Landsat TM e dados SRTM. In: **SIMPÓSIO BRASILEIRO DE SENSORIAMENTO REMOTO**, INPE, Natal, v.14, p.3151-3158, 2009
- ANTUNES, F. de S.; NEVES, L. V.; SANTOS, K. da S.; GRAÇA, A. J. S. Análise da integração entre Sensoriamento Remoto e SIG na classificação da Cobertura da terra em Duque de Caxias/RJ. **Revista Brasileira de Geomática**, Curitiba, v. 7, n. 1, p. 82-102, 2017. <http://dx.doi.org/10.3895/rbgeo.v5n1.5503>.
- ASF DAAC 2014, ALOS PALSAR_Radiometric_Terrain_Corrected_high_res; Includes Material © JAXA/METI 2011. <https://doi.org/10.5067/JBYK3J6HFSVF>.
- BEDINI, E.; RASMUSSEN, T. M. Use of airborne hyperspectral and gamma-ray spectroscopy data for mineral exploration at the Sarfartoq carbonatite complex, southern West Greenland. **Geosciences Journal**, v. 22, n. 4, p. 641-651, 2018. <https://doi.org/10.1007/s12303-017-0078-5>.
- BIZZI, L. A.; SCHOBENHAUS, C.; GONÇALVES, J. H.; BAARS, F. J.; DELGADO, I. de M.; ABRAM, M. B.; LEÃO NETO, R. MATOS, G. M. M. de; SANTOS, J. O. S. **Geologia, tectônica e recursos minerais do Brasil: texto, mapas e SIG**. Brasília: CPRM - Serviço Geológico do Brasil, 2003.
- BRIGGS, C. I., Machine contouring using minimum curvature. **Geophysics**, v. 39, n. 1, p. 39-48. 1974. <https://doi.org/10.1190/1.1440410>.
- CLARK, D.A. Magnetic petrophysics and magnetic petrology: aids to geological interpretation of magnetic surveys. **AGSO Journal of Australian Geology & Geophysics**. v. 17, n 2, p. 83–103. 1997.
- CPRM - SERVIÇO GEOLÓGICO DO BRASIL. Projeto Aerogeofísico Escudo do Rio Grande do Sul: relatório final do levantamento e processamento dos dados magnetométricos e gamaespectrométricos. Rio de Janeiro, RJ: **Lasa Prospecções**, v. 27. Programa Geologia do Brasil - PGB, 2010.
- DENTITH, M. e MUDGE, S. T. **Geophysics for the Mineral Exploration Geoscientist**. New York, NY: Cambridge University Press, 2014.
- FERREIRA, F. J. F., SOUZA, J. de, BONGIOLO, A. de B e S., CASTRO, L. G., ROMEIRO, M. A. T. Realce do gradiente horizontal total de anomalias magnéticas usando a inclinação do sinal analítico. Parte I - Aplicação a dados sintéticos. **IV Simpósio brasileiro de geofísica**. 2010. p. 1-6. <http://dx.doi.org/10.22564/4simbgf2010.062>.

FERREIRA F. J. F., FORNAZZARI NETO L., SZAMEITAT L. A. A., GUIMARÃES G. B., MARTIN V. M. O., PRAZERES FILHOS H., ULBRICH H. U. Gamma-ray spectrometry as a tool for mapping petrographic domains in granitoids: The examples of the Cunhaporanga and Três Córregos granitic complexes, Paraná state, Southern Brazil. **Revista Brasileira de Geofísica**, v. 32, n. 3, p. 465-479, 2014. <http://dx.doi.org/10.22564/rbqf.v32i3.521>.

GROCHOWSKI, J.; KUCHENBECKER, M.; BARBUENA, D.; NOVO, T. A. Integrating geological and airborne geophysical data to review the cartography of Rio Itanguá Batholith, Araçuaí Orogen, Brazil. **Brazilian Journal of Geology**, v. 49, n. 3, 2019. <http://dx.doi.org/10.1590/2317-4889201920190019>.

HANSEN, R. O.; MIYAZAKI, Y. Continuation of potential fields between arbitrary surfaces. **GEOPHYSICS**, v. 49, p. 787-795, 1984. <https://doi.org/10.1190/1.1441707>.

HASENACK H., WEBER E. Base cartográfica vetorial contínua do Rio Grande do Sul - escala 1:50.000. Porto Alegre: **UFRGS Centro de Ecologia**, 2010. 1 DVD-ROM. (Série Geoprocessamento n.3). ISBN 978-85-63483-00-5 (livreto) e ISBN 978-85-63843-01-2 (DVD).

HOFF, R.; ROLIM, S. B. A.; BASTOS NETO, A. C.. Mapeamento aerogamaespectrométrico da alteração hidrotermal associada à mineralização no distrito fluorítico de Santa Catarina, Brasil. **Revista Brasileira de Geofísica**, v. 22, n. 1, p. 45-55, 2004. <https://doi.org/10.1590/S0102-261X2004000100004>.

IBGE – INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. Geomorfologia da folha São Gabriel – SH.21-Z-B Escala 1:250.000. **Gerência de Recursos Naturais**. Unidade estadual de Santa Catarina. 2003.

KEAREY, P.; BROOKS, M.; HILL, I. **Geofísica de Exploração**. Tradução Maria Cristina Moreira Coelho. São Paulo: Oficina de textos, 2009.

LAUX J. H. Geologia e recursos minerais da folha Lagoa da Meia Lua, SH.21-Z-B-VI: estado do Rio Grande do Sul. Porto Alegre: **CPRM**, p. 255. 2017. <http://rigeo.cprm.gov.br/jspui/handle/doc/18035>.

MENEZES, P. de T. L.; ROIG, H. L.; SILVA, G. B.; MANE, M. A. Prospecção mineral no Grupo Paranoá. Reprocessamento de dados aerogamaespectrométricos e interpretação integrada a imagens TM- LANDSAT 5. **Revista Brasileira de Geofísica**, v. 24, n. 3, p. 343-355, 2006. <http://dx.doi.org/10.1590/S0102-261X2006000300004>.

NABIGHIAN, M.N. The Analytic Signal of Two-Dimensional Magnetic Bodies with Polygonal Cross-Section: Its Properties and use for Automated Anomaly Interpretation. **Geophysics**, v. 37, p. 507-517. 1972. <http://dx.doi.org/10.1190/1.1440276>.

NABIGHIAN, M.N. Additional Comments on the Analytic Signal of Two-Dimensional Magnetic Bodies with Polygonal Cross-Section. **Geophysics**, v. 39, p. 85-92. 1974. <https://doi.org/10.1190/1.1440416>.

O'LEARY, D.W., FRIEDMAN, J.D., AND PHN, H.A., Lineament, Linear, Lineation: Some proposed new standard for old terms. **Geological Society of America Bulletin**, v. 87, n. 10, p. 1463-1469. 1976. [https://doi.org/10.1130/0016-7606\(1976\)87%3C1463:LLLSPN%3E2.0.CO;2](https://doi.org/10.1130/0016-7606(1976)87%3C1463:LLLSPN%3E2.0.CO;2).

PHILIPP, R. P.; PIMENTEL, M. M.; CHEMALE JR, F. Tectonic evolution of the Dom Feliciano Belt in Southern Brazil: Geological relationships and U-Pb geochronology. **Brazilian Journal of Geology**, São Paulo, v. 46, supl. 1, p. 83-104, 2016. <https://doi.org/10.1590/2317-4889201620150016>.

POUR, A. B., HASHIM, M. Structural mapping using PALSAR data in the Central Gold Belt, Peninsular Malaysia. **Ore Geology Reviews**. v. 64, p. 13-22, 2015. <https://doi.org/10.1016/j.oregeorev.2014.06.011>.

RIBEIRO, V. B.; MANTOVANI, M. S. M.; LOURO, V. H. A. Aerogamaespectrometria e suas aplicações no mapeamento geológico. **Terræ Didática**, v. 10, n. 1, p. 29-51, 2014. <https://doi.org/10.20396/td.v10i1.8637386>.

SOARES, P.C. & FIORI, A. Lógica e sistemática na análise e interpretação de fotografias aéreas em geologia. **Notícias Geomorfológicas**, Campinas, v. 16, n. 32, p. 71-104, 1976.

TELFORD, W.; GELDART, L.; & SHERIFF, R. **Applied Geophysics**. Cambridge: Cambridge University Press, 1990. <https://doi.org/10.1017/CBO9781139167932>.

TONIOLO J. A.; KIRCHNER C. A. Resultados da prospecção para ouro na área RS-01 – Lavras do Sul, Caçapava do Sul, subárea Cambaizinho Rio Grande do Sul. **Informe de Recursos Minerais, Série Ouro – Informes Gerais**. v. 1, n. 14, p. 12. 2001. <http://rigeo.cprm.gov.br/jspui/handle/doc/1589>.

3 CONCLUSÃO E FECHAMENTO

Diversas técnicas de processamento e interpretação de dados podem ser aplicáveis no âmbito da exploração mineral. O presente estudo evidencia que, a existência de diversas alternativas quando à bases de domínio público atualmente disponíveis, permitem a otimização de custos nas primeiras etapas de pesquisa (*greenfield*).

À região a ser detalhada, é caracterizada por ocorrências de ferro, associadas ao Complexo Metamórfico Palma – Unidade Pelítico-calcissilicática, com limites regionais confirmáveis pela geoquímica indireta de dados aerogamaespectrométricos, anomalias magnetométricas e estruturas geomorfológicas.

Estas informações subsidiaram o planejamento e execução de uma campanha exploratória e caracterização lito/geofísica, onde foram encontradas amostras de formações ferríferas bandadas com altos valores de susceptibilidade magnética em contraste as litologias encaixantes.

Estes resultados são correlacionáveis com a bibliografia técnica e além de caracterizar a susceptibilidade magnética de amostras de mão BIFs indicam ocorrências de zonas com potenciais mineralização para ferro. Aliados aos padrões de relevo positivos/negativos delineados e interpretados pelo MDE, foram delimitados alvos para o refinamento através de novos métodos complementares à pesquisa apresentada.

Recomenda-se para a delimitação geométrica e detalhamento em subsuperfície destes prováveis corpos mineralizados, novas campanhas de investigação através de métodos geofísicos de eletrorresistividade, polarização induzida, magnetometria e gravimetria, estes refinando e apontando áreas para investigação geoquímica e execução de furos de sondagens.

O presente estudo corrobora com evidências de ocorrência de ferro para região, através de breve descrição petrográfica e medidas de susceptibilidade magnética *in situ*, localizando dois alvos com potencial mineral e propondo métodos para a caracterização da zona mineralizada com possível valor econômico agregado.

REFERÊNCIAS

- ALMEIDA, F. F. M. de; HASUY Y.; NEVES, B. B. de B.; FUCK, R. A.; O Cráton do São Francisco. **Revista Brasileira de Geociências**, Campina Grande, v. 7, n. 4, p.349-364, 1977.
- ANDRADES FILHO, C.O.; FONSECA L.M.G. Lineamentos estruturais a partir de imagem Landsat TM e dados SRTM. In: **SIMPÓSIO BRASILEIRO DE SENSORIAMENTO REMOTO**, INPE, Natal, v.14, p.3151-3158, 2009
- ANTUNES, F. de S.; NEVES, L. V.; SANTOS, K. da S.; GRAÇA, A. J. S. Análise da integração entre Sensoriamento Remoto e SIG na classificação da Cobertura da terra em Duque de Caxias/RJ. **Revista Brasileira de Geomática**, Curitiba, v. 7, n. 1, p. 82-102, 2017. Disponível em: <http://dx.doi.org/10.3895/rbgeo.v5n1.5503>. Acesso em: 29 mar. 2020.
- ASF DAAC 2014, ALOS PALSAR_Radiometric_Terrain_Corrected_high_res; Includes Material © JAXA/METI 2011. Disponível em: <https://doi.org/10.5067/JBYK3J6HFSVF>. Acesso em 18 mar. 2020.
- BEDINI, E.; RASMUSSEN, T. M. Use of airborne hyperspectral and gamma-ray spectroscopy data for mineral exploration at the Sarfartoq carbonatite complex, southern West Greenland. **Geosciences Journal**, v. 22, n. 4, p. 641-651, 2018. Disponível em: <https://doi.org/10.1007/s12303-017-0078-5>. Acesso em: 18 abr. 2020.
- BIZZI, L. A.; SCHOBENHAUS, C.; GONÇALVES, J. H.; BAARS, F. J.; DELGADO, I. de M.; ABRAM, M. B.; LEÃO NETO, R. MATOS, G. M. M. de; SANTOS, J. O. S. **Geologia, tectônica e recursos minerais do Brasil: texto, mapas e SIG**. Brasília: CPRM - Serviço Geológico do Brasil, 2003.
- BRIGGS, C. I., Machine contouring using minimum curvature. **Geophysics**, v. 39, n. 1, p. 39-48. 1974. <https://doi.org/10.1190/1.1440410>.
- CLARK, D.A. Magnetic petrophysics and magnetic petrology: aids to geological interpretation of magnetic surveys. **AGSO Journal of Australian Geology & Geophysics**. v. 17, n 2, p. 83–103. 1997.
- CPRM - SERVIÇO GEOLÓGICO DO BRASIL. Projeto Aerogeofísico Escudo do Rio Grande do Sul: relatório final do levantamento e processamento dos dados magnetométricos e gamaespectrométricos. Rio de Janeiro, RJ: **Lasa Prospecções**, v. 27. Programa Geologia do Brasil - PGB, 2010.
- DENTITH, M. e MUDGE, S. T. **Geophysics for the Mineral Exploration Geoscientist**. New York, NY: Cambridge University Press, 2014.
- FERREIRA, F. J. F., SOUZA, J. de, BONGIOLO, A. de B e S., CASTRO, L. G., ROMEIRO, M. A. T. Realce do gradiente horizontal total de anomalias magnéticas usando a inclinação do sinal analítico. Parte I - Aplicação a dados sintéticos. **IV Simpósio brasileiro de geofísica**. 2010. p. 1-6. Disponível em: <http://dx.doi.org/10.22564/4simbqf2010.062>. Acesso em: 15 jan. 2021.

FERREIRA F. J. F., FORNAZZARI NETO L., SZAMEITAT L. A. A., GUIMARÃES G. B., MARTIN V. M. O., PRAZERES FILHOS H., ULBRICH H. U. Gamma-ray spectrometry as a tool for mapping petrographic domains in granitoids: The examples of the Cunhaporanga and Três Córregos granitic complexes, Paraná state, Southern Brazil. **Revista Brasileira de Geofísica**, v. 32, n. 3, p. 465-479, 2014. Disponível em: <http://dx.doi.org/10.22564/rbqf.v32i3.521>. Acesso em 21 mai. 2020.

GROCHOWSKI, J.; KUCHENBECKER, M.; BARBUENA, D.; NOVO, T. A. Integrating geological and airborne geophysical data to review the cartography of Rio Itanguá Batholith, Araçuaí Orogen, Brazil. **Brazilian Journal of Geology**, v. 49, n. 3, 2019. Disponível em: <http://dx.doi.org/10.1590/2317-4889201920190019>. Acesso em: 18 jun. 2020.

HASENACK H., WEBER E. Base cartográfica vetorial contínua do Rio Grande do Sul - escala 1:50.000. Porto Alegre: **UFRGS Centro de Ecologia**, 2010. 1 DVD-ROM. (Série Geoprocessamento n.3). ISBN 978-85-63483-00-5 (livreto) e ISBN 978-85-63843-01-2 (DVD).

HOFF, R.; ROLIM, S. B. A.; BASTOS NETO, A. C.. Mapeamento aerogamaespectrométrico da alteração hidrotermal associada à mineralização no distrito fluorítico de Santa Catarina, Brasil. **Revista Brasileira de Geofísica**, v. 22, n. 1, p. 45-55, 2004. Disponível em: <https://doi.org/10.1590/S0102-261X2004000100004>. Acesso em: 14 abr. 2020.

IBGE – INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. Geomorfologia da folha São Gabriel – SH.21-Z-B Escala 1:250.000. **Gerência de Recursos Naturais**. Unidade estadual de Santa Catarina. 2003.

KEAREY, P.; BROOKS, M.; HILL, I. **Geofísica de Exploração**. Tradução Maria Cristina Moreira Coelho. São Paulo: Oficina de textos, 2009.

LAUX J. H. Geologia e recursos minerais da folha Lagoa da Meia Lua, SH.21-Z-B-VI: estado do Rio Grande do Sul. Porto Alegre: **CPRM**, p. 255. 2017. Disponível em: <http://rigeo.cprm.gov.br/jspui/handle/doc/18035>. Acesso em: 03 mar. 2020.

MENEZES, P. de T. L.; ROIG, H. L.; SILVA, G. B.; MANE, M. A. Prospecção mineral no Grupo Paranoá. Reprocessamento de dados aerogamaespectrométricos e interpretação integrada a imagens TM- LANDSAT 5. **Revista Brasileira de Geofísica**, v. 24, n. 3, p. 343-355, 2006. Disponível em: <http://dx.doi.org/10.1590/S0102-261X2006000300004>. Acesso em: 15 abr. de 2020.

NABIGHIAN, M.N. The Analytic Signal of Two-Dimensional Magnetic Bodies with Polygonal Cross-Section: Its Properties and use for Automated Anomaly Interpretation. **Geophysics**, v. 37, p. 507-517. 1972. Disponível em: <http://dx.doi.org/10.1190/1.1440276>. Acesso em: 20 jun. de 2021.

NABIGHIAN, M.N. Additional Comments on the Analytic Signal of Two-Dimensional Magnetic Bodies with Polygonal Cross-Section. **Geophysics**, v. 39, p. 85-92. 1974. Disponível em: <https://doi.org/10.1190/1.1440416>. Acesso em 20 jun. de 2021.

O'LEARY, D.W., FRIEDMAN, J.D., AND PHN, H.A., Lineament, Linear, Lineation: Some proposed new standard for old terms. **Geological Society of America Bulletin**, v. 87, n. 10, p. 1463-1469. 1976. Disponível em: [https://doi.org/10.1130/0016-7606\(1976\)87%3C1463:LLLSPN%3E2.0.CO;2](https://doi.org/10.1130/0016-7606(1976)87%3C1463:LLLSPN%3E2.0.CO;2).

PHILIPP, R. P.; PIMENTEL, M. M.; CHEMALE JR, F. Tectonic evolution of the Dom Feliciano Belt in Southern Brazil: Geological relationships and U-Pb geochronology. **Brazilian Journal of Geology**, São Paulo, v. 46, supl. 1, p. 83-104, 2016. Disponível em: <https://doi.org/10.1590/2317-4889201620150016>. Acesso em: 20 dez. 2020.

POUR, A. B., HASHIM, M. Structural mapping using PALSAR data in the Central Gold Belt, Peninsular Malaysia. **Ore Geology Reviews**. v. 64, p. 13-22, 2015. Disponível em: <https://doi.org/10.1016/j.oregeorev.2014.06.011>. Acesso em: 15 abr. 2020.

RIBEIRO, V. B.; MANTOVANI, M. S. M.; LOURO, V. H. A. Aerogamaespectrometria e suas aplicações no mapeamento geológico. **Terra Didática**, v. 10, n. 1, p. 29-51, 2014. Disponível em: <https://doi.org/10.20396/td.v10i1.8637386>. Acesso em: 10 jun. 2020.

SOARES, P.C. & FIORI, A. Lógica e sistemática na análise e interpretação de fotografias aéreas em geologia. **Notícias Geomorfológicas**, Campinas, v. 16, n. 32, p. 71-104, 1976.

TELFORD, W.; GELDART, L.; & SHERIFF, R. **Applied Geophysics**. Cambridge: Cambridge University Press, 1990. Disponível em: <https://doi.org/10.1017/CBO9781139167932>.

TONIOLO J. A.; KIRCHNER C. A. Resultados da prospecção para ouro na área RS-01 – Lavras do Sul, Caçapava do Sul, subárea Cambaizinho Rio Grande do Sul. **Informe de Recursos Minerais, Série Ouro – Informes Gerais**. v. 1, n. 14, p. 12. 2001. Disponível em: <http://rigeo.cprm.gov.br/jspui/handle/doc/1589>. Acesso em: 18 de jun. 2020.