UNIVERSIDADE DE BRASÍLIA – UnB
INSTITUTO DE GEOCIÊNCIAS – IG
PROGRAMA DE PÓS-GRADUAÇÃO EM GEOLOGIA

OS DEPÓSITOS SERROTE DA LAJE E CABOCLO (CU – Au), NORDESTE DO BRASIL: SULFETOS MAGMÁTICOS HOSPEDADOS EM ROCHAS RICAS EM MAGNETITA E ILMENITA ASSOCIADAS A INTRUSÕES MÁFICAS-ULTRAMÁFICAS.

GUILHERME FERREIRA CANEDO

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Orientador: Prof. Dr. César Fonseca Ferreira Filho (IG-UnB)

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RESUMO

Intrusões máfica-ultramáficas são amplamente conhecidas por hospedar depósitos sulfetados de Ni-Cu-EGP formados a partir da segregação e concentração de gotas de um líquido de sulfeto de magmas máficos ou ultramáficos. A assembleia de sulfetos dos depósitos de Ni-Cu-EGP consiste essencialmente de pirrotita, pentlandita e calcopirita. A origem de depósitos sulfetados ricos em Cu hospedados em intrusões máfica-ultramáficas, como os depósitos de Caraíba (Brasil) e Okiep (África do Sul), permanecem como uma questão controversa, com modelos genéticos muito distintos sendo propostos (de magmático a hidrotermal). Este estudo apresenta a descrição de dois depósitos ricos em sulfeto de Cu, hospedados em intrusões máfica-ultramáficas, e discute a origem da mineralização sulfetada.

Os depósitos do Serrote da Laje e Caboclo estão localizados na Faixa Sergipana (Província Borborema). As rochas máfica-ultramáficas que hospedam a mineralização de Cu-Au consistem em corpos irregulares de rochas mafica-ultramáficas interpretadas como pequenos diques e/ou *pipes*. Embora essas intrusões estejam parcialmente modificadas pelo metamorfismo de alto grau e associadas a um tectonismo dúctil, texturas e minerais magmáticos primários estão amplamente preservados. As intrusões máfica-ultramáficas consistem principalmente de ortopiroxenito, magnetitito, norito e gabronorito. A sequência de cristalização consiste em ortopiroxênio e óxidos de Fe-Ti, seguidos por plagioclásio e depois clinopiroxênio. O acamamento destes tipos de rochas é resultante do fracionamento a partir do magma parental, seja em *situ* ou devido sucessivos pulsos de magmas com fracionamento variável. As composições dos ortopiroxênios variam entre En65,5 a En79,2 mol % indicando composições primitivas a mais fracionadas para o magma parental. Tipos de rochas incomuns com flogopita e/ou granada abundante, comumente associadas com as rochas máfica-ultramáficas, são interpretadas como produto da assimilação das encaixantes gnáissicas durante a ascensão do magma. A assimilação de rochas crustais mais antigas também é consistente com os dados isotópicos de Sm-Nd do depósito Serrote da Laje, indicado pela alta variabilidade e dispersão dos valores de $\varepsilon Nd_{(T = 1.99\ Ga)}$ (-4,33 a 3,87).

Os sulfetos disseminados nos depósitos Serrote da Laje e Caboclo são intersticiais ou inclusos dentro de piroxênios e óxidos de Fe-Ti cúmulos. A forte associação de magnetita e sulfetos nestes depósitos é indicada pela correlação positiva de FeO e Ti-V nas rochas máfica-ultramáficas hospedeiras, combinadas com a correlação positiva de FeO e S-Cu-Au no minério sulfetado. Características texturais e químicas descritas nos depósitos Serrote da Laje e Caboclo suportam a interpretação que os sulfetos de Cu são magmáticos e diretamente associados com as rochas ricas em magnetita. As assembleias de sulfetos de ambos os depósitos consistem principalmente de bornita e calcopirita, com razão Cu/Fe variando entre 1, em amostras de minério ricas em calcopirita, e 5 em amostras ricas em bornita. Os resultados dos isótopos de enxofre para calcopirita e bornita têm uma estreita gama de valores, entre -1,0 e 2,5 δ34S ‰, suportando a origem magmática do minério. A combinação de cristalização fracionada do magma parental combinada com a oxidação do magma é sugerida como mecanismo apropriado para formar sulfetos magmáticos ricos em Cu com alta razão Cu/Fe dos depósitos Serrote da Laje e Caboclo.

Mineralização de Cu sulfetada subordinada ocorre em veios e/ou brechas em rochas máfica-ultramáficas alteradas. Resultados de isótopos de enxofre em pirita, pirrotita e calcopirita de veios ou brechas variam entre 7,5 to 13,0 δ34S ‰, sugerindo origem hidrotermal. Esta mineralização secundária é interpretada como resultado da percolação de fluidos pelas rochas máfica-ultramáficas mineralizadas que remobilizou parcialmente os sulfetos do minério primário. Esta interpretação não indica a existência de uma mineralização hidrotermal de Cu-Au robusta, que poderia indicar diferentes alvos de exploração além dos investigados neste estudo.

A idade magmática das rochas máficas-ultramáficas hospedeiras dos depósitos Serrote da Laje (ca. 1,99 Ga) e Caraíba (ca 2,05 Ga) sugerem que importantes depósitos de Cu localizados próximos a borda norte do Cráton do São Francisco estão associados a intrusões Paleoproterozóicas.

Palavras-chave: sulfetos magmáticos, cobre, ouro, Serrote da Laje, Caboclo, rochas máfica-ultramáficas

ABSTRACT

Mafic-ultramafic intrusions are widely known for hosting Ni-Cu-PGE sulfide deposits formed as the result of the segregation and concentration of droplets of liquid sulfide from mafic or ultramafic magma. The bulk sulfide assemblage of Ni-Cu-PGE deposits consists essentially of pyrrhotite, pentlandite and chalcopyrite. The origin of Cu-rich sulfide deposits hosted in mafic-ultramafic intrusions, exemplified by the Caraíba (Brazil) and Okiep (South Africa) deposits, remains however a controversial issue, and highly distinct genetic models have been proposed (from magmatic to hydrothermal). This study present the description of two Cu-rich deposits hosted by mafic-ultramafic intrusions and discuss the origin of the sulfide mineralization.

The Serrote da Laje and Caboclo deposits are located in the Sergipano Belt (Borborema structural province). The mafic-ultramafic rocks hosting Cu-Au mineralization in the Serrote da Laje and Caboclo deposits consist of irregular bodies of mafic-ultramafic rocks interpreted as small dikes and/or pipes. Although these intrusions are partially modified by high-grade metamorphism and associated ductile tectonism, primary magmatic textures and minerals are largely preserved. Mafic-ultramafic intrusions consist mainly of variably textured orthopyroxenite, magnetitite, norite and gabbronorite. The crystallization sequence consists of orthopyroxene and Fe-Ti oxides followed by plagioclase and then by clinopyroxene. Systematic interlayering of these rock types are consistent with all rock types resulting from fractionation from a parental magma, either in situ or due to successive pulses of variably fractionated magma. Orthopyroxene compositions ranging from En65.5 to En79.22 mol % indicate moderately primitive to fractionated compositions for the parental magma. Unusual rock types with abundant phlogopite and/or garnet, commonly associated with mafic-ultramafic rocks, are interpreted as products of assimilation of country gneissic rocks during magmatic emplacement. Assimilation of older crustal rocks is also consistent with Sm-Nd isotopic data of the Serrote da Laje Complex, as indicated by highly variable and scattered $\varepsilon_{Nd (T = 1.99 Ga)}$ values (-4.33 to 3.87).

Disseminated sulfides in both Serrote da Laje and Caboclo deposits are interstitial to or enclosed into cumulus orthopyroxene and Fe-Ti oxides. The close association of magnetite and sulfides in the Serrote da Laje deposit is indicated by positive correlations of FeO and Ti-V in hosted mafic-ultramafic rocks matched with positive correlations of FeO and S-Cu-Au in sulfide ore. Textural and chemical features described in the Serrote da Laje and Caboclo deposits support the interpretation that Cu-rich sulfides are magmatic and closely associated with magnetite-rich rocks.

The sulfide assemblages in both deposits consist mainly of bornite and chalcopyrite, with Cu/Fe ratio in sulfides ranging from about 1 in chalcopyrite-rich ore samples to about 5 in bornite-rich samples. Sulfur isotope results for chalcopyrite and bornite has a narrow range of values from -1.0 to 2.5 δ34S ‰, thus supporting a magmatic origin for the ore. A fractional crystallization of the parental magma combined with magmatic oxidation is suggested as an appropriate mechanism to generate the Cu-rich magmatic sulfides with high Cu/Fe ratios of the Serrote da Laje and Caboclo deposits.

Subordinated Cu-sulfide mineralization occurs in veins and/or breccia in altered mafic-ultramafic rocks. Sulfur isotope results for pyrite, pyrrhotite and chalcopyrite in veins or breccia range from 7.5 to 13.0 δ34S ‰, suggesting a hydrothermal origin. This secondary ore is interpreted as the result of sulfides from hydrothermal fluids that percolate the Cu-Au mineralized mafic-ultramafic rocks and partially remobilized the primary ore. This interpretation does not indicate the existence of a robust Cu-Au hydrothermal mineralization that may lead to different exploration targets than those investigated in this study.

Close magmatic ages of mafic-ultramafic rocks of the Serrote da Laje deposit (ca. 1.99 Ga) and the Caraíba deposit (ca. 2.05) suggest that significant Cu deposits are associated with Paleoproterozoic mafic-ultramafic intrusions in the region located close to the northern border of the São Francisco Craton in Brazil.

Key Words: magmatic sulfides, copper, gold, Serrote da Laje, Caboclo, mafic-ultramafic rocks

CONSIDERAÇÕES GERAIS

Introdução

Trabalhos de exploração e avaliação desenvolvidos pela Aura Minerals Inc. (www.auraminerals.com) nos depósitos de Cu-Au do Serrote da Laje e Caboclo indicaram grande recurso mineral (~750 kt de Cu contido) hospedado em uma associação de rochas máfica-ultramáficas compostas por piroxenito norito e ilmenita-magnetitito acamadados. Além do aumento significativo dos recursos minerais, os trabalhos desenvolvidos pela Aura Minerals propiciaram um melhor entendimento da estrutura geológica-estratigráfica dos complexos máfico-ultramáficos e mineralizações de Cu-Au.

Trabalhos anteriores desenvolvidos pela DOCEGEO sugerem um modelo de mineralização magmática para o depósito de Serrote da Laje (Horbach & Marimon, 1988). Segundo estes autores a mineralização está hospedada em um complexo máfico-ultramáfico submetido a intensos processos pós-magmáticos, incluindo um evento metamórfico de alto grau. As características do depósito de Serrote da Laje são, contudo, distintas daquelas observadas nos depósitos de Ni-Cu associados a complexos máficos-ultramáficos (Naldrett, 2004, 2010). Intrusões máfico-ultramáfica são conhecidas por hospedar depósitos de Ni-Cu-PGE sulfetado originados pela segregação de um líquido imiscível de sulfeto a partir de magmas máfico-ultramáficos (Barnes & Lightfoot, 2005). A origem de depósitos ricos em Cu associados a intrusões máfico-ultramáficas é, contudo, controversa. A origem destes depósitos, exemplificados pelos depósitos de Caraíba (Bahia) e Okiep (África do Sul), tem sido interpretada como resultante de processos magmáticos (i.e., segregação de um líquido imiscível de sulfeto; Oliveira and Tarney, 1995; Clifford and Barton, 2012), como resultado de processos magmáticos transformados por processos metamórficos de alto grau (Cawthorn & Meyer, 1993; Barnes & Maier, 1999) e, mais recentemente, como depósitos hidrotermais do tipo IOCG (Williams et al., 2005; Groves et al., 2010; Maier et al., 2012). Os trabalhos de exploração mineral desenvolvidos pela Aura Minerals indicam a existência de diferentes tipos de mineralizações e/ou remobilizações no depósito Serrote da Laje, sugerindo que o depósito tem uma origem mais complexa do que aquela aventada nos trabalhos anteriores.

A proposta do projeto é apresentar descrição geológica dos depósitos Serrote da Laje e Caboclo, utilizando os dados de exploração adquiridos pela Aura Minerals Inc, e resultados obtidos neste estudo, incluindo litogeoquímica, química mineral e dados isotópicos de enxofre, U-Pb e Sm-Nd, e, com isso contribuir para a definição da origem da mineralização sulfetada destes depósitos e auxiliar nos trabalhos de exploração mineral.

Localização e fisiografia

O depósito do Serrote da Laje está localizado à aproximadamente 10 km a noroeste da cidade de Arapiraca, na porção central do estado de Alagoas (Figura i). A cidade de Arapiraca possui aproximadamente 210.0000 habitantes (IBGE, 2009), sendo a segunda maior do Estado de Alagoas, e é o centro social, político e econômico da região do Agreste Alagoano. O acesso a partir de Maceió é feito através da rodovia pavimentada BR-316, BR-101 e AL-220, com percurso total em torno de 136 km. Já o depósito do Caboclo está localizado à aproximadamente 15km a noroeste do depósito Serrote da Laje, próximo da cidade de Craíbas que possui cerca de 22.000 habitantes. O acesso a partir de Arapiraca é feito pela através da rodovia pavimentada AL-115, com percurso em torno de 20 km.

A região em que se inserem os depósitos é caracterizada principalmente por áreas planas, com cotas que variam de 265 a 300 metros, arrasadas e de baixa declividade. Essa paisagem é interrompida apenas por poucos inselbergs, como o Serrote da Laje.

O clima é definido por temperaturas elevadas, com a média anual de 25ºC e precipitação segundo o intervalo de 750 a 1000 mm. Os três meses mais chuvosos são maio, junho e julho, concentrando geralmente mais de 50% do total anual, e os mínimos pluviométricos são registrados na primavera ou no verão, com variação de quatro a cinco meses de seca.

A vegetação da região é típica do Agreste, rala e de pequeno porte, como mirtáceas, combretáceas, leguminosas e cactáceas. A região apresenta intensa degradação, principalmente para cultivo de fumo, milho e pastagem.

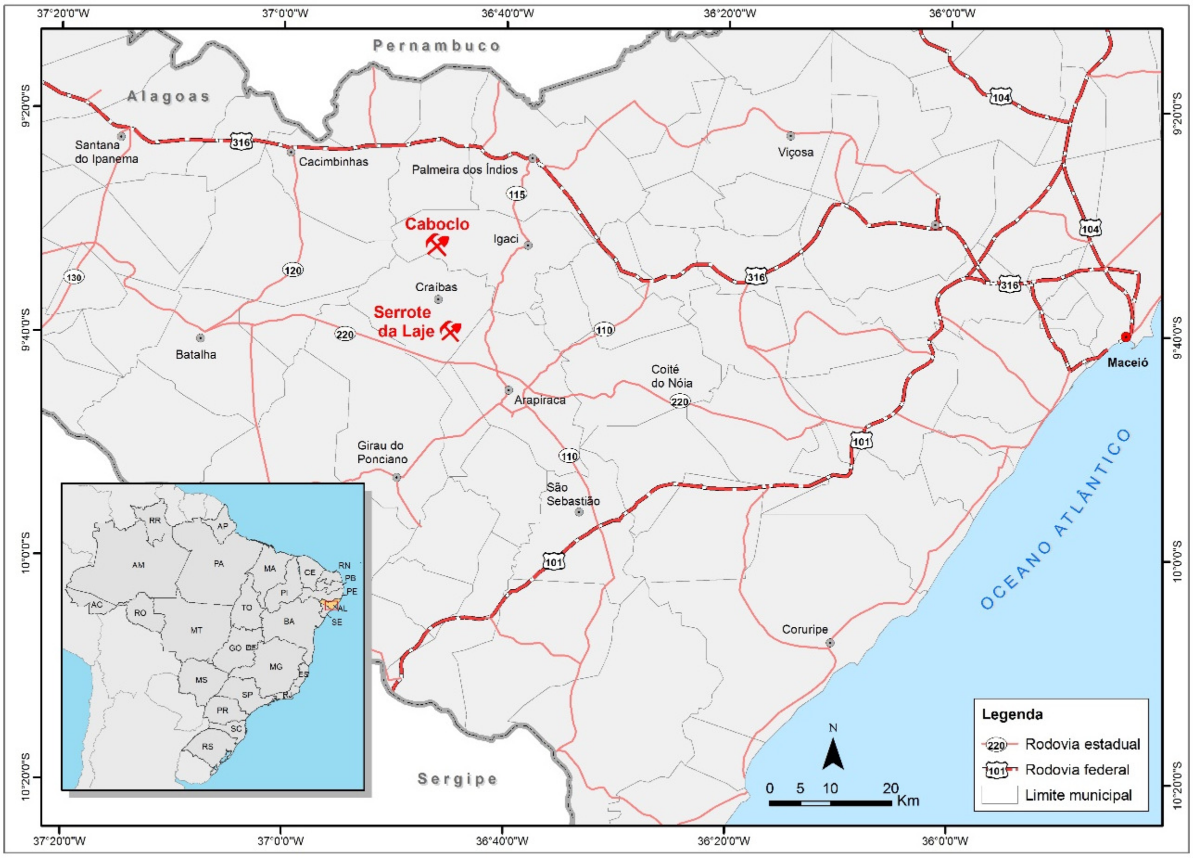

Figura i – Mapa de localização dos depósitos de Cu-Au do Serrote da Laje e Caboclo.

Justificativa e objetivos

O objetivo do projeto é o determinar a origem dos sulfetos de Cu nos depósitos do Serrote da Laje e Caboclo, contemplando os diferentes tipos de mineralização identificados. Estudos específicos que foram desenvolvidos incluem a caracterização detalhada dos aspectos petrográficos-petrológicos das rochas que compõem o complexo máfico-ultramáfico, a idade da intrusão e a caracterização do minério (petrografia, litogeoquímica, isótopos de S).

A utilização de modelos genéticos, ou processos metalogenéticos, como ferramenta na exploração de depósitos de Cu-Au associados a rochas máfica-ultramáficas é dificultada pela existência de propostas marcadamente distintas. O melhor entendimento destes processos nos depósitos de Serrote da Laje e Caboclo, especialmente considerando a existência de diferentes tipos de mineralização, deve subsidiar os trabalhos de exploração mineral para mineralizações deste tipo.

Métodos

- Levantamento bibliográfico

Para o alcance destes objetivos foi realizado levantamento bibliográfico referente ao contexto geológico regional da área de estudo, bem como publicações existentes sobre o depósito Serrote da Laje. O estado da arte enfocando a metalogênses dos depósitos de sulfetos magmáticos, em especial os processos que propiciam o enriquecimento em Cu nos líquidos sulfetados, foi criticamente avaliada nesta fase.

- Petrografia

Foram desenvolvidos trabalhos petrográficos em 292 amostras das intrusões máfica-ultramáficas, bem como das respectivas encaixantes. Destas, 250 amostras são do banco de dados da Aura Minerals Inc e 42 são novas laminas (30 do depósito Serrote da Laje e 12 do depósito Caboclo), confeccionadas a partir de amostras de 2 furos representativos selecionados para trabalhos específicos do projeto.

- Geoquímica mineral

Análises químicas de mineral em microssonda eletrônica foram realizadas utilizando o equipamento JEOL JXA-8230 do Laboratório de Microsonda Eletrônica da Universidade de Brasília. As análises foram realizadas de forma sistemática apenas em cristais de ortopiroxênios, sendo realizado o tratamento dos dados em planilha Excel. Os resultados analíticos encontram-se no Anexo 1.

- Geoquímica de rocha

As análises litogeoquímicas foram realizadas de forma sistemática pela Aura Minerals Inc., sendo utilizado como laboratório principal o da SGS Geosol Ltda. Resultados para 35 elementos foram obtidos utilizando ICP-MS. Resultados de Cu foram adquiridos por análises de AA, enquanto Au, Pt e Pd foram obtidos por fire assay, utilizando ICP-MS para finalizar. A descrição completa dos procedimentos analíticos é disponibilizada pela SGS Geosol (www.sgs.com). Ao todo, foram realizadas análises em cerca de 49.000 amostras, tomadas de forma contínua, em intervalos de 1 m dentro do intervalo de rochas máfica-ultramáficas, respeitando-se os contatos litológicos. Foram selecionados os resultados analíticos de 2 furos representativos para ilustrar as importantes características litogeoquímicas destas rochas.

- Isótopos de S

Composições isotópicas de pirrotita, bornita, calcopirita e pirita foram determinadas pelo Laboratório de Geocronologia do Instituto de Geociências da Universidade de Brasília. Um total de 09 amostras, incluindo 06 amostras de minério classificado como tipo 1 e 03 amostras de minério tipo 2, foram coletadas para este estudo, ambas do depósito Serrote da Laje (Tabela 2). As composições dos isótopos de enxofre foram reportadas em notação relativa ao V-CDT, com valores de 32S/34S de 22,6436 (Ding et al., 2001).

- Isótopos de Sm-Nd

As análises de isótopos de de Sm-Nd seguiram o método descrito por Gioia & Pimentel (2000), e foram realizados no Laboratório de Geocronologia da Universidade de Brasília. A análise baseia-se no decaimento do isótopo 147 Sm para 143Nd com emissão de uma partícula α. Ao todo foram realizadas análises em 07 amostras e os resultados obtidos estão no Tabela 5.

- Isótopos de U-Pb

Concentrados de zircão foram extraídos de amostras de sondagem diamantada usando técnicas convencionais gravimétricas e magnéticas, e a partir de seleção manual com lupa binocular no Laboratório de Geocronologia da Universidade de Brasília. As análises U-Pb LA-ICPMS seguiram os procedimentos analíticos descritos por Buhn et al (2009), e foram realizados no Laboratório de Geocronologia da Universidade de Brasília. As amostras selecionadas incluem norito (SRLJ 28) e leuconorito (SRLJ 17) com zircões magmáticos associados e os resultados obtidos são apresentados nas tabelas 3 e 4.

Escopo do estudo

Esta dissertação de mestrado apresenta-se em estruturada em forma de artigo à ser submetido para publicação em periódico com corpo editorial. Esta forma de apresentação está prevista no regulamento do Curso de Pós-graduação em Geologia da Universidade de Brasília. O artigo é apresentado na mesma forma que será submetido, mantendo o formato previsto no periódico.

O artigo “***The Serrote da Laje and Caboclo Cu-Au deposits, northeast Brazil: Magmatic Sulfides hosted by ilmenite-magnetite-bearing mafic-ultramafic intrusions***” foi elaborado durante o ano de 2016 e será submetido à revista ***Economic Geology***. O artigo tem como objetivo principal descrever as características petrológicas, geoquímicas e isotópicas dos depósitos e propor a origem dos sulfetos de Cu

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THE SERROTE DA LAJE AND CABOCLO CU-AU DEPOSITS, NORTHEST BRAZIL: MAGMATIC SULFIDES HOSTED BY ILMINITE-MAGNETITE-BEARING MAFIC-ULTRAMAFIC INTRUSIONS

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Abstract

Mafic-ultramafic intrusions are widely known for hosting Ni-Cu-PGE sulfide deposits formed as the result of the segregation and concentration of droplets of liquid sulfide from mafic or ultramafic magma. The compositions of the segregated Ni-Cu-PGE sulfide melts are controlled by the fractionation of monosulfide solid solution (mss), such that the last sulfide composition before complete crystallization takes place should be close to the intermediate solid solution (iss). The bulk sulfide assemblage of Ni-Cu-PGE deposits consists essentially of pyrrhotite, pentlandite and chalcopyrite. The origin of Cu-rich sulfide deposits hosted in mafic-ultramafic intrusions, exemplified by the Caraíba (Brazil) and Okiep (South Africa) deposits, remains however a controversial issue, and highly distinct genetic models have been proposed (from magmatic to hydrothermal). In this study we present the description of two Cu-rich deposits hosted by mafic-ultramafic intrusions and discuss the origin of the sulfide mineralization.

The mafic-ultramafic bodies hosting Cu-Au mineralization in the Serrote da Laje and Caboclo deposits consist of irregular bodies of mafic-ultramafic rocks interpreted as small dikes and/or pipes. Although these intrusions are partially modified by high-grade metamorphism and associated ductile tectonism, primary magmatic textures and minerals are largely preserved. Mafic-ultramafic intrusions consist mainly of variably textured orthopyroxenite, magnetitite, norite and gabbronorite. The crystallization sequence consists of orthopyroxene and Fe-Ti oxides followed by plagioclase and then by clinopyroxene. Systematic interlayering of these rock types are consistent with all rock types resulting from fractionation from a parental magma, either in situ or due to successive pulses of variably fractionated magma. Orthopyroxene compositions ranging from En65.5 to En79.2 mol % indicate moderately primitive to fractionated compositions for the parental magma. Unusual rock types with abundant phlogopite and/or garnet, commonly associated with mafic-ultramafic rocks, are interpreted as products of assimilation of country gneissic rocks during magmatic emplacement. Assimilation of older crustal rocks is also consistent with Sm-Nd isotopic data of the Serrote da Laje Complex, as indicated by highly variable and scattered ε_{Nd} (T = 1.99 Ga) values (-4.33 to 3.87).

Disseminated sulfides in both Serrote da Laje and Caboclo deposits are interstitial to or enclosed into cumulus orthopyroxene and Fe-Ti oxides. The close association of magnetite and sulfides in the Serrote da Laje deposit is indicated by positive correlations of FeO and Ti-V in hosted mafic-ultramafic rocks matched with positive correlations of FeO and S-Cu-Au in sulfide ore. Textural and chemical features described in the Serrote da Laje and Caboclo deposits support the interpretation that Cu-rich sulfides are magmatic and closely associated with magnetite-rich rocks. The sulfide assemblages in both deposits consist mainly of bornite and chalcopyrite, with Cu/Fe ratio in sulfides ranging from about 1 in chalcopyrite-rich ore samples to about 5 in bornite-rich samples. Sulfur isotope results for chalcopyrite and bornite has a narrow range of values from -1.0 to 2.5 δ34S ‰, thus supporting a magmatic origin for the ore. Fractional crystallization of the parental magma combined with magmatic oxidation is suggested as an appropriate mechanism to generate the Cu-rich magmatic sulfides with high Cu/Fe ratios of the Serrote da Laje and Caboclo deposits.

Subordinated Cu-sulfide mineralization occurs in veins and/or breccia in altered mafic-ultramafic rocks. Sulfur isotope results for pyrite, pyrrhotite and chalcopyrite in veins or breccia range from 7.5 to 13.0 δ34S ‰, suggesting a hydrothermal origin. We interpreted this secondary ore as the result of sulfides from hydrothermal fluids that percolate the Cu-Au mineralized mafic-ultramafic rocks and partially remobilized the primary ore. This interpretation does not indicate the existence of a robust Cu-Au hydrothermal mineralization that may lead to different exploration targets than those investigated in this study.

Close magmatic ages of mafic-ultramafic rocks of the Serrote da Laje deposit (ca. 1.99 Ga) and the Caraíba deposit (ca. 2.05) suggest that significant Cu deposits are associated with Paleoproterozoic mafic-ultramafic intrusions in the region located close to the northern border of the São Francisco Craton in Brazil.

Keywords: mafic-ultramafic intrusion, Cu-rich sulfide, magnetite, orthopyroxene, sulfur isotope, oxidation

1 - Introduction

Recent data from Aura Minerals (www.auraminerals.com) for the Serrote da Laje and Caboclo Cu-Au sulfide deposits indicate a large (~750 Kt of contained metal) resource hosted in interlayered pyroxenite, norite and ilmenite-magnetitite. Mafic-ultramafic intrusions are widely known for hosting Ni-Cu-PGE sulfide deposits formed as the result of the segregation and concentration of droplets of liquid sulfide from mafic or ultramafic magma (e.g., Naldrett, 2004; Barnes and Lightfoot, 2005). The origin of Cu-rich sulfide deposits hosted in mafic-ultramafic intrusions, exemplified by the Caraíba (Brazil) and Okiep (South Africa) deposits, remains however a controversial issue. These deposits were interpreted as the result of primary magmatic origin (e.g., Oliveira and Tarney, 1995; Clifford and Barton, 2012), of high-grade metamorphic modification of an originally magmatic deposit (e.g., Cawthorn and Meyer, 1993; Barnes and Maier, 1999) and more recently as a member of IOCG-type hydrothermal deposits (e.g., Williams et al., 2005; Groves et al., 2010; Maier et al., 2012). The use of genetic models for the exploration of such deposits is hampered by such distinct and unrelated propositions. In this study we present a geological description of the Serrote da Laje and Caboclo deposits based upon extensive exploration data acquired by Aura Minerals Inc. These geological descriptions, together with geochemical results from this study, including lithogeochemistry, mineral compositions and sulfur, U-Pb and Sm-Nd isotopic data, provide a basic framework to constraint the origin of the Cu-Au sulfide mineralization. The Serrote da Laje and Caboblo Cu-Au deposits are interpreted in this study to belong to a significant but yet poorly investigated class of Cu-rich magmatic deposits.

2 - Exploration History

A brief description of more than 30 years of exploration in the Serrote da Laje is provided by Aura Minerals Ltd (www.auraminerals.com). The Brazilian Geological Survey (previously known as Companhia de Pesquisa de Recursos Minerais - CPRM; a state-owned exploration company), reported anomalous copper and nickel values associated with mafic intrusion in the region of Arapiraca in 1979. This report described the Serrote da Laje as a magnetite-rich outcrop that contained anomalous values of copper (up to 0.03 wt. %), zinc (up to 0.50 wt. %), vanadium (up to 0.20 wt. %) and chromium (> 0.50 wt. %). Upon confirming the anomalous values reported by CPRM, Rio Doce Geologia e Mineração (DOCEGEO), the former exploration arm of VALE S.A., began in 1982 a detailed exploration campaign guided by geochemical and geophysical surveys in the area. The resulting geochemical anomaly maps for copper and nickel indicated a good agreement with the ground magnetic and gravity anomaly maps. The anomalous geochemical and geophysical maps were used to direct subsequent drilling programs. By 1991 DOCEGEO reported an estimated mineral resource of 26.7 Mt @ 0.72% Cu based on 37 drill holes (10,818 m). Exploration in the Serrote da Laje was interrupted in the 1990s when the new discoveries of copper deposits in the Carajas Mineral Province (e.g., Alemao, Cristalino, Sossego and Solobo) became VALE's main focus of exploration. From 1998 to 2002 a second drilling campaign was undertaken by VALE aiming to increase mineral resources of the Serrote da Laje deposit. During this campaign VALE drilled 52 drill holes (15,348 m) totalling 89 drill holes (26,166) and an estimated resource of 73.9 Mt @ 0.62% Cu was reported in 2002.

On July 2007, Aura Minerals acquired the property, through its subsidiary, Mineração Vale Verde Ltda. (MVV). MVV conducted additional exploration work between 2007 and 2010, including 291 drill holes totalling 62,686 m. Most holes were drilled vertically with depths ranging from 30 to 507 m. The exploration work by MVV resulted in a measured and indicated resource for Serrote da Laje deposit of 137.46 Mt @ 0.49% Cu. The MVV completed the feasibility study in 2012 and negotiations for project financing and development are currently (i.e., 2016) under way.

In the Caboclo deposit, from 1999 to 2001, VALE conducted a drilling campaign, totalling 18 drill holes (2,349 m). MVV conduct additional exploration work between 2007 and 2010, including 174 diamond drill holes (24,950 m), on five targets including the Rogerio and Zeze. MVV estimated a measure and indicated resource of 10.91 Mt @ 0.51% Cu for Rogerio target, and inferred resources of 2.26 Mt @ 0.61% Cu for Zeze target.

3 - Tectonic Setting

3.1 - Borborema Province

The Serrote da Laje and Caboclo deposits, northeast of Brazil, are located in the Borborema structural province (BP), a mosaic of paleo-neoproterozoic metassedimentary fold belts and massifs separated by a complex system of continental-scale strike-slip shear zones (Almeida et al., 1981). These sequences together with the voluminous granitic magmatism are the most outstanding features of this province (Caby et al., 1991) (Fig. 1). Neoproterozoic events (Brasiliano Cycle), including the continental-scale EW shear zones (e.g., Patos and Pernambuco lineaments in Fig. 1) and NE megastructures, separate the major subprovinces and domains (Santos 1996; 1998; 2000) (Fig. 1). The Meridional subprovince occurs between the Pernambuco shear zone and the São Francisco craton and is comprised of a tectonic collage of various blocks, terranes, or domains ranging in age from Archean to Neoproterozoic (Van Schmus et al, 2011). The Meridional subprovince is composed by Pernambuco-Alagoas massif and Rio Preto, Riacho do Pontal and

Sergipano fold belts (Brito Neves et al, 2000). The Sergipano Fold Belt (SB), a sedimentary basin that was generated and deformed in the proterozoic, separates the BP from the São Francisco Craton.

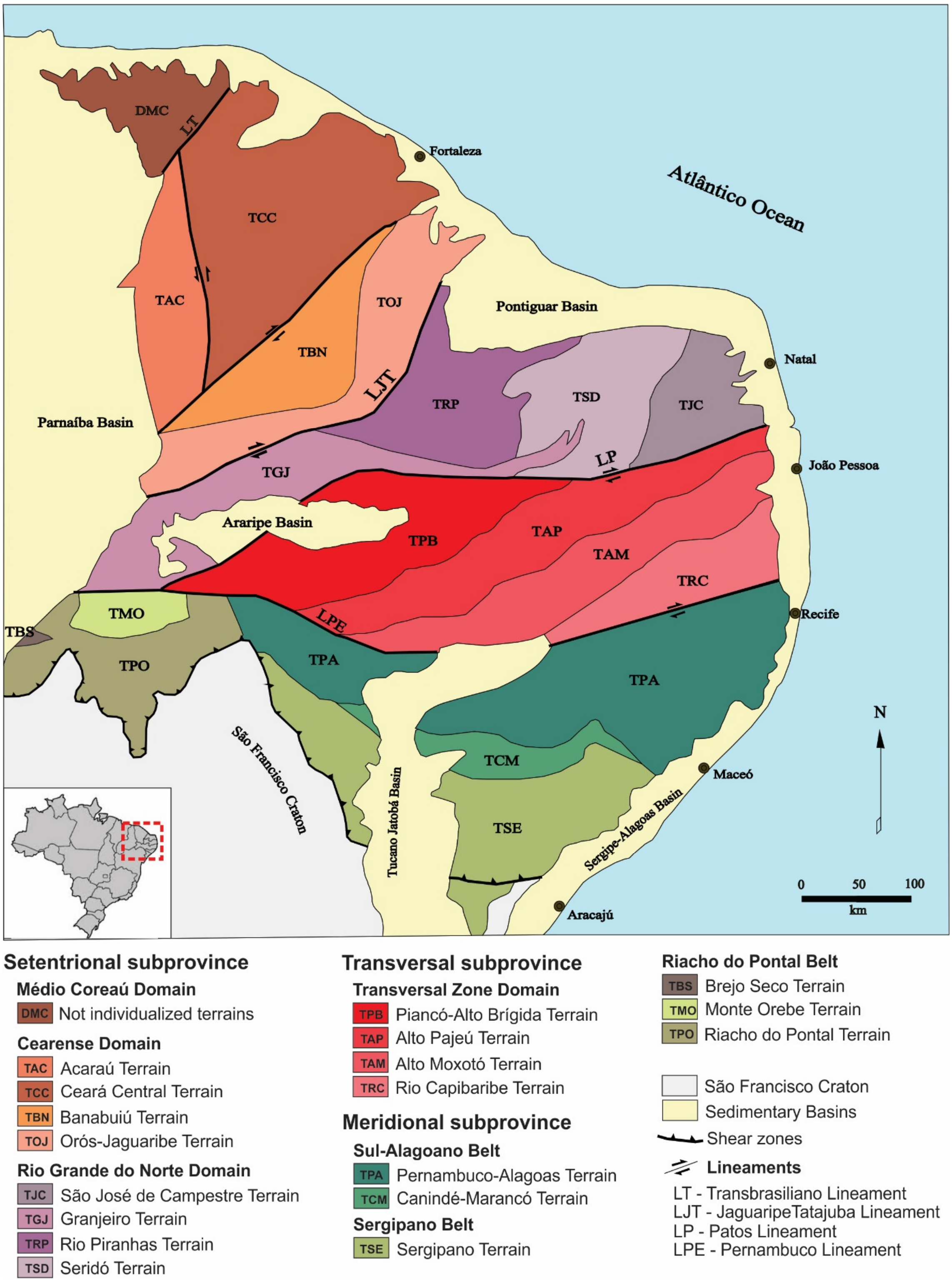

Figure 1 - Borborema structural province map indicating the location of the Meridional subprovince, highlighted in green tones. Adapted from Santos (1998, 2000).

3.2 - Sergipano Belt

The Sergipano Belt (SB) was formed by the continental collision of the São Francisco-Congo Craton and the Pernambuco-Alagoas massif during the Brasiliano/Pan-African orogeny (Brito Neves et al., 1977). The SB (Fig. 2) is divided into lithostratigraphic domains separated by strike-slip shear zones (Davison and Santos, 1989; Silva Filho and Torres, 2002). The southern portion of the SB consists of metavolcanics and metasedimentary rocks deposited around Archean/Paleoproterozoic basement gneiss. In the northern portion occur domain of paragneisses, partially migmatised, and metasediments, besides domains with syn and tardi granitic intrusions. Silva Filho and Torres (2002) separated the Sergipano Belt in 5 domains: Macururé, Vaza Barris, Estância, Rio Coruripe and Viçosa. The Rio Coruripe domain contains rift-related volcano-sedimentary sequence, metabasalts and iron-formation bearing, intruded by mafic-ultramafic layered intrusion.

The Serrote da Laje and Caboclo deposits are part of the Rio Coruripe domain, which includes the Jaramataia Group and the Serrote da Laje suite of rocks of Proterozoic age (Figure 3). The Jaramataia Group is composed of a metavolcanosedimentary sequence in which the dominant lithotypes are quartz-feldspathic gneisses and garnet-biotite gneisses. Marbles, calcsilicate rocks and iron-formations are also common. A mafic-ultramafic intrusion forms the Serrote da Laje suite.

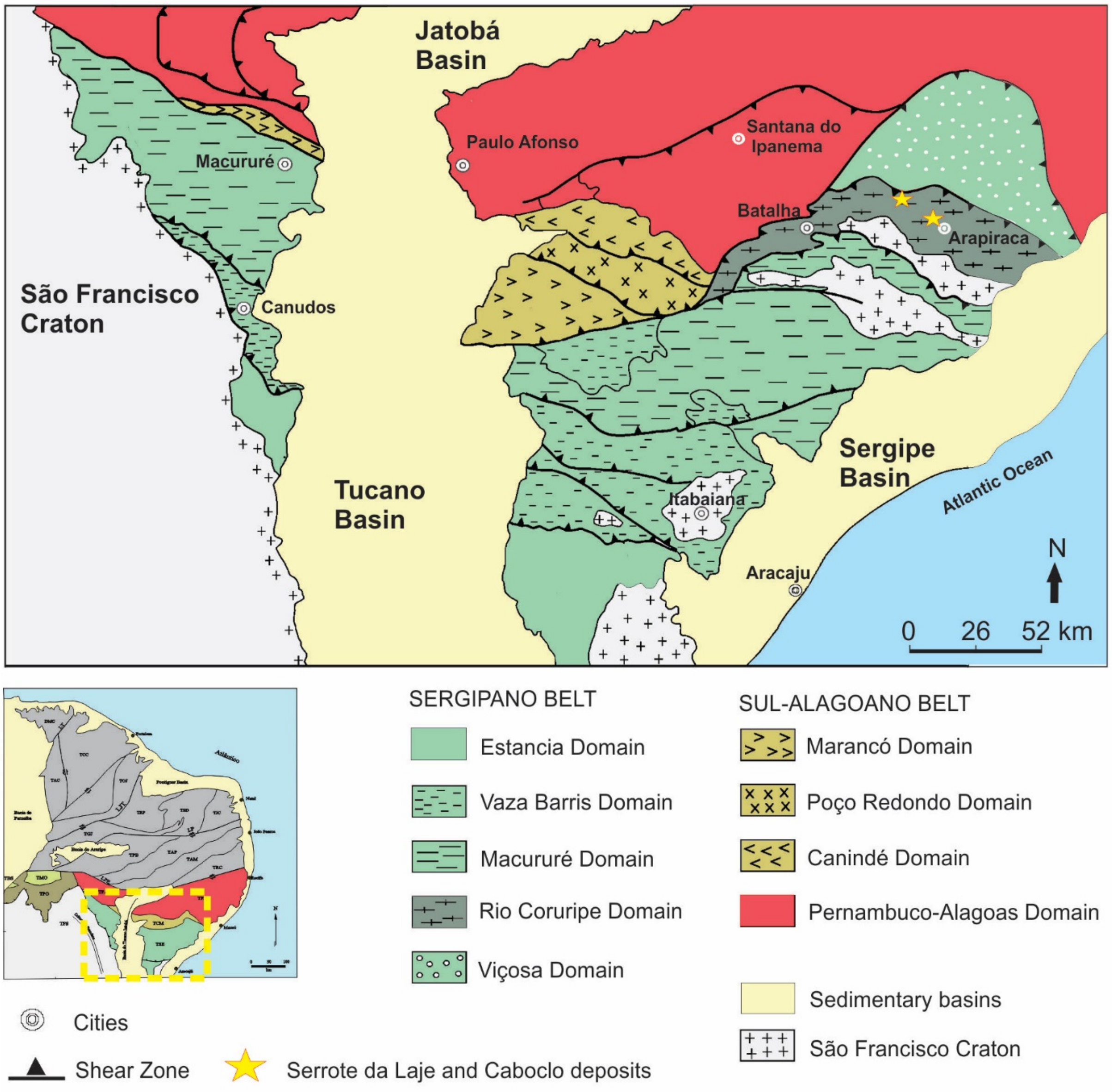

Figure 2 - Lithostratigraphic domains of the Sergipano Belt. Adapted from Silva Filho et al. (2003).

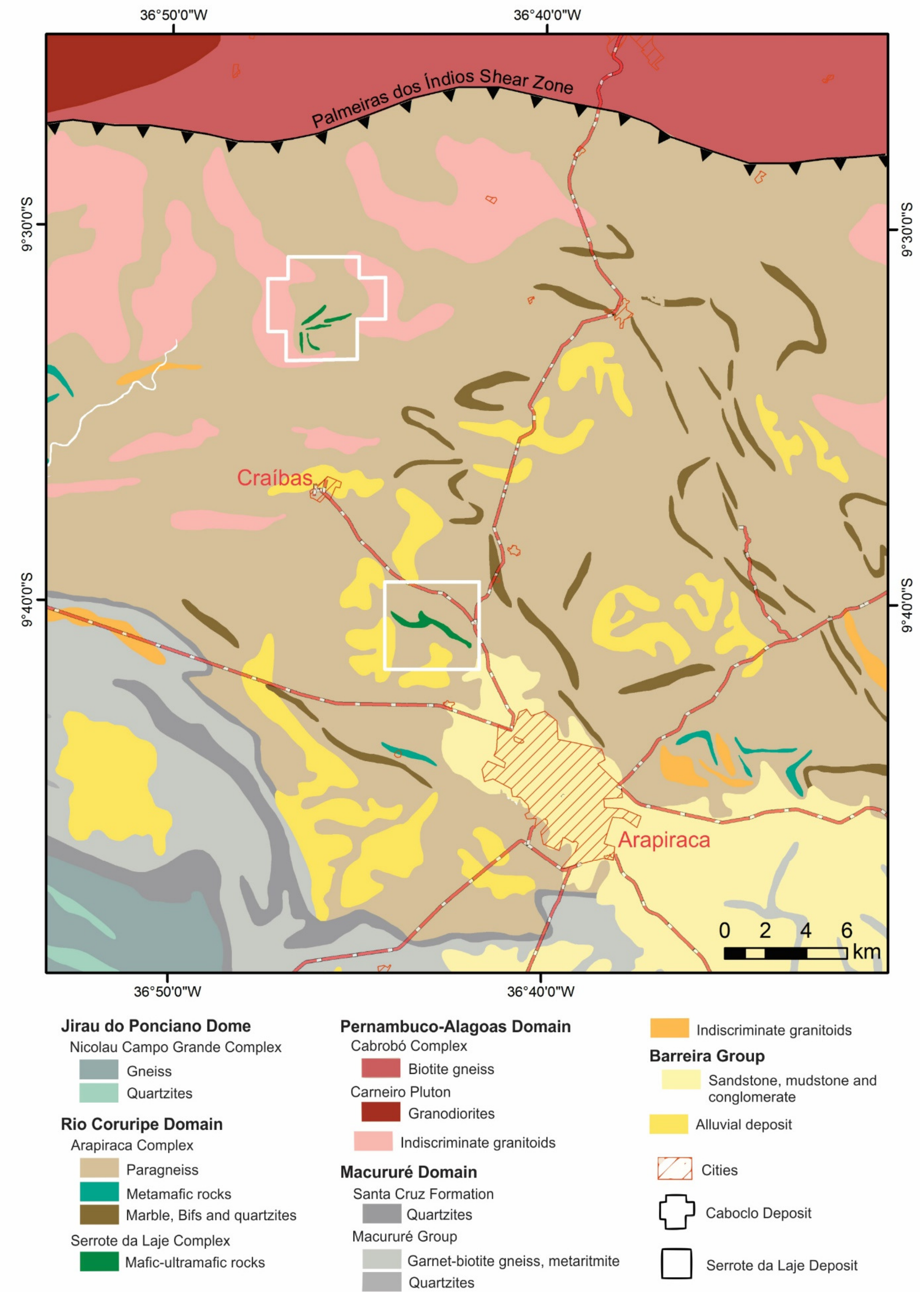

Figure 3 – Geological map of central part of Alagoas state, showing the localization of the Serrote da Laje and Caboclo deposits. Adapted from Mendes et al. (2009).

3.3 - Layered MUM intrusions of the SB

The geology and Cu mineralizations of the Serrote da Laje deposit were previously described by Horbach and Morimon (1988). This study, based on data provided by the exploration program developed by DOCEGEO from 1982 to 1986, provided a broad geological description of the mafic-ultramafic rocks, sulfide mineralization and its country rocks.

The mafic-ultramafic rocks are hosted in paragneiss of the Jaramataia group. Horbach and Marimon (1988) identified two main country rocks, the quartz-feldspar gneiss, pinkish color, and the garnet gneiss, grayish color. Both gneiss has medium grained and they have silimanite and cordierite in their composition, indicating a high grade of metamorphism. Mafic-ultramafic rocks were described as a tectonically disrupted layered intrusion composed by hypersthenites, norites, gabbronorites, gabbros and anorthosites. Magnetitite bodies occur associated with hypersthenites and norites. The author's recognized two types of mineralization: i. disseminated sulfides associated with hypersthenites, norites and magnetitites, and ii. sulfide-bearing veins mainly associated with gabbroic rocks. The main ore minerals are chalcopyrite and bornite, in the sulfide zone, and malachite in the oxidized zone.

The metamorphism of the deposit reached the granulite facies (Horbach and Marimon, 1988), as indicated by the occurrence of the sillimanite±garnet+biotite+quartz paragenesis in the metasedimentary rocks; as well as metamorphic orthopyroxene in the mafic-ultramafic rocks. During the evolution of the deformation some reactions of re-equilibrium occurred, reaching high amphibolite facies (Amcoff and Figueiredo, 1990). Probably due to uplift movements associated to granitc intrusions, a hydrated paragenesis were developed, and marked the metassomatism common to all rock types of the deposit.

Previous works (Brito et al., 2000) suggested that the age of the mafic-ultramafic intrusion is Paleoproterozoic. U-Pb zircon data from the metanorite provided a crystallization age for the copper-bearing mafic-ultramafic suite at 1965 Ma, whilst a round zircon fraction, present in the same sample, yielded an inherited age of 2.049 Ga. Metanorite, metamorphosed magnetite-hypersthenite and related fine-grained metagabbro display TDM model ages from 2.4 Ga to 2.74 Ga. The country rocks apparently have two types sediments source with different ages. One with 207Pb/206Pb radiometric ages between 2.03 and 2.25 Ga and provided Archaean TDM model ages around 2.7 Ga and the other with detrital Pb-Pb ages varying from 2.4 to 2.52 Ga and Sm-Nd T_{DM} model ages that span from 2.89 to 3.1 Ga.

4 - Methods

4.1 - Petrography of mafic-ultramafic rocks

Detailed petrography was performed in a large collection (about 250 samples) of thin-polished sections from the Aura Minerals database, as well as 42 new thin-polished sections of Serrote da Laje (30 samples) and Caboclo (12 samples) deposits. These new thin sections were cut from samples collected from two representative drill holes, one of Serrote da Laje deposit and another of Caboclo deposit. The petrographic study was developed in optical microscopes of the Mineralogy Laboratory of the Geosciences Institute, University of Brasilia.

4.2 - Microprobe analyses

Mineral analyses were performed on polished thin section using a 5-spectrometer JEOL JXA-8230 SuperProbe at the Electron Microprobe Laboratory of the University of Brasília (Brazil). The wavelength dispersive (WDS) analyses were performed at an accelerating voltage of 15 kV and a beam current of 10 nA. Both synthetic and natural mineral standards were used for the analyses and the same standards and procedure were retained throughout the analytical work. Systematic WDS analyses were obtained just for orthopyroxene (see supplementary material for microprobe analyses).

4.3 - Lithogeochemistry

SGS Geosol Ltda was used as the principal analytical laboratory by Aura Minerals Inc. Assays were checked with additional analyses, following the same analytical procedures, by ALS Chemex Laboratory (ALS). Results for 35 elements were obtained by 4-acid digestion Inductive Coupled Plasma Mass Spectroscopy (ICP-MS). A complete description of analytical methods is available in the SGS Geosol (www.sgs.com) and ALS Chemex Home Page (www.alsglobal.com). Results for 35 elements were obtained from half drill core whole-rock samples. They were sampled continuously at approximately 1-m intervals. Cu assays by AA were also obtained. Samples with FeO contents higher than 20 wt. % by ICP-MS analyses were submitted to a lithium tetraborate fusion and analysis by x-ray fluorescence (XRF). Au, Pt and Pd were determined by 50 g fire assay (ALS Chemex code FD50) using an ICP-MS finish. Results for two representative drill holes of Aura Minerals Inc database (drill holes SLJE-272 and CBCR-71) were used to illustrate significant lithogeochemical features (Appendix 01).

4.4 - Sulfur isotopes

Sulfur isotope compositions of pyrrhotite, pentlandite, chalcopyrite, and pyrite were determined at the Geochronology Laboratory of the Geosciences Institute of the University of Brasilia. A total of nine samples, including six samples of ore type 1 and three samples of ore type 2 were collected from the Serrote da Laje deposit for sulfur isotopic study. Representative sulfides of each ore type were hand picked and individually mounted. Thin polished sections of the samples were prepared and cleaned in an ultrasonic bath. The laser equipment employed was a New Wave UP 213 laser with 213-µm wavelength, coupled to a Finnigan-Neptune multicollector inductively coupled plasma mass spectrometer. The laser was run at 9-Hz frequency and 36% energy. The Helium gas flux through the sample chamber was 0.35 l/min. The MCICPMS was run in medium resolution, a forward power of 930W, and an Ar gas flux of 0.857 l/min, using the procedures described in Bender et al. (2007). Analytical precision was better than ±0.4‰ 1 sigma standard deviation. The external reproducibility (accuracy) measured against a second standard was ±0.3‰ 1 s SD. Sulfur isotope compositions are reported in the δ notation relative to V-CDT with a 32S/34S value of 22.6436 (Ding et al., 2001).

4.5 - Sm-Nd isotopes

Sm-Nd isotopic analyses followed the method described by Gioia and Pimentel (2000) and were carried out at the Geochronology Laboratory of the University of Brasília. Whole-rock powders (~300 mg) were mixed with 149Sm-150Nd spike solution and dissolved in Savillex bombs. Sm and Nd extraction of whole-rock samples followed conventional cation exchange techniques. The isotopic measurements were carried out on a multi-collector Finnigan MAT 262 mass spectrometer in static mode. The 143Nd/144Nd ratios were normalized to 146Nd/144Nd of 0.7219 and the decay constant used was 6.54 x 10-12 yr^{-1}. The TDM values were calculated using the model of DePaolo (1981). Nd procedure blanks were better than 100 pg. Sm-Nd results for 07 samples are shown in Table 5.

4.6 - U-Pb isotopes

Zircon concentrates were extracted from drill core samples using conventional gravimetric and magnetic techniques at the Geochronology Laboratory of the University of Brasília. Selected samples include a norite (SRLJ 28) and a leuconorite (SRLJ 17) with accessory zircon crystals. Clear fine-grained prismatic euhedral crystals with growth zoning were handpicked under a binocular microscope. For U-Pb isotopic LA-ICPMS analyses, the sample was mounted in an especially adapted laser cell and loaded into a New Wave UP213 Nd:YAG laser, linked to a Thermo Finnigan Neptune Multi-collector ICPMS. The laser was run at a frequency of 10 Hz and energy of ~100 mJ/cm2 with a spot diameter of 30 mm. The U-Pb LA-ICPMS analyses followed the analytical procedure described in detail by Buhn et al. (2009) and were carried out at the Geochronology Laboratory of the University of Brasília. U-Pb results for samples SRLJ-17 and SRLJ-28 are shown in Tables 3 and 4.

5. Results

The ore types and host rocks of Serrote da Laje and Caboclo deposits are very similar and will be described together in this study. Both deposits are associated with mafic-ultramafic intrusions consisting mainly of magnetitite, orthopyroxenite, norite and gabbronorite. Mafic-ultramafic intrusions are concordant with host paragneiss and occur as several tectonically dismembered bodies (Fig. 3). Due to tectonism and post-magmatic transformation of the original igneous rocks the magmatic architecture of these intrusions is hard to decipher. Post-magmatic processes include metamorphism up to high-grade conditions (granulite facies) as well as hydrothermal alteration. Despite these processes, primary mafic-ultramafic rocks partially preserve primary igneous mineralogy and texture, except for discrete highly sheared and/or altered zones.

5.1 - Geology and structure of the Serrote da Laje Deposit

In the area of the Serrote da Laje Deposit, ultramafic rocks crop out just in the south portion of the NWN-SES elongated intrusion, which extends for 2 km as defined by drilling and trenching information (Fig. 4). Mafic-ultramafic bodies are concordant with host rocks, the later consisting of two easily recognized different types of quartz-feldspathic paragneiss, designated as pink gneiss and garnet gneiss by the geologists of Aura Minerals Inc. (Fig. 4 and Fig. 5). The pink gneiss is a medium-grained granolepidoblastic banded rock composed mainly by quartz + K-feldspar + plagioclase + sillimanite + cordierite (Fig. 5A), whereas the garnet gneiss is a medium-grained porphyroblastic rock composed mainly by quartz + biotite + garnet + cordierite + plagioclase (Fig. 5B). The thickness of partially disrupted mafic-ultramafic bodies is up to 140m, with width variable from 100 to 1000m and up to 800m in length (Fig. 4 and Fig. 7). Two main WEW faults crosscut the intrusion, dividing the deposit in north, central and south domain (Fig. 6). In the north domain the mafic-ultramafic bodies are larger and more continuous (Fig. 4 and Fig. 7). The regional foliation follows an average 120/20-30^{o} trend, which are disturbed by the

WEW faults. The central domain, located between the fault zones, has the most hydrothermally altered rocks.

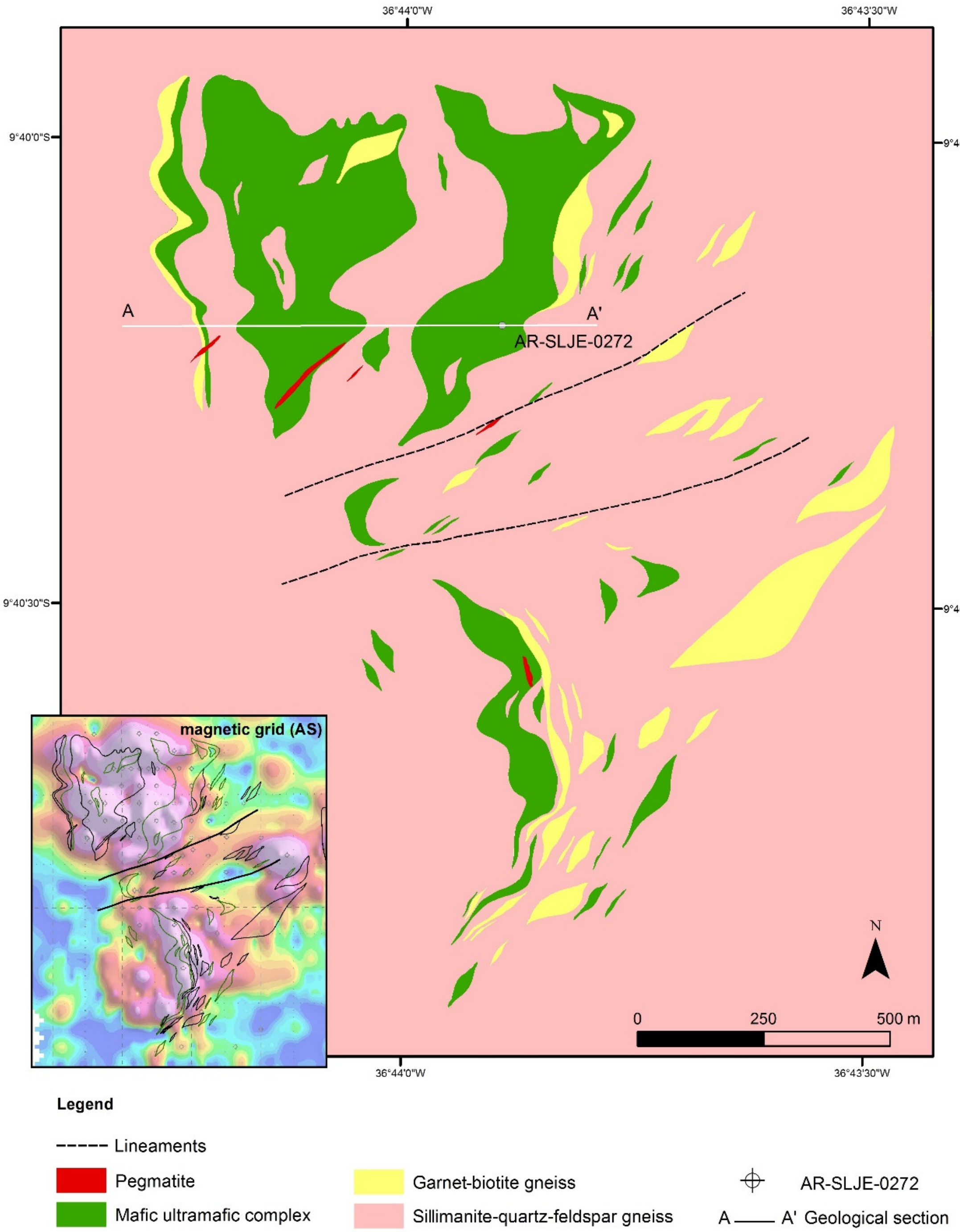

Figure 4 – Geological map from Serrote da Laje Deposit. The insert shows the analytical signal image of the mapped area. Note the close fit of the mafic-ultramafic intrusion with domains with high magnetic signal. The cross section A-A´ is illustrated in figure 6.

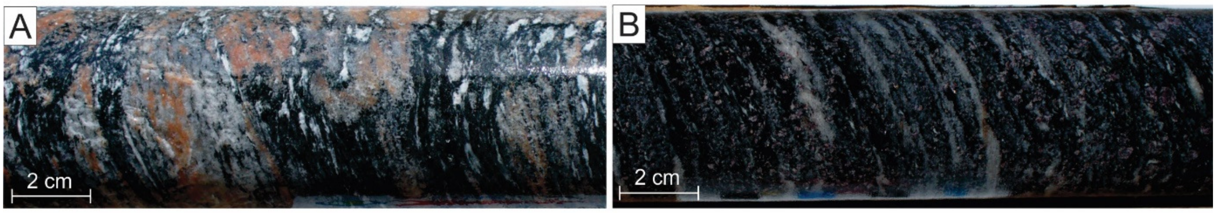

Figure 5 – Country rocks of the Serrote da Laje and Caboclo deposits. a) pink gneiss composed by quartz + K-feldspar + plagioclase + sillimanite + cordierite. b) garnet gneiss composed by quartz + biotite +garnet + plagioclase + cordierite.

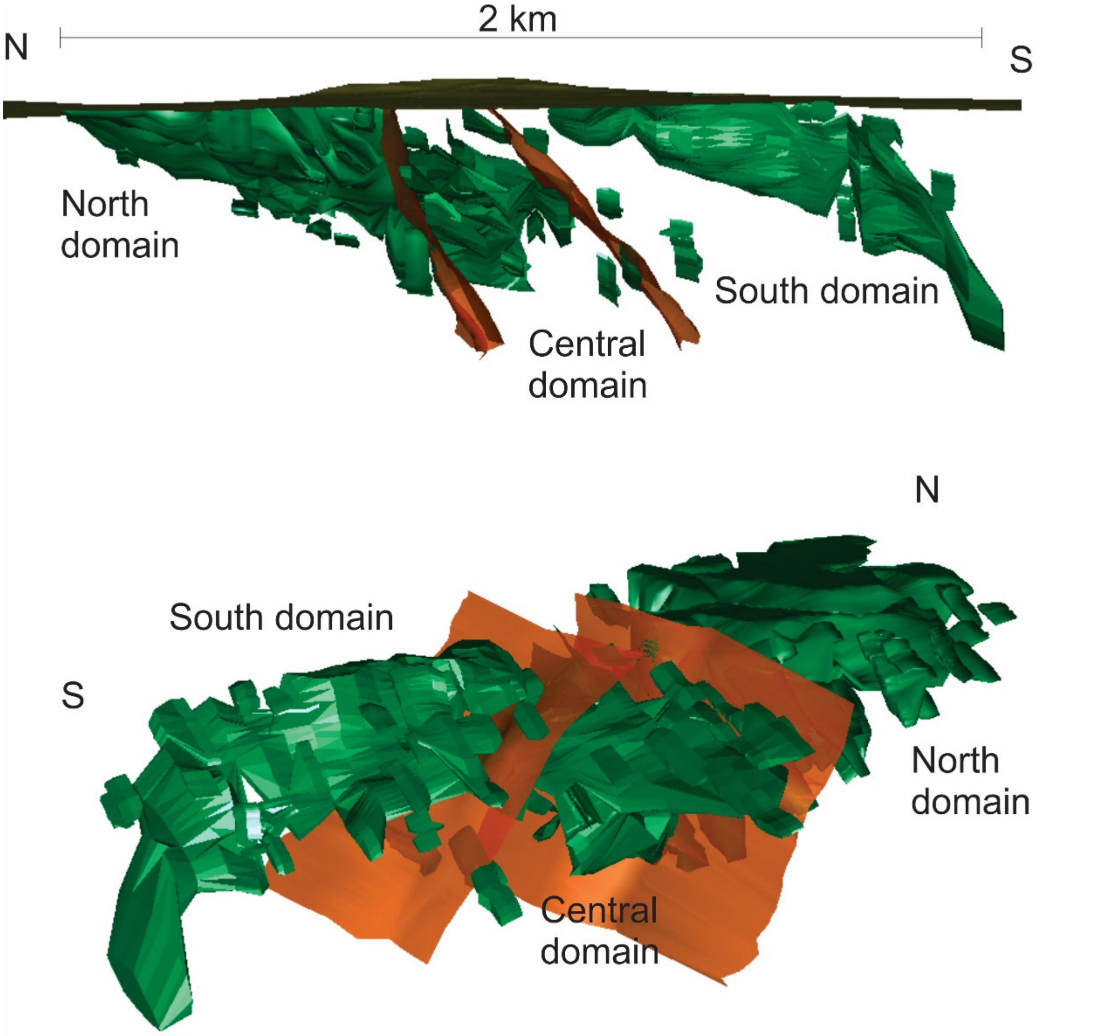

Figure 6 – 3D view of the mafic-ultramafic rocks (greenish color) and major faults (reddish color) of the Serrote da Laje Deposit. The north, central and south domains are shown in different projections.

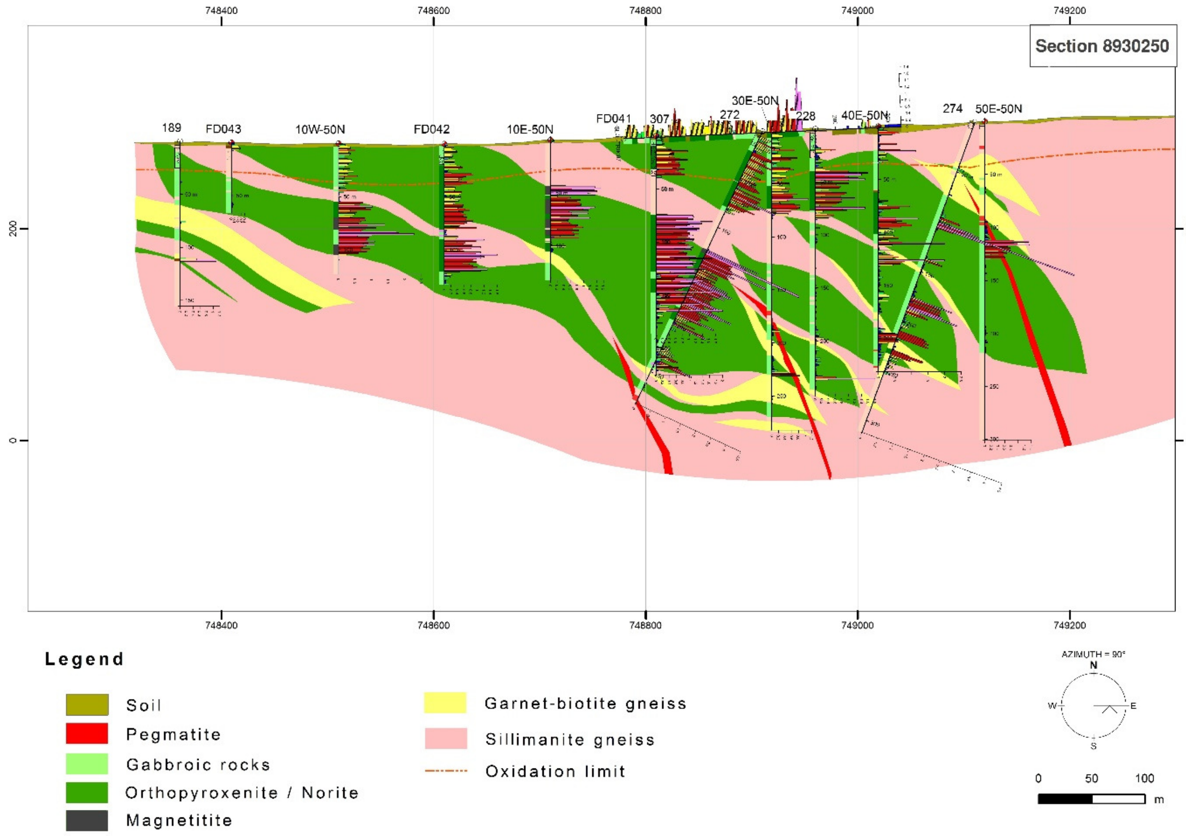

Figure 7 – Geological E-W cross section of the north domain of the Serrote da Laje Deposit.

5.2 - Geology and structure of the Caboclo Deposit

The Caboclo Deposit, located 15 km to the NW, is smaller but is hosted by very similar mafic-ultramafic rocks compared to the Serrote da Laje Deposit. Divided in 5 bodies (i.e., Rogerio, Zeze, Petrucio, Adriano and Maninho) separated by shear zones (Fig. 8), the Caboclo Deposit has better outcrops of ultramafic rocks than those in the Serrote da Laje deposit. The main body is Rogerio, which extends for 800 m as defined by drilling and trenching information. In Rogerio, the bodies' thickness is up to 60m, with width variable from 50 to 375m and up to 500m in length (Fig. 9). The Sn foliation trend is very variable in Caboclo deposit area, from 040-050/20-40^o (Rogerio) to 300/20^o (Maninho and Petrucio). The Caboclo Deposit is more segmented than the Serrote da Laje Deposit, probably due the proximity with the faulted contact with the Pernambuco-Alagoas Domain (Fig. 2).

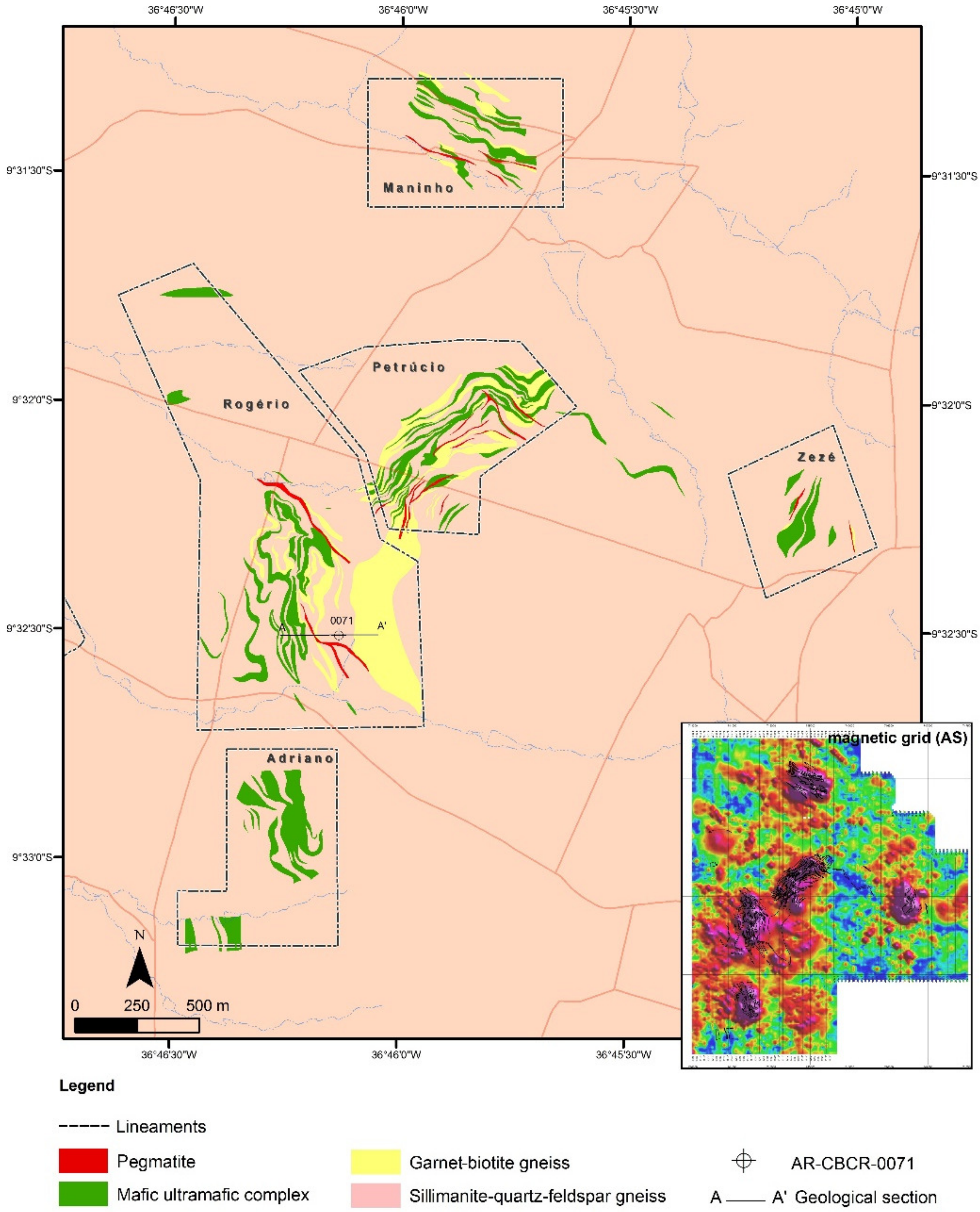

Figure 8 - Geological map of the Caboclo Deposit. The insert shows the analytical signal image of the mapped area. Note the close fit of the main bodies (i.e., Rogerio, Zeze, Maninho, Petrucio and Adriano) with domains with high magnetic signal. The cross section A-A´ is illustrated in figure 9.

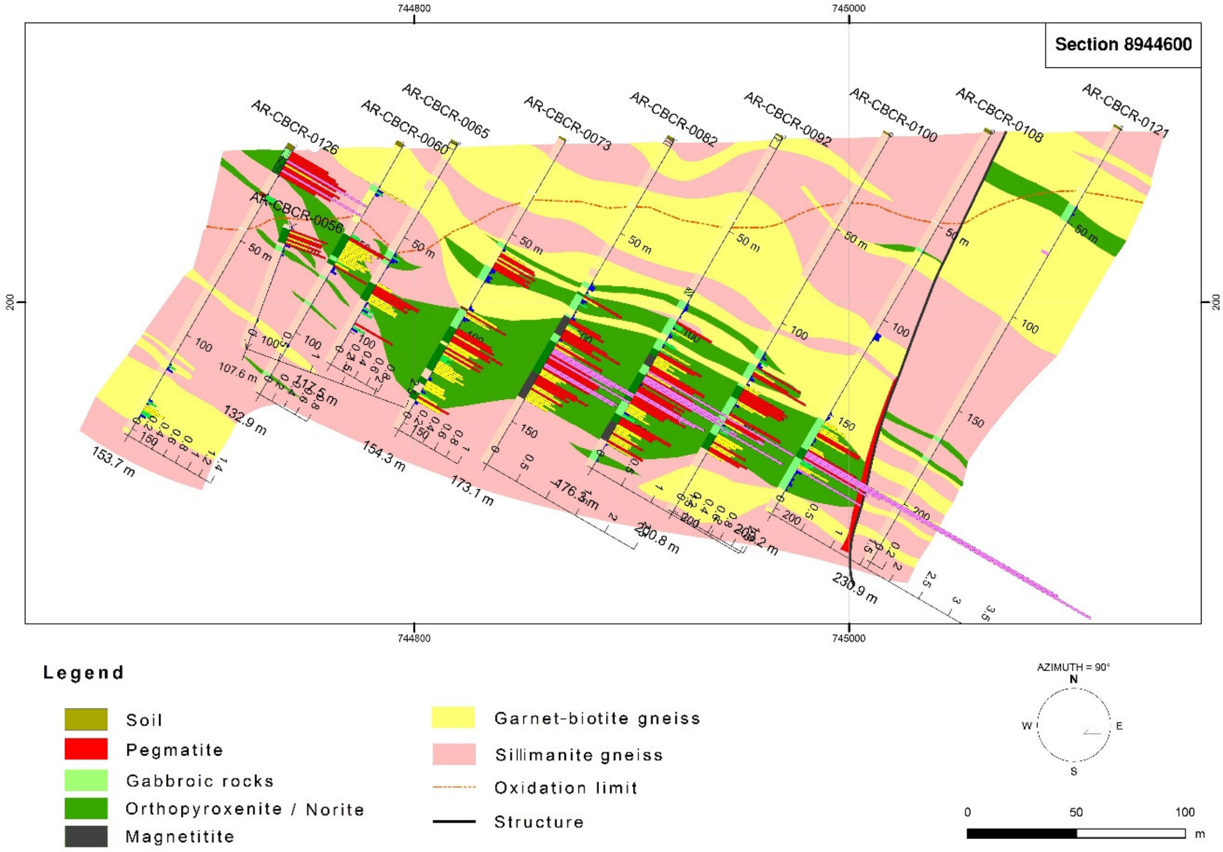

Figure 9 - Geological E-W cross section of the Rogerio target. See figure 8 for location of the section.

5.3 - Petrography of mafic-ultramafic rocks

The main rock types of the mafic-ultramafic intrusions of the Serrote da Laje and Caboclo deposits are magnetitite, magnetite orthopyroxenite, orthopyroxenite, norite and gabbronorite (Table 1).

Orthopyroxenite is a medium- to coarse-grained adcumulate composed of cumulus orthopyroxene (> 90 vol. %) and Fe-Ti oxides (usually 1-5 vol. %) with minor intercumulus plagioclase and phlogopite (Fig. 10A and 10B). Orthopyroxene occurs as short prismatic pleochroic (colorless to light reddish) crystals. Fe-Ti oxides consist mainly of magnetite and ilmenite with minor associated dark green spinel (hercynite). Magnetite orthopyroxenite and magnetitite are closely associated with orthopyroxenites as irregular pods or layers in variable scales, from few centimeters to dozens of meters thick (Fig. 10A and 10F). The modal proportion of Fe-Ti oxides spread from 1 % in orthopyroxenite to massive (up to 100 %) in ilmenite magnetitite. Magnetite orthopyroxenite consists of large orthopyroxene crystals, commonly enclosing tiny euhedral Fe-Ti oxides, surrounded by an aggregate of Fe-Ti oxides (Fig. 10E). The later consists of fine- to medium-grained euhedral to subeuhedral magnetite and ilmenite crystals with polygonal contacts and dihedral angle close to 120°. The modal proportion of magnetite relative to ilmenite is variable but magnetite prevail over ilmenite (magnetite:ilmenite ratios are usually at the 3 to 10 range). The ilmenite to magnetite proportion does not vary with the amount of Fe-Ti oxides in orthopyroxene-magnetite-ilmenite cumulates. Subsolidus textures are abundant in Fe-Ti oxide crystals. Magnetite commonly exhibits different types of intergrowth, including ilmenite lamellae as trellis and tiny lenses, thin ulvospinel lamellae, as well as small irregular ilmenite grains on the margins. Ilmenite crystals are relatively homogeneous (i.e., compared with magnetite) with rare magnetite lamellae.

Rock types	*cumulus mineral*	*intercumulus mineral*	*Disseminated Cu sulfide (%vol.)*
Magnetitite	Magnetite+Ilmenite (>50%) Hercynite Opx	Plagioclase Phlogopite	5-10
Mag Orthopyroxenite	Opx Magnetie+Ilmenite (10-50%) Hercynite	Plagioclase Phlogopite	5-10
Orthopyroxenite	Opx Magnetite+Ilmenite (1-5%) Hercynite	Plagioclase Phlogopite	5-10
Norite	Opx Plagioclase Magnetite+Ilmenite (0-5%) Apatite	Phlogopite Magnetite+Ilmenite	1-5
Gabbro-norite	Opx Plagioclase Cpx Apatite	Phlogopite	-

Table 1 - Petrographic summary of the rock types in the Serrote da Laje and Caboclo deposits.

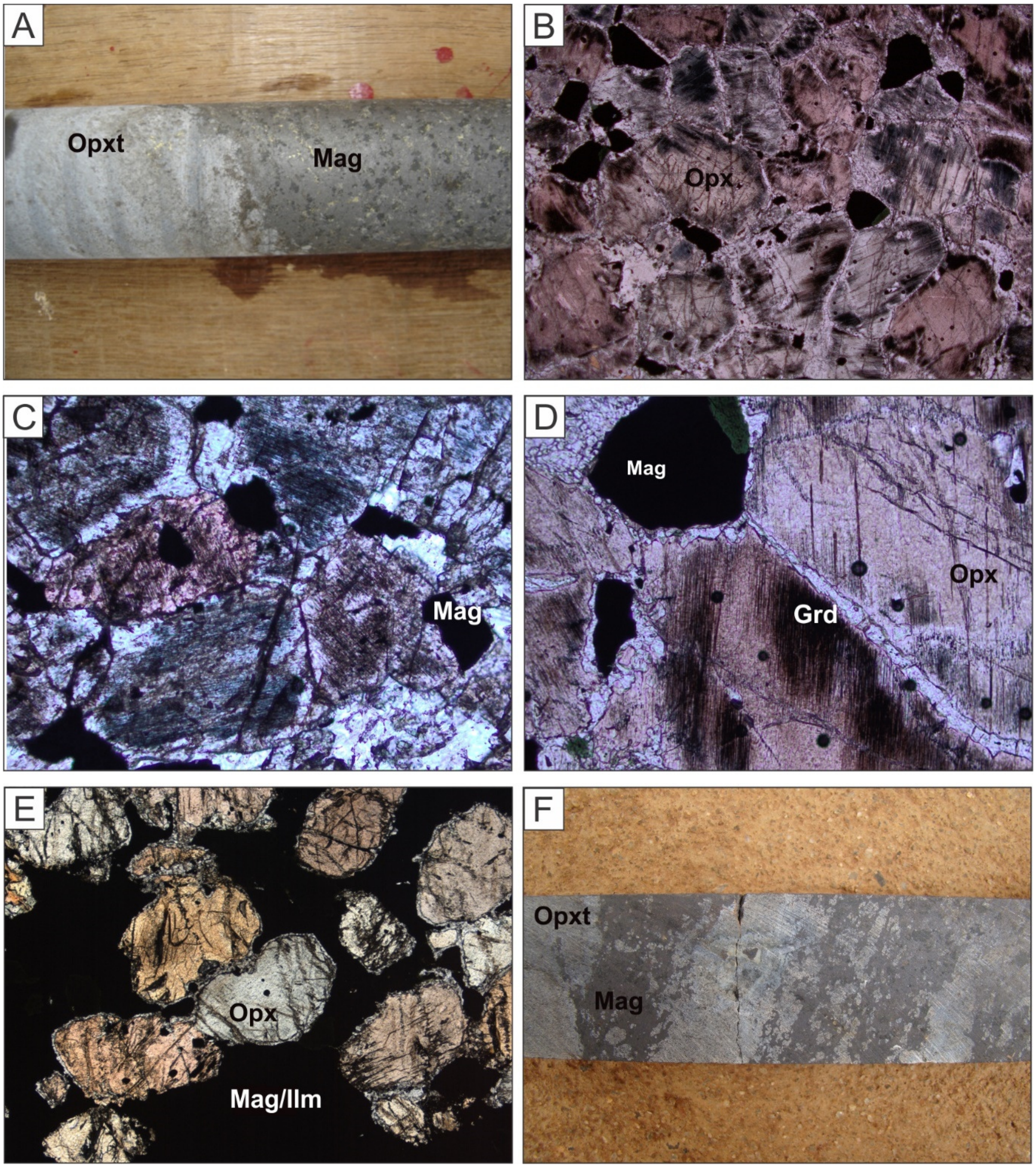

Figure 10 - Photographs and photomicrographs of representative rock textures of orthopyroxenite, magnetite orthopyroxenite and magnetitite in the Serrote da Laje and Caboclo deposits. A) Contact of orthopyroxenite (Opxt) and magnetitite (Mag); B) Orthopyroxenite consisting mainly of cumulus orthopyroxene (Opx) and Fe-Ti oxides (opaque minerals); C) Fe-Ti oxides (opaque mineral) enclosed in orthopyroxene (Opx) or associated with interstitial plagioclase (whitish mineral) in orthopyroxenite; D) Detail of corona of garnet between orthopyroxene (Opx) crystals. Note also green spinel (hercynite) associated with magnetite (Mag) crystal; E) Fe-Ti oxides (Mag/Ilm) enclosed in or interstitial to orthopyroxene in magnetite orthopyroxenite; F) Irregular magnetite-rich domains (Mag) in orthopyroxenite.

Norite and gabbronorite are the common plagioclase-bearing rocks in the Serrote da Laje and Caboclo deposits. Norite is closely associated with orthopyroxenite and the progressive transition of orthopyroxene cumulates with intercumulus plagioclase with meso- to orthocumulate textures to orthopyroxene-plagioclase adcumulates are common. Norite is a medium-grained orthopyroxene-plagioclase cumulate (Fig. 11A) commonly with accessory FeTi-oxides and apatite, as well as minor interstitial phlogopite. Gabbronorite is a medium-grained orthopyroxene-clinopyroxene-plagioclase cumulate commonly with accessory apatite (Fig. 11E) and minor interstitial phlogopite. Accessory Fe-Ti oxides in norite consist of magnetite and ilmenite with minor associated dark green spinel (hercynite). Apatite is a common accessory mineral in both norite and gabbronorite and occurs as fine- to medium-grained euhedral crystals or aggregates (Fig. 11B).

Primary igneous minerals and textures are commonly partially modified by post-magmatic processes including high-grade metamorphism (granulite facies) as well as hydrothermal alteration. Gabbroic rocks (i.e., norite and gabbronorite) are usually more extensively deformed and recrystallized during metamorphism than orthopyroxenites and associated rocks with abundant Fe-Ti oxides. High-grade metamorphism and associated ductile deformation include common minor bending and rim recrystallization of igneous minerals, as well as discrete zones where igneous rocks were completely transformed into fine- to medium-grained rocks with granoblastic textures and metamorphic assemblages. Garnet is a common mineral associated with orthopyroxene, clinopyroxene and plagioclase in these metamorphic assemblages. In partially recrystallized rocks, garnet occurs in corona around orthopyroxene and/or Fe-Ti oxides, usually formed at the expense of plagioclase (Fig. 10D). Discrete zones of highly transformed rocks may have unusual mineralogical compositions associated with metassomatic processes. These up to 1 meter-thick zones include garnet-rich rocks (> 50 vol. %) and phlogopite-rich rocks (> 75 vol. %).

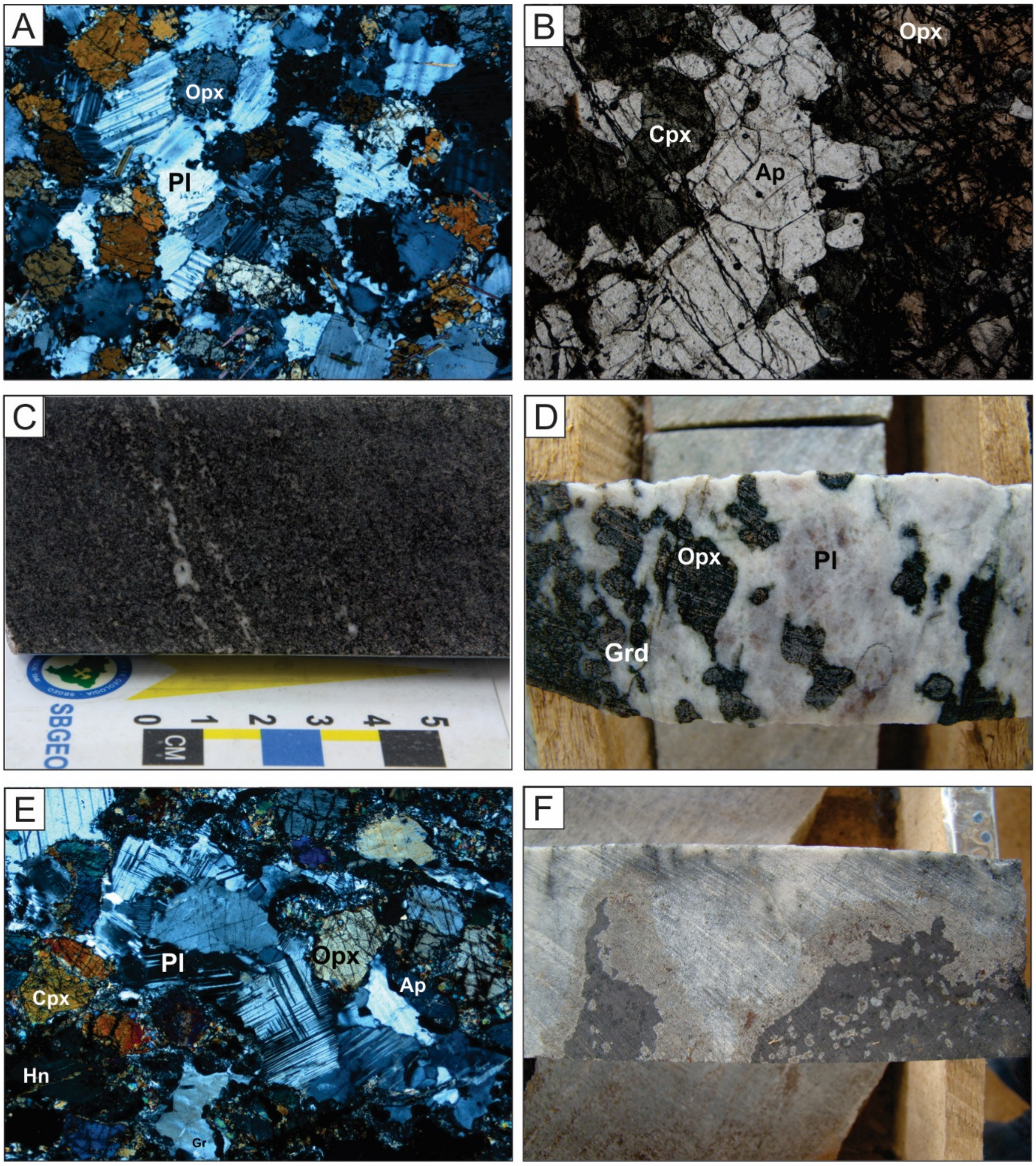

Figure 11 – Photographs and photomicrographs of representative rock textures of norite and gabbronorite in the Serrote da Laje and Caboclo deposits. A) Photomicrograph of norite with adumulus texture; B) Photomicrograph of norite with abundant apatite. C) Core sample of banded norite. The intercalated white bands are composed by plagioclase; D) Core sample of leuconorite. The dark brown minerals are orthopyroxene with dark green alteration rim of talc. E) Photomicrograph of gabbronorite consisting of cumulus orthopyroxene, clinopyroxene, plagioclase and apatite. Hornblende occurs as an alteration of pyroxenes. F) Core sample showing veins and bag-like bodies of magnetite in leuconorite.

5.4 - Whole-rock geochemistry

Two representative drill holes were used to illustrate the lithogeochemical variations of the host rocks of the Serrote da Laje and Caboclo deposits (drill holes SLJE-272 and CBCR-71). Each sample represents an approximately 1-m interval of variably layered mafic-ultramafic rocks, such that variable amounts of different rock types may be included in several samples. Because the Serrote da Laje and Caboclo deposits are hosted by mafic-ultramafic cumulate rocks, major and minor elements contents are mainly controlled by the type and relative proportion of cumulus minerals. The distribution of FeO, Ti, CaO, Cr, V and Ni in mafic-ultramafic rocks of the Serrote da Laje (Fig. 12A) and Caboclo (Fig. 12B) deposits indicates the predominance of orthopyroxene, Fe-Ti oxides, plagioclase and clinopyroxene cumulates. Orthopyroxenite and magnetitite (i.e., orthopyroxene + Fe-Ti oxide cumulates) have higher contents of FeO and lower contents of CaO compared to plagioclase-bearing cumulates (norite and gabbronorite). The plots of FeO vs Ti, Cr, V and Ni show a positive correlation (Fig. 13) indicating that these minor elements are mainly hosted in Fe-Ti oxides and orthopyroxene. The close match in the distribution of V, Ni and Cr indicates that their contents are mainly controlled by magnetite (Fig. 12 and 13). The plot of FeO vs CaO shows a negative correlation proportional to the abundance of plagioclase and clinopyroxene in these rocks (Fig. 13). The distribution of major and minor elements in the mafic-ultramafic rocks hosting the Serrote da Laje and Caboclo deposits are remarkably similar.

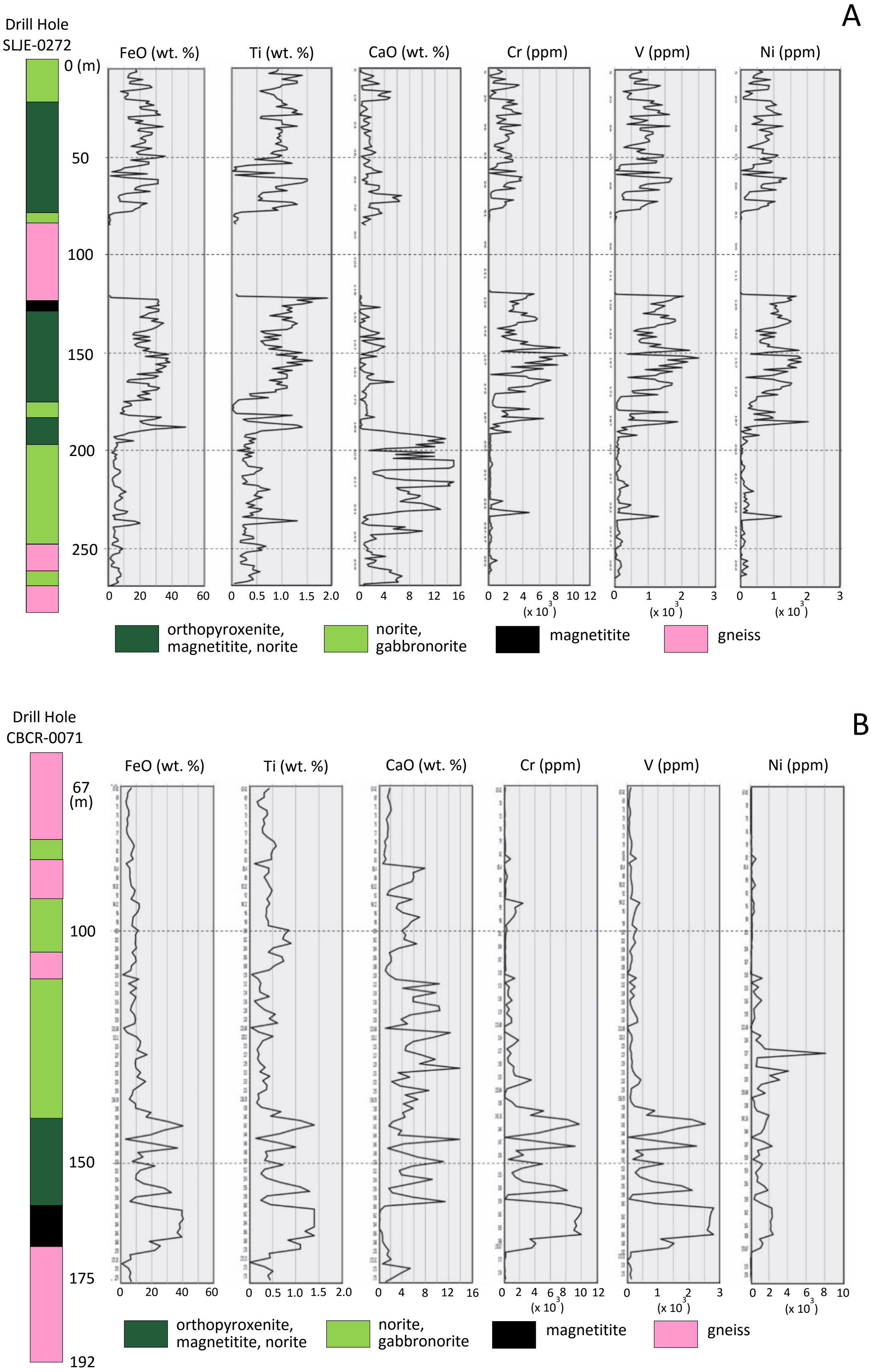

Figure 12 – Stratigraphic variations of selected major and minor elements. A) Drill hole SLJE-0272 in the Serrote da Laje Deposit. B) Drill hole CBCR-0071 in the Caboclo Deposit.

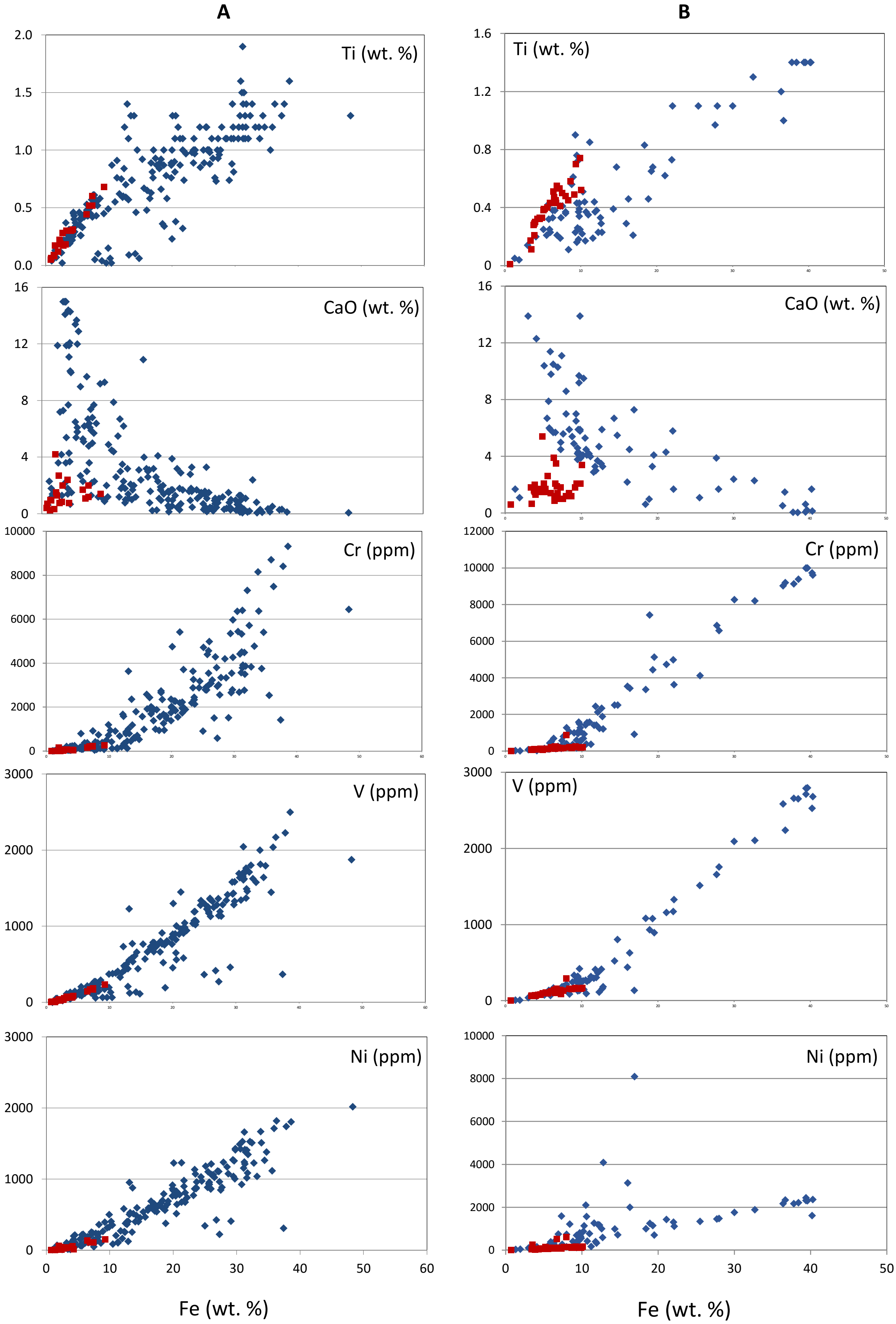

Figure 13 – Plot of FeO content versus major oxides and selected minor elements. A) Drill hole SLJE-0272 in the Serrote da Laje Deposit. B) Drill hole CBCR-0071 in the Caboclo Deposit.

5.5 - Mineral chemistry

Systematic studies of mineral chemistry were limited to orthopyroxene (Opx) analyses in 15 samples (~ 90 analyses) of mafic and ultramafic cumulates from drill hole SLJE-0272 (see Appendix 1 for the complete dataset). Orthopyroxene compositions range from En65.49 to En79.22 mol % through the thickest interval of ultramafic cumulates in drill hole SLJE-0272 (Fig. 14). Results indicate no base-to-top systematic variation in Opx composition along with significant variation in En mol % (up to 5-9 mol. %) for adjacent samples. The later possibly indicates compositional shifts due to different amounts of intercumulus minerals (Barnes, 1986). Although the average En content for orthopyroxene in gabbroic rocks (i.e., norite and gabbrobonite) is lower than in ultramafic rocks (i.e., orthopyroxenite and magnetite orthopyroxenite), the range in En contents does not separate gabbroic (En65.49 to 79.22 mol. %) and ultramafic rocks (En71.95 to 77.26 mol. %). The later have En contents close 75 mol. % through the interval. Contents of minor elements in Opx are scattered due to abundant exsolution of Fe-Ti minerals (i.e., scattered Ti, Cr, Ni) and clinopyroxene (i.e., scattered Ca). Al_2O_3 content in Opx is higher in ultramafic rocks (4.12-8.52 wt. %; average of 6.46 wt. %) than in mafic rocks (0.88-6.64 wt. %; average of 3.27 wt. %).

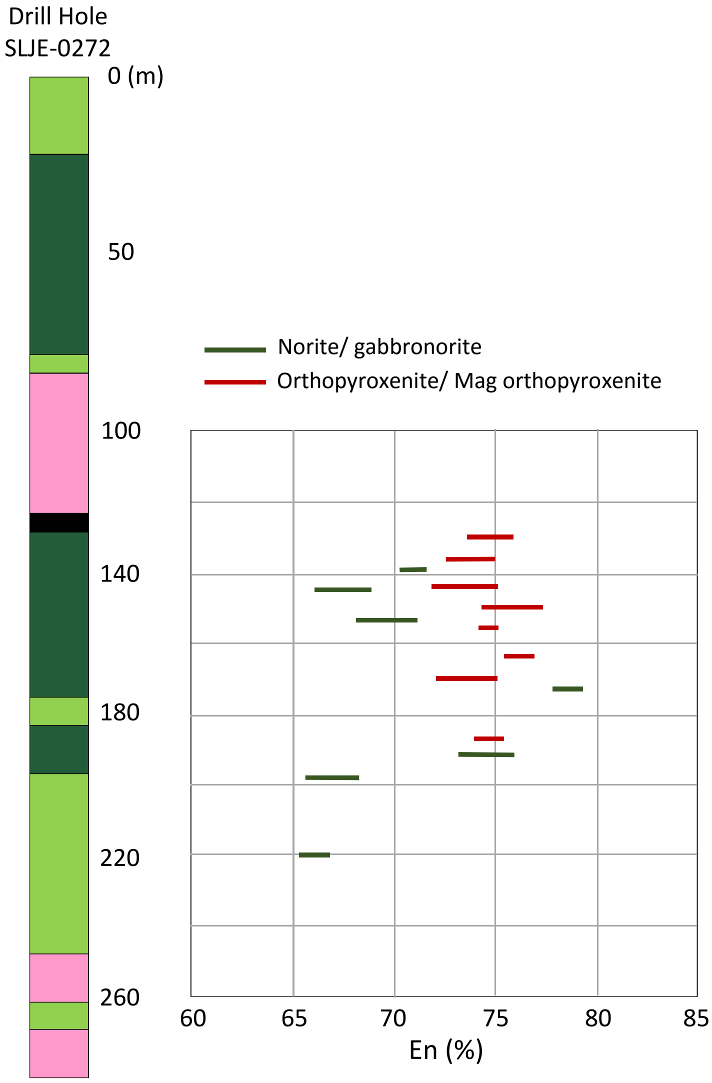

Figure 14 – Stratigraphic variation of En content in orthopyroxene through drill hole SLJE-0272.

5.6 - Petrography, mineralogy and geochemistry of the sulfide ore

Two distinct types of sulfide ore occur in the Serrote da Laje and Caboclo deposits. The first type (indicated as type 1), associated with orthopyroxenite, magnetite and norite, encompass the bulk of the Cu-Au resources. The second type (indicated as type 2), associated with sulfide veins and/or extensively altered rocks, is just important in the hydrothermally altered central domain of the Serrote da Laje deposit located between the fault zones (Fig. 4 and 7). Type 2 ore commonly overprints type 1 ore in both deposits. While type 1 ore is restricted to orthopyroxenite, magnetite and norite, type 2 ore may also occur in gabbronorite and host gneissic rocks adjacent to the mafic-ultramafic bodies.

Sulfides in type 1 ore of the Serrote da Laje and Caboclo deposits consist mainly of disseminated chalcopyrite and bornite (Fig. 15A) with minor associated chalcocite. Disseminated sulfides are abundant (5-10 vol. %) in magnetitite and orthopyroxenites, becoming less abundant in norite (1-5 vol. %) and gabbronorite (< 1 vol. %). Sulfides are interstitial to magnetite and orthopyroxene and net-texture characterizes the ore in sulfide-rich samples (Fig. 15B). The relative modal proportion of chalcopyrite and bornite is highly variable within a meter scale, such that samples consisting mainly of bornite are closely associated with those consisting mainly of chalcopyrite. Bornite and chalcopyrite occur either as fine-grained (< 1 mm) polycrystalline granular aggregates or complex intergrowth of both minerals (Fig. 15B). Rounded sulfide blebs (< 0.5 mm diameter) consisting of variable modal proportions of bornite and chalcopyrite are enclosed in orthopyroxene (Fig. 15D) or Fe-Ti oxides. Gold occurs as fine-grained crystals enclosed in chalcopyrite and/or bornite, as well as filling fractures within sulfides.

Sulfides in type 2 ore of the Serrote da Laje and Caboclo deposits occur in veins associated with hydrothermally altered rocks (Fig. 15C), as well as disseminated (up to 5-10 vol. %) adjacent to highly veined rocks or within highly altered rocks. Sulfides consist mainly of pyrite, pyrrhotite and chalcopyrite of variable grain size. Coarse- to medium-grained sulfides occur within veins while fine-grained sulfides prevail in disseminated ore.

Drill hole SLJE-0272 was used to illustrate the geochemical features associated with different ore types of the Serrote da Laje and Caboclo deposits. This drill core intersected a representative interval of type 1 ore hosted by orthopyroxenite/magnetite/norite, and an interval of type 2 ore hosted by gabbronorite (Fig. 16).

The distribution of FeO, S, Cu, Au and Pd through drill core SLJE-0272 (Fig. 16) indicates that type 1 ore is associated with rocks enriched in magnetite and orthopyroxene, as indicated by high FeO contents (see also Fig. 12A and 13A for positive correlation of FeO with Ti-V-C-Ni). Type 2 ore in drill core SLJE-0272 is hosted by gabbronorite and, therefore, not associated with FeO-rich rocks. The plot of S vs Cu for the interval hosting type 1 ore indicates a strong positive correlation (Fig. 17). Type 1 ore samples plot between Cu/S ratios of bornite and chalcopyrite as expected based upon petrographic studies of the sulfide ore, which indicate highly variable modal proportions of bornite and chalcopyrite. The plot of S vs Au and S vs Pd for the interval hosting type 1 ore indicate a weak positive correlation and low contents for Au (< 0.5 ppm) and Pd (< 300 ppm, but mainly < 100 ppm).

The plot of S vs Cu for the interval hosting type 2 ore does not indicate a positive correlation (Fig. 17). Type 2 ore samples plot mainly between Cu/S ratios of chalcopyrite and Cu/S equal zero as expected based upon petrographic studies of the sulfide ore, which indicate variable modal proportions of pyrite, pyrrhotite and chalcopyrite. Compared to type 1 ore, Cu-Au-Pd contents in type 2 ore much lower.

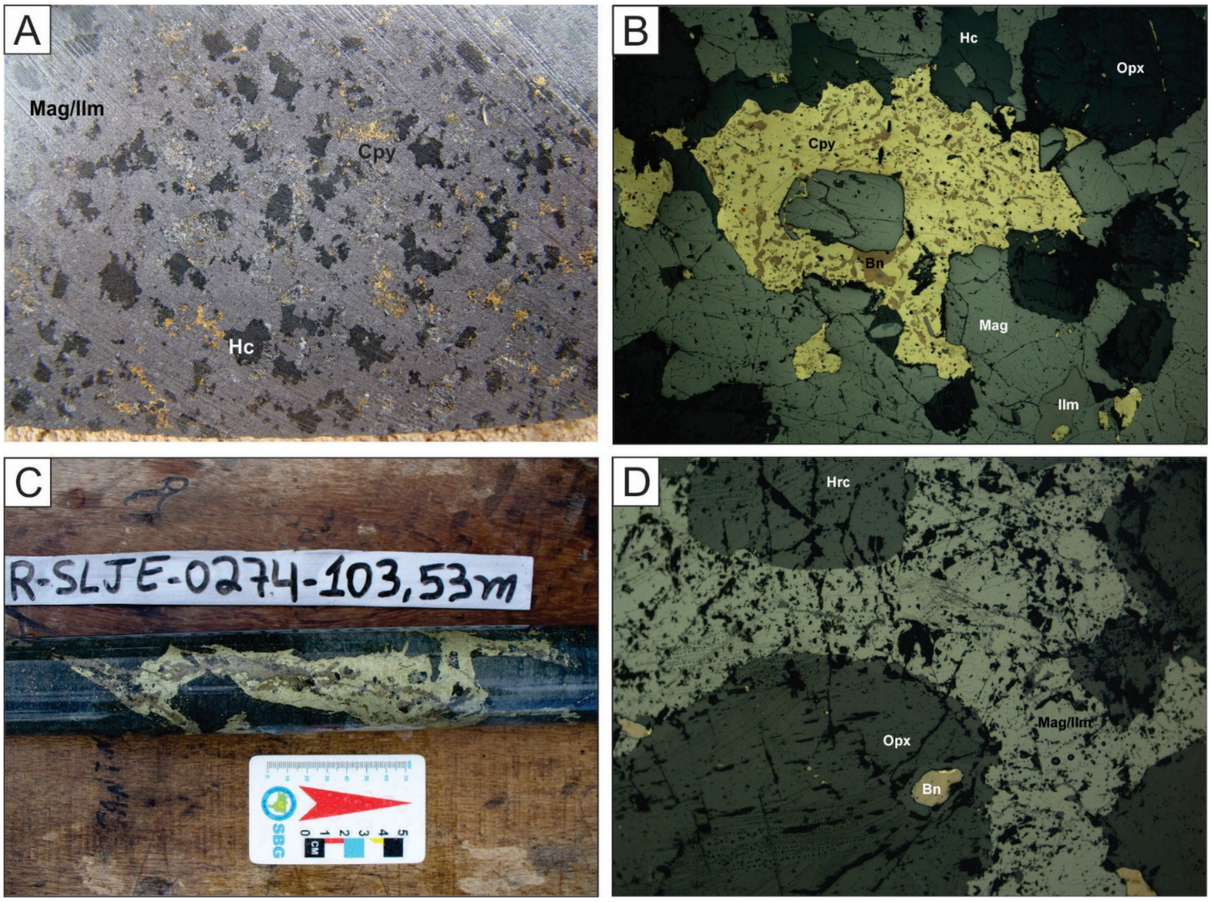

Figure 15 – Representative sulfide textures of ore. A) Disseminated sulfides (mainly chalcopyrite) in a magnetitite core sample (typical type 1 ore). B) Photomicrograph of sulfides interstitial to Fe-Ti oxides and orthopyroxene (type 1 ore). Sulfides consist of an intergrowth of bornite and chalcopyrite. C) Sulfide vein cross cutting a hydrothermally altered gabbroic rock (typical type 2 ore). Sulfides consist mainly of pyrite (yellow) and pyrrhotite (bronze color). D) Photomicrograph of a bornite-rich sulfide bleb enclosed in an orthopyroxene crystal. The rock is a magnetite orthopyroxenite.

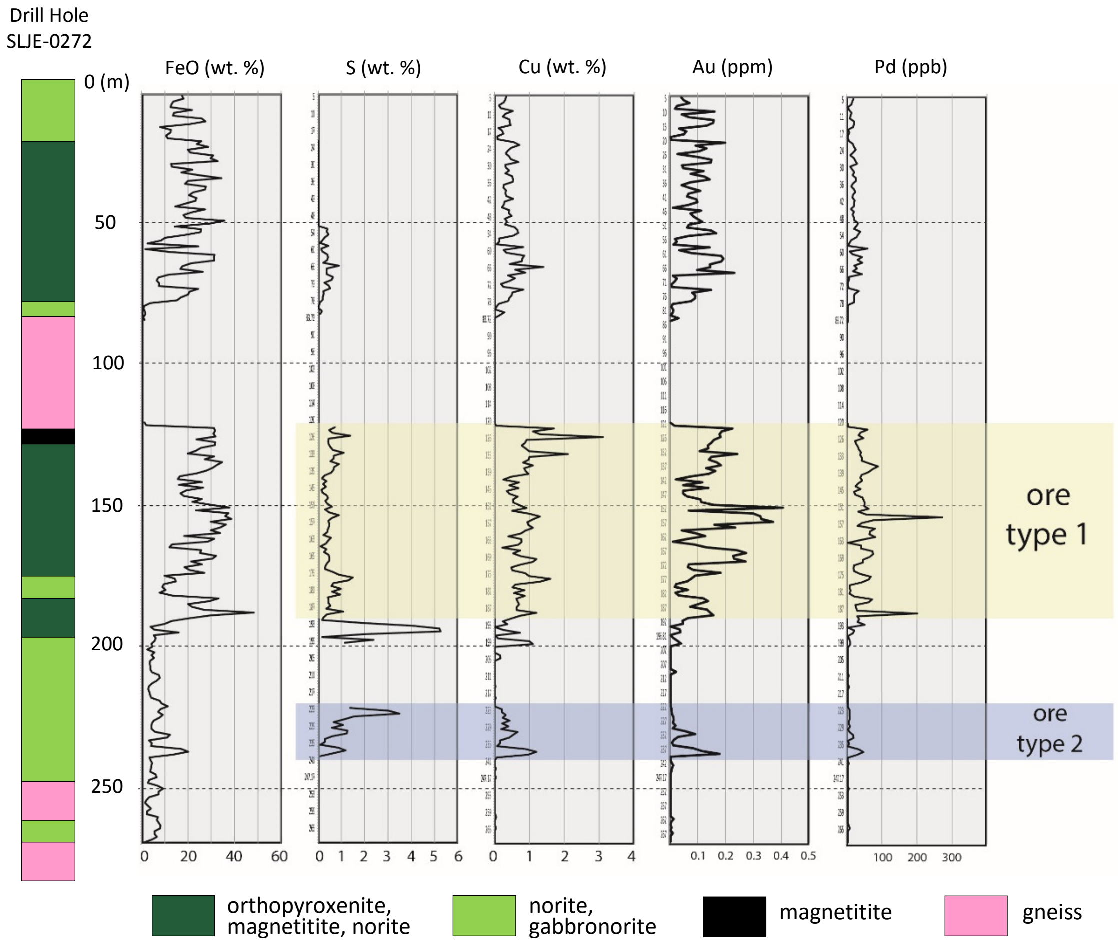

Figure 16 – Stratigraphic variations of FeO, S, Cu, Au and Pd through drill hole SLJE-0272 in the Serrote da Laje Deposit.

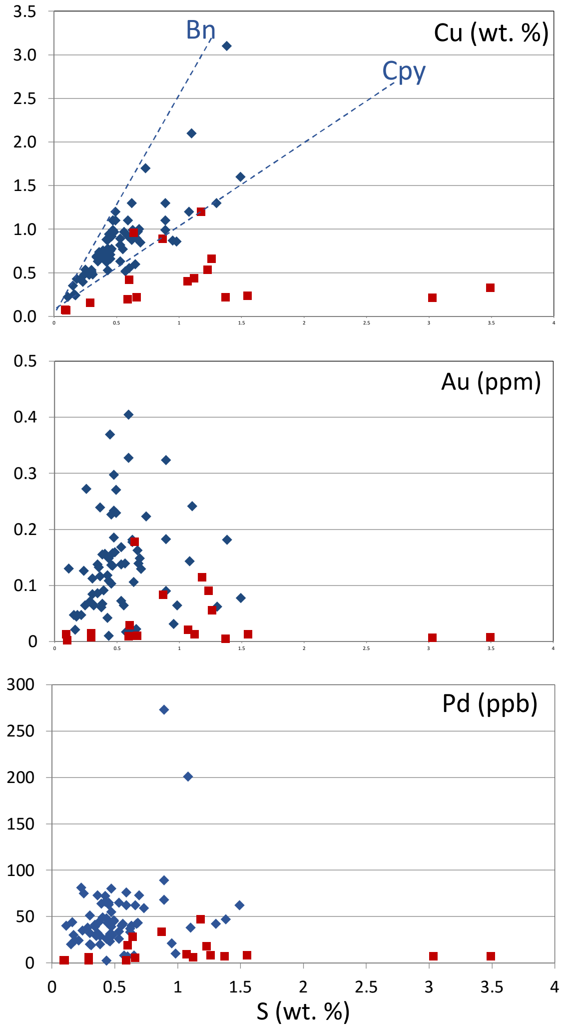

Figure 17 – Plot of S content versus Cu, Au and Pd for type 1 (blue) and type 2 (red) ore intervals in drill hole SLJE-0272 in the Serrote da Laje Deposit (see Fig. 16 for location of indicated ore intervals). Cu/S ratios for bornite (Bn) and chalcopyrite (Cpy) in the S-Cu plot are based on average microprobe analyses of sulfides (Aura Minerals internal report).

5.7 - Sulfur isotopes

Sulfur isotopic analyses were obtained in disseminated chalcopyrite and bornite in samples of ultramafic rocks (type 1 ore), and in pyrite, pyrrhotite and chalcopyrite that occurs in veinlets in samples of altered mafic rocks (type 2 ore). The sulfides were analysed in a LA-MC-ICPMS and the $\delta^{34}S$ results were related with the Cañon Diablo Troilite (V-CDT). The sulfur isotopic compositions obtained are listed in the Table 2.

Results for disseminated chalcopyrite and bornite in type 1 ore hosted by ultramafic rocks have a narrow range of values from -1.0 to 2.5 δ34S ‰ (Fig. 18). The results are the same for chalcopyrite and bornite and indicate an isotopic composition similar to mantle-derived sulfur.

Pyrite, chalcopyrite and pyrrhotite in type 2 ore hosted by hydrothermally altered gabbroic rocks have isotopic values from 7.5 to 13.0 δ^{34}S ‰ (Fig. 18). The higher values of δ34S ‰ indicate values distinct from mantle-derived sulfur, thus suggesting that sulfides in type 2 ore may partially originate from hydrothermal fluids from the host rocks (paragneiss).

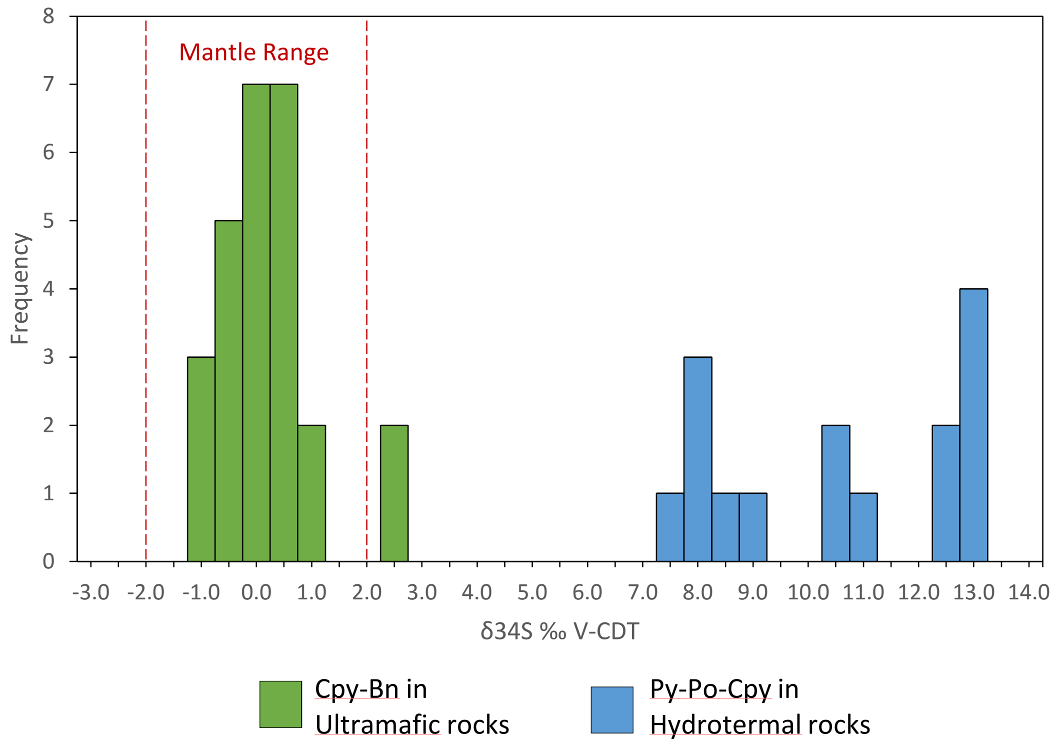

Figure 18 – Histogram of δ34S ‰ V-CDT values of sulfides from ultramafic rocks (type 1 ore) and hydrothermally altered gabbroic rocks (type 2 ore) of the Serrote da Laje deposit.

Sample	*Litology*	*Mineral*	*‰ V-CDT*	*Depth (m)*	*Ore Type*
SLJE-25	Orthopyroxenite	cpy	0.61	129.8	Type 1
SLJE-25	Orthopyroxenite	cpy	0.39	129.8	Type 1
SLJE-25	Orthopyroxenite	bn	2.36	129.8	Type 1
SLJE-25	Orthopyroxenite	bn	2.1	129.8	Type 1
SLJE-25	Orthopyroxenite	cpy	1.1	129.8	Type 1
SLJE-25	Orthopyroxenite	cpy	1.26	129.8	Type 1
SLJE-21	Orthopyroxenite	cpy	-0.12	143.7	Type 1
SLJE-21	Orthopyroxenite	cpy	-0.74	143.7	Type 1
SLJE-18	Mag Orthopyroxenite	cpy+bn	0.63	149.6	Type 1
SLJE-18	Mag Orthopyroxenite	cpy+bn	-0.13	149.6	Type 1
SLJE-18	Mag Orthopyroxenite	cpy+bn	0.25	149.6	Type 1
SLJE-18	Mag Orthopyroxenite	cpy+bn	-0.51	149.6	Type 1
SLJE-18	Mag Orthopyroxenite	cpy	-0.5	149.6	Type 1
SLJE-18	Mag Orthopyroxenite	cpy	-0.36	149.6	Type 1
SLJE-18	Mag Orthopyroxenite	bn	-0.51	149.6	Type 1
SLJE-18	Mag Orthopyroxenite	bn	-0.22	149.6	Type 1
SLJE-16	Mag Orthopyroxenite	bn	0.43	155.1	Type 1
SLJE-16	Mag Orthopyroxenite	bn	0.15	155.1	Type 1
SLJE-16	Mag Orthopyroxenite	bn	0.42	155.1	Type 1
SLJE-16	Mag Orthopyroxenite	bn	0.52	155.1	Type 1
SLJE-16	Mag Orthopyroxenite	cpy	0.18	155.1	Type 1
SLJE-16	Mag Orthopyroxenite	cpy	0.12	155.1	Type 1
SLJE-10	Magnetitite	bn	0.85	189.2	Type 1
SLJE-10	Magnetitite	bn	0.55	189.2	Type 1
SLJE-10	Magnetitite	cpy	0.79	189.2	Type 1
SLJE-10	Magnetitite	cpy	0.63	189.2	Type 1
SLJE-04	Gabbro	cpy	11.16	224.2	Type 2
SLJE-04	Gabbro	py	10.61	224.2	Type 2
SLJE-04	Gabbro	py	10.86	224.2	Type 2
SLJE-02	Gabbro	po	12.86	231	Type 2
SLJE-02	Gabbro	po	12.69	231	Type 2
SLJE-02	Gabbro	po	13.23	231	Type 2
SLJE-02	Gabbro	po	13.29	231	Type 2
SLJE-02	Gabbro	py	13.42	231	Type 2
SLJE-02	Gabbro	py	13.28	231	Type 2
SLJE-28	Mag Orthopyroxenite	cpy	9.17	69.5	Type 2
SLJE-28	Mag Orthopyroxenite	cpy	8.69	69.5	Type 2
SLJE-12	Garnetitite	cpy	8.05	182.6	Type 2
SLJE-12	Garnetitite	cpy	7.95	182.6	Type 2
SLJE-12	Garnetitite	cpy	8.5	182.6	Type 2
SLJE-12	Garnetitite	cpy	8.49	182.6	Type 2

Table 2 - Sulfur isotope data for sulfide minerals of the Serrote da Laje deposit

5.8 – U-Pb and Sm-Nd isotopes

Two samples from mafic-ultramafic intrusion of the Serrote da Laje deposit produced appropriated concentrate of zircons for U-Pb geochronology. The results are presented in table 3. Sample SLJE-17 is a leuconorite and U-Pb isotopic analyses of zircon crystals render several concordant to slightly discordant U-Pb dates (Fig. 19A). Twenty-five spot analyses define a Discordia line with an upper intercept age of 1982±17 Ma (MSWD=13). Sample SLJE-28 is a magnetite orthopyroxenite and U-Pb isotopic analyses of zircon crystals render several concordant to slightly discordant U-Pb dates (Figure 19B). Twenty-nine spot analyses define a Discordia line with an upper intercept age of 1997±20 Ma (MSWD=20). These ages overlap at ca. 1.99 Ga and are interpreted as the crystallization age of magmatic zircons and, therefore, the age of magmatic crystallization of the mafic-ultramafic intrusion of the Serrote da Laje deposit.

Spot	*U(ppm)*	*Th(ppm)*	*Th/U*	*206Pb/204Pb*	*Ratio 7/6**	*2s (%)*	*Age 7/6*	*2s (Ma)*	*Ratio 7/5**	*2s (%)*	*Age 7/5*	*2s (Ma)*	*Ratio 6/8**	*2s (%)*	*Age 6/8*	*2s (Ma)*
23-Z14	492.81	139.43	0.28	761672.97	0.11052	0.6	1808.1	11.3	3.67098	3.1	1565.1	24.7	0.24089	3.1	1391.3	38.3
33-Z19	769.62	221.53	0.29	842537.72	0.11700	0.9	1910.9	16.5	5.56815	1.7	1911.2	14.7	0.34516	1.4	1911.5	23.8
28-Z17	391.83	71.12	0.18	794354.57	0.11727	0.5	1915.0	8.5	5.54879	1.5	1908.2	12.8	0.34318	1.4	1901.9	23.4
04-Z2	476.61	143.65	0.30	979111.41	0.11983	0.7	1953.7	11.7	6.28138	1.5	2015.9	13.2	0.38017	1.4	2077.1	24.1
40-Z24	159.36	23.72	0.15	141388.89	0.12129	0.6	1975.3	10.3	5.87446	2.3	1957.5	20.1	0.35127	2.3	1940.7	38.0
18-Z11	239.09	45.25	0.19	510934.70	0.12153	0.7	1978.8	12.9	5.28647	2.3	1866.7	19.7	0.31549	2.2	1767.7	34.2
22-Z13	158.23	26.64	0.17	326075.78	0.12169	0.6	1981.1	10.3	6.09580	1.5	1989.6	12.9	0.36331	1.4	1997.9	23.5
11-Z7	155.34	25.33	0.16	345657.04	0.12191	0.8	1984.4	14.3	6.77298	1.8	2082.2	15.4	0.40293	1.6	2182.5	28.9
29-Z18	87.23	13.91	0.16	206553.71	0.12200	0.8	1985.7	14.6	6.23006	1.6	2008.7	14.1	0.37037	1.4	2031.2	24.3
27-Z16	130.10	19.01	0.15	375336.74	0.12230	0.8	1990.1	14.1	6.38126	2.1	2029.7	18.0	0.37842	1.9	2068.9	33.6
34-Z20	173.36	21.29	0.12	323359.52	0.12246	0.6	1992.3	10.4	6.42184	1.4	2035.3	12.2	0.38035	1.3	2077.9	22.4
09-Z5	147.05	26.09	0.18	283391.53	0.12291	1.1	1998.9	18.8	6.26559	1.7	2013.7	15.0	0.36972	1.4	2028.1	23.6
24-Z15	290.66	43.58	0.15	680187.76	0.12296	0.5	1999.6	9.2	6.60615	2.5	2060.2	21.9	0.38965	2.5	2121.2	44.3
03-Z1	113.74	15.91	0.14	284476.56	0.12296	1.1	1999.6	19.8	6.42528	1.6	2035.7	13.7	0.37899	1.1	2071.5	19.3
05-Z3	150.89	20.26	0.13	117986.45	0.12302	1.4	2000.5	23.9	6.54024	2.6	2051.3	22.6	0.38559	2.2	2102.3	39.7
06-Z4	124.63	23.47	0.19	340095.64	0.12312	0.8	2001.9	13.8	6.64450	1.7	2065.3	15.3	0.39142	1.6	2129.4	28.2
35-Z21	131.24	18.43	0.14	330942.39	0.12339	0.8	2005.9	13.3	6.50514	1.2	2046.6	10.3	0.38235	0.9	2087.3	16.0
17-Z10	90.48	15.20	0.17	268378.65	0.12341	0.7	2006.2	12.8	6.86002	1.2	2093.5	11.0	0.40314	1.0	2183.5	18.8
15-Z8	157.47	25.05	0.16	360385.15	0.12366	1.0	2009.7	18.0	6.58332	1.5	2057.1	13.5	0.38610	1.2	2104.7	20.7
16-Z9	108.06	15.27	0.14	117815.81	0.12388	0.8	2012.8	13.9	6.29857	1.4	2018.3	12.0	0.36876	1.1	2023.6	19.6
39-Z23	173.96	24.44	0.14	386730.51	0.12413	0.7	2016.4	12.4	6.43384	1.5	2036.9	13.0	0.37593	1.3	2057.2	23.0
10-Z6	105.49	15.97	0.15	274212.48	0.12411	0.8	2016.2	14.9	7.00321	1.4	2111.8	12.5	0.40924	1.1	2211.4	21.3
21-Z12	86.18	13.28	0.15	270578.07	0.12459	1.0	2023.0	17.7	5.77286	2.3	1942.3	19.5	0.33605	2.0	1867.6	33.0
41-Z25	136.44	26.26	0.19	2872.05	0.11951	1.4	1949.0	24.1	5.78630	2.4	1944.4	20.8	0.35114	2.0	1940.0	33.5
36-Z22	66.30	9.00	0.14	123048.54	0.12613	0.8	2044.7	14.3	6.68886	1.8	2071.2	15.5	0.38462	1.6	2097.8	28.0

Table 3 - U-Pb LA-MC-ICPMS data for sample SLJE-17.

Spot	*U(ppm)*	*Th(ppm)*	*Th/U*	*206Pb/204Pb*	*Ratio 7/6**	*2s (%)*	*Age 7/6*	*2s (Ma)*	*Ratio 7/5**	*2s (%)*	*Age 7/5*	*2s (Ma)*	*Ratio 6/8**	*2s (%)*	*Age 6/8*	*2s (Ma)*
38-Z24	512.65	25.63	0.05	31082.79	0.09405	1.1	1509.1	19.8	2.08732	2.1	1144.6	14.5	0.16097	1.8	962.2	16.4
23-Z14	362.68	27.40	0.08	7219.26	0.10034	1.2	1630.4	21.5	1.95618	4.5	1100.6	29.8	0.14140	4.3	852.6	34.7
53-Z34	173.82	32.30	0.19	74365.47	0.10811	1.7	1767.8	30.8	3.86135	6.6	1605.6	51.6	0.25905	6.3	1485.0	83.5
46-Z29	261.55	40.09	0.15	252977.02	0.10890	0.9	1781.0	15.7	3.48020	3.0	1522.7	23.2	0.23179	2.8	1343.9	34.4
52-Z33	202.80	63.23	0.31	243640.69	0.11024	1.2	1803.3	21.6	3.76399	4.1	1585.1	32.2	0.24764	3.9	1426.3	49.7
45-Z28	456.28	57.36	0.13	303354.49	0.11312	0.8	1850.1	14.1	3.90480	1.7	1614.7	13.4	0.25037	1.5	1440.4	19.0
24-Z15	226.93	24.48	0.11	268588.05	0.11668	0.7	1906.0	12.0	4.54381	2.3	1739.0	18.6	0.28243	2.2	1603.6	30.6
33-Z20	193.53	41.01	0.21	321313.34	0.11767	0.8	1921.1	13.7	3.99936	2.2	1634.1	17.6	0.24651	2.0	1420.5	26.0
10-Z6	553.40	52.60	0.10	441312.64	0.11824	0.6	1929.8	11.3	5.63080	6.0	1920.8	50.9	0.34538	6.0	1912.5	98.8
16-Z9	247.69	46.28	0.19	562338.96	0.11849	1.0	1933.5	18.5	5.43885	1.7	1891.0	14.4	0.33292	1.3	1852.5	21.4
22-Z13	685.54	46.38	0.07	13608.43	0.11799	0.7	1926.0	11.8	4.85881	1.5	1795.1	12.9	0.29866	1.4	1684.7	20.6
39-Z25	292.17	37.33	0.13	302947.74	0.11986	0.9	1954.2	15.4	4.67780	2.0	1763.3	16.7	0.28305	1.8	1606.7	25.8
51-Z32	280.56	37.38	0.13	18445.07	0.11932	0.6	1946.0	10.9	5.99311	2.0	1974.8	17.0	0.36429	1.9	2002.5	32.2
47-Z30	679.02	24.73	0.04	734922.78	0.12041	0.9	1962.3	16.6	6.45874	2.2	2040.3	19.1	0.38903	2.0	2118.3	35.8
34-Z22	231.28	31.05	0.13	288710.09	0.12054	0.8	1964.3	14.0	5.53424	1.2	1905.9	10.7	0.33298	1.0	1852.8	15.5
17-Z10	321.68	42.53	0.13	822439.72	0.12131	1.0	1975.6	18.0	6.25195	1.4	2011.7	12.4	0.37378	1.0	2047.2	17.5
27-Z16	129.16	26.58	0.21	281577.40	0.12169	0.6	1981.2	10.8	5.78966	1.7	1944.9	14.5	0.34506	1.6	1911.0	26.0
03-Z1	405.10	39.16	0.10	11095.96	0.12096	0.5	1970.4	9.1	4.91688	1.5	1805.2	12.3	0.29482	1.4	1665.6	20.1
06-Z4	287.78	59.13	0.21	383093.47	0.12252	0.3	1993.3	5.9	5.90594	3.2	1962.1	27.0	0.34960	3.1	1932.7	52.2
29-Z18	144.78	20.23	0.14	531717.99	0.12266	0.9	1995.3	15.2	5.69006	1.4	1929.9	12.4	0.33645	1.2	1869.6	18.7
30-Z19	111.85	25.71	0.23	275621.69	0.12315	0.7	2002.3	11.6	5.90792	2.0	1962.4	17.2	0.34794	1.9	1924.8	31.2
05-Z3	180.81	28.15	0.16	525318.09	0.12336	0.4	2005.4	6.7	6.00820	1.8	1977.0	15.4	0.35324	1.7	1950.0	29.2
09-Z5	193.92	128.93	0.66	188881.31	0.12338	0.6	2005.7	10.6	6.40078	3.6	2032.4	30.9	0.37624	3.5	2058.7	61.7
40-Z26	266.56	46.87	0.18	221017.95	0.12354	0.9	2008.0	15.7	5.62573	1.3	1920.0	11.5	0.33026	1.0	1839.7	15.9
33-Z21	136.85	83.71	0.61	274669.61	0.12421	0.6	2017.5	11.5	6.21464	1.5	2006.5	12.6	0.36288	1.3	1995.8	22.3
11-Z7	156.65	43.80	0.28	9973.39	0.12317	1.4	2002.7	25.2	6.91662	5.6	2100.8	48.3	0.40726	5.4	2202.4	99.7
18-Z11	258.38	41.77	0.16	548644.71	0.12497	0.9	2028.4	15.0	5.98504	1.7	1973.7	14.9	0.34734	1.5	1921.9	24.9
28-Z17	128.82	53.21	0.41	6156.59	0.12334	0.6	2005.1	10.9	5.22993	1.4	1857.5	11.9	0.30753	1.3	1728.5	19.0
50-Z31	715.42	236.23	0.33	24067.53	0.12591	0.9	2041.6	16.1	6.44323	3.2	2038.2	27.5	0.37114	3.0	2034.8	52.7

Table 4 - U-Pb LA-MC-ICPMS data for sample SLJE-28.

The Sm-Nd isotopic data of the Serrote da Laje Complex are listed in Table 5. Nd isotopic data obtained for mafic and ultramafic lithotypes render Nd model ages between 1.92 and 3.01 Ga, with highly variable ε_{Nd} (T = 1.99 Ga) values (-4.33 to 3.87). Plotted against the stratigraphy, the Sm-Nd data are scattered and do not correlate with the layering sequence.

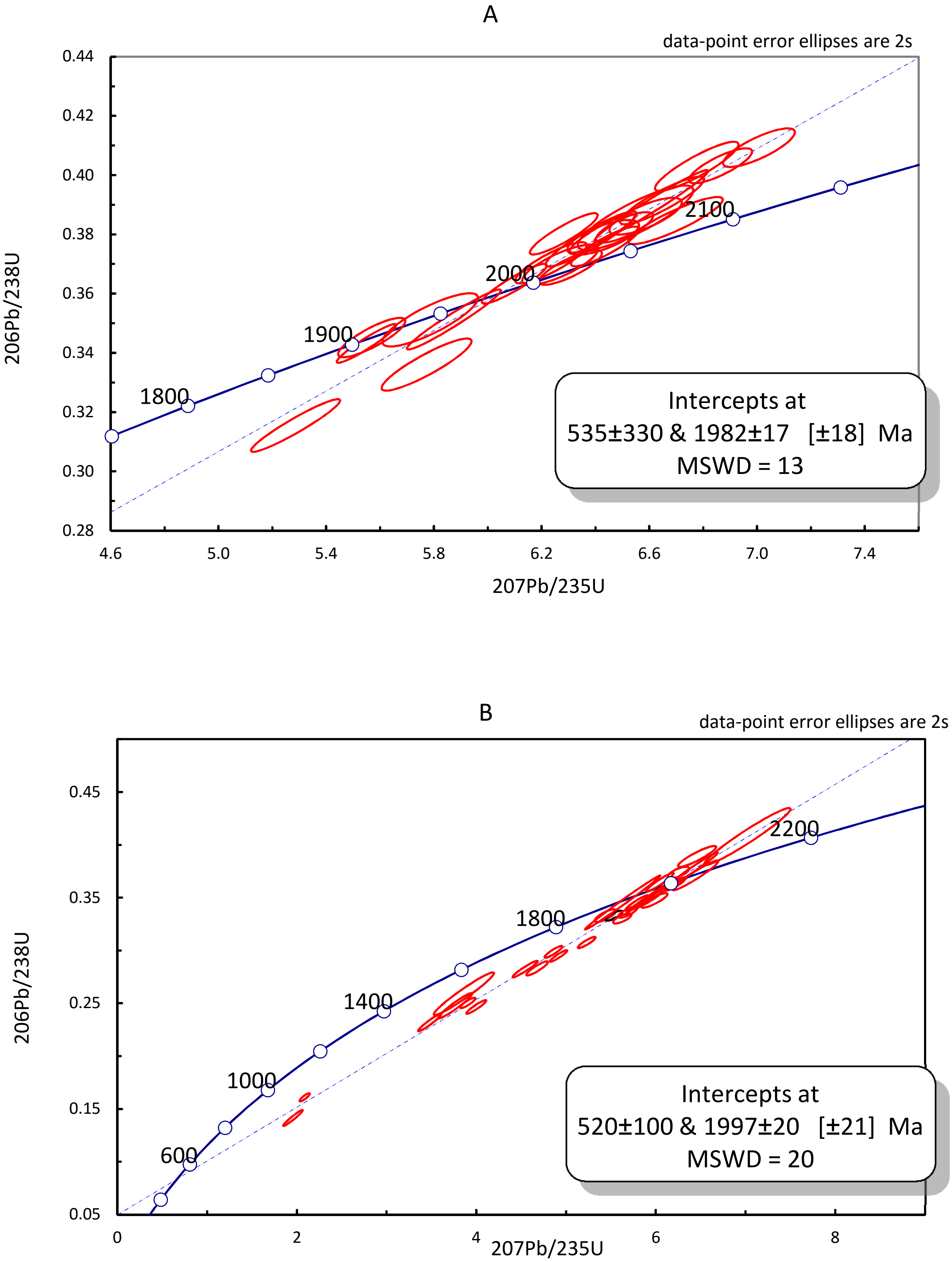

Figure 19 – Concordia diagram of U-Pb analyses of zircons. A) Sample SLJE-17 (leuconorite). B) Sample SLJE-28 (magnetite orthopyroxenite).

Sample	*Sm(ppm)*	*Nd(ppm)*	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$ *(± 2SE)*	$\varepsilon_{N\delta\ (0)}$	$T_{DM\ (Ga)}$	*ENd(t)*
SRLJ 01	4,984	36,346	0,0829	0,511367+/-18	-24,80	1,94	+4,09
SRLJ 07	8,131	39,781	0,1233	0,511461+/-12	-22,96	2,67	-4,33
SRLJ 09	1,079	4,112	0,1587	0,512341+/-57	-5,79	1,92	+3,87
SRLJ 17	0,826	4,272	0,1169	0,511558+/11	-21,07	2,34	-0,81
SRLJ 25	0,121	0,292	0,2497	0,513330+/-31	13,50	-	+0,05
SRLJ 27	0,527	2,972	0,1073	0,511281+/-9	-26,47	2,52	-3,78
SRLJ 28	1,801	7,069	0,1540	0,511876+/-17	-14,87	3,01	-4,03

Table 5 - Sm-Nd isotopic data for the Serrote da Laje Complex (t=1.99 Ga).

6 - Discussion

6.1 - Magmatic structure and composition of mafic-ultramafic bodies

The mafic-ultramafic bodies hosting Cu-Au mineralization in the Serrote da Laje and Caboclo deposits consist of small bodies partially obliterated by regional tectonism and metamorphism. These irregular bodies of mafic-ultramafic rocks are interpreted as small dikes and/or pipes consisting of restricted rock types consisting mainly of orthopyroxenite, magnetitite, norite and gabbronorite. Orthopyroxene is the most prominent mineral and is commonly associated with Fe-Ti oxides, plagioclase, clinopyroxene, as well as minor apatite and phlogopite. Primary magmatic compositions and textures are highly variable, a feature consistent with small size irregular intrusions. Interlayered orthopyroxenite, an orthopyroxene cumulate with variable proportions of intercumulus plagioclase (i.e., adcmulate to orthocumulate textures), and norite/leuconorite, a plagioclase + orthopyroxene cumulate, occurs in metric to centimetric scale. Similar features characterize interlayered magnetitite, magnetite orthopyroxenite and orthopyroxenite. The crystallization sequence consists of orthopyroxene and Fe-Ti oxides followed by plagioclase and then by clinopyroxene. Magnetitite are mainly interlayered with orthopyroxenite and minor norite but very rare in association with gabbronorite. Apatite is a common cumulus mineral in norite and gabbronorite but very rare in association with magnetitite and orthopyroxenite. Systematic interlayering of these rock types are consistent with all rock types resulting from fractionation from a parental magma, either in situ or due to successive pulses of variably fractionated magma. Orthopyroxene compositions ranging from En65.49 to En79.22 mol % indicate moderately primitive to fractionated compositions for the parental magma. The average En content for orthopyroxene in gabbroic rocks is lower but not significantly different from ultramafic rocks, which is consistent with progressive fractionation of a parental magma that crystallize Fe-Ti oxides.

Unusual rock types with abundant phlogopite and/or garnet are commonly associated with mafic-ultramafic rocks of the Serrote da Laje and Caboclo deposits. Rocks consisting largely of phlogopite (> 50 %) were considered as glimmerites in the Koperberg Suite that host the Okiep deposit in South Africa (Clifford and Barton, 2012), or as the result of post-magmatic K metasomatism of the mafic-ultramafic rocks that host the Caraíba deposit in Brazil (Garcia, 2013). Although we don't intend to address in detail the processes associated with the origin of phlogopite-rich rocks in the Serrote da Laje and Caboclo deposits, it is worth to point out that such rocks are usually located in the contact of mafic-ultramafic bodies and host gneissic rocks. This close association may result from the assimilation of country gneissic rocks during magmatic emplacement. Assimilation of older crustal rocks is also consistent with Sm-Nd isotopic data of the Serrote da Laje Complex, as indicated by highly variable and scattered $\varepsilon_{Nd\ (T = 1.99\ Ga)}$ values (-4.33 to 3.87).

6.2 - The origin of magnetitite

The origin of magnetite in mafic-ultramafic intrusions remains controversial (see Maier et al., 2013 for a review of proposed models). While some studies proposed that the Fe-Ti oxide-rich rocks formed by accumulation of cumulus minerals from basaltic magmas (e.g., Ganino et al., 2008; Maier et al., 2013) others propose an origin by silicate-oxide liquid immiscibility (e.g., Naslund, 1983; Zhou et al., 2005). Some textural features described in this study suggest that Fe-Ti-rich melts intruded norite or leuconorite (Fig. 11F). These contacts are characterized by a halo of altered plagioclase and highly altered plagioclase enclosed into ilmenite-magnetite rich veins. However, within the predominant orthopyroxenite and magnetitite association, textures typical of cumulate rocks, including euhedral Fe-Ti oxides enclosed in cumulus orthopyroxene prevail (Fig. 10). Independent of the favored model for the origin of magnetitites, higher oxidation states are known to promote the crystallization of Fe-Ti oxides in mafic magmas (Toplis and Carrol, 1995; Ganino et al., 2008). However, the abundance of magmatic sulfides (i.e., type 1 ore) in both Serrote da Laje and Caboclo deposits indicates that the oxidation state should be below the FMQ-+1.5 buffer (Jugo et al., 2005). In fact, Fe-Ti oxides and Cu sulfides in type 1 ore are closely associated in these deposits, as indicated by interstitial sulfides enclosing cumulus oxides (Fig. 15B) and sulfide blebs enclosed in oxides (Fig. 15D). The association of magmatic sulfides and Fe-Ti oxides suggests that their origin is closely related, as will be discussed in the following discussion.

6.3 - How Cu-Au magmatic sulfides are formed?

Magmatic Ni-Cu-PGE sulfide deposits are formed as the result of the segregation and concentration of droplets of liquid sulfide from mafic or ultramafic magma (e.g., Naldrett, 2004; Barnes and Lightfoot, 2005). The origin of Cu-rich sulfide deposits hosted in mafic-ultramafic intrusions remains however a controversial issue. The composition of Ni-Cu-PGE sulfide deposits are determined by the composition of the associated silicate magma (i.e., the magma that segregated the sulfide liquid), and the relative volumes of silicate and sulfide liquid (i.e., the "R" factor, Campbell and Naldrett, 1979). The compositions of the segregated Ni-Cu-PGE sulfide melts are controlled by the fractionation of monosulfide solid solution (mss, Naldrett, 2004), such that the last sulfide composition before complete crystallization takes place should be close to the intermediate solid solution (iss, Naldrett 2004). The bulk sulfide assemblage would consist essentially of pyrrhotite, pentlandite and chalcopyrite. The fractionation of the sulfide liquid coupled with the migration of the most fractionated fraction from residual mss explains the origin of Cu-Pt-Pd-rich liquids and Cu/Fe ratios up to values close to 1. This explanation has been used for the origin of Cu-Pt-Pd rich sulfide bodies closely associated with larger Ni-Cu deposits (e.g., Li et al., 1996). However, this is likely to be a more localized process, and not appropriate for deposits consisting entirely of Cu-rich sulfide assemblages, especially when bornite is a significant sulfide and Cu/Fe ratios are well above 1 (e.g., Caraíba deposit, Oliveira and Tarney, 1995; Serrote da Laje and Caboclo deposits, this study).

Textural and chemical features described in the Serrote da Laje and Caboclo deposits support the interpretation that Cu-rich sulfides are magmatic and closely associated with magnetite-rich rocks. In both deposits disseminated sulfides are interstitial to or enclosed into cumulus orthopyroxene and Fe-Ti oxides (Fig. 15A-B-D), as commonly described in typical magmatic Ni-Cu-PGE deposits (e.g., Limoeiro Ni-Cu-PGE deposit, Mota-e-Silva et al., 2013; several deposits described in Naldrett 2004), where sulfides are interstitial to or enclosed into cumulus silicates (usually olivine, pyroxenes and/or plagioclase). The close association of magnetite and sulfides in the Serrote da Laje deposit is indicated by positive correlations of FeO and Ti-V in hosted mafic-ultramafic rocks (Fig. 12A and 13A) matched with positive correlations of FeO and S-Cu-Au (Fig. 16 and 17) in sulfide ore. The sulfide assemblages in both deposits consist mainly of bornite and chalcopyrite (Fig. 17), with Cu/Fe ratio in sulfides ranging from about 1 in chalcopyrite-rich ore samples to about 5 in bornite-rich samples. Sulfur isotope results for chalcopyrite and bornite in type 1 ore indicate a narrow range of values from -1.0 to 2.5 δ34S ‰ (Fig. 18), thus supporting a magmatic origin for the ore. The close association of magnetite and sulfides in the Serrote da

Laje and Caboclo deposits suggests that sulfide oxidation may be an appropriate mechanism to increase the Cu content and Cu/Fe ratio of a sulfide melt. Experimental study of the phase relations in the Fe-Ni-Cu-PGE indicates that higher Cu contents of a sulfide melt increases the bulk metal/S ratios and lower its liquidus and solidus temperatures (Ballhaus et al., 2001). The same study indicates that relatively Cu-rich and S-rich sulfide melts (i.e., metal/S < 1) will solidify in the iss stability field, while S-poor sulfide melts (i.e., metal/S > 1) can fractionate past the iss stability field up to bornite crystallization. Experimental work by Wohlgemuth-Ueberwasser et al. (2013) has shown that a combination of fractional crystallization with magmatic oxidation is an appropriate mechanism to generate Cu-rich magmatic sulfides with high Cu/Fe ratios. The authors' results also indicate that the timing and magnitude of sulfide oxidation will determine the extent of the increase in Cu/Fe ratio, such that sulfide melts oxidized above the mss liquidus would fractionated to higher Cu/Fe ratios. These results may be applied to the Serrote da Laje and Caboclo ores considering that magnetite crystallized due to the oxidation of the magma, thus leading to Cu/Fe increase in sulfides due to strong partition of Ni and Fe to magnetite.

6.4 - Classification of the Serrote da Laje and Caboclo Cu-Au deposits

Magmatic nickel-copper-PGE sulfide deposits form as the result of the segregation and concentration of droplets of liquid sulfide from mafic or ultramafic magma and the partitioning of chalcophile elements into these droplets from the silicate magma (e.g., Naldrett, 2004). The deposits are grouped into those that are mined primarily for their Ni and Cu contents and those for their PGE contents (Fig. 20). The Serrote da Laje and Caboclo deposits are mined for their Cu-Au contents and plot outside the compositional range of Ni-Cu-PGE deposits (Fig. 20). Magmatic Cu-Au deposits, such as Serrote da Laje, Caboclo, Okiep and Caraíba are not considered into the different classes proposed for magmatic sulfides (e.g., Naldrett, 2004; 2010; Barnes and Lightfoot, 2005) and should be considered as a different class of a broader group of Ni-Cu-PGE-Au magmatic deposits. The origin of Cu-rich sulfide deposits hosted in mafic-ultramafic intrusions remains a controversial issue (i.e., they were interpreted in different studies either as primary magmatic, or metamorphic transformed magmatic deposits, or as well as a member of IOCG-type hydrothermal deposits) and genetic classifications are consequently compromised. The main features described in magmatic Cu sulfides (i.e., type 1 ore) in the Serrote da Laje and Caboclo deposits that are considered significant for a descriptive classification of these deposits are listed below.

a) Host rocks consist essentially of orthoyroxenite, magnetitite and norite.

b) Cu-Au contents have strong positive correlation with FeO contents and modal Fe-Ti oxides. The latter also reflects a strong positive correlation of Cu-Au contents with Ti, V, Cr and Ni (predominantly hosted in Fe-Ti oxides).

c) Sulfide minerals consist mainly of chalcopyrite and bornite.

d) Cu/Ni ratio in the sulfide fraction is very high (> 100).

e) Cu/Fe ratio ranges from ~ 1 (chalcopyrite-rich ore) to ~ 4 (bornite-rich ore).

f) Isotopic compositions of sulfides are similar to mantle-derived sulfur.

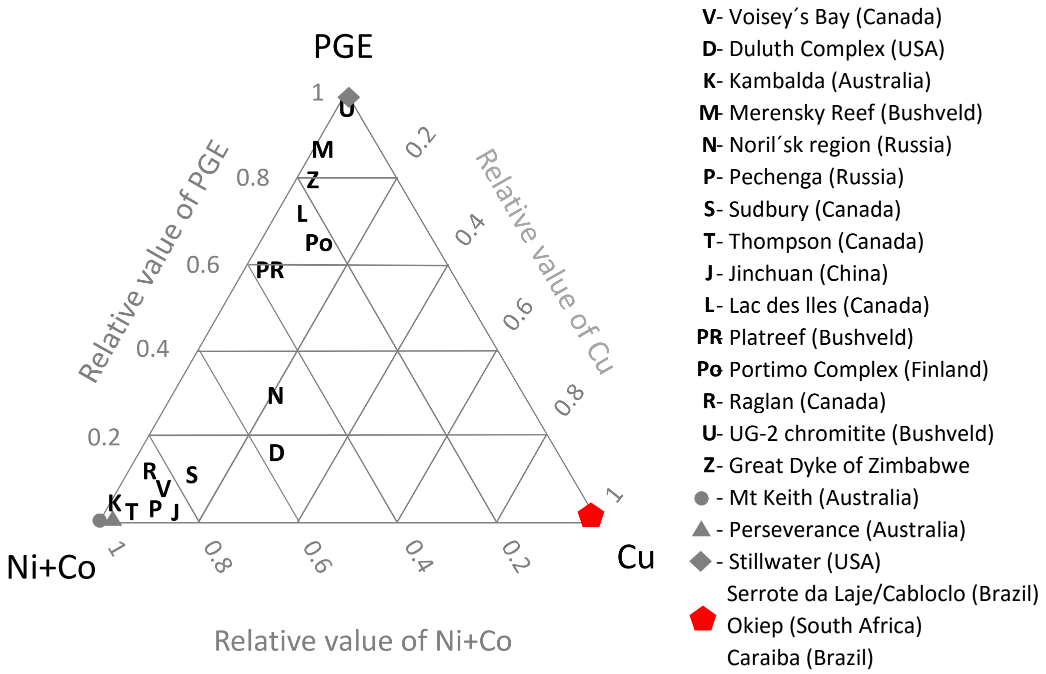

Figure 20 – Relative value of the contributions of Ni, Cu, and PGE to magmatic sulfide deposits. Modified from Naldrett (2004).

6.5 - Implications for exploration

Copper mineralization in the Serrote da Laje and Caboclo deposits is restricted to mafic-ultramafic rocks. Although two distinct types of ore were recognized in both deposits, just the primary magmatic mineralization (i.e., type 1 ore; Fig. 16) is significant for the reserves (> 70 vol. %) and Cu-Au supply for the system. Type 1 ore has a strong positive correlation with FeO contents and modal magnetite. This association has important implications for exploration in the region, once magnetic anomalies characterize mineralized ultramafic bodies in the Serrote da Laje and Caboclo deposits. Due to the small size and poor outcropping of these irregular bodies of mafic-ultramafic rocks, magnetic surveys provide a prime target selecting criteria in the region. The close association of Cu-Au sulfides and Fe-Ti oxides also reflects in combined Cu-Ti-V-Cr-Ni anomalies in geochemical surveys.

The subordinated mineralization that occurs in veins and/or breccia in altered mafic-ultramafic rocks (i.e., type 2 ore; Fig. 16) has been used to suggest the potential for hydrothermal Cu-Au deposits in the region. However, type 2 ore is always closely associated with type 1 ore and does not extend beyond the mafic-ultramafic bodies. Sulfur isotope results for sulfides (pyrite, pyrrhotite and chalcopyrite) in type 2 ore range from 7.5 to 13.0 δ34S ‰ (Fig. 18). This range of values is remarkably different from the one obtained in type 1 ore and suggests a hydrothermal origin for type 2 ore. Although minor sulfide-rich veins or disseminated sulfides are commonly intersected in drill cores of gneissic host rocks, they consist mainly of pyrite and/or pyrrhotite and bear no economic importance. In this study we interpret the type 2 ore as the result of sulfides from hydrothermal fluids that percolate the Cu-Au mineralized mafic-ultramafic rocks and partially remobilized the primary ore (i.e., type 1 ore). Our interpretation suggests that hydrothermal fluids percolated from host rocks through the mafic-ultramafic bodies, but their Cu-Au-Pd contents were remobilized from primary ore. This interpretation implies that type 2 ore does not indicate the existence of a robust Cu-Au hydrothermal mineralization that may lead to different exploration targets than those investigated in this study.

LA-ICPM U-Pb data of zircons from two samples of mafic-ultramafic rocks of the Serrote da Laje deposit indicate a crystallization age at ca. 1.99 Ga for the intrusion. This age close to but younger than the 2056±9.2 Ma SHRIMP U-Pb zircon age of a pyroxenite associated with Cu mineralization in the Caraíba deposit (Garcia et al., 2016). These results suggest that significant Cu deposits are associated with Paleoproterozoic mafic-ultramafic intrusions in the region located close to the northern border of the São Francisco Craton in Brazil.

7 - Conclusions

The principal conclusions of this study are as follows:

a) The Serrote da Laje and Caboclo deposits are hosted in irregular dikes and/or pipes consisting mainly of orthopyroxenite, magnetitite, norite and gabbronorite. Orthopyroxene compositions ranging from En65.49 to En79.22 mol % indicate moderately primitive to fractionated compositions for the parental magma.

b) Textural and chemical features support the interpretation that Cu-Au mineralization is magmatic and closely associated with magnetite-rich rocks.

c) Sulfide minerals in Cu-Au ore consist mainly of chalcopyrite and bornite, reflecting very high Cu/Ni (> 100) and Cu/Fe ratios (from 1~ 1 to ~5) in the sulfide fraction.

d) Isotopic compositions of sulfides are similar to mantle-derived sulfur (-1.0 to 2.5 δ34S ‰), except for minor remobilized hydrothermal ore associated with altered mafic-ultramafic rocks (7.5 to 13.0 δ34S ‰).

e) A combination of fractional crystallization of the parental magma combined with magmatic oxidation is an appropriate mechanism to generate the Cu-rich magmatic sulfides with high Cu/Fe ratios of the Serrote da Laje and Caboclo deposits.

f) Subordinated mineralization that occurs in veins and/or breccia in altered mafic-ultramafic rocks, consisting of pyrite, pyrrhotite and chalcopyrite, have isotopic composition ranging from 7.5 to 13.0 δ34S ‰. This mineralization does not indicate the existence of a robust Cu-Au hydrothermal system that may lead to different exploration targets than those investigated in this study.

g) Magmatic ages of mafic-ultramafic rocks of the Serrote da Laje deposit (ca. 1.99 Ga) and a pyroxenite associated with Cu mineralization in the Caraíba deposit (ca. 2.05; Garcia et al., 2016) suggest that significant Cu deposits are associated with Paleoproterozoic mafic-ultramafic intrusions in the region located close to the northern border of the São Francisco Craton in Brazil.

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CONCLUSÕES

As principais conclusões do estudo foram:

1) Os depósitos Serrote da Laje e Caboclo são hospedados em diques e/ou *pipes* irregulares, consistindo principalmente de ortopiroxenitos, magnetititos, noritos e gabronoritos. As composições dos ortopiroxênios variam entre En65.49 to En79.22 mol % indicando composições moderadamente primitivas a mais fracionadas para o magma parental.

2) Características texturais e químicas suportam a interpretação de que a mineralização de Cu-Au é magmática e fortemente associada com rochas ricas em magnetita.

3) Os minerais de sulfeto da mineralização de Cu-Au consistem principalmente de calcopirita e bornita, refletindo alta razão Cu/Ni (>100) e Cu/Fe (entre 1 e 5) na fração sulfeto.

4) As composições isotópicas dos sulfetos são similares às composições de enxofre derivado do manto (-1.0 a 2.5 δ34S ‰), exceto no minério remobilizado hidrotermal associado com rochas máfica-ultramáficas alteradas (7.5 to 13.0 δ34S ‰).

5) A combinação de cristalização fracionada do magma parental com a oxidação do magma é um mecanismo apropriado para a geração de sulfetos magmáticos ricos em Cu, com alta razão Cu/Fe, dos depósitos Serrote da Laje e Caboclo.

6) A mineralização subordinada que ocorre em veios e/ou brechas nas rochas máfica-ultramáficas alteradas consiste em pirita, pirrotita e calcopirita, tem composição isotópica variando entre 7.5 to 13.0 δ34S ‰. Esta mineralização não indica a existência de um sistema robusto de Cu-Au hidrotermal, que poderia indicar diferentes alvos além dos investigados neste estudo.

7) A idade magmática das rochas máfica-ultramáficas hospedeiras dos depósitos Serrote da Laje (ca. 1,99 Ga) e Caraíba (ca. 2.05; Garcia et al., 2016) sugerem que importantes depósitos de Cu localizados próximos a borda norte do Craton do São Francisco estão associados a intrusões máfica-ultramáficas Paleoproterozóicas.

ANEXOS

Resultados de química mineral – microssonda - ortopiroxênios

Depósito Serrote da Laje

Sample	*Rock*	*Depth (m)*	*SiO2*	*TiO2*	*Al2O3*	*Fe2O3*	*Cr2O3*	*FeO*	*MnO*	*MgO*	*CaO*	*Na2O*	*K2O*	*BaO*	*NiO*	*Total*
SRLJ05 2C	Leuconorite	219.85	52.84	0.04	0.98	0.00	0.01	21.44	0.97	23.05	0.48	0.04	0.01	0.00	0.02	99.87
SRLJ05 2C	Leuconorite	219.85	52.97	0.05	0.88	0.00	0.06	21.32	0.89	22.88	0.45	0.04	0.00	0.07	0.00	99.61
SRLJ05 1C	Leuconorite	219.85	53.43	0.00	0.94	0.00	0.02	21.33	0.88	23.38	0.48	0.00	0.00	0.02	0.12	100.59
SRLJ05 1C	Leuconorite	219.85	53.38	0.06	0.94	0.00	0.05	21.00	0.78	23.37	0.39	0.01	0.02	0.00	0.09	100.09
SRLJ05 1C	Leuconorite	219.85	52.47	0.03	0.98	0.00	0.05	20.83	0.88	23.06	0.44	0.04	0.00	0.00	0.01	98.80
SRLJ07 2C	Gabbronorite	198.10	52.54	1.30	1.28	0.00	0.04	20.69	0.58	23.62	0.42	0.02	0.00	0.05	0.05	100.57
SRLJ07 2C	Gabbronorite	198.10	53.10	0.00	1.14	0.00	0.01	21.91	0.81	23.08	0.42	0.01	0.01	0.00	0.08	100.57
SRLJ07 2C	Gabbronorite	198.10	53.24	0.09	1.36	0.00	0.02	21.05	0.57	23.63	0.38	0.02	0.00	0.00	0.08	100.46
SRLJ07 1C OPXN	Gabbronorite	198.10	52.86	0.02	1.43	0.00	0.00	21.31	0.73	23.03	0.67	0.02	0.00	0.12	0.07	100.25
SRLJ07 1C OPXB	Gabbronorite	198.10	52.86	0.00	1.38	0.00	0.05	21.34	0.76	23.06	0.39	0.03	0.01	0.00	0.02	99.92
SRLJ07 1C OPXN	Gabbronorite	198.10	52.50	0.11	1.55	0.00	0.01	21.38	0.73	22.78	0.50	0.00	0.00	0.00	0.13	99.70
SRLJ09 1C OPXN 1.1	Norite	190.90	51.40	0.00	5.32	0.00	0.02	17.35	0.25	25.10	0.08	0.03	0.00	0.00	0.30	99.86
SRLJ09 1C OPXN 1.2	Norite	190.90	51.52	0.09	5.15	0.00	0.02	18.12	0.29	25.15	0.08	0.00	0.01	0.03	0.09	100.56
SRLJ09 1C OPXN 1.3	Norite	190.90	50.51	0.44	5.65	0.00	0.04	19.34	0.24	24.10	0.06	0.00	0.00	0.04	0.16	100.58
SRLJ09 2C OPXN 1.1	Norite	190.90	51.16	0.03	5.75	0.00	0.00	18.13	0.18	24.46	0.09	0.02	0.00	0.00	0.10	99.92
SRLJ09 2C OPXN 1.2	Norite	190.90	50.87	0.05	5.88	0.00	0.04	18.35	0.27	24.29	0.06	0.04	0.00	0.06	0.19	100.10
SRLJ09 2C OPXB 1.3	Norite	190.90	50.42	0.01	5.61	0.00	0.06	18.31	0.25	24.48	0.08	0.03	0.00	0.07	0.31	99.63
SRLJ11 1C OPXN 1.1	Opxt	186.45	49.11	0.04	8.35	0.00	0.13	18.27	0.22	23.83	0.03	0.01	0.02	0.02	0.20	100.22
SRLJ11 1C OPXN 1.2	Opxt	186.45	49.85	0.00	7.48	0.00	0.04	18.23	0.28	23.83	0.05	0.00	0.01	0.02	0.15	99.92
SRLJ11 1C OPXN 1.3	Opxt	186.45	49.37	0.09	8.26	0.00	0.15	17.80	0.16	23.94	0.03	0.06	0.00	0.00	0.10	99.96
SRLJ11 2C OPXB 1.1	Opxt	186.45	50.73	0.01	5.81	0.00	0.09	18.29	0.17	24.33	0.05	0.00	0.01	0.00	0.19	99.69
SRLJ11 2C OPXN 1.2	Opxt	186.45	50.41	0.04	6.48	0.00	0.07	18.41	0.26	24.18	0.00	0.02	0.01	0.00	0.22	100.10
SRLJ11 2C OPXB 1.3	Opxt	186.45	49.87	0.07	6.53	0.00	0.06	18.54	0.20	24.34	0.03	0.02	0.00	0.00	0.19	99.85
SRLJ13 1C OPXB 1.1	Norite	172.80	52.69	0.03	3.40	0.00	0.33	15.98	0.34	27.00	0.18	0.00	0.00	0.00	0.22	100.17
SRLJ13 1C OPXB 1.2	Norite	172.80	52.69	0.02	3.59	0.00	0.46	15.50	0.31	26.82	0.17	0.05	0.01	0.03	0.20	99.83
SRLJ13 1C OPXB 1.3	Norite	172.80	52.10	0.04	3.87	0.00	0.48	15.44	0.28	26.46	0.21	0.00	0.00	0.03	0.20	99.09
SRLJ13 2C OPXN 1.1	Norite	172.80	52.42	0.00	3.83	0.00	0.46	15.10	0.30	26.41	0.22	0.04	0.00	0.00	0.27	99.05
SRLJ13 2C OPXN 1.2	Norite	172.80	52.46	0.06	3.95	0.00	0.44	15.57	0.27	26.77	0.09	0.01	0.00	0.00	0.20	99.83
SRLJ13 2C OPXN 1.3	Norite	172.80	52.39	0.15	3.95	0.00	0.44	15.52	0.25	26.52	0.16	0.00	0.00	0.00	0.32	99.70
SRLJ14 1C OPXN 1.1	Opxt	169.25	50.58	0.07	5.28	0.00	0.10	19.11	0.38	24.18	0.09	0.01	0.00	0.03	0.04	99.88
SRLJ14 1C OPXN 1.2	Opxt	169.25	50.40	0.05	5.36	0.00	0.13	18.63	0.36	24.35	0.11	0.02	0.01	0.01	0.27	99.71
SRLJ14 1C OPXN 1.3	Opxt	169.25	52.06	0.05	4.54	0.00	0.08	19.01	0.36	24.88	0.09	0.00	0.01	0.00	0.16	101.25
SRLJ14 2C OPXB 1.1	Opxt	169.25	51.36	0.06	4.89	0.00	0.14	18.30	0.37	24.28	0.08	0.00	0.03	0.07	0.07	99.65
SRLJ14 2C OPXB 1.2	Opxt	169.25	51.95	0.01	4.12	0.00	0.09	18.58	0.38	24.71	0.10	0.00	0.01	0.03	0.13	100.12

Sample	*Rock*	*Depth (m)*	*SiO2*	*TiO2*	*Al2O3*	*Fe2O3*	*Cr2O3*	*FeO*	*MnO*	*MgO*	*CaO*	*Na2O*	*K2O*	*BaO*	*NiO*	*Total*
SRLJ14 2C OPXN 1.3	Opxt	169.25	50.74	0.00	6.02	0.00	0.16	18.97	0.33	23.68	0.10	0.00	0.00	0.07	0.25	100.32
SRLJ15 1C OPXB 1.1	Magnetitite	162.90	51.28	0.04	5.29	0.00	0.08	16.73	0.41	25.53	0.08	0.00	0.00	0.04	0.10	99.58
SRLJ15 1C OPXN 1.2	Magnetitite	162.90	49.98	0.06	7.58	0.00	0.10	17.65	0.38	24.73	0.08	0.00	0.03	0.00	0.16	100.75
SRLJ15 1C OPXN 1.3	Magnetitite	162.90	50.28	0.08	4.97	0.00	0.10	18.15	0.36	24.90	0.12	0.02	0.00	0.07	0.15	99.18
SRLJ15 2C OPXB 1.1	Magnetitite	162.90	50.80	0.01	6.36	0.00	0.10	17.59	0.28	24.89	0.10	0.00	0.01	0.00	0.10	100.24
SRLJ15 2C OPXB 1.2	Magnetitite	162.90	50.85	0.04	6.52	0.00	0.07	16.98	0.31	25.14	0.08	0.00	0.01	0.00	0.13	100.13
SRLJ15 2C OPXN 1.3	Magnetitite	162.90	50.82	0.03	6.38	0.00	0.08	16.99	0.32	24.71	0.04	0.06	0.03	0.07	0.12	99.67
SRLJ16 1C OPXN 1.1	Mag-Opxt	155.10	50.84	0.03	5.90	0.00	0.14	18.44	0.25	24.26	0.06	0.08	0.01	0.00	0.13	100.14
SRLJ16 1C OPXN 1.2	Mag-Opxt	155.10	50.15	0.02	6.38	0.00	0.16	18.66	0.29	24.38	0.07	0.02	0.00	0.00	0.26	100.40
SRLJ16 1C OPXN 1.3	Mag-Opxt	155.10	51.57	0.05	4.92	0.00	0.08	18.20	0.28	24.81	0.10	0.01	0.00	0.02	0.04	100.08
SRLJ16 2C OPXN 1.1	Mag-Opxt	155.10	51.28	0.02	5.46	0.00	0.08	18.04	0.33	24.65	0.07	0.02	0.00	0.00	0.24	100.18
SRLJ16 2C OPXN 1.2	Mag-Opxt	155.10	50.72	0.00	6.03	0.00	0.10	18.80	0.32	24.32	0.08	0.03	0.02	0.00	0.16	100.58
SRLJ16 2C OPXN 1.3	Mag-Opxt	155.10	50.43	0.07	6.62	0.00	0.10	18.35	0.22	24.41	0.08	0.00	0.00	0.00	0.17	100.45
SRLJ17 2C OPXN 1.1	Leuconorito	153.30	49.97	0.04	5.67	0.00	0.04	21.14	0.24	22.00	0.12	0.03	0.04	0.00	0.25	99.54
SRLJ17 2C OPXB 1.2	Leuconorito	153.30	51.75	0.02	3.36	0.00	0.06	20.94	0.26	23.22	0.09	0.00	0.02	0.06	0.09	99.87
SRLJ17 2C OPXB 1.3	Leuconorito	153.30	50.41	0.00	4.87	0.00	0.02	21.23	0.23	22.64	0.13	0.01	0.01	0.01	0.22	99.77
SRLJ17 1C OPXB 1.1	Leuconorito	153.30	51.77	0.02	2.74	0.00	0.05	20.56	0.31	23.66	0.06	0.02	0.00	0.00	0.16	99.35
SRLJ17 1C OPXN 1.2	Leuconorito	153.30	52.27	0.00	2.36	0.00	0.03	20.73	0.31	23.75	0.19	0.00	0.01	0.07	0.16	99.89
SRLJ17 1C OPXN 1.3	Leuconorito	153.30	52.18	0.02	2.57	0.00	0.03	20.61	0.34	23.88	0.11	0.00	0.04	0.03	0.23	100.05
SRLJ18 1C OPXN 1.1	Mag-Opxt	149.60	49.37	0.08	6.64	0.00	0.14	20.02	0.26	24.58	0.06	0.04	0.01	0.00	0.22	101.42
SRLJ18 1C OPXB 1.2	Mag-Opxt	149.60	50.01	0.10	6.56	0.00	0.09	17.60	0.26	24.70	0.06	0.02	0.00	0.00	0.09	99.50
SRLJ18 1C OPXB 1.3	Mag-Opxt	149.60	51.91	0.00	4.60	0.00	0.05	17.66	0.32	24.98	0.05	0.04	0.02	0.00	0.18	99.80
SRLJ18 2C OPXB 1.1	Mag-Opxt	149.60	50.85	0.00	6.04	0.00	0.06	17.82	0.20	24.84	0.12	0.02	0.01	0.01	0.19	100.17
SRLJ18 2C OPXN 1.2	Mag-Opxt	149.60	50.52	0.00	6.70	0.00	0.13	17.79	0.23	24.42	0.13	0.02	0.02	0.00	0.00	99.97
SRLJ18 2C OPXB 1.3	Mag-Opxt	149.60	51.25	0.08	5.82	0.00	0.10	18.25	0.21	24.84	0.12	0.04	0.02	0.00	0.20	100.93
SRLJ20 1C OPXB 1.1	Gabronorite	144.32	52.91	0.09	1.59	0.00	0.06	20.92	0.32	22.67	1.18	0.04	0.02	0.00	0.04	99.85
SRLJ20 1C OPXN 1.2	Gabronorite	144.32	52.93	0.00	1.49	0.00	0.10	21.78	0.34	23.32	0.43	0.00	0.00	0.00	0.06	100.46
SRLJ20 1C OPXB 1.3	Gabronorite	144.32	52.54	0.00	1.57	0.00	0.02	22.17	0.37	22.80	0.38	0.02	0.00	0.00	0.02	99.89
SRLJ20 2C OPXB 1.1	Gabronorite	144.32	52.60	0.08	1.37	0.00	0.07	21.91	0.40	22.73	0.40	0.04	0.00	0.00	0.08	99.70
SRLJ20 2C OPXN 1.2	Gabronorite	144.32	53.02	0.01	1.57	0.00	0.09	21.30	0.32	23.48	0.47	0.00	0.00	0.03	0.07	100.34
SRLJ20 2C OPXB 1.3	Gabronorite	144.32	52.94	0.06	1.31	0.00	0.06	21.79	0.42	23.41	0.36	0.02	0.03	0.02	0.12	100.53
SRLJ21 1C OPXB 1.1	Opxt	143.70	48.97	0.06	8.52	0.00	0.05	18.51	0.35	22.78	0.16	0.00	0.03	0.00	0.13	99.57
SRLJ21 1C OPXN 1.2	Opxt	143.70	48.54	1.08	7.58	0.00	0.05	19.64	0.24	23.06	0.06	0.01	0.03	0.06	0.08	100.44
SRLJ21 1C OPXB 1.3	Opxt	143.70	49.94	0.08	7.07	0.00	0.02	18.44	0.23	24.07	0.04	0.08	0.01	0.00	0.15	100.15

Sample	*Rock*	*Depth (m)*	*SiO2*	*TiO2*	*Al2O3*	*Fe2O3*	*Cr2O3*	*FeO*	*MnO*	*MgO*	*CaO*	*Na2O*	*K2O*	*BaO*	*NiO*	*Total*
SRLJ21 2C OPXB 1.1	Opxt	143.70	49.70	0.00	7.39	0.00	0.04	18.84	0.24	23.68	0.09	0.04	0.00	0.00	0.13	100.15
SRLJ21 2C OPXN 1.2	Opxt	143.70	49.11	0.09	8.43	0.00	0.06	18.59	0.33	22.73	0.17	0.03	0.03	0.04	0.15	99.76
SRLJ21 2C OPXB 1.3	Opxt	143.70	48.17	0.05	7.16	0.00	0.11	19.75	0.20	22.85	0.09	0.04	0.03	0.00	0.07	98.50
SRLJ22 1C OPXN 1.1	Norite	139.10	50.03	0.00	5.99	0.00	0.01	20.27	0.21	22.85	0.10	0.00	0.00	0.03	0.12	99.61
SRLJ22 1C OPXB 1.2	Norite	139.10	50.55	0.00	5.96	0.00	0.05	20.46	0.18	23.02	0.09	0.02	0.00	0.00	0.22	100.54
SRLJ22 1C OPXB 1.3	Norite	139.10	50.02	0.03	6.40	0.00	0.00	20.21	0.18	23.20	0.14	0.00	0.00	0.00	0.17	100.38
SRLJ22 2C CPXN 1.2	Norite	139.10	49.62	0.00	6.38	0.00	0.02	20.18	0.18	22.64	0.10	0.03	0.00	0.00	0.12	99.26
SRLJ22 2C CPXB 1.3	Norite	139.10	49.70	0.03	6.64	0.00	0.05	20.84	0.17	22.94	0.09	0.02	0.02	0.00	0.16	100.66
SRLJ23 1C OPXN 1.1	Opxt	136.10	49.39	0.11	7.32	0.00	0.06	19.06	0.34	23.13	0.14	0.02	0.00	0.11	0.18	99.84
SRLJ23 1C OPXB1.2	Opxt	136.10	50.16	0.10	6.48	0.00	0.10	18.77	0.25	24.19	0.08	0.01	0.04	0.04	0.16	100.38
SRLJ23 1C OPXB1.3	Opxt	136.10	48.22	0.00	6.80	0.00	0.13	21.58	0.27	23.28	0.08	0.02	0.00	0.08	0.16	100.62
SRLJ23 2C OPXN 1.1	Opxt	136.10	49.94	0.01	7.19	0.00	0.07	18.27	0.28	23.54	0.03	0.04	0.03	0.00	0.03	99.44
SRLJ23 2C OPXN 1.2	Opxt	136.10	48.61	0.89	6.29	0.00	0.06	19.40	0.24	23.37	0.03	0.00	0.00	0.07	0.14	99.11
SRLJ23 2C OPXB 1.3	Opxt	136.10	50.05	0.04	6.90	0.00	0.04	18.31	0.29	24.10	0.03	0.03	0.03	0.00	0.09	99.91
SRLJ25 1C OPXB 1.1	Mag-Opxt	129.80	50.88	0.07	5.94	0.00	0.05	17.58	0.24	24.64	0.06	0.01	0.01	0.04	0.12	99.65
SRLJ25 1C OPXN 1.2	Mag-Opxt	129.80	49.51	0.05	7.39	0.00	0.04	18.07	0.25	23.99	0.08	0.02	0.01	0.00	0.08	99.49
SRLJ25 1C OPXB 1.3	Mag-Opxt	129.80	49.52	0.18	7.22	0.00	0.03	18.14	0.24	24.17	0.00	0.01	0.00	0.06	0.17	99.75
SRLJ25 2C OPXB 1.1	Mag-Opxt	129.80	51.15	0.00	5.62	0.00	0.06	17.86	0.26	25.03	0.08	0.00	0.03	0.09	0.17	100.36
SRLJ25 2C OPXN 1.2	Mag-Opxt	129.80	49.61	0.08	7.38	0.00	0.07	18.87	0.33	23.53	0.20	0.04	0.04	0.08	0.14	100.35
SRLJ25 2C OPXN 1.3	Mag-Opxt	129.80	49.80	0.04	7.53	0.00	0.02	18.44	0.33	23.88	0.04	0.03	0.02	0.00	0.07	100.20