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INSTITUTO DE GEOCIÊNCIAS – IG
PROGRAMA DE PÓS-GRADUAÇÃO EM GEOLOGIA

Geologia, geoquímica e geocronologia das rochas da Suíte Rio Branco, Cinturão Nova Brasilândia e implicações na evolução do orógeno Sunsás no sudoeste do Cráton Amazônico

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A evolução geológica do Cinturão Nova Brasilândia no sudoeste do Cráton Amazônico, em Rondônia, ocorreu de forma progressiva durante o Mesoproterozoico e início do Neoproterozoico, entre aproximadamente 1241 Ma e 910 Ma, período que abrange estágios pré-orogênico, orogênico e pós-orogênico. Novos dados geológicos de campo, geoquímicos, geocronológicos U-Pb em zircão (LA-ICP-MS) e de isótopos de Sr-Nd obtidos na parte sul do cinturão, associados a reinterpretação de informações anteriormente publicadas, permitem estabelecer cronologia mais precisa entre os episódios de sedimentação, deformação, metamorfismo e magmatismo, bem como a caracterização da afinidade química do magmatismo máfico, fonte, ambiente tectônico da Suíte Rio Branco e os estágios ou fases de evolução do cinturão durante a orogenia Nova Brasilândia.

O ambiente tectônico de *emplacement* do magma máfico-félsico da Suíte Rio Branco é importante na caracterização dos eventos orogenéticos do Mesoproterozoico (Esteniano), no sudoeste do Cráton Amazônico, que antecederam à formação do supercontinente Rodínia. A Suíte Rio Branco, alvo de estudo, é composta por rochas máficas-félsicas que inclue metagabros, metagabro-noritos, metatroctolitos, metabasaltos maciços, metadiabásios, anfibolitos, metagranitos, rochas metavulcânicas félsicas e metatrondhjemitos (equivalentes de plagiogranitos), expostos na forma de *stocks* alongados, arredondados ou ovais, *sills* e enxames de diques, além de derrames. A encaixante regional (Formação Rio Branco) é representadas por rochas de alto grau metamórfico, incluindo gnaisses calciossilicáticos, biotita paragnaisses, gnaisses trondhjemíticos, anfibolitos e granulitos (paraderivados, máficos ou félsicos).

Idades U-Pb (LA-ICP-MS) obtidas em cristais de zircão em rochas do Domínio Rio Branco (constituído por rochas metavulcanossedimentares, metamáficas e metafélsicas), parte sul do Cinturão Nova Brasilândia, sugerem episódios de metamorfismo de alto grau entre 1137 ± 9 Ma e 1127.6 ± 2.3 Ma. Portanto, anterior ao *emplacement* das rochas máficas e félsicas da Suíte Rio Branco, datado entre 1119.7 ± 2.7 Ma e 1106.2 ± 2.8 Ma, portanto de geração muito próxima ao metamorfismo. Cristais de zircão recristalizados provenientes de paragnaisse de alto grau e granito anatético da Formação Rio Branco e de metagabro da Suíte Rio Branco mostram, respectivamente, idades U-Pb (LA-ICP-MS) de 1019 ± 5 Ma, 1011.3 ± 9.6 Ma e 1016.7 ± 3.9 Ma que representam, possivelmente, registros isotópicos de episódio mais jovem de deformação, metamorfismo e migmatização ocorrido no Cinturão Nova Brasilândia.

Dados geoquímicos (rocha total) demonstram que as rochas metamáficas da Suíte Rio Branco são composicionalmente sub-alcalinas toleíticas de baixo a médio Ti, com assinaturas de sobreposição de MORB-*like,* IAT e BABB. Nos diagramas de multi-elementos normalizados ao Manto Primitivo, as rochas metamáficas da Suite Rio Branco apresentam enriquecimento em

elementos litófilos de íons grandes (LILE) em relação elementos de elevado potencial iônico (HFSE), anomalias negativas de Nb e Ta, positivas de Pb, e enriquecimento gradativo em Th em relação a Nb e Ta. Por outro lado, apresentam razões Ti/V = 10-50, La/Yb = 1,74-12,33 e Th/Yb = 0,10-3,56, razões Ce/Y (4,12-24,67) variando de baixa a alta e razões baixa para Ce/Pb (3,3-20,5), Nb/U (3,2-16,25) e Th/La (0,01-0,30). A composição isotópica de Sr-Nd mostrou εNd com valores levemente negativos a positivos entre -2,89 e +1,66 (para t=1120 Ma), próximos ao CHUR, e variadas relações $^{87}Sr/^{86}Sr$ (0,702-0,714) e baixas relações $^{143}Nd/^{144}Nd$ (~ 0,512) sugerindo contaminação crustal ou metassomatismo da cunha mantélica. Os dados geológicos e as assinaturas geoquímicas e isotópicas da Suíte Rio Branco, juntamente com os *trends* petrogenéticos definidos nos diagramas de variação, multi-elementos normalizados, ETR`s normalizados e discriminantes tectônicos, foram considerados eficazes no diagnóstico de subducção.

A proposta de evolução tectônica para o Cinturão Nova Brasilândia, apresentada nessa tese de doutorado, sugere que a parte sul do Cinturão Nova Brasilândia representa um fragmento incompleto de um sistema arco-bacia, contendo registros de dois estágios evolutivos desenvolvidos durante a orogenia Nova Brasilândia. O primeiro acrecionário, entre aproximadamente 1137 Ma e 1106 Ma, envolve subducção intraoceânica, metamorfismo de alto grau (granulítico), magmatismo máfico-félsico e formação de sistema *arc – back-arc*. O segundo colisional, entre aproximadamente 1096 Ma e 1010 Ma, envolve espessamento crustal, deformação (tectônica transpressiva e transcorrência sinistral tardia), metamorfismo de alto grau (anfibolito superior) e migmatização. Os estágios acrecionário e colisional da orogenia Nova Brasilândia no Mesoproterozoico (Esteniano), associados à evolução do orógeno Sunsás e a montagem de Rodínia, ocorreu mediante interações entre o bloco Paraguá, proto-Cráton Amazônico e fragmentos menores de terrenos, envolvendo articulações tectônicas oblíquas e/ou frontais entre grandes massas crustais representadas por Laurentia e Amazônia. Esse novo cenário tectônico é diferente do modelo de *rift* intracontinental proposto anteriormente, principalmente na fase de inversão da bacia e início do fechamento de um oceano porque envolve subducção intraoceânica e formação de um sistema *arc – back-arc*.

Nesse novo cenário tectônico considera-se a orogenia Nova Brasilândia no sudoeste do Cráton Amazônico como do tipo acrecionária-colisional, com evolução entre 1137 e 1010 Ma, posterior a formação de um oceano (fase de oceanização) entre o Bloco Paraguá (acrescido de terrenos alóctones e faixas móveis) e o proto-Cráton Amazônico entre 1241 e 1137 Ma.

Palavras-chave: Magmatismo Mesoproterozoico, Geoquímica, Geocronologia U-Pb, Isótopos de Sr-Nd, Cinturão Nova Brasilândia, Subducção

Geological evolution of the Nova Brasilândia belt in the southwestern Amazonian Craton in Rondônia occurred progressively during the Mesoproterozoic and early Neoproterozoic, between ca. 1241 Ma and 910 Ma, a period that encompasses pre-orogenic, orogenic and post-orogenic stages. New field geological, geochemical, geochronological U-Pb (LA-ICP-MS) and Sr-Nd isotopes data obtained from southern belt rocks, together with the reinterpretation of previously published information, allow for more accurate chronology of sedimentation, deformation, metamorphism and magmatism episodes, and to define the chemical affinity of mafic magmatism, sources, tectonic environment of the Rio Branco Suite. As well as the evolution stages of the belt during the Nova Brasilândia orogeny.

The tectonic emplacement environment of the Rio Branco Suite mafic-felsic magma is important in characterizing of the Mesoproterozoic (Stenian) orogenetic events in the southwestern of the Amazonian Craton, prior to the Rodínia supercontinent assembly. The Rio Branco Suite, target of the studies, is composed by mafic-felsic rocks classified as metagabbros, metagabbronorites, metatroctolites, massive metabasalts, metadiabases, amphibolites, metagranites, metavolcanic rocks and metatrondhjemites (plagiogranite equivalents) exposed to rounded or ellipticals stocks, sills, dike swarms and spills. The host rock of the Rio Branco Suite include high-grade rocks consisting of calc-silicate gneisses, biotite paragneisses, amphibolites and granulites (paraderived, mafic or felsic).

U-Pb ages (LA-ICP-MS) obtained from rock zircon crystals from the Rio Branco domain (composed of metavolcanosedimentary, metafelsic and metamafic rocks) in the southern part of the Nova Brasilândia belt suggest an episode of high-grade metamorphism that occurred between 1137 ± 9 Ma and 1127.6 ± 2.3 Ma. Therefore, prior to the emplacement of the Rio Branco Suite mafic-felsic magma dated between 1119.7 ± 2.7 Ma and 1106.2 ± 2.8 Ma, more of very close generation. Recrystallized zircon crystals from high-grade paragneiss and anatectic granite of the Rio Branco Formation, and Rio Branco Suite metagabbro presented, respectively, U-Pb ages (LA-ICP-MS) of 1019 ± 5 Ma, 1011.3 ± 9.6 Ma and 1016.7 ± 3.9 Ma possibly representing isotopic records of a youngest episode of deformation, metamorphism and migmatization that occurred during the evolution of the Nova Brasilândia belt.

Geochemical data (whole rock) demonstrates that the Rio Branco Suite metamafic rocks are compositionally low- to medium Ti tholeitic sub-alkaline, with overlap signatures of MORB-like, IAT and BABB. In the Mantle-normalized multi-element diagrams of the Rio Branco Suite, metamafic rocks show enrichment in large ion lithophile elements (LILE) relative to high-field-strength elements (HFSE), negative Nb and Ta anomalies, Pb positive anomalies, gradual Th

enrichment in relation to Nb and Ta, and enrichment in K and Sr. On the other hand, Ti/V = 10-50, La/Yb = 1.74-12.33 and Th/Yb = 0.10-3.56 rations, Ce/Y (4.12-24.67) ratios ranging from low to high and low ratios to Ce/Pb (3.3-20.5), Nb/U (3.2-16.25) and Th/La (0.01-0.30). Sr-Nd isotopic composition showed εNd with slightly negative to positive values between -2.89 and +1.66 (for T = 1120 Ma), close to CHUR, and varied $^{87}Sr/^{86}Sr$ (0.702-0.714) and low ratios $^{143}Nd/^{144}Nd$ ratios (~ 0.512) suggesting enrichment/contamination or mantelic wedge metasomatism. The geological data, geochemical and isotopic signatures of the Rio Branco Suite metamafic component, together with the petrogenetic trends defined in the variation diagrams, normalized multi-elements patterns (spidergrams), normalized REEs patterns and tectonic discriminants were effective in the diagnostic of subduction.

The tectonic evolution proposal for the Nova Brasilândia belt presented in this doctoral thesis suggests that the southern part of the Nova Brasilândia belt is an incomplete fragment of arc-basin system containing records of two evolutionary stages developed during the Nova Brasilândia orogeny. The first accretionary, between ca. 1137 Ma and 1106 Ma, involves intra-oceanic subduction, high-grade metamorphism (granulitic) and arc - back-arc system formation. The second collision, between ca. 1096 Ma and 1010 Ma, involves crustal thickening, deformation (transpressive tectonics and late sinistral transcurrence), high-grade metamorphism, and migmatization, as proposed in previous work. The accretionary and collisional stages of the Nova Brasilândia orogeny in the Mesoproterozoic (Stenian), associated with the evolution of the Sunsás orogen and Rodinia assembly, occurred through interactions between the Paraguá block, Amazonian proto-Craton and smaller terrane fragments, involving oblique and/or frontal tectonic joints between large crustal masses represented by Laurentia and Amazônia. This new tectonic scenario is partly different from the intracontinental rift model previously proposed, mainly in the basin inversion phase and the beginning of an ocean closure because it involves intra-oceanic subduction and formation of an arc - back-arc system.

In this new tectonic scenario it is considered that the nature of the Nova Brasilândia orogeny in southwestern Amazonian Craton, in Rondônia, is of the accretionary-collisional type between ca. 1137 and 1010 Ma. Therefore, after the formation of an ocean (oceanization phase) between a Paraguá block (increased of allochthonous terranes and mobile belts) and the Amazonian proto-Craton between ca. 1241 and 1137 Ma.

Keywords: *Mesoproterozoic magmatism, Geochemistry, U-Pb Geochronology, Sr-Nd Isotopes, Nova Brasilândia belt, Subduction*

SUMÁRIO

1. Introdução

1.1 Apresentação do tema

Essa pesquisa abrange informações geológicas de campo, petrológicas e geocronológicas da região sudeste do Estado de Rondônia, enfocando rochas mesoproterozoicas da Suíte Rio Branco e encaixante regional. Tais informações constituem a base da proposta de um novo cenário tectônico de subducção para a porção sul do Cinturão metavulcanossedimentar Nova Brasilândia, apresentado nesta tese de doutorado intitulada "**Geologia, geoquímica e geocronologia das rochas da Suíte Rio Branco, Cinturão Nova Brasilândia e implicações na evolução do orógeno Sunsás no sudoeste do Cráton Amazônico**", aplicado como requisito à obtenção do título/grau de Doutorado em Geologia pela Universidade de Brasília (UnB).

O estudo da gênese das suítes magmáticas máficas é importante porque estas representam registros geológicos que podem ser associados a diversos ambientes extensionais ou convergentes, continentais ou intraoceânicos, com índice de preservação relativamente baixo em função de serem, em geral, consumidas durante os processos orogenéticos acrecionários ou colisionais. Portanto, são registros de episódios magmáticos de natureza máfica ou máfica-ultramáfica de significância global e relevante importância geodinâmica e metalogenética, marcadoras de grandes eventos tectônicos globais. São também indicadores da natureza e composição das fontes mantélicas e dos processos de contaminação e metassomatismo do manto, durante subducção ou residência crustal. Neste contexto, o magmatismo máfico-félsico da Suíte Rio Branco no sudoeste do Cráton Amazônico em Rondônia se destaca pela sua importância no cenário de evolução do Cinturão Nova Brasilândia no Mesoproterozoico, possivelmente registro na Amazônia de uma fase de oceanização, seguida de subducção intraoceânica e formação de arco de ilhas e bacias *back-arc*.

O Cinturão metavulcanossedimentar Nova Brasilândia, conhecido também como Cinturão Nova Brasilândia, é entidade geotectônica de *trend* E-W, com inflexões para NW e SW, desenvolvido no Mesoproterozoico (Esteniano) entre o Bloco Paraguá (acrescido de terrenos alóctones) e o proto-Cráton Amazônico a partir da reativação da zona de sutura Guaporé que havia sido formada anteriormente, durante a orogenia Rondoniana-San Ignácio entre 1,47-1,35 Ga (Rizzotto *et al.*, 2014). Segundo Rizzotto (1999), pioneiro no estudo dessa região, as rochas metavulcanossedimentar que compõem o Cinturão Nova Brasilândia originaram-se a partir de um ciclo de Wilson, com abertura e fechamento de bacia do tipo *rift* intracontinental, que evoluiu para margem passiva e formação de proto-oceano. Na fase de inversão da bacia, as rochas do *rift* foram metamorfizadas em médio a alto grau (atingindo fácies granulito) durante a orogenia Nova Brasilândia, inicialmente atribuída ao intervalo de tempo entre 1180 e 1100 Ma.

1.2. Justificativas técnico-científicas

Diversos cenários tectônicos têm sido apresentados para explicar a formação do supercontinente Rodínia no final do Mesoproterozoico (Esteniano), envolvendo a colisão do proto-Cráton Amazônico com a parte leste da América do Norte representada pela Laurentia, envolvendo articulações locais com o Bloco Paraguá e o embasamento Arequipa-Antofala. Sadowski e Bettencourt (1996) apresentaram uma das primeiras tentativas de correlação global que sugerem a justaposição entre Amazônia e Laurentia, durante a amalgamação do Supercontinente Rodínia. Dados paleomagnéticos do sudoeste do Cráton Amazônico publicados anteriormente sugerem correspondências entre a deformação Grenvilliana e as do sudoeste do Cráton Amazônico, durante o Mesoproterozoico, conectando a Amazônia e a Laurentia (Rogers e Santosh, 2003; Tohver *et al.*, 2002, 2004, 2005a). Três importantes cinturões metassedimentares na borda sudoeste do Cráton Amazônico, denominados de Nova Brasilândia e Aguapeí expostos ao longo da fronteira entre Bolívia e Brasil, e Sunsás na Bolívia, são considerados áreas-chave para a compreensão dos eventos orogenéticos do Mesoproterozoico (Esteniano) porque preservam registros das atividades de aglutinação de massas cratônicas para formar o supercontinente Rodínia (Fig. 1). Portanto, são áreas geologicamente importantes para estabelecer correlações entre a Província Sunsás (ou Sunsás-Aguapeí), no Cráton Amazônico, e a Província Grenville, no sul da Laurentia (Fig. 1) (Rizzotto *et al.*, 1999; Litherland e Bloomfield, 1981; Litherland *et al.*, 1986; Boger *et al.*, 2005; Ruiz, 2005; Santos *et al.*, 2008, Teixeira *et al.*, 2010, Rizzotto *et al.*, 2014). Os cinturões Nova Brasilândia, Aguapeí e Sunsás foram, recentemente, considerados como pertencentes a uma única unidade geotectônica, denominada de Cinturão Móvel da Amazônia Ocidental, desenvolvida no final do Mesoproterozoico em ambiente de *rift* intracontinental (Rizzotto *et al.*, 2014).

No Cinturão Nova Brasilândia, área de interesse dessa pesquisa, estudos pioneiros realizados por Rizzotto (1999) e Rizzotto *et al.* (1999, 2001) na região de Nova Brasilândia, em Rondônia, permitiram a caracterização da Orogênese Nova Brasilândia, que corresponde a um Ciclo de Wilson desenvolvido aproximadamente entre 1,23 e 1,10 Ga, envolvendo abertura e fechamento de uma bacia denominada de *rift* Nova Brasilândia. Nesse *rift*, a sedimentação mesoproterozoica ocorreu no Esteniano e está representada na parte norte do cinturão pelas rochas da Formação Migrantinópolis (idades máximas de sedimentação em 1215 Ma, Rizzotto, 1999; 1211 Ma, Santos *et al.*, 2000; ou 1122 Ma, Rizzotto *et al.*, 2014), constituída por turbiditos de composição siliciclástica-carbonática. Na parte sul do Cinturão Nova Brasilândia, rochas metassedimentares em alto grau associam-se espacialmente com rochas plutônicas metamáficas, sendo este conjunto englobados na Formação Rio Branco, conforme a concepção original de Rizzotto (1999). Nesse contexto as unidades metassedimentares representam a sedimentação relacionada à fase *rift*

intracontinental, que evoluiu para margem passiva, e as rochas metamáficas associadas ao magmatismo gerado nas fases *rift-drift* a *drift,* com formação de proto-oceano (Rizzotto, 1999).
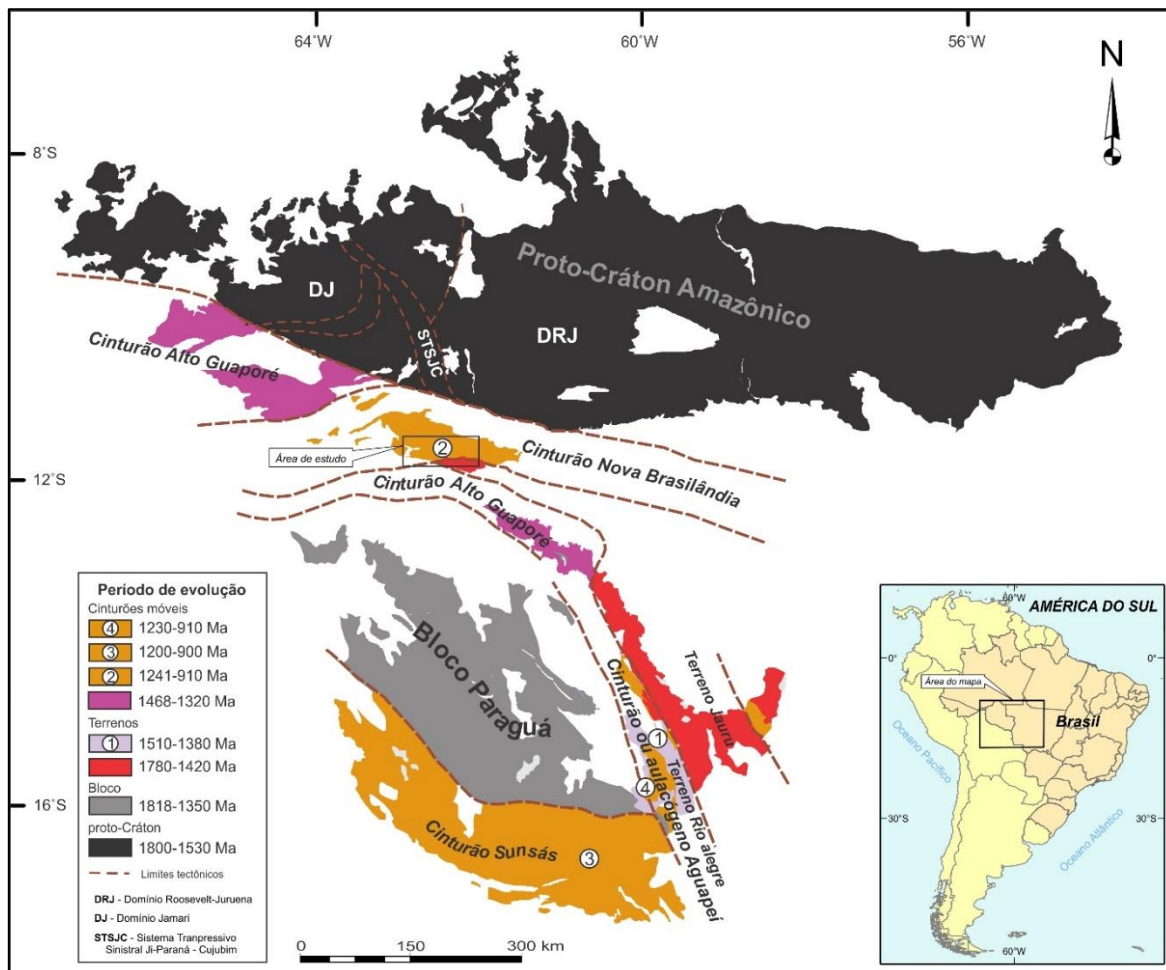
Fig. 1. *Cenário tectônico esquemático Mesoproterozoico do sudoeste do Cráton Amazônico com a localização da área estudada (adaptado de Ruiz, 2005; Bettencourt et al., 2010; Teixeira et al., 2010; D'Agrella-Filho et al., 2012; Rizzotto et al., 2014).*

Considerando cenário inicial de evolução em ambiente de *rift* intracontinental, duas relações geológica observadas no campo chamaram a atenção em relação a sequência evolutiva neste tipo de ambiente. A primeira se refere à existência de rochas máficas intrusivas (*stocks*, *sills* e enxames de diques) em rochas metavulcanossedimentares em alto grau metamórfico, sugerindo a existência de episódio de metamorfismo de alto grau (granulítico) anterior ao *emplacement* do magma máfico. A segunda envolve existência de estruturas deformacionais (dobras, cavalgamentos oblíquos, zonas de cisalhamento/milonitização e lineações de estiramento) mais jovens e que afetam todo o conjunto rochoso, associadas à transpressão e transcorrência tardia, descritas anteriormente por Rizzotto (1999) e Tohver *et al*. (2004, 2005a, 2005b). Essas relações apontam para uma história geológica bem mais complexa do que simplesmente abertura e fechamento de um *rift* intracontinental, onde a

3

associação de rochas metavulcanossedimentares em alto grau teve seus protólitos depositados e metamorfizados anterior ao *emplacement* do magmatismo máfico da Suíte Rio Branco. Essas relações espaciais entre as rochas sinalizavam para a possibilidade de geração em ambiente orogênico compressional, como forma de explicar a deformação (dobras, cavalgamentos, transpressão e transcorrência), metamorfismo de alto grau (granulítico) e o magmatismo (máfico-félsico), espacialmente associados.

Neste contexto, o desenvolvimento da pesquisa de doutorado foi pautado na obtenção de dados geológicos, geoquímicos, geocronológicos U-Pb e isotópicos Sr-Nd das rochas da parte sul do Cinturão Nova Brasilândia, com ênfase principal na definição das idades das rochas, afinidade química, fonte e ambiente tectônico do magmatismo máfico da Suíte Rio Branco, bem como no estabelecimento dos intervalos de tempo dos eventos geológico reconhecidos na área de estudo. As informações obtidas serviram de base científica para elucidar dúvidas e questionamentos relacionados ao ambiente tectônico do magmatismo máfico e sua formação em cenários continentais ou oceânicos, divergentes ou convergentes. Dessa forma, o objetivo de nossa pesquisa foi estabelecido em busca do aperfeiçoamento do modelo de *rift* intracontinental, anteriormente proposto, bem como apresentar um novo cenário tectônico alternativo, diferente do que já havia sido proposto para o Cinturão Nova Brasilândia. Por fim, contribuir de forma pontual, através de nossos estudos, para o aperfeiçoamento dos modelos globais de reconstituição dos eventos tectônicos que levaram a formação do supercontinente Rodínia.

1.3 Objetivos

O objetivo principal da pesquisa consistiu no estudo das rochas metamáficas da Suíte Rio Branco, aflorantes no Domínio Rio Branco, parte sul do Cinturão Nova Brasilândia, mediante a caracterização geológica, petrográfica, geoquímica (rocha total), geocronológica U-Pb em zircão (LA-ICP-MS) e estudos dos isótopos de Sm, Nd e Sr. O estudo foi direcionado para a definição da idade, afinidade química, fonte e ambiente tectônico gerador do magmatismo máfico da Suíte Rio Branco, bem como na cronologia dos eventos geológicos. Pretendeu-se, também, definir se essas rochas metamáficas faziam parte de intrusões acamadadas, arco de ilhas ou se pertenciam a uma sequência ofiolítica, possivelmente marcadora de importante zona de sutura na região. Esta pesquisa de doutorado buscou, com base na caracterização da afinidade química e nos *trends* petrogenéticos apresentados pelas rochas metamáficas da Suíte Rio branco nos diagramas de classificação da série (AFM), diagramas de correlação tipo Harker, diagramas ETR (normalizados), diagramas multi-elementos ou *spidergrams* (normalizados) e nos diagramas discriminantes tectônicos específicos (que utilizam elementos menores), complementados pelos estudos de Sr-Nd, identificar se o magmatismo máfico da Suíte Rio Branco estava relacionado à evolução de *rift* intracontinental com

possível geração de proto-oceano (tipo MORB), conforme proposto inicialmente por Rizzotto (1999), ou se parte do magmatismo máfico da Suíte Rio Branco poderia ser correlacionado a ambiente orogenético compressivo, envolvendo subducção intraoceânica e formação de arco e bacias. Este estudo objetivou, também, a caracterização da natureza isotópica e geoquímica das fontes mantélicas com base na determinação das razões isotópicas de Sr e Nd e na análise de dados geoquímicos de elementos traços considerados imóveis. Finalizando, teve o objetivo de fornecer novos subsídios à evolução geodinâmica do Mesoproterozoico do sudoeste do Cráton Amazônico, em Rondônia, com base na definição do ambiente tectônico de geração do magmatismo máfico Suíte Rio Branco e seu contexto geotectônico regional na evolução do Cinturão Nova Brasilândia e do orógeno Sunsás.

1.4 Localização e acesso

Este estudo foi desenvolvido na porção sudoeste do Cráton Amazônico, Rondônia, mais especificamente na parte sul do Cinturão Nova Brasilândia, denominada de Domínio Rio Branco. A área estudada localiza-se mais especificamente no sudeste de Rondônia, distante aproximadamente 525 km por via rodoviária da capital Porto Velho. Corresponde a polígono retangular com vértices de coordenadas geográficas S11º48'55"/W61º41'25", S12º02'51"/W61º41'25", S12º02'51"/W62º26'55" e S11º48'55"/W62º26'55", medindo 26 km de largura e 82 km de comprimento, abrangendo área de aproximadamente 2132 km^2. A área estudada abrange partes dos municípios de Alta Floresta d´Oeste e Santa Luzia d´Oeste (Fig. 2). O acesso à área pode ser realizado a partir da cidade de Porto Velho, pela rodovia federal BR-364, até o entroncamento com a rodovia estadual RO-479, seguindo nessa rodovia estadual até Santa Luzia d´Oeste e em seguida em direção a Alta Floresta d´Oeste. Além desse principal acesso, outras rotas podem ser estabelecidas para acessar a área de pesquisa. O deslocamento no interior da área pode ser realizado por meio de estradas vicinais, denominadas de linhas de colonização, trafegáveis de forma satisfatória durante a época do verão amazônico. Alta Floresta d´Oeste é cidade que pode ser utilizada como base de apoio para as atividades de campo.

1.5 Metodologia e materiais

Para alcançar os objetivos proposto nesta pesquisa foram utilizadas técnicas e métodos de investigação, descritos a seguir:

1.5.1 Análise bibliográfica e aquisição de dados

Consistiu na análise e síntese de materiais bibliográfico de cunho científico, publicados anteriormente, que constituem acervo de informações geológicas das regiões de Rondônia, Mato Grosso e Bolívia. Foram consultadas diversas publicações científicas específicas e voltadas para a temática da pesquisa, métodos analíticos aplicados e problemas geológicos semelhantes. As informações analisadas que serviram de suporte científico a esta pesquisa estão contidas principalmente em livros, revistas, periódicos nacionais e internacionais, dissertações de mestrado e teses de doutorado.
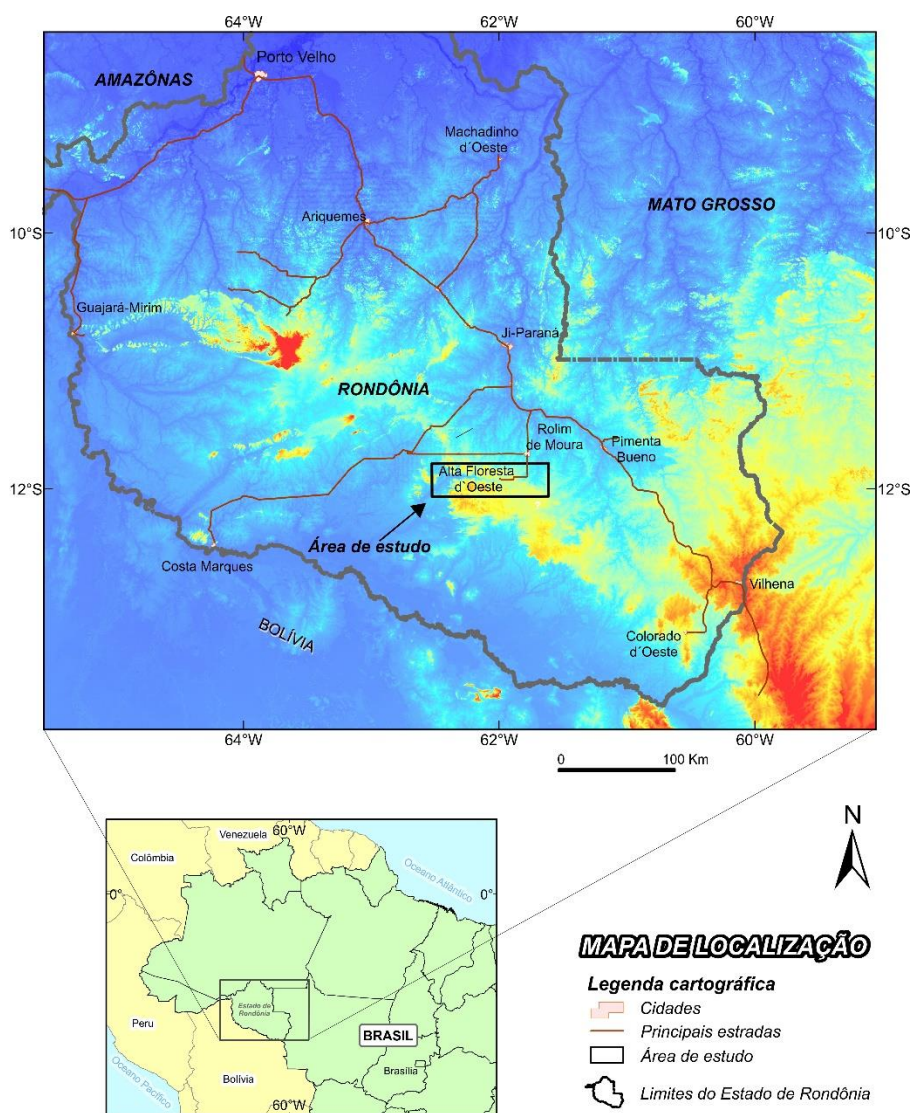
Fig. 2. *Mapa de localização da área de estudo (imagem de fundo corresponde ao modelo digital SRTM).*

1.5.2 Atividades de campo e elaboração do mapa geológico

Para caracterizar as rochas e compreender as relações geológicas entre as unidades litoestratigráficas da área de pesquisa, foram realizados trabalhos de campo mediante descrição de afloramentos, coleta de amostras de rocha para análises petrográficas, geoquímicas e isotópicas. O

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mapa geológico foi elaborado a partir da compilação de informações geológicas existentes e disponibilizadas pela CPRM-Serviço Geológico do Brasil, obtenção de novas informações de campo, integração geológico-geofísico (aeromagnetometria e aerogamaespectrometria), acrescida de informações petrológicas e geocronológicas. O mapa geológico em formato digital (escala 1:100.00), inserido como figuras nos artigos e no texto da tese, foi elaborado mediante o emprego do *software* de geoprocessamento ArcGIS, ajustado as bases cartográfica do IBGE (escala 1:100.000), as imagens do SRTM-*Shuttle Radar Topographic Mission* e apresentado em valores UTM, *datum* SIRGAS 2000.

1.5.3 Geoquímica em rocha total (elementos maiores e traços)

Os estudos geoquímicos em rocha total envolveram coleta, descrição petrográfica, seleção e análise de 34 amostras de rochas metamáficas provenientes do Domínio Rio Branco, parte sul do Cinturão Nova Brasilândia. A geoquímica de rocha total foi realizada na ALS Laboratório, conforme certificado BH17273983. Os métodos analíticos incluem ICP-AES e ICP-MS para os principais óxidos e elementos traços. O trabalho analítico solicitou um pacote de preparação das amostras (PREP-31), com códigos da ALS de preparação CRU-31 (*fine crushing* − 70% < 2 mm), LOG-22 (*sample login – red w/o BarCode*), PUL-31 (*pulverize split to* 85% < 75 µm), SPL-21 (*split sample-riffle splitter*) and WEI-21 (*received sample weight*). O pacote analítico solicitado foram ME-4ACD81 (*base metals by 4-acid dig., instrument ICP-AES*) para análises dos elementos Ag, As, Cd, Co, Cu, Li, Mo, Ni, Pb, Sc, Tl e Zn, ME-ICP06 (*whole rock package-ICP-AES*) para a análise dos óxidos Al_2O_3, BaO, CaO, Cr_2O_3, Fe_2O_3, K_2O, MgO, MnO, Na_2O, P_2O_5, SiO_2, SrO e TiO_2, o pacote ME-MS81 (*lithium borate fusion ICP-MS*) para a análise dos elementos Ba, Ce, Cr, Cs, Dy, Er, Eu, Ga, Gd, Hf, Ho, La, Lu, Nb, Nd, Pr, Rb, Sm, Sn, Sr, Ta, Tb, Th, Tm, U, V, W, Y, Yb e Zr, o pacote OA-GRA05 (*loss on ignition at 1000ºC, instrument ICP-MS*) para cálculo do LOI e o pacote TOT-ICP06/ME-MS81D (*total calculation for ICP06, instrument ICP-AES*) para o cálculo total de fechamento da amostra. Descrições detalhadas dos métodos e dos pacotes ALS de análises utilizados podem ser consultados ou obtidos na *home page* da ALS (www.alsglobal.com).

Para análise dos elementos maiores procedeu-se com os recálculos dos valores obtidos para base anidra, em seguida a utilização dos diagramas de classificação usando-se os gráficos AFM (Irvine e Baragar, 1971) e TAS (Cox *et al.*, 1979). O índice de diferenciação escolhido, isto é, os óxidos e elementos considerados imóveis que mais variam na série ou suíte, foi o MgO e Zr. Para elaboração dos diagramas discriminantes das séries, foram utilizados os diagramas de ETR´s normalizados ao Condrito (Boynton, 1984) e diagramas de multi-elementos (*spidergrams*) normalizados ao Manto Primitivo (McDonough e Sun, 1995). Para a identificação do ambiente tectônico da Suíte Rio Branco, foram utilizados diagramas discriminantes tectônicos aplicados

especificamente a rochas máficas. Os *trends* petrogenéticos obtidos foram comparados com os padrões pré-estabelecidos em cada diagrama utilizado, conforme a concepção original do autor. Foram também comparados com outros *trends* petrogenéticos obtidos em outras regiões, bem mais estudadas, e com assinaturas geoquímicas semelhantes, tanto aquelas relacionadas a ambientes tectônicos antigos, como também modernos do Fanerozoico (Pearce, 1982, 2008; Pearce *et al.*, 1984; Shervais, 1982; Wood, 1980; Cabanis e Lecolle, 1989; Dilek e Furnes, 2011; Saccani *et al.*, 2013, 2014; Dey *et al.*; 2018; Chen *et al.*, 2014; Xia e Li, 2019).

A finalidade do uso desses diagramas de elementos maiores e traços foi estabelecer os *trends* petrogenéticos das rochas metamáficas da Suíte Rio Branco e, dessa forma, estabelecer afinidades geoquímicas que possam ser correlacionadas com basaltos alcalinos ou subalcalinos/toleíticos, bem como, estabelecer *trends* petrogenéticos que possam indicar o ambiente tectônico em que as rochas foram geradas, tais como basaltos de dorsais meso-oceânicas (MORBs), basaltos de ilhas oceânicas (IOBs), basaltos de grandes províncias ígneas (LIPs, p. ex. basaltos de platôs oceânicos-OFBs, basaltos de platôs continentais-CFBs, basaltos de *rift* intracontinental IRBs) ou basaltos associados à subducção (toleitos de arco de ilhas-IAT, basaltos de bacias de *back-arc*, basaltos de margens continentais ativas). Os resultados das análises químicas, diagramas elaborados, discussões e intepretações dos dados encontram-se em detalhe no artigo constante no Capítulo 4.

1.5.4 Geocronologia U-Pb em zircão (LA-ICP-MS)

O método U-Pb através da técnica analítica de "ablação" a laser associada com um espectrômetro de massas com plasma indutivamente acoplado, conhecida pela sigla LA-ICP-MS, é indicado para todos os tipos de rochas (magmáticas félsicas ou máficas, metamórficas e sedimentares), inclusive as polideformadas. Consiste na análise pontual (*in situ*), tamanho do *spot* mínimo de cerca de 25 μm, direcionada para áreas específicas dos grãos ou cristais minerais de interesse, tais como zircão, monazita, rutilo, titanita, perovskita, badeleíta, xenotima, e outros minerais ricos em U e pobres em Pb. Neste método, a informação obtida se refere as idades de cristalização magmática, metamorfismo e migmatização, além de informações isotópicas da derivação mantélica e fontes.

Nesse estudo isotópico o procedimento adotado envolve, inicialmente, descrição detalhada de afloramentos e amostragem de materiais geológicos direcionadas para análise geocronológica U-Pb, levando-se em consideração a identificação do problema geológico a ser solucionado. Considera-se, também, as relações geológicas de campo e o mapa geológico existente, como orientativo para a escolha do material e local mais adequado para coleta das amostras, bem como para espacialização dos pontos coletados em relação a área de estudo. Portanto, coletou-se sete amostras de rocha do Domínio Rio Branco, obtendo-se em torno 8 kg de rocha metassedimentar ou

metafélsica e 20 a 30 kg de rocha metamáfica, por amostra. As amostras foram preparadas nos laboratórios da CPRM-Serviço Geológico do Brasil em Porto Velho e Belém, conforme os procedimentos laboratoriais de preparação de amostras descritos por Castro *et al.* (2012). Para identificar estruturas internas do mineral de interesse (no caso, zircão), os *mounts* foram imageados por elétrons retroespalhados (BSE) no microscópio eletrônico de varredura (MEV) do laboratório do Centro de Geocronologia do Instituto de Geociências da Universidade de Brasília (Geocron-IG/UnB). Os dados isotópicos de zircão U-Pb (LA-ICP-MS) foram obtidos no mesmo laboratório e seguiram o procedimento analítico descrito por Bühn *et al.* (2009). Antes das análises no LA-ICP-MS, os *mounts* foram limpos por lavagem com HNO_3 diluído (2%). Uma vez totalmente secas, as amostras foram montadas junto com o zircão padrão GJ1 (Jackson *et al.*, 2004) em uma célula especialmente adaptada para ser utilizada dentro do New Wave UP213 Nd: YAG (213 nm) laser, que se encontra concectado ao Thermo Finnigan Neptune Multicoletor ICP-MS. O Hélio (H) foi utilizado como gás de arraste, que foi misturado com Argônio (Ar) antes de entrar no ICP-MS (Plasma por Acoplamento Indutivo com Espectrômetro de Massa). O laser foi operado a uma frequência de 10 Hz. Os isótopos de Pb 204 e 207 foram coletados com contadores de íons e ^{238}U e ^{206}Pb foram analisados em um copo de Faraday. O conteúdo de ^{202}Hg foi monitorado em um contador de íons para correção da interferência isobárica entre ^{204}Hg e ^{204}Pb. Os sinais durante a "ablação" a laser foram obtidos em 40 ciclos de 1 segundo cada e para avaliação dos dados, apenas intervalos coerentes de resposta do sinal foram considerados. A redução dos dados foi realizada em planilha do Excel desenvolvida pelos técnicos da Geocron-IG/UnB, que considera valores em branco, composição dos padrões de zircão e propagação de erros. A intensidade do sinal de ^{204}Pb foi calculada usando uma razão natural de $^{202}Hg/^{204}Hg$ de 4,346. A correção de Pb comum foi aplicada para grãos de zircão com $^{206}Pb/^{204}Pb$ menor que 1000, aplicando uma composição de chumbo comum seguindo o modelo de Stacey e Kramers (1975). A plotagem dos dados de U-Pb foi realizada por ISOPLOT v. 4.15 (Ludwig, 2003). Erros para razões isotópicas são apresentados no nível 1σ. Para o cálculo dos diagramas integrados por idade, foram considerados apenas grãos de zircão de concordância > 90% paraderivadas e cristais de zircão > 95% de concordância para rochas ortoderivadas, principalmente para os cálculos das idades mais precisas (idades concórdia).

O sistema U-Th-Pb em zircão (LA-ICP-MS) foi utilizado no estudo das rochas da parte sul do Cinturão Nova Brasilância na obtenção das idades de cristalização magmática e de metamorfismo das rochas metaígneas máficas e félsicas da Suíte Rio Branco e idades máximas de sedimentação das rochas metassedimentares em alto-grau da Formação Rio Branco. A partir da obtenção das idades pico, concórdia e de intercepto superior, foi definida idades das rochas e, consequentemente, a definição dos intervalos dos episódios magmáticos, deformação, metamorfismo e de sedimentação durante as fases pré, sin e pós-orogênica da orogenia Nova

Brasilândia. Os resultados das novas análises geocronológicas U-Pb (LA-ICP-MS) em zircão, bem como discussões e interpretações, constam em detalhes nos artigos da tese apresentados nos capítulos 3 e 4.

1.5.5 Estudos isotópicos Sm-Nd e Sr-Sr em rocha total

O Samário (Sm) e o Neodímio (Nd) são elementos terras raras (ETR) que ocorrem em pequenas quantidades em diversos minerias constituintes de rocha, tais como silicatos, fosfatos e carbonatos, enquanto que o Estrôncio (Sr) é um metal alcalino-terroso (do grupo 2 ou IIA) da Classificação Periódica dos Elementos, abundante na natureza na forma de sulfatos e carbonatos, sendo encontrado em vários tipos de rocha. Esses elementos, em função de suas propriedades químicas e isotópicas, apresentam informações sobre a evolução da Terra e do sistema solar, podendo ser utilizados como ferramento para solucionar problemas geológicos (Sato e Tassinari, 1997; Gioia e Pimentel, 2000; Geraldes, 2010) . O Sm e o Nd são elementos litófilos fortemente enriquecidos na crosta continental e na crosta oceânica da ordem de 10 a 100 vezes mais do que em relação aos reservatórios mantélicos (Hermann, 1970). Sm e Nd são elementos terras raras (ETR) com valência +3 e raios iônicos similares, portanto, apresentam comportamento geoquímico equivalentes (Wassemburg *et al.*, 1981). São elementos químicos considerados incompatíveis durante a cristalização magmática, sendo apenas aceitos nos sítios cristalográficos das fases residuais, por isso, são muito utilizados em estudos de processos ígneos responsáveis pelas variações composicionais dos diversos reservatórios terrestres.

Para o estudo isotópico Sm-Nd e determinação da razão Sr-Sr (^{87}Sr/^{86}Sr) utilizamos o método descrito por Gioia e Pimentel (2000). As análises foram realizadas no Laboratório de Geocronologia da Universidade de Brasília. Os procedimentos químicos de preparação das amostras para as análises isotópicas foram realizados em salas limpas equipadas com capelas de fluxo laminar, destiladores em quartzo e em PTFE (tipo 2 garrafas), colunas de troca iônica em PTFE e quartzo, *clean boxes,* chapas quentes, purificadores de água do tipo Nanopure e Milli-Q e micro-balanças analíticas. Os brancos de procedimento para Sr e Nd foram menores que 100 pg. No laboratório, pós de rocha total (aprox. 50 mg) foram misturados com uma solução de ^{149}Sm-^{150}Nd e dissolvidos em cápsulas de Savillex. A extração de Sm, Nd e Sr de amostras de rocha total seguiu as técnicas convencionais de troca catiônica, utilizando colunas de Teflon contendo resina LN-Spec (HDEHP - ácido dietil-hexil fosfórico suportado em pó de PTFE). As amostras de Sm e Nd foram carregadas em filamentos de re-evaporação e em conjuntos de filamentos duplos. As medições isotópicas de Sr-Nd foram realizadas em espectrômetro de massas de multi-coletor Finnigan MAT-262, equipamento termo-iônico dotado de sete coletores tipo copo Faraday móveis e uma multiplicadora de elétrons central.

As incertezas para as proporções Sm/Nd e ^{143}Nd/^{144}Nd são melhores que + 0,5% (2σ) e + 0,005% (2σ), respectivamente, com base em análises repetidas dos padrões internacionais de rocha BHVO-1 e BCR-1. As razões ^{143}Nd/^{144}Nd foram normalizadas para ^{146}Nd/^{144}Nd de 0,7219 e a constante de decaimento utilizada foi 6,54 x 10^{-12} a $^{-1}$. Os valores de TDM foram calculados usando o modelo de De Paolo (1981). O cálculo das idades modelo TDM foram realizadas medianto o uso do *sftware* ISOPLOT 4.15 (Ludwig, 2008). Os resultados das análises constam em tabelas inseridas no artigo constante no capítulo 4 dessa tese, com suas respectivas interpretações geológicas.

Na metodologia Sm-Nd, o estudo se baseia no decaimento radioativo do ^{147}Sm para ^{143}Nd em taxa muito baixa, com meia-vida do ^{147}Sm póximo de 106 Ga, sendo equivalente a 23 vezes a idade da Terra (Anders e Ebihara, 1982). O método Sm-Nd foi aplicado no estudo de idades modelo de manto empobrecido (TDM) e de fonte (parâmetros petrogenéticos), a partir da análise das razões iniciais ^{143}Nd/^{144}Nd como indicadoras da origem crustal ou mantélica das rochas metamáficas da Suíte Rio Branco, mediante o uso do parâmetro εNd (epsilon Nd) comparando as diferentes razões das rochas analisadas. Neste caso, utilizamos a notação matemática εNd={[(^{143}Nd/^{144}Nd)^0/(^{143}Nd/^{144}Nd)$_{CHUR}$]-1}x10^4, sendo (^{143}Nd/^{144}Nd)$_{CHUR}$ correspondente ao valor da razão ^{143}Nd/^{144}Nd em meteoritos condríticos para a idade considerada e CHUR (reservatório condrítico uniforme). Neste caso, assumindo que a Terra foi formada por materiais semelhantes aos dos meteroritos condríticos, valores de εNd próximos de 0 (zero) teriam sido derivados de manto primitivo, entretanto, como a crosta continental se desenvolveu a partir do manto, por processos de cristalização, fusão, retrabalhamento e diferenciação, e o Nd é mais incompatível que o Sm, por ter raio iônico um pouco maior, com o decorrer do tempo o manto adquire razões Sm/Nd maiores que o CHUR, sendo este chamado de manto empobrecido, devido à perda de elementos litófilos, implicando em valores de εNd positivos (+), comuns em rochas derivadas de manto empobrecido (fonte mantélica). Por outro lado, rochas com εNd com valores negativos (-), razões Sm/Nd menores que o CHUR, são ditas crustais (fontes crustais), oriundas de magmas formados por fusão parcial na crosta continental.

As idades modelos T$_{DM}$ (DM=Manto Empobrecido) das rochas metamáficas da Formação Rio Branco foram utilizadas associadas às idades "t" oriundas das idades de cristalização U-Pb obitidas, com o objetivo de definir rochas ou protólitos derivados do manto (idades TDM próximas das idades U-Pb cristalização), definindo se são rochas juvenis, e associá-las a eventos de formação crustal. Alternativamente, se são rochas de fontes crustais ou de fontes mistas, em que as idades modelo são um pouco mais antigas do que as idades de cristalização U-Pb (t), podendo em alguns casos não ter a componente juvenil ou em outros sugerir superposição de eventos magmáticos envolvendo fusão parcial.

Estrôncio (Sr) é um metal alcalino terroso pertencente ao Grupo 2 da Tabela Periódica. Possui número atômico 38, portanto, forma cátions com valência $^{+2}$ e menos móveis do que os metais alcalinos (Faure e Powell, 1972; Faure, 1986). O que regula a ocorrência de Sr na natureza é a intensidade com a qual acontece a substituição de Ca por Sr. Portanto, Sr^{+2} (raio iônico de 1.13 Å) pode substituir Ca^{+2} (raio iônico de 0.99 Å) em diversos minerais, tais como apatita, calcita, clinopiroxênio, plagioclásio e titanita, sendo que a quantidade de Sr nos minerais vai ocorrer em função da coordenação de sítios (8 ou 6). Eventualmente, Sr^{+2} pode ser capturado pela estrutura de feldspatos potássicos no lugar do K^+, devido à razão carga/raio, ou também, pode formar seus próprios minerais, tais como celestita ($SrSO_4$) e estroncianita ($SrCO_3$). O Sr tem quatro isótopos naturais, ^{84}Sr, ^{86}Sr, ^{87}Sr e ^{88}Sr, todos estáveis. Contudo, a composição isotópica do Sr é bastante variável e dependente da razão Rb/Sr, visto que ^{87}Sr é produzido a partir do decaimento radioativo de ^{87}Rb (constante de decaimento de ^{87}Rb = 1,42 x 10-11 y-1). O valor de $^{87}Sr/^{86}Sr$ do magma a partir do qual uma rocha ou mineral se cristalizaram depende não apenas do decaimento de ^{87}Rb para ^{87}Sr, mas também da razão Rb/Sr do sistema, que irá variar de acordo com o comportamento geoquímico destes elementos (Faure e Powell, 1972; Faure, 1986; Oliveira, 2015). Atualmente, considera-se que os isótopos de Sr, bem como de outros elementos pesados (p.ex., Nd), não são fracionados durante os processos de fusão parcial em equilíbrio ou cristalização fracionada. Desta maneira, considera-se que a composição isotópica do magma e das rochas cristalizadas a partir dele é igual à composição isotópica da área fonte. Logo, é possível utilizar a razão inicial das rochas ou minerais para identificar a origem dos diversos tipos de magma (Faure e Powell, 1972; Faure, 1986; Allègre e Othman, 2008).

1.6 Estrutura organizacional da Tese

Esta tese de doutorado está estruturada em cinco capítulos (introdução, contexto geológico regional, artigo científico 1, artigo científico 2 e discussões e conclusões) e direcionada para apresentação na forma de artigos destinados à publicação em periódicos científicos internacionais e especializados na linha de pesquisa que foi desenvolvida. Os dois artigos abordam principalmente aspectos relacionados a geologia, geocronologia U-Pb em zircão (LA-ICP-MS), geoquímica (rocha total) e estudos de isótopos de Sr-Nd (rocha total), conforme os objetivos estabelecidos visando responder questões relacionadas à geologia e evolução tectônica da região. O detalhamento de cada tópico proposto com as respectivas metodologias utilizadas, resultados obtidos e interpretações, encontram-se presentes de forma detalhada nos artigos e de forma sucinta no volume da tese.

2. Contexto geológico regional

2.1 Sudoeste do Cráton Amazônico em Rondônia

O Cráton Amazônico, uma das principais entidades geotectônicas pré-cambrianas da América do Sul, encontra-se exposto predominantemente em território brasileiro, mas estende-se para Guiana, Suriname, Venezuela, Colômbia e Bolívia. Corresponde a uma das maiores áreas cratônicas do mundo e com extensão de aproximadamente 5.600.000 km², sendo que em território brasileiro sua área é de aproximadamente 4.400.000 km². O Cráton Amazônico é limitado tectonicamente a leste pelo Cinturão Araguaia e a sul e sudeste pelo Cinturão Paraguai. Grande parte do Cráton Amazônico é coberto por sedimentos fanerozoicos, sendo a leste os da Bacia do Parnaíba, a sul das bacias do Xingu e Alto Tapajós, a sudoeste da Bacia dos Parecis, a oeste da Bacia do Solimões, a norte da Bacia do Tacutu e na porção central do cráton por sedimentos da Bacia do Amazonas. O Cráton Amazônico se estende sob os depósitos cenozoicos até a Pré-Cordilheira Andina, devido à presença de rochas com idades mesoproterozoicas na porção mais oriental do Cinturão Andino (Cordani *et al.*, 2000; Kroonenberg, 1982; Priem *et al.*, 1989).

O Cráton Amazônico foi inicialmente subdividido em dois escudos denominados de Escudo Brasil Central, a sul, e Escudo das Guianas, a norte, separados pelas extensas áreas sedimentares depositadas sobre a sinéclise do Amazonas. Amaral (1974) subdividiu o cráton em três províncias geocronológicas: Amazônia Oriental, Amazônia Central e Amazônia Ocidental. A partir do modelo proposto por Amaral (1974), diversos modelos evolutivos foram propostos com o intuito de aperfeiçoar e adaptar os modelos anteriormente propostos, todos fundamentados em dados geocronológicos (p. ex. Cordani *et al.*, 1979; Teixeira *et al.*, 1989). Hasui *et al.* (1984) e Costa e Hasui (1997) propuseram modelos alternativos com base em dados geofísicos e estruturas geológicas, definindo doze blocos ou placas de idades arqueanas a proterozoicas, separados por cinturões móveis, nos quais o processo tectônico gerador predominante envolveu a colisão de massas crustais, com posteriores reativações dos cinturões móveis durante eventos tectônicos mais jovens.

Cordani *et al*. (1979) propuseram modificações na nomenclatura das províncias geocronológicas mediante a introdução da Província Rondoniana. A Província Amazônia Central passou a ser denominada Província Maroni-Itacaiúnas (2,1 Ga a 1,8 Ga); a Província Amazônia Ocidental (>2,1 Ga) teve sua nomenclatura mantida; a Província Amazônia Ocidental foi subdividida nas províncias Rio Negro-Juruena (1,7 Ga a 1,45 Ga) e Rondoniana (1,4 Ga a 1,1 Ga). Teixeira *et al*. (1989) introduziram modificações no modelo de Cordani *et al*. (1979), com base em um vasto acervo de idades Rb-Sr e K-Ar, propondo apenas a caracterização da Província Amazônia

Central como uma província, propriamente dita, e as demais como faixas móveis. Teixeira *et al.* (1989) propuseram o desmembramento de parte da Província Maroni-Itacaiúnas e o agregaram à Província Amazônia Central.

Tassinari e Macambira (1999) com base em novos dados geocronológicos, em especial Sm-Nd, propuseram para a região sudoeste do Cráton Amazônico a subdivisão das províncias Rio Negro-Juruena (1,80-1,55 Ga), Rondoniana-San Ignácio (1,45-1,30 Ga) e Sunsás (1,25-1,00 Ga) (Fig. 3). Santos *et al.* (1999, 2000) e Santos (2004) reinterpretaram a configuração das províncias geocronológicas, com base em dados U-Pb e Sm-Nd, e individualizaram as províncias Rio Negro e Rondônia-Juruena, anteriormente definidas como uma única província denominada de Rio Negro-Juruena e também estenderam os limites da Província Sunsás mais para leste, avançando sobre o território brasileiro, englobando a Província Rondoniana-San Ignácio na Província Sunsás (1,25-1,00 Ga) (Fig. 3).
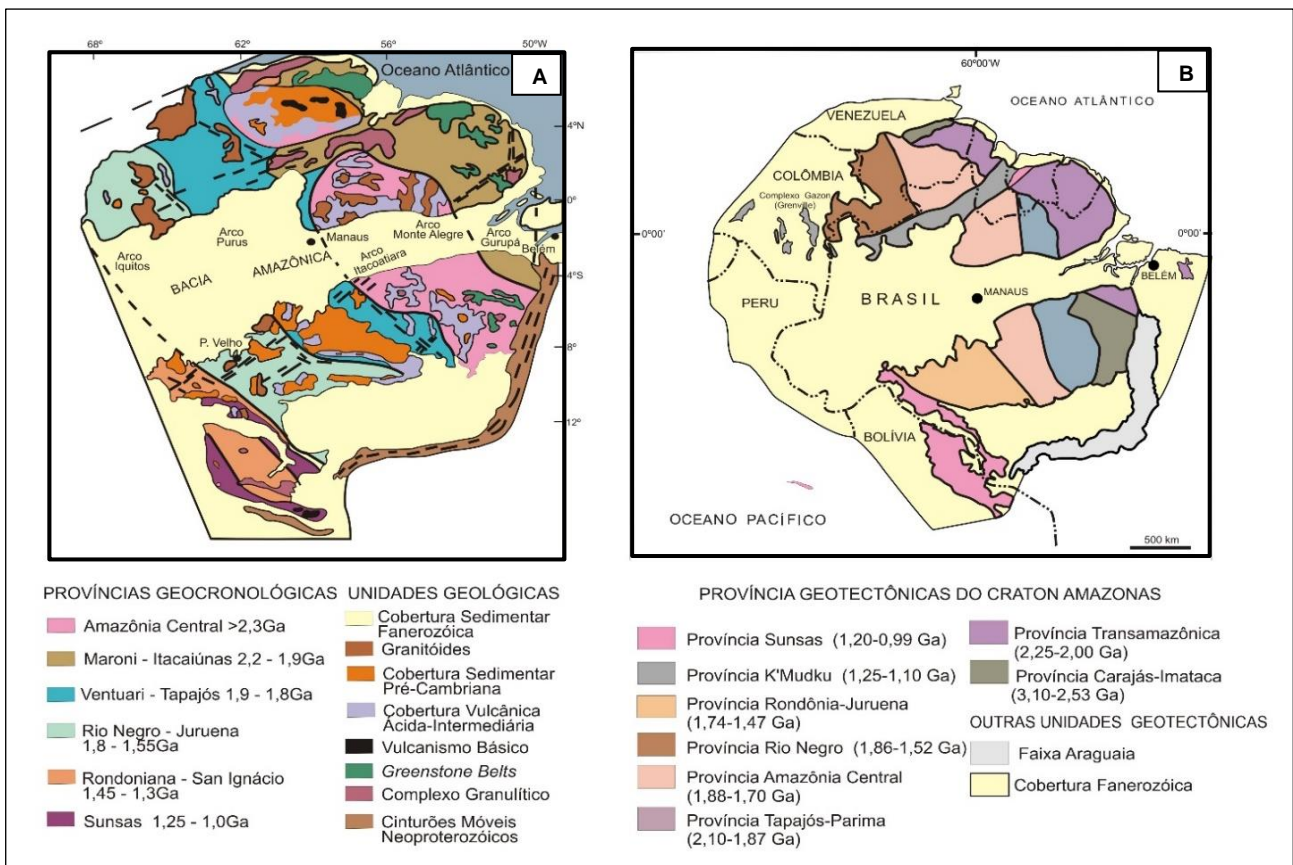
Fig. 3. *Províncias geocronológicas do Cráton Amazônico, segundo Tassinari e Macambira (1999) em (A) e Santos et al. (2003) em (B).*

A estruturação do setor sudoeste do Cráton Amazônico e adjacências também foi considerada em diversos trabalhos de síntese e de revisão regional (Pinto Filho *et al.*, 1977; Litherland e Bloomfield, 1981; Litherland *et al.*, 1986; Casquet *et al.*, 2006, 2008; Scandolara *et al.*, 1999; Loewy *et al.*, 2003, 2004) e em trabalhos específicos (Rizzotto, 1999; Rizzotto *et al.*, 1999; Rizzotto *et al.*, 2001; Rizzotto *et al.,* 2002; Ruiz, 2005; Ruiz *et al.*, 2007; Scandolara, 2006; Teixeira *et al.*, 2010), todos com ênfase na litoestratigráfica e evolução crustal. Outros trabalhos regionais discutiram a importância das rochas mesoproterozoicas da América do Sul na formação do supercontinente Rodinia e relacionaram parte delas à evolução tectônica do orógeno Sunsás, como produto da colisão entre o Cráton Amazônico e a borda leste e sudeste da Laurentia (Sadowski e Bettencourt, 1996; Geraldes *et al.,* 2001; Kroner e Cordani, 2003, Tohver *et al.*, 2002; Santos *et al.*, 2002; Tohver *et al.*, 2005a; Tohver *et al.*, 2005b; Li *et al.*, 2008; Bettencourt *et al.*, 2010; Rizzotto *et al.*, 2013; Rizzotto *et al.*, 2014; Cawood e Pisarevsky, 2017). Destes trabalhos citados, o arcabouço estrutural proposto por Tohver *et al.* (2005b) sugere a existência de uma zona de sutura oculta (*cryptic suture zone*) ao longo da qual se desenvolveu o Cinturão Nova Brasilândia, estando este relacionado a colisão do Cráton Amazônico com a Laurentia em aproximadamente 1,2-1,0 Ga. Alternativamente, Scandolara (2006) apresentou proposta de compartimentação tectono-estratigráfica para o sudoeste do Cráton Amazônico, em Rondônia, baseada na subdivisão terrenos, definidos descritivamente como entidades geológicas de extensão regional com características petrológicas, estruturais, geoquímicas, geofísicas e geocronológicas próprias, limitados por sistemas de falhas ou zonas de cisalhamento de grande expressão regional. Neste contexto individualizaram o Terreno Jamari, Terreno Roosevelt e o Terreno Nova Brasilândia.

Adotando-se as subdivisões de Províncias Geocronológicas de Tassinari e Macambira (1999), a região sudoeste do Cráton Amazônico em Rondônia abrange parte das províncias Rio Negro-Juruena, Rondoniana-San Ignácio e Sunsás, descritas nas seções 2.1.1, 2.1.2 e 2.1.3. A área de pesquisa deste doutorado ocupa parte da Província Sunsás (Fig. 3).

2.1.1 Província Rio Negro-Juruena

Na proposta de Tassinari e Macambira (1999), a Província Rio Negro-Juruena (1,80-1,55 Ga) estende-se desde o extremo oeste de Rondônia até a bacia hidrográfica do alto curso do rio Teles Pires, no Mato Grosso, a leste. A parte abrangida pelos estados de Rondônia e noroeste de Mato Grosso foi subdividida em dois terrenos, denominados de Roosevelt e Jamari (Scandolara, 2006).

O Terreno Roosevelt, também conhecido como Terreno Roosevelt-Juruena (Scandolara, 2006; Quadros et al., 2011), abrange o extremo-nordeste do estado de Rondônia e o noroeste do estado de Mato Grosso e é constituído nestas regiões pelas unidades Suíte Intrusiva São Romão e Grupo Roosevelt. A Suíte Intrusiva São Romão (aproximadamente 1770 Ma) reúne vários corpos

de granitos metaluminosos a peraluminosos, cálcio-alcalinos de alto potássio, tardi- a pós-colisionais, representados por monzogranitos finos, subordinadamente magnetita microgranitos e granodioritos, com variáveis intensidades de deformação e metamorfismo. O Grupo Roosevelt (aproximadamente 1740 Ma) que é composto por rochas metavulcanossedimentares compreendendo dacitos e riolitos com intercalações de basaltos e tufos, ignimbritos e conglomerados vulcanoclásticos subordinados, sotopostos por meta-argilitos e metassiltitos interdigitados com *metacherts*, formações ferríferas e metatufos (Santos *et al*., 2000; Lacerda Filho *et al*., 2004; Quadros e Rizzotto, 2007).

O Terreno Jamari ocupa a porção centro-ocidental do Estado de Rondônia, sendo constituído, dominantemente, por rochas ortoderivadas e, subordinadamente, paraderivadas em alto grau metamórfico, rochas metavulcanossedimentares e metassedimentares em médio a baixo grau metamórfico, localmente na fácies xisto-verde, além de diversos metagranitos foliados a gnaissificados. No contexto do embasamento ortoderivado do Terreno Jamari, ocorre o Complexo Jamari (aproximadamente 1750 a 1730 Ma), denominação dada por Isotta *et al*., (1978), composto por ortognaisses tonalíticos, enderbíticos e quartzo dioríticos, com intercalações subordinadas de lentes de gnaisses calciossilicáticos e anfibolitos, exibindo intensidades variáveis de migmatização e milonitização, em geral metamorfizados em condições P e T condizentes com a fácies anfibolito superior a granulito. As idades U-Pb do Complexo Jamari foram obtidas em ortognaisses tonalíticos, quartzo dioríticos e enderbíticos em 1750 ± 24 Ma, 1761 ± 3 Ma (MSWD = 0.43) e 1730 ± 22 Ma, respectivamente (Payolla *et al*., 2002; Santos *et al*., 2002; Scandolara, 2006). A deformação e o metamorfismo superimpostos em todas as rochas desse complexo são destacados por sobrecrescimentos de cristais de zircão, os quais forneceram idades de recristalização em torno de 1,33 Ga (Santos *et al*., 2003; Scandolara, 2006). As paraderivadas em alto grau aflorantes no Terreno Jamari, nas porções central e norte-nordeste de Rondônia, foram englobadas posteriormente no Complexo Quatro Cachoeiras, designação dada por Rizzotto *et al*. (2004), constituído por alternâncias de gnaisses paraderivados de alto grau, extensão e espessura variáveis, aflorantes na região a norte de Jaru e Ouro Preto do Oeste, ao longo do igarapé Quatro Cachoeiras, e entre os municípios de Vale do Anari e Machadinho d'Oeste. Essa unidade litoestratigráfica é constituída por biotita-cordierita-granada gnaisses, gnaisses calciossilicáticos, sillimanita-granada gnaisses, biotita-quartzo gnaisses e gnaisses quartzo-feldspáticos finos, todos com intensidade variável de deformação e migmatização. As paragêneses dessa unidade são compatíveis com metamorfismo de alto grau, na transição da fácies anfibolito superior para a fácies granulito. Payolla *et al*. (2002) atribuiu a idade 1660 Ma como a máxima sedimentação dos protólitos sedimentares do Complexo Quatro Cachoeiras obtida em amostra de paragnaisse em alto grau da região de Machadinho d´Oeste.

Rochas metavulcanossedimentares de baixo grau ocorrem na parte noroeste do Terreno Jamari, sendo representada principalmente pela Formação Mutum-Paraná (Lobato *et al*., 1966), constituída por uma unidade inferior de filitos, ardósias, meta-argilitos, meta-arenitos arcoseanos, quartzitos, metacherts e metatufos cinza e uma unidade superior de quartzo meta-arenitos e metassiltitos, depositados em ambiente marinho raso, epicontinental, com restritos episódios de sedimentação continental e vulcanismo. Uma amostra de metatufo félsico da base da sequência foi datada pelo método U-Pb (SHRIMP) e apresentou várias populações de grãos de zircão herdado e de idades arqueana até paleoproterozoica. A população principal apresentou idade concordante de 1731 ± 17 Ma, interpretada como a de cristalização do tufo (Santos *et al*., 2001).

Na região da serra da Providência, parte leste do Terreno Jamari, ocorre a Formação Igarapé Lourdes composta por associação de rochas metavulcanossedimentares de baixo grau e idade atribuída inicialmente ao Paleoproterozoico, apenas com base em suas relações estratigráficas com as unidades espacialmente associadas (Quadros e Rizzotto, 2007). Nessa região, as rochas da Formação Igarapé Lourdes estão representadas por meta-arenitos e metaconglomerados, na base, e por metassiltitos, metapelitos manganesífero e metassiltitos avermelhados, no topo. Na região de Presidente Médici, ocorrem intercalações de meta-arenitos, metassiltitos, clorita xistos, quartzitos, metatufos, metavulcânicas ácida e formações ferrífera de origem hidrotermal. Essas rochas estão, em geral, metamorfizadas na fácies xisto-verde. Dados geocronológicos U-Pb, em amostra de xisto, apresentados por Quadros *et al*. (2011) revelaram idade de 1367 Ma, considerada como a máxima sedimentação dos protólitos sedimentares da Formação Igarapé Quinze, posicionando-a no Mesoproterozoico.

Nas regiões centro-leste, nordeste, noroeste e central do Terreno Jamari ocorre a Suíte Intrusiva Serra da Providência, constituída por monzogranitos porfiríticos (piterlitos e viborgitos), sienogranitos, charnockitos, mangeritos e gabros, intrusivos no embasamento do Terreno Jamari (Tassinari, 1984; Scandolara, 2006; Quadros e Rizzotto, 2007). Trata-se de uma suíte subalcalina, metaluminosa a fracamente peraluminosa e intraplaca do tipo A, que se estende desde o noroeste de Mato Grosso, sul do Amazonas, porção centro-norte de Rondônia, chegando até próximo ao limite estadual com o Acre. Suas rochas variam de isotrópicas a deformadas, sendo que os tipos deformados mostram ampla variação estrutural e textural, desde fracamente foliados até protomilonitos e milonitos, até tipos bandados. Os protomilonitos são mais frequentes na borda oeste do batólito Serra da Providência e em largas zonas da associação charnockito-granito entre as cidades de Ouro Preto do Oeste e Ji-Paraná. As partes mais deformadas e gnaissificadas são observadas no maciço Rio Crespo, região de Ariquemes e adjacências. A Suíte Serra da Providência engloba diversos episódios magmáticos que ocorreram por um período de tempo superior a 80 Ma e seu pulso mais antigo está representado por biotita sienogranito porfirítico de idade U-Pb de 1606

± 24 Ma, seguida por hornblenda-biotita monzogranito de idade U-Pb de 1573 ± 15 Ma (Bettencourt *et al*., 1999). Uma amostra de piterlito e outra de viborgito forneceram idades idênticas de 1566 ± 5 Ma e 1566 ± 3 Ma, respectivamente. Uma fácies de biotita-sienogranito pórfiro forneceu idade de 1554 ± 47 Ma. A fase final do magmatismo, representada pelo quartzo sienito do Maciço União, forneceu idade de 1532 ± 5 Ma (Bettencourt *et al*., 1999). A deformação e o metamorfismo das rochas da Suíte Serra da Providência ocorreram em condições de médio a alto-grau com ápice, principalmente, em aproximadamente 1,33 Ga, associada à Orogenia Rondoniana-San Ignácio (Quadros e Rizzotto, 2007; Santos *et al*., 2002, 2008; Scandolara, 2006; Scandolara *et al*., 1999; Silva *et al*., 2002; Bettencourt *et al.*, 2010; Quadros et al., 2011).

2.1.2 Província Rondoniana-San Ignácio

A Província Rondoniana-San Ignácio (1,47-1,33 Ga) abrange a porção sudoeste do Cráton Amazônico e encontra-se representada em Rondônia, principalmente pelo Cinturão Alto Guaporé (1,47-1,31 Ga) que aflora na região de Colorado d´Oeste e Corumbiara, estendendo-se em direção à região de Nova Mamoré, no noroeste de Rondônia. No Terreno Jamari o reflexo dessa tectônica promoveu o retrabalhamento da crosta mais antiga na região de Ariquemes, Jaru e Ouro Preto do Oeste, em Rondônia (Scandolara, 2006; Quadros e Rizzotto, 2007; Bettencourt *et al*., 2010; Rizzotto *et al.*, 2013).

O Cinturão Alto Guaporé consiste em segmento crustal NW-SE com rochas de ortoderivação e paraderivação, representado por sequências metavulcanossedimentares em alto grau metamórfico, rochas metamáficas e metaultramáficas, além de diversas gerações de granitos sin-, tardi- e pós-orogenéticos, formado a partir da colisão do Bloco Paraguá com o proto-Cráton Amazônico durante a Orogenia Rondoniana-San Ignácio (Rizzotto *et al.*, 2013). Inclui-se no Cinturão Alto Guaporé o Complexo Nova Mamoré (definido por Rizzotto *et al*., 2005a, 2005b), constituído por gnaisses polideformados e migmatizados expostos na região oeste-noroeste de Rondônia, entre as cidades de Guajará-Mirim, Nova Mamoré e Nova Califórnia, compreendendo rochas paraderivadas representadas por gnaisses quartzo-feldspáticos, granada-biotita-quartzo gnaisses, granofels quartzo-feldspáticos, gnaisses calciossilicáticos bandados e silimanita-granada-biotita-quartzo xistos. Essas rochas se encontram em grau metamórfico de fácies anfibolito superior (zona da silimanita). Zonas de fusão parcial são comuns e não raro com geração de migmatitos com neossoma em forma lentes e bolsões pegmatóides, compostos por k-feldspato, quartzo e biotita e alongados segundo a estruturação regional. No limite norte-noroeste do Cinturão Alto Guaporé em Rondônia aflora o Complexo São Felipe, com área de ocorrência distribuída ao longo de uma faixa que se estende desde as imediações da cidade de São Felipe, a oeste, até o rio Pimenta Bueno, a leste (Quadros *et al*., 2007). Em geral, as rochas desse complexo ocorrem como corpos alongados e

imbricados segundo a direção da foliação regional WNW-ESSE. As principais rochas são augen-gnaisses de composição granodiorítica a monzogranítica, paragnaises e ortognaisses monzograníticos com graus variados de migmatização.

Na região sudeste de Rondônia, o Cinturão Alto Guaporé é composto pelo Complexo Colorado (Rizzotto *et al*., 2013) que foi inicialmente subdividido nas unidades metapelítica, metapsamítica e ferromanganesífera. O referido complexo tem ampla distribuição na região de Colorado do Oeste e Corumbiara, onde ocorre como faixa descontínua e alongada segundo a direção NNW-SSE, com cerca de 130 km de comprimento e 30 km de largura. É constituído por rochas supracrustais clastoquímicas compostas por plagioclásio-biotita-quartzo paragnaisses bandados e parcialmente migmatizados, granada-silimanita paragnaisses migmatíticos, xistos heterogêneos, biotita-gnaisses, formações ferríferas bandadas, gnaisses calciossilicáticos, metamargas, talco xistos, além de xistos grafitosos e anfibolitos subordinados (Quadros e Rizzotto, 2007; Rizzotto e Hartmann, 2012; Rizzotto *et al.*, 2013). Nesta mesma região encontra-se o Complexo Trincheira (~1.47 Ga), designação dada inicialmente por Romanini (2000), que representa parte de uma sequência ofiolítica marcadora de uma zona de sutura na região (Sutura Guaporé), constituído predominantemente por anfibolitos e gnaisses anfibolíticos, com frequentes intercalações de gnaisses paraderivados, paranfibolitos, formações ferríferas bandadas, metabasaltos e xistos. Metagabros, metagabronoritos e leucometagabros com texturas e estruturas ígneas reliquiares também são comuns. Tremolititos, actinolita xistos e intercalações de gnaisses calciossilicáticos são litologias subordinadas (Rizzotto e Hartmann, 2012; Rizzotto *et al.*, 2013).

O magmatismo granítico Mesoproterozoico (Ectasiano) na Província Rondoniana-San Ignácio corresponde a uma série de corpos e maciços graníticos isotrópicos a foliados, de natureza sin-, tardi- a pós-colisional com idades de cristalização no intervalo entre 1387 Ma e 1309 Ma. Esses corpos são englobados nas suítes intrusivas Santo Antônio (monzogranitos, quartzo monzonitos, diques pegmatíticos e aplíticos, rochas híbridas e diques de diabásio), Teotônio (microclínio granitos, microclínio-quartzo sienitos e sienogranitos), Igarapé Enganado (sienogranitos, monzogranitos, granodioritos e raros tonalitos), Cerejeiras (granada-biotita monzogranitos, biotita sienogranitos e raros granodioritos), Alto Escondido (biotita sienogranitos e biotita monzogranitos), Alto Candeias (hornblenda-biotita monzogranitos, biotita monzogranitos, charnockitos e quartzo monzonitos) e São Lourenço-Caripunas (monzogranitos, sienogranitos, granitos pórfiros subvulcânicos, aplitos e quartzo sienitos, com mineralização de cassiterita e wolframita em *greisen* e em veios de quartzo), além da Suíte Laje (granitos tipo S leucocráticos com biotita e granada) (Rizzotto *et al*., 2005a, 2005b; Scandolara, 2006; Quadros e Rizzotto, 2007; Bettencourt *et al*., 2010).

2.1.3 Província Sunsás

A Província Sunsás (1,25-0,95 Ga), também conhecida como Província Sunsás-Aguapeí, ocorre no extremo-sudoeste do Cráton Amazônico em Rondônia, Mato Grosso e Bolívia e tem sido cronologicamente correlacionada à Província Grenville na Laurentia, principalmente em relação as idades dos eventos orogenéticos reconhecidos (Fig. 4). O termo Sunsás foi originalmente utilizado para denominar um cinturão orogênico de *trend* NW, na Bolívia, de idade em torno de 1000 Ma (Litherland *et al.*, 1989), conhecido como Cinturão Sunsás. Posteriormente, esse cinturão foi correlacionado com o Cinturão Aguapeí, no Brasil, passando a constituir uma única unidade geotectônica (Tassinari *et al.*, 1996). Estudos isotópicos, geoquímicos e de geologia estrutural em áreas-chaves da Província Sunsás (cinturões Nova Brasilândia, Sunsás e Aguapeí, além de áreas de cráton retrabalhado), no Brasil e na Bolívia, tem proporcionado avanços significativos na reconstituição do arcabouço dessa província e nas discussões sobre a evolução do orógeno Sunsás (Geraldes *et al.,* 2001; Rizzotto et al., 2013; Santos *et al.*, 2003, 2008; Tassinari e Macambira, 1999, 2004; Tohver et al., 2006; Boger *et al.*, 2005; Ruiz, 2005; Teixeira *et al.*, 1996, 2006, 2010; Vargas-Mattos, 2006; Cordani e Teixeira, 2007; Elming *et al.*, 2009).
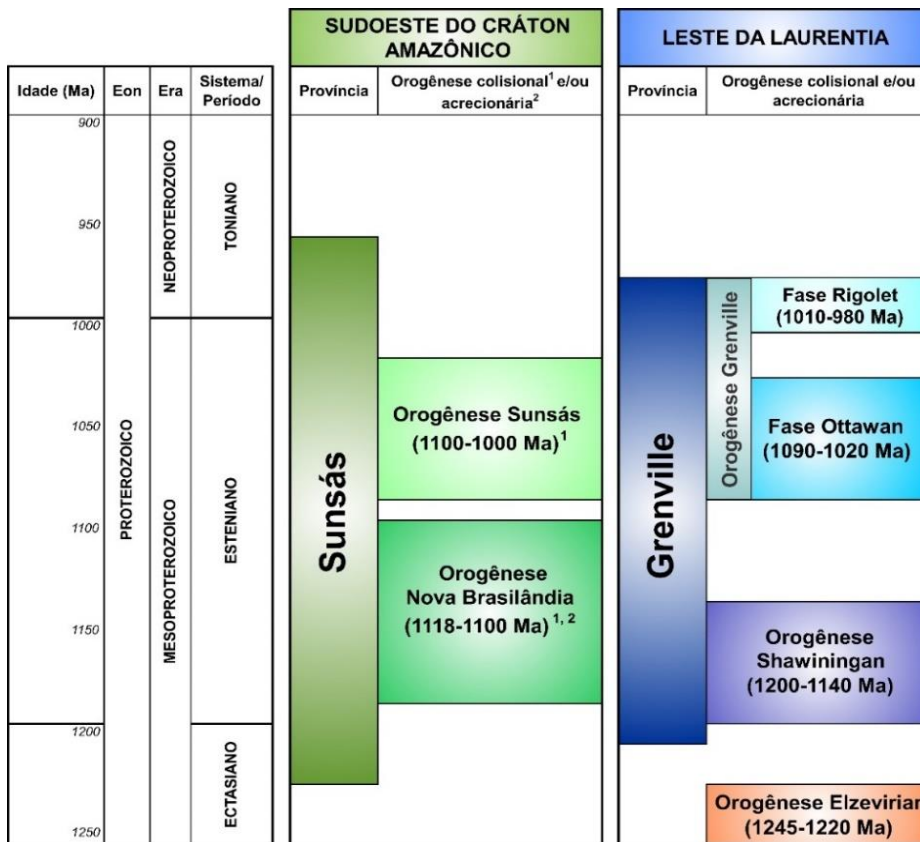
Fig. 4. *Quadro comparativo entre a cronologia dos eventos orogenéticos mesoproterozoicos (Esteniano-Toniano) registrados nas províncias Sunsás e Grenville (adaptado de Rizzotto, 1999; Rivers, 2008; Teixeira et al., 2010; McLelland et al., 2010).*

No sudoeste do Cráton Amazônico, em Rondônia, consideramos que a Província Sunsás se encontra representada pelo Cinturão Nova Brasilândia e pelo Sistema Transpressivo Sinistral Ji-Paraná – Cujubim (STSJC) (Figs. 1, 5, 6). O Cinturão Nova Brasilândia constitui unidade geotectônica alongada na direção E-W a NW-SE, medindo 170 km de comprimento por 40 km de largura, aflorante em meio a sedimentos neoproterozoicos e fanerozoicos. Encontra-se limitado a norte pelo *Graben* Pimenta Bueno, a sul pelo complexo São Felipe, a leste pela Bacia dos Parecis e a oeste por coberturas sedimentares cenozoicas. Fortes anomalias magnéticas indicam que o Cinturão Nova Brasilândia se estende para leste e para sudoeste, além dos seus limites aflorantes (Figs. 5A, 5B). Sugere ainda a existência de estrutura tectônica E-W de escala regional, possivelmente marcadora de limites de blocos crustais. Essas anomalias magnéticas encontram-se bem evidenciadas na parte sul do cinturão, apresentando *trend* magnético regional E-W impresso nas rochas metassedimentares em alto-grau da Formação Rio Branco (gnaisses cálciossilicáticos, biotita paragnaisses e granulitos) (Figs. 5A, 6). Parte das anomálias magnéticas são geradas por corpos ígneos máficos e por diques máficos, enquanto que baixos magnéticos são evidenciados por materiais geológicos diversos, de origem sedimentar (rochas metassedimentares da Formação Migrantinópolis e sedimentos do Fanerozoico) e magmática félsica (granitos) (Fig. 5A). A interpretação qualitativa dos dados magnéticos revelou feições lineares magnéticas que podem representar estruturas geológicas que contornam corpos ígneos máficos, permitindo a identificação de domínios magnéticos distintos (Fig. 5B). A aerogamaespectrometria, principalmente o mapa de composição ternária RGB (K, eTh, eU), foi utilizada como ferramenta auxiliar na individualização das unidades geológicas e na delimitação mais precisa dos traçados dos contatos geológicos. Foi possível ainda estabelecer correlação entre as informações geológicas de campo e a resposta radiométrica apresentada no mapa de composição ternária, permitindo detalhar a cartografia geológica na área estudada (Fig. 5C).

O Cinturão Nova Brasilândia é constituído por rochas metavulcanossedimentares em médio a alto grau que fazem parte do Grupo Nova Brasilândia, composto de uma unidade dominante de metaturbiditos terrígeno-carbonáticos (Formação Migrantinópolis) e uma unidade máfico-félsica bimodal com intercalações de paragnaisses (Formação Rio Branco), conforme definição inicial dada por Rizzotto (1999) (Fig. 6). Além destas, ocorre no extremo noroeste do cinturão a Formação Terra Boa composta por intercalações de meta-arenitos e metassiltitos metamorfizados em baixo-grau (Quadros e Rizzotto, 2007). A fase magmática tardi- a pós-orogênica encontra-se representada pelos granitos das suítes Rio Branco e Rio Pardo e anorogênica pelas rochas das suítes Novo Mundo (máfica) e Costa Marques (félsica). O modelo de evolução do Cinturão Nova Brasilândia proposto inicialmente envolve a abertura e fechamento de *rift* intracontinental, margem passiva e formação

de proto-oceano, desenvolvido em dois ciclos entre 1250 e 1110 Ma (Rizzotto, 1999; Tohver *et al*., 2004, 2005a).
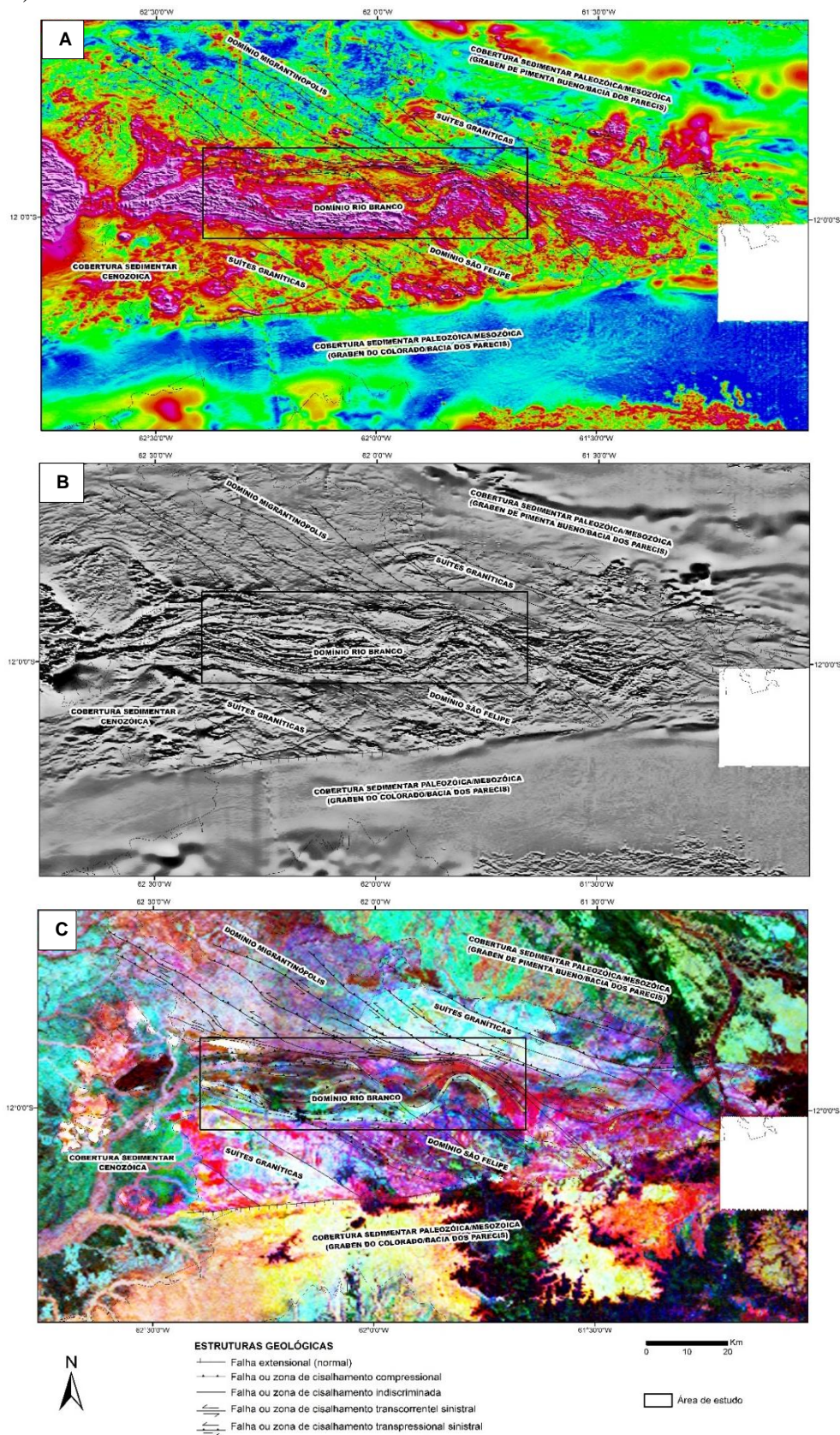
Fig. 5. *Recobrimento aerogeofísico do Cinturão Nova Brasilândia e adjacências. (A) aeromagnetometria de Amplitude do Sinal Analítico (ASA), (B) aeromagnetometria primeira derivada horizontal (DZ) e (C) aerogamaespectrometria mostrando a composição ternária RGB (K, eTh, eU) (fonte: CPRM, 2014 - Projeto Aerogeofísico Sudoeste de Rondônia).*

O primeiro, mais antigo, corresponde à fase de extensão continental e formação de *rift*, magmatismo intraplaca, sedimentação turbidítica e início de formação de crosta oceânica. O segundo, mais novo, refere-se à fase de colisão com transpressão e espessamento crustal, constituindo assim a orogênese Nova Brasilândia que é cronocorrelata da orogênese Shawiningan na Província Grenville (Fig. 4) (Rizzotto, 1999; Tohver *et al*., 2004, 2005a; Santos *et al*., 2008; Teixeira *et al*., 2010).

Portanto, com base em nossas pesquisas, cujo conteúdo encontra-se registrado nos artigos anexados ao documento da tese, uma proposta alternativa para a evolução tectônica do Cinturão Nova Brasilândia está sendo apresentada, bem como a natureza dos estágios evolutivos e a cronologia dos eventos geológicos estão sendo definidas com mais precisão, baseados na metodolia utilizada na pesquisa.
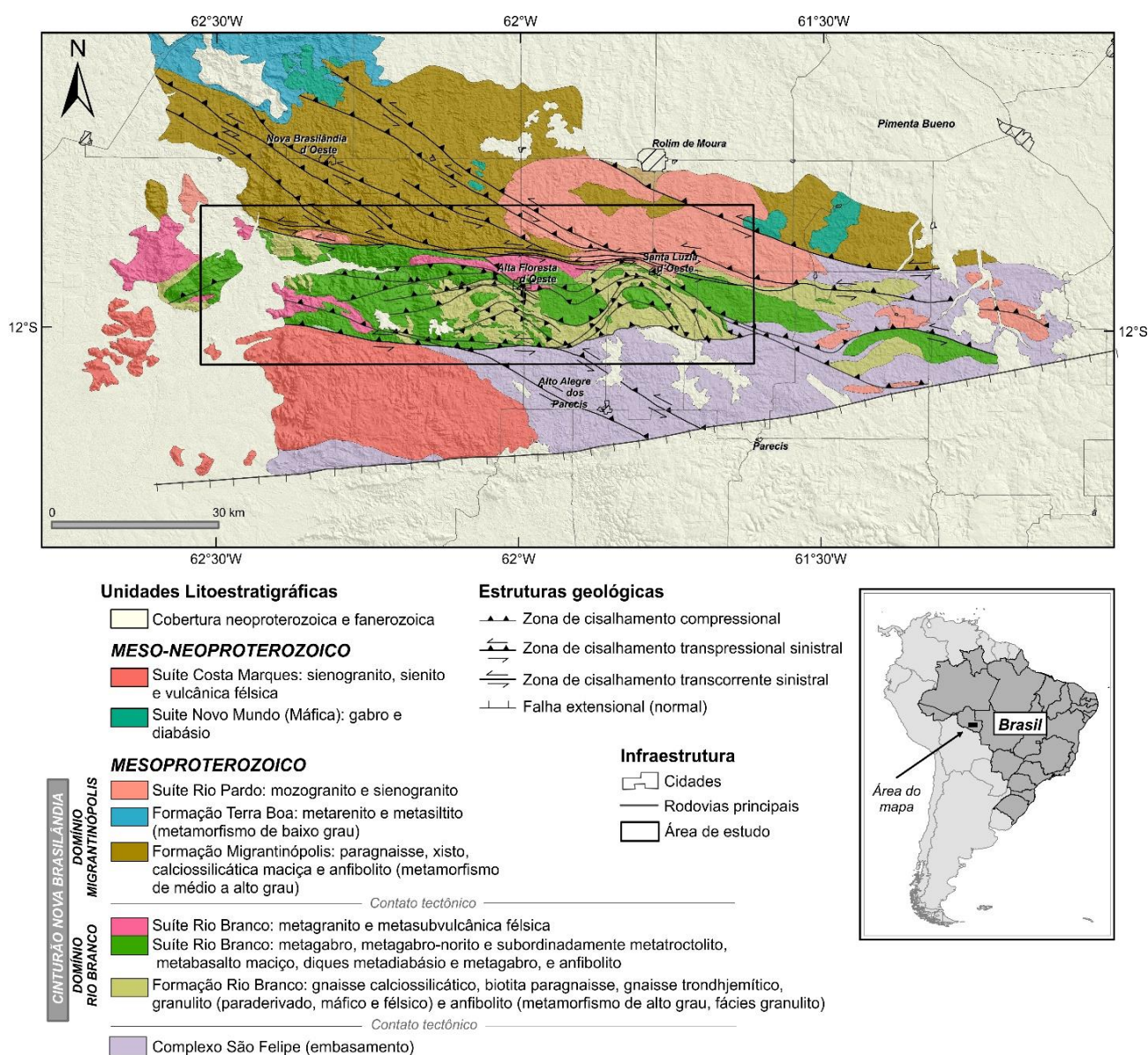
Fig. 6. *Mapa geológico do Cinturão Nova Brasilândia, sudoeste do Cráton Amazônico, Rondônia. Compilado e modificado de Scandolara e Rizzotto (1998), Bahia e Silva (1998) e Bergami et al. (2018).*

Na região cratônica a noroeste do Cinturão Nova Brasilândia, no contexto do embasamento do Terreno Jamari, encontra-se o Sistema Transpressivo Sinistral Ji-Paraná – Cujubim (Quadros *et al.*, 2011, 2014), que consiste no prolongamento da Zona de Cisalhamento Ji-Paraná, em direção à região noroeste de Rondônia (Scandolara *et al.*, 1999; Tohver *et. al.*, 2005a, 2005b), ou do Sistema Transpressivo Sinistral Ji-Paraná (Scandolara, 2006) (Fig. 1). Esse sistema corresponde a uma faixa com aproximadamente 35-80 km de largura e mais de 300 km de extensão, com *trend* geral NW-SE. Foi gerado no Esteniano (~1,13 Ga) a partir do retrabalhamento crustal das rochas que compõem a Província Rondônia-Juruena, mais especificamente o Terreno Jamari, durante uma fase específica da Orogenia Nova Brasilândia. Entretanto, seu contexto evolutivo necessita ainda de estudos adicionais para sua inserção na nova proposta de evolução do Cinturão Nova Brasilândia que está sendo apresentada nessa tese de doutorado. Adicionalmente, destacamos que o sistema transpressivo abrange várias zonas de cisalhamento dúcteis, métricas a quilométricas, subverticais, com milonitização em fácies anfibolito baixo a superior. O metamorfismo ao longo das zonas de cisalhamento na porção leste-suldeste do sistema alcançou temperaturas em torno de 450-550°C e a deformação ocorreu entre 1,18-1,15 Ga (Tohver *et al.*, 2005). Dados geocronológicos U-Pb em zircão obtidos por Quadros *et al.,* (2011, 2014) em granito anatético (fusão de metassedimentos) gerado ao longo desse sistema transpressivo revelaram a idade de cristalização de 1138 ± 8 Ma, interpretada como idade do pico do metamorfismo ao longo do Sistema Transpressivo Sinistral Ji-Paraná –Cujubim.

Nessa mesma região cratônica, o magmatismo granítico anorogênico com idades de cristalização no intervalo entre 1082 e 950 Ma representa as manifestações magmáticas pós-evolução do orógeno Sunsás, mais especificamente pós-orogenia Nova Brasilândia (Bettencourt *et al.*, 1999; Quadros e Rizzotto, 2007). A geração mais antiga é representada pelas rochas da Suíte Intrusiva Santa Clara, designação dada por Bettencourt *et al.* (1997), que engloba dezessete maciços graníticos subcirculares a subalongados, com destaque para os maciços Oriente Novo, Oriente Velho, Santa Clara, Montenegro, Manteiga, Retiro, Jararaca, Jatuarana, Primavera, Moisés e Massaranduba (Quadros *et al.*, 2011). A Suíte Santa Clara é constituída por monzogranitos porfiríticos, sienogranitos porfiríticos, monzogranitos finos, quartzo pórfiros, traquitos, albita leucogranitos, microssienitos e, mais raramente, aplitos e pegmatitos. Apresenta idades de cristalização pelo método U-Pb em zircão e Pb-Pb entre 1080 e 1082 Ma (Bettencourt *et al.,* 1999; Quadros *et al.*, 2011). Diferentes estilos de mineralizações de cassiterita e elementos associados ocorrem nos granitos da Suíte Intrusiva Santa Clara e compreendem *stockwork* em *greisens*, *lodes* de quartzo-cassiterita e quartzo-cassiterita-wolframita, veios de quartzo-topázio-fluorita, pegmatitos com albita, microclínio, berílio, topázio, molibdenita e cassiterita. A geração mais jovem é representada pelas rochas da Suíte Intrusiva Rondônia, descrita por Kloosterman (1968) como

"*Younger Granites of Rondônia*", que engloba diversos maciços graníticos (batólitos e *stocks*) com ampla distribuição no centro-norte de Rondônia. Essa unidade é constituída por sienogranitos equigranulares, monzogranitos porfiríticos e ortoclásio granitos, ocorrências subordinadas de topázio-albita granitos e topázio-quartzo-feldspato pórfiro, além de microssienitos e quartzo pórfiros. Corpos de granitos datados por Bettencourt *et al.* (1999), pelo método U-Pb em zircão, apresentaram idades de cristalização entre 998 e 974 Ma. Os corpos datados por Sparrenberger *et al.* (2002), pelo método U-Pb em monazita, obtiveram idades de cristalização entre 993 e 989 Ma. A maioria dos granitos das suítes intrusivas Santa Clara e Rondônia contém mineralizações de Sn, W, Nb-Ta, Be e F, em parte associadas às fases tardias do magmatismo representadas por albita-leucogranitos (p. ex. Mina de Bom Futuro).

Geology and LA-ICP-MS U-Pb geochronology of the Nova Brasilândia belt, southwest of the Amazonian Craton: New ages, re-evaluation of existing geochronological data and implications on the Sunsás orogen evolution

Geology and LA-ICP-MS U-Pb geochronology of the Nova Brasilândia belt, southwest of the Amazonian Craton: New ages, re-evaluation of existing geochronological data and implications on the Sunsás orogen evolution

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A B S T R A C T

New geological and LA-ICP-MS U-Pb geochronological data combined with data compiled from previously published articles provide information needed to characterize more precisely the tectonic evolution timing of the Nova Brasilândia belt in southwestern Amazonian Craton, Rondônia. The LA-ICP-MS U-Pb ages were obtained in zircon crystals from the rocks of Rio Branco domain, southern part of the belt. Isotopic data of the Rio Branco Formation revealed sedimentation period between 1241 ± 7.5 Ma and 1137 ± 9 Ma and high-grade metamorphism between 1137 ± 9 Ma and 1127.6 ± 2.3 Ma. The magmatism mafic-felsic of the Rio Branco Suite was dated between 1119.7 ± 2.7 Ma and 1106.2 ± 2.8 Ma. U-Pb ages obtained in specific groups of recrystallized zircon (cores and rims) extracted from high-grade calc-silicate gneiss (1019 ± 15 Ma), metagabbro (1016.7 ± 3.9 Ma) and anatectic granite (1011.3 ± 9.6 Ma) represent possible reflections of metamorphic recrystallization and migmatization youngest. The LA-ICP-MS U-Pb zircon ages of sedimentation, metamorphism, migmatization and magmatism obtained in the Rio Branco domain rocks establish the time period of two orogenetic phases recorded in the Nova Brasilândia belt between ca. 1137 Ma and 1106 Ma (accretionary phase) and between ca.1096 Ma and 1011 Ma (overprint metamorphic during collisional phase). Thus, the Nova Brasilândia orogeny recorded on the southwest margin of the Amazonian Craton is can be considered as accretionary-collisional type, and developed between ca. 1137 and 1010 Ma.

1. Introduction

The Rodinia supercontinent was formed in the late Mesoproterozoic to early Neoproterozoic (ca. 1.0 Ga) as result of several collisional belts collectively referred to as the Grenville orogeny, which culminated in the agglutination of cratons and blocks, including Laurentia and Amazônia. Several proposals for tectonic reconstructions of Rodinia, particularly those describing the agglutination of the Laurentian and Amazonian cratons, have been presented and include alternative paleogeographic reconstructions for these cratons in the Mesoproterozoic (e.g. Dalziel, 1991; Hoffman, 1991; Keppie and Ortega-Gutierrez, 1999; Rogers and Santosh, 2003; Loewy et al., 2003, 2004; Casquet et al., 2006; Li et al., 2008; Chew et al., 2011; Cawood and Pisarevsky, 2017). Important revisions that address the aspects of the geological and tectonic history of the Mesoproterozoic basement in the Andes region, the western part of the Amazon and of Bolivia, have also been well synthesized by Cawood and Pisarevsky (2017), Ramos (2010, 2008), Cardona et al. (2010), Cordani et al. (2009, 2010), Miskovic et al. (2009), Fuck et al. (2008), Li et al. (2008), Cordani and Teixeira (2007), and Johansson (2009, 2014).

In the Amazonian Craton, the Sunsás Province (ca. 1.20-0.95 Ga), also known as the Sunsás-Aguapeí Province, is a key area for studying the Rodinia supercontinent assembly. The Sunsás Province is related chronologically to the Grenville Province and together they represent two of the main global orogens forming Rodinia (Tohver et al., 2002, 2004; Santos et al., 2008). The geological and tectonic record of the continental mass agglutination that formed Rodinia is well recorded in the southwestern margin of the Amazonian Craton, in the states of Rondônia and Mato Grosso, as well as in its counterparts in Bolivia. The Nova Brasilândia, Aguapeí and Sunsás orogenic belts and the Ji-Paraná - Cujubim sinistral transpressive System, which includes the Ji-Paraná Shear Zone, are the geotectonic units that record the mesoproterozoic orogenetic activities on the southwestern fringe of the Amazonian Craton associated with Rodinia assembly (see Rizzotto, 1999; Rizzotto et al., 2001, 2014; Santos et al., 2003, 2008; Tohver et al., 2002, 2004, 2005a, 2005b; Boger et al., 2005; Ruiz, 2005; Scandolara, 2006; Ruiz et al., 2007; Teixeira et al., 2010; Quadros et al., 2011).

The term Sunsás was originally designated in Bolivia to name an orogenic belt NW-SE formed in 1000 Ma (Litherland et al., 1989). The Sunsás Orogen was formed during the Mesoproterozoic and comprises the western part of the Amazonian Craton in South America, and is best exposed in the eastern Bolivia and western Brazil in Rondônia and Mato Grosso states (Santos et al., 2008). The timing of the Sunsás orogeny was first estimate in 1100–900 Ma through Rb-Sr and K-Ar isotopic studies carried out on granitic rocks and pegmatites from the Sunsás collisional belt, in Bolivia (Litherland et al., 1986, 1989). The Sunsás collisional belt was correlated with the Aguapeí belt in Brazil, becoming a single geotectonic unit (Tassinari et al., 1996). Recently, the Nova Brasilândia, Aguapeí and Sunsás belts were grouped into a unique geotectonic unit termed the Western Amazon belt (Rizzotto et al., 2014).

Four periods of orogenic activity are identified within the Sunsás Orogen: Santa Helena orogeny (1465–1427 Ma), Candeias orogeny (1371–1319 Ma), San Andrés orogeny (ca. 1275 Ma), and Nova Brasilândia orogeny (1180–1110Ma) (Rizzotto 1999; Santos et al., 2008). Bettencourt et al. (2010) suggested the Rondonian-San Ignacio Orogeny as responsible for the formation of a complex accretionary orogen (1556-1430 Ma) developed from the oblique collision (1370-1320 Ma) of the Paraguá block with the proto-Amazonian Craton. Teixeira et al. (2010) characterized the Sunsás orogen with an allochthonous collisional-type belt formed between (1.11–1.00 Ga), considering as the youngest of the events recorded on the southwest margin of the Amazonian Craton. In our conception, based on the works of Santos et al. (2008), Teixeira et al. (2010), Bettencourt et al. (2010), Rizzotto (1999), and Rizzotto et al. (2014), the Sunsás orogen comprises the Nova Brasilândia, Aguapeí and Sunsás collisional belts, and the reworked craton areas (transpressive or transcurrent shear zone/systems). This orogen was formed approximately between 1.25 and 1.00 Ga, reflection of the Nova Brasilândia orogeny (1180–1110 Ma; Rizzotto, 1999) and Sunsás orogeny (1100-1000 Ma; Teixeira et al., 2010).

107   The area investigated in the present study is located in the Rio Branco domain, southern part
108 of the Nova Brasilândia belt, which represents an incomplete fragment of ocean floor added to the
109 southwest margin of the Amazonian Craton during the collisional phase of the Nova Brasilândia
110 orogeny orogen (Rizzotto, 1999; Rizzotto et al., 1999, 2001) (Fig. 1).
111   This paper presents new geological and isotopic data obtained by the method LA-ICP-MS
112 (Laser Ablation–Inductively Coupled Plasma–Mass Spectrometer) U-Pb zircon in rocks from the
113 Rio Branco domain. It also presents U-Pb, ^{40}Ar-^{39}Ar and Sm-Nd geochronological data compiled
114 of previously published articles. Our main objective was to compose a work proposal based on the
115 new results combined with previously published information another researchers, as well as to
116 establish the chronology of sedimentation, magmatism and deformation/metamorphism events. The
117 integration and reinterpretation of geological and geochronological data provided improvements in
118 the evolution models of the Nova Brasilândia belt and provided new subsidies for the presentation
119 of alternative proposals to characterize the nature of the Nova Brasilândia orogeny. Finally, this
120 research also contributes to the discussion of the tectonic models of the Rodinia supercontinent
121 reconstruction.
122
123 **2. Geological and tectonic setting**
124
125   The Amazonian Craton was subdivided initially into two shields, named the Central Brazil
126 Shield in the south and the Guyana Shield in the north, separated by extensive Phanerozoic
127 sedimentary areas deposited in the Solimões and Amazon basin. Amaral (1974) subdivided the
128 craton into three geochronological provinces: Eastern Amazon, Central Amazon and Western
129 Amazon. Following, several evolutionary proposals have been suggested, improving and adapting
130 the first proposed model, mainly based on new geochronological data (e.g., Cordani et al., 1979;
131 Teixeira et al., 1989). Hasui et al. (1984) and Costa and Hasui (1991) presented models combining
132 geophysical and structural data to define twelve blocks or paleoplates ranging in age from Archean
133 to Paleoproterozoic. Accordingly, these blocks are separate by mobile belts formed dominantly by
134 continental collision, with subsequent reactivation during younger tectonic events. Tassinari and
135 Macambira (1999) reviewed the provinces concept in the subdivision of the Amazonian Craton,
136 proposing a new model supported by Sm-Nd geochronological data, in which the southwestern
137 region of the Amazonian Craton consists of the Rio Negro-Juruena Province (1.80-1.55 Ga), the
138 Rondoniana-San Ignacio Province (1.45-1.3 Ga) and the Sunsás Province (1.25-1.00 Ga). In
139 contrast, Santos et al. (2003) defined only two geochronological provinces in the southwestern
140 Amazonian Craton: the Rondônia-Juruena (1.74-1.47 Ga) and the Sunsás (1.20-0.99 Ga) provinces.
141   The structure of the southwestern sector of the craton was also initially approached in regional
142 geological mapping (Pinto Filho et al., 1977; Litherland et al., 1986, Scandolara et al., 1999) and in
143 specific academic research (Rizzotto, 1999; Ruiz, 2005; Scandolara, 2006), all of which with
144 lithostratigraphic connotation. Other works focused on the tectonic evolution of the Sunsás orogen,
145 i.e., the collision between the Amazonian Craton and the east and southeast edges of Laurentia (see
146 Priem et al., 1989; Sadowski and Bettencourt, 1996; Tohver et al., 2002; Rizzotto et al., 2013, 2014).
147 From the works cited above, the structural framework proposed by Tohver et al. (2005a, 2005b)
148 suggests the existence of an unexposed suture zone along which the Nova Brasilândia belt
149 developed, in relation to the collision of the Amazonian Craton with Laurentia at ca. 1.2-1.0 Ga.
150 Alternatively, Scandolara (2006) presented a tectonostratigraphic subdivision for the southwestern
151 Amazonian Craton in Rondônia. In this proposal, each geologic terrane presents its own
152 petrographic, structural, geochemical, geophysical and geochronological characteristics and limited
153 by regional-scale fault systems or shear zones, individualized as the Jamari, Roosevelt and Nova
154 Brasilândia terranes.
155   In the Alto Guapore belt of southeastern Rondônia was characterized the ophiolitic complex
156 (1.47-1.35 Ga), represented by the Trincheira Complex rocks, showing a WNW-ESE paleo-suture
157 zone (Guapore Suture Zone) associated with the evolution of an accretionary orogen formed by
158 oceanic plate subduction between 1.47-1.43 Ga (Rizzotto and Hartmann, 2012; Rizzotto et al.,

159 2013). Rizzotto et al. (2014) suggested that the Nova Brasilândia basin was formed in the late
160 Mesoproterozoic from the reactivation of Guaporé Suture Zone generated an intracontinental rift.
161 Previously, Tohver et al. (2004) suggested that the Nova Brasilândia belt was formed during oblique
162 collision followed by a strike-slip movement between the Amazonian Craton and Laurentia.
163
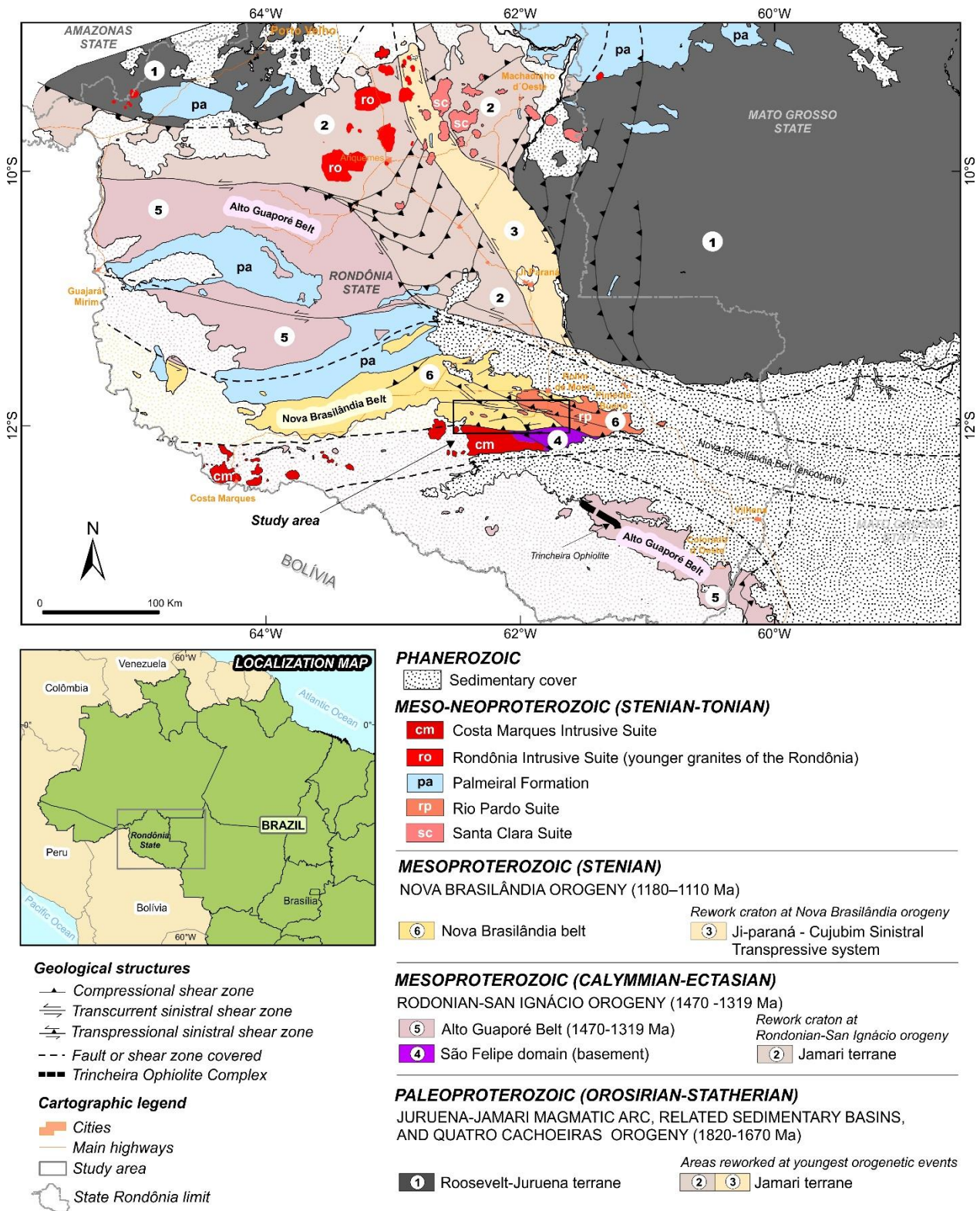
164
165
166 ***Fig. 1.*** *Simplified map of the southwestern Amazonian Craton in Rondônia with the approximate boundaries*
167 *of the main belts, terranes, units, tectonic elements, lithologic units, and sedimentary covers. Also shown is*
168 *the location of the study area. After Scandolara et al. (1999); Scandolara (2006), Quadros and Rizzotto*
169 *(2007); Santos et al. (2000, 2008); Bettencourt et al. (2010), Quadros et al. (2011) and Rizzotto et al. (2014).*

Recently, the mafic-felsic magmatism of the Rio Branco Suite were correlated with a LIP (Large Igneous Province) event in the southwestern Amazonian Craton that took place at ca. 1.1 Ga and correlated temporally to the intraplate magmatism of the Rincon Del Tigre Complex and the Huanchaca sills and dikes, both in Bolivia (Teixeira et al., 2018). Article published by Quadros et al. (submitted) as part of this research suggest that the medium- to low Ti tholeitic sub-alkaline mafic magmatism of the Rio Branco Suite exhibits characteristic petrogenetic patterns that can be associated with subduction. These rocks also present overlapping of MORB-like (mid-ocean ridge basalt), IAT (island arc tholeiite) and BAB (back-arc basalt) characteristics. Therefore, these authors suggest an important accretionary phase (ca. 1137 and 1106 Ma) in the evolution of the Nova Brasilândia belt.

Finally, our simplified view of the tectonic structure of southwestern Amazonian Craton in Rondônia and part of Mato Grosso, presented in this article, was elaborate from the reinterpretation of geological and aerogeophysical maps previously published by CPRM-Geological Survey of Brazil, articles, dissertations and theses, added to the geological and geochronological new data obtained in our research (Fig. 1).

3. Local geological and tectonic framework – previous data

The Sunsás orogen, in our understanding, comprises the Nova Brasilândia, Aguapeí and Sunsás collisional belts, and the reworked craton areas (transpressive or transcurrent shear zone or systems). This orogen was formed approximately between 1.25 and 1.00 Ga, reflection of the Nova Brasilândia orogeny (1180–1110 Ma) and Sunsás orogeny (1100-1000 Ma) (see Santos et al., 2008, Teixeira et al., 2010; Bettencourt et al., 2010; Rizzotto et al., 2014).

The Nova Brasilândia belt, also known as the Nova Brasilândia metasedimentary belt, is the target of our research takes place in the southwest portion of the Amazonian Craton and stretches in the E-W direction to NW-SE for approximately 170 km long by 40 km wide (Fig. 2A). The belt is limited to the north by the sedimentary rocks of the Pimenta Bueno graben, to the south by the metamorphic rocks of the São Felipe Complex (> 1.24 Ga), to the east by the sedimentary rocks of the Parecis Basin, and to the west by Cenozoic sedimentary covers (Fig. 2A). This belt was subdivided into two lithostructural domains, the Migrantinópolis domain to the north and the Rio Branco domain to the south, separated by the Rio Branco sinistral transcurrent shear zone (Fig. 2B).

The metavolcanic-sedimentary rocks ware initially named as the Nova Brasilândia Metavolcanic-sedimentary Sequence (Scandolara and Rizzotto, 1998), and later as the Nova Brasilândia Group (Rizzotto, 1999; Rizzotto et al., 2001). It comprises two distinct units (Fig. 2A). The Migrantinópolis Formation consists of a metaturbidite unit with siliciclastic-carbonate composition metamorphosed under medium- to high-grade conditions, composed of quartz-feldspathic gneisses, mica schists, quartzites and subordinate massive calc-silicates rocks. In addition, metagabbro sills, amphibolites and, more rarely, massive metabasalts were inserted into this lithostratigraphic unit. Planar structures are represented by gneissic *banding*, shistosity, mylonitic foliation and asymmetric folds, as well as boudins of quartz veins. The foliation regional trend is approximately N40º-50ºW, with dip around 40º-60º to NE. Details of the geological-structural framework of the Nova Brasilândia belt were detailed by Luft et al. (2000). The zircon U-Pb (SHRIMP) age of 1122 Ma defines the maximum sedimentation age of the protoliths of the Migrantinópolis Formation, considered as the opening age for the basin (Rizzotto et al., 2014).

The Rio Branco Formation, in the initial concept (Rizzotto, 1999; Rizzotto et al., 1999, 2001), includes metamafic rocks represented by sills and stocks of metagabbro, metagabbronorite and metadiabase, with subordinate intercalations of calc-silicate gneisses and paragneisses and schists, in addition to amphibolites and mafic granulites. In the mafic set, two units of magmatism were identified in the Rio Branco domain. The first unit was contemporary to the sedimentation of the Rio Branco Formation protoliths, occurring as elongated bodies and lenses of mafic granulites originated from the high-grade metamorphism (granulite facies) of gabbros and gabbronorites (protoliths), and medium-grained amphibolites founds along of shear zones.
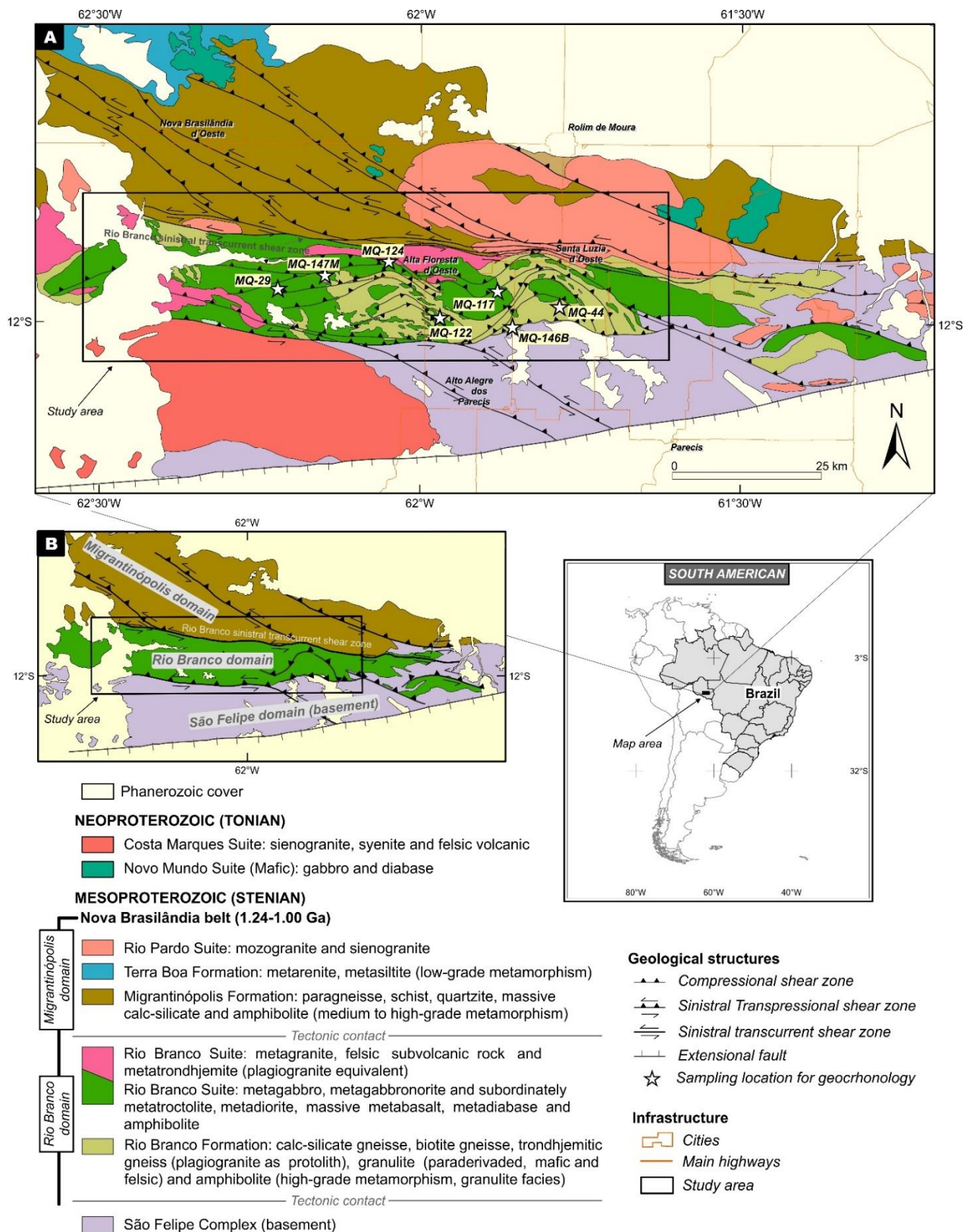
Fig. 2. *Geological map of the Nova Brasilândia belt in southwestern Amazonian Craton, Rondônia. Modified after Scandolara and Rizzotto (1998), Bahia and Silva (1998) and Bergami et al. (2018).*

The second unit is composed of dykes and stocks of metagabbro and metadiabase, respectively, intrusives in high-grade metasedimentary rocks of the Rio Branco Formation. The foliation regional trend is approximately NNE and SSW, with double dips nearly to 70º-80º/NE or 40º-50º/SW. These intrusions formed at shallow levels of the crust, evidenced by sub-ophytic

32

textures partially preserved in fine-grained metamafic rocks. In general, bodies have oval or tabular forms, with their partially preserved igneous characteristics. In these portions of the rocks occurs igneous foliation incipient defined by the alignment of amphibole prisms, pyroxene and tabular crystals of plagioclase. In the deformed parts of the rock, metamorphic foliation overlaps the primary igneous textures. The magmatic and metamorphic textures alternate at all scales as a function of the intensity or absence of deformation, according to its location in relation to the main shear zones. Part this set of metabasic rocks was metamorphosed in high-grade (see Rizzotto, 1999; Rizzotto et al., 2001) and was heterogeneously deformed (mylonitized) and transformed to amphibolites along transpressive and transcurrent shear zones.

Metagranites of monzogranitic composition included in the Rio Branco Granite unit and with U-Pb age of 1113 ± 56 Ma Ma occur as intrusions in metasedimentary rocks of the Rio Branco Formation (Rizzotto, 1999). In the region southeast of Nova Brasilândia d'Oeste occur foliated monzogranites and syenogranites of the Rio Pardo Suite (Silva et al., 1992) with U-Pb (zircon) crystallization age of 1005 ± 41 Ma, Sm-Nd model age of 1.50 Ga, and εNd (t) = + 0.50 (Rizzotto, 1999). The late emplacement of post-tectonic granites of the Rio Pardo Suite and generation of the Palmeiral Formation rocks in cratonic area were associated with extensional phase and final orogenic collapse between ca.1005-970 Ma (Rizzotto et al., 2001).

Geological structures suggest a complex history of various deformation and metamorphism stages in the context of progressive deformation associated with convergence, transpression and late transcurrent movements that occurred during the evolution of the Nova Brasilândia orogeny. Initially, these processes formed banded gneisses and foliation with low to medium dip trending NW-SE or E-W and isoclinal folds with horizontal axes as compressive tectonic products. With the progression of regional deformation, transpressive shear zones became dominant, and late transcurrent sinistral shear zones caused the development of high-angle mylonitic foliation, subvertical to subhorizontal stretching lineations, boudins and folds, with intense transposition and parallelization of structures within the shear zones (see Rizzotto, 1999; Rizzotto et al., 1999, 2001; Tohver et al., 2004).

Previous proposals for tectonic scenarios in the Nova Brasilândia belt involve periods of extension, compression, transtension and transpression, developed along a dominantly strike-slip margin between the Amazônia and Laurentia. Cycles of contraction-extension and intraplate magmatism during the geological evolution of the Nova Brasilândia belt were defined (Scandolara and Rizzotto, 1992; Rizzotto, 1999; Rizzotto et al., 2001). These authors proposed a first cycle by continental extension marked by intraplate plutonism and turbidite sedimentation, closing with transpression and crustal thickening between 1250 Ma and 1110 Ma during Nova Brasilândia orogeny. The second cycle between 1005 Ma and 910 Ma comprised post-orogenic collapse forming a cratonic intracontinental basin (Palmeiral Formation), accompanied by intraplate felsic magmatism with metallogenetic interest for Sn, W, Nb, Ta and ETR. In this phase, lateral movements of crustal blocks generated wide late transcurrent shear zones, with highlight to Rio Branco sinistral transcurrent shear zone (Fig. 2).

The Nova Brasilândia belt was also interpreted as resulting from crustal thickening by imbrication caused by transpressive suturing of the Amazonian and Paraguá Craton at ca. 1.09 Ga, based on structural data, thermobarometric calculations and U-Pb (titanite and monazite) and ^{40}Ar/^{39}Ar (biotite and hornblende) geochronology. This data revealed a long history of metamorphism, tectonic exhumation and cooling in the range of 1.09 -1.06 Ga to 0.97-0.91 Ga (Tohver et al., 2004, 2005a, 2006).

The main geochronological ages obtained in the rocks of the Nova Brasilândia belt by the U-Pb methods (TIMS, SHRIMP and LA-ICP-MS) in zircon, monazite, titanite and rutile crystals, ^{40}Ar-^{39}Ar in hornblende and biotite and Sm-Nd in whole rocks are summarized in table 1.

Table 1.

Synthesis of U-Pb and Ar-Ar isotopic ages in metasedimentary and metamafic rocks and metagranites of the Nova Brasilândia belt, southwest of the Amazonian Craton in Rondônia.

Lithology	Location	Method	Age (Ma) or (Ga)	Interpretation of age	Reference
Rio Pardo Suite					
Monzogranite (sample GR-23)	S 11°54'19" W 62°02'11"	U-Pb SHRIMP zircon Sm-Nd (whole rock)	1005 ± 41 Ma* (n=4, upper intercept) 1,50 Ga** (TDM)	Crystallization age (*) and model age (**)	Rizzotto (1999)
Monzogranite (sample GR-345)	S 12°05'49" W 61°25'24"	U-Pb LA-ICP-MS zircon	1010 ± 15 Ma (n=10)	Crystallization age	Rizzotto et al. (2014)
Terra Boa Formation					
Metarenite (sample GB-427)	S 11°30'26" W 62°32'05"	U-Pb LA-ICP-MS zircon	Ages between 2070 and 1143 Ma. Main peaks with ages of 2031 Ma, 1536 Ma* (main peak, n=17), 1307 Ma and 1143 Ma. Peak youngest age of 1143 Ma** (n=2)	Age of the main source (*) and maximum sedimentation age in 1143 Ma (**)	Trindade Neto et al. (2018)
Migrantinópolis Formation					
Fine-grained banded paragneiss (sample GR-66)	S 11°50'35" W 62°04'18"	U-Pb SHRIMP zircon Sm-Nd (whole rock)	U-Pb ages between 2090 and 1122 Ma. Ages peak of 1417 ± 35 Ma (n=3), 1320 ± 20 Ma (n=5), 1215 ± 20 Ma* (n=7) and 1122 ± 12 Ma (n=2) 1, 85 a 1, 91 Ga** (TDM)	Maximum sedimentation age in 1215 ± 20 Ma (*), first interpretation of the data by the author. Model ages (**)	Rizzotto (1999), Rizzotto et al. (2001)
Metasandstone (sample GR-66)	S 11°50'35" W 62°04'18"	U-Pb SHRIMP zircon	The ages spread from 2090 to 1103 Ma. Oldest zircons with 2090, 2020, 1904, 1748, 1716, 1546 and 1540 Ma. The younger zircons were grouped into three populations with ages of 1417 ± 35 Ma, 1320 ± 20 Ma and 1211 ± 18 Ma*	Maximum sedimentation age in 1211 ± 18 Ma (*)	Santos et al. (2000)
Fine-grained banded paragneiss (sample GR-66)	S 11°50'35" W 62°04'18"	U-Pb SHRIMP zircon	Ages between 2090 and 1122 Ma. Ages peak of 1417 ± 35 Ma (n=3), 1320 ± 20 Ma (n=5), 1215 ± 20 Ma (n=9) and 1122 ± 12 Ma* (n=2)	Maximum sedimentation age in 1122 Ma (*). Re-interpretation of data by the author	Rizzotto et al. (2014)
Anatectic Leucogranite (sample GR-20)	S 11°43'30" W 62°09'15"	U-Pb SHRIMP zircon Sm-Nd (whole rock)	1110 ± 8 Ma* (n=7) 1,66 Ga**	Crystallization age (climax age of metamorphism)* and model ages (**)	Rizzotto (1999)
Mica schist (sample 324a)	S 11°48'47" W 62°18'48"	^{40}Ar-^{39}Ar	964 ± 1 Ma bio*	Cooling Age	Tohver et al. (2005a)
Mica schist (sample 325)	S 11°48'51" W 62°18'40"	^{40}Ar-^{39}Ar	957 ± 2 Ma bio*	Cooling Age	Tohver et al. (2005a)
Mica schist (sample 326)	S 11°40'45" W 62°11'50"	U-Pb monazite ^{40}Ar-^{39}Ar	1082 ± 6 Ma m 948 ± 2 bio*	Growth of the monazite below its closing temperature through dynamic recrystallization and Cooling Age	Tohver et al. (2004)
Mica schist (sample 127)	S 11°40'50" W 62°11'50"	^{40}Ar-^{39}Ar	930 ± 3 Ma bio*, 928 ± 4 Ma bio, 923 ± 3 Ma bio*, 920 ± 3 Ma bio	Cooling Age	Tohver et al. (2005a)
Calc-silicate (sample 316)	S 11°49'20" W 61°51'05"	U-Pb monazite	1020 ± 15 Ma m	Isotopic resetting age	Tohver et al. (2005a)
Rio Branco Suite (felsic component)					
Foliated monzogranite (sample GR-10a)	S 11°55'52" W 62°09'04"	U-Pb SHRIMP zircon Sm-Nd (whole rock)	1113 ± 56 Ma* (n=5, upper intercept) 1.63 Ga** (TDM)	Crystallization age (climax age of metamorphism) (*) and model ages (**)	Rizzotto (1999)
Foliated granite dike (sample MQ-147M)	S 11°55'59" W 62°08'55"	U-Pb LA-ICP-MS zircon	1113 ± 6.7 Ma (n=15, concordia age)	Crystallization age	**This work**
Fine-grained metagranite subvolcanic or felsic volcanic (sample MQ-124)	S 11°54'20" W 62°02'57"	U-Pb LA-ICP-MS zircon	1112.3 ± 1.9 Ma (n=16, concordia age)	Crystallization age	**This work**
Rio Branco Suite (mafic component and other associated lithologies)					
Metaggabro (sample GR-05)	S 11°59'50" W 62°02'40"	U-Pb SHRIMP zircon	1110 ± 10 Ma (n=4, upper intercept)	Metamorphism age	Rizzotto (1999)
Banded leucrocatic trondhjemite (sample GRT-02)	S 11°57'04" W 61°45'01"	U-Pb SHRIMP zircon and titanite	1089 ± 9 Ma* (zr, n=4) and 986 ± 6 Ma** (ti, n=5)	Metamorphism age (*) and cooling age (**)	Rizzotto et al. (2014)
Mafic granulite (sample GRT-01)	S 11°57'49" W 61°44'58"	U-Pb SHRIMP zircon	1114 ± 5 Ma* (n=4, upper intercept) and 1014 Ma** (n=1)	peak metamorphism age (*) and later metamorphic event (**)	Rizzotto et al. (2014)
Banded Trondhjemite (sample GRT-03)	S 11°53'11" W 62°29'11"	U-Pb SHRIMP zircon and titanite	1103 ± 17 Ma (zr, n=3 + ti, n=6)	Metamorphic recrystallization age	Rizzotto et al. (2014)
Fine-grained amphibolite (sample GRT-04)	S 11°53'23" W 62°29'16"	U-Pb SHRIMP zircon	1103 ± 7 Ma (n=9)	Peak metamorphism age	Rizzotto et al. (2014)
Coarse-grained amphibolite (sample GRT-05)	S 11°57'08" W 63°05'57"	U-Pb SHRIMP zircon and rutile	1103 ± 5 Ma* (zr, n=3) and 949 ± 9 Ma** (ru, n=6)	Metamorphic recrystallization age (*) another late recrystallization phase after 1.0 Ga (**)	Rizzotto et al. (2014)
Metagabbro (sample MQ-117)	S 11°57'05" W 61°52'48"	U-Pb LA-ICP-MS zircon	1119.7 ± 2.7 Ma* (n=8, concordia age), 1016 ± 3.9 Ma** (n=3, concordia age)	Inherited zircons (*) and crystallization age (**)	**This work**
Folicted metatrondhjemite (sample MQ-29)	S 11°56'55" W 62°13'20"	U-Pb LA-ICP-MS zircon	1106.2 ± 2.8 Ma (n=8, concordia age)	Crystallization age	**This work**
Rio Branco Formation					
Calc-silicate gneiss (sample 135)	S 11°55'49" W 62°02'12"	U-Pb titanite ^{40}Ar-^{39}Ar	1061 ± 14 Ma ti (intercept) 961 ± 4 hb*, 966 ± 3 hb	Metamorphic recrystallization age and Cooling Age	Tohver et al. (2004), Tohver et al. (2005a)
Calc-silicate gneiss (sample 319)	S 11°57'29" W 61°51'11"	U-Pb monazite	993 ± 12 Ma m (intercept)	Growth of the monazite below its closing temperature through dynamic recrystallization	Tohver et al. (2004)
Metagabbro (sample 133)	S 11°54'37" W 61°46'51"	^{40}Ar-^{39}Ar	994 ± 6 Ma hb*, 983 ± 7 Ma hb, 1005 ± 7 Ma hb*	Cooling Age	Tohver et al. (2005a)
Mylonitic paragneiss (sample 134)	S 11°54'55" W 61°46'49"	U-Pb monazite ^{40}Ar-^{39}Ar	1096 ± 6 Ma m 912 ± 2 bio*, 910 ±2 bio, 914 ±2 bio*	Metamorphic recrystallization age and Cooling Age	Tohver et al. (2004), Tohver et al. (2005a)
High-grade calc-silicate gneiss (sample MQ-44)	S 11°58'30" W 61°46'59"	U-Pb LA-ICP-MS zircon	Ages between 1575 and 1012 Ma. Ages peak of 1578 Ma, 1480 Ma, 1432 Ma, 1386 Ma, 1241 ± 7.5 Ma*, 1137 ± 9 Ma** and 1019 ± 5 Ma***. Low Th/U ratio (0,02-0,09) peak age in 1137 ± 9 Ma** (n=4, rim or overgrowth of zircon around detritic core). Youngest peak age in 1019 ± 15 Ma*** (n=5, Th/U=0,14-0,21)	Maximum sedimentation age in 1241 ± 7.5 Ma*. High-grade metamorphism age in 1137 ± 9 Ma**. Another late metamorphic recrystallization or migmatization phase in 1019 ± 5 Ma***	**This work**
High-grade trondhjemitic gneiss (sample MQ-122)	S 11°59'33" W 61°58'09"	U-Pb LA-ICP-MS zircon	1127.6 ± 2.3 Ma* (n=12, concordia age), 1121.6 ± 5.9 Ma (n=27, upper intercept)	Precise crystallization age (*)	**This work**
Anatectic granite lens in paragneiss (sample MQ-146B)	S 12°00'23" W 61°51'23"	U-Pb LA-ICP-MS zircon	Ages between 1559 and 986 Ma. Concordia age in 1137.7 ± 4.7Ma* (n=3, Th/U=0,1-0,3) and discordia age in 1011.3 ± 9.6 Ma** (n=11, Th/U=0,01-0,03)	Inherited zircons (*) and crystallization age (**)	**This work**
São Felipe Complex					
Fine-grained dark banded gneiss with granitic leucosome (sample GR336)	S 12°00'23" W 61°27'29"	U-Pb LA-ICP-MS zircon	Ages peaks in 1512 Ma (n=4); 1420 Ma (n=1), 1337 Ma* (n=8) and 1068 ±20 Ma** (n=2)	Maximum sedimentation age in 1337 Ma (*) and migmatization age (granitic leucosome) in 1068 Ma (**)	Rizzotto et al. (2014)
Migmatite gneiss (GB-611)	S 11°56'31" W 61°31'49"	U-Pb SHRIMP zircon	1552 ± 4 Ma* (n=7, concordia age), 1328 ± 12 Ma** (n=2, rim with low Th/U ratio, weighted average age)	Crystallization age (*) and later metamorphism age (**)	Trindade Neto et al. (2018)
Coarse-grained tonalitic orthogneiss (GR-337) with granitic dike	S 12°00'31" W 61°28'32"	U-Pb LA-ICP-MS zircon	1435 ± 2 Ma* zr (n=6, low Th/U, intercept age) and 1012 ± 22 Ma* cas (weighted average age)	Metamorphic age (*) and weighted average ^{207}Pb/^{206}Pb ages of granitic dike**	Rizzotto et al. (2013)

Target minerals: bio=biotite (plateau age), bio*=biotite (total gas age), hb=hornblende (plateau age), hb*=hornblende (total gas age), m=monazite, ti=titanite, ru=rutile, zr=zircon, cas=cassiterite, * and (*) = correlation of the age with interpretation, n=number of crystals or grains analyzed. SIRGAS 2000 is the reference Datum of the geographics coordinates of the samples. Ma - Millions of Years and Ga - Billions of Years.

4. Analytical methods

The field works consisted of systematic mapping at the 1:100,000 scale and in the field detailing of areas of geological interest. Systematic profiles involving detailed description of outcrops and sampling for U-Pb geochronological analysis were developed. Seven samples of the Rio Branco domain were collected and analyzed (Fig. 2). The samples (~8 kg of metasedimentary or felsic rock, ~20-30 kg of metamafic lithotypes) were prepared in the laboratories of CPRM-Geological Survey of Brazil in Porto Velho and Belém. Samples were initially crushed, after processed in the Frantz magnetic separator and subjected to densimetric separation in dense liquids. Zircon crystals were separated and mounted on adhesive tape and after embedded in epoxy resin. In order to identify internal structures, mounts were imaged by backscattered electrons (BSE) in the scanning electron microscope (SEM) at the laboratory of the Geocronology Center of the Institute of Geosciences of the University of Brasilia (Geocron-IG/UnB). The U-Pb (LA-ICP-MS) zircon isotopic data were obtained at the same Center and followed the analytical procedure described by Bühn et al. (2009). Before LA-ICP-MS analyses, mounts were cleaned by rinsing with dilute HNO_3 (2%). Once fully dry, the samples were mounted together with GJ1 standard zircon (Jackson et al., 2004) in a specially adapted laser cell and loaded into a New Wave UP213 Nd:YAG laser (213 nm), linked to a Thermo Finnigan Neptune Multi-collector ICP-MS. Helium was used as the carrier gas and mixed with argon before entering the ICP. The laser was run at a frequency of 10 Hz. Pb isotopes 204 and 207 were collected with ion counters; ^{238}U and ^{206}Pb were analyzed on a Faraday cup. The content of ^{202}Hg was monitored on an ion counter for correction of the isobaric interference between ^{204}Hg and ^{204}Pb. The signals during ablation were taken in 40 cycles of 1 sec each. For data evaluation, only coherent intervals of signal response were considered. Data reduction was performed with an Excel spreadsheet developed by Geocron-IG/UnB technicians, which considers blank values, zircon standards composition and error propagation. The ^{204}Pb signal intensity was calculated using a natural $^{202}Hg/^{204}Hg$ ratio of 4.346. Common-Pb correction was applied for zircon grains with $^{206}Pb/^{204}Pb$ lower than 1000, applying a common lead composition following the Stacey and Kramers (1975) model. Plotting of U-Pb data was performed by ISOPLOT v. 4.15 (Ludwig, 2003). Errors for isotopic ratios are presented at the 1σ level. For the calculation of age integrated diagrams, only > 90% concordance grains or crystal to paraderived rocks and > 95% concordance to orthoderived rocks were considered.

5. Results - New field geological data

5.1 The high-grade metamorphic rocks of Rio Branco Formation

In the study area, the Rio Branco Formation constitutes a high-grade metavolcanic-sedimentary unit. It consists of calc-silicate gneisses, biotite paragneisses, trondhjemitic gneisses, lenses of fine- to medium-grained amphibolites, as well as pelitic and mafic granulites (Fig. 3). These rocks form an E-W oriented belt marked by E-W trending compositional banding dipping at a high angle to N or S. Folds and late shear zones were observed in the lithological set of this formation (Figs. 3A, 4A, 4B, 4C). In the outcrops, gneissic rocks are grayish-green and whitish, fine- to medium-grained, non-magnetic, banded or locally massive. In the banded calc-silicate gneisses, there is alternation between clear centimetric bands formed of plagioclase and subordinate quartz and dark centimetric bands formed of hornblende, diopside, garnet and titanite (Figs. 3C, 3D, 3E). Massive calc-silicates are light green to locally white, medium-grained, and dominantly composed of plagioclase, containing epidote and amphibole as varietal minerals and garnet as accessory. Some calc-silicate gneisses are composed dominantly of plagioclase rimmed by garnet may suggest a dehydration reaction. Porphyroblastic, symplectitic textures with intergrowths of cordierite and hornblende around subhedral garnet cores and local reaction coronae between diopside cores and plagioclase rims with hornblende intergrowths are common in these rocks. Reaction coronas and simplectectites provide useful information about PT conditions during high-

grade metamorphism, however, detailed studies are necessary to understand the metamorphic conditions in which the Rio Branco Formation rocks were submitted, as well as the mineralogical reactions that occurred during the exhumation process.
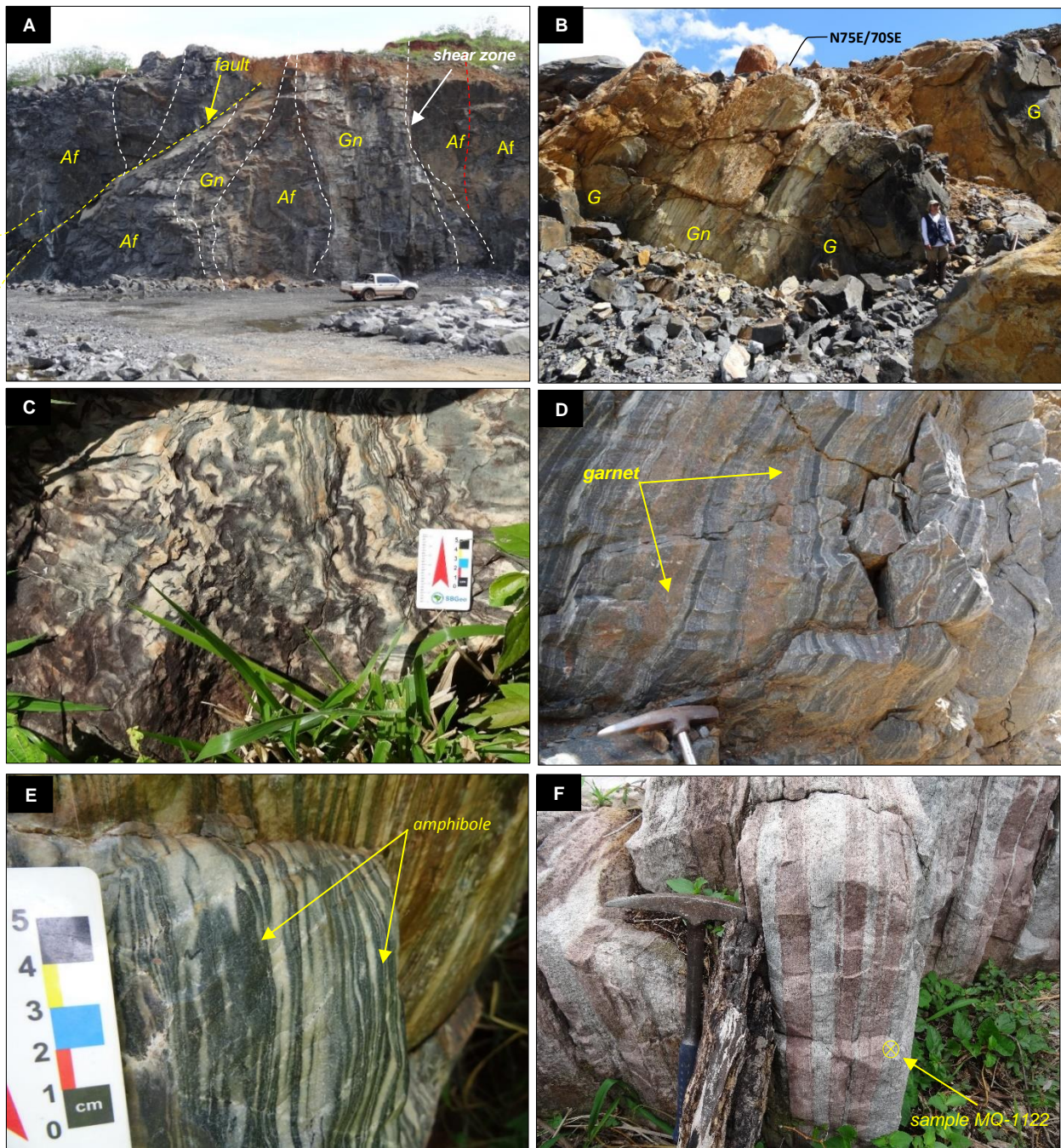
Fig. 3. *Field aspect of high-grade metasedimentary rocks of the Rio Branco Formation and related metamafic rocks. (A) calc-silicate gneisses (Gn) with fine-grained amphibolite lenses (Af) in outcrop located in a quarry south of Alta Floresta d'Oeste. (B) general aspects of intercalation of calc-silicate gneisses (Gn) with granulite lens (G) in outcrop 5 km to the south of Alta Floresta d´Oeste. (C) calc-silicate gneiss (B). (D) calc-silicate gneiss with garnet-rich bands. (E) calc-silicate gneiss with intercalation of amphibole-rich bands and quartz-plagioclase-rich bands. (F) trondhjemitic gneiss (dated by U-Pb in this work).*
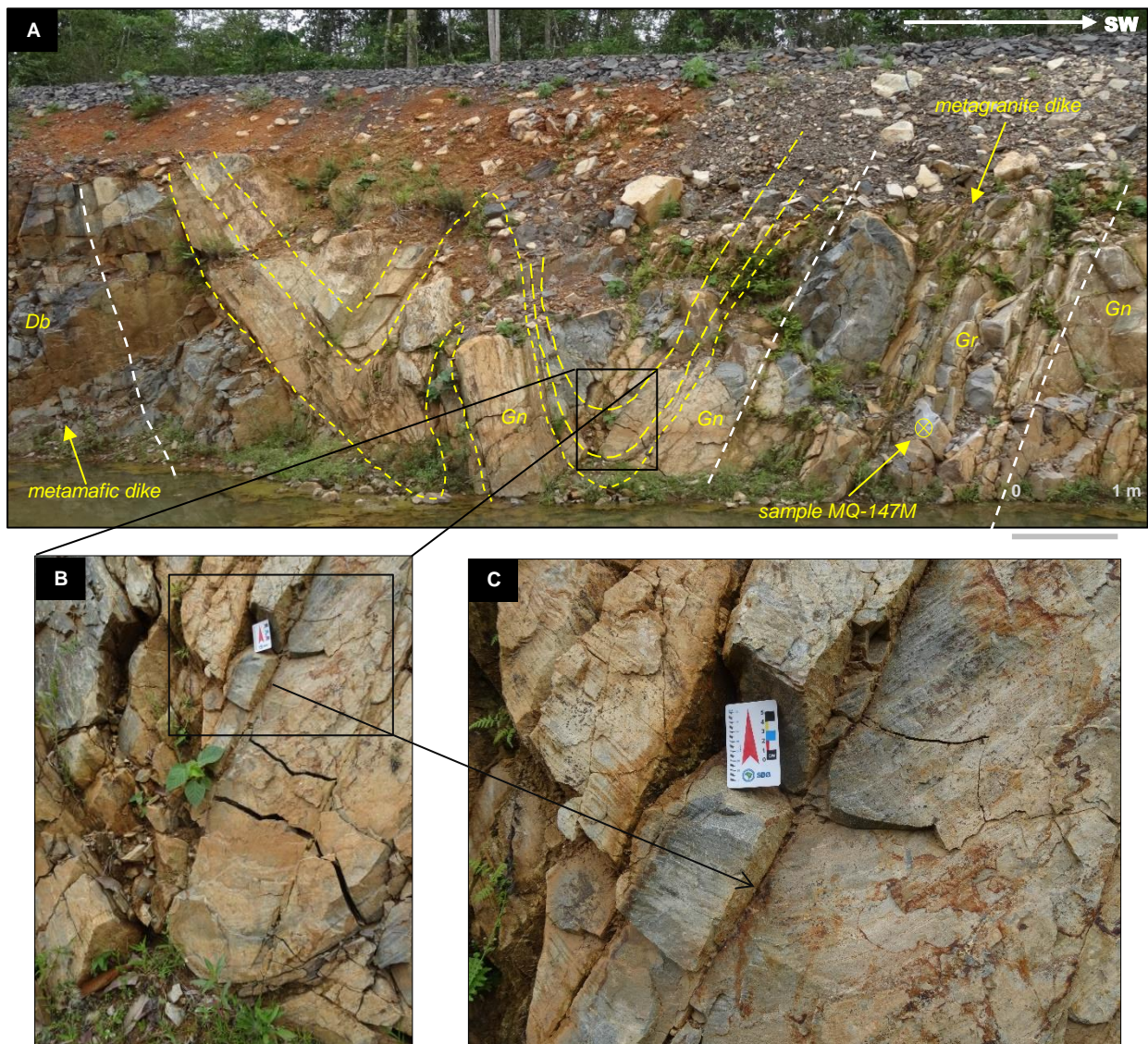
Fig. 4. *Outcrop located at the Cachimbo Alto Hydroelectric to the west of Alta Floresta d'Oeste. (A) general aspect of calc-silicate folded gneiss (Gn) of the Rio Branco Formation, cut by metadiabase dikes (Db) and metagranite dikes (Gr) of the Rio Branco Suite. (B) detail of the apical zone of the largest fold in calc-silicate gneiss. (C) detail of (B). Yellow traces = banding and foliation, white traces = contacts of the dikes. Sample MQ-147M of this outcrop was dated by U-Pb in this work.*

Amphibolite lenses and mafic granulites bodies occur intercalated with high-grade metasedimentary rocks (Figs. 3A, 3B). Amphibolites were found mainly along the shear zones and are dark gray, medium- to fine-grained, and moderately to strongly magnetic, with nematoblastic, foliated and mylonitic textures. The amphibolites are composed essentially of hornblende and plagioclase, with diopside and orthopyroxene relics, secondary actinolite, opaque minerals and titanite as accessory phases and clay minerals, chlorite and biotite as hydrothermal alteration minerals. The mafic granulites occur locally in cores preserved or unaffected by shear, and are composed mainly of curved plagioclase, diopside, curved orthopyroxene and opaque minerals. Metamorphic history needs to be better evaluated in later studies. In some places, sulfides occur in lenses and fractures filled by massive aggregates or disseminations of fine-grained sulfides

(pyrrhotite, pyrite, chalcopyrite and subordinate bornite) within amphibolites and calc-silicate gneisses.

Three samples from the Rio Branco Formation were selected for LA-ICP-MS U-Pb zircon dating and represent, respectively, a high-grade calc-silicate gneisses (samples MQ-44), high-grade trondhjemitic gneiss (MQ-122) and anatectic granite (sample MQ-146B). Isotopic data of these samples are reported in sections 6.1 and 6.4.

5.2 The Rio Branco Suite (mafic-felsic magmatism)

This association of igneous rocks was first named as Rio Branco Suite (Rizzotto, 1999), corresponding to mafic-felsic magmatism that occurs in the form of elongated stocks and planar massive bodies (sills and dike swarms), intrusive in high-grade metasedimentary rocks of the Rio Branco Formation. Usually present different intensity of deformation in rocks that ranging from isotropic, foliated or banded, locally migmatized.

The metamafic rocks of plutonic origin are locally deformed, but often exhibit preserved mineralogy and igneous textures except in the portions affected by shear. Petrographic classification of the Rio Branco Suite rocks revealed metagabbros, olivine metagabbros, coronitic metagabbros and metagabbronorites, with subordinate metatroctolites and medium to fine-grained amphibolites in the most deformed portions of bodies. Metagabros are predominantly and exhibits dark gray color, coarse- to medium-grained, moderately magnetic, and massive or slightly foliated. They are formed essentially of plagioclase, clinopiroxene (diopside) and orthopyroxene, opaque minerals and titanite as accessories, and clay minerals, hornblende, biotite and sericite as secondary minerals (Fig. 5A). At the contact between paragneisses of the Rio Branco Formation and gabbros of the Rio Branco Suite hybrid rocks containing altered amphibolite xenoliths (chloritized/epidotized) occur, evidencing an intrusion relationship (Fig. 5B). Locally within the metaggabros occur magmatic breccias composed of angular fragments of mafic rocks surrounded by felsic materials (granitic or trondhjemitic in composition) composed of feldspar, quartz and amphibole. Sample MQ-117, corresponding to a metagabbro, was selected for U-Pb dating by LA-ICP-MS and the isotopic data are reported in section 6.2.
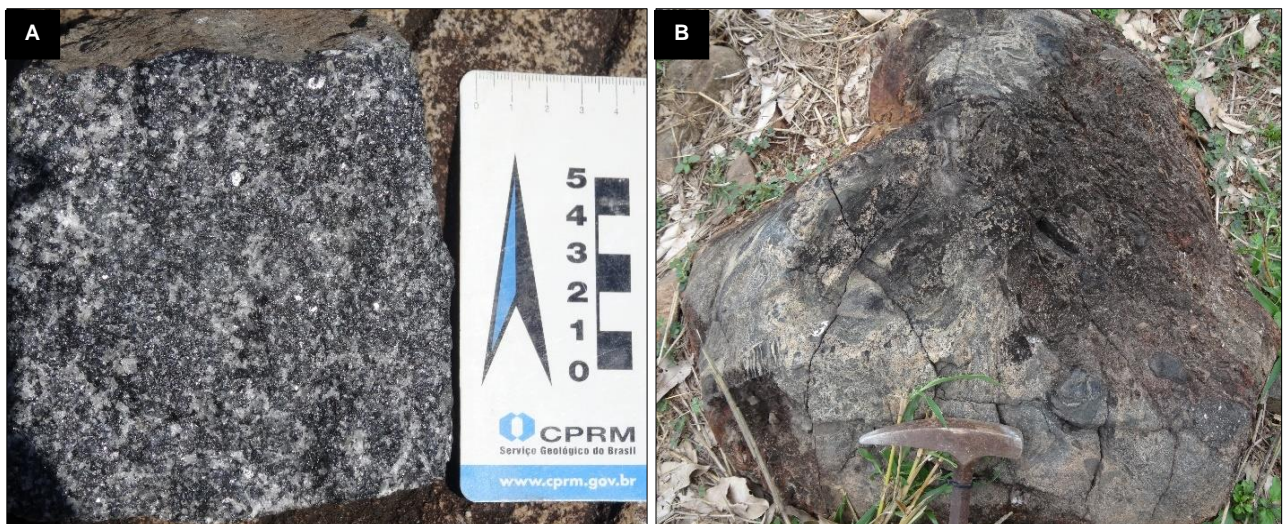
Fig. 5. *Field aspect of the rocks of Rio Branco Suite. (A) medium-grained massive metagabbro and (B) metagabbro with xenoliths of calc-silicate gneiss.*

471   The plutonic to subvolcanic felsic-mafic rocks (dikes, sills and elongated bodies) consist of
472 fine-grained foliated metagranites, metavolcanic felsic rocks, fine-grained metagabbros, massive
473 metabasalts, metadiabases and fine-grained amphibolites, generally trending EW, NW-SE and
474 NE-SW. The fine-grained metagabbros and metadiabases are grayish-green in color, varying from
475 fine-grained to aphanitic, representing several generations of parallel dikes, with thicknesses
476 ranging from 15 to 30 centimeters. They are magnetic to nonmagnetic and are concordant and/or
477 discordant with the regional structure. The volcanic felsic-mafic rocks consist of massive
478 metabasalts and massive fine-grained amphibolites present dark-gray color and are locally
479 magnetic. They are composed of plagioclase phenocrysts and magnetite in a fine-grained foliated
480 matrix with preserved subofitic texture. This set mafic rock occur spatially associated with felsic
481 igneous rocks of granitic and trondhjemitic composition (Rizzotto et al., 2009), with medium- to
482 fine-grained equigranular texture, foliated when deformâmed and pink in color. This mafic and felsic
483 set is interdigitated and mixed, suggesting temporal coexistence where the mafic and felsic bands
484 interdigitate (coeval magmatism), and their contacts are oriented according to the regional foliation
485 trend, following a N80°W trend with a high-angle to subvertical dip (Figs. 6A, B, C, D). In these
486 metamafic-metafelsic rocks, it is common the occurrence of high-angle transpressive shear zones,
487 observed mainly along the outcrops in the Cachimbo Alto Hydroelectric spillway (Fig. 6A).
488   In outcrop located at Cachimbo Alto Waterfall, three generations of metamafic dikes ware
489 defined based on field relations, called M1, M2 and M3 (Fig. 7). Based on field relationships, M1
490 dike corresponds to the oldest pulse and characterized by foliated, fine-grained non-magnetic
491 amphibolites. M2 dike differs from M1 due to its magnetic signature and corresponds to an
492 intermediary pulse. M3 dike consists of a medium-grained, slightly foliated non-magnetic
493 amphibolite with plagioclase fenocrystals.
494   The elongated felsic stocks of the Rio Branco Suite are represented by gray-red porphyritic
495 biotite metagranite, which vary from protomylonites to mylonites along the shear zones (Fig. 8A,
496 B). Two samples were selected for LA-ICP-MS U-Pb zircon analysis: sample MQ-147M is from a
497 foliated granite dike intruded in high-grade calc-silicate gneiss of the Rio Branco Formation from
498 the spillway of the Cachimbo Alto hydroelectric dam (Fig. 4A, sampling location). Sample MQ-
499 124 is a fine-grained subvolcanic metagranite intruded in metamafic rocks, from an outcrop along
500 the Linha-45 road (Fig. 8C). The locations of the samples can be observe in figure 4 and the isotopic
501 data of these samples are presented in section 6.3.
502   The metatrondhjemites occur in association with metamafic rocks and appear in the form of
503 small elongated bodies, lenses (<500 m) or dikes, sub concordant with the regional structure. They
504 are banded or foliated types, usually leucocratic and fine- to medium-grained, composed mainly of
505 quartz and saussuritized plagioclase, and subordinately of amphibole, clinopyroxene, titanite,
506 magnetite and zircon (Fig. 8D). Sample MQ-29 of medium-grained leucocratic metatrondhjemite
507 was selected for dating by the LA-ICP-MS zircon U-Pb method. The isotopic data of this sample
508 are described in section 6.3.
509
510 *5.3 Rio Pardo Suite (post-tectonic magmatism)*
511
512   In the study area, felsic rocks are represented by post-tectonic granites (ages 1.02-1.00 Ga),
513 intrusive in metasedimentary rocks of the Nova Brasilândia Group. These granites occur as elliptic
514 and elongated bodies in the direction of the regional E-W or NW-SE foliation trend. The suite
515 consists of monzogranites, syenogranites and rare aplitic dikes, as well as veins and pockets of
516 associated pegmatites. In general, they are isotropic to foliated rocks, locally mylonitized (augen
517 gneiss) and banded (gneiss).
518   These leucocratic to mesocratic rocks range from pink to gray, coarse- to medium-grained
519 showing equigranular or porphyritic textures. In the Rio Branco domain, there is an elongated body
520 of the Rio Pardo Suite intruded in calc-silicate gneiss of the Rio Branco Formation, and metamafic
521 rocks of the Rio Branco Suite.
522
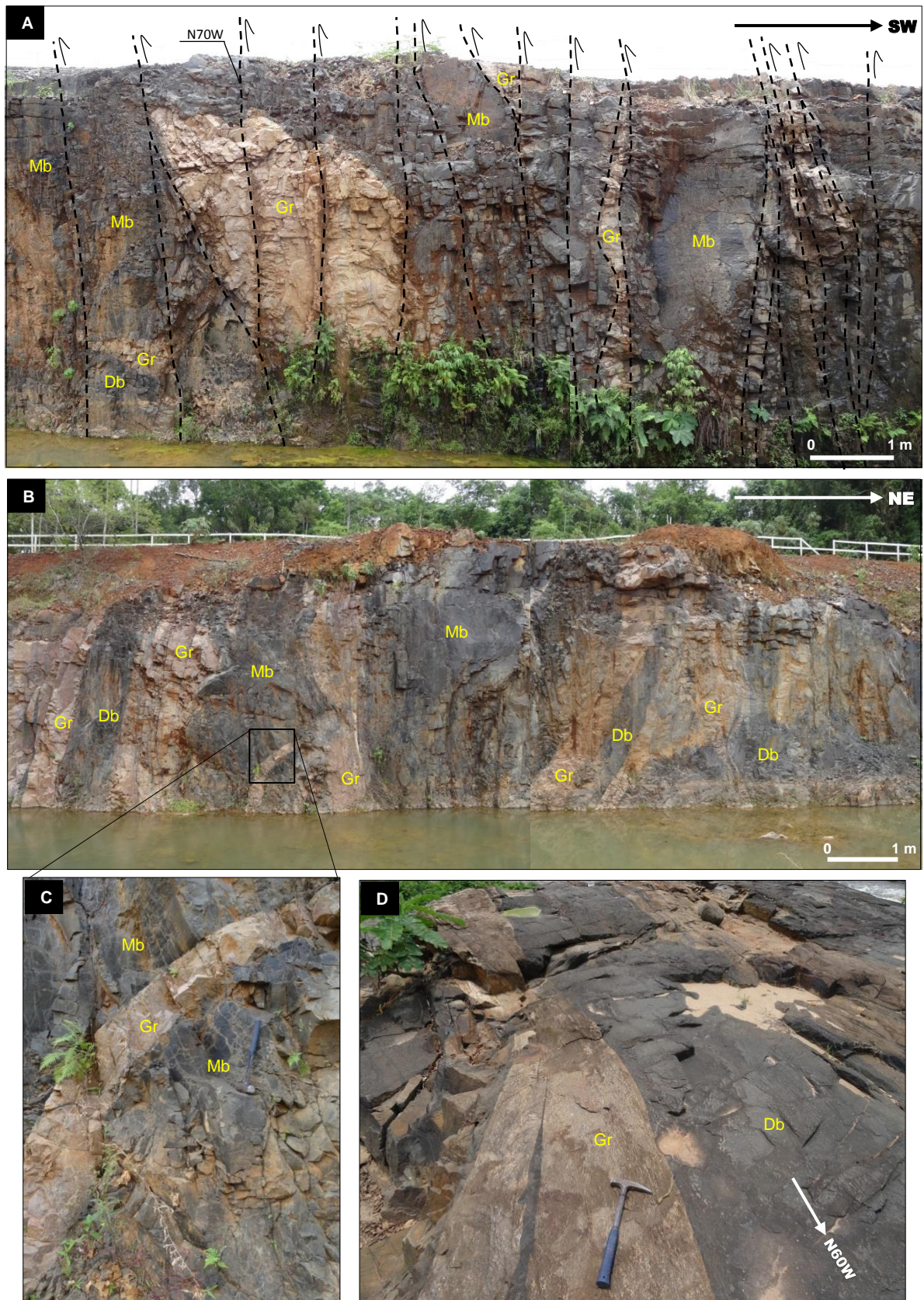
Fig. 6. (A) and (B) field general aspects of the spatial relations of multiple intrusion of dikes and coeval magmatic activity between foliated metabasalt (Mb), foliated metagranite (Gr) and metadiabase (Db), of the Rio Branco Suite. (C) detail of metagranite dike cutting metadiabase. (D) Detail in plan showing the contact relation between metadiabase and metagranite dikes. Black traces in (A) mark transpressive shear zones.
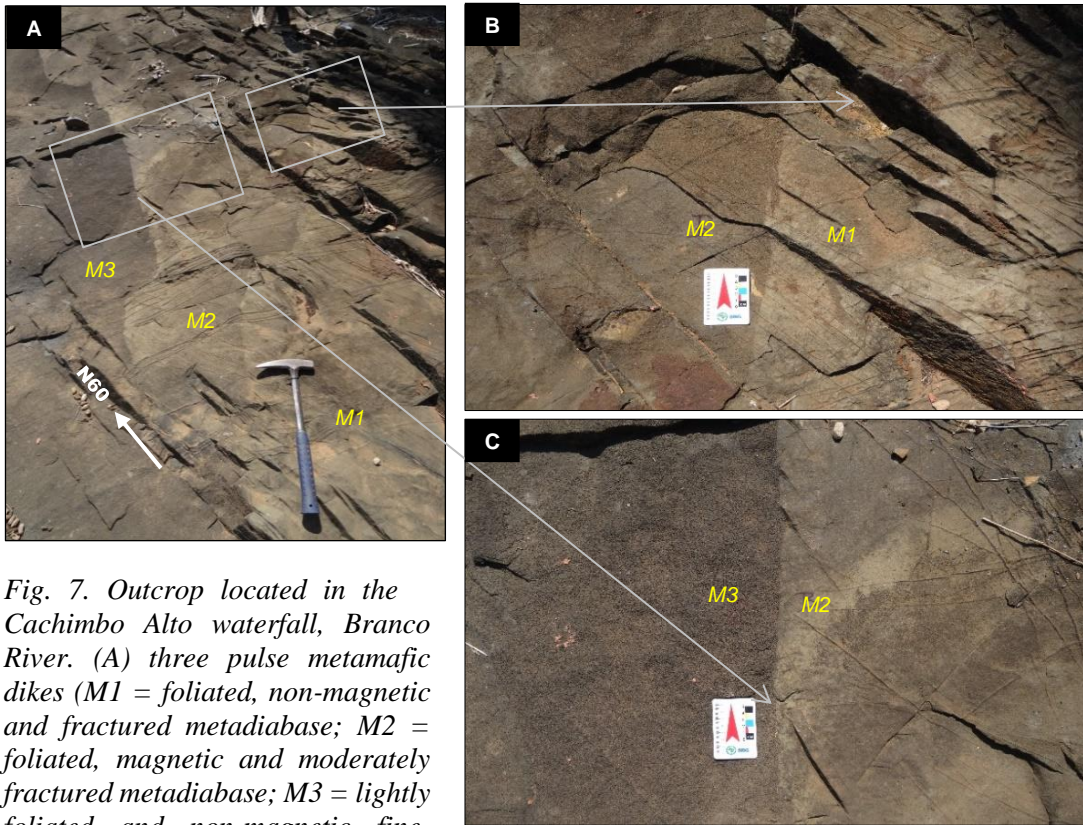
Fig. 7. Outcrop located in the Cachimbo Alto waterfall, Branco River. (A) three pulse metamafic dikes (M1 = foliated, non-magnetic and fractured metadiabase; M2 = foliated, magnetic and moderately fractured metadiabase; M3 = lightly foliated and non-magnetic fine-grained metaggabro). (B) and (C) field details of intrusive contact between dikes.
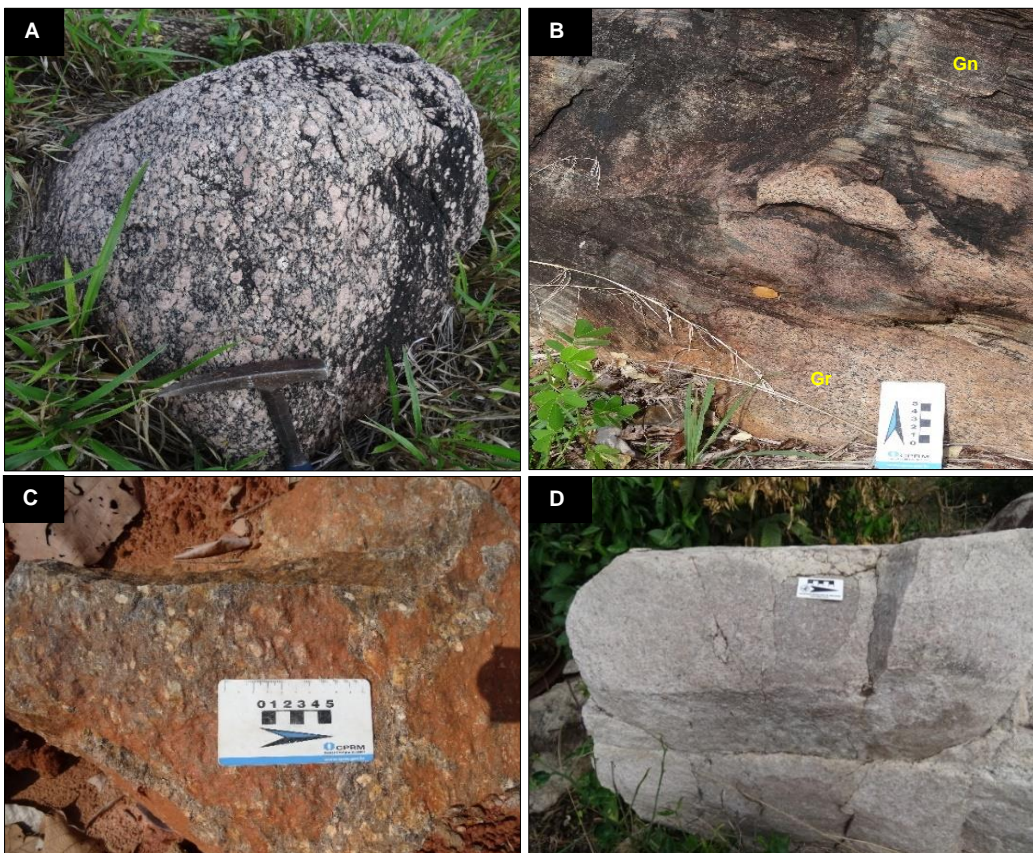
Fig. 8. Field aspect in (A) porphyritic biotite metagranite, (B) intrusive contact between calc-silicate gneisse (Gn) and metagranite (Gr), (C) subvolcanic porphyritic metagranite (sample MQ-124), and (D) foliated metatrondhjemite (sample MQ-29).

41

6. Results - LA-ICP-MS zircon U-Pb analysis

Below, we will present zircon LA-ICP-MS U-Pb analytical results of the seven samples of the Rio Branco domain from outcrops located to the south and west of Alta Floresta d'Oeste and Santa Luzia d'Oeste (Table 2). The selected samples included high-grade calc-silicate gneiss (sample MQ-44), high-grade trondhjemitic gneiss (sample MQ-122), metagabbro (sample MQ-117), metagranite dike (sample MQ-147M), felsic subvolcanic rock/metagranite (Sample MQ-124), metatrondhjemite (sample MQ-29) and anatectic granite (sample MQ-146B) (Fig. 2).

6.1 High-grade metamorphic rocks (Rio Branco Formation)

Sample MQ-44 (S11°58'30"/W61°46'59") is a high-grade calc-silicate gneiss that occurs associated with metamafic rocks. Zircon grains from this sample mostly ranges from 50 to 350 μm, some grains with core and rim features (Fig. 9). Internally, the crystals present a pattern of radial and concentric fractures, where the radial fractures start at the central margin of the core and propagate to the outermost layers of the grains (Fig. 9, crystal D). Based on BSE images, sixty-four points located on the core and rims of zircon crystals were selected for analysis with the interest of identifying the ages of the overgrowth phases. Of these, fifty-six zircon crystals (zircons data in normal black font style, sample MQ-44, Table 2) were analyzed and presented concordance > 90 % (Fig. 10A, B) and were used in the Concordia diagram and probability density plot (PDP) (Fig. 10B). These zircon crystals present Th/U ratios ranging from 0.02 to 0.38 and ages between 1575 Ma and 1012 Ma. In this sample, a group of small homogeneous zircon grains (<100 μm), subrounded to elliptical, has Th/U ratios < 0.10. Another group of larger zircon grains (100-270 μm) presents core and rims and tends to be prismatic with smoothly rounded contours, exhibiting luminescent rims and low Th/U ratios from 0.02 to 0.09. Isotopic data from the first group and rims of the second group (ages 1123 to 1181 Ma, see Fig. 9A, 9G) were used to calculate the Concordia age of 1137 ± 9 Ma (n=4, MSWD=0.61), interpreted as the age of the high-grade metamorphism that affected the calc-silicate gneisses of the Rio Branco Formation (Figs. 9B, G, I, J, 10B). Zircon core analyses provide Th/U ratios between 0.10 and 0.38 and $^{207}Pb/^{206}Pb$ ages that define major peaks at approximately 1575, 1480 Ma, 1432 Ma, 1386 Ma and 1241 Ma (Fig. 10B). These isotopic results are considered the ages of the main source areas of the Rio Branco Formation sedimentary protoliths (Figs. 9A, 9B, 9C, 9D, 9E, 9F, 9G, 9H). The $^{207}Pb/^{206}Pb$ age of 1241 ± 7.5 Ma is interpreted as possible maximum age of the sedimentation of the Rio Branco Formation protoliths and 1137 ± 9 Ma age is interpreted as the age of high-grade metamorphism (granulitic) (Fig. 10B). Detailed work is still need to define sedimentation and metamorphism precise ages.

In the sample MQ-44, some larger concordant zircon fragments (sizes 100-200 μm) are homogeneous, locally fractured, partially recrystallized and have Th/U ratios between 0.14 and 0.21. Data from these zircon fragments allowed the calculation of the Concordia age of 1019 ± 15 Ma (n = 5), preliminarily interpreted as the age of metamorphic recrystallization or migmatization (partial fusion) and possibly associated with a younger metamorphic pulse (Fig. 10A, B). Alternatively, can represent an age from contamination by granitic vein injections (Fig. 9K, L, M).

Sample MQ-122 (S11°59'33"/W61°58'09") is a high-grade trondhjemitic gneiss light-colored, fine-grained, banded, occurring in the form of lenses spatially associate with mafic granulites. The essential mineralogy is saussuritized plagioclase and quartz, additionally magnetite, amphibole, titanite, zircon and epidote. The texture is granoblastic with polygonal contacts. The zircon crystals extracted from this sample are euhedral to subhedral short prisms with slightly rounded extremities, sizes ranging from 80 to 200 μm, containing some inclusions and fractures. BSE images show discrete to well-marked oscillatory zoning, but some crystals or overgrowths have many irregular luminescent places, profusion of inclusions and radial or irregular fractures. From sample MQ-122, thirty-six zircon crystals were analyzed (Table 2, sample MQ-122).

Table 2.
LA-ICP-MS U-Pb zircon isotopic data from seven rock samples of the Rio Branco domain, Nova Brasilândia belt in southwest Amazonian Craton, Rondônia.

					Radiogenic ratios					Ages[5]						
Identifier	Th/U	f206 (%)	$^{207}Pb/^{206}Pb$	1σ %	$^{207}Pb/^{235}U$	1σ %	$^{206}Pb/^{238}U$	1σ %	Rho	$^{207}Pb/^{206}Pb$	2σ abs	$^{206}Pb/^{238}U$	2σ abs	$^{207}Pb/^{235}U$	2σ abs	% U-Pb disc[4]
Rio Branco Formation, high-grade calc-silicate gneisse (sample MQ-44)																
047-ZR33	0.10	0.0480	0.07706	1.31	2.040	2.02	0.1919	1.50	0.74	1123	52	1132	31	1129	27	-0.81
074-ZR53B	0.08	0.0663	0.07847	1.94	2.047	3.57	0.1892	2.97	0.83	1159	76	1117	61	1131	48	3.60
065-ZR47	0.02	0.0491	0.07894	1.71	2.138	2.61	0.1964	1.93	0.74	1171	67	1156	41	1161	36	1.24
057-ZR41	0.08	0.0805	0.07934	2.56	2.051	3.70	0.1875	2.65	0.72	1181	99	1108	54	1133	50	6.18
046-ZR32B	0.08	0.0143	0.07881	0.76	2.067	1.30	0.1902	0.99	0.76	1167	30	1123	20	1138	18	3.84
006-ZR04	0.05	0.0223	0.07862	1.07	1.930	2.78	0.1780	2.54	0.91	1163	42	1056	49	1092	37	9.15
038-ZR28	0.06	0.0024	0.08127	0.62	2.346	1.07	0.2094	0.78	0.73	1228	24	1225	17	1226	15	0.20
064-ZR46	0.09	0.0080	0.08917	0.71	2.959	1.69	0.2407	1.49	0.88	1408	27	1390	37	1397	25	1.25
016-ZR11B	0.08	0.0019	0.09225	0.41	3.472	1.18	0.2730	1.05	0.89	1472	15	1556	29	1521	19	-5.67
035-ZR25	0.09	0.0206	0.09739	1.32	3.755	2.96	0.2796	2.63	0.89	1575	49	1590	74	1583	47	-0.94
023-ZR16	0.14	0.0223	0.07293	0.85	1.667	1.32	0.1658	0.93	0.71	1012	34	989	17	996	17	2.28
026-ZR18	0.19	0.0385	0.07322	1.10	1.745	1.67	0.1728	1.20	0.72	1020	44	1028	23	1025	21	-0.75
019-ZR14	0.20	0.0306	0.07364	1.08	1.754	1.81	0.1728	1.40	0.77	1032	43	1027	27	1029	23	0.41
077-ZR56	0.22	0.0366	0.07383	1.01	1.739	1.57	0.1708	1.14	0.73	1037	40	1017	22	1023	20	1.96
075-ZR54	0.22	0.0240	0.07469	0.72	1.792	1.29	0.1740	1.00	0.78	1060	29	1034	19	1043	17	2.46
040-ZR30	0.21	0.0062	0.07579	0.79	1.928	1.44	0.1844	1.14	0.79	1090	32	1091	23	1091	19	-0.15
054-ZR38	0.15	0.0296	0.07612	1.05	1.916	1.80	0.1825	1.42	0.79	1098	42	1081	28	1087	24	1.59
010-ZR08	0.13	0.0068	0.07710	0.61	2.072	1.14	0.1949	0.90	0.78	1124	24	1148	19	1140	16	-2.12
029-ZR21	0.17	0.0093	0.07764	0.79	2.056	1.21	0.1921	0.84	0.69	1138	31	1133	17	1134	16	0.45
008-ZR06	0.14	0.0096	0.07765	0.61	2.086	1.10	0.1948	0.84	0.76	1138	24	1148	18	1144	15	-0.84
066-ZR48	0.18	0.0288	0.07807	0.98	2.140	1.67	0.1988	1.30	0.78	1149	39	1169	28	1162	23	-1.77
079-ZR58	0.11	0.0514	0.08027	2.06	2.098	3.13	0.1895	2.33	0.75	1204	80	1119	48	1148	43	7.04
027-ZR19	0.15	0.0081	0.08166	0.76	2.390	1.92	0.2123	1.73	0.90	1237	30	1241	39	1240	27	-0.28
048-ZR34	0.14	0.0144	0.08192	0.74	2.399	1.28	0.2123	0.98	0.76	1244	29	1241	22	1242	18	0.18
017-ZR12	0.10	0.0192	0.08213	0.73	2.267	1.25	0.2002	0.94	0.75	1249	28	1176	20	1202	17	5.79
033-ZR23	0.11	0.0591	0.08304	1.77	2.610	2.53	0.2280	1.77	0.70	1270	68	1324	42	1304	37	-4.24
004-ZR02	0.17	0.0113	0.08417	0.73	2.496	1.17	0.2151	0.83	0.71	1296	28	1256	19	1271	17	3.14
049-ZR35	0.23	0.0282	0.08454	0.66	2.577	1.14	0.2211	0.85	0.75	1305	26	1287	20	1294	17	1.35
003-ZR01	0.13	0.0065	0.08558	0.59	2.579	1.26	0.2185	1.05	0.83	1329	23	1274	24	1295	18	4.11
056-ZR40	0.11	0.0184	0.08573	0.80	2.577	1.19	0.2180	0.80	0.67	1332	31	1271	18	1294	17	4.56
067-ZR49	0.18	0.0178	0.08631	0.74	2.668	1.42	0.2242	1.16	0.81	1345	28	1304	27	1320	21	3.08
078-ZR57	0.22	0.0021	0.08646	0.59	2.860	1.25	0.2399	1.03	0.83	1348	23	1386	26	1371	19	-2.78
014-ZR10	0.15	0.0124	0.08754	0.61	2.726	0.98	0.2258	0.68	0.69	1372	23	1312	16	1335	15	4.37
076-ZR55	0.16	0.0306	0.08782	0.87	2.865	1.70	0.2366	1.41	0.83	1379	33	1369	35	1373	25	0.71
055-ZR39	0.11	0.0173	0.08800	0.94	2.811	1.42	0.2316	1.01	0.71	1383	36	1343	24	1358	21	2.86
059-ZR43	0.13	0.0118	0.08800	0.75	2.813	1.18	0.2318	0.82	0.70	1383	29	1344	20	1359	18	2.80
013-ZR09	0.12	0.0198	0.08813	0.99	2.680	1.59	0.2206	1.19	0.75	1385	38	1285	28	1323	23	7.26
009-ZR07	0.10	0.0198	0.08825	1.06	2.936	1.69	0.2413	1.26	0.75	1388	41	1393	32	1391	25	-0.39
005-ZR03	0.19	0.0287	0.08841	0.82	2.998	1.28	0.2459	0.91	0.71	1392	31	1417	23	1407	19	-1.86
034-ZR24	0.12	0.0281	0.08873	1.07	2.760	1.64	0.2256	1.19	0.73	1398	41	1311	28	1345	24	6.23
036-ZR26	0.11	0.0169	0.08909	0.80	2.874	1.35	0.2340	1.03	0.76	1406	30	1355	25	1375	20	3.61
073-ZR53N	0.18	0.0017	0.09016	0.58	3.314	1.03	0.2665	0.77	0.74	1429	22	1523	21	1484	16	-6.59
007-ZR05	0.18	0.0028	0.09023	0.40	3.066	0.80	0.2465	0.59	0.73	1430	15	1420	15	1424	12	0.71
060-ZR44	0.28	0.0016	0.09101	0.77	3.296	1.42	0.2627	1.13	0.80	1447	29	1503	30	1480	22	-3.92
024-ZR17N	0.15	0.0062	0.09123	0.73	3.110	1.12	0.2472	0.77	0.69	1451	28	1424	20	1435	17	1.89
080-ZR59	0.38	0.0008	0.09136	0.75	3.424	1.22	0.2718	0.89	0.73	1454	28	1550	25	1510	19	-6.60
063-ZR45	0.13	0.0170	0.09254	0.98	3.162	1.62	0.2478	1.23	0.76	1478	37	1427	31	1448	25	3.48
053-ZR37	0.17	0.0031	0.09267	0.69	3.483	1.11	0.2726	0.78	0.71	1481	26	1554	22	1523	17	-4.91
043-ZR31N	0.13	0.0050	0.09267	0.62	3.317	1.24	0.2595	1.01	0.82	1481	23	1487	27	1485	19	-0.42
058-ZR42	0.19	0.0165	0.09281	0.80	3.265	1.27	0.2551	0.92	0.72	1484	30	1465	24	1473	20	1.29
028-ZR20	0.12	0.0349	0.09299	0.96	3.381	1.82	0.2637	1.51	0.83	1488	36	1509	40	1500	28	-1.43
030-ZR22	0.27	0.0035	0.09313	0.79	3.703	1.19	0.2883	0.81	0.68	1491	30	1633	23	1572	19	-9.57
018-ZR13	0.11	0.0085	0.09326	0.65	3.384	1.15	0.2632	0.88	0.76	1493	25	1506	24	1501	18	-0.86
045-ZR32N	0.13	0.0059	0.09364	0.51	3.436	1.05	0.2661	0.85	0.80	1501	19	1521	23	1513	17	-1.34
015-ZR11N	0.21	0.0041	0.09434	0.47	3.575	1.15	0.2748	0.98	0.85	1515	18	1565	27	1544	18	-3.32
020-ZR15	0.18	0.0078	0.09441	0.70	3.436	1.18	0.2639	0.88	0.74	1516	26	1510	24	1513	19	0.43
070-ZR52	*0.09*	*0.0194*	*0.07686*	*1.00*	*2.243*	*1.51*	*0.2117*	*1.06*	*0.70*	*1118*	*40*	*1238*	*24*	*1195*	*21*	*-10.74*
069-ZR51	*0.13*	*0.0412*	*0.07149*	*1.81*	*1.848*	*2.77*	*0.1874*	*2.07*	*0.75*	*972*	*73*	*1107*	*42*	*1063*	*36*	*-13.98*
068-ZR50	*0.13*	*0.0674*	*0.07393*	*1.90*	*1.990*	*3.05*	*0.1952*	*2.36*	*0.77*	*1040*	*76*	*1149*	*50*	*1112*	*41*	*-10.57*
044-ZR31B	*0.28*	*0.0201*	*0.09804*	*0.62*	*2.797*	*1.61*	*0.2069*	*1.44*	*0.89*	*1587*	*23*	*1212*	*32*	*1355*	*24*	*23.63*
039-ZR29	*0.16*	*0.0112*	*0.08106*	*1.32*	*1.911*	*3.10*	*0.1710*	*2.78*	*0.90*	*1223*	*51*	*1017*	*52*	*1085*	*41*	*16.81*
037-ZR27	*0.13*	*0.0613*	*0.08775*	*1.65*	*2.459*	*2.80*	*0.2032*	*2.24*	*0.80*	*1377*	*63*	*1193*	*49*	*1260*	*40*	*13.39*
025-ZR17B	*0.13*	*0.0062*	*0.08651*	*0.53*	*2.152*	*1.51*	*0.1804*	*1.37*	*0.90*	*1350*	*20*	*1069*	*27*	*1166*	*21*	*20.77*
050-ZR36	*0.10*	*0.0618*	*0.09332*	*4.42*	*2.208*	*6.57*	*0.1922*	*4.86*	*0.74*	*1277*	*168*	*1133*	*100*	*1184*	*90*	*11.24*

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Continuation.

Identifier	Th/U	f206 (%)	$^{207}Pb/^{206}Pb$	1σ %	$^{207}Pb/^{235}U$	1σ %	$^{206}Pb/^{238}U$	1σ %	Rho	$^{207}Pb/^{206}Pb$	2σ abs	$^{206}Pb/^{238}U$	2σ abs	$^{207}Pb/^{235}U$	2σ abs	% U-Pb disc[4]
					Radiogenic ratios							**Ages**[5]				
Rio Branco Formation, high-grade trondhjemitic gneiss (sample MQ-122)																
053-ZR30	0.32	0.0376	0.07657	1.58	1.987	2.15	0.1882	1.41	0.66	1110	62	1111	29	1111	29	-0.14
016-ZR08B	0.21	0.0138	0.07768	0.63	2.023	1.08	0.1889	0.80	0.74	1139	25	1115	16	1123	15	2.06
048-ZR28B	0.17	0.0406	0.07762	0.46	2.032	0.97	0.1898	0.77	0.79	1137	18	1121	16	1126	13	1.46
009-ZR05B	0.37	0.1101	0.07733	0.46	2.027	1.23	0.1901	1.08	0.88	1130	18	1122	22	1125	17	0.70
046-ZR27	0.31	0.0401	0.07581	1.04	1.997	1.35	0.1910	0.77	0.57	1090	42	1127	16	1114	18	-3.39
018-ZR10	0.49	0.0339	0.07641	1.08	2.013	1.66	0.1911	1.20	0.73	1106	43	1127	25	1120	22	-1.94
028-ZR16	0.42	0.0185	0.07724	0.80	2.038	1.20	0.1913	0.81	0.68	1127	32	1129	17	1128	16	-0.10
029-ZR17N	0.24	0.0120	0.07617	0.71	2.010	1.15	0.1913	0.82	0.72	1099	28	1129	17	1119	16	-2.65
035-ZR20N	0.21	0.0095	0.07668	0.58	2.041	1.02	0.1930	0.76	0.74	1113	23	1138	16	1129	14	-2.22
039-ZR23	0.25	0.0077	0.07610	0.67	2.031	1.15	0.1935	0.86	0.75	1098	27	1140	18	1126	16	-3.88
068-ZR42	0.35	0.0126	0.07765	0.70	2.073	1.35	0.1937	1.09	0.81	1138	28	1141	23	1140	18	-0.28
024-ZR13	0.25	0.0137	0.07698	0.67	2.063	1.09	0.1944	0.77	0.71	1121	27	1145	16	1137	15	-2.17
037-ZR21	0.23	0.0120	0.07631	0.76	1.924	1.98	0.1829	1.79	0.91	1103	30	1083	36	1090	26	1.86
038-ZR22	0.23	0.0252	0.07726	0.65	1.973	1.08	0.1852	0.77	0.72	1128	26	1095	16	1106	14	2.90
069-ZR43	0.29	0.0131	0.07717	0.62	1.992	1.35	0.1872	1.14	0.84	1126	25	1106	23	1113	18	1.75
013-ZR07N	0.33	0.0201	0.07712	0.56	2.078	1.09	0.1954	0.85	0.78	1124	22	1151	18	1142	15	-2.36
025-ZR14	0.11	0.0090	0.07651	0.49	2.065	0.93	0.1957	0.70	0.75	1109	20	1152	15	1137	13	-3.95
060-ZR36	0.25	0.0369	0.07589	0.96	2.057	1.52	0.1966	1.12	0.74	1092	38	1157	24	1135	21	-5.92
023-ZR12B	0.37	0.0423	0.07713	1.26	2.092	1.90	0.1967	1.37	0.72	1125	50	1158	29	1146	26	-2.94
008-ZR05N	0.49	0.0088	0.07680	0.50	2.092	1.00	0.1975	0.78	0.78	1116	20	1162	17	1146	14	-4.12
065-ZR39	0.23	0.0056	0.07740	0.51	2.110	1.07	0.1976	0.87	0.81	1132	20	1163	18	1152	15	-2.74
043-ZR25N	0.28	0.0051	0.07617	0.57	2.076	1.11	0.1976	0.87	0.79	1100	23	1163	19	1141	15	-5.74
070-ZR44	0.24	0.0223	0.07628	0.76	2.091	1.15	0.1988	0.79	0.68	1103	30	1169	17	1146	16	-6.02
056-ZR33N	0.54	0.0147	0.07633	0.72	2.113	1.99	0.2008	1.82	0.91	1104	29	1180	39	1153	27	-6.88
040-ZR24	0.20	0.0115	0.07585	0.61	2.120	1.20	0.2026	0.97	0.80	1091	25	1190	21	1155	17	-9.01
057-ZR33B	0.30	0.0122	0.07685	0.37	2.169	1.07	0.2047	0.94	0.87	1117	15	1200	21	1171	15	-7.44
004-ZR02N	0.06	0.0030	0.07585	0.42	2.172	1.34	0.2077	1.22	0.91	1091	17	1217	27	1172	19	-11.49
049-ZR29N	*0.15*	*0.0053*	*0.07863*	*0.50*	*2.120*	*1.23*	*0.1956*	*1.06*	*0.86*	*1163*	*20*	*1151*	*22*	*1155*	*17*	*0.98*
047-ZR28N	*0.61*	*0.0170*	*0.07879*	*0.74*	*2.116*	*1.52*	*0.1948*	*1.28*	*0.84*	*1167*	*29*	*1147*	*27*	*1154*	*21*	*1.66*
005-ZR02B	*0.07*	*0.0054*	*0.07517*	*0.36*	*1.995*	*0.84*	*0.1925*	*0.67*	*0.79*	*1073*	*14*	*1135*	*14*	*1114*	*11*	*-5.75*
054-ZR31	*0.32*	*0.0203*	*0.07521*	*0.73*	*1.834*	*1.29*	*0.1768*	*1.00*	*0.77*	*1074*	*29*	*1050*	*19*	*1058*	*17*	*2.28*
063-ZR37	*0.56*	*0.0609*	*0.07937*	*0.96*	*1.985*	*1.36*	*0.1813*	*0.90*	*0.66*	*1181*	*38*	*1074*	*18*	*1110*	*18*	*9.06*
026-ZR15N	*0.18*	*0.0730*	*0.07971*	*0.66*	*2.153*	*1.18*	*0.1958*	*0.90*	*0.76*	*1190*	*26*	*1153*	*19*	*1166*	*16*	*3.10*
034-ZR19	*0.18*	*0.0113*	*0.07381*	*0.62*	*1.890*	*1.16*	*0.1857*	*0.91*	*0.78*	*1036*	*25*	*1098*	*18*	*1078*	*15*	*-5.98*
045-ZR26	*0.34*	*0.0129*	*0.07990*	*0.76*	*2.087*	*1.40*	*0.1894*	*1.11*	*0.79*	*1194*	*30*	*1118*	*23*	*1144*	*19*	*6.39*
030-ZR17B	*0.12*	*0.0301*	*0.07993*	*0.77*	*2.179*	*1.27*	*0.1977*	*0.94*	*0.74*	*1195*	*30*	*1163*	*20*	*1174*	*18*	*2.69*

Identifier	Th/U	f206 (%)	$^{207}Pb/^{206}Pb$	1σ %	$^{207}Pb/^{235}U$	1σ %	$^{206}Pb/^{238}U$	1σ %	Rho	$^{207}Pb/^{206}Pb$	2σ abs	$^{206}Pb/^{238}U$	2σ abs	$^{207}Pb/^{235}U$	2σ abs	% U-Pb disc[4]
					Radiogenic ratios							**Ages**[5]				
Rio Branco Suite, metagabbro (sample MQ-117)																
010-ZR08	0.16	0.0064	0.07259	0.86	1.717	1.30	0.1715	0.91	0.70	1003	35	1020	17	1015	17	-1.79
006-ZR04	0.18	0.0108	0.07272	0.56	1.729	0.96	0.1724	0.68	0.71	1006	23	1026	13	1019	12	-1.94
029-ZR23	0.28	0.0093	0.07296	0.74	1.702	1.15	0.1692	0.80	0.70	1013	30	1008	15	1009	15	0.50
015-ZR11	0.23	0.0081	0.07650	0.60	2.013	1.13	0.1908	0.88	0.78	1108	24	1126	18	1120	15	-1.59
019-ZR15	0.51	0.0024	0.07654	0.62	2.043	1.25	0.1936	1.01	0.81	1109	25	1141	21	1130	17	-2.86
037-ZR29	0.81	0.0009	0.07676	0.51	1.974	0.95	0.1865	0.71	0.75	1115	20	1103	14	1107	13	1.10
025-ZR19	0.05	0.0037	0.07693	0.46	2.048	0.97	0.1931	0.77	0.79	1119	18	1138	16	1132	13	-1.66
018-ZR14	0.13	0.0045	0.07710	0.64	2.002	1.10	0.1883	0.82	0.74	1124	25	1112	17	1116	15	1.02
038-ZR30	0.03	0.0042	0.07738	0.80	2.020	1.54	0.1893	1.27	0.82	1131	32	1118	26	1122	21	1.16
035-ZR27	0.34	0.0001	0.07742	0.53	2.002	0.96	0.1876	0.72	0.74	1132	21	1108	15	1116	13	2.10
033-ZR25	0.54	0.0058	0.07758	0.68	2.046	1.34	0.1913	1.09	0.81	1136	27	1128	23	1131	18	0.70
034-ZR26	*0.06*	*0.0078*	*0.07666*	*0.59*	*1.923*	*1.09*	*0.1819*	*0.84*	*0.77*	*1112*	*24*	*1078*	*17*	*1089*	*15*	*3.13*
004-ZR02	*0.16*	*0.0065*	*0.07473*	*0.59*	*1.881*	*1.14*	*0.1825*	*0.90*	*0.79*	*1061*	*24*	*1081*	*18*	*1074*	*15*	*-1.83*
013-ZR09	*0.18*	*0.0124*	*0.07389*	*0.83*	*1.826*	*1.60*	*0.1793*	*1.32*	*0.82*	*1038*	*33*	*1063*	*26*	*1055*	*21*	*-2.36*
027-ZR21	*0.40*	*0.0039*	*0.07602*	*0.52*	*1.995*	*0.98*	*0.1903*	*0.75*	*0.76*	*1096*	*21*	*1123*	*15*	*1114*	*13*	*-2.50*
017-ZR13	*0.31*	*0.0056*	*0.07498*	*0.54*	*1.923*	*1.02*	*0.1860*	*0.78*	*0.77*	*1068*	*22*	*1100*	*16*	*1089*	*14*	*-2.99*
039-ZR31	*0.24*	*0.0158*	*0.07682*	*0.79*	*1.922*	*1.29*	*0.1814*	*0.95*	*0.73*	*1116*	*31*	*1075*	*19*	*1089*	*17*	*3.74*
016-ZR12	*0.21*	*0.0080*	*0.07660*	*0.58*	*2.357*	*1.56*	*0.2232*	*1.40*	*0.90*	*1111*	*23*	*1299*	*33*	*1230*	*22*	*-16.91*
009-ZR07	*0.13*	*0.0093*	*0.07628*	*1.69*	*2.209*	*2.47*	*0.2101*	*1.76*	*0.71*	*1102*	*67*	*1229*	*39*	*1184*	*34*	*-11.51*
024-ZR18	*0.41*	*0.0115*	*0.07453*	*0.62*	*2.001*	*1.52*	*0.1947*	*1.34*	*0.88*	*1056*	*25*	*1147*	*28*	*1116*	*20*	*-8.59*
026-ZR20	*0.19*	*0.0032*	*0.07599*	*0.54*	*2.096*	*1.24*	*0.2001*	*1.06*	*0.85*	*1095*	*21*	*1176*	*23*	*1148*	*17*	*-7.40*
023-ZR17	*0.41*	*0.0023*	*0.07618*	*0.54*	*2.073*	*1.35*	*0.1973*	*1.18*	*0.87*	*1100*	*22*	*1161*	*25*	*1140*	*18*	*-5.55*
008-ZR06	*0.20*	*0.0079*	*0.07574*	*0.68*	*2.036*	*1.20*	*0.1950*	*0.91*	*0.76*	*1088*	*27*	*1148*	*19*	*1128*	*16*	*-5.52*
028-ZR22	*0.25*	*0.0177*	*0.07403*	*0.97*	*1.892*	*1.91*	*0.1853*	*1.60*	*0.84*	*1042*	*39*	*1096*	*32*	*1078*	*25*	*-5.14*
005-ZR03	*0.27*	*0.0056*	*0.07577*	*0.60*	*2.029*	*1.09*	*0.1942*	*0.83*	*0.76*	*1089*	*24*	*1144*	*17*	*1125*	*15*	*-5.06*
003-ZR01	*0.11*	*0.0056*	*0.07719*	*0.61*	*2.134*	*1.10*	*0.2005*	*0.84*	*0.76*	*1126*	*24*	*1178*	*18*	*1160*	*15*	*-4.62*
030-ZR24	*0.17*	*0.0089*	*0.07602*	*0.76*	*1.834*	*1.71*	*0.1749*	*1.48*	*0.87*	*1096*	*30*	*1039*	*28*	*1058*	*22*	*5.15*

Continuation.

Identifier	Th/U	f206 (%)	$^{207}Pb/^{206}Pb$	1σ %	$^{207}Pb/^{235}U$	1σ %	$^{206}Pb/^{238}U$	1σ %	Rho	$^{207}Pb/^{206}Pb$	2σ abs	$^{206}Pb/^{238}U$	2σ abs	$^{207}Pb/^{235}U$	2σ abs	% U-Pb disc[4]
						Radiogenic ratios						**Ages**[5]				
Rio Branco Suite, foliated granite dike (sample MQ-147M)																
004-ZR02	0.38	0.0291	0.07736	0.88	1.963	1.43	0.1840	1.07	0.75	1131	35	1089	21	1103	19	3.69
027-ZR21	0.47	0.0217	0.07809	0.70	1.983	1.53	0.1842	1.31	0.86	1149	27	1090	26	1110	21	5.18
029-ZR23	0.51	0.0223	0.07835	0.93	2.002	1.44	0.1853	1.03	0.72	1156	37	1096	21	1116	19	5.18
023-ZR17	0.33	0.0085	0.07631	0.69	1.953	1.09	0.1856	0.76	0.69	1103	28	1097	15	1099	15	0.51
016-ZR12	0.58	0.0246	0.07682	1.02	1.984	1.54	0.1873	1.10	0.71	1117	40	1107	22	1110	21	0.88
018-ZR14	0.51	0.0402	0.07737	0.82	2.001	1.56	0.1875	1.28	0.82	1131	32	1108	26	1116	21	2.03
017-ZR13	0.56	0.0224	0.07547	0.80	1.956	1.35	0.1880	1.02	0.75	1081	32	1111	21	1101	18	-2.72
019-ZR15	0.31	0.0106	0.07665	0.71	1.989	1.13	0.1882	0.80	0.71	1112	28	1112	16	1112	15	0.03
009-ZR07	0.52	0.0444	0.07838	0.79	2.037	1.70	0.1884	1.46	0.86	1156	31	1113	30	1128	23	3.77
015-ZR11	0.34	0.0072	0.07640	0.79	1.993	1.27	0.1891	0.92	0.73	1106	31	1117	19	1113	17	-1.00
028-ZR22	0.50	0.1030	0.07666	1.19	2.001	1.93	0.1893	1.48	0.76	1112	47	1118	30	1116	26	-0.47
026-ZR20	0.59	0.0150	0.07641	0.69	2.008	1.29	0.1906	1.02	0.79	1106	27	1125	21	1118	17	-1.70
030-ZR24	0.46	0.0317	0.07674	1.32	2.017	3.34	0.1906	3.04	0.91	1114	52	1125	63	1121	45	-0.94
006-ZR04	0.30	0.0134	0.07700	0.69	2.038	1.20	0.1920	0.90	0.76	1121	27	1132	19	1128	16	-0.98
038-ZR30	0.38	0.0174	0.07605	0.59	2.024	1.10	0.1930	0.85	0.78	1096	23	1138	18	1124	15	-3.77
014-ZR10	*0.55*	*0.0135*	*0.07692*	*0.76*	*1.934*	*1.17*	*0.1823*	*0.81*	*0.69*	*1119*	*30*	*1080*	*16*	*1093*	*16*	*3.53*
008-ZR06	*0.54*	*0.0254*	*0.07556*	*1.11*	*1.905*	*1.83*	*0.1829*	*1.41*	*0.77*	*1083*	*44*	*1083*	*28*	*1083*	*24*	*0.08*
005-ZR03	*0.38*	*0.0188*	*0.07655*	*0.58*	*2.050*	*1.08*	*0.1942*	*0.83*	*0.77*	*1109*	*23*	*1144*	*17*	*1132*	*15*	*-3.13*
003-ZR01	*0.35*	*0.0156*	*0.07647*	*0.65*	*2.067*	*1.23*	*0.1961*	*0.97*	*0.79*	*1107*	*26*	*1154*	*21*	*1138*	*17*	*-4.21*
010-ZR08	*0.56*	*0.1542*	*0.07975*	*0.87*	*1.790*	*2.36*	*0.1628*	*2.16*	*0.92*	*1191*	*34*	*972*	*39*	*1042*	*31*	*18.35*
037-ZR29	*1.02*	*0.1054*	*0.07988*	*0.98*	*1.834*	*2.27*	*0.1665*	*2.01*	*0.89*	*1194*	*39*	*993*	*37*	*1058*	*30*	*16.85*
036-ZR28	*1.07*	*0.0548*	*0.07285*	*1.64*	*1.691*	*2.08*	*0.1683*	*1.23*	*0.59*	*1010*	*66*	*1003*	*23*	*1005*	*26*	*0.71*
020-ZR16	*0.47*	*0.0157*	*0.07897*	*0.66*	*1.838*	*1.81*	*0.1688*	*1.64*	*0.91*	*1171*	*26*	*1005*	*31*	*1059*	*24*	*14.18*
007-ZR05	*0.27*	*0.0427*	*0.07489*	*0.94*	*1.782*	*1.45*	*0.1725*	*1.05*	*0.72*	*1065*	*37*	*1026*	*20*	*1039*	*19*	*3.70*
040-ZR32	*0.28*	*0.0196*	*0.07639*	*0.96*	*1.873*	*1.58*	*0.1778*	*1.20*	*0.76*	*1105*	*38*	*1055*	*23*	*1072*	*21*	*4.57*

Identifier	Th/U	f206 (%)	$^{207}Pb/^{206}Pb$	1σ %	$^{207}Pb/^{235}U$	1σ %	$^{206}Pb/^{238}U$	1σ %	Rho	$^{207}Pb/^{206}Pb$	2σ abs	$^{206}Pb/^{238}U$	2σ abs	$^{207}Pb/^{235}U$	2σ abs	% U-Pb disc[4]
						Radiogenic ratios						**Ages**[5]				
Rio Branco Suite, fine-grained metagranite subvolcanic (sample MQ-124)																
029-ZR23	0.18	0.0116	0.07595	0.64	1.987	1.35	0.1898	1.13	0.84	1094	26	1120	23	1111	18	-2.41
026-ZR20	0.20	0.0057	0.07601	0.79	1.957	1.19	0.1867	0.81	0.68	1095	31	1104	16	1101	16	-0.76
014-ZR10	0.31	0.0122	0.07611	0.71	1.978	1.22	0.1885	0.92	0.75	1098	28	1113	19	1108	16	-1.38
016-ZR12	0.20	0.0080	0.07613	0.62	1.957	1.01	0.1865	0.70	0.70	1098	25	1102	14	1101	14	-0.35
007-ZR05	0.17	0.0130	0.07615	0.62	1.970	1.09	0.1876	0.81	0.75	1099	25	1109	17	1105	15	-0.87
018-ZR14	0.26	0.0184	0.07620	0.53	1.962	0.98	0.1868	0.73	0.75	1100	21	1104	15	1103	13	-0.32
030-ZR24	0.23	0.0142	0.07621	0.64	1.996	1.21	0.1899	0.96	0.79	1101	26	1121	20	1114	16	-1.85
027-ZR21	0.19	0.0084	0.07644	0.50	2.019	0.92	0.1915	0.67	0.73	1107	20	1129	14	1122	12	-2.06
028-ZR22	0.24	0.0080	0.07645	0.60	1.982	1.10	0.1881	0.85	0.77	1107	24	1111	17	1110	15	-0.38
005-ZR03	0.21	0.0132	0.07650	0.61	1.990	1.13	0.1886	0.88	0.78	1108	24	1114	18	1112	15	-0.52
008-ZR06	0.25	0.0096	0.07668	0.59	1.961	1.06	0.1855	0.79	0.75	1113	24	1097	16	1102	14	1.45
004-ZR02	0.31	0.0104	0.07674	0.61	2.018	1.07	0.1907	0.80	0.75	1114	24	1125	17	1122	15	-0.99
015-ZR11	0.17	0.0169	0.07686	0.52	2.011	0.96	0.1898	0.72	0.75	1117	21	1120	15	1119	13	-0.23
006-ZR04	0.34	0.0202	0.07699	0.90	2.009	1.40	0.1892	1.01	0.72	1121	36	1117	21	1118	19	0.34
009-ZR07	0.18	0.0121	0.07717	0.64	2.009	1.08	0.1889	0.79	0.73	1125	26	1115	16	1119	15	0.92
036-ZR28	0.28	0.0181	0.07765	0.54	2.023	0.95	0.1889	0.69	0.73	1138	21	1115	14	1123	13	1.97
013-ZR09	*0.53*	*0.0387*	*0.07797*	*0.77*	*2.092*	*1.19*	*0.1946*	*0.83*	*0.70*	*1146*	*30*	*1146*	*17*	*1146*	*16*	*0.00*
024-ZR18	*0.19*	*0.0095*	*0.07666*	*0.64*	*2.047*	*1.14*	*0.1936*	*0.86*	*0.76*	*1112*	*25*	*1141*	*18*	*1131*	*15*	*-2.58*
034-ZR26	*0.35*	*0.0126*	*0.07638*	*0.86*	*2.132*	*2.11*	*0.2025*	*1.89*	*0.90*	*1105*	*34*	*1189*	*41*	*1159*	*29*	*-7.57*
020-ZR16	*0.22*	*0.0129*	*0.07614*	*0.78*	*2.035*	*1.17*	*0.1938*	*0.79*	*0.68*	*1099*	*31*	*1142*	*17*	*1127*	*16*	*-3.91*
017-ZR13	*0.30*	*0.0720*	*0.08031*	*0.77*	*1.788*	*1.31*	*0.1615*	*0.99*	*0.76*	*1205*	*30*	*965*	*18*	*1041*	*17*	*19.90*
023-ZR17	*0.24*	*0.0148*	*0.09072*	*1.03*	*2.676*	*1.55*	*0.2139*	*1.09*	*0.71*	*1441*	*39*	*1249*	*25*	*1322*	*23*	*13.29*
010-ZR08	*0.46*	*0.1696*	*0.09358*	*1.18*	*2.234*	*2.06*	*0.1731*	*1.65*	*0.80*	*1500*	*44*	*1029*	*31*	*1192*	*29*	*31.36*
037-ZR29	*0.32*	*0.0083*	*0.10001*	*1.21*	*3.984*	*2.27*	*0.2889*	*1.89*	*0.83*	*1624*	*45*	*1636*	*54*	*1631*	*37*	*-0.72*
038-ZR30	*0.49*	*0.0099*	*0.11805*	*1.26*	*6.047*	*2.37*	*0.3715*	*1.97*	*0.83*	*1927*	*45*	*2037*	*69*	*1983*	*41*	*-5.69*
033-ZR25	*0.33*	*0.0256*	*0.13502*	*1.50*	*6.858*	*2.43*	*0.3684*	*1.87*	*0.77*	*2164*	*52*	*2022*	*65*	*2093*	*43*	*6.59*

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Identifier	Th/U	f206 (%)	207Pb/206Pb	1σ %	207Pb/235U	1σ %	206Pb/238U	1σ %	Rho	207Pb/206Pb	2σ abs	206Pb/238U	2σ abs	207Pb/235U	2σ abs	% U-Pb disc[4]
						Radiogenic ratios						Ages[5]				
Rio Branco Suite, medium-grained leucocratic metatrondhjemite (plagiogranite equivalent) (sample MQ-29)																
019-ZR15	0.47	0.0147	0.07669	0.85	1.952	1.39	0.1846	1.03	0.74	1113	34	1092	21	1099	19	1.89
003-ZR01	0.39	0.0096	0.07586	0.60	1.943	1.09	0.1858	0.83	0.76	1091	24	1098	17	1096	15	-0.65
009-ZR07	0.39	0.0118	0.07722	0.55	1.986	1.31	0.1865	1.13	0.86	1127	22	1103	23	1111	18	2.15
039-ZR31	0.55	0.0125	0.07685	0.79	1.977	1.21	0.1865	0.84	0.69	1117	31	1103	17	1108	16	1.32
005-ZR03	0.60	0.0135	0.07625	0.62	1.969	1.12	0.1873	0.85	0.76	1102	25	1107	17	1105	15	-0.45
007-ZR05	0.18	0.0067	0.07631	0.48	1.978	0.99	0.1880	0.78	0.79	1103	19	1110	16	1108	13	-0.64
023-ZR17	0.38	0.0148	0.07613	0.75	1.982	1.19	0.1888	0.84	0.71	1098	30	1115	17	1109	16	-1.50
006-ZR04	0.63	0.0197	0.07540	0.97	1.990	1.52	0.1914	1.11	0.73	1079	39	1129	23	1112	20	-4.61
010-ZR08	*0.55*	*0.0310*	*0.07619*	*1.07*	*1.901*	*1.70*	*0.1810*	*1.26*	*0.74*	*1100*	*43*	*1072*	*25*	*1081*	*22*	*2.53*
020-ZR16	*0.68*	*0.0005*	*0.07691*	*0.88*	*1.919*	*1.61*	*0.1810*	*1.29*	*0.80*	*1119*	*35*	*1072*	*26*	*1088*	*21*	*4.17*
013-ZR09	*0.38*	*0.0192*	*0.07723*	*0.69*	*1.934*	*1.18*	*0.1816*	*0.88*	*0.75*	*1127*	*27*	*1076*	*17*	*1093*	*16*	*4.58*
030-ZR24	*0.17*	*0.0019*	*0.07623*	*0.60*	*1.917*	*1.16*	*0.1824*	*0.92*	*0.79*	*1101*	*24*	*1080*	*18*	*1087*	*15*	*1.92*
024-ZR18	*0.40*	*0.0101*	*0.07649*	*0.50*	*2.048*	*0.91*	*0.1942*	*0.67*	*0.73*	*1108*	*20*	*1144*	*14*	*1132*	*12*	*-3.25*
025-ZR19	*0.41*	*0.0472*	*0.07670*	*0.50*	*2.056*	*1.04*	*0.1944*	*0.83*	*0.80*	*1114*	*20*	*1145*	*17*	*1134*	*14*	*-2.85*
034-ZR26	*0.58*	*0.0030*	*0.07510*	*0.66*	*2.020*	*1.38*	*0.1950*	*1.15*	*0.84*	*1071*	*26*	*1149*	*24*	*1122*	*19*	*-7.23*
008-ZR06	*0.36*	*0.0363*	*0.07649*	*0.94*	*2.062*	*2.02*	*0.1955*	*1.75*	*0.87*	*1108*	*37*	*1151*	*37*	*1136*	*27*	*-3.91*
038-ZR30	*0.61*	*0.0289*	*0.07645*	*0.96*	*2.068*	*1.86*	*0.1962*	*1.54*	*0.83*	*1107*	*38*	*1155*	*33*	*1138*	*25*	*-4.32*
037-ZR29	*0.29*	*0.0218*	*0.07612*	*0.91*	*2.068*	*1.74*	*0.1970*	*1.43*	*0.82*	*1098*	*36*	*1159*	*30*	*1138*	*24*	*-5.57*
035-ZR27	*0.25*	*0.0171*	*0.07679*	*0.65*	*2.171*	*1.53*	*0.2051*	*1.33*	*0.87*	*1116*	*26*	*1203*	*29*	*1172*	*21*	*-7.78*
014-ZR10	*0.80*	*0.0456*	*0.07798*	*0.67*	*2.233*	*1.76*	*0.2076*	*1.58*	*0.90*	*1146*	*27*	*1216*	*35*	*1191*	*24*	*-6.10*
040-ZR32	*0.56*	*0.0398*	*0.07885*	*0.73*	*2.067*	*1.91*	*0.1901*	*1.72*	*0.90*	*1168*	*29*	*1122*	*35*	*1138*	*26*	*3.97*
017-ZR13	*0.42*	*0.0509*	*0.07876*	*0.73*	*2.055*	*1.60*	*0.1892*	*1.38*	*0.86*	*1166*	*29*	*1117*	*28*	*1134*	*22*	*4.18*
026-ZR20	*0.38*	*0.0259*	*0.07895*	*0.53*	*1.901*	*1.21*	*0.1746*	*1.03*	*0.85*	*1171*	*21*	*1037*	*20*	*1081*	*16*	*11.42*
036-ZR28	*0.36*	*0.0146*	*0.07790*	*1.13*	*2.021*	*1.90*	*0.1881*	*1.48*	*0.78*	*1144*	*45*	*1111*	*30*	*1123*	*26*	*2.90*
015-ZR11	*0.39*	*0.0528*	*0.07960*	*1.25*	*2.193*	*2.53*	*0.1998*	*2.17*	*0.86*	*1187*	*49*	*1174*	*46*	*1179*	*35*	*1.09*

Identifier	Th/U	f206 (%)	207Pb/206Pb	1σ %	207Pb/235U	1σ %	206Pb/238U	1σ %	Rho	207Pb/206Pb	2σ abs	206Pb/238U	2σ abs	207Pb/235U	2σ abs	% U-Pb disc[4]
						Radiogenic ratios						Ages[5]				
Anatectic granite in paragneiss of Rio Branco Formation (sample MQ-146B)																
014-ZR09	0.02	0.0074	0.07201	0.68	1.735	1.15	0.1747	0.85	0.74	986	27	1038	16	1022	15	-5.26
027-ZR20	0.02	0.1367	0.07222	0.79	1.728	1.13	0.1735	0.72	0.63	992	32	1031	14	1019	15	-3.96
039-ZR30	0.02	0.0131	0.07237	0.67	1.640	1.15	0.1643	0.86	0.75	996	27	981	16	986	14	1.56
026-ZR19	0.02	0.0042	0.07297	0.52	1.851	1.12	0.1840	0.92	0.82	1013	21	1089	18	1064	15	-7.44
017-ZR12	0.04	0.0020	0.07306	0.53	1.814	1.03	0.1801	0.80	0.77	1016	22	1067	16	1051	13	-5.10
003-ZR01	0.02	0.0053	0.07306	0.62	1.674	0.97	0.1662	0.65	0.67	1016	25	991	12	999	12	2.44
005-ZR03	0.02	0.0045	0.07307	0.52	1.684	0.90	0.1671	0.63	0.71	1016	21	996	12	1002	11	1.95
028-ZR21	0.02	0.0073	0.07307	0.65	1.672	1.17	0.1659	0.90	0.77	1016	26	990	17	998	15	2.58
037-ZR28	0.02	0.0094	0.07313	0.50	1.772	1.04	0.1757	0.83	0.80	1018	20	1043	16	1035	13	-2.53
015-ZR10	0.03	0.0046	0.07324	0.56	1.744	1.05	0.1727	0.81	0.77	1021	23	1027	15	1025	14	-0.62
024-ZR17	0.02	0.0041	0.07327	0.59	1.754	1.11	0.1736	0.86	0.78	1021	24	1032	16	1029	14	-1.03
009-ZR06	*0.17*	*0.0061*	*0.07756*	*0.90*	*2.082*	*1.37*	*0.1947*	*0.96*	*0.70*	*1136*	*36*	*1147*	*20*	*1143*	*19*	*-1.00*
040-ZR31	*0.30*	*0.0035*	*0.07800*	*0.77*	*2.044*	*1.17*	*0.1900*	*0.81*	*0.69*	*1147*	*30*	*1122*	*17*	*1130*	*16*	*2.21*
019-ZR14	*0.22*	*0.0075*	*0.07814*	*0.81*	*2.092*	*1.22*	*0.1941*	*0.84*	*0.69*	*1150*	*32*	*1144*	*18*	*1146*	*17*	*0.60*
029-ZR22	*0.02*	*0.0520*	*0.07459*	*0.73*	*1.710*	*1.17*	*0.1663*	*0.84*	*0.72*	*1057*	*29*	*992*	*15*	*1012*	*15*	*6.22*
004-ZR02	*0.36*	*0.0137*	*0.07875*	*0.62*	*2.057*	*0.96*	*0.1895*	*0.64*	*0.66*	*1166*	*24*	*1118*	*13*	*1135*	*13*	*4.07*
033-ZR24	*0.27*	*0.1458*	*0.08306*	*1.19*	*2.484*	*1.83*	*0.2169*	*1.34*	*0.73*	*1271*	*46*	*1265*	*31*	*1267*	*26*	*0.42*
036-ZR27	*0.14*	*0.0108*	*0.09078*	*0.69*	*2.954*	*1.37*	*0.2360*	*1.12*	*0.82*	*1442*	*26*	*1366*	*28*	*1396*	*21*	*5.29*
007-ZR05N	*0.25*	*0.0087*	*0.09430*	*0.59*	*3.401*	*1.05*	*0.2616*	*0.78*	*0.74*	*1514*	*22*	*1498*	*21*	*1505*	*16*	*1.08*
020-ZR15	*0.18*	*0.0178*	*0.09658*	*1.23*	*3.795*	*1.79*	*0.2849*	*1.25*	*0.70*	*1559*	*46*	*1616*	*36*	*1592*	*29*	*-3.65*

[1] Convertion factor from mV to CPS is 62500000

[2] concentration uncertainty c.20%

[3] not corrected for common-Pb

[4] Discordance calculated as (1-(206Pb/238U age/207Pb/206Pb age))*100

Decay constants of Jaffey et al. (1971) used

Note: Zircon analysis results in italics (gray) were data not used for precise age calculations

In preparing the concordia diagram, we initially used isotopic data from twenty-seven zircon crystals (normal black font style zircons data, sample MQ-122, Table 2). For age calculation, isotopic data from twelve concordant zircon crystals (highlighted in bold in Table 2, sample MQ-122) we used to calculate the Concordia age of 1127.6 ± 2.3 Ma, MSWD = 1.8, probability (agreement) = 0.18 and Th / U ratios between 0.16 and 0.49, interpreted as magmatic crystallization age of the protolith (Fig. 11).

6.2 Metamafic component (Rio Branco Suite)

Sample MQ-117 (S11°59'33''/W61°58'09'') is a gray, foliated, not magnetic, medium-grained metagabbro, with a subhedral to anhedral granular texture, composed essentially of plagioclase, augite and orthopyroxene, having hornblende as a secondary mineral, on the rims of pyroxene crystals. Zircon crystals extracted from this rock are generally subhedral (1:3, 1:2 and 1:1), rounded prismatic, ranging between 70 and 400 μm, containing fractures and inclusions. In BSE images, the internal structure is dominantly homogeneous, sometimes with oscillatory zonation. Eventually, zircon crystals have irregular luminescent stain with radial fracture

concentration. Twenty-seven zircon crystals from this sample were analyzed (Table 2). Their Th/U ratios vary between 0.03 and 0.81, present ages with low discordance, mainly around 1200-1050 Ma, except three younger grains with concondant data of ~1000 Ma. The regression of the main group indicates the upper and low intercepts at 1073 ± 28 Ma and 519 ± 260 Ma, respectivelly (MSWD of 4.1). The selection of most concordant data (range 015-ZR11 to 033-ZR25 in Table 2, sample MQ-117) allow to calculate the Concordia age of 1119.7 ± 2.7 Ma , interpreted as the best estimate of the magmatic crystallization age of the rock (Fig. 12). Age possibility reinforced by the field geological relations that suggest contemporaneity between the metamafic and metafelsic components of the Rio Branco Suite (see sections 5.2 and 6.3). The set of three zircon crystals (grains ZR04, ZR08 and ZR23) was used for calculation of the Concordia age of 1016.7 ± 3.9 Ma (MSWD = 0.29), interpreted as record of the possible youngest metamorphic pulse (Fig. 12).

6.3 Metafelsic component (Rio Branco Suite)

Sample MQ-147M (S11°55'59"/W62°08'55") is from a foliated granitic dike intrusive in high-grade calc-silicate gneiss and biotite paragneiss of the Rio Branco Formation (Figs. 4A, 6A, 6B, 6C). It is a medium to fine-grained equigranular, leucocratic, foliated metagranite, composed of plagioclase, k-feldspar and quartz, and present hornblende, biotite, tianite, allanite, zircon and opaque minerals as accessories and secondary minerals are represented by white mica, epidote and iron oxides. The foliation is marked by stretched quartz and feldspar crystals and by the orientation of mafic minerals, concentrated along the more deformed portions of the rock. Only twenty-five zircon crystals could be extracted from this rock and they were analysed for LA-ICP-MS U-Pb (Table 2). They are prismatic crystals, euhedral to subhedral, 1:2 and 1:3 ratios, between 100 and 300 μm long, and exhibiting some fractures. The BSE images show well-marked oscillatory zonation and irregular areas with high luminescence, especially in the rims of the crystals. Among the data of the analyzed twenty-five spots, only the analytical result of fifteen more concordant crystals (range 004-ZR02 to 038-ZR30 in Table 2, sample MQ-147M) were used in the calculations. They present Th/U between 0.29 and 0.59 and their isotopic data indicates the of the Concordia age of 1113 ± 6.7 Ma (MSWD = 1.4), which represents the age of magmatic crystallization of the felsic dyke (Fig. 13A).

Fig. 9. BSE (Backscattered Electron) images of selected zircon grains of sample MQ-44 (calc-silicate gneiss of the Rio Branco Formation) showing usually recrystallized forms and varied internal morphologies. (A) zircon presenting core with high Th/U ratio, convolute zoning and overgrowth with low Th/U ratio (metamorphic rim). (B), (C), (D), (E), (F), (G) and (H) homogeneous and partially recrystallized zircon grains showing detrital core and metamorphic rims with low Th/U ratio and radial fractures. (I) sub-rounded and homogeneous zircon with low Th/U ratio. (J) homogeneous zircon fragment with low Th/U ratio. (K), (L) homogeneous and fractured zircon fragments. (M), (N) zircon with features of partial recrystallization. Circles indicate the analyzed spot location. Numbers represent $^{207}Pb/^{206}Pb$ ages and the color circles mean yellow=crystallization, green=overgrowth or metamorphic recrystallization, red= metamorphic recrystallization and/or migmatization. Based on Corfu et al. (2003) and Harley et al. (2007).
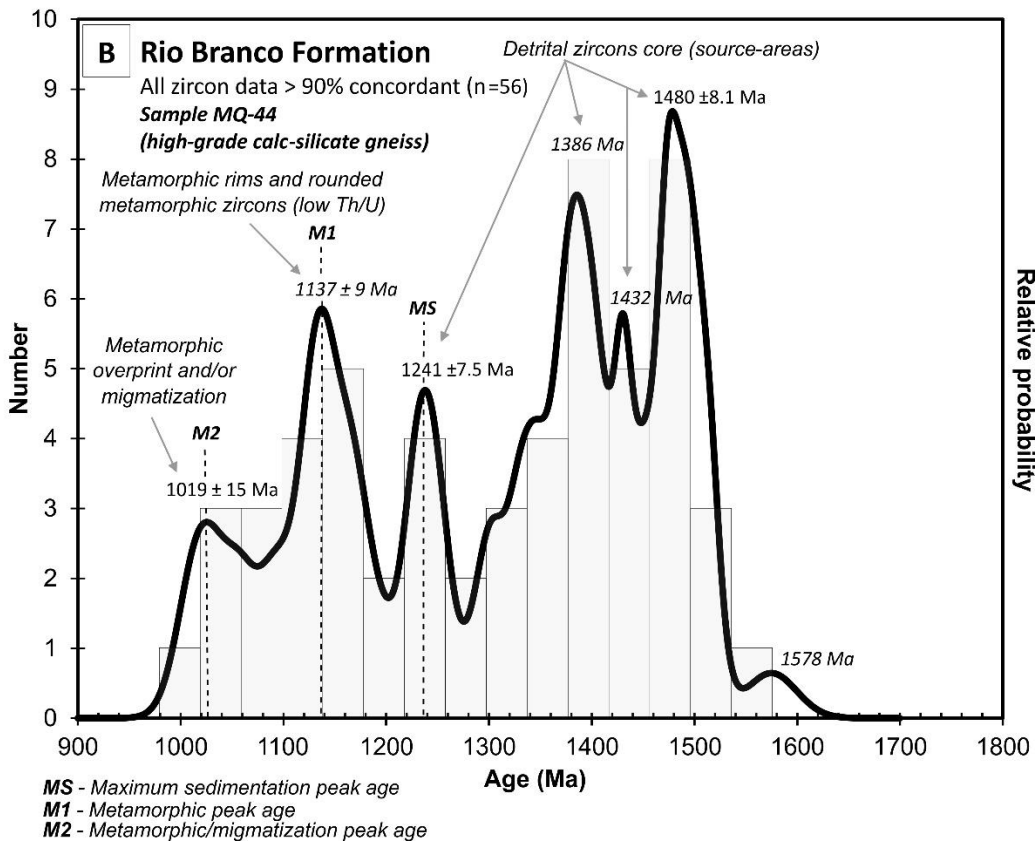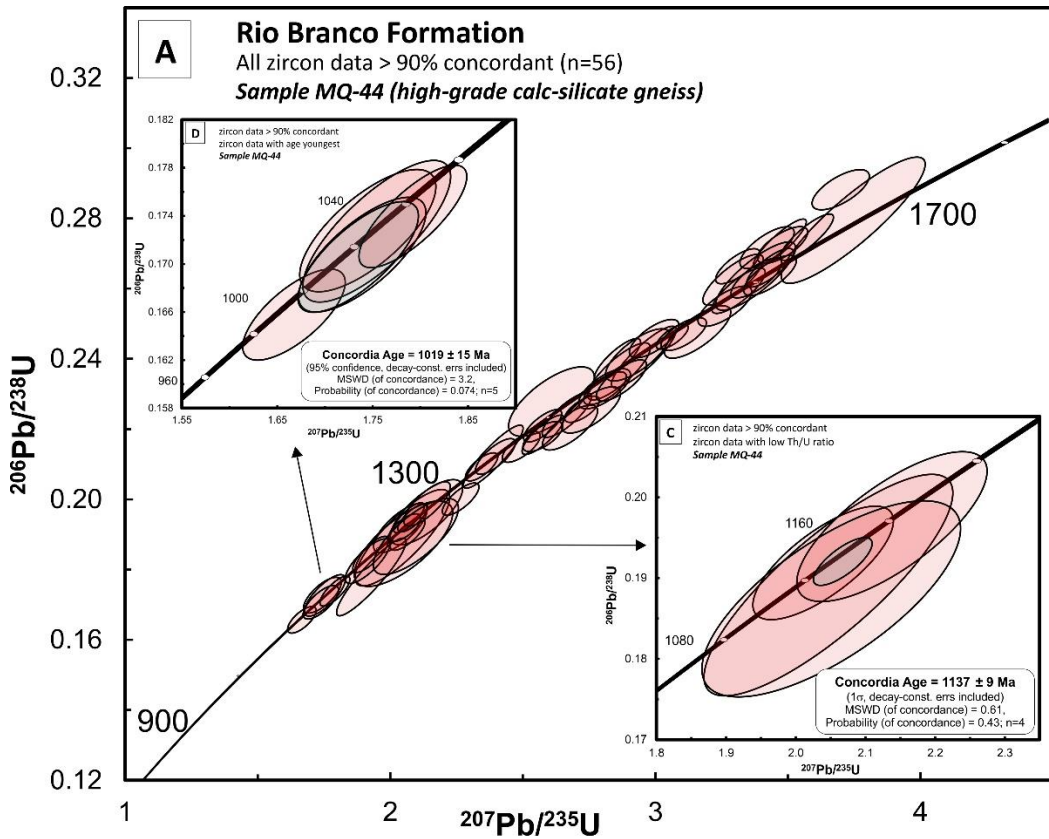
Fig. 10. (A) U-Pb (LA-ICP-MS) Concordia diagram and (B) relative probability histogram for $^{207}Pb/^{206}Pb$ ages of the detrital zircon grains of high-grade calc-silicate gneiss of the Rio Branco Formation (sample MQ-44). (D) Concordia age of high-grade metamorphism age in 1137 ± 9 Ma (M1) and (D) another late metamorphic recrystallization or migmatization phase in 1019 ± 15 Ma (M2). The Maximum sedimentation age in 1241 ± 7.5 Ma (MS).
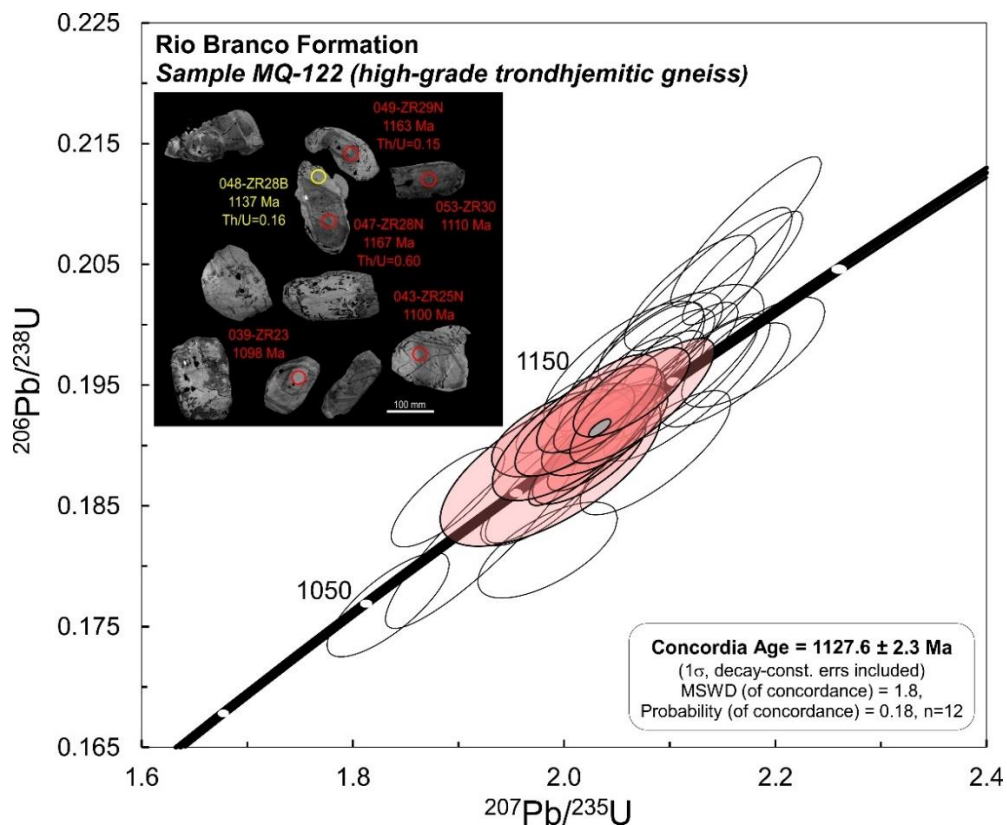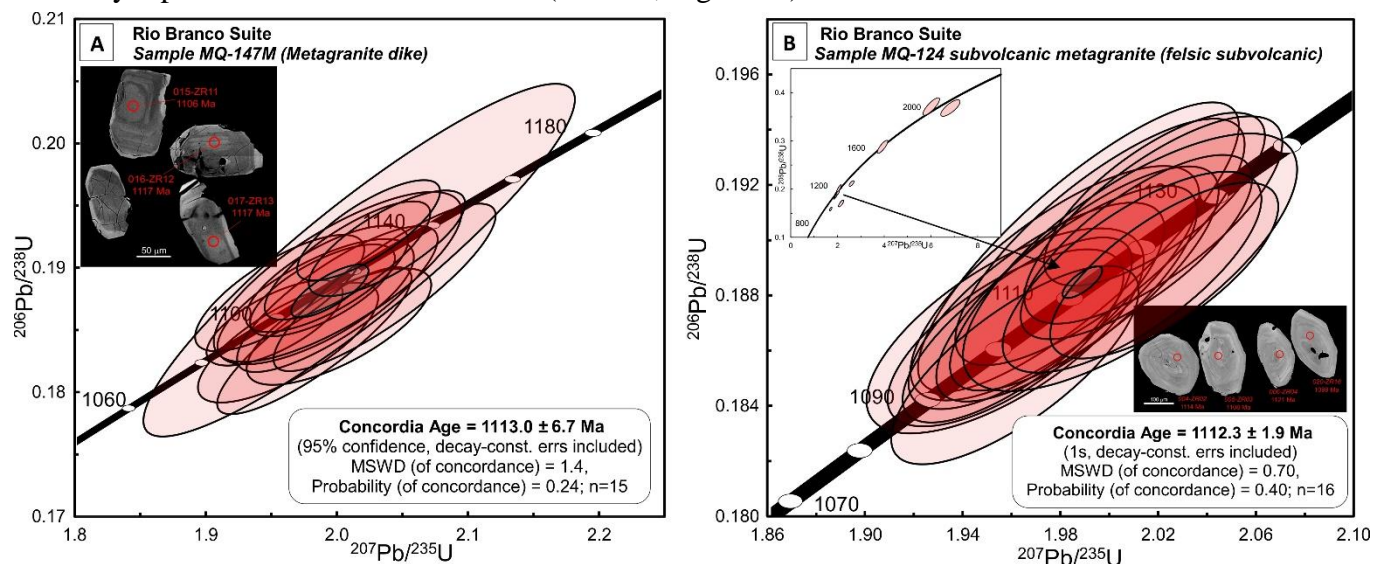
Fig. 11. U-Pb Concordia diagram of concordant zircon of high-grade trondhjemitic gneiss (sample MQ-22) from the Rio Branco Domain, Nova Brasilândia belt.
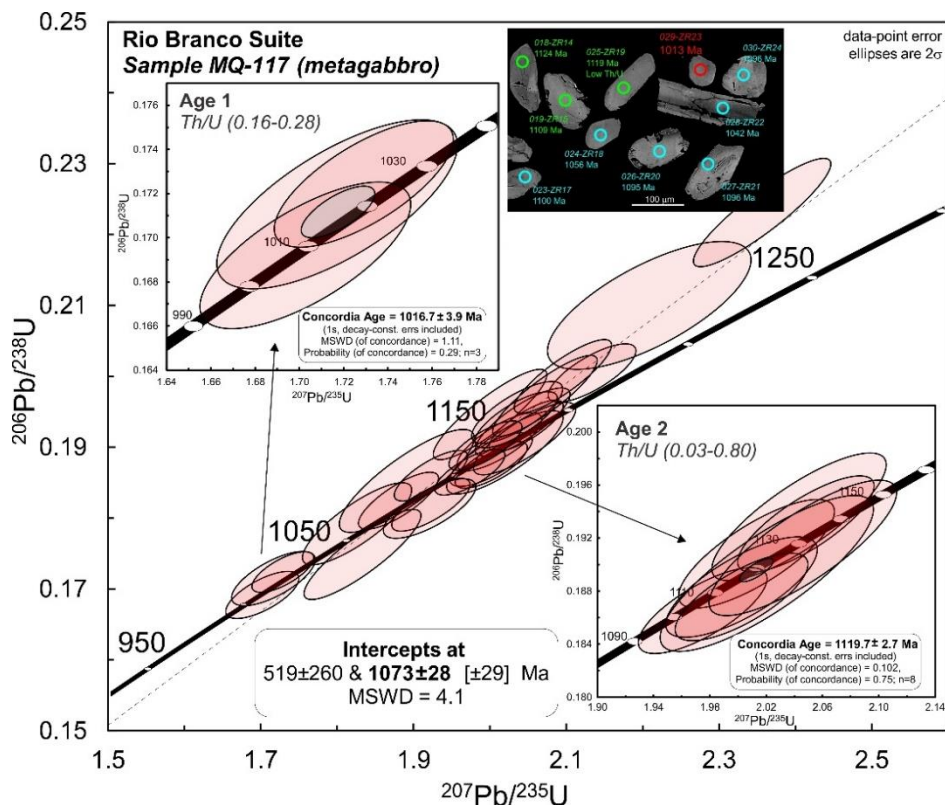
Fig. 12. U-Pb Discordia and Concordia diagrams of metagabbro (sample MQ-117) from the Rio Branco domain, displaying primary population of zircon (zoned core and light rim) with Concordia age of 1120±3 Ma (n=8), low-high Th/U ratios (0.03-0.80), and second population of zircon (rounded and homogeneous) with Concordia age of 1017±4 Ma (n=3), Th/U (0.16-0.28).

Sample MQ-124 (S11°54'20"/W62°02'57") is a fine-grained subvolcanic metagranite (metafelsic subvolcanic), which occurs in the form of a body elongated in the E-W direction, measuring approximately 16 km x 1.6 km. The metagranite intruded fine-grained amphibolite. It is a porphyritic felsic rock with fine-grained to aphanitic matrix, containing stretched porphyroclasts of k-feldspar and xenoliths of foliated metamafic rocks (Fig. 8C). From this sample, twenty-six zircon crystals were extracted and classified into two groups based on their morphology and internal structure, observed on BSE images (Table 2). The first group consists of small zircon grains (25-110 μm), usually prismatic or rounded, homogenous or with concentric zoning and micro fractures. Subordinately in this group occur round crystals exhibiting characteristics of light gray core and thin dark gray rims and crystals with bipyramidal forms. The second zircon group consists of large, prismatic and elongated crystals with bipyramidal terminations, measuring 150-400 μm, internally exhibiting concentric or oscillatory zoning. Analyzes of the first group revealed a wide dispersion of ages, with $^{207}Pb/^{206}Pb$ Paleoproterozoic ages of 2164 Ma, 1927 Ma and 1624 Ma. Sixteen zircon crystals of the second group were analysed and proved to be the most concordant and with Th/U ratios ranging from 0.16 to 0.34 (range 029-ZR23 to 036-ZR28 in Table 2, sample MQ-124), were used in the calculation of the Concordia age of 1112.3 ± 1.9 Ma (MSWD = 0.70), interpreted as the magmatic crystallization age of the rock (Fig. 13B). The oldest ages up to 1624 Ma and 2164 Ma may represent crustal contamination (Table 2, Fig. 13 B).

Fig. 13 . *U-Pb Concordia diagrams of concordant zircon from samples from the Rio Branco Domain, Nova Brasilândia belt. (A) metagranite dike intrusive in folded high-grade calc-silicate gneisses of the Rio Branco Formation. (B) felsic metasubvolcanic rock of the Rio Branco Suite, intrusive in metamafic rocks*.

Sample MQ-29 (S11°56'55"/W62°13'20") is a medium-grained leucocratic metatrondhjemite (plagiogranite equivalent), which occurs in the form of lenses within metamafic rocks, with about 400 m length and 80 m width, spatially associated with metagabbros (Fig. 8D). It consists essentially of quartz and generally saussuritized plagioclase, containing approximately 10 % of interstitial mafic minerals (amphibole and clinopyroxene), with titanite, magnetite and zircon traces. From this sample were extracted and analyzed twenty-five zircon crystals (Table 2). They are prismatic crystals from euhedral to subhedral, with rounded ends, sizes varying between 40 and 350 μm and with frequent inclusions (Fig. 15). The BSE images exhibit crystals oscillatory zoning remnants and abundant irregular dark and luminescent areas. Areas with oscillatory zoning are more common in larger crystals. In general, zircon of the MQ-29 sample presents Th/U ratios between 0.16 and 0.79, compatible with those of zircon of magmatic origin. The regression of all data indicates the upper intercept of 1106.7 ± 8.2 Ma (MSWD=1.16, n=20) (Fig. 14). In order to obtain a more accurate age, the most concordant data (> 95 % concordance, Table 2), were used in the calculation of Concordia age of 1106.2 ± 2.8 Ma (MSWD = 0.026 and probability = 0.87, n=8), interpreted as the age of magmatic crystallization (Fig. 14).

6.4 Anatectic granite (in Rio Branco Formation)

Sample MQ-146B (S12°00'23"/W61°51'23") is from a weathered white anatectic granite lens in paragneiss. This sample was selected for dating by the LA-ICP-MS U-Pb zircon method in an attempt to characterize the age of deformation and metamorphism that generated partial melting (or migmatization) of the metasedimentary component of the Rio Branco Formation, during the climax of metamorphism. The twenty zircon crystals extracted from this sample were classified into three morphologically distinct groups. The main group consists dominantly of large (435-260 μm), homogeneous or zoned, fractured subhedral crystals, with 1:3 and 1:2 proportions. The analysis of these crystals (n=20) shows a wide dispersion of Mesoproterozoic ages, associated with Th/U ratios between 0.01 and 0.03 (Fig. 15). Among them, a set of eleven points analyzed showed some alignment (range 014-ZR09 to 024-ZR17 in Table 2, sample MQ-146B) that allowed the calculation of the regression, whose upper intercept is 1011.3 ± 9.6 Ma MSWD=0.70 (Fig. 15). The second zircon set consisting of three rounded and homogeneous crystals (1:1 and 1:2), sizes between 230 and 130 μm and Th/U ratios between 0,17 and 0,30 (crystals 009- ZR06, 040-ZR31 and 019-ZR14 in Table 2) furnished the Concordia age of 1137.7 ± 4.7 Ma (MSWD=0.6) (Fig. 15). The third group of zircon grains is represented by small rounded crystals (100-50 μm) presenting core and rims, radial fractures and ratio width vs. length of 1:1 to 1:2. The third zircon group presented cores with Mesoproterozoic $^{207}Pb/^{206}Pb$ ages in 1559 Ma, 1514 Ma, 1442 Ma, 1271 Ma, 1166 Ma and 1057 Ma, not used for calculation of age rock (Fig. 15). Thus, we interpret the upper intercept of 1011.3 ± 9.6 Ma as the crystallization age of the anatectic granite originate from partial fusion (or migmatization) of the metasedimentary rocks of the Rio Branco Formation during the climax of a possible second metamorphic pulse. In the sample MQ-146B, the U-Pb ages of 1137.7 ± 4.7 Ma interpreted as inheritance and 1011.3 ± 9.6 Ma interpreted as migmatization (Fig. 15) are identical or very close to the metamorphic U-Pb ages found in the MQ-44 (paragneiss) and MQ-117 (metagabbro) samples (Figs. 10A, 12).
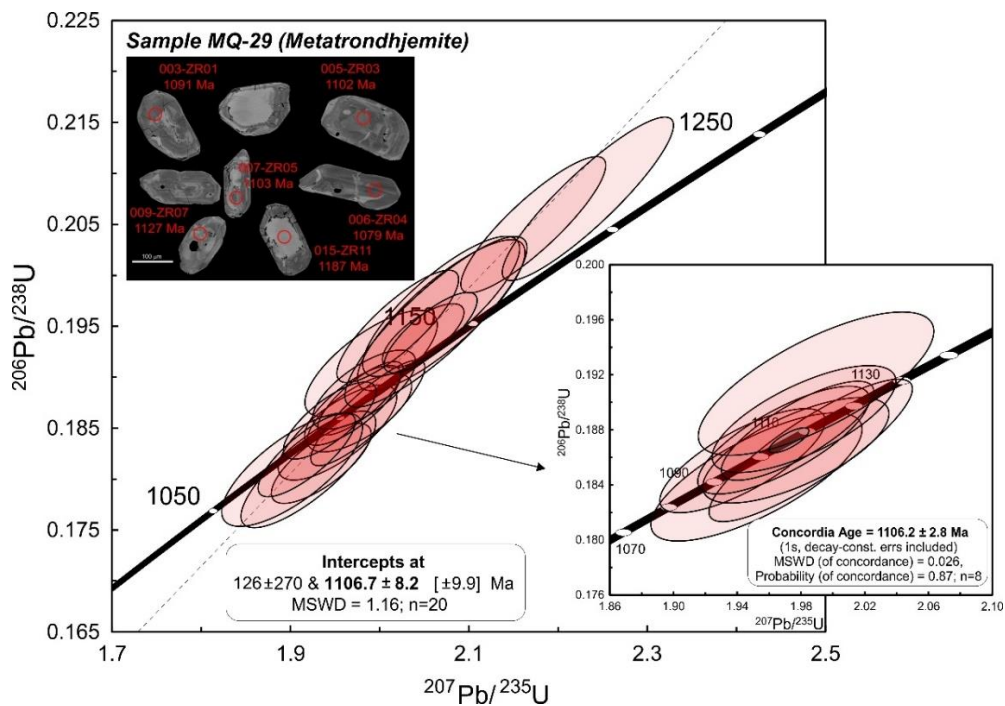
Fig. 14*. U-Pb (LA-ICP-MS) Concordia diagram of concordant zircon grains from metatrondhjemite sample of the Rio Branco Domain, Nova Brasilândia belt.*
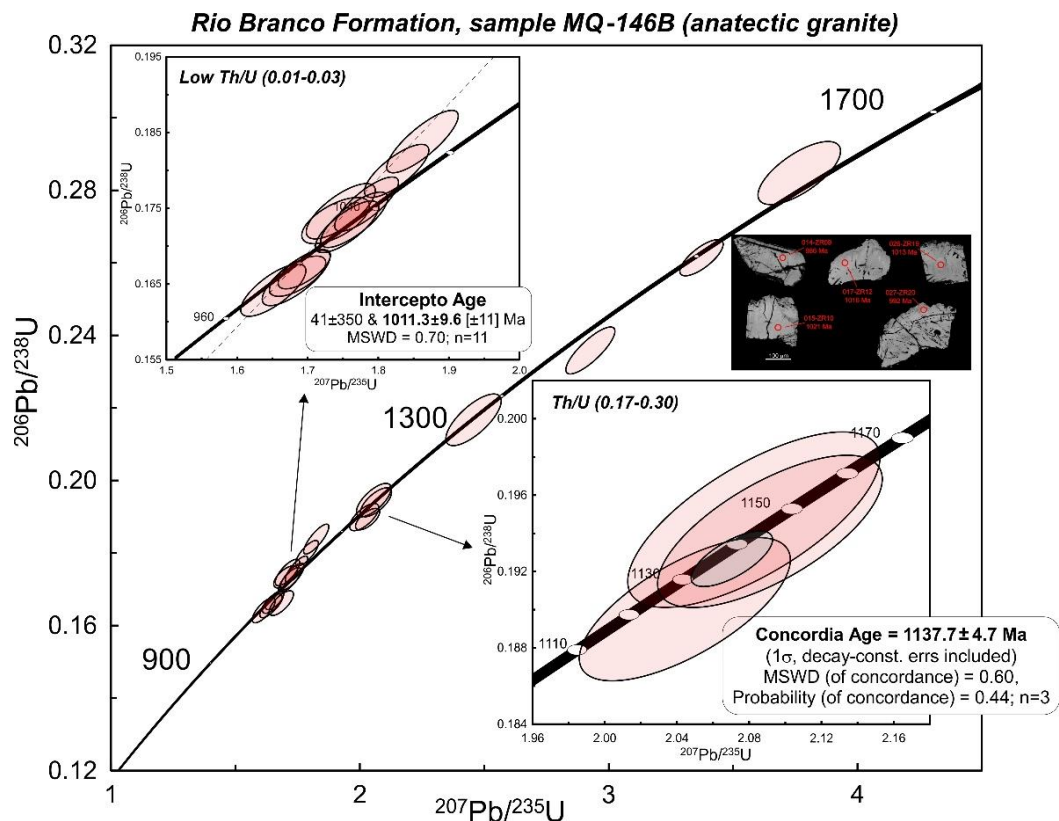
Fig. 15. *U-Pb (LA-ICP-MS) Discordia and Concordia diagrams showing zircon ages of the two main populations of anatectic granite (sample MQ-146B) in paragneiss of the Rio Branco Formation. The age range of 1150-1136 Ma (n=3) includes metamorphic and magmatic zircon grains based on BSE images and Th/U ratios and provides an age of 1137.7 ± 4.7 Ma. The range of 1021-986 Ma (n=11) includes zircon grains with low Th/U ratio (0.01-0.03), rendering an intercept age of 1011.3 ± 9.6 Ma on the Discordia diagram.*

7. Discussion

The association of high-grade metavolcanic-sedimentary rocks (calc-silicate gneisses, biotite paragneisses and granulites paraderived, mafic or felsic) with mafic-felsic metaigneous rocks (metagabbros, massive metabasalts, metadiabases, amphibolites, metatrondhjemites massive or banded and metagranites) at Rio Branco domain in the southern portion of the Nova Brasilândia belt was initially interpreted as an incomplete fragment of seafloor (Rizzotto, 1999). These rocks were folded, sheared and metamorphosed in high-grade (amphibolite- to granulite-facies). Field features demonstrate that the metamafic and metafelsic components present intrusion relations with high-grade metasedimentary rocks, in the form of stocks, small elongate bodies, sills and dikes.

The evaluation of field geological data and LA-ICP-MS U-Pb zircon geochronological analyzes obtained in our research, combined with the re-interpretation of previously published U-Pb, [40]Ar-[39]Ar and Sm-Nd geochronological data (Table 1) provided a temporal understanding of the geological events recorded in the Nova Brasilândia belt occurred during the Mesoproterozoic (Stenian) and early Neoproterozoic (Tonian). The timing of sedimentation, magmatism, deformation and metamorphism episodes provided a better understanding of the geological evolution of the Nova Brasilândia belt, during the Nova Brasilândia orogeny (Table 3). The use of different isotopic systems, analytical methods and analyzed materials provided ages with different meanings, which were used to establish the of crystallization, deposition, deformation, metamorphism and cooling ages of the rocks, as well as identifying sources-areas.

Accordingly, the new isotopic data of the Rio Branco domain described in section 4.2 with those available in literature were used to support our interpretations in relation of the progression of Nova Brasilândia belt geological events over time.

7.1 Maximum sedimentation ages

U-Pb detrital zircon ages from the northern portion of the Nova Brasilândia Belt indicate maximum depositional ages of 1122 ± 12 Ma (Rizzotto et al., 2014) for Migrantinópolis Formation and 1143 Ma for Terra Boa Formation (Trindade Neto et al., 2018). These studies identified source ages compatible with the rocks of the Jamari Complex (~ 1174 Ma) and Serra da Providência Suite (~ 1554 Ma) located north of the Nova Brasilândia belt, and also with rocks from the Rio Branco domain, southern portion of the Nova Brasilândia belt. Therefore, they presented zircon contribution from oldest units located north of the Nova Brasilândia belt.

The new U-Pb LA-ICP-MS data presented in this article reveal the maximum sedimentation age of 1241 ± 7.5 Ma, obtained in detrital zircon from high-grade calc-silicate gneiss (sample MQ-44) from the Rio Branco Formation in the southern portion of the Nova Brasilândia belt (Rio Branco domain). The other analyzed zircon grains presented $^{207}Pb/^{206}Pb$ ages distributed into three peaks with approximately 1480 Ma, 1432 Ma and 1386 Ma. These ages are compatible with source areas located south of the Nova Brasilândia belt composed of rocks from the Colorado and Trincheira complexes (Rizzotto et al., 2013, 2014).

7.2 Magmatic crystallization ages

The previously published U-Pb magmatic crystallization ages (Table 1) include data of: a) The Rio Branco Suíte – a foliated monzogranite of 1113 ± 56 Ma (Rizzotto, 1999); b) The Migrantinópolis Formation – an anatectic leucogranite of 1110 ± 8 M derived from paragneiss (Rizzotto, 1999); and, c) Rio Pardo Suite – two samples of monzogranite of 1005 ± 41 Ma (Rizzotto, 1999) and 1010 ± 15 Ma (Rizzotto et al., 2014). These ages, according to the authors cited above, were interpreted as marking the peak of a metamorphism of the Nova Brasilândia belt (ca. 1113-1110 Ma), as well as the post-tectonic granitic magmatism represented by the Rio Pardo Suite (1010-1005 Ma). We would like to point out that despite the reasonable number of analyzes, some of them are inaccurate, as they are associated with high errors.

In our research, new magmatic crystallization U-Pb zircon ages were obtained by LA-ICP-MS for Rio Branco Suite. These results present low errors and MSWD, providing more accuracy in the chronology of geological events: a) Medium-grained metagabbro (sample MQ-117) intrusive in high-grade calc-silicate gneiss and biotite paragneiss of the Rio Branco Formation of 1119.7 ± 2.7 Ma; b) Foliated metagranite dike (sample MQ-147M) intrusive in high-grade calc-silicate gneiss of the Rio Branco Formation of 1113 ± 6.7 Ma; c) Fine-grained subvolcanic metagranite (sample MQ-124) coeval with massive metabasalt of the Rio Branco Suite of 1112.3 ± 1.9 Ma; d) Metatrondhjemite (sample MQ-29) that occurs as lens inside metagabbro of the Rio Branco Suite of 1106.2 ± 2.8 Ma. High-grade metatrondhjemitic gneiss (sample MQ-122) spatially associated with Rio Branco Formation presented Concordia age of 1127.6 ± 2.3 Ma. These ages of Rio Branco Suíte define the timing of mafic-felsic magmatic event between 1119.7 ± 2.7 Ma and 1106.2 ± 2.8 Ma. The age of 1127.6 ± 2.3 Ma obtained from trondhjemitic gneiss approximates the high-grade metamorphic age of 1137 ± 9 Ma, considering the dating method used error. Therefore, the age of 1127.6 ± 2.3 Ma was preliminarily interpreted in this paper as possible magmatic crystallization age that may represent the fusion of mafic rock during the orogenetic event and very close to the peak of high-grade metamorphism. However, further studies are needed to confirm this hypothesis.

7.3 Metamorphism and cooling ages

U-Pb (TIMS and SHRIMP) ages of metamorphic recrystallization or metamorphism obtained in zircon, monazite, titanite and rutile crystals of rocks from the Nova Brasilândia belt were compiled from previously published articles (Table 1). Of these published ages, we highlight the metamorphic recrystallization age of 1096 ± 6 Ma (monazite in mylonitic paragneiss), 1089 ± 9 Ma (titanite in banded leucrocatic trondhjemite), 1082 ± 6 Ma (monazite in mica schist), 1061 ±

935 14 Ma (intercept age in titanite of the calc-silicate gneiss), 1020 ± 15 Ma (monazite in calc-silicate)
936 (Tohver et al., 2004, 2005a; Rizzotto et al., 2014). A high-grade metamorphic pulse accompanied
937 by low pressure (3.1 Kb) and high temperature migmatization was characterized with U-Pb age
938 (SHRIMP) of 1110 ± 8 Ma obtained in zircon crystal from a granitic leucosome sample and age of
939 1110 ± 10 Ma of a metagabbro of the Nova Brasilândia Group (see Rizzotto, 1999).

940   During our research, new U-Pb ages (LA-ICP-MS) obtained from specific groups of zircon
941 crystals from the Rio Branco domain rocks also revealed metamorphic recrystallization and
942 migmatization ages: a) The ^{207}Pb/^{206}Pb peak age of 1137 ± 9 Ma and peak age of 1019 ± 15 Ma in
943 calc-silicate gneiss (sample MQ-44); b) Concordia age of 1016.7 ± 3.9 Ma in metagabbro (sample
944 MQ-117); and, c) Upper intercept age of 1011.3 ± 9.6 Ma in anatectic granite (sample MQ-146B)
945 in biotite paragneiss of the Rio Branco Formation.

946   Two main high-grade metamorphic pulse were identified based on the new U-Pb zircon
947 dating (LA-ICP-MS) and the reinterpretation of previously published geochronological data (see
948 Table 1). The geological field relations of rocks reinforce the identification and timing of distinct
949 metamorphic pulses. The oldest metamorphic pulse (amphibolite- to granulite-facies) was recorded
950 in high-grade gneisses and granulite of Rio Branco Formation in the Rio Branco domain between
951 approximately 1138 and 1128 Ma, therefore developed prior to the emplacement of Suite Rio
952 Branco mafic-felsic magmatism. The varying conditions of P-T for oldest metamorphic pulse were
953 initially established based on the paragneisses. High-temperature metamorphic conditions between
954 670 ° - 800 ° C and low-pressure around 3.1 kbars (Rizzotto, 1999). In the southern part of the belt,
955 peak T-conditions of maximum 750 ° C and maximum P of 7.9 kbars for granulitic paragenesis
956 (Tohver et al., 2004, 2005a). Low-grade ranges (*greenschist facies)* occur locally along shear zones
957 and in the occurrence regions of the Migrantinópolis Formation rocks especially in the northern part
958 of the Nova Brasilândia Belt (Scandolara and Rizzotto, 1998; Quadros and Rizzotto, 2007). These
959 varied P-T conditions suggest juxtaposition of high-temperature/low-pressure (HT/LP) and high-
960 temperature/high-pressure (HT/HP) metamorphic domains, where metamorphism has reached
961 amphibolite- to granulite-facies conditions. Additionally, the age of 1110 ± 8 Ma of the anatectic
962 leucogranite in Migrantinópolis Formation paragneisses (sample GR-20) was also interpreted as the
963 record of regional metamorphic peak that affected the Migrantinópolis Formation rocks (Rizzotto,
964 1999).

965   The second and youngest metamorphic pulse between 1096 ± 6 Ma and 1011.3 ± 9.6 Ma
966 was recorded in high-grade gneisses of Rio Branco Formation and the metamafic component of Rio
967 Branco Suite. This had been characterized in previous studies involving geological characterization
968 in the field, petrography and geochronology (Rizzotto, 1999; Tohver et al., 2004, 2005a; Rizzotto
969 et al., 2014). This second pulse possibly corresponds to the high-grade metamorphism (amphibolite-
970 facies) from crustal thickening that partially marks the suturing of the Paraguá block to the southern
971 margin of the Amazonian proto-Craton in latest Mesoproterozoic times (Tohver et al., 2004). U-Pb
972 monazite ages of 1090 Ma and titanite ages of approximately 1060 Ma record cooling from the peak
973 metamorphic conditions (Tohver et al., 2004). The published ^{40}Ar-^{39}Ar data clearly show the age
974 range of cooling episodes that occurred in the Nova Brasilândia belt between 1005 ± 7 Ma (in
975 hornblende from metagabbro) and 910 ± 2 Ma (in biotite from mylonitic paragneiss) (Tohver et al.,
976 2004, 2005a, 2005b).

977

978 *7.4 Tectonic evolution*

979

980   The geological and geochronological data available in the literature on the Nova Brasilândia
981 belt, in association with the new geological field data and U-Pb zircon (LA-ICP-MS) data for the
982 Rio Branco domain presented in this paper, suggest that the tectonic evolution of this belt occurred
983 diachronically in the Mesoproterozoic (Stenian) and early Neoproterozoic (Tonian). We propose
984 that the Nova Brasilândia belt records three evolutionary phases (pre-orogenic, orogenic and post-
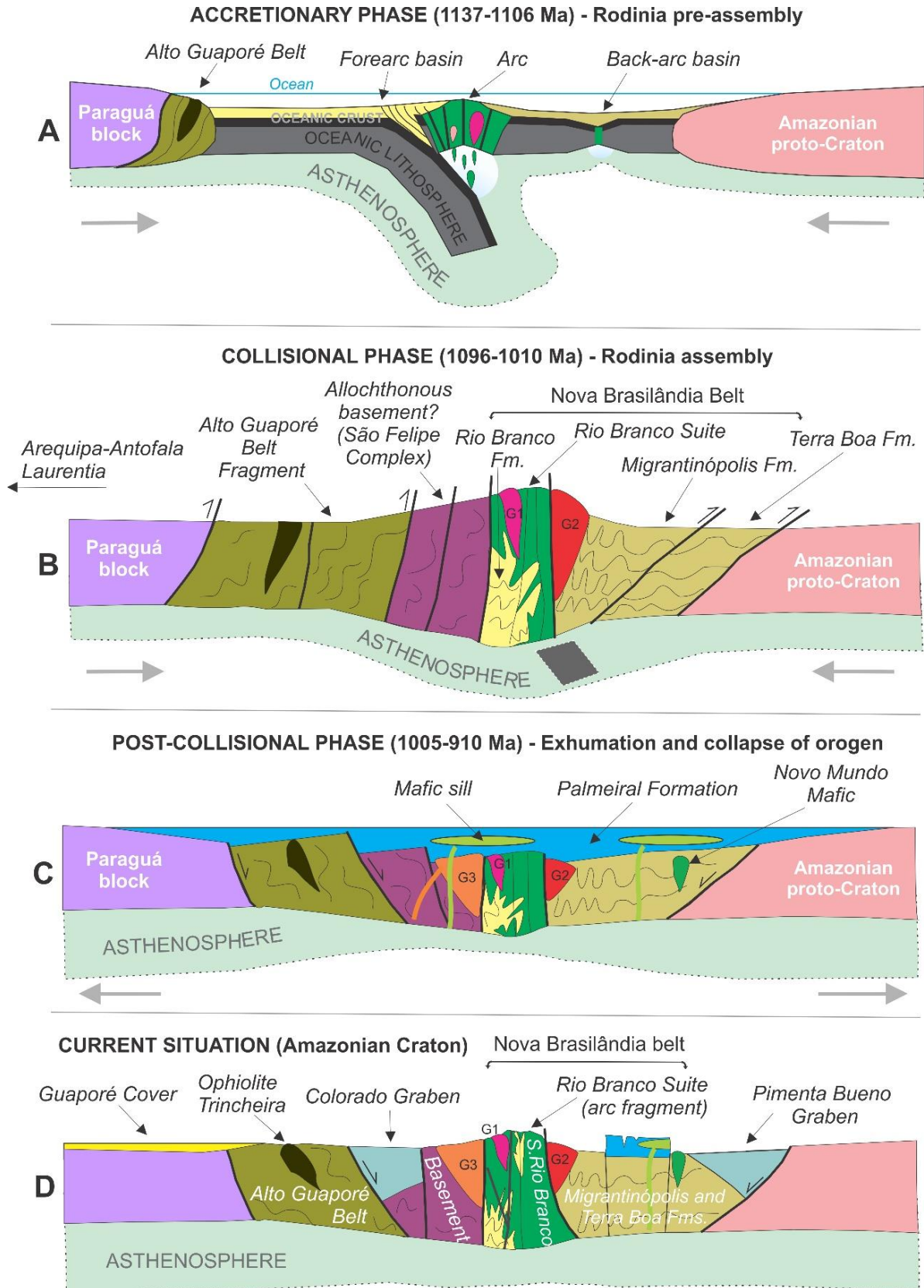985 orogenic) occurred between ca. 1241 Ma and 910 Ma. These phases resulting from the

986 fragmentation and agglutination of crustal masses associated with final Rodinia assembly, followed
987 by the subsequent final exhumation and orogenic collapse (Fig. 16, Table 3).
988   Pre-orogenic phase (ca. < 1241 and 1137 Ma) corresponds to extension (rift, rift-drift and
989 drift) with formation of passive margin and proto-ocean (Rizzotto, 1999). The first orogenetic phase
990 (ca. 1137 and 1106 Ma) mark the oldest event of the Nova Brasilândia orogeny. It is being proposed
991 in this paper based on geological and geochronological new data, adding to the information and
992 interpretations initially presented by Rizzotto (1999), Rizzotto et al. (2001, 2014) and Tohver et al.
993 (2004, 2005a, 2005b, 2006). It possibly corresponds to the beginning of subduction and closure of
994 a pre-existing ocean, associated with the initial phase of an accretionary orogeny (Fig. 16A),
995 according to Quadros et al. (submitted). An intra-oceanic subduction environment is being attributed
996 to this phase of the Nova Brasilândia orogeny and may be the key to explaining the deformation and
997 metamorphism of high-grade that occurred prior to mafic-felsic magmatism (Rio Branco Suite), as
998 well the positioning of the high-grade metamorphic rocks below the Rio Branco Suite metamafic
999 rocks (Quadros et al., submitted). Another features to be highlighted are the episodes of
1000 sedimentation, metamorphism, deformation and magmatism between ca. 1137 and 1106 Ma,
1001 therefore, with very close ages and associated with a short time for developed of the geological
1002 episodes during the Nova Brasilândia belt tectonic evolution. The presence of metatrondhjemites
1003 (plagiogranites equivalent) with crystallization ages very close to high-grade metamorphism
1004 reinforces the thesis of the intra-oceanic subduction between two oceanic plates.
1005   During the first orogenetic phase (ca. 1137 and 1106 Ma), there were a series of magmatic
1006 pulses of mafic and mafic-felsic nature (Rio Branco Suite) intruding high-grade metasedimentary
1007 rocks of the Rio Branco Formation, but with crystallization age very close to that of high-grade
1008 metamorphism. Emplacement of the Rio Branco Suite rocks occurred between 1119.7 ± 2.7 Ma and
1009 1106.2 ± 2.8 Ma (according to the ages of samples MQ-117, MQ-147M, MQ-124 and MQ-29) and
1010 lasted approximately between 19 Ma and 8 Ma considering analysis error (Table 3). Field relations
1011 and isotopic data suggest that this mafic-felsic magmatism occurred in three distinct pulse. The first
1012 pulse had a predominantly mafic nature, represented by metagabbro, with emplacement at deeper
1013 crustal levels at 1119.7 ± 2.7 Ma (sample MQ-117) and under high-temperature conditions, as
1014 evidenced by olivine reaction coronae with plagioclase in metagabbro and metatroctolite. The
1015 second pulse was mafic-felsic, the mafic component represented by sills and dikes of fine-grained
1016 metagabbros (preserved subophitic textures), fine-grained amphibolites (basalt and diabase
1017 protoliths), metadiabases and massive metabasalts, with emplacement at shallow crustal levels at up
1018 to surface overflow. The felsic component of the second pulse is represented by elongated bodies
1019 and dikes of metagranites (porphyritic or fine-grained equigranular) and felsic metavolcanic rocks
1020 with ages of 1113 ± 6.7 Ma (sample MQ-147M), 1112.3 ± 1.9 Ma (sample MQ-124). The third
1021 pulse of magmatism, the youngest associated with first orogenetic phase, corresponds to the
1022 generation of lenses and dikes of metatrondhjemites occurring at approximately of 1106.2 ± 2.8 Ma
1023 (sample MQ-29) and corresponding to small volumes of residual magmas probably formed during
1024 fractional crystallization processes or from the fusion of mafic rocks.
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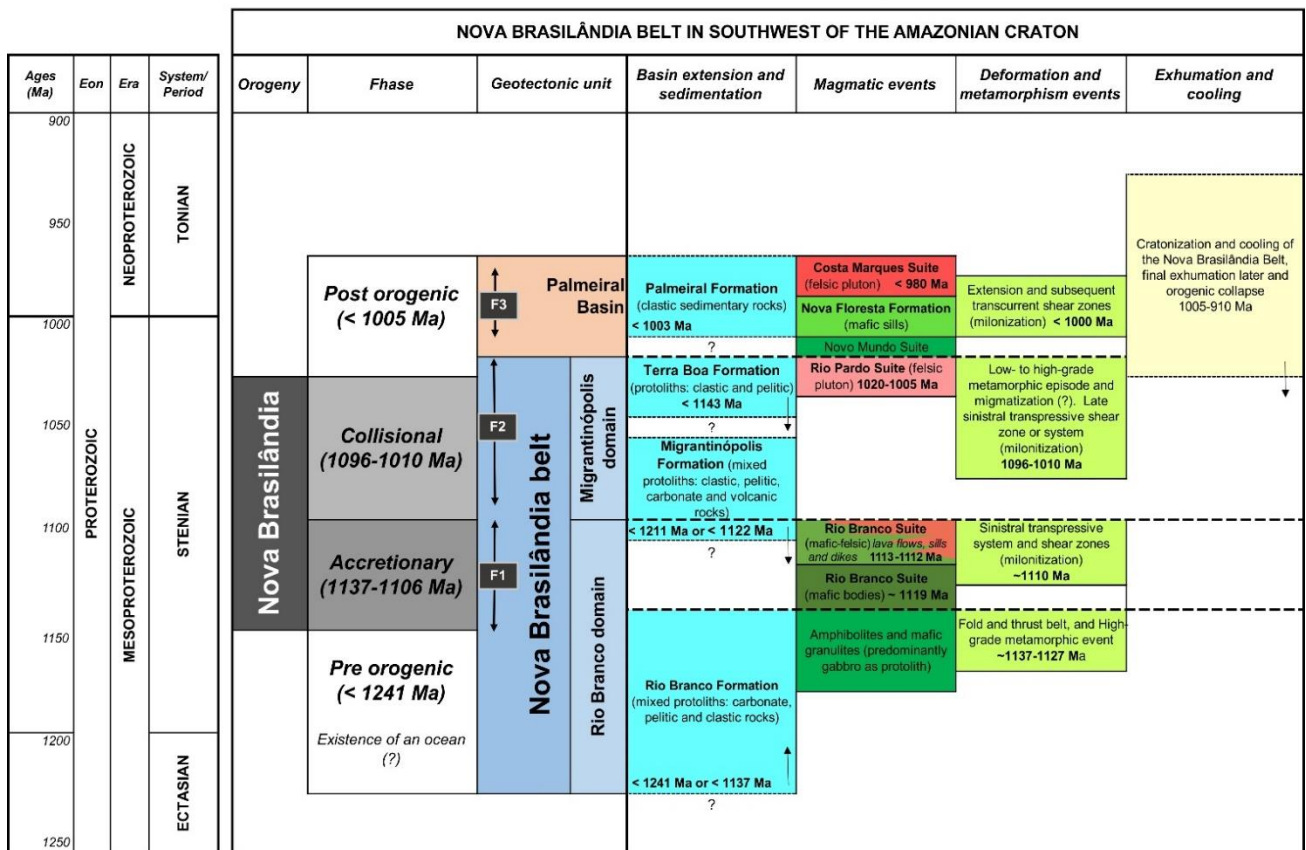1027
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ACCRETIONARY PHASE (1137-1106 Ma) - Rodinia pre-assembly

Alto Guaporé Belt *Forearc basin* *Arc* *Back-arc basin*

A **Paraguá block** OCEANIC CRUST OCEANIC LITHOSPHERE ASTHENOSPHERE Ocean **Amazonian proto-Craton**

COLLISIONAL PHASE (1096-1010 Ma) - Rodinia assembly

Allochthonous basement? (São Felipe Complex) Nova Brasilândia Belt

Arequipa-Antofala Laurentia *Alto Guaporé Belt Fragment* *Rio Branco Fm.* *Rio Branco Suite* *Migrantinópolis Fm.* *Terra Boa Fm.*

B **Paraguá block** G1 G2 ASTHENOSPHERE **Amazonian proto-Craton**

POST-COLLISIONAL PHASE (1005-910 Ma) - Exhumation and collapse of orogen

Mafic sill *Palmeiral Formation* *Novo Mundo Mafic*

C **Paraguá block** G3 G1 G2 ASTHENOSPHERE **Amazonian proto-Craton**

CURRENT SITUATION (Amazonian Craton) Nova Brasilândia belt

Guaporé Cover *Ophiolite Trincheira* *Colorado Graben* *Rio Branco Suite (arc fragment)* *Pimenta Bueno Graben*

D *Alto Guaporé Belt* Basement G3 G1 S. Rio Branco G2 *Migrantinópolis and Terra Boa Fms.* ASTHENOSPHERE

Fig. 16. Simplified model for the Mesoproterozoic (Stenian-Tonian) tectonic evolution proposed for the Nova Brasilândia belt of the southwestern part of the Amazonian Craton, Rondônia.

Second orogenetic phase (about 1096 and 1010 Ma) was presumably evidenced from younger U-Pb (LA-ICP-MS) ages obtained from recrystallized zircon crystals, suggesting metamorphic overprint between 1019 ± 15 Ma and 1011.3 ± 9.6 Ma. In this context, calc-silicate gneiss (sample MQ-44) from the Rio Branco Formation provides a peak $^{207}Pb/^{206}Pb$ age of 1019 ± 15 Ma, interpreted as metamorphic recrystallization associated with the younger event. The U-Pb age of 1011.3 ± 9.6 Ma (upper intercept) recorded in an anatectic granite (sample MQ-145B) occurring as a lens within the paragneiss of the Rio Branco Formation is considered the melt crystallization age during the peak of the second metamorphic pulse. Among the recovered zircon populations from a metagabbro (sample MQ-117) of the Rio Branco Suite, one of them provides the Concordia age of 1016 ± 3.9 Ma, interpreted as the isotopic record of the younger metamorphic pulse. However, this youngest age set is still insufficient for accurately demonstrate the participation of an event of deformation and metamorphism that generated partial melting (or migmatization) of the metasedimentary component of the Rio Branco Formation when analyzed in isolation.

Table 3.

Time-stratigraphy of Mesoproterozoic (Stenian-Tonian) geological events in the southwest Amazonian Craton recorded in the rocks of the Nova Brasilândia belt, in Rondônia. F1, F2 and F3 are phases of evolution. Arrows indicate change at the beginning of sedimentation and cooling (after Rizzotto, 1999; Scandolara and Rizzotto, 1998; Rizzotto et al., 2001, 2014; Santos et al., 2003, 2008; Tohver et al., 2002, 2004, 2005a; Teixeira et al., 2010, 2018).

Ages (Ma)	Eon	Era	System/Period	Orogeny	Fhase	Geotectonic unit	Basin extension and sedimentation	Magmatic events	Deformation and metamorphism events	Exhumation and cooling
						NOVA BRASILÂNDIA BELT IN SOUTHWEST OF THE AMAZONIAN CRATON				
900–950	PROTEROZOIC	NEOPROTEROZOIC	TONIAN	Nova Brasilândia						Cratonization and cooling of the Nova Brasilândia Belt, final exhumation later and orogenic collapse 1005-910 Ma
~1000					Post orogenic (< 1005 Ma) F3	Palmeiral Basin	Palmeiral Formation (clastic sedimentary rocks) < 1003 Ma	Costa Marques Suite (felsic pluton) < 980 Ma; Nova Floresta Formation (mafic sills); Novo Mundo Suite	Extension and subsequent transcurrent shear zones (milonization) < 1000 Ma	
1050		MESOPROTEROZOIC	STENIAN		Collisional (1096-1010 Ma) F2	Nova Brasilândia belt — Migrantinópolis domain	Terra Boa Formation (protoliths: clastic and pelitic) < 1143 Ma; Migrantinópolis Formation (mixed protoliths: clastic, pelitic, carbonate and volcanic rocks) < 1211 Ma or < 1122 Ma	Rio Pardo Suite (felsic pluton) 1020-1005 Ma	Low- to high-grade metamorphic episode and migmatization (?). Late sinistral transpressive shear zone or system (milonitization) 1096-1010 Ma	
1100					Accretionary (1137-1106 Ma) F1	Nova Brasilândia belt — Rio Branco domain		Rio Branco Suite (mafic-felsic) lava flows, sills and dikes 1113-1112 Ma; Rio Branco Suite (mafic bodies) ~ 1119 Ma	Sinistral transpressive system and shear zones (milonitization) ~1110 Ma	
1150					Pre orogenic (< 1241 Ma)		Rio Branco Formation (mixed protoliths: carbonate, pelitic and clastic rocks) < 1241 Ma or < 1137 Ma	Amphibolites and mafic granulites (predominantly gabbro as protolith)	Fold and thrust belt, and High-grade metamorphic event ~1137-1127 Ma	
1200–1250			ECTASIAN		Existence of an ocean (?)					

A high-grade metamorphic episode in the Nova Brasilândia belt was previously characterized by Rizzotto (1999). The author obtained the age of 1110 ± 8 Ma (zircon U-Pb, SHRIMP) in an anatectic leucogranite (GR-20) originating from the Migrantinópolis Formation metatubirdite fusion, generated at the metamorphic peak. Additional, ages of 1096 Ma, 1080 Ma and 1085 Ma, and 1020 Ma obtained from metamorphic monazite and titanite, respectively, by the U-Pb TIMS method in metasedimentary rocks of the Mingrantinópolis and Rio Branco formations constrain the time of deformation transpressive and metamorphism (Tohver et al., 2004). These ages possibly represent younger metamorphism that occurred after the emplacement of the Rio Branco Suite rocks. A brief analysis together with the new ages presented in this paper and the U-Pb ages of

previous works (Rizzotto, 1999; Tohver et al., 2004, 2005a; Santos et al., 2008; Rizzotto et al., 2014) reinforces the characterization of a youngest metamorphism between 1096 ± 5 Ma and 1011.3 ± 9.6 Ma. We suggest that the youngest metamorphism may be associated with the collisional phase of the Nova Brasilândia orogeny (Fig. 16B), as a reflection of the interactions between Laurentian and Amazonian cratons, as well as, participation of other cratons, fragments and smaller blocks (e.g., the Arequipa-Antofala basement, Paraguá block, Alto Guaporé belt fragment and São Felipe basement). The felsic magmatism of the Rio Pardo Suite at ca. 1005 ± 41 Ma (see Rizzotto, 1999) registers the beginning of post-tectonic stage of this second orogenetic evolutionary phase in the Nova Brasilândia belt.

In order to improve the tectonic models of joints between craton, block or terraine fragments during the development of Mesoproterozoic mobile belts of southwestern Amazonian Craton (Nova Brasilândia, Sunsás and Aguapeí belts), we present a simplified scenario that demonstrates the possible cratonic masses involved during the evolution of the Nova Brasilândia belt (Fig. 17). Complex interactions occurred between Amazonian proto-Craton, Paraguá block, Arequipa-Antofala basement and allochthonous terrane fragments that need to be better understood. Our proposal is partly according to the models proposed by Tohver et al. (2002, 2004, 2005b), Loewy et al. (2004), Boger et al. (2005) and Rizzotto et al. (2014), however, inserted an intra-oceanic subduction phase in the evolution of the Nova Brasilândia belt (see Quadros et al., submitted).

The post-orogenic phase (<1005 Ma) was not evaluated in this research. It was, developed in the interval between 1005 and 910 Ma has been recorded in the northern portion of the Nova Brasilândia belt, reworked cratonic areas (Fig. 16C, Table 3), and marks the collapse of part of Sunsás orogen (based in Santos et al., 2008). Corresponds to an extensional phase (~980-910 Ma) post-convergence and exhumation of the orogen, with basin formation and continental siliciclastic sedimentation (Palmeiral Formation), anorogenic felsic alkaline intrusions (Costa Marques Suite), and mafic dikes, sills and stocks (Nova Floresta Formation and Novo Mundo Suite). Important sinistral transcurrent shear zones (e.g., Rio Branco shear zone) werw generated at this phase. In the cratonic area northwest of the study area, several anorogenic granite bodies with Sn-polymetallic mineralizations (~ 1.08-0.98 Ga), called Santa Clara Suite and Rondônia Suite were generated during this extensional phase (see Rizzotto, 1999; Santos et al., 2000, 2008; Rizzotto et al., 2001, 2014; Tohver et al., 2005b, 2006; Quadros and Rizzotto, 2007). Studies by Tohver et al. (2004, 2006) showed U-Pb (titanite and monazite) and $^{40}Ar/^{39}Ar$ (amphibole and biotite) metamorphic ages at time intervals between 1.09-1.06 Ga and 0.97-0.91 Ga, suggesting a long history of metamorphism, tectonic exhumation and cooling (Table 1). The indication of the minimum metamorphism age and deformation (shear) at 970-966 Ma and 965 ± 23 Ma, respectively, were determined by $^{40}Ar/^{39}Ar$ and K-Ar (amphibole) analyses of amphibolites (Tohver et al., 2004).

The transtension-transpression recorded by the shear zones that affect the rocks of the Nova Brasilândia belt may be related to late tectonic extrusion associated with movements and mass escapes in the late phases of the oblique collisonal orogeny. It is possible to establish based on the available field geological, U-Pb and ^{40}Ar-^{39}Ar geochronological data (Table 1), that there are at least three shear phases involving transtension-transpression developed at approximately 1110 Ma and 1010 Ma. These periods of transtension-tranpression occurred after the acretionary phase identified in our research in the Rio Branco domain. These possibilities mentioned above need to be better evaluated in future studies. Finally, the Figure 16D represents the current stage of the Nova Brasilândia belt after tectonic reactivations, grabens formation, sedimentation, and erosion along the Phanerozoic.

Fig. 17. *Schematic tectonic scenarios of the late Mesoproterozoic (Stenian) with the phase of evolution of the Nova Brasilândia belt involving the break-up of the Amazonian proto-Craton, followed by the accretion of the Paraguá block and the Arequipa-Antofala basement to the western margin of the Amazonian proto-Craton (modified from Boger et al., 2005; Rizzotto et al., 2014).*

8. Conclusion

The new geological and LA-ICP-MS U-Pb zircon geochronological data presented in this article and the reinterpretation of previously published information allow us to establish a more accurate chronology of the sedimentation, deformation, metamorphism and magmatism episodes.

- The new ages LA-ICP-MS U-Pb obtained in zircon crystals from the Rio Branco domain, southern part of the Nova Brasilândia belt restricted the deposition period of the Rio Branco Formation sedimentary protoliths between 1241 Ma and 1137 Ma. The study of metamorphic zircon grains (cores and rims) suggest a high-grade metamorphism between 1137 ± 9 Ma and 1127.6 ± 2.3 Ma, before the onset of mafic-felsic magmatism of the Rio Branco Suite generated between 1119.7 ± 2.7 Ma and 1106.2 ± 2.8 Ma. Therefore, ages close between high-grade metamorphism and mafic magmatism of Suite Rio Branco suggest an orogenetic tectonic environment for the formation of the studied rocks.

- We also identified recrystallized zircon crystals from rocks of the Rio Branco Formation and the Rio Branco Suite with ages U-Pb that possibly represent the record of an episode of youngest metamorphism and migmatization in the evolution of the Nova Brasilândia belt, occurred between 1019 ± 15 Ma and 1011.3 ± 9.6 Ma.

59

- The time interval of the two orogenic phases developed during the Nova Brasilândia orogeny was identified. The first phase mark an accretionary orogenetic event occurred between ca. 1137 Ma and 1106 Ma comprises a tectonic scenario involving intra-oceanic subduction and magmatic arc formation and back-arc basin. Our proposal implies in the existence of a small ocean between the Paraguá block (added of allochthonous terranes fragments) and the Amazonian proto-Craton in the period between ca. 1241 Ma and 1137 Ma, formed prior to the accretionary phase proposed in this article. The second phase corresponds to the subsequent collision of the Amazonian proto-Craton with the Paraguá block (added of allochthonous terranes) which conditioned the crustal thickening and youngest high-grade metamorphism in the Nova Brasilia belt at about 1096 Ma as previously proposed by Tohver et al. (2004). In addition, the youngest zircon U-Pb ages obtained in our research between 1019 ± 15 Ma and 1011.3 ± 9.6 Ma, associated with the U-Pb and K-Ar ages obtained by Rizzotto (1999), Rizzotto et al. (2014) and Tohver et al. (2004, 2005b, 2006), suggest the time interval between ca. 1096 and 1010 Ma for the collisional phase, second episode of metamorphism and inception of orogen cooling.

- This new compressional tectonic scenario involving intra-oceanic subduction is different from those previously proposed involving alternating of transpression and transtension episodes that conditioned the opening of an intracontinental rift, evolution to passive margin, proto-ocean formation and basin closure (Rizzotto, 1999; Rizzotto et al., 1999; Tohver et al., 2004). Therefore, the data from our research presented in this article and those published by Quadros et al. (submitted) suggest that the nature of the Nova Brasilândia orogeny is accretionary-collisional type, developed between ca. 1137 and 1010 Ma.

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Geology, geochemistry and Sr-Nd isotopes of the Rio Branco Suite, Nova Brasilândia belt in southwest of the Amazonian Craton: Evidence of a Rodinia pre-assembly accretionary phase (ca. 1137 and 1106 Ma) during the evolution of the Nova Brasilândia orogeny

Geology, geochemistry and Sr-Nd isotopes of the Rio Branco Suite, Nova Brasilândia belt in southwest of the Amazonian Craton: Evidence of a Rodinia pre-assembly accretionary phase (ca. 1137 and 1106 Ma) during the evolution of the Nova Brasilândia orogeny

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ARTICLE INFO

ABSTRACT

The tectonic affinity of the Rio Branco Suite magmatism in the Nova Brasilândia belt, southwest of the Amazonian Craton, Rondônia, is important for understanding the role of the Rio Branco domain in the identification of the Mesoproterozoic orogenetic events associated the Rodinia supercontinent pre-assembly. The regional country rocks (Rio Branco Formation) is composed of calc-silicate gneiss, biotite paragneiss, amphibolite and granulite with ages of provenacne between ca. 1241-1137 Ma submitted to high-grade metamorphism between ca. 1137-1127 Ma. The Rio Branco Suite (ca. 1119-1106 Ma) is composed of coeval mafic-felsic rocks classified as metagabbro, metatroctolite, massive metabasalt, metadiabase, amphibolite, metagranite, felsic metavolcanic rocks and metatrondhjemite, exposed as rounded or oval intrusions, sills and dykes. Whole-rock geochemical data show that the metamafic rocks of the Rio Branco Suite are of sub-alkaline medium- to low Ti tholeitic with composition and signature of overlapping of MORB-like (mid-ocean ridge basalt), IAT (island arc tholeiite) and BAB (back-arc basalt). In multi-element diagrams of the metamafic rocks show negative anomalies of Nb and Ta, positive of Pb, and gradual enrichment in Th relative to Nb and Ta. On the other hand, features Ti/V=10-50, La/Yb=1.74-12.33 and Th/Yb=0.10-3.56, low to high Ce/Y (4.12-24.67) ratios and low-ratios Ce/Pb (3.3-20.5), Nb/U (3.2-16.25) and Th/La (0.01-0.30), are subduction environment characteristics. Sr-Nd isotope composition showed εNd with slightly negative to positive values between -2.89 and +1.66 (t=1120 Ma) close to CHUR and varied $^{87}Sr/^{86}Sr$ ratios (0.702-0.713) and low $^{143}Nd/^{144}Nd$ ratios (~ 0.512) suggests crustal contamination. The geological data, geochemical and isotopic signatures of the Rio Branco Suite metamafic component shown in discriminated tectonic diagrams and trace elements diagrams are considered effective in the diagnostic of subduction environment. Results presented here demonstrate that the collisional orogenetic phase of the Nova Brasilândia orogeny associated with assembly of Rodinia were preceded by a Mesoproterozoic accretionary phase between ca. 1137 and 1106 Ma that provided the development of arc - back-arc system. Closure of an ocean prior to the amalgamation of Rodinia occurred through intra-oceanic subduction between of Paraguá block (with allochthonous terranes accreted) and Amazonian proto-Craton during oblique or frontal tectonic interactions between large crustal masses represented by Laurentia and Amazon.

1. Introduction

The geological events of the late Mesoproterozoic and Neoproterozoic (ca. 1241-910 Ma) recorded on the southwestern margin of the Amazonian Craton, in the Brazilian states of Rondônia and Mato Grosso and in Bolivia, are generally referred to as Sunsás Province or Sunsás-Aguapeí Province (Tassinari and Macambira, 1999; Santos *et al.,* 2000, Teixeira *et al.*, 2010). Local denominations have been assigned such as Nova Brasilândia, Sunsás-Nova Brasilândia, Sunsás, Sunsás-Aguapeí or Aguapeí, as names to define provinces, mobile belts, orogen or orogenies (Tassinari and Macambira, 1999; Santos *et al.,* 2000, 2008; Teixeira *et al*., 2010). Globally, Sunsás Orogen is the representative of the Supercontinent Rodinia assembly event in the Amazon, along with Grenville orogen that extends from Labrador in northeastern Canada to the Adirondack Mountains and southwestward under the coastal plain of the eastern United States, as well as several orogens correlated from others parts of the earth. The first proposals of Rodinia assembly demonstrated that it was evident that western South America was part of the supercontinent Rodinia (Hoffman, 1991; Dalziel, 1997). Sadowski and Bettencourt (1996) introduced the tectonic scenario that Grenville front in North America and Canada was consequence of the collision between Laurentia and Amazon. Paleogeographic reconstructions for the Mesoproterozoic have suggested a long period of interaction between large crustal masses of North and South America, known as Laurentia and Amazonia, respectively.

The recognition of the geological similarities between the Grenville and Sunsás provinces as the end products of continent-continent collision during the consolidation of Rodinia led to the proposal of the juxtaposition of the grenvillian mobile belts in Laurentia with those of the southwestern region of the Amazonian Craton (Sunsás, Aguapei and Nova Brasilândia belts) (see Tohver et al., 2002, 2004, 2005a, 2005b, 2006; Santos et al., 2008; Teixeira et al., 2010; Rizzotto et al., 2014).

This paper presents new field geological data and a detailed geochemical and isotopic Sr-Nd assessment performed on the Rio Branco Suite metamafic rocks. The objective is contributing to the discussion of the Rio Branco Suite meaning in the tectonic evolution of Nova Brasilândia belt and Sunsás Orogen in the southwest of the Amazonian Craton, Rondônia (Fig. 1). New field geological data provided and allow a better definition of the spatial and temporal relationships between the lithological units. The geochemical and isotopic signatures of the mafic magmatism ware investigated to unravel the magma sources, nature of the mantle reservoirs and tectonic affinity. In addition, this paper it presents new information that can use to improve the global geotectonic models that try to explain the Rodinia supercontinent assembly.

2. Geological background

2.1 Regional context

The Amazonian Craton is one of the principal Precambrian geotectonic units of South America. It is exposed mainly in Brazil, but extends into Guyana, Suriname, Venezuela, Colombia and Bolivia. It is one of the world´s largest cratonic areas covering about 5,600,000 km², of which about 4,400,000 km² are in Brazil. The Amazonian Craton is tectonically limited by the Araguaia belt to the E, and by the Paraguay Belt to the S and SE. A large part of the Amazonian Craton is covered by Phanerozoic sedimentary sequences of the Parnaiba Basin, to the E; by the Xingu and Alto Tapajós basins to the S, and by those of the Parecis Basin to the SW. To the W, the Amazonian Craton is covered by the Solimões Basin, and to the N by the Tacutu Basin. In the central region of the Craton the overlying sediments are those of the Amazonas Basin. The basement of the Amazonian Craton extends under Cenozoic deposits up to the Andean pre-Cordillera, where Mesoproterozoic are exposed (Kroonenberg, 1982; Priem et al., 1989).
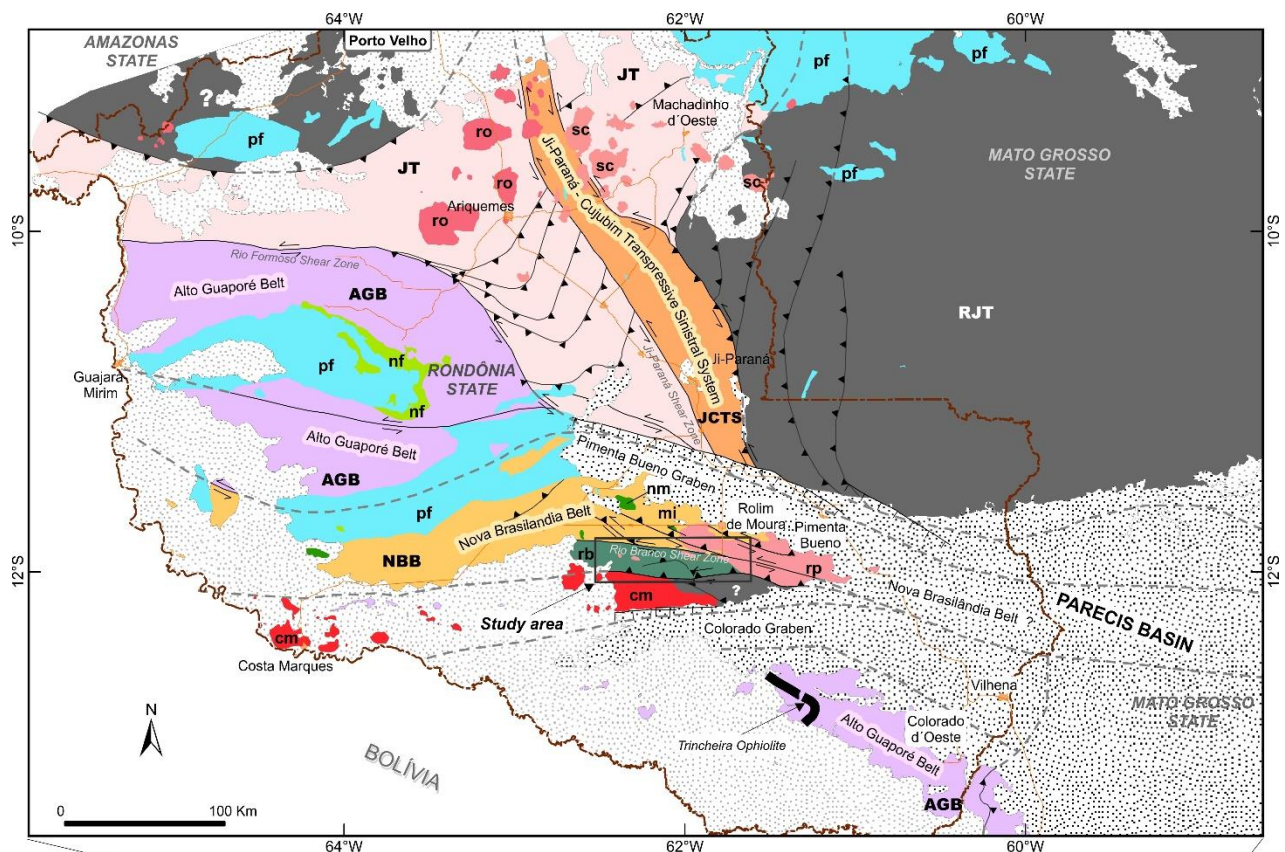
The Amazonian Craton was initially subdivided into two shield areas, known as southern Central Brazil and northern Guiana Shield, separated by extensive sedimentary cover of the Amazonas Syneclise. Several evolutionary models have been proposed based on geochronological data (eg, Cordani et al., 1979; Teixeira et al., 1989) or on geophysical and structural data (Hasui et al., 1984; Costa and Hasui, 1997). However, Tassinari and Macambira (1999) returned to the concept of provinces in the sub-division of the Amazonian Craton, suggesting a new model based on Sm-Nd geochronological data. In this work, the southwestern region of the Amazonian Craton was referred to as the Rio Negro-Juruena (1.80-1.55 Ga), Rondonian-San Ignacio (1.45-1.3 Ga) and Sunsás provinces (1.25-1.00 Ga). In the model proposed by Santos et al. (2000), however, the same area consists of only two geochronological provinces referred to as Rondônia-Juruena (1.74-1.47 Ga) and Sunsás provinces (1.20-0.99 Ga).

Alternatively, Scandolara (2006) proposed a tectono-stratigraphic compartmentation of the southwestern Amazonian Craton in Rondônia. The subdivision in terranes was defined based on the descriptive aspects of geological units of regional extent, including their petrological, structural, geochemical, geophysical and geochronological characteristics, and divided by faults or shear zones. These terranes are known as the Jamari, Roosevelt and Nova Brasilândia terranes.

Southwestern of Amazonian Craton and its surroundings have also been the main target in regional and local geological mapping projects carried out by researchers from various government and research institutions, with emphasis on lithostratigraphy and crustal evolution (Litherland and Bloomfield, 1981; Litherland et al., 1986; Scandolara et al., 1999; Rizzotto, 1999; Santos et al., 2002; Ruiz, 2005; Scandolara, 2006; Quadros and Rizzotto, 2007; Ruiz et al., 2007; Salinas, 2010). Other studies on the Amazonian Craton related the tectonic evolution of the Sunsás Orogen to the collision between the Amazonian Craton and the eastern and southeast margins of Laurentia (Sadowski and Bettencourt, 1996; Tohver et al., 2002, 2005b; Santos et al., 2008; Bettencourt et al., 2010; Teixeira et al., 2010; Ramos, 2010; Rizzotto et al., 2013, 2014; Cawood and Pisarevsky, 2017).

Three important metasedimentary belts on the southwest border of the Amazonian craton called Nova Brasilândia, Aguapeí and Sunsás are considered key areas for understanding the late Mesoproterozoic (Stenian) orogenetic events that make them important records in the Amazon of orogenetic activities resulting from the assembly of supercontinent Rodinia. Table 1 shows the main geological and tectonic characteristics of the orogenies recorded in southwestern of the Amazonian Craton in Rodônia, Mato Grosso and Bolivia associated with the evolution of the Sunsás orogen, with emphasis on the comparison between the Sunsás, Aguapeí and Nova Brasilândia belts. The Nova Brasilândia belt stands out for its important phase of oceanization after the break-up of the Amazonian proto-Craton in the Stenian (< 1241 Ma) and for presenting a complex tectonic history in relation to other late Mesoproterozoic mobile belts, according to data presented in this article. These are important areas for establishing a correlation between the Sunsás Province, in the Amazonian Craton, and the Grenville Province, in southern Laurentia. The Nova Brasilândia and Aguapeí belts are exposed along the Bolivia-Brazil border and Sunsás belt in Bolivia, all positioned at the rims of the Paraguá block.

The Nova Brasilândia belt positioned between the northwest margin of the Paraguá block and the southwestern Amazonian proto-Craton was previously considered to originate from the opening and closing of an intracontinental rift with formation of a proto-ocean in the opening phase (Rizzotto, 1999). It is also representative of a crypt suture zone developed during the collision of the Amazonian Craton with Laurentia in ca. 1.2-1.0 Ga (Tohver et al., 2005a). This belt is constituted by the Nova Brasilândia Group (ca. 1215-1122 Ma; Rizzotto, 1999; Rizzotto et al., 2014) which is composed of the Migrantinópolis and Rio Branco formation considered originally of a supracrustal unit of deep sea turbidites of siliceous-clastic-to-carbonatic composition and metamorphosed in upper amphibolite to granulite facies during Nova Brasilândia orogeny (ca. 1180-1110 Ma; Santos et al., 2008). Metamafic and metafelsic rocks of the Rio Branco Granite and metagranites Rio Pardo Suite are the magmatic representatives in the belt (Rizzotto, 1999; Rizzotto et al., 2009, 2001, 2014; Quadros et al., submitted) (Fig. 1).

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Fig. 1. *Simplified map of the southwestern Amazonian Craton in Rondônia and adjacent areas, showing the boundaries of the main tectono-stratigraphic terranes and of the geochronological provinces (modified after Tassinari e Macambira, 1999, Santos et al., 2003; Scandolara, 2006; Bettencourt et al., 2010; Quadros et al., 2011; Rizzotto et al., 2014).*

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The metasedimentary Aguapeí belt is an aulacogen or aborted rift developed in the eastern borders of the Paraguá block in the southwestern of Mato Grosso. This one comprises a folded metasedimentary unit called the Aguapeí Group (ca. 1167 and 1149 Ma) that represent a thick sequence of silicy rocks composed of the Fortuna, Promise Valley and Crystalline formations deposited in marine environment, exhibits only localized deformation and low-grade metamorphism between ca. 960–910 Ma, late reflexes of the Sunsás orogeny (Geraldes et al., 1997, 2001; Saes 1999; Saes et al., 1992; Santos et al., 2005; Fernandes et al., 2006; Ruiz et al., 2005, 2007; Teixeira et al., 2010).

The Sunsás belt (ca. 1100–900 Ma) is structurally marked by extensive fronts of sinistral shear zones (or mylonitization zones), denominated Santa Catalina, Rio Negro and San Diablo tectonic fronts that developed low grade metamorphism during tectonic active along the southern margin of the Paraguá block between ca. 1080 and 1050 Ma, associated with Sunsás orogeny (Litherland et al., 1986; Saes et al., 1992; Teixeira et al., 2010). The belt is comprised by the metamorphosed Sunsás and Vibosi sequences deposited in an alluvial to deltaic system in an intracontinental rift environment also by the Rincón del Tigre mafic–ultramafic Complex and granitic intrusive suites (Litherland and Bloomfield, 1981; Saes et al., 1992; Boger et al., 2005; Teixeira, et al., 2010, 2015).

Table 1.
Main geological and tectonic characteristics of the orogenies recorded in southwestern Amazonian Craton in Rodônia, Mato Grosso and Bolívia (compiled from Litherland et al., 1986; Rizzotto, 1999; Sadowski and Bettencourt, 1996; Boger et al., 2005; Ruiz, 2005; Tohver et al., 2004, 2005a; Santos et al., 2008; Rizzotto et al. 2014; Teixeira et al., 2010, 2015, Lima et al., 2017).

Orogen	Orogeny	Nature of orogeny	Período	Tectonic unit	Main tectonic characteristics	Regional unit	Mafic or felsic magmatism. Pre-orogenic[1], orogenic[2], post-orogenic[3] and anorogenic[4] intrusions in region
Sunsás	Sunsás	**Reflection of the Sunsás orogeny** (deformation/ metamorphism)	1030-910 Ma	**Aguapeí aulacogen or belt**	Aborted intracontinental rift (aulacogen) in Paraguá block, later deformed (folds, thrust and extensional shear zones-SZ, such as: Indiaví-Lucialva SZ and Piranitinga SZ). Low-grade metamorphism (greenschist facies)	Pre-orogenic platform covers: Aguapeí Groups (Fortuna, Vale da Promissão and Morro Cristalina Formations)	Guapé[4], São domingos[4] and Sararé[4] suites (939-917 Ma)
		Pre-orogenic phase (rift)	< 1260 Ma (1167-1149 Ma)				Huanchaca mafic sills[1] (1111 Ma)
	Sunsás	**Collisional**	1100-1000 Ma	**Sunsás belt:** Rio Negro, Santa Catalina and San Diablo fronts	Collisional type, on the south border of the Paraguá block, effects of crustal rework on craton areas (sinistral transcurrent shear systems or zones) and contemporary rifts. Low-grade metamorphism (greenschist facies)		Felsic intrusions (Sunsás Intrusive Suite[2, 3, 4]): Casa de Piedra[3, 4] (1005 Ma), Don Mario[2, 3] (1014 Ma), Taperas[3, 4] (1076 Ma), Naranjito[3,4] (1070 Ma), Primavera[3, 4] (~1090 Ma) and El Carmen[3,4] (1092 Ma) and Santa Teresa[2, 3] (1105 Ma).
		Pre-orogenic phase (passive margin)	< 1200 Ma			Passive margin sequence: Sunsás and Vibosi Groups	Rincon del Tigre Complex[1] (1110 Ma)
	Nova Brasilândia	**Collisional** (contemporary of the Sunsás orogeny)	1096-1010 Ma	**Nova Brasilândia belt:** Migrantinópolis and Rio Branco domains, Ji-Paraná - Cujubim Sinistral Tranpressive System	Accretionary-collisional type on the southwestern margin of the Amazonian proto-Craton and rework effects on craton areas (systems and shear zones). Low (greenschist facies)- to high-grade metamorphism (amphibolite- to granulite-facies). Early phase of oceanization followed by arc - back-arc system in the subduction phase	Pos-orogenic platform covers: Palmeiral Formation (Vila Palmeiral, Pacaás Novos and Uopianes ridge). Pre-orogenic covers: Terra Boa Formation and Nova Brasilândia Group (Rio Branco and Migrantinópolis Formations)	Mafic sills (Nova Floresta) associated with platform covers. Anorogenic felsic magmatism in cratonic areas: Rondônia Intrusive Suite/Younger Granites of Rondônia[4] (0.95-0.96 Ga), Costa Marques[4] (0.98-0.96 Ga) and Santa Clara[4] (1.08–1.07 Ga) intrusive Suites. Orogenic and post-orogenic magmatism in the belt: Rio Pardo Suite[3] (1.05 Ga) and mafic-felsic magmatism of the Rio Branco Suite[2] (1.11-1.10 Ga)
		Accretionary	1137-1106 Ma				
		Pre-orogenic phase (rift, rift-drift and drift phases: ocean formation and passive margin. Oceanization phase)	< 1241 Ma				

(Orogen column, spanning all rows: Sunsás)

Recently, the Nova Brasilândia, Aguapeí and Sunsás belts were considered to belong to a single geotectonic unit, called the Western Amazon Mobile Belt, developed at the late Mesoproterozoic in intracontinental rift environment from by reactivating of the Guaporé suture zone (Rizzotto et al., 2014).

2.2. The Nova Brasilândia belt

Consists of metavolcanic-sedimentary rocks displayed in an E-W to NW-SE elongated belt that strikes approximately 170 km long by 40 km as a window in Phanerozoic sediments. The Nova Brasilândia belt is tectonically limited to the north by the Pimenta Bueno Graben, and by the São Felipe (> 1.23 Ga) basement rocks to the south. To the east, it is cover by the Parecis Basin sediments and to the west by sediments and extensive weathering profiles of the Guaporé cover (Figs. 2, 3). Strong magnetic anomalies observed in the southern part of the belt with an E-W trend show that it extends to E and SW beyond the exposure limits (Figs. 1, 2).

The Nova Brasilândia belt comprises migmatized quartz-feldspathic paragneiss, schist, calc-silicate gneiss, quartzite, amphibolite, granulite, metamafic rocks and metagranite (Fig. 2). Previous studies by Rizzotto (1999) defined the Nova Brasilândia Group as consisting of two distinct units: the first of metavolcanic-sedimentary origin represented by the Migrantinópolis Formation, consisting of a medium- to high-grade turbiditic unit of siliclastic to carbonatic composition, consisting of gneiss, quartz-feldspar mica schist and subordinate calc-silicate gneiss, in addition to sills of metagabbro and amphibolite (Fig. 2A, 2C). The second unit, known as the Rio Branco Formation, consists of metamafic rocks, showing geochemical affinities with P-MORB, and felsic rocks, trondhjemites, and, locally, metabasalt with subordinate intercalations of calc-silicate gneiss, biotite-garnet paragneiss and fine-grained schist (see Scandolara and Rizzotto, 1998; Rizzotto, 1999; Rizzotto *et al.*, 1999, 2001). In this paper, the association of intrusive mafic-felsic rocks from the southern portion of the belt that were initially incorporated into the Rio Branco Formation and Rio Branco Granite became part of the Rio Branco Suite (Fig. 2D). The Nova Brasilândia belt is subdivided in lithostructural domains called of Rio Branco Domain (southern part), which is noted for the strong magnetic anomalies, and Migrantinópólis Domain (northern part) with lower magnetic anomalies except at specific locations within this domain. These two domains are tectonically separated from each other or with the São Felipe Domain rocks by regional scale shear zones (Figs. 2C, 2D). Therefore, two episodes of mafic magmatism were described in the Nova Brasilândia belt (Rizzotto, 1999). The first consists of sills coeval to the deposition of the paragneiss protoliths. The second episode is manifested in the form of intrusive bodies (dykes and stocks) within the turbiditic deposits, as well as in the previous mafic sills. These bodies are located in shallow crustal levels, as evidenced by the ophitic textures and the fine-grained granulation. Generally, the intrusive bodies are oval in shape, but rarely layered and showing partially preserved igneous textures. These mafic rocks were subsequently deformed and metamorphosed in amphibolite facies, locally granulite facies. The incipient foliation is observe by the alignment of amphibole, plagioclase and pyroxene crystals, although the superimposed metamorphic textures alternate at all scales (Rizzotto, 1999; Rizzotto *et al.*, 2001). Also in the Nova Brasilândia belt, several pulse of felsic magmatisms are observed. These rocks are monzogranite to syenogranite in composition and vary from isotropic to foliated. The first generation (ca. 1113-1112 Ma) was called the Rio Branco Granite (Rizzotto, 1999; Rizzotto et al., 2001), and the second generation (ca. 1005 Ma) of the Rio Pardo Suite (Silva et al., 1992; Rizzotto, 1999). In addition, small lenticular bodies (5 to 60 meters) of high-silica metatrondhjemites occur spatially associated with mafic rocks (Rizzotto, 1999).

The first model for the tectonic evolution of the Nova Brasilândia belt suggested the opening of an intracontinental rift, which evolved to a passive margin with the formation of a proto-ocean (Rizzotto, 1999). This model would involve a complete Wilson Cycle over a period of about 40 Ma. More recently, Rizzotto and Hartmann (2012) considered that the Nova Brasilândia rift developed as the result of the reactivation along the Guaporé suture zone, a mega-structure that marked the collage of the Paraguá block with the proto-Amazonian Craton at the Late Calymmian to Early Ectasian (ca. 1470 and 1320 Ma). In this sense, the Rio Branco and Migrantinópolis formations were interpreted, by these authors, as a relict section of a fossil oceanic crust part incorporated to the margins of the Amazonian Craton during continent-continent collision associated with the final phase of the evolution of the Sunsás Orogen in the Meoproterozoic (ca. 1.10-1.00 Ga).
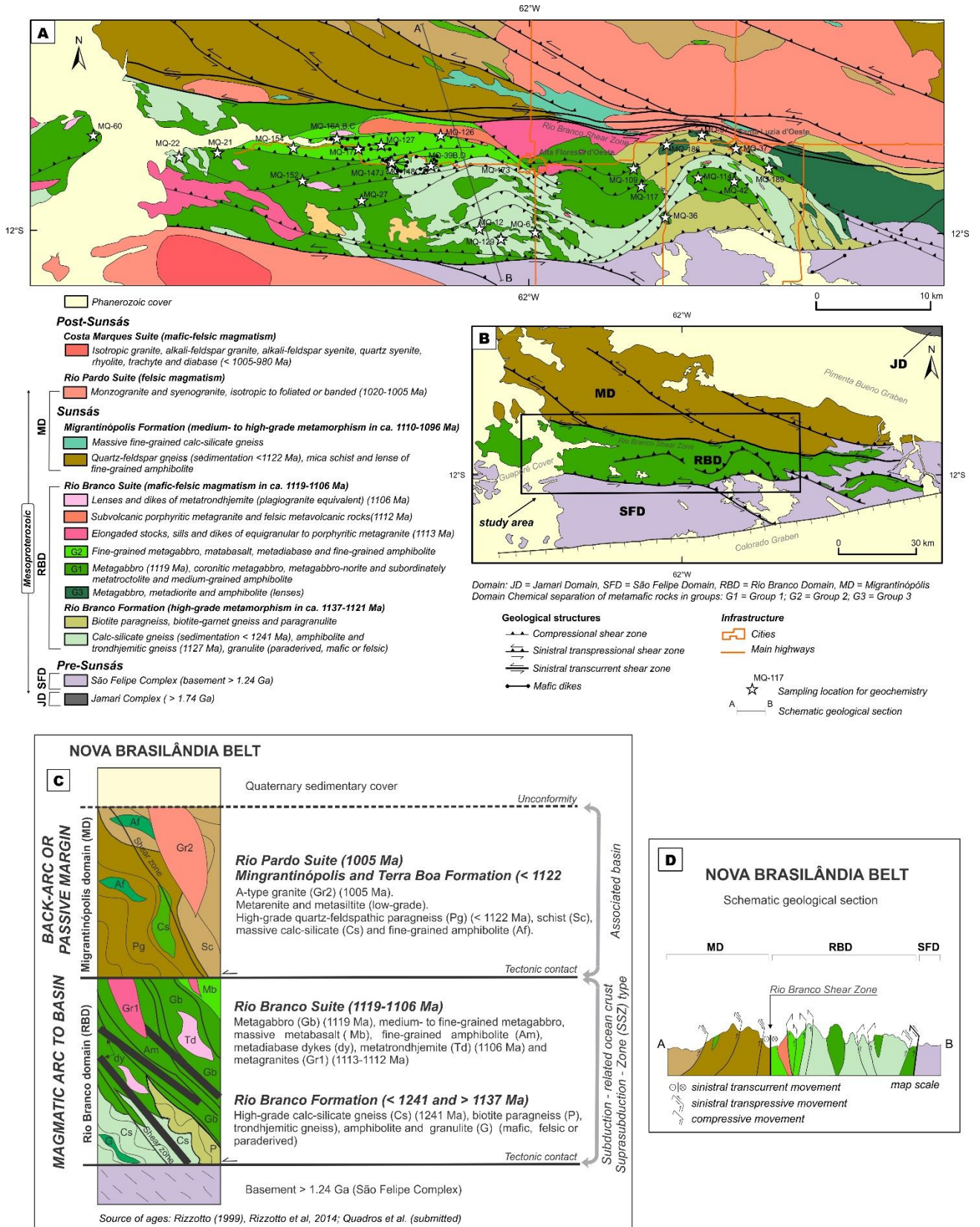
Fig. 2. *(A) geological map of the study area in the Nova Brasilândia belt, southwestern Amazonian Craton. (B) subdivision of Nova Brasilândia belt in domain. (C) section showing the stratigraphy of the Nova Brasilândia belt with their respective domains and tectonic environments. (D) schematic geological section and subdivision into domains.*

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3. Analytical methods

3.1 Whole-rock geochemistry (major and trace elements)

The analyses of the whole-rock geochemistry (major and trace elements) of the samples of metamafic rocks collected from the Rio Branco Suite were carried out at the ALS Laboratory (certificate BH17273983). The analytical methods included ICP-AES and ICP-MS for the main oxides and trace elements. The analytical work requested preparation package (PREP-31), with ALS preparation codes CRU-31 (fine crushing − 70% < 2 mm), LOG-22 (sample login − red w/o BarCode), PUL-31 (pulverize split to 85% < 75 μm), SPL-21 (Split sample-riffle splitter) and WEI-21 (received sample weight). The analytical package requested was ME-4ACD81 (Base metals by 4-acid dig., instrument ICP-AES) for the analysis of elements Ag, As, Cd, Co, Cu, Li, Mo, Ni, Pb, Sc, Tl and Zn, ME-ICP06 (whole-rock package-ICP-AES) for the analysis of oxides Al_2O_3, BaO, CaO, Cr_2O_3, Fe_2O_3, K_2O, MgO, MnO, Na_2O, P_2O_5, SiO_2, SrO and TiO_2; packet ME-MS81 (Lithium borate Fusion ICP-MS) for the analysis of elements Ba, Ce, Cr, Cs, Dy, Er, Eu, Ga, Gd, Hf, Ho, La, Lu, Nb, Nd, Pr, Rb, Sm, Sn, Sr, Ta, Tb, Th, Tm, U, V, W, Y, Yb and Zr; and the preparation package OA-GRA05 (Loss on ignition at 1000ºC, instrument ICP-MS) for the calculation of LOI; and preparation packet TOT-ICP06/ME-MS81D (Total calculation for ICP06, instrument ICP-AES) for the total closure calculation for the sample. Detailed descriptions of the methods and the ALS packages used may be consulted, or obtained, from the ALS Home Page (www.alsglobal.com). For analysis of the major elements we proceeded with the recalculation for the anhydrous base, followed by the usage of classification diagrams using AFM graphs (Irvine and Baragar, 1971) and TAS (Cox *et al.*, 1979). The differentiation index chosen, this is to say the element that varied the most within the series or suite was MgO and Zr. For the elaboration of the discrimination diagrams for the series we used REE diagrams chondrite-normalized (CNb) (Boynton, 1984) and multi-element diagrams (spidergrams) primitive mantle-normalized (PMN) (McDonough and Sun, 1995). For the classification of the tectonic environment we used the discriminant tectonic diagrams applied to mafic rocks and compared these with their applications in the definition of ancient tectonic environments as well as with modern Phanerozoic environments (see Pearce, 1982, 2008; Pearce *et al.*, 1984; Shervais, 1982; Wood, 1980; Cabanis and Lecolle, 1989; Dilek and Furnes, 2011; Saccani et al., 2013, 2014; Dey et al. 2018, Chen et al., 2014; Xia and Li, 2019).

3.2 Sm-Nd and Sr isotopic analyses

Most of the metamafic rocks collected from the Rio Branco Suite were in general, not affected by post-magmatic alteration processes such as metamorphism, hydrothermal alteration and weathering. All are processes that frequently change the composition of the mobile and trace elements, leading to imprecise calculations of the initial isotope ratios, and particularly the Sr isotopes. However, in an attempt to minimize the impact of post-magmatic alteration of the selected samples for Sm-Nd and Sr (whole-rock) isotope analysis, the samples were carefully selected for petrographic and chemical analysis with the objective of eliminating samples that were altered or significantly deformed, and principally those samples collected along the shear zones.

Sm-Nd and Sr isotope 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 (ca. 50 mg) were mixed with ^{149}Sm-^{150}Nd spike solution and dissolved in Savillex capsules. Sm and Nd extraction of whole-rock samples followed conventional cation exchange techniques, using Teflon columns containing LN-Spec resin (HDEHP − diethylhexil phosphoric acid supported on PTFE powder). Sm and Nd samples were loaded on re-evaporation filaments of double filament assemblies and the isotope measurements were carried out on a multi-collector Finnigan MAT 262 mass spectrometer in static mode. Uncertainties for Sm/Nd and ^{143}Nd/^{144}Nd ratios are better than +0.5% (2σ) and +0.005% (2σ), respectively, based on repeated analyses of international rock standards BHVO-1 and BCR-1. The ^{143}Nd/^{144}Nd ratios were normalized to

311 $^{146}Nd/^{144}Nd$ of 0.7219, and the decay constant used was 6.54 x 10^{-12} a $^{-1}$.The TDM values were
312 calculated using the model of De Paolo (1981).
313   The Sr-Sr isotopic analyzes were performed using Thermo Scientific TRITON™ Plus
314 Thermal Ionization Mass Spectrometry (TIMS) at the Geodynamic, Geochronological and
315 Environmental Laboratory of the Institute of Geosciences of the University of Brasília (UnB).
316 Samples were deposited with 50% HNO3 on double-array Re filaments. The Sr was analyzed in
317 multi-dynamic rotational mode, where the isotopic ratios are composed of 10 blocks of 15 cycles
318 each, with integration time of 17 seconds per cycle, totaling about 40 minutes of analysis for each
319 sample. The mass fractionation of the instrument for Sr isotope ratios was corrected by the $^{88}Sr/^{86}Sr$
320 ratio to 8.375209 (equivalent to $^{86}Sr/^{88}Sr$ ratio of 0.1194) employing an exponential law.
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323 **4. Results**
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325   The Nova Brasilândia belt is subdivided, in this work, in lithostructural domains called of
326 Rio Branco Domain (southern part), which is noted for the strong magnetic anomalies, and
327 Migrantinópólis Domain (northern part) with lower magnetic anomalies except at specific locations
328 within this domain. These two domains are tectonically separated from each other or with the São
329 Felipe Domain rocks by regional scale shear zones (Fig. 2C).
330   Our field investigations in an area in the Rio Branco domain (vertex polygon: S 11° 48'
331 55"/W 61° 41 '25", S 12° 02' 51"/W 61° 41' 25", S 12° 02' 51"/W 62° 26' 55" and S 11°48 '55"/W
332 62° 26' 55") revealed an incomplete sequence of a possible magmatic arc and related basins partially
333 preserved in the Nova Floresta d´Oeste, Rondônia (Fig. 2A). During our study of the Rio Branco
334 Domain, in the southern part of the Nova Brasilândia belt, we found high-grade metavolcanic-
335 sedimentary rocks consisting of calc-silicate gneiss, biotite paragneiss and lenses of fine- to
336 medium-grained amphibolite, trondhjemitic gneiss (trondhjemite as protolith) and paraderived
337 granulite (pelitic protolith) and mafic granulite (gabbroic rocks as protoliths) (Figs. 3A, 3B). We
338 kept this rock association under the name of Rio Branco Formation (sedimentation between ca. 1241
339 Ma and 1137 Ma; Quadros et al., submitted). The intrusive mafic and felsic rocks within the Rio
340 Branco Formation are describe in this article under the name of Rio Branco Suite. The mafic
341 component (~ 80% of the suite) occurs as semi-circular or elliptical plutons of metaggabros (ca.
342 1119 Ma), metagabbronorites, and metatroctolites and their deformed and transformed varieties to
343 amphibolites, or as sills and dykes of fine-grained metagabbros, massive metabasalts and
344 metadiabases (Figs. 3C, 3D, 3F). The felsic component of the Rio Branco Suite (~20%) includes
345 dykes of metagranites (ca. 1113 Ma) and metatrondhjemites (plagiogranite equivalent), and elongate
346 bodies of porphyritic metagranites and subvolcanic metagranites (ca. 1112 Ma), spatially associated
347 with fine-grained metamafic dykes (Fig. 3C). This felsic assemblage was maintain in the Rio Branco
348 Suite according to the initial definition of Rizzotto (1999).
349   New geological field observations have shown that Rio Branco Suite mafic-felsic rocks are
350 clearly intrusive on the high-grade metamorphic rocks principally in calc-silicate gneiss and biotite
351 paragneiss of the Rio Branco Formation. Mafic granulite (orthopyroxene+clinopyroxene+
352 plagioclase±amphibole±biotite±opaque minerals) and some of the amphibolites (amphibole+
353 plagioclase+ biotite± opaque minerals) occur as lenses or as intercalations in metasedimentary rocks
354 of the Rio Branco Formation (Figs. 4A, 4B, 4C). Evidence for intrusion was observed in the contact
355 zone between the metagabbros and their host rocks, where hybrids containing xenoliths of altered
356 amphibolite (chloritization/epidotization) and calc-silicate gneiss are observed. Presence of dyke
357 swarms intrusive in high-grade metasedimentary rocks (Fig. 4D, 4E). Magmatic breccia may occur,
358 locally, composed of angular mafic rock fragments surrounded by leucogranite with quartz, feldspar
359 and amphibole forming pockets in outcrops of mafic rocks (Fig. 4F).
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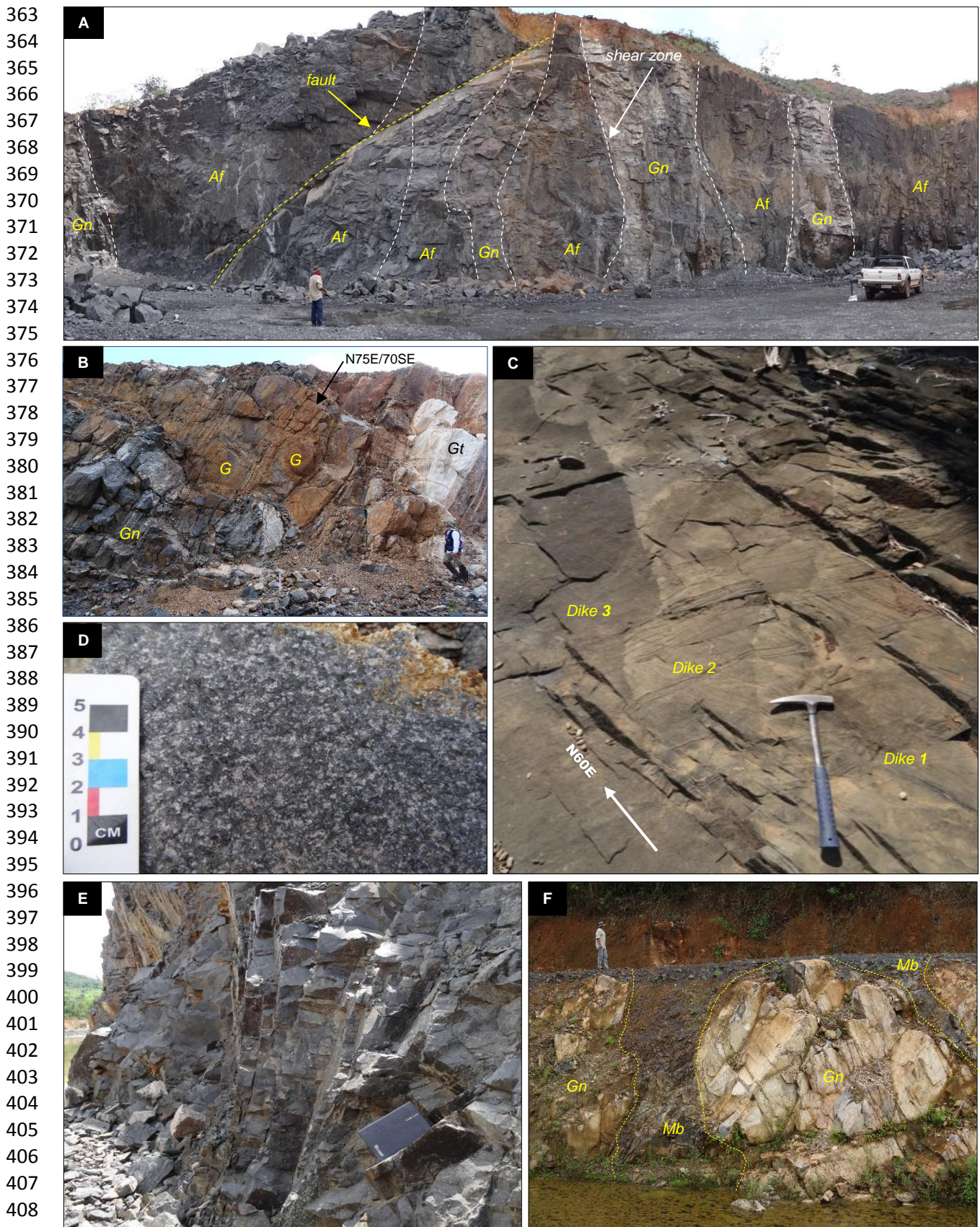
Fig. 3. *Field aspects of calc-silicate gneisses of the Rio Branco Formation and metamafic rocks of the Rio Branco Suite. (A) calc-silicate gneiss (Gn) with fine-grained amphibolite lenses (Af). (B) calc-silicate gneiss (Gn) with lenses of trondhjemitic gneiss (Gt) and mafic granulite (G) in outcrops situated in a quarry south of Alta Floresta d'Oeste. (C) medium-grained metagabbro. (D) three generations of mafic dykes (dykes 1, 2 and 3), (E) fine-grained amphibolite (massive basalt as protolith) and (F) dykes of metabasalt (Mb) intrusive in calc-silicate gneisse (Gn) in outcrops situated at the Cachimbo Alto Hydroelectric installation situated to the west of Alta Floresta d'Oeste.*

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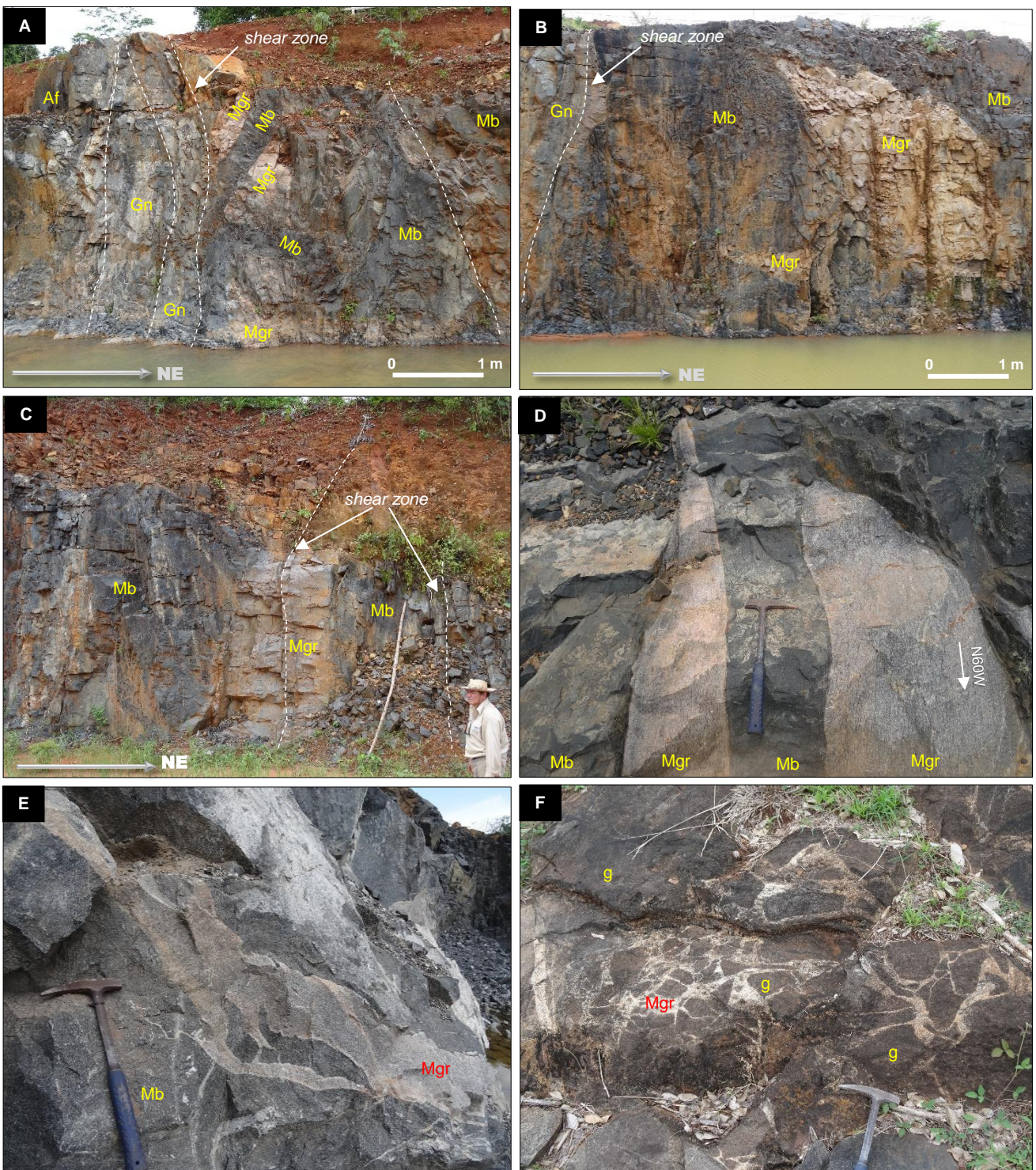
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Fig. 4. *(A), (B) and (C) general field aspects of the spatial relationships of coeval mafic-felsic magmatism of the Rio Branco Suite. (D) detail in plan view showing the contact relationships between metamafic and metafelsic rocks. (E) monzogranite dike in amphibolite (F) Magmatic breccia. Outcrops of the Rio Branco Suite at the Cachimbo Alto Hydroelectric installation and in a quarry located, respectively, to the west and in the south of Alta Floresta d'Oeste (Gn-Calc-silicate gneiss; Af- amphibolite; Mb-foliated fine-grained metagabbro/massive metabasalt; g-granulite; Mgr-foliated fine-grained metagranite).*

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4.1 Petrography

The main petrographic characteristics of the metamafic rocks of the Rio Branco Suite described in this article are summarized in Table 2. With respect to the crustal level in which these rocks crystallized we observed one group formed at deeper levels (plutonic rocks), consisting of medium to fine-grained gabbroid rocks, and a second group consisting of metamafic rocks emplaced at shallow depths (subvolcanic rocks), consisting of fine-grained metagabbro, massive metabasalt and metadiabase (sills and dykes) in addition to fine-grained amphibolite. In general, these rocks were exposed to varying intensities of deformation and metamorphism, with mineralogical and textural transformations forming massive amphibolite and foliated and/or mylonitized amphibolite, principally along shear zones (Fig. 5).

However, the occurrence of mafic rocks with mineralogical assemblages and preserved primary igneous textures is very common, including deformed/sheared intervals with important textural and mineralogical transformations, with wedging and curving of the plagioclase twinning, sub-grain formation on the rims of plagioclase and pyroxene crystals, mineral orientation and alteration products of pyroxene to hornblende (Figs. 5C, 5G, 5H). Petrographically, these rocks are fine- to medium-grained metagabbronorite and subordinately metatroctolite, in addition to massive metabasalt and metadiabase.

Metagabbro and metagabbronorite are the main rock-types. They are dark grey in colour, and medium to fine-grained, locally coarse-grained. They may be moderately magnetic, slightly foliated, and composed mainly of plagioclase, diopside and small amounts of orthopyroxene. Hornblende is present in variable quantities, along with titanite, apatite and opaque minerals. Magnetite and ilmenite are accessory and biotite and sericite are secondary minerals. Textures are ophitic to sub-ophitic (Fig. 5A, 5D). Locally, reaction coronas (coronitic texture) between olivine and plagioclase consisting of amphibole and pyroxene (orthopyroxene and clinopyroxene) are still preserved. Olivine crystals are frequently serpentinized (Fig. 5B).

Metadiabase, massive metabasalt and fine-grained metagabbro are grey-green in colour, and vary from fine-grained to aphanitic. They represent several generations of parallel dykes, with thickness from 15-30 cm to several meters. These dykes may be magnetic or non-magnetic. They are concordant and/or discordant with the regional trend of foliation. Sub-ophitic textures predominate.

Medium-grained metamafic granulite (gabbro protolith) is grey in colour, foliated, non-magnetic, and has a granular subhedral to anhedral texture. It is composed essentially of plagioclase, clinopyroxene (augite) and orthopyroxene that shows exsolution of augite. Hornblende is a secondary mineral. Deformation microtextures are characterized by flame-shaped or wedge twinning, undulatory extinction, curving of the plagioclase twinning, and subgrains formation in plagioclase (Figs. 5C, 5G, 5H). Subgrains formation in clinopiroxene rims and granoblastic textures predominate. Orthopyroxene with kink bands (curved), undulatory extinction and subgrains rims are considered indicative of granulite facies conditions (additional information in Rizzotto, 1999). Superimposed mylonitic textures are common along the shear zones (Fig. 5H). However, relict igneous textures are observed locally in high-grade metamafic rocks.

Amphibolite is fine-grained (basalt and fine-grained gabbro protolith). These rocks are dark grey in colour, magnetic and composed of phenocrystals of plagioclase and magnetite in a foliated aphanitic matrix. They are spatially associated with felsic equigranular igneous rocks that are fine to medium-grained, pink in colour and foliated.

4.2. Geochemistry

The following results are those of 34 samples of metamafic rocks collected within the Rio Branco Domain in the southern part of the Nova Brasilândia belt (Figs. 2A, 2B). Included in these geochemical analyses are samples of metagabbro, metagabbronorite, metatroctolite, fine-grained massive metabasalt and amphibolite, massive metabasalt and dykes of fine-grained metagabbro,

479 metabasalt and metadiabase (Table 3). Most samples analyzed showed low loss on ignition (L.O.I.),
480 between -0.06 % and 0.84 % Wt (weight percent), suggesting that they were little affected by
481 metamorphism and superimposed alteration. However, the values of the major elements (oxides)
482 obtained were recalculated to 100 % Wt in a volatile free base (anhydrous base) and values of trace
483 elements in ppm (parts per million) were chondrite-normalized (CN) and primitive mantle-
484 normalized (PMN). These were the values used in the elaboration of the diagrams of correlation,
485 classification, discriminants of the series, REE (rare-earth elements), multi-element (spidergram)
486 and in the definition of the tectonic environment. The results of the geochemical analysis of the Rio
487 Branco domain metamafic rocks shown in the table 3, with original values of the laboratory analysis
488 and without recalculation or normalization.
489
490 *Table 2*
491 *Summary of the main petrographic characteristics of the Rio Branco Suite (metamafic rocks), Nova*
492 *Brasilândia Belt. Abbreviations, ol: olivine; cpx: clinopyroxene; opx: orthopyroxene; pl: plagioclase; ap:*
493 *apatite; Ti-py: titanite pyrite; Sp: sphene; op: opaque minerals; serp: serpentine; Fe-ox: Fe-oxides; amp:*
494 *amphibole; bt: biotite; cl: chlorite.*

Rock	Texture	Mineral assemblage
Metagabbro	Ophitic to sub-ophitic, cumulate and interstitial, porphyritica. Granuloblastic when deformed and metamorphosed. Amphibole crystals surrounding pyroxene	cpx (augite)+opx+pl (anortite-bytonite)±anp (hornblende)±bt±ap±op±Fe-ox
Metagabbronorite	Ophitic to sub-ophitic, cumulate and interstitial. Granuloblastic when deformed and metamorphosed	cpx (augite)+opx+pl±op±Fe-ox
Metatroctolite	Porphyritic, interstitial and reaction corona (coronitic texture)	pl (anortite-bytonite)+ol (Mg-fosterite)+cpx (augite)+Ti-py+amp(Mg-hornblende/tschemakite)±serp±op±Fe-ox (ilmenite)
Metabasalt and metadiabase dikes	Sub-ophitic and aphanitic predominantly, granoblastic when deformed and metamorphosed	cpx+pl+amp (horblende)±bt±sp±op±Fe-ox (ilmenite and magnetite)±cl
Massive metabasalt	Aphanitic and sub-ophitic predominantly. Porphyritic or/and aphyric	pl+cpx+amp (horblende)±bt±sp±op±Fe-ox +cl
Amphibolite (gabbro protolith)	Porfiroblastic, porfiroclastic, granoblastic (mylonitic terms) and granonematoblastic. Foliated (mylonitic) or microbended	amp (hornblende)+plg+bt+op±Fe-ox±cl
Mafic granulite (protolith is gabbro). *Associated with the rocks of Rio Branco Formation*	Granoblastic predominantly. Plagioclase with flame-shaped or wedge twinning, undulatory extinction, curving of the twinning, and subgrain. Orthopyroxene with kink bands, undulating extinction and subgrain rims	plg+opx+Cpx (diopside)±amp (hornblende as a mineral of alteration in the pyroxene rims)±op

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497   The geochemical characteristics of the metamafic rocks studied are described using the
498 major elements and trace elements that are considered immobile during low temperature alteration
499 processes or during metamorphism (see Pearce and Norry, 1979). These include many incompatible
500 trace elements such as Ti, P, Zr, Y, Sc, Nb, Ta, Hf, Th, and medium rare earth elements (MREE),
501 heavy rare earth elements (HREE), as well as some transition metals such as Ni, Co, Cr, V. In
502 general, the metamafic rocks of the Rio Branco Suite contain SiO_2 (45.40-52.95 Wt. %) and
503 moderate amounts of MgO (2.45-11.44 Wt. %), Al_2O_3 (12.42-24.83 Wt. %), Fe_2O_3 (3.78-17.22 Wt.
504 %), Na_2O (2.33-2.92 Wt. %), K_2O (0.18-1.09 Wt. %), low values of TiO_2 (0.34-3.16 Wt %) and
505 CaO concentrations (9.15-13.27 Wt. %) (Table 3).
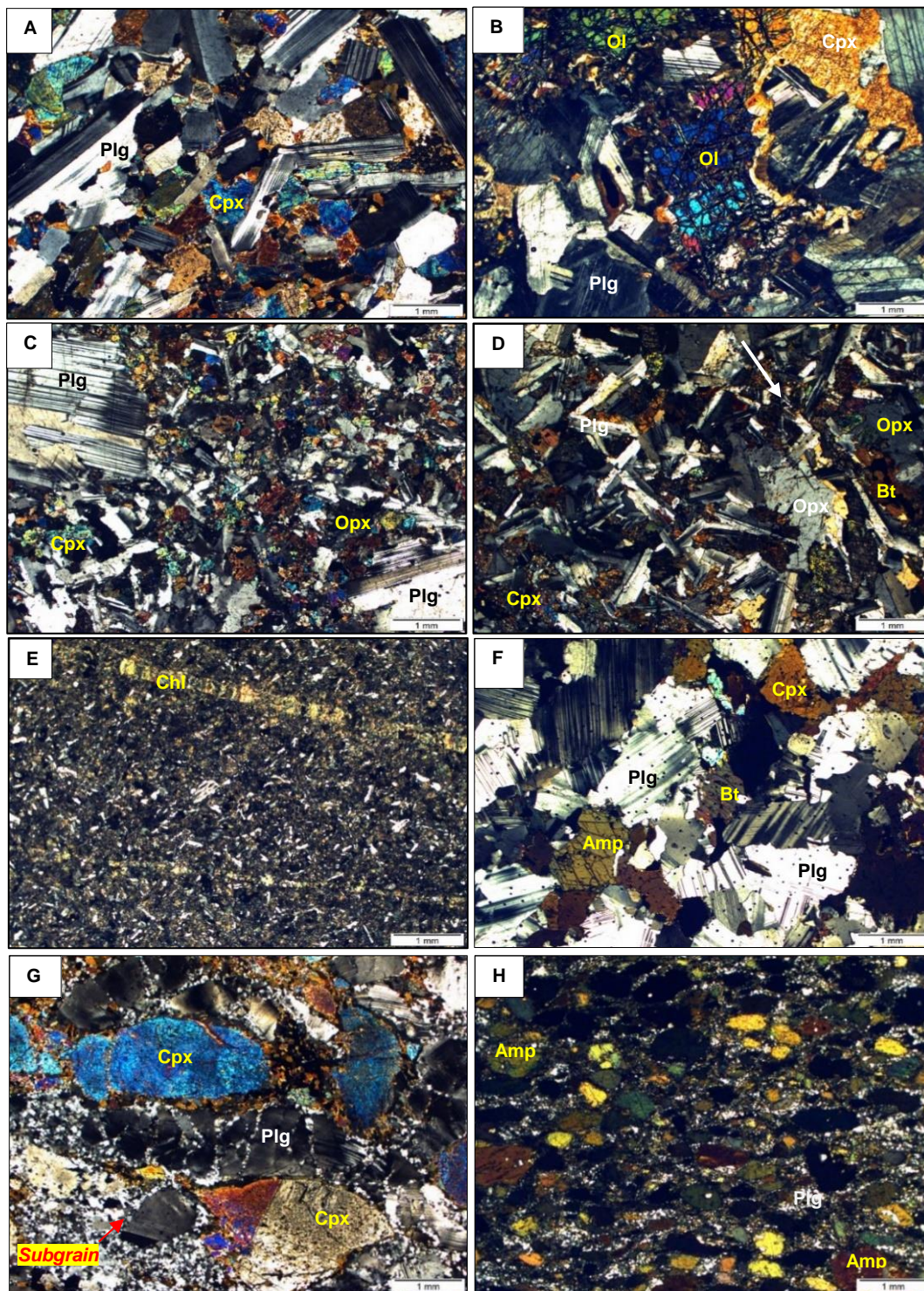
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507 ***Fig. 5.*** *Photomicrographs of metamafic rocks from the Rio Branco Suite. (A) medium-grained metagabbro*
508 *composed of plagioclase, clinopyroxene, orthopyroxene, amphibole and biotite. (B) medium-grained*
509 *metatroctolite with corona texture composed of olivine (fosterite), plagioclase and clinopyroxene (augite).*
510 *The reaction rims around the olivine are formed of amphibole (tschermakite), ilmenite and Ti-pyrite. (C)*
511 *medium-grained metagabbro composed of phenocrysts of plagioclase surrounded by a matrix containing*
512 *plagioclase, clinopyroxene, orthopyroxene, amphibole and biotite. (D) medium-grained metagabbro*
513 *composed of plagioclase, clinopyroxene, orthopyroxene, amphibole (hornblende) and biotite, with sub-*
514 *ophitic texture. (E) metabasalt dyke with sub-ophitic texture and chlorite+epidote veins. (F) medium-grained*
515 *metagabbro composed of plagioclase, clinopyroxene, amphibole and biotite. (G) foliated metagabbro with*
516 *plagioclase sub-grains. (H) mylonitic amphibolite in of shear zone. Symbols: Plg, plagioclase; Amp,*
517 *amphibole; Chl, chlorite; Cpx, clinopyroxene; Opx, orthopyroxene; Bt, biotite; epd, epidote.*

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518   Values of Mg# in the metamafic rocks vary from 33.8 to 71.6 Wt %. According to the
519 patterns of the major elements (oxides) and trace elements observed in the diagrams of the
520 classification, variation, rare earth element (REE) and multi-elements chondrite-normalized or
521 primitive mantle-normalized, the Rio Branco Suite comprise an evolved mafic magmatic series
522 without hiatus with LREE enrichment and variable Eu anomaly (positive to negative with magmatic
523 fractionation). Three groups were individualized based on lithological data, crustal level of the rocks
524 cristalization and geochemical trends, and denominated of the Group 1, Group 2 and Group 3. On
525 the oxide variation diagrams for Al_2O_3 vs. MgO, CaO vs. MgO, TiO_2 vs. MgO, K_2O vs. MgO and
526 FeOt vs. MgO, the samples of the metamafic rocks of Groups 1 and 2 showed a good correlation.
527 Al_2O_3 and CaO show a positive correlation, following a tendency for the fractionation of olivine,
528 orthopyroxene clinopyroxene, plagioclase and apatite, with a trend suggesting an evolved mafic
529 series (Fig. 6). In the TiO_2 vs. MgO, FeOt vs. MgO and K_2O vs. MgO diagrams the samples of
530 groups 1 and 2 show a negative correlation in respect to MgO, with an increase in Ti, K and Fe in
531 function of the fractionation of biotite, magnetite and Ti-sulphides (eg. pyrite), chiefly in the
532 samples of Group 2, which are the most fractionated rocks of the suite. The binary diagrams for Zr
533 vs. Ti, Nb, Nd, Th, La, Y and Yb show a good correlation, and the chemical variation between the
534 samples display a positive linear trend of magmatic fractionation without a hiatus (Fig. 6). The
535 relations La versus La/Yb and La versus La/Sm suggest that the compositions of the rocks of the
536 Rio Branco Suite (particularly Group 1 and Group 2) were mainly generated by fractional
537 crystallization. The samples of Group 3 do not show a defined correlation in the variation diagrams.
538   Group 1 (seven samples) consists of metagabbro, metagabbronorite, and medium-grained
539 amphibolite present as intrusive bodies occurring in the form of sub-rounded to elongate stocks
540 varying from 5 to 10 km across. This group consists of sub-alkaline tholeiitic metamafic rocks with
541 SiO_2=47.95-51-59 Wt. %, TiO_2=0.70-1.87 Wt. % (low Ti), MgO=6.84-11.44 Wt. %, P_2O_5=0.04-
542 0.10 Wt. %, V=182-569 ppm, Zr=37-106 ppm, Ni=59-199 ppm (sample MQ-129 with 199 ppm
543 Ni), Cr=240-690 ppm (sample MQ-114 with 690 ppm Cr), Cu=21-68 ppm, Nb=1.0-2.7 ppm (low
544 Nb) and Mg#=51.31-71.62. Trace element ratios are Ti/V=19.71-29.81, Ti/Y=191.84-531.56 (low),
545 Nb/Y=0.07-0.12 (low), La/Yb=1.74-3.32 (low), Ce/Y=4.07-7.75 (low), Th/Yb =0.07-0.43,
546 Ce/Pb=3.55-8.6 (low), Nb/U=3.2-16.25 (low), Th/La=0.03-0.15 (low), Ta/Yb=0.03-0.09 (low),
547 Zr/Y=2.14-3.98 (high) and Zr/Nb=25.45-46-15 (high) (Figs. 7, 8, 9).
548   Group 2 (twenty-three samples) consists of mafic to metamafic bodies hosted in shallow
549 crust levels, in the form of sills or dyke swarms, has lenticular shape (stretched) when deformed.
550 They have metric to kilometer thicknesses are relate to fractures, failures or other weaknesses in
551 calc-silicate gneisses and biotite paragnaises of the Rio Branco Formation, and in Group 1
552 metamafic rocks. Part of this magmatism possibly crystallized over or near the surface. Twenty-
553 three rock samples analyzed characterize group 2 that similarly to the Group 1, correspond to sub-
554 alkaline tholeiitic mafic rocks with SiO_2=46.68-50.83 Wt. %, TiO2=1.09-3.16 Wt. % (medium- to
555 low Ti), MgO=4.45-7.70 Wt. %, P_2O_5=0.10-0.41 Wt. %, V=246-488 ppm, Zr=93-273 ppm, Ni=25-
556 121 ppm, Cr=90-360 ppm, Cu=3-106 ppm, Nb = 3.0-9.8 ppm (low Nb) and Mg#=33.88-58.82.
557 Trace element ratios are Ti/V=20-50, Ti/Y= 175.88-343.95 (low), Nb/Y=0.06-0.12 (low),
558 Nb/La=0.08-0.53 (low), La/Yb=1.95-3.56 (low); Ce/Y=4.12-8.07 (low), Ce/Pb=3.6-20.5 (low),
559 Nb/U=3.9-13.04 (low), Th/La=0.05-0.30 (low), Th/Yb =0.17-1.05, Ta/Yb=0.03-0.09 (low),
560 Zr/Y=1.91-3.58 (high) and Zr/Nb=21.52-36.00 (high) (Figs. 7, 8, 9).
561   Group 3 (four samples) consist of metagabbro and subordinate fine-grained amphibolite.
562 They form discordant intrusive, lenticular, elliptical or irregular bodies, which geometry is
563 controlled by the regional structures. These bodies are generally less than 30 km^2 and are referred
564 to as elongated stocks intruded into calc-silicate gneiss, biotite paragneiss, and granulite of the Rio
565 Branco Formation. This group consists of sub-alkaline tholeiitic metamafic rocks having much
566 lower quantities of Th, Nb, Zr, Hf, high K in relation to group 1 and group 2, and very high and
567 anomalous contents of Sr between 1680 and 1285 ppm. This group of rocks is represented by four
568 samples with SiO_2=45.40-52-95 Wt. %, TiO_2=0.34-1.61 Wt. % (medium- to low Ti), MgO=2.48-
569 5.16 Wt. %, P_2O_5=0.04-0.99 Wt. %, V=92-623 ppm, Zr=6-13 ppm (low Zr), Ni=10-43 ppm (low),

570 Cr=30-160 ppm (low), Cu=4-496 ppm (sample MQ-37 with 496 ppm de Cu), Nb = 0.3-0.9 ppm
571 (very low Nb) and Mg#=44.89-56-55. This group shows element ratios Ti/V=13.51-20.55, Ti/Y=
572 495.73-887.74 (high), Nb/Y=0.06-0.09 (low), La/Yb=6.33-12.33 (high), Ce/Y=13.47-24.67 (high),
573 Ce/Pb=3.3-9.7 (low), Nb/U=6.0-12.85 (low), Th/La=0.01 (low), Th/Yb=0.10-0.17, Ta/Yb=0.11-
574 0.33 (high), Zr/Y=0.90-1.46 (low) and Zr/Nb=14.44-20.00 (low) (Figs. 7, 8, 9).

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579 *Table 3.*
580 *Chemical compositions (major and trace elements) of the metamafic rocks of the Rio Branco Suite, Nova*
581 *Brasilândia belt, southwest of the Amazonian Craton. The table contains of original data of the analyses,*
582 *values of REE not normalized and of non-recalculated oxides for anhydrous basis.*

Sample	MQ-97	MQ-186	MQ-37	MQ-109	MQ-129	MQ-36	MQ-117	MQ-42	MQ-114	MQ-60	MQ-189	MQ-27
Rock	mgmg	mgn	mg	mg	mg	mg	mgmg	mgmg	mg (p)	mg	mg	mg
Group	3	3	3	3	1	1	1	1	1	1	1	2
SiO$_2$	53.1	48.7	45.2	48.8	46.3	50.6	50.3	51.5	49	49.1	47	50.5
Al2O$_3$	24.9	23.6	19.1	24	14.9	15.25	17.7	15.35	16.15	14.8	14.25	15.75
Fe$_2$O$_3$t	3.79	6.19	12.5	6.31	9.31	10.35	9.07	7.36	7.56	14.4	12.45	10.65
CaO	10.4	11.5	11	11.2	10.6	11.25	10.8	13.25	13.1	10.65	11.85	10.9
MgO	2.49	2.55	5.14	2.94	11.05	7.46	6.8	8.56	9.63	7.66	7.76	7.68
Na$_2$O	4.63	4.04	3.36	3.9	2.79	3.48	3.03	2.61	2.3	2.45	2.55	2.25
K$_2$O	0.33	0.32	0.38	0.29	0.54	0.49	0.41	0.19	0.18	0.23	0.67	0.62
TiO$_2$	0.34	0.74	1.6	0.77	0.76	1.31	1.06	0.77	0.69	1.9	1.08	1.09
MnO	0.06	0.07	0.13	0.07	0.14	0.16	0.14	0.13	0.13	0.19	0.18	0.16
P$_2$O$_5$	0.04	0.04	0.99	0.04	0.04	0.1	0.08	0.06	0.05	0.09	0.08	0.11
LOI	0.56	0.51	0.64	0.53	0.73	0.52	0.51	0.49	0.47	0.37	0.72	0.2
Total	100.85	98.5	100.2	99.06	97.28	101.08	99.96	100.32	99.38	101.93	98.67	99.98
Ba	114	204	129	128	108	98.8	106	48.2	65.3	111	79.1	100.5
Ce	7.4	6.6	19.4	6.8	19.6	17.2	13.3	7.2	7.1	11.4	13.2	25.7
Cr	160	40	30	50	680	510	260	240	690	360	390	330
Cs	0.45	0.05	0.07	0.02	0.46	0.13	0.17	0.19	0.34	0.67	0.06	0.95
Dy	0.81	1.12	2.54	1.01	4.22	4.9	3.81	2.85	2.66	3.65	4.75	6
Er	0.34	0.62	1.29	0.7	2.4	3.13	2.57	1.8	1.64	2.36	2.98	3.48
Eu	1.08	0.87	1.15	0.85	1.09	1.34	1.08	0.73	0.66	1.11	1.28	1.15
Ga	25.8	26.6	25.7	27.1	16.8	21.4	19.6	17.8	17.3	21.8	19.5	19.7
Gd	0.84	1.34	3.51	1.09	3.9	4.91	3.6	2.8	2.65	3.27	4.08	5.59
Hf	0.2	0.2	0.5	0.3	1.8	3	2.4	1.3	1.2	1.7	1.8	3
Ho	0.15	0.22	0.48	0.22	0.81	1	0.77	0.65	0.55	0.71	1.04	1.18
La	3.7	3.1	8.7	3.5	8.4	7.9	5.9	3.3	2.6	4.8	5	11.7
Lu	0.04	0.06	0.13	0.06	0.37	0.37	0.38	0.22	0.2	0.32	0.43	0.54
Nb	0.3	0.3	0.9	0.5	1.8	2.4	2.7	1.3	1	2.2	1.3	4
Nd	3.3	4	13.8	4.1	11.2	11.6	8.5	5.8	5	7.6	9.6	14.4
Pr	0.85	0.74	2.83	0.89	2.64	2.43	1.82	1.13	0.97	1.59	1.73	3.25
Rb	2.2	2.2	2.8	0.9	14.5	14.9	9.7	5.1	8.3	3.5	8.9	31.7
Sm	0.81	0.99	2.95	0.93	2.86	3.44	2.43	1.94	1.53	2.21	2.89	3.86
Sn	1	1	1	1	2	2	1	1	1	1	3	2
Sr	1475	1680	1285	1475	108.5	232	200	166	172.5	206	128	130
Ta	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.2	0.1	0.3
Tb	0.14	0.18	0.51	0.18	0.73	0.87	0.61	0.49	0.45	0.58	0.74	0.94
Th	0.05	0.05	0.1	0.05	1.08	1.23	0.9	0.45	0.23	0.2	0.19	3.52
Tm	0.09	0.08	0.2	0.1	0.38	0.42	0.36	0.27	0.25	0.35	0.44	0.59
U	0.05	0.05	0.07	0.05	0.56	0.73	0.54	0.28	0.17	0.17	0.08	1.05
V	92	335	623	228	182	262	245	217	193	569	300	246
W	1	1	1	1	1	1	1	1	1	1	1	1
Y	4.1	5.1	14.4	5.6	24.6	26.6	23.0	17.5	15.6	21.1	28.0	33.4
Yb	0.3	0.49	0.95	0.45	2.53	2.87	2.5	1.77	1.48	2.23	2.87	3.36
Zr	6	6	13	8	56	106	88	44	37	56	60	101
Co	13	15	38	18	48	41	34	35	41	52	47	44
Cu	17	279	496	4	31	21	31	68	61	58	49	75
Mo	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	1
Ni	43	10	13	12	199	59	70	59	114	103	78	121
Pb	3	2	2	2	4	2	2	2	2	2	2	2
Sc	6	11	18	11	35	43	33	50	43	41	46	38
Zn	35	41	91	47	59	56	58	39	46	91	69	71

Symbol of rock types: mn - metagabbronorite, mg - metagabbro, mg (p) - metagabbro (parental), mt – metatroctolite, mgmg - medium-grained metagabbro, fgmg - fine-grained metagabbro, fga - fine-grained amphibolite, fgmgd - fine-grained metagabbro dike, mmb - massive metabasalt, mmbd - massive metabasalt dike and mdd - metadiabase dike.
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584 Fe$_2$O$_3$t= Fe$_2$O$_3$ total.
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Table 3 (continuation)

Sample	MQ-152	MQ-118D	MQ-17	MQ-22	MQ-126	MQ-21	MQ-6	MQ-16C	MQ-147J	MQ-147B	MQ-154	MQ-148B
Rock	mt	mdd	fgmg	mgmg	mmb	mgmg	fga	mdd	mmb	mmb	fgmg	fgmgd
Group	2	2	2	2	2	2	2	2	2	2	2	2
SiO_2	50.7	49.1	49.8	51	49.5	50.4	48.9	49.9	48	48.1	50.1	48.6
$Al2O_3$	16.3	13.35	15.1	15.25	14.05	15.05	12.8	12.55	12.6	12.9	13.3	12.7
Fe_2O_3t	10.8	14.5	11.6	11.75	12.95	12.2	13.45	17.4	16.1	14.95	14.25	16.3
CaO	12.55	10.25	11.25	10.85	10.8	11.55	9.25	9.24	9.94	9.79	11.15	10.05
MgO	7.09	6.69	6.86	7.06	6.77	7.75	5.52	4.5	5.64	6.56	6.56	5.76
Na_2O	2.23	2.91	3.54	2.2	2.28	2.28	3.85	2.56	2.83	2.88	2.66	2.66
K_2O	0.41	1.04	0.51	0.5	0.61	0.4	0.67	0.93	0.54	1.07	0.42	0.52
TiO_2	1.11	1.65	1.49	1.32	1.43	1.38	2.36	3.19	2.48	1.81	1.61	2.34
MnO	0.17	0.2	0.16	0.17	0.16	0.18	0.14	0.29	0.25	0.2	0.23	0.25
P_2O_5	0.1	0.14	0.14	0.16	0.15	0.14	0.21	0.41	0.26	0.2	0.17	0.28
LOI	0.25	0.7	0.67	0.08	0.69	0.1	0.8	0.35	0.32	0.8	0.26	-0.06
Total	101.79	100.6	101.17	100.41	99.46	101.51	98	101.37	99.01	99.32	100.76	99.44
Ba	72	112.5	85.2	131	62.7	94.8	110.5	221	147.5	118	107	122
Ce	20.7	33.7	41	26.7	25.3	25.9	31.9	53.2	42.6	29.6	25.2	35.9
Cr	350	300	150	330	300	360	130	110	150	210	170	90
Cs	0.44	0.09	4.09	0.8	0.42	0.46	0.07	1.28	1.12	0.31	0.82	0.53
Dy	5.17	9.08	8.8	5.76	6.68	6.78	8.76	14.15	11.15	7.43	7.44	10
Er	3.37	5.99	5.16	3.46	4.23	4.18	5.33	8.53	6.69	5	4.78	6.04
Eu	1.14	1.52	1.57	1.28	1.5	1.36	1.83	2.68	2.31	1.79	1.55	1.95
Ga	20.7	24.7	20.6	20.7	21.2	21.1	23.1	25.1	24.4	22.1	22.3	21.6
Gd	5.18	8.35	7.93	5.51	6.43	6.06	8.48	12.9	10	7.45	7.18	8.95
Hf	2.7	3.9	2.6	2.9	3.5	3.9	4.4	7.6	6.4	4.1	3.6	5.8
Ho	1.1	1.98	1.66	1.25	1.36	1.44	1.8	2.9	2.23	1.6	1.54	2.01
La	9.4	12.4	15.2	12.2	11.2	11.7	12.6	22	18.1	11.6	10.3	15
Lu	0.47	0.88	0.77	0.5	0.58	0.57	0.76	1.33	0.95	0.68	0.64	0.84
Nb	3.3	6.6	4.2	4.2	3.8	4.2	4.7	9.8	6.8	4.3	4.5	6
Nd	12.6	22.4	27.6	15.7	16.1	16	23	35.9	26.4	19.1	16.5	24.4
Pr	2.86	4.95	6.83	3.6	3.45	3.63	5.19	8.41	5.65	4.16	3.54	5
Rb	16.5	14.7	18.9	15.5	13.9	16.1	7.4	37.4	21.5	23.8	16	14.6
Sm	3.47	6.47	7.11	4.29	4.52	4.4	6.97	9.64	7.51	5.11	5.08	6.39
Sn	2	3	2	1	5	2	4	4	3	3	2	2
Sr	147	126	175.5	146	137	129	154.5	140	140	120	137.5	129
Ta	0.3	0.4	0.3	0.3	0.3	0.3	0.4	0.7	0.4	0.3	0.3	0.4
Tb	0.88	1.51	1.41	0.95	1.09	1.11	1.49	2.28	1.78	1.3	1.26	1.65
Th	2.2	3.06	1.82	1.94	2.3	2.23	2.46	4.05	3.28	2.07	1.66	2.56
Tm	0.5	0.9	0.81	0.55	0.64	0.64	0.85	1.3	0.98	0.72	0.69	0.9
U	0.64	1.93	0.78	0.56	0.75	0.71	0.92	1.14	0.87	1.42	0.59	0.72
V	258	377	310	299	321	307	431	387	488	403	357	420
W	1	1	1	1	2	1	1	2	1	1	1	1
Y	32.2	56.3	48.7	34.4	39.6	39.9	52.2	82.8	64.5	45.2	43.6	57.3
Yb	3.61	5.98	5.08	3.53	4.14	4.18	5.5	8.82	6.71	4.69	4.39	6.02
Zr	94	142	93	102	123	143	158	273	219	141	127	206
Co	42	43	34	42	45	48	44	44	46	48	52	51
Cu	84	36	3	88	91	80	31	42	56	65	83	66
Mo	<1	<1	<1	1	<1	1	1	1	<1	<1	<1	<1
Ni	65	49	44	77	50	112	33	25	46	62	52	42
Pb	2	2	2	2	2	2	2	9	10	5	7	3
Sc	42	50	43	44	44	43	49	46	49	49	51	50
Zn	69	99	67	83	50	82	33	204	112	94	105	136

Symbol of rock types: mn - metagabbronorite, mg - metagabbro, mg (p) - metagabbro (parental), mt – metatroctolite, mgmg - medium-grained metagabbro, fgmg - fine-grained metagabbro, fga - fine-grained amphibolite, fgmgd - fine-grained metagabbro dike, mmb - massive metabasalt, mmbd - massive metabasalt dike and mdd - metadiabase dike. Fe_2O_3t = Fe_2O_3 total.

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618 *Table 3 (continuation)*
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Sample	MQ-20	MQ-118E	MQ-118A	MQ-16A	MQ-148A	MQ-148C	MQ-16B	MQ-12	MQ-39B	MQ-127
Rock	fgmg	mmb	mmb	fgmg	mmbd	fgmgd	fgmg	fgmg	fgmg	mmb
Group	2	2	2	2	2	2	2	2	2	2
SiO_2	47.8	49	48.9	48.4	48.7	48.7	48.4	46.8	49.1	48.6
$Al2O_3$	14.2	12.6	12.5	12.65	13.15	13.05	15	13.9	13.75	12.7
Fe_2O_3t	12.7	15.5	16.2	15.5	13.55	15.55	12.15	15.3	13	14.5
CaO	9.78	10.5	10.1	9.99	11.45	10.35	11.05	10.45	11.75	10.3
MgO	6.75	6.12	5.85	5.6	6.87	6.64	7.14	6.63	7.16	6.14
Na_2O	3.56	2.65	2.52	2.8	2.44	2.58	2.6	3.33	2.45	2.58
K_2O	0.72	0.67	0.52	0.46	0.36	0.35	0.37	0.44	0.34	0.53
TiO_2	1.42	2.09	2.39	2.13	1.7	2.17	1.42	2.83	1.46	1.72
MnO	0.19	0.23	0.24	0.25	0.24	0.22	0.2	0.24	0.22	0.21
P_2O_5	0.17	0.23	0.24	0.22	0.16	0.2	0.17	0.28	0.15	0.15
LOI	0.79	0.55	0.01	0.29	0.38	0.14	0.29	0.16	0.37	0.84
Total	98.15	100.2	99.53	98.34	99.08	100.01	98.86	100.42	99.83	98.33
Ba	120.5	114	144.5	115	150	93.8	119	129	94.9	165
Ce	26.1	34.4	36.3	28.3	24.6	32.7	22.7	30.4	19.2	24.2
Cr	260	250	150	130	300	210	330	170	350	160
Cs	0.72	0.19	0.72	1.05	1.41	1.35	0.88	0.49	0.59	0.7
Dy	6.28	8.96	10.25	9.12	7.36	9.3	6.36	8.62	6.39	10.15
Er	3.87	5.8	6.53	5.62	4.59	5.79	3.67	4.77	4.35	6.07
Eu	1.53	1.84	2	1.85	1.47	1.66	1.49	1.99	1.41	2.35
Ga	20.3	23.4	23	21.8	21.3	23.2	20.5	24.5	22	21.7
Gd	5.75	9.07	9.8	8.21	6.71	8.46	5.95	8.21	5.94	9.88
Hf	3	5.1	5.9	4.5	3.7	5.2	3.1	4.6	3.1	3.6
Ho	1.31	1.91	2.11	1.92	1.54	1.87	1.25	1.75	1.37	2.02
La	11.3	14.4	15	12	10.2	13.3	9.6	12.3	7.5	18.9
Lu	0.62	0.75	0.89	0.91	0.66	0.83	0.53	0.69	0.53	0.83
Nb	3.9	5.9	5.9	5.1	4.2	5.1	3.5	5.2	3	3.6
Nd	17.4	22.1	23.6	19.6	16.5	21.8	15.1	22.4	14.4	32.4
Pr	4.4	4.85	5.11	4.7	3.53	4.86	3.63	5.03	2.61	7.59
Rb	28.6	15.1	14.8	17.5	23.2	13	12.3	13.7	11.9	14.9
Sm	4.72	6.63	6.6	5.76	5.06	6.23	4.25	6.41	4.48	8.65
Sn	5	2	3	2	1	2	1	2	2	3
Sr	154.5	140	140.5	138	142	145	147.5	183.5	139	122
Ta	0.2	0.4	0.4	0.4	0.3	0.3	0.3	0.4	0.2	0.2
Tb	0.99	1.6	1.65	1.53	1.21	1.52	1.03	1.43	1.01	1.83
Th	1.32	2.21	2.46	1.87	1.52	2.08	1.07	1.47	0.99	1.02
Tm	0.57	0.82	0.91	0.87	0.65	0.83	0.56	0.74	0.58	0.86
U	1	0.71	0.7	0.59	0.33	0.71	0.31	0.58	0.23	0.48
V	313	431	487	459	378	442	321	452	353	424
W	1	2	1	1	2	1	1	1	3	1
Y	37.8	54.3	60.2	52.9	43.7	54.4	35.5	49.2	37.8	57.5
Yb	4.17	5.71	6.42	5.74	4.36	5.45	3.76	4.54	3.85	5.87
Zr	115	177	203	156	138	180	115	172	108	124
Co	41	47	48	47	45	44	46	49	49	57
Cu	9	74	62	63	87	36	80	40	106	55
Mo	<1	1	1	1	<1	<1	<1	<1	<1	1
Ni	66	44	55	44	55	74	82	58	64	58
Pb	4	2	4	5	14	7	4	2	3	2
Sc	43	49	49	49	50	49	45	48	49	50
Zn	75	107	117	116	144	72	118	91	137	97

Symbol of rock types: mn - metagabbronorite, mg - metagabbro, mg (p) - metagabbro (parental), mt – metatroctolite, mgmg - medium-grained metagabbro, fgmg - fine-grained metagabbro, fga - fine-grained amphibolite, fgmgd - fine-grained metagabbro dike, mmb - massive metabasalt, mmbd - massive metabasalt dike and mdd - metadiabase dike. $Fe_2O_3t = Fe_2O_3$ total.

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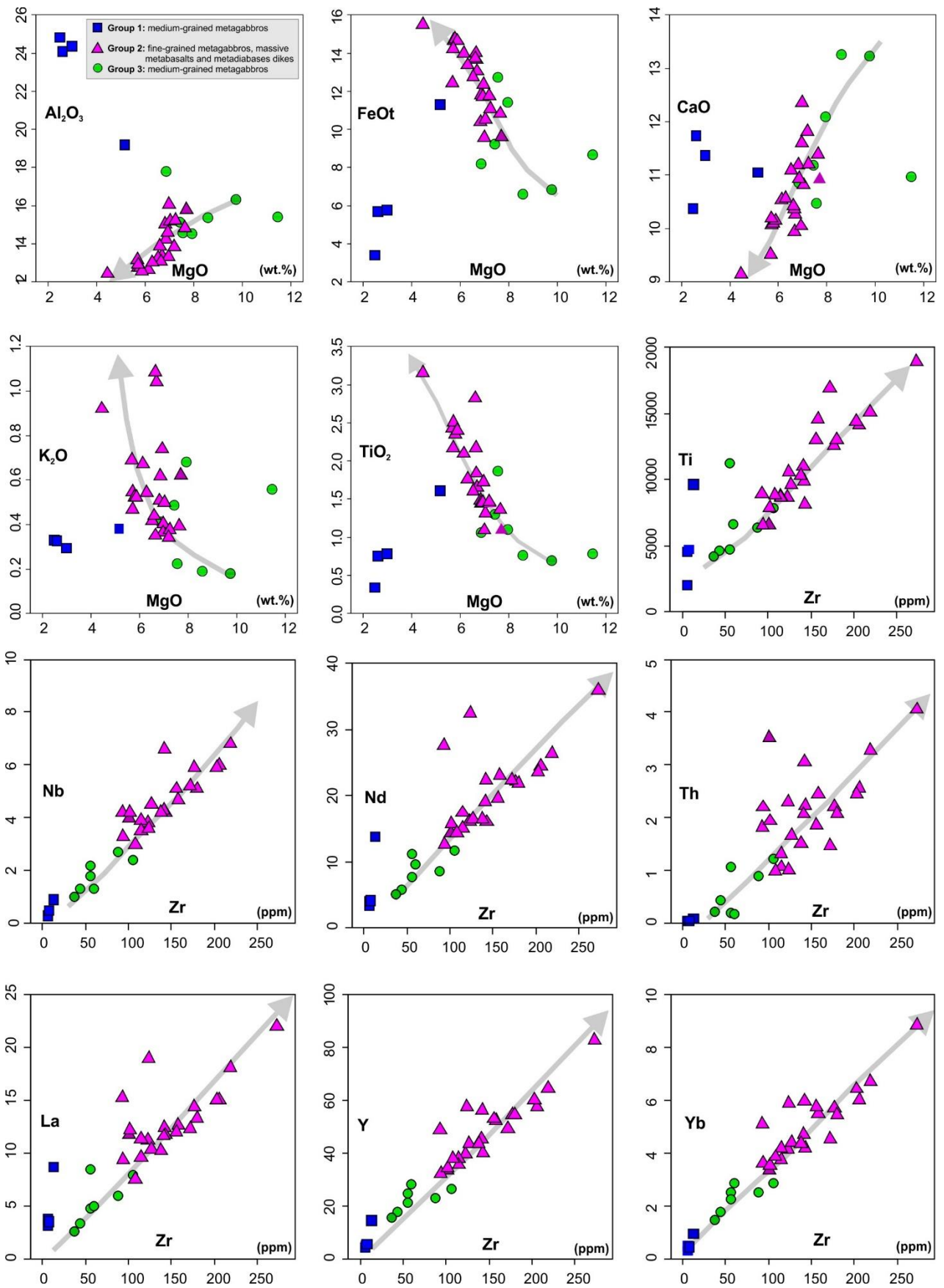
Fig. 6. *Variation diagrams of selected major and trace elements vs. MgO and Zr, respectively, for metamafic rocks from the Rio Branco Suite. Oxides were recalculated on anhydrous bases. Grey arrows indicate inferred magmatic fractionation trends for different groups of metamafic rocks.*

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625 The mafic samples from the Rio Branco Suite plot in the field of the tholeiitic series on the
626 AFM classification diagrams of Irvine and Baragar (1971) (Fig. 10A). On the classification diagram
627 TAS (SiO_2 vs. Na_2O+K_2O) of Cox et al. (1979) the samples plot in the gabbro/basalt field defining
628 a sub-alkaline tholeiitic series (Fig. 10B). The chondrite-normalized EER diagrams (Boynton, 1984)
629 and primitive mantle-normalized multi-elements diagrams (McDonough and Sun, 1989) show
630 specific characteristics in relation to the behavior of trace elements allowing the separation of the
631 analyzed rocks into groups (Group 1 , Group and Group 3). These groups with characteristic patterns
632 allow for the identification of different degrees of fractionation, as well as enrichment and depletion
633 in certain trace elements which that are indicators of geological processes that can assist in the
634 identification of the tectonic environment (Figs. 7, 8, 9).

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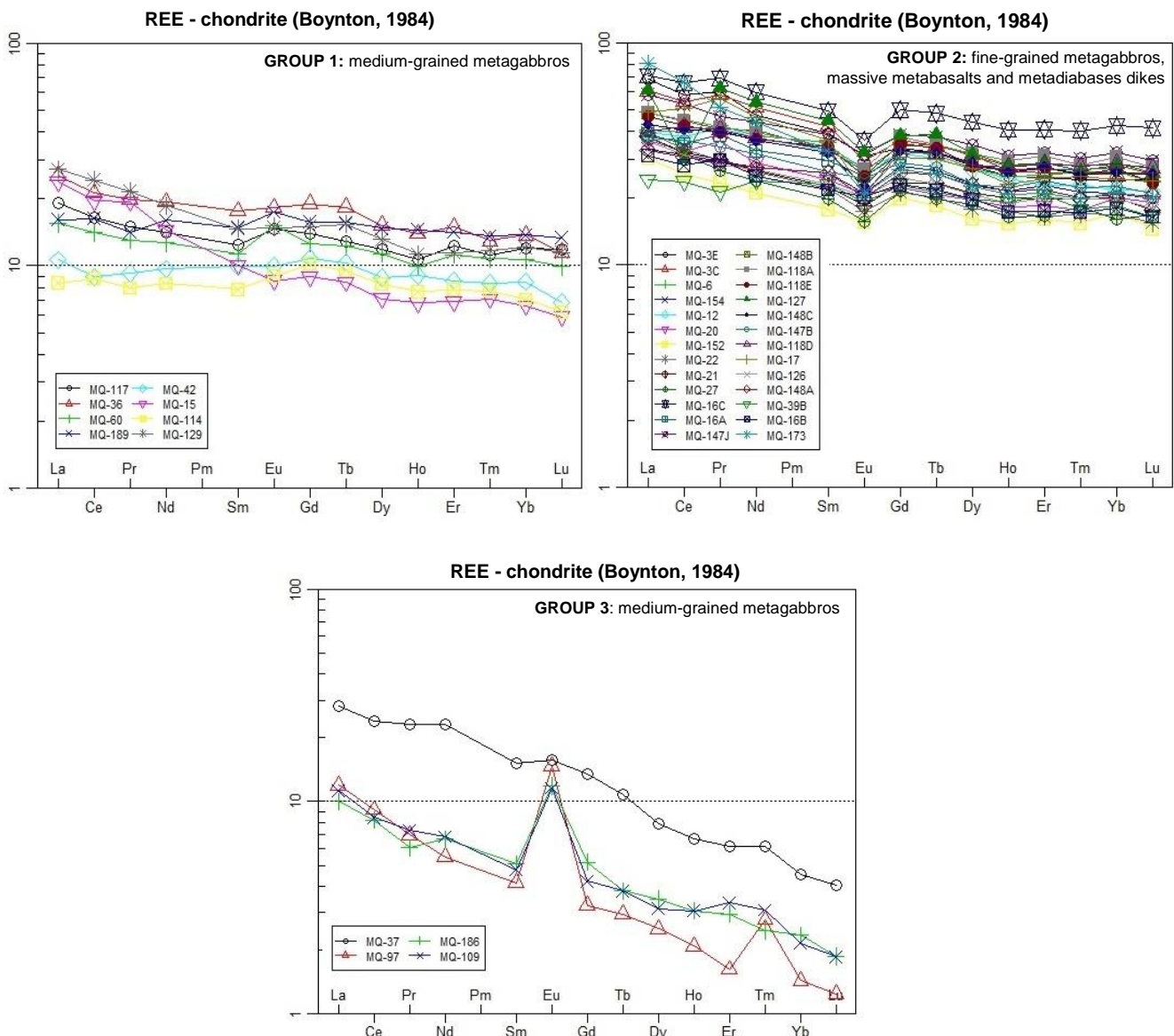
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640 ***Fig. 7***. *Chondrite-normalized REE patterns presented by the metamafic*
641 *rocks from the Rio Branco Suite.*

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The rocks of Group 1 and Group 2 have broad similar geochemical signatures, with pronounced negative anomalies of Nb and Ta, negative anomalies of Th, Ti and P, enrichment in large ion lithophile elements (LILE) (Ba, Rb, Sr), pronounced positive anomalies of Pb and U and discrete positive anomalies for Sr and K. These same rocks show enrichment in Ce, La, K, Rb and Cs, with discrete enrichment in incompatible elements. The high field strength elements (HFSE) (Zr, Nb, Ti) have a sub-horizontal pattern. The main difference resides in the Eu negative anomaly, only observed in rocks from Group 2. The Group 3 show pronounced negative anomalies of Zr, Nb, Th and Hf, enrichment in LILE (Ba, Rb, K, Ce and Sr), pronounced positive anomalies of Eu, Sr (anomalous), Pb, K, U and Ba, enrichment in La and P and depletion in HFSE (Y, Zr, Nb, Ti). In Group 3, positive Sr anomalies are considered very high (anomalous), but were presented by the four analyzed samples of this group. In all three groups is clear the LILE enrichment and HFSE depletion with respect to REE concentrations.
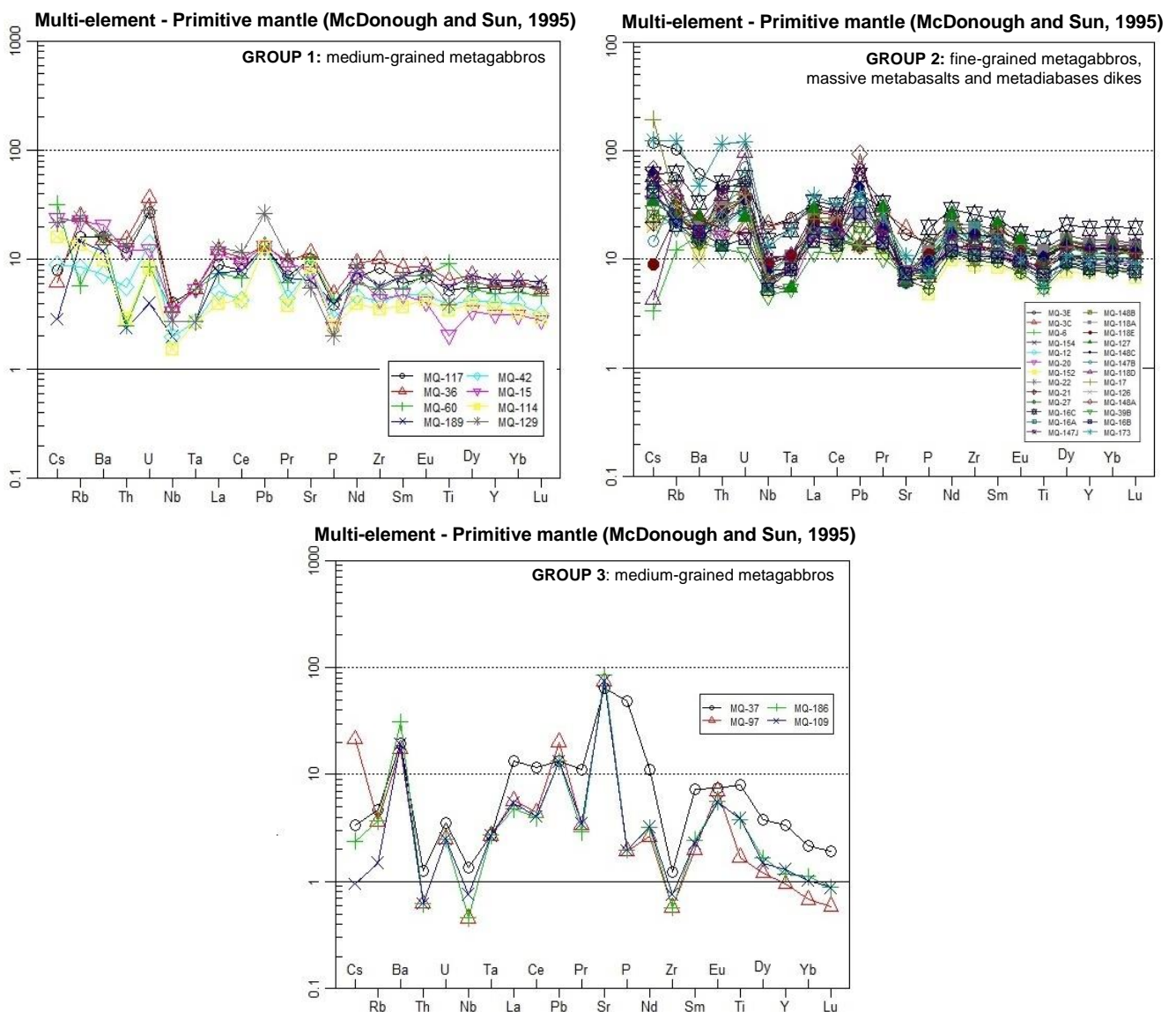
Fig. 8. Primitive mantle-normalized multi-element patterns presented by the metamafic rocks from the Rio Branco Suite.

The metamafic rocks of the Rio Branco Suite still show chondrite-normalized (CN) REE patterns, enriched in LREE ((La/Sm)CN = 1.05-2.87, and (La/Yb)CN = 1.17-8.32), suggesting a IAT-type signature. Additionally, this is confirmed by the primitive mantle-normalized (PMN) spidergrams (McDonough and Sun, 1995), where the arc signature is reinforced by the negative Nb anomalies (Groups 1, 2, 3), Ta (Groups 1, 2, 3), Zr (Groups 1, 3) and Hf (Group 3), positive Pb anomalies (in all groups) and low grades of Ti. The geochemical behaviour of Th, Nb, Ta and Pb is fundamental for the understanding of the tectonic environment because of the gradual enrichment in Th in relation to Nb and Ta, in the metamafic rock of Groups 1, 2 and 3 is indicative of a supra-subduction zone (Dilek and Furnes 2014; Pearce, 2014; Saccani, 2015). The positive anomalies of Pb reinforce the geochemical signature associated with subduction zones, and the elevated values for K and increased values for La suggest the participation of a crustal contamination component. The Ce/Pb, Nb/U and Th/La ratios are particularly useful in identifying differences in magma sources because they are sensitive indicators of crustal contamination of mantle-derived mafic magmas indicated either crustal contamination during stagnation in the crust, or contribution by the upper oceanic crust and overlying sediments that make up the subducting slab (Kessel et al., 2005; Xu et al., 2017). We highlight that in all groups of the Rio Branco Suite metamafic rocks, low-ratios Ce/Pb (3.3-20.5), Nb/U (3.2-16.25) and Th/La (0.01-0.30) is also consider effective in interpretation of mafic-felsic magmatism of the Rio Branco Suite as subduction-related.
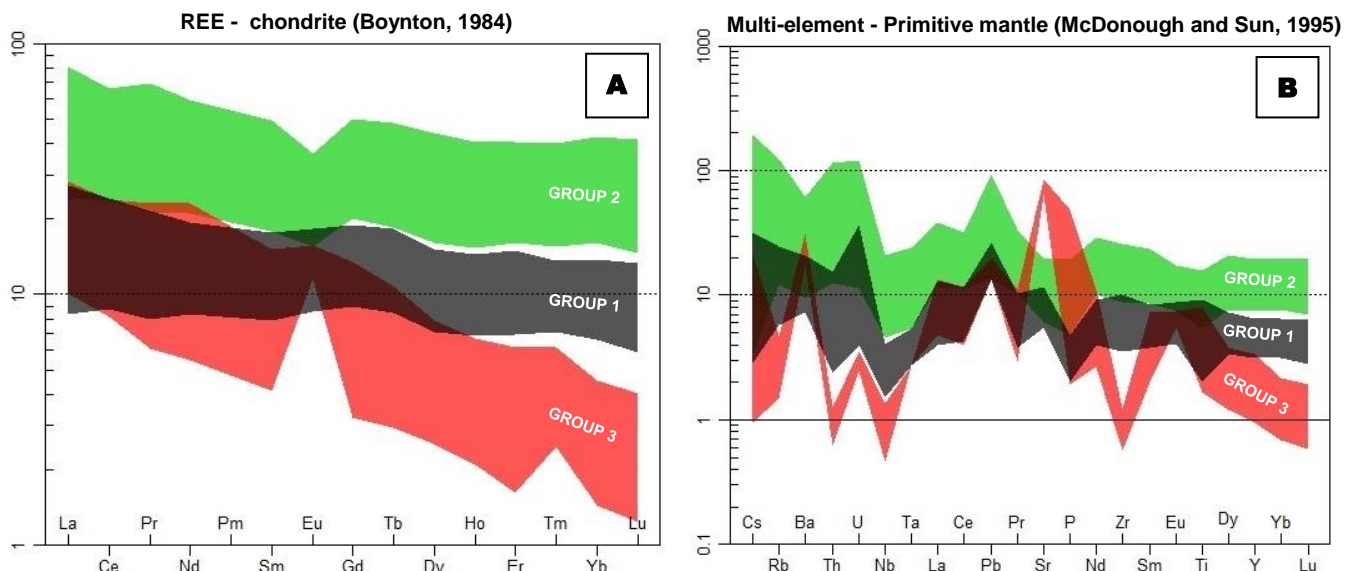
Fig. 9. (A) chondrite-normalized REE envelope patterns presented by the metamafic rocks groups from the Rio Branco Suite. (B) primitive mantle-normalized multi-elements envelope patterns presented by the metamafic rocks groups from the Rio Branco Suite.

4.3. Sr-Nd isotopes

The most of the metamafic rocks collected from the Rio Branco Suite were generally little affected by post-magmatic alteration processes such as metamorphism, hydrothermalism and weathering. They are all processes that frequently alter the composition of the mobile and trace elements, leading to imprecise calculations of the initial isotope ratios, and particularly the Sr isotopes, considering that Rb and Sr are mobile large ion lithophile elements. However, in an attempt to minimize the impact of post-magmatic alteration of the selected samples for Sm-Nd and Sr (whole-rock) isotope analysis, the samples were carefully selected for petrographic and chemical analysis with the objective of eliminating samples that were altered or significantly deformed, and principally those associated with zones of high strain. The Sr and Nd isotope data were obtained from fourteen samples of metamafic rock of the Rio Branco Suite (metagabbro, metadiabase and fine-grained amphibolite) and are listed on Table 4. The interval of the Sr and Nd isotope

composition show varied values (from high to low) of $^{87}Sr/^{86}Sr$ ratios between 0.702 and 0.714, low $^{143}Nd/^{144}Nd$ ratios of 0.512, and Sm/Nd ratios < 2.

Specifically, the interval of the Sr and Nd isotope composition of samples of the metamafic rocks of the Rio Branco Suite by group when compared to present mantle reservoirs, allow us to infer some considerations, although with some caution. Group 1 have average $^{87}Sr/^{86}Sr$ ratios of 0.705-0.706 and average $^{143}Nd/^{144}Nd$ ratios of 0.512, thus corresponding to a set of rocks that best approximate those of the mantle. Group 2 shows medium to high $^{87}Sr/^{86}Sr$ ratios of 0.708-0.714 and average $^{143}Nd/^{144}Nd$ ratios of 0.512. Group 3 shows average $^{87}Sr/^{86}Sr$ ratios of about 0.702, and average $^{143}Nd/^{144}Nd$ ratios of 0.512. Group 3 presents a negative correlation between Sr and Nd that deviates from the usual pattern for this rock type, based on the contrasting geochemical behavior of the Rb and Sm antecedents, which makes this group highly suspicious and without a well-defined geochemical pattern. If the Nd isotope composition ratio were expressed using the notation εNd, the εNd was calculated on only five samples of fourteen analyzed from of Rio Branco Suite, recalculated for T=1120 Ma (age of crystallization obtained from Group 2 metagabbro, sample MQ-117), come to between -2.89 and +1.66, suggesting mantle source and crustal contamination.

Table 4

Sm–Nd and Sr isotopic compositions of the metamafic rocks of Rio Branco Suite.

Sample	Group	Rock	Sm (ppm)	Nd (ppm)	$\frac{^{147}Sm}{^{144}Nd}$	$^{143}Nd/^{144}Nd$	εNd (0)	T_{DM} (Ga)	Time (t)	εNd (1120 Ma)	$^{87}Sr/^{86}Sr$
MQ-117	1	Medium-grained metaggabro	2.77	9.03	0.1853	0.5127	1.08		1120		0.706
MQ-158	1	Metatroctolite	0.81	4.82	0.1011	0.5126	-1.04		1120		0.705
MQ-15	2	Metagabbro	1.98	8.25	0.1448	0.5121	-10.33	2.05	1120	-2.89	0.714
MQ-21	2	Metagabbro	4.83	17.25	0.1694	0.5125	-2.38		1120		0.711
MQ-118A	2	Massive metabasalt	7.82	26.53	0.1781	0.5127	0.51		1120		0.709
MQ-118D	2	Metagabbro	3.49	17.17	0.1229	0.5121	-9.81	1.51	1120	0.77	0.711
MQ-118E	2	Fine-grained metagabbro	7.16	24.71	0.1752	0.5126	-0.32		1120		0.709
MQ-147B	2	Fine-grained metagabbro	6.32	23.15	0.1651	0.5123	-7.34		1120		0.714
MQ-148A	2	Massive metabasalt dike	5.49	18.17	0.1826	0.5127	0.71		1120		0.710
MQ-148B	2	Fine-grained metagabbro dike	7.81	23.64	0.1998	0.5126	-0.85		1120		0.708
MQ-148C	2	Fine-grained metagabbro dike	7.14	1.93	2.2335	0.5120	-12.30		1120		0.709
MQ-176B	2	Fine-grained metagabbro	4.85	17.73	0.1654	0.5125	-2.83	1.71	1120	1.66	0.711
MQ-37	3	Metaggabro	3.49	14.71	0.1435	0.5123	-6.26	1.56	1120	1.37	0.702
MQ-97	3	Medium-grained metagabbro	1.01	3.77	0.1625	0.5122	-8.76		1120		0.702

5. Discussion

5.1 Tectonic Setting

A wider geochemical examination of the involvement of other magma reservoirs and geodynamic setting, together with the behaviour of Sr-Nd isotopic systems in the metamafic rocks of the Rio Branco Suite provide important clues to elucidate the tectonic environment and better understanding of the geochemical signatures of the Rio Branco Suite. Since these rocks have been subjected to high-grade metamorphism, trace elements, especially those considered immobile, were applied in discriminant diagrams, which will be discussed below.

The mafic samples from the Rio Branco Suite plot predominantly in the tholeiite field on the AFM diagram of Irvine and Baragar, except two samples that plot in the calc-alkaline field because they are enriched in alkalis. We highlight that sample position that represents the less evolved magma of suite (sample MQ-114), having a tholeiitic affinity (Fig. 10A). On the classification diagram, more specifically on the TAS graph (SiO_2 vs. Na_2O+K_2O) of Cox et al. (1979), the samples plot in the gabbro/basalt field defining a sub-alkaline tholeiitic series (Fig. 10B). In the Ti vs. Zr graphic (after Pearce, 1982) the metamafic rocks of the Rio Branco Suite show a clear trend formed by samples from Groups 1 and 2, defining fractionation due to the crystallization of olivine,

clinopyroxene, orthopyroxene and plagioclase resulting in an increase in Ti and Zr, while the fractionation of magnetite causes a diminution of Ti, and the fractionation of amphibole or biotite may bring about a depletion in Ti and Zr (Murphy, 2007) (Fig. 11A). This relative enrichment in Ti and Zr in the more evolved rocks of the Rio Branco Suite might have been influenced by the participation of a contaminant component during magma-crust interactions (Fig. 11A). In the Ti/1000 vs. V diagram of Shervais (1982), the magmatic differentiation trend displayed by the rocks of the Rio Branco Suite may coincide with the ARC (arc tholeiitic), MORB (mid-ocean ridge basalt) and BAB (back-arc basalt) fields (relation Ti/V>10 and Ti/V< 50), as a function of the relative increase in Ti in the more evolved rocks (Fig. 11B).
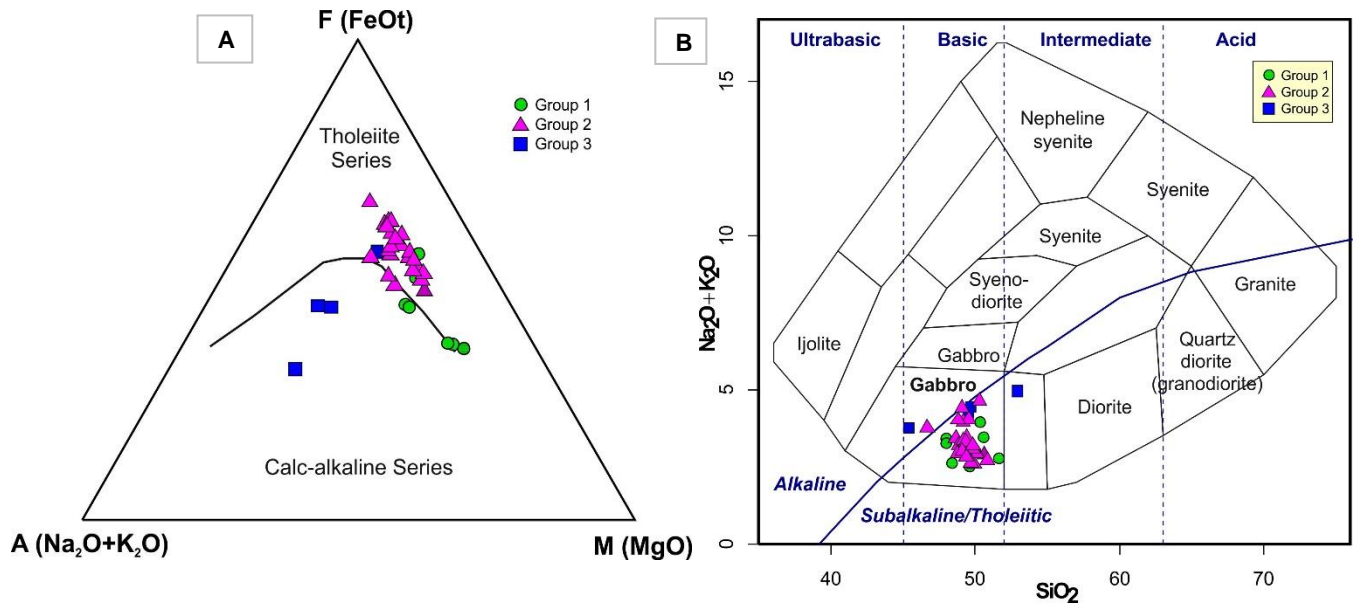
Fig. 10. *Classification diagrams of the series. (A) AFM diagram (Irvine and Baragar, 1971) and (B) TAS (SiO$_2$ vs. Na$_2$O+K$_2$O) diagram of Cox et al. (1979).*
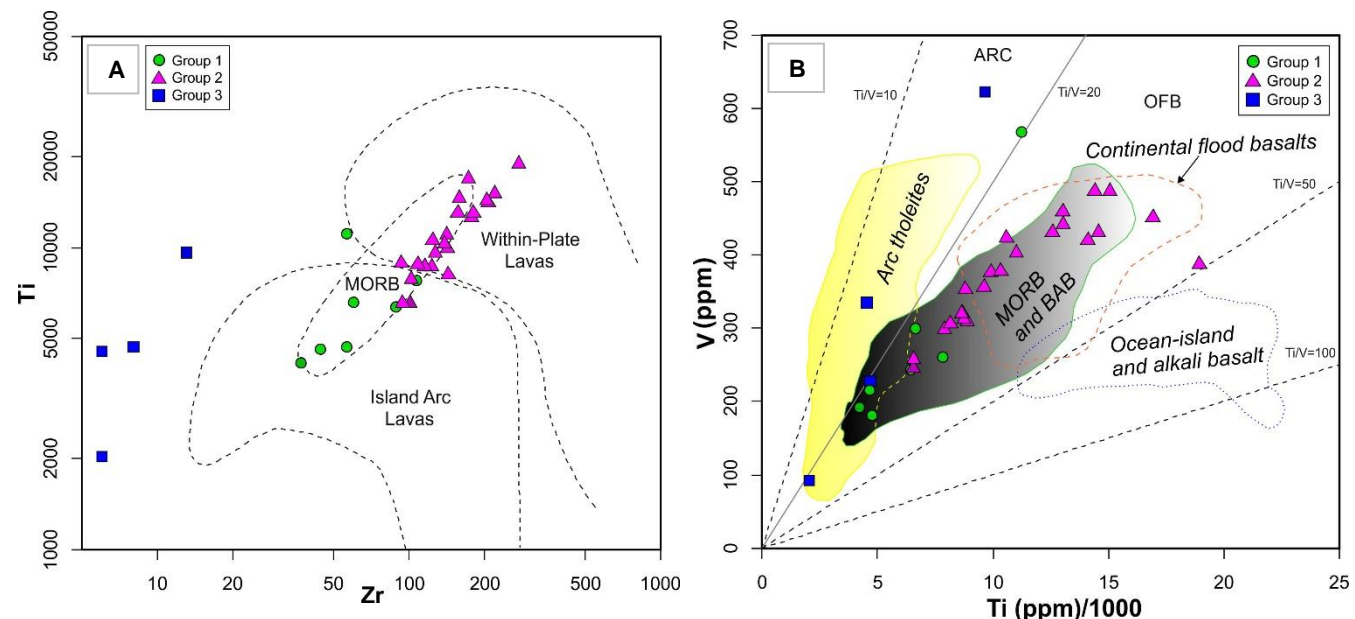
Fig. 11. *(A) Ti vs. Zr diagram (Pearce, 1982) and (B) Ti/1000 vs. V (Shervais, 1982), showing the fractionation trends observed in the metamafic rocks of the Rio Branco Suite (ARC-arc; MORB-mid-ocean ridge basalt; BAB-back-arc basalt; OFB-ocean floor basalt).*

In the diagram Th/Yb vs. Nb/Yb (Pearce, 2008), the Rio Branco Suite samples show an almost vertical trend from the N-MORB source towards the volcanic arc array suggesting the geochemical influence of contamination components that increased Zr/Nb and Zr/Y ratios (Group 1 and Group 2) relative to a less contaminated mantle source (Group 3). This chart shows a gradual enrichment of Th in relation to Nb (Fig. 12). Accordingly, the samples from Group 1, Group 2 and Group 3 show characteristics typical of subduction zones. Notwithstanding, those of Groups 1 and 2 display more significant evidence for magma-crust interactions, whereas those of Group 3 have, for the best part, preserved evidence for the magma source with less evidence for magma-crust interaction. However, these are characteristics associated with an oceanic arc formed in the environment of a supra-subduction zone, with the formation of rocks from different sources with the participation of a contamination component. A question to consider is the possibility that the negative Nb anomalies may have resulted from a process other than subduction. However, according to Pearce (2008), it is possible to distinguish genuine subduction anomalies from false ones created by contamination processes from the fractionation trend showed by the rocks analysed, and plotted on Th/Yb vs. Nb/Yb diagram (Fig. 12). In this diagram, the diagonal (inclined) magmatic fractionation trends with variable enrichment in Th, may be better explained by variable amounts of crustal contamination. On the other hand, the sub-vertical trends indicating variable enrichment of Th, in relation to Nb, from the N-MORB font may be associated with a subduction component (Pearce, 2008).

Therefore, the metamafic rocks of the Rio Branco Suite may have formed from the partial melting of a depleted mantle wedge, in which the upward moving magma may have partially assimilated the country rocks. This may have occurred during the magmatic evolution or during magma-crust interactions leading to the formation of an island arc, the rocks of which are typically enriched in Ce, La, K, Th, Rb. However, the influence of a subducted plate of deep oceanic origin along with sea water with strong contaminants cannot be discarded.
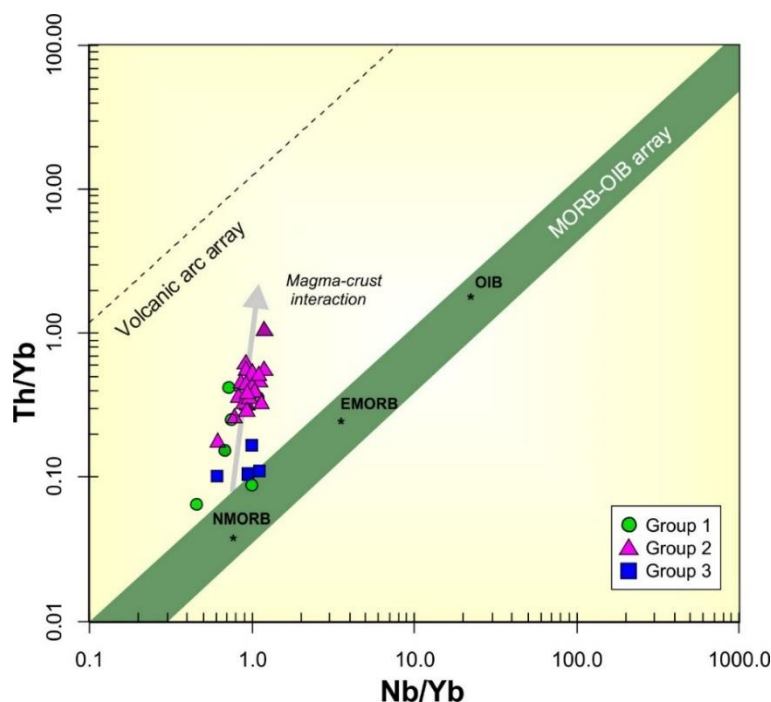
Fig. 12. *Nb/Yb vs. Th/Yb diagram (after Pearce, 2008) for metamafic rocks from the Rio Branco Suite (NMORB: normal (depleted) mid-ocean ridge basalts; EMORB: enriched mid-ocean ridge basalts; OIB: oceanic island basalts). The grey arrow indicates the inferred petrogenetic trend.*

790   The use of trace elements (Th, Hf, Zr, La, Y, Ta and Nb) from the Rio Branco Suite samples
791 (Groups 1, 2 and 3) in Wood (1980) and Cabanis and Lecolle (1989) diagrams revealed geochemical
792 signatures compatible with compressive orogenic environment dominantly, although these diagrams
793 demonstrate also compatibility with back-arc basin basalts and MORB-like chemistry (Figs. 13, 14).
794 A large part of the samples of the Rio Branco Suite plot both in the island arc tholeiite (IAT) and
795 calc-alkaline basalt field (CAB) of the Wood (1980) diagrams, which occurs in function of the
796 gradual enrichment in Th with respect to Hf, Nb and Zr possibly during subduction (Fig. 13).
797 However, these diagrams also reveal the influence of the supra-subduction components (subduction
798 zone enrichment) with petrogenetic trend characteristic of the enrichment in supra-subduction zone
799 (SSZ) in the chemistry of the trace elements of the mafic rocks of the Rio Branco Suite (Fig. 14).
800   Also, in the Cabanis and Lecolle (1989) diagrams, part of the rocks of Groups 1 and 2 plot
801 in the island arc tholeiite field (arc field), whereas the samples from Group 3 fall in the calc-alkaline
802 field (Fig. 14). The samples of the island arc tholeiite (IAT) that fall in the calc-alkaline field are
803 the result of enrichment or contamination in La during subduction and the magma-crust interaction,
804 which implies an interpretation that these samples are not necessarily calc-alkaline mafic rocks but
805 crustal contaminated tholeiite, as previously suggested in figure 14.
806   Finally, in the tectonic discriminant diagrams presented in this paper, the metamafic rocks
807 of Suite Rio Branco also present overlapping geochemical signature features that mainly suggest
808 IAT (island arc tholeiite) and BAB (back-arc basalt) affinities. Our preferred hypothesis for the
809 origin of Rio Branco Suite (metamafic rocks) and of Rio Branco and Migrantinópolis formations
810 (high-grade metavolcanic-sedimentary rocks) is that they were formed in a transition of the arc -
811 back-arc environments. Geotectonic configurations developed in response to a subduction during
812 the Mesoproterozoic (Stenian), between ca. 1137 Ma and 1106 Ma.
813
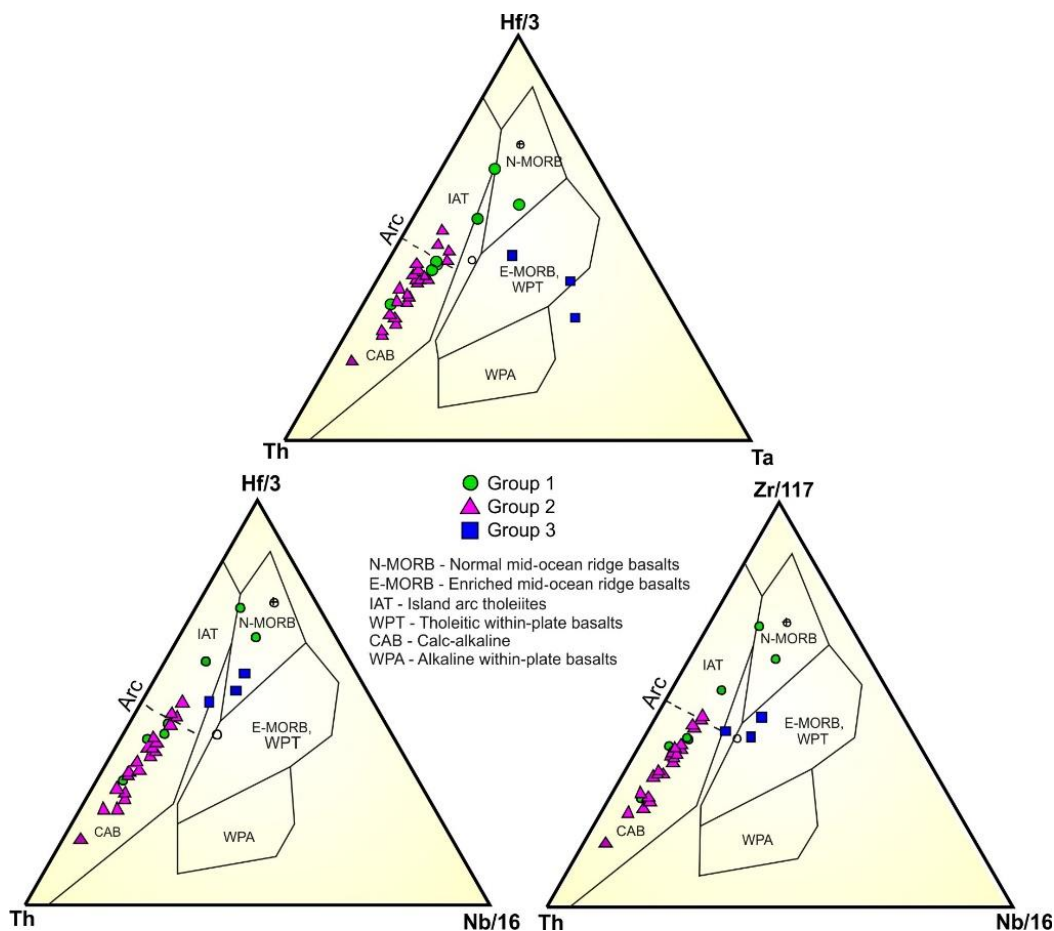
814
815   **Fig. 13.** *Triangular diagrams of the Th-Hf-Ta-Zr-Nb system (Wood, 1980) used to*
816   *identify the subduction components of the metamafic rocks from the Rio Branco Suite.*
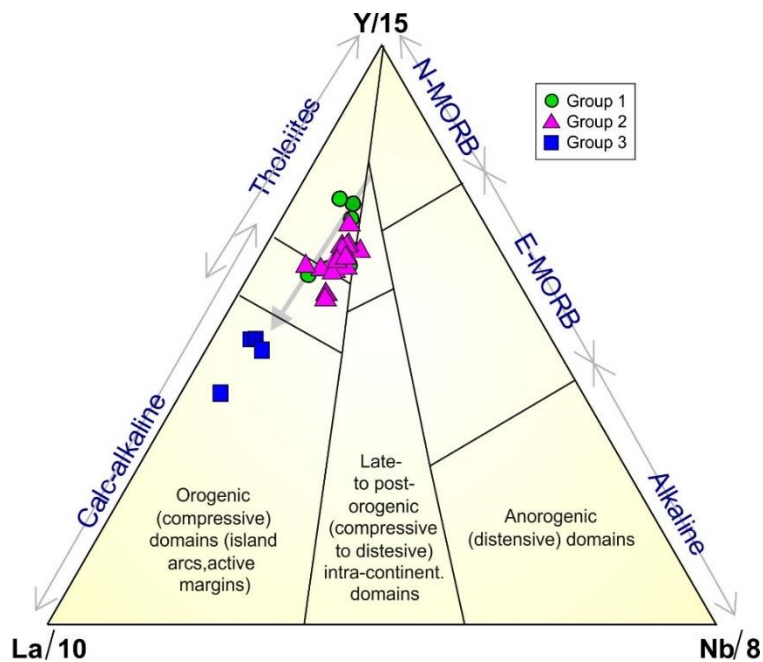
Fig. 14. *La/10 (ppm) vs. Y/15 (ppm) vs. Nb/8 (ppm) diagram of Cabanis and Lecolle (1989) for metamafic rocks from the Rio Branco Suite. The grey arrow indicates the inferred petrogenetic trend, characteristic of the enrichment in supra-subduction zone (SSZ).*

5.2 Nd-Sr isotopic constraints and the source of mafic magmas

The association of the Sr and Nd isotopic composition of rocks from the Rio Branco Suite by group, when compared to present mantle reservoirs, allow us to infer that the metamafic rocks are compatible with mantle magmatism in arc environment with the participation of an important contaminant, which carried an enriched or contaminated mantle reservoir signature. The εNd obtained in mafic rock of the Rio Branco Suite, recalculated for t=1120 Ma, come to slightly negative to positive (-2.89 and +1.66) values near CHUR, suggesting crustal contamination or metasomatic fluids that may be associated with subduction (Figs. 15, 16B). The model ages of the depleted mantle (TDM) of the metamafic rock samples from the Rio Branco Suite ware between 2.05 Ga and 1.51 Ga (Table 4, Fig. 15). The mafic magma of the Rio Branco Suite may have been submitted to varying degrees of crustal contamination, partially from magma-crust interaction, from an enriched reservoir or from the interaction of the subducted oceanic plate with the mantle wedge. Additionally, the source is indicated by the low La/Ta ratios (between 24.00 and 94.50) vs. εNd (T=1120 Ma, between +1.66 and -2.89) and the low La/Yb vs. Nb/La ratios, between approximately 0.52 and 4 for the rocks of Group 1 and Group 2, and between 0.13 and 12.3 for the rocks of Group 3. These isotopic and geochemical signatures of the Rio Branco Suite rocks identified in this research are similar in value to those previously observed in several melts derived from lithospheric mantle (see Watson, 1993; Lawton and McMillan, 1999; Chen et al., 2014).

Combined Nd and Sr isotopic data (Fig. 16) reveal that rocks from Group 1 best approximate the isotopic composition of those of the Bulk Silicate Earth (BSE), extending towards the lower end of the mantle array. This suggests a degree of mixing of depleted mantle magmas and enriched reservoirs (Fig. 16A). Moreover, from the diagram rocks from Group 2 and Group 3 might be interpreted as evolutionary trend indicating the mixing between magmas with a signature similar to Group 1 (BSE signature) with different enriched sources (EM I and EM II). However, two samples from Group 3 with low $^{87}Sr/^{86}Sr$ ratios, low $^{143}Nd/^{144}Nd$ ratios and and high Sr (ppm) content (considered anomalous) fall into the "forbidden zone field" in $^{87}Sr/^{86}Sr$ vs. $^{143}Nd/^{144}Nd$ diagram,

851 which should be better evaluated in future studies within the context of a subduction environment
852 and the P and T conditions involved during metamorphism.
853
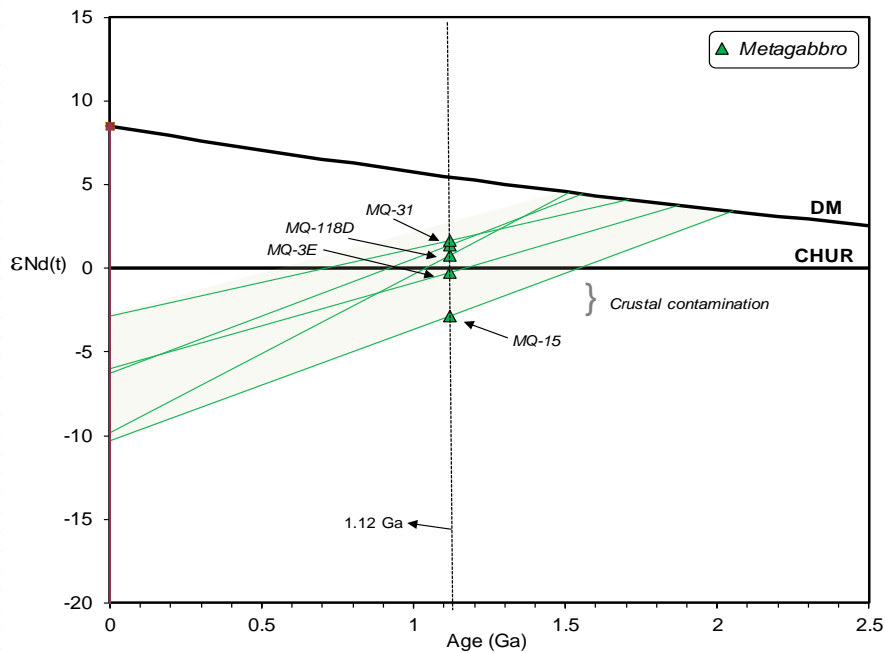
854 **_Fig. 15._** _Plots of whole-rock εNd (t) versus age for the metamafic_
855 _rocks in the Rio Branco Suite. The εNd (t) values of the_
856 _Mesoproterozoic metamafic rocks were re-calculated to t=1120 Ma._
857
858

5.3. The evolution of the Rio Branco Suite in the context of the Rodinia supercontinent
assembly

861

862   Available literature has shown that some mafic suites are formed in supra-subduction zones,
863 and which evolve to form island arcs or volcanic arcs. In the initial phase of subduction and the
864 formation of a proto-island arc, we usually observe a sequential geochemical evolution with
865 components having the characteristics of MORB, IAT (tholeiitic island arc) and even boninites that
866 occur vertically or laterally in complete magmatic sequences, principally in younger (Phanerozoic)
867 tectonic oceanic environments, where their structure is well preserved and more complete (see Dilek
868 and Furnes, 2009, 2011; Reagan et al., 2010). In this type of subduction environment (associated
869 with a supra-subduction zone or a volcanic arc), the mafic magmatism occurs in the initial stages of
870 arc formation. In this setting, an older pre-existing piece of oceanic crust of MORB-type is necessary
871 to serve as the host for gabbroic plutonic bodies, basalt dykes and diabase in the lower part of the
872 crust, as well as serving as a substrate for basalt flows, principally for the types associated with
873 supra-subduction zones. Depending on the evolution and maturation of the arc, and the subduction
874 progress, there exists the possibility for the formation of trondhjemite, tonalite and even granite
875 bodies in the middle zone of the crust, in addition to andesite volcanos, rhyolite flows and dyke
876 intrusions in the upper crust. Additionally, there may occur flows (massive mafic flows and pillow
877 lava), volcanoclastic and pyroclastic rocks the surface (see Dilek and Furnes, 2011). In general, the
878 formation of a volcanic arc is the result of prolonged subduction (~ 20-40 Ma) that may not evolve
879 to a continent-continent collision phase in the same event of arc formation (Dilek and Flower, 2003).
880
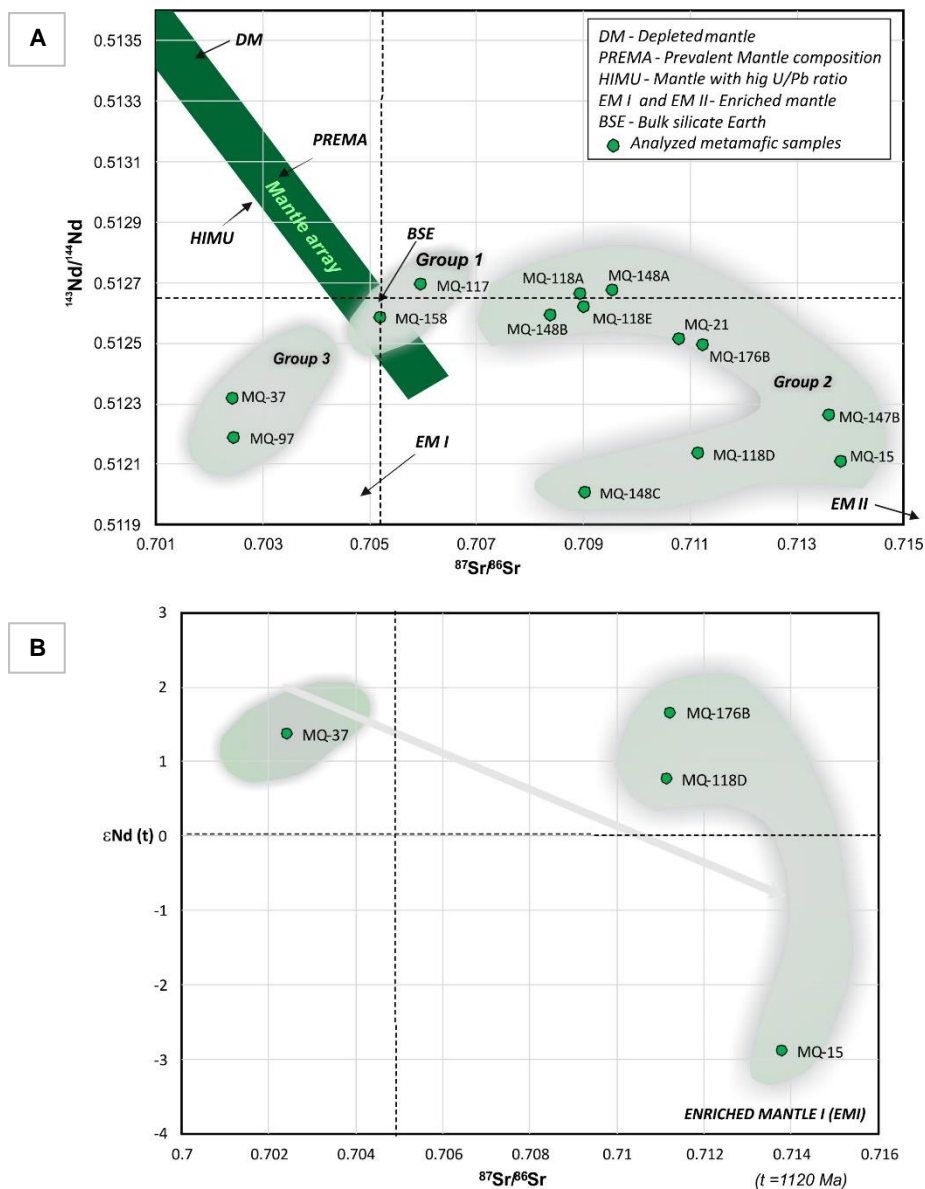
Fig. 16. (A) isotope correlation diagram of $^{143}Nd/^{144}Nd$ vs. $^{87}Sr/^{86}Sr$ of the metamafic rock samples of the Rio Branco Suite and their positions in relation to the main oceanic mantle reservoirs according to Zindler and Hart (1986). (B) correlation diagram of εNd vs. $^{87}Sr/^{86}Sr$ for time t=1120 Ma.

Based on our study, we chose to consider it as the first possibility of mafic sub-alkaline tholeiitic medium- to low Ti magmatism of the Rio Branco Suite was generated by intra-oceanic subduction between ca. 1137 Ma and 1106 Ma, with peak of high-grade metamorphism at ca. 1137 Ma and 1127 Ma probably related to the initial phase of the subduction (see Wakabayashi *et al.*, 2010). Our first suggestion involves magmatic arc formation magmatic (possible island arc) between ca. 1119 Ma and 1106 Ma, which we named of Rio Branco arc, after the high-grade metamorphism recorded in the metavolcanic-sedimentary rocks of the Rio Branco Formation, but of very close ages and possibly associated with the same tectonic event. The second possibility is suggest due to the overlapping of IAT and BAB geochemical signatures in the tectonic discriminant diagrams presented in this paper, leading to the interpretation that the Rio Branco Suite rocks were formed in an arc - back-arc environment (Fig. 16).

This scenario observed in Rio Branco domain, southern part of the Nova Brasilândia belt, suggests Rodinia pre-assembly accretionary phase on the border of the Amazonian proto-Craton

between ca. 1137 Ma and 1106 Ma. As proposed above, we suggest the possibility that during the formation of the Rio Branco magmatic arc at ca. 1119 Ma and 1106 Ma, local extensions might have been active during the early phase of intra-oceanic subduction, causing the rise of the *mantle wedge* and partial melting. Therefore, this close association between the high-grade metamorphism and the voluminous mafic magmatism may be interpreted, provisionally, as being associated with the evolution of a "hot orogen" (see Wakabayashi *et al.*, 2010). In this context, at about 1137 Ma, the margins of the Laurentia and Amazonian cratons were dominated by the convergent interaction between two plates and blocks associated with the beginning of the closure of a pre-existing ocean that was formed approximately between ca. 1241 and 1137 Ma.

The Paraguá block and Amazonian proto-Craton was amalgamated during the Rondonian-San Ignácio Orogeny between 1470 and 1350 Ma (Boger et al., 2005; Bettencourt et al., 2010; Rizzotto et al., 2013). The scenario of intra-oceanic subduction proposed in our research suggests the existence of an ocean formed between the Amazonian proto-Craton and a block (composed by the Paraguá block, fragments of the Alto Guaporé belt, São Felipe basement and other allochthonous terranes located in Bolivia and the Mato Grosso territory). The formation of this ocean occurred possibly after ca. 1241 Ma and before ca. 1137 Ma, during the rift-to-drift phases originated as from reactivation of EW structures pre-existing along the Guaporé suture, promoting the break-up of the Amazonian proto-Craton that had been assembled during the Rondonian-San Ignácio orogeny (ca. 1350 Ma). This possibility of the existence of this block (Rio Guaporé block as a suggested name) needs to be better evaluated in later studies.

In our proposal, the Nova Brasilândia orogeny begins with subduction and formation of an arc - back-arc system between ca. 1137 and 1106 Ma (accretionary phase), originated from of re-approximation of the Paraguá block and Amazonian proto-Craton after the break-up of the Amazonian proto-Craton and oceanization between ca. 1241 and 1137 Ma. The final collision and crustal thickening (collisonal phase) occurred only between ca. 1096 and 1010 Ma, presumably driven by the collision and accretion of the Arequipa-Antofalla Basement to the western margin of the Paraguá block, reflecting in the rocks inside the Nova Brasilândia belt (Loewy et al., 2004; Tohver et al, 2004; Quadros et al, submitted).

In this same period or near to it, magmatic arcs and metavolcanic-sedimentary belts was formed along of cratons margins, such as the Composite Metasedimentary belt of northern Grenville, Nova Brasilândia belt in the southwestern of the Amazonian Craton, Coal Creek Arc of the Llano uplift, and basement inliers in the Andean Cordillera such as the Arequipa-Antofala basement (Cawood and Pisarevsky, 2017). Orogenic events of this period (ca. 1.2 and 1.1 Ga) are known of Nova Brasilândia orogeny at the Sunsás Province and Shawinigan orogeny at the Grenville Province.

Finally, based on geological, geochemical and Sr-Nd isotope new data obtained during this study and the reinterpretation of data previously published by Rizzotto (1999), Rizzotto et al. (2001, 2014), Tohver et al. (2002, 2004, 2005a, 2005b, 2006 and references therein), we propose in this article a new scenario for the tectonic evolution of the Nova Brasilândia orogeny, with emphasis on the Rio Branco domain on the southern part of the Nova Brasilândia belt. In general terms, our proposal centers around the Mesoproterozoic evolution of the Nova Brasilândia belt, which is part of the Sunsás Orogen. We suggest a Rodinia pre-assembly accretionary phase between ca. 1137 and 1106 Ma (Fig. 17) and we associate the Nova Brasilândia orogeny that was initially named by Rizzotto (1999). At this stage there was an intra-oceanic subduction event and formation of a magmatic arc and arc-related basins, as the start of the closure of the ocean that formed between ca. 1241 and 1137 Ma (Fig. 17). This accretionary phase (ca. 1137 and 1106 Ma) recorded in the Nova Brasilândia belt was not recorded in the Aguapeí and Sunsás belts suggesting that only the Nova Brasilândia belt underwent an oceanization phase between ca. 1241 and 1137 Ma.

This new compressive scenario involving subduction contrast with the one previously defined for the Nova Brasilia belt as a product of intracratonic reactivations that occurred during the development of the Sunsás orogen, involving opening and closing an intracontinental rift (Rizzotto, 1999; Teixeira et al., 2010; D'Agrella-Filho et al., 2012; Rizzotto et al., 2014). This partially

contrasts with the proposed scenario of collision and suture between the Amazonian proto-Craton and Paraguá block (Tohver et al., 2004), as it presents a new scenario involving the break-up of the Amazonian proto-Craton into two blocks after its consolidation during the last Rondonian-San Ignácio orogeny (ca. 1350 Ma). Consequently occurred the opening of an ocean between ca. 1241 and 1137 Ma, followed by an acretionary-collisional orogenetic phase between ca.1137 and 1010 Ma (Nova Brasilândia orogeny). In addition, there is possibility that part intraplate mafic magmatism (gabbro) associated with the Nova Floresta Fomation, Rondônia, dated by the K-Ar (biotite and plagioclase) method in ca. 1201 and 1196 Ma (Tohver et al., 2002) may be associated to the break-up between Amazonian proto-Craton and Paraguá block by the relative rotation between Amazon and Laurentia (see Johansson , 2009). This rotation may have provided continental rifting and oceanization between 1241 and 1137 Ma, followed by the beginning of the ocean closure and intra-oceanic subduction between 1137 and 1106 Ma.

At this phase, finally there was a second accretion of the Paraguá block, together with the Arequipa-Antofala basement and smaller fragments (Alto Guaporé belt fragment, São Felipe basement, Rio Branco arc and related-basins), to the Amazonian proto-Craton for Rodinia supercontinent assembly at the late Mesoproterozoic. Reworked craton portions on the basement to the north and northwest of the Nova Brasilândia belt well record two Mesoproterozóic collisional phases (Ectasian-Stenian) of crustal mass accretion to the Amazonian proto-Craton, in regions along of the Jamari domain and Ji-Parana - Cujubim sinistral transpressive system at approximately 1350 Ma and 1110 Ma, respectively (Fig. 1).

ACCRETIONARY PHASE (1137-1106 Ma)
Rodinia pre-assembly
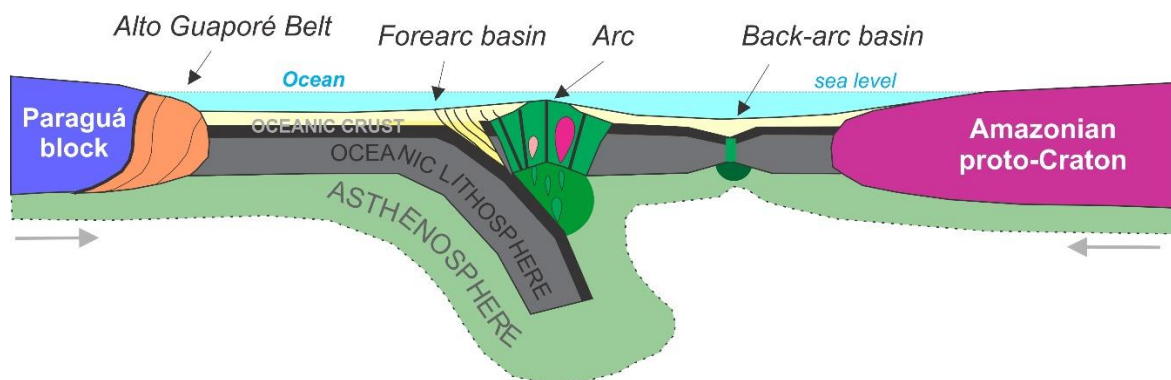
Fig. 17. *Simplified new scenario accretionary proposed for the evolution of the Nova Brasilândia belt in southwestern Amazonian Craton, Rondonia, during the Mesoproterozoic (Stenian).*

The insertion of an accretionary phase in the evolution of the Nova Brasilândia belt generates several implications that with the advancement of research promoted the improvement of the previously proposed model involving transtension/transpression, formation of intracontinental rift, passive margin and proto-ocean, and deformation/high-grade metamorphisms during subduction and collision. Based on this new proposal presented in this paper, new tectonic models of paleogeographic reconstitution of paleocontinents in Mesoproterozoic may be suggest by involving data from this southwestern portion of the Amazonian Craton, an important area of the Amazon for understanding the geological processes of the assembly of Rodinia.

6. Conclusion

New geological, geochemical (whole-rock) and isotopic (Sm-Nd and Sr) data of the Rio Branco Suite metamafic rocks presented in this paper led to the proposal of a new evolutionary

geotectonic scenario for the Nova Brasilândia belt in the southwest region of the Amazonian Craton in Rondônia, and its significance in evolution Mesoproterozoic (Stenian) of the Sunsás orogen. The main conclusions of our work are summarize as follows:

1. The metamafic component of the Rio Branco Suite (ca. 1119 and 1106 Ma) show of a tholeiitic sub-alkaline composition with intermediate- to low Ti and geochemical signature overlay that suggest MORB-like (mid-ocean ridge basalt), IAT (island arc tholeiite) and BAB (back-arc basalt) affinities. The identified groups of metamafic rock (Group 1, 2, 3) show negative anomalies of Nb and Ta, gradually enriched in Th relative to Nb and Ta, positive anomalies of Pb, and positive anomalies of K. Besides Ti/V ratios (10 and 50), La/Yb ratios (between 1.74 and 12.33), Th/Yb ratios (between 0.10 and 3.56), and low-ratios Ce/Pb (3.3 and 20.5), Nb/U (3.2 and 16.25), and Th/La (0.01 and 0.30). The εNd (recalculated for t = 1120 Ma) of the metamafic rocks of Rio Branco Suite with slightly negative to positive values (between -2.89 and +1.66) close to CHUR suggests crustal contamination that may be associated with subduction. Sr-Nd isotopic compositions demonstrate that in Group 1 average $^{87}Sr/^{86}Sr$ ratios of 0.705-0.706 and average $^{143}Nd/^{144}Nd$ ratios of 0.512, Group 2 shows medium to high $^{87}Sr/^{86}Sr$ ratios of 0.708-0.714 and average $^{143}Nd/^{144}Nd$ ratios of 0.512, and Group 3 (anomalous considered) shows $^{87}Sr/^{86}Sr$ low ratios of about 0.702, and $^{143}Nd/^{144}Nd$ low ratios of 0.512. All these geochemical and isotopic characteristics considered effective in interpreting the subduction tectonic environment for the generation of mafic magmatism of the Rio Branco Suite.

2. Geochemical, isotopic and geological evidence recorded in the Rio Branco domain suggests that tholeiitic mafic magmatism with low to medium titanium of the Suite Rio Branco (ca. 1119 and 1106 Ma) was generated during intra-oceanic subduction, possibly in a tectonic environment associated with the arc - back-arc system (Fig. 17). Additionally, in this scenario, the metatrondhjemites spatially associated with metamafic rocks are probably of the oceanic arc-type and reinforced the tectonic environment of subduction proposed in this article. Therefore, the Rio Branco Suite represents an incomplete fragment of magmatic arc (island arc) associated with ocean-ocean subduction.

3. Based on our research we suggest that the southern part of the Nova Brasilândia belt (Rio Branco domain) is the record of an important Mesoproterozoic (Stenian) activity convergent accretionary that occurr between ca. 1137 and 1106 Ma. The high-grade metavolcanic-sedimentary (Rio Branco Formation) and metamafic-metafelsic (Rio Branco Suite) rocks are products of this event of subduction (Fig. 17).

4. This accretionary phase in the Nova Brasilândia belt marks the beginning of the closure of an existing ocean between the a large block consisting of the Paraguá block and smaller blocks or terrane fragments (such as Alto Guaporé belt fragment, São Felipe basement and others on the Bolivia and Brazil). We associate this accretionary phase with the beginning of the Nova Brasilândia orogeny (Table 1).

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5. Discussões e conclusões

Os novos dados geológicos, geoquímicos (rocha total), geocronológicos U-Pb em zircão (LA-ICP-MS) e isotópicos Sr-Nd (rocha total) apresentados nesta tese de doutorado, intitulada "**Geologia, geoquímica e geocronologia das rochas da Suíte Rio Branco, Cinturão Nova Brasilândia e implicações na evolução do orógeno Sunsás no sudoeste do Cráton Amazônico**", atingiram os objetivos principais propostos inicialmente no plano de pesquisa, tais como a obtenção das idades de máxima sedimentação e do metamorfismo de alto-grau das rochas metassedimentares da Formação Rio Branco, idades de cristalização do magmatismo máfico-félsico da Suíte Rio Branco e idades de *overprint* metamórfico, caracterização da afinidade química e fonte do magmatismo máfico da Suíte Rio Branco e definição do ambiente tectônico. Os dados obtidos nessa pesquisa servem, também, de base científica para estabelecer a cronologia dos estágios ou fases de evolução tectônica mesoproterozoica (esteniana) nas quais as rochas do Cinturão Nova Brasilândia foram submetidas, durante a orogenia Nova Brasilândia (Tabela 1, Fig. 7).

Os dados obtidos proporcionaram a concepção de um novo cenário tectônico alternativo para o Cinturão Nova Brasilândia, envolvendo subducção intraoceânica e colisão de massas cratônicas continentais. Elucidaram também o significado do magmatismo máfico da Suíte Rio Branco na evolução mesoproterozoica do Cinturão Nova Brasilândia e, consequentemente, do orógeno Sunsás. As principais discussões e conclusões desta pesquisa constam nos artigos e estão apresentadas de forma resumida nas seções seguintes:

5.1 Fase pré-orogênica (< 1241 Ma)

O cenário tectônico compressivo (margem ativa) envolvendo subducção intraoceânica proposto nesta tese de doutorado contrasta, em parte, do modelo anteriormente definido para o Cinturão Nova Brasilândia envolvendo reativações tectônicas ao longo da zona de sutura Guaporé, abertura e fechamento de *rift* intracontinental e formação de proto-oceano (Rizzotto, 1999; Rizzotto *et al*., 1999, 2001, 2014). Contrasta parcialmente também do modelo tectônico de colisão e suturamento entre o proto-Cráton Amazônico e o Bloco Paraguá entre 1096 e 1000 Ma (Tohver *et al*., 2004). Entretanto, as fases *rift, rift-drift* e *drift* proposta inicialmente por Rizzotto (1999), envolvendo episódios de transtensão que condicionaram a abertura de *rift* intracontinental, que evoluiu para margem passiva, não é totalmente inviabilizada e continua sendo considerada para explicar a existência de um proto-oceano no Esteniano, muito embora na parte sul do Cinturão Nova Brasilândia os registros geológicos dessa fase não claramente evidenciados. A existência desta fase extensional que proporcionou a abertura de um oceano se torna necessário para que a subsequente

subducção intraoceânica possa ter sido desenvolvida, entretanto, ainda não existem dados e informações geológicas suficientes que possam sugerir a dimensão desse oceano e sua idade precisa, mas provavelmente tratava-se de um oceano relativamente pouco desenvolvido, possivelmente um proto-oceano, em função do curto período de tempo para sua abertura e o fechamento. O curto período de tempo para o desenvolvimento deste oceano e bem evidenciado nas idades U-Pb em zircão provenientes das rochas da parte sul do Cinturão Nova Brasilândia (ver artigo 1, submetido).

Tabela 1. Principais características geológicas e tectônicas do Cinturão Nova Brasilândia no sudoeste do Cráton Amazônico em Rondônia (após Scandolara e Rizzotto, 1998; Bahia e Silva, 1998; Rizzotto, 1999; Tohver et al., 2004, 2005a; Santos et al., 2008; Rizzotto et al., 2014).

Orógeno	Orogenia	Natureza da orogenia[1,2]	Período	Unidade tectônica	Principais cacacterísticas tectônicas	Unidade regional	Magmatismo máfico e félsico na região. Intrusões orogênicas[1], pós-orogênicas[2] e anorogênicas[3]
Sunsás	Nova Brasilândia	Colisional (contemporânea da orogenia Sunsás)	1096-1010 Ma	Cinturão Nova Brasilândia: domínios Migrantinópolis e Rio Branco. No cráton: Sistema Tranpressivo Sinistral Ji-Paraná - Cujubim	Tipo acrecionário-colisional na margem sudoeste do proto-Cráton Amazônico e efeitos de retrabalhamento crustal sobre as áreas do cráton (sistemas e zonas de cisalhamento). Metamorfismo variando de baixo grau (fácies xisto-verde) até alto grau (fácies anfibolito a granulito). Fase inicial de oceanização. Sistema *arc - back-arc* na fase acrecionária (subducção)	Cobertura de plataforma pós-colisional: Formação Palmeiral (Vila Palmeiral, serras do Pacaás Novos e Uopianes). Coberturas pré-colisionais: Formação Terra boa e Grupo Nova Brasilândia (formações Rio Branco e Migrantinópolis)	Sills máficos (Nova Floresta[3]) associados as coberturas plataformais. Magmatismo félsico anorogênico em áreas cratônicas: suítes intrusivas Rondônia[3] (*Younger Granites of Rondônia*) (0,98-0,95 Ga), Costa Marques[3] (0,98-0,96 Ga) e Santa Clara[3] (1,08–1,07 Ga). Magmatismo orogênico a pós-orogênico no cinturão: Suíte Intrusiva Rio Pardo[2] (1.05 Ga), magmatismo máfico-félsico da Suíte Rio Branco[1,2] (1,11-1,10 Ga)
		Acrecionária	1137-1106 Ma				
		Fase pré-orogênica (*rift, rift-drift* e *drift*): formação de oceano e margem passiva. Fase de oceanização	< 1241 Ma				

No cenário pré-orogenia Nova Brasilândia, a fusão inicial do Bloco Paraguá com o proto-Cráton Amazônico (parte que corresponde a Província Rio Negro-Juruena ou Provínica Rondônia-Juruena) ocorreu aproximadamente entre 1350 e 1320 Ma, ao final da orogenia Rondôniana-San Ignácio, conforme registros geológicos contindos principalmente nas rochas do Cinturão Alto Guaporé (Scandolara, 2006; Bettencourt *et al*., 2010; Rizzotto *et al*., 2013). Entretando, a fase pré-orogênica na evolução do Cinturão Nova Brasilândia sugere a existência de um oceano entre aproximadamente 1241 e 1137 Ma, situado entre o proto-Cráton Amazônico e um novo bloco composto pelo Bloco Paraguá, acrescido de terrenos alóctones e faixas móveis (p.ex. embasamento São Felipe e Cinturão Alto Guaporé). Portanto, este oceano Esteniano pode ter sido formado por consequência da quebra de segmento crustal composto pelo Bloco Paraguá, Cinturão Alto Guaporé e parte da Provínica Rio Negro-Juruena, após sua cratonização inicial ocorrida no Ectasiano (1350 Ma), ao final da orogenia Rondoniana-San Ignácio.

A dinâmica para explicar sucessivas fases de aglutinação e quebra de massas cratônicas envolve a rotação relativa entre a Amazônia e Laurentia, conforme postulado por Johansson (2009).

Essa rotação pode ter proporcionado a formação de *rifts* intracontinentais na borda sudoeste do proto-Cráton Amazônico e blocos adjacentes, que podem ter sido abortados (p. ex. *rift* Aguapeí) ou que evoluíram para formação de oceano (p. ex. Nova Brasilândia) (Tabela 1, Fig. 7).
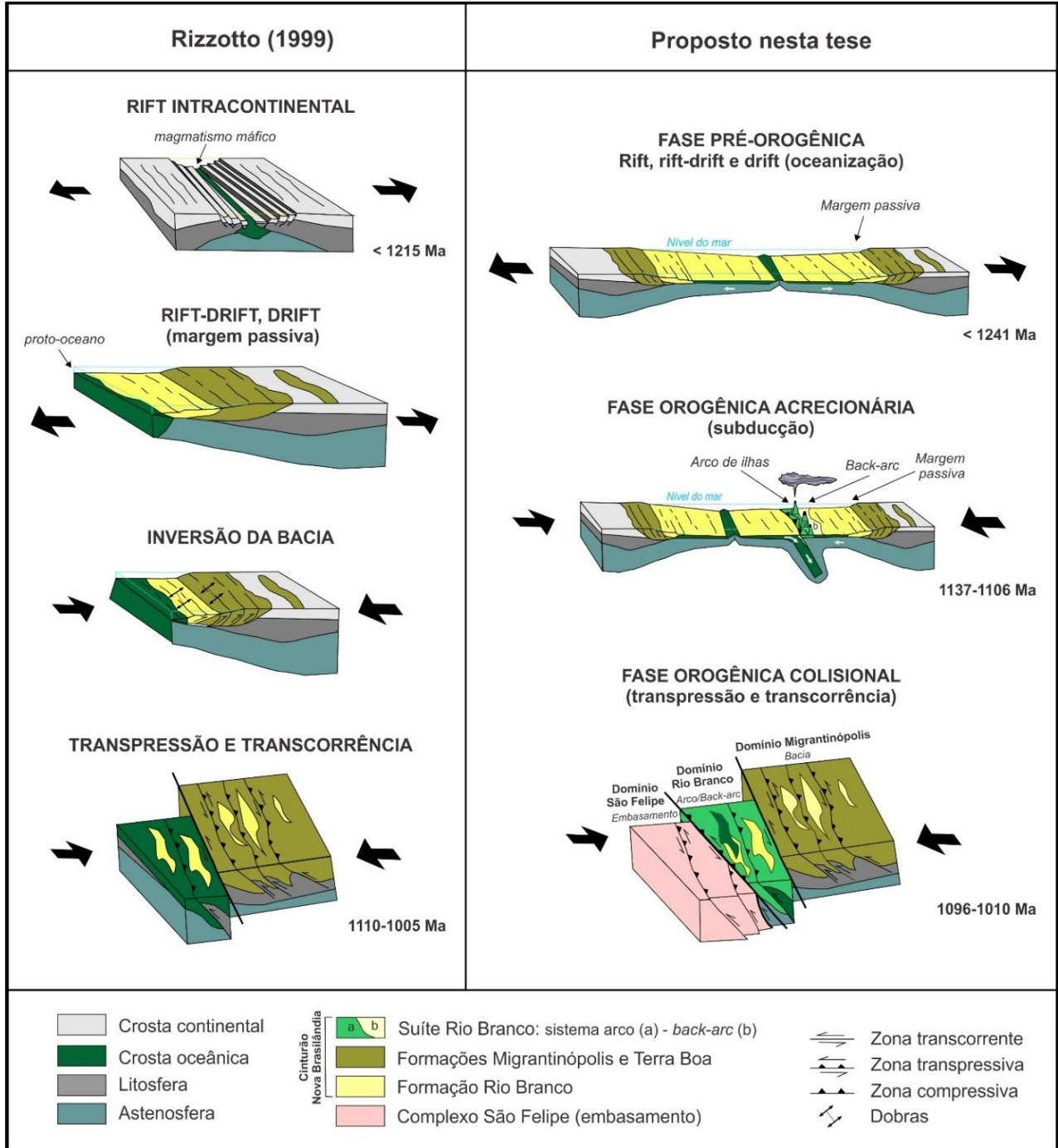

Fig. 7. *Quadro comparativo com os cenários de evolução tectônica propostos para o Cinturão Nova Brasilândia, sudoeste do Cráton Amazônico, Rondônia, no Mesoproterozoico (Esteniano).*

5.2 Fase orogênica acrecionária (1137-1106 Ma)

A fase acrecionária ocorrida entre 1137 e 1106 Ma, proposta pela primeira vez nesta tese de doutorado e artigos relacionados, corresponde a cenário tectônico compressional que envolve subducção intraoceânica, formação de arco de ilhas e bacias relacionadas a arco (*forearc* ou *back-arc*) (Tabela 1, Fig. 7). Esta proposta alternativa de subducção difere do modelo anteriormente definido para o cinturão de Nova Brasília como produto de reativações intracratônicas, abertura e o fechamento de *rift* intracontinental (Rizzotto, 1999; Rizzotto *et al*., 1999, 2014). Para explicar o condicionamento de um ambiente tectônico envolvendo subducção, considera-se também as prováveis rotações relativas entre a Amazônia e Laurentia proposta por Johansson (2009) para explicar nova abertura e fechamento de um oceano, envolvendo subducção intraoceânica entre 1137 e 1106 Ma.

O cenário de subducção identificado nas rochas parte sul do Cinturão Nova Brasilândia foi diagnosticado com base nos dados geoquímicos e de isótopos de Sr-Nd. O contexto geológico e geocronológico U-Pb demostram que o metamorfismo de alto grau (fácies granulito) ocorreu aproximadamente entre 1137 e 1127 Ma e o magmatismo máfico-félsico toleítico de médio a baixo Ti da Suíte Rio Branco foi gerado aproximadamente entre 1119 e 1106 Ma (ver artigo1). Portanto, a constatação de episódios geológicos com idades de metamorfismo de alto grau e de magmatismo máfico muito próximas entre si, aliados as assinaturas geoquímicas e isotópicas Sr-Nd diagnósticas de subducção, são condizentes com ambiente tectônico de *arc – back-arc* e, portanto, reforçam a tese de subducção para explicar a geração das rochas da Suíte Rio Branco (ver artigo 2, submetido).

A história metamórfica do Cinturão Nova Brasilândia é ainda considerada complexa e necessita de estudos adicionais aprofundados para caracterizar, em cada domínio, a trajetória pressão-temperatura (P-T). As condições variadas de P-T foram, inicialmente, estabelecidas com base nas paragêneses de rochas metapelíticas. Rizzotto (1999) identificou condições metamórficas de alta temperatura entre 670°-800°C e baixa pressão em torno de 3.1 Kb. Na parte sul do cinturão, Tohver et al. (2004, 2005a) definiram condições de pico em T máxima de 750°C e P máxima de 7,9 kbars para paragêneses granulíticas. Faixas em baixo-grau ocorrem localmente ao longo de zonas de cisalhamento e, principalmente, na parte norte do Cinturão Nova Brasilândia. Estas variadas condições de P-T sugerem justaposição de domínios metamórficos de alta temperatura e baixa pressão (HT/LP) e alta temperatura e alta pressão (HT/HP), locais onde o metamorfismo atingiu condições de fácies anfibolito superior a granulito, com migmatização do componente metassedimentar, seguido de re-equilíbrios retrometamórficos em baixo grau, reflexos dos processos de subducção, colisão e exumação do orógeno. Processos que necessitam ser avaliados em estudos futuros.

Dados geoquímicos (rocha total) da Suite Rio Branco revelam que o componente metamáfico apresenta afinidade geoquímica subalcalina toleítica de baixo a médio Ti com sobreposição de assinaturas MORB-*like* (semelhante com basalto de cadeia meso-oceânica), IAT (toleito de arco de ilhas) e BABB (basalto de bacia *back-arc*) nos diagramas (ver artigo 2). Esses configuram padrões bem definidos de distribuição de elementos traços nos diagramas ETRs´normalizados ao Condrito que demonstram leve enriquecimento em LREE em relação a HREE. Nos diagramas multi-elementos (*spidergrams*) normalizados ao Manto Primitivo apresentam enriquecimento LILE em relação a HFSE, enriquecimento em Pb, anomalias negativas de Nb e Ta, anomalias positivas de K e Sr e enriquecimento gradativo de Th em relação ao Nb e Ta, consideradas características diagnósticas de subducção. Além disso, razões Ti/V (entre 10 e 50), La/Yb (entre 1.74 e 12.33), Th/Yb (entre 0.10 e 3.56) e baixas razões Ce/Pb (3.3 e 20.5), Nb/U (3.2 e 16.25) e Th/La (0.01 e 0.30) sugerem e reforçam o cenário de subducção (Kessel et al., 2005; Xu et al., 2017). Nos diagramas discriminantes tectônicos de Wood (1980), Cabanis e Lecolle (1989) e de Pearce (2008) os *trends* petrogenéticos exibidos pelas rochas metamáficas da Suíte Rio Branco são característicos de ambiente de arco, mais específico de arco de ilhas, com algumas amostras sugerindo ambiente de bacia *back-arc,* entretanto, destaca-se que nos diagramas discriminantes tectônicos as amostras da Suíte Rio Branco plotam principalmente em campos específicos e de possível associação à ambiente orogenético compressivo (margem ativa).

Dados isotópicos Sr-Nd (rocha total) foram utilizados na interpretação das fontes do magmatismo máfico e dos processos ocorridos no manto (contaminação ou metassomatismo), levando-se em consideração as limitações dos resultados analíticos inerentes ao método utilizado. Os εNd das rochas metamáficas da Suíte Rio Branco (recalculados para t=1120 Ma) apresentaram valores levemente positivos e negativos entre -2.89 e +1.66, porém próximos do CHUR, e sugerem contaminação crustal ou metassomatismo da cunha mantélica, possivelmente associados a subducção. Composições isotópicas de Sr-Nd das rochas metamáficas da Suíte Rio Branco demonstram que as rochas do Grupo 1 apresentam razões médias de $^{87}Sr/^{86}Sr$ entre 0.703 e 0.705 e razões média de $^{143}Nd/^{144}Nd$ de 0.512 e do Grupo 2 razões médias a altas de $^{87}Sr/^{86}Sr$ entre 0.708 e 0.713 e razões médias de $^{143}Nd/^{144}Nd$ de 0.512. Nesses grupos, as variações composicionais de Sr e Nd podem ser associadas a fontes mantélicas mistas (manto depletado ou manto enriquecido) e as altas razões $^{87}Sr/^{86}Sr$ indicam contaminação crustal influenciada por fluídos da placa subductante, durante subducção e geração magmática. As rochas metamáficas do Grupo 3 (4 amostras) apresentam baixas razões $^{87}Sr/^{86}Sr$, em torno de 0.702, e baixas razões $^{143}Nd/^{144}Nd$, em torno de 0.512, e conteúdo muito alto de Sr (1680-1285 ppm) considerado anômalo. Entretanto, estudos adicionais se fazem necessários para avançar no entendimento da origem e evolução das rochas do

Grupo 3, envolvendo fontes e condições específicas de pressão (P) e temperatura (T) durante a subducção e exumação do orógeno.

As características geológicas, geoquímicas e isotópicas das rochas da parte sul do Cinturão Nova Brasilândia, descritas nesta tese de doutorado, foram consideradas efetivas no diagnóstico de ambiente de subducção intraoceânica, com possível formação de arco magmático (arco de ilhas) e bacia relacionada a arco (*back-arc*), que serviram de base para definir uma fase convergente acrecionária entre 1137 e 1106 Ma na evolução do Cinturão Nova Brasilândia. Destacamos, ainda, que as idades U-Pb (zircão) muito próximas entre os episódios de sedimentação, metamorfismo de alto grau e magmatismo máfico-félsico da Suíte Rio Branco serviram, também, de critérios para caracterizar o ambiente orogenético convergente, desenvolvido durante a fase inicial da orogenia Nova Brasilândia.

5.3 Fase orogênica colisional (1096-1010 Ma)

A fase acrecionária da orogenia Nova Brasilândia evoluiu, posteriormente, para fase de colisão continente-continente, entre aproximadamente 1096 e 1010 Ma, quando provavelmente as rochas metamáficas da Suíte Rio Branco foram acrecionadas na borda sudoeste do Cráton Amazônico, durante o suturamento entre um novo bloco (constituído pelo Bloco Paraguá, acrescido de terrenos alóctones e faixas móveis) e o proto-Cráton Amazônico (parte ocidental da Provínica Rio Negro-Juruena), consolidando assim a formação do Cráton Amazônico em aproximadamente 1.0 Ga (Tabela 1, Fig. 7). A deformação e o metamorfismo impresso nas rochas metamáficas da Suíte Rio Branco que ocorreu posteriormente entre 1096 e 1010 Ma, pode ser o reflexo da fase colisional continente-continente. Esta fase representa as atividades orogenéticas finais que culminaram com aglutinação de massas cratônicas (Laurentia e Amazônia e demais blocos, fragmentos de blocos e terrenos alóctones) para formar o Supercontinente Rodínia (Rizzotto, 1999; Rizzotto *et al*., 1999, 2014; Tohver *et al*., 2002, 2004, 2005b).

A fase colisional da orogenia Nova Brasilândia está consolidada na literatura geológica da região em diversas pesquisas (Rizzotto, 1999; Tohver *et al*., 2002, 2004, 2005b). Essa foi levada em consideração na tentativa de explicar as idades U-Pb em zircão (LA-ICP-MS) de *overprint* metamórfico encontradas nas rochas paraderivadas e produtos anatéticos (Formação Rio Branco) e em ortoderivadas metamáficas (Suíte Rio Branco) da parte sul do cinturão, as quais coincidem com dados geocronológicos publicados anteriormente. As idades U-Pb (zircão) obtidas foram ainda analisadas em conjunto comas as idades U-Pb de trabalhos anteriores (Rizzotto, 1999; Tohver *et al*., 2004, 2005a; Santos *et al*., 2008; Rizzotto *et al*., 2014), com a finalidade de reforçar a interpretação de que as rochas do Domínio Rio Branco foram afetadas por um segundo episódio mais jovem de deformação e metamorfismo entre 1096 ± 5 Ma e $1011,3 \pm 9,6$ Ma, sobreposto ao pulso metamórfico

de alto grau mais antigo entre 1137 ± 9 Ma e 1127,6 ± 2,3 Ma (ver artigo 1). Portanto, optamos em sugerir que o metamorfismo mais jovem registrado no cinturão pode estar associado à fase colisional da orogenia Nova Brasilândia (Tabela 1, Fig. 7), onde o magmatismo félsico da Suíte Rio Pardo em cerca de 1005 ± 41 Ma registra o início do estágio pós-tectônico desta segunda fase evolutiva do cinturão. Nesta fase, houve a justaposição tectônica de blocos representados pelos domínios Migrantinópolis, Rio Branco e São Felipe (Figs. 3, 7).

Esse novo cenário tectônico alternativo envolvendo subducção e geração de arco magmático e bacia *back-arc*, seguido de colisão, espessamento crustal, exumação e resfriamento do orógeno caracteriza a orogenia Nova Brasilândia no sudoeste do Cráton Amazônico como do tipo acrecionária-colisional, desenvolvida entre aproximadamente 1137 e 1010 Ma (Fig. 7).

Finalizando, destacamos ainda que os dados obtidos nesta pesquisa fornecem importantes informações petrogenéticas e geocronológicas que permitem um grande avanço na definição do ambiente tectônico de geração das rochas da Suíte Rio Branco, com implicações significativas no entendimento da evolução geotectônica do Cinturão Nova Brasilândia no sudoeste do Cráton Amazônico, bem como no estabelecimento de correlações geológicas com a Provínica Grenville. Os produtos publicados desta pesquisa (artigos e volume da tese) servem de fonte de informações geocientíficas para o aperfeiçoamento dos cenários globais de montagem do supercontinente Rodínia.

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120