



Universidade de Brasília

Instituto de Geociências

Programa de Pós-graduação em Geologia

O Complexo Metamórfico Uruaçu, Brasil Central: Significado geológico e implicações na evolução tectono-metamórfica do Orógeno Brasília

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Dissertação de Mestrado N°

Orientador: Prof. Dr. Claudinei Gouveia de Oliveira

Co-orientadora: Prof.^a Dra. Eliza Inez Nunes Peixoto

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“Exageramos sempre as coisas que não conhecemos.”
Albert Camus

RESUMO

O Complexo Uruaçu é um terreno metamórfico neoproterozoico (690-650 Ma) de forma dômica exposto sob as rochas supracrustais do Grupo Serra da Mesa, na porção central da Faixa Brasília Norte, entre os complexos máfico-ultramáficos e o Arco Magmático de Mara Rosa. Neste estudo, combinamos dados de campo, modelagem metamórfica por pseudoseção e proveniência de zircões detríticos para determinar o ambiente tectônico e a evolução tectônica do Complexo Uruaçu e das suas rochas adjacentes associadas ao Grupo Serra da Mesa. As principais rochas encontradas no Complexo Uruaçu são ortognaisses de composição tonalítica a granítica e paragnaisses. Os anfibolitos ocorrem como pequenos corpos dispersos no complexo. As pseudosseções calculadas para o paragneisse e anfibolito, juntamente com geotermobarômetros convencionais indica o pico metamórfico em ~7 kbar e 700°C, com retrometamorfismo em ~4.42 e 551°C. O Grupo Serra da Mesa é principalmente composto de quartzitos e xistos, com ocorrências menores de mármore. A modelagem por pseudosseção com base no perfil composicional da granada prevê uma trajetória *P-T* de 4.3 kbar e 547°C até 5.9 kbar e 616°C para o granada xisto do Grupo Serra da Mesa. Além disso, foram observadas estruturas normais cortando a foliação regional, implicando em evidências preliminares de tectônica extensional na Faixa Brasília Norte. Os zircões detríticos coletados do Grupo Serra da Mesa sugerem que os sedimentos foram depositados em três bacias distintas: (1) bacia intracontinental paleo- mesoproterozoica a qual pode ser correlata ao Grupo Traíras; (2) Bacia de retroarco neoproterozoica nas margens do Arco Magmático de Mara Rosa e (3) Bacia de antepaís neoproterozoica, que também é associada à porção oriental da Sequência Santa Terezinha. Combinando esses novos dados, propomos que o Complexo Uruaçu foi exumado por meio de diapirismo durante a fase colisional do Orógeno Brasília.

Palavras-chave: Complexo Uruaçu; Grupo Serra da Mesa; Modelamento metamórfico; U-Pb em zircão detrítico; Orógeno Brasília.

ABSTRACT

The Uruaçu Complex is a Neoproterozoic domed-shaped metamorphic terrain (690-650 Ma) exposed underneath the supracrustal rocks of the Serra da Mesa Group in the central portion of the Northern Brasília Belt between the mafic-ultramafic complexes and the Mara Rosa Magmatic Arc. In this study, we combine field data, metamorphic modelling, and U-Pb detrital zircon provenance to constrain the tectonic setting and the evolution of the Uruaçu Complex and its surrounding rocks from the Serra da Mesa Group. The main rocks from the Uruaçu Complex are orthogneisses with tonalitic to granitic composition, and paragneisses. The amphibolites occur as scattered bodies through the complex. The pseudosection from the paragneiss and the amphibolite coupled with conventional geothermobarometers constrains the peak metamorphic at ~7 kbar and 700°C with retrogressive metamorphism at ~ 4.42 kbar and 551°C. The Serra da Mesa Group is mainly composed of quartzites and schist with minor occurrences of marble. The pseudosection modelling based on the garnet compositional profile predicts a *P-T* path from 4.3 kbar and 547°C to 5.9 kbar and 616°C for the garnet schist from the Serra da Mesa Groups. In addition, normal structures were observed cross-cutting the regional foliation implying in preliminary evidence for extensional tectonics in the Northern Brasília Belt. The U-Pb detrital zircons collected from the Serra da Mesa Group suggest that the sediments were deposited in three different basins: (1) Paleo-Mesoproterozoic intracontinental extensional basin which can be the lateral correlative of the Traíras Group; (2) Neoproterozoic back-arc basin in the margins of the Mara Rosa Magmatic Arc, and (3) Neoproterozoic foreland basin also associated with the eastern portion of the Santa Terezinha Sequence. Combining these new data, we proposed that the Uruaçu Complex underwent a diapiric ascent during the collisional stage of the Brasília Orogen.

Keywords: Uruaçu Complex; Serra da Mesa Group; Metamorphic modelling; U-Pb detrital zircon; Brasília Orogen

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CAPÍTULO 1

INTRODUÇÃO

1 INTRODUÇÃO

1.1 Apresentação

Complexo de núcleo metamórfico (*Metamorphic core complex*) é uma estrutura geológica arqueada ou domal composta por rochas deformadas ductilmente e intrusões associadas subjacentes a uma zona dúctil-rúptil de alta deformação que experimentou um deslocamento de sentido normal em resposta à extensão litosférica (Whitney et al. 2013). A evolução de um complexo de núcleo metamórfico envolve a exumação de rochas da crosta média a inferior por meio de falhas de descolamento (Davis e Lister, 1988; Whitney et al., 2013; Platt et al., 2015). Essas falhas são zonas de cisalhamento extensionais que justapõe rochas cristalinas de alto grau metamórfico (lapa) sobre rochas sem metamorfismo ou de baixo grau metamórfico (capa).

Tais complexos possuem ampla distribuição espacial e temporal. Ocorrendo em ambientes tectônicos diversos e desde orógenos proterozóicos a atuais. Nesse sentido, a existência de um complexo de núcleo metamórfico dentro do Orógeno Brasília foi brevemente discutida por Cordeiro et al. (2014) e Winge (1995), os quais associaram tal estrutura à exumação dos Complexo Uruaçu e Complexo Anápolis-Itaçu, respectivamente. O Complexo Uruaçu é um terreno metamórfico neoproterozoico (690-650 Ma), exposto em meio às rochas supracrustais do Grupo Serra da Mesa (1.6 Ga a 1.5 Ga), localizado na porção centro-sul do Domínio Campinorte, Faixa Brasília Setentrional (Oliveira et al. 2006; Marques, 2009; Cordeiro et al. 2014; Cordeiro e Oliveira, 2017).

Dessa forma, esta dissertação apresenta uma investigação metamórfica e geocronológica a respeito do Complexo Uruaçu e unidades adjacentes, a fim de aprofundar o conhecimento sobre sua gênese e evolução, bem como sua implicação regional dentro da evolução tectônica do Orógeno Brasília.

1.2 Objetivos e justificativas

O projeto tem como objetivo principal melhorar o entendimento a respeito da geração e evolução do Complexo Uruaçu através de mapeamento, petrografia, geoquímica de rocha total e em química mineral para a determinação das condições *P-T* do complexo. A investigação também envolve estudo de proveniência sedimentar do Grupo Serra da Mesa a fim de ampliar o conhecimento a respeito da cobertura metassedimentar do complexo. Dessa forma, pretende-se: 1) Investigar o quadro estrutural no qual o complexo está inserido e sua relação com as unidades adjacentes; 2)

determinar as condições de *P-T* do Complexo Uruaçu e do Grupo Serra da Mesa; 3) Melhorar a contextualização do Complexo Uruaçu e do Grupo Serra da Mesa no panorama evolutivo do Orógeno Brasília

1.3 Estado da arte

1.3.1 Introdução

Complexo de núcleo metamórfico (MCC – *metamorphic core complex*) é definido como uma estrutura geológica arqueada ou domal composta por rochas deformadas ductilmente e intrusões associadas subjacentes a uma zona dúctil-rúptil de alta deformação que experimentou um deslocamento de sentido normal em resposta à extensão litosférica (Coney, 1980; Whitney et al., 2013). É uma estrutura de escala crustal na qual sua formação envolve a exumação de rochas provenientes da crosta média/inferior até níveis crustais rasos por meio de falhas normais de baixo ângulo.

O termo *metamorphic core complex* foi primeiramente empregado para denominar o conjunto de terrenos metamórficos isolados aflorantes ao longo da Cordilheira Norte Americana, os quais definem uma faixa sinuosa que parte do noroeste do México até o sudoeste canadense. O início dos estudos relacionados a esses complexos se deu com o trabalho de Misch (1960) na Província Estrutural de Nevada. Nesse estudo é enfatizado a existência de uma descontinuidade estrutural regional, denominada *décollement*, que separa a cobertura sedimentar paleozoica do substrato metamórfico. Posteriormente, Armstrong e Hans (1966) estruturaram a relação desses elementos, denominando as rochas metamórficas dúcteis do substrato de “infraestrutura” e as rochas sedimentares rígidas de “supraestrutura”. Somente após os trabalhos de Coney (1974, 1980), Davis e Coney (1979) e Coney e Harms (1984) que os complexos de núcleo metamórfico foram caracterizados como estruturas extensionais. Com a difusão desse conceito vários outros foram identificados ao redor do mundo e em ambientes tectônicos diversos (Figura 1).

Em geral, a extensão litosférica que acarreta a formação desses complexos é conduzida pela divergência de placas, como nas cadeias meso-oceânicas (e.g. Godzilla megamullion no Mar das Filipinas; Ohara et al., 2001). O regime extensional também pode ocorrer em limites convergentes devido ao colapso orogênico, que ocorre em função da carga gravitacional de uma crosta espessa (e.g. complexo de núcleo metamórfico de Shuwsap na Cordilheira Canadense; Vanderhaegue et al., 1999). Em regiões de retroarco

1.3.2 Modelos de desenvolvimento de complexos de núcleo metamórfico

Desde o reconhecimento dos complexos de núcleo metamórfico, modelos conceituais, baseados em estudos de campo e geofísicos, foram propostos para explicar a sua gênese e desenvolvimento. Davis e Coney (1979) propuseram o conceito de *megaboudinage* no qual o MCC é interpretado como o equivalente de escala crustal das dobras formadas entre dois *boudins* (Figura 3A).

Novos modelos foram propostos levando em conta a atuação da zona de descolamento no processo formador desses complexos conforme essa estrutura ganhou destaque e reconhecimento como uma estrutura primária. Wernick (1981, 1985) propôs que a zona de cisalhamento seria o traço superior de uma falha normal de baixo ângulo de escala litosférica. Esse modelo predizia que o rejeito normal da Moho teria amplitude comparável com deslocamento extensional da superfície (Figura 3B). Esse deslocamento de grande magnitude resulta em ascensão das rochas da lapa em resposta à denudação tectônica, conduzindo, também, ao soerguimento e arqueamento da falha de descolamento. A sinuosidade do traço da falha principal desenvolve quatro domínios estruturais distintos: 1) uma área não afetada por falhas extensionais; 2) placa superior sinformal; 3) elevação antiformal e 4) placa superior em forma de cunha (Spencer, 1984) (Figura 3C).

Após a realização da Transecta 40° COCORP (*Consortium for Continental Reflection Profiling*), ao longo da Província de *Basin and Range*, não foram observadas evidências significativas desse deslocamento da Moho, contrariando o modelo proposto por Wernick (Allmendinger et al., 1987). Dessa forma, um novo modelo conceitual foi proposto por Wernick e Axen (1988) e foi denominado, posteriormente, de modelo de rolagem de charneira (*rolling hinge model*). Nesse modelo a falha de descolamento é resultado do desenvolvimento sequencial de falhas normais de alto ângulo. Com a progressão da extensão e o soerguimento isostático da placa inferior, cada nova falha é rotacionada para um mergulho mais baixo e abandonada conforme uma outra falha surge na placa superior (Figura 3D). Atualmente, esse é o modelo conceitual mais aceito e aplicado a vários complexos de núcleo metamórfico.

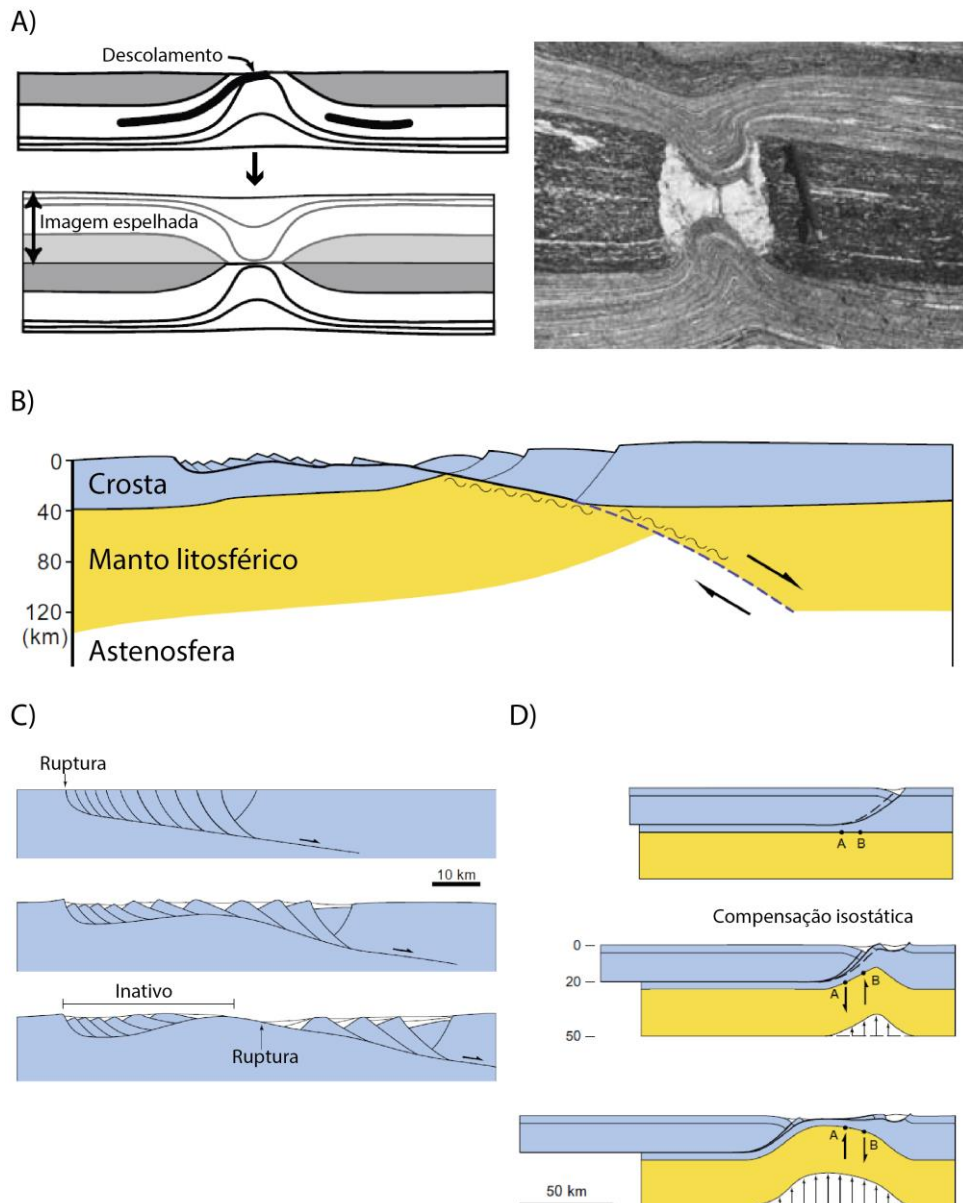


Figura 3. Modelos conceituais de complexos de núcleo metamórfico. **a)** Modelo de Megaboudinage (Davis e Coney, 1979), MCC interpretado como o equivalente crustal da região entre dois boudins. À direita fotografia de boudins em escala de afloramento (retirado de Tirel et al., 2008). **b)** Modelo da zona de descolamento de escala litosférica (Wernick, 1981, 1985; retirado de Brun et al., 2018). **c)** Modelo de arqueamento da falha de descolamento (Spencer, 1984; retirado de Brun et al., 2018). **d)** Modelo de rolagem de charneira (Wernick e Axen, 1988; retirado de Brun et al., 2018).

Com o advento da modelagem numérica começaram a surgir modelos dinâmicos de desenvolvimento de complexos de núcleo metamórfico. A geoterma é o principal parâmetro utilizado nesses modelamentos, já que é um fator controlador da viscosidade da crosta inferior e, portanto, influencia na interação entre a placa superior e inferior. A magnitude do acoplamento entre as placas é fortemente controlada pelo gradiente geotérmico. Assim, em um gradiente geotérmico normal a crosta inferior é

mecanicamente acoplada com a crosta superior, portanto a deformação na crosta inferior é uma resposta às forças de limite de placas. Já em condições com gradientes geotérmicos mais elevados a crosta inferior é mais plástica e flui tanto em resposta a esforços tectônicos quanto por esforços gravitacionais (Whitney et al. 2013).

Assim, modelos numéricos que utilizam o parâmetro de viscosidade dependente de temperatura demonstram que a extensão em uma geoterma fria resulta em mais falhas normais na crosta superior rúptil e a extensão é homogênea na crosta inferior dúctil (Figuras 4a, 4b). Por outro lado, um gradiente geotérmico mais elevado resulta em uma extensão mais localizada na crosta superior rúptil o que conduz o fluxo na crosta profunda (Figuras 4c, 4d; Whitney et al. 2013).

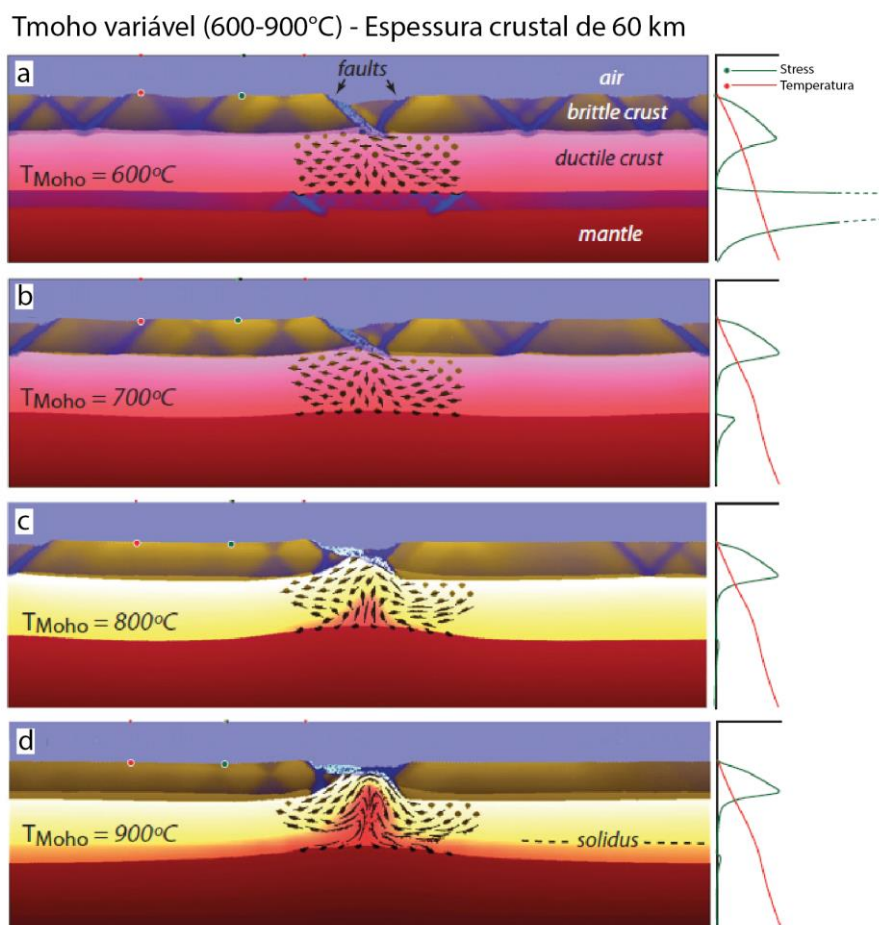


Figura 4. Influência da geoterma na distribuição de deformação em complexos de núcleo metamórfico. **a) e b)** Extensão sob um regime de geoterma fria, sem fusão parcial. **c) e d)** Extensão sob regime de geoterma mais quente.

A taxa de deformação e a quantidade de material fundido também são variáveis utilizadas em experimentos numéricos relacionados com o desenvolvimento de complexos de núcleo metamórfico. A partir dessas variáveis os MCC com núcleo migmatítico podem ser distinguidos em rápidos e lentos. Experimentos feitos sem a

presença de fundido ressaltam o papel da taxa de extensão. Uma taxa de extensão elevada ($2 \times 10^{-15} \text{ s}^{-1}$) promove considerável advecção de calor e deformação interna na região de ressurgência o que produz um MCC mais extenso, enquanto taxas de extensão lentas ($2 \times 10^{-16} \text{ s}^{-1}$) não geram perturbações significativas nas isothermas (Rey et al. 2009a) (Figura 5a e 5b).

Nos experimentos com presença de fundido há uma leve ampliação do núcleo metamórfico, seja em taxas de deformação lentas ou rápidas. Extensão rápida com presença de fundido gera uma advecção de calor ainda maior, o que soergue a curva *solidus* para níveis crustais rasos (<10 km) e gera um domo nucleado por uma zona com mais de 30% de fundido. Já no modelo de extensão lenta com presença de fundido há aumento do movimento ascendente da crosta inferior, quando comparado com o modelo sem fundido, levando à exumação de rochas que estavam parcialmente fundidas. A curva *solidus* se mantém relativamente plana e localizada em 27 km de profundidade (Figuras 5c e 5d; Rey et al. 2009a).

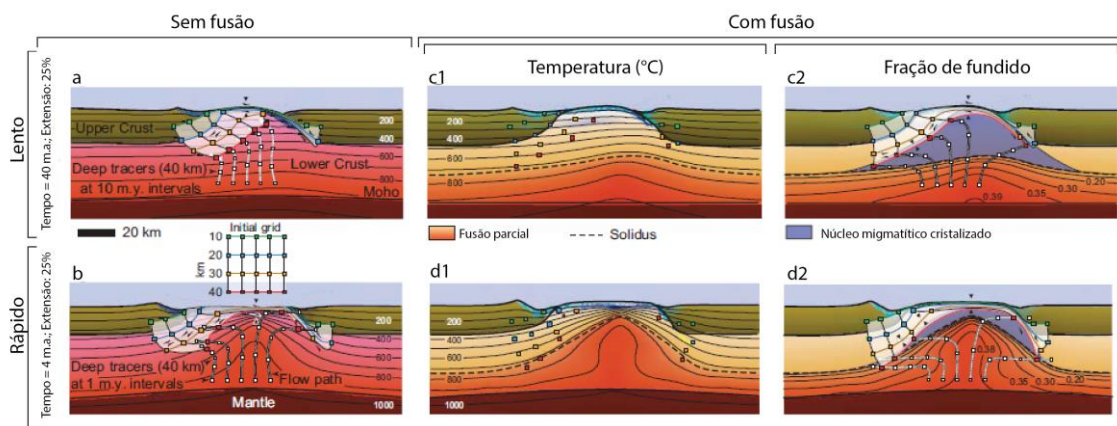


Figura 5. **a) e c)** Extensão com taxa de deformação de $2 \times 10^{-16} \text{ s}^{-1}$; **b) e d)** Extensão com taxa de deformação de $2 \times 10^{-15} \text{ s}^{-1}$. **a) e b)** Modelos sem fusão parcial; **c) e d)** Modelos com fusão parcial (retirado de Rey et al., 2009a).

1.3.3 Metamorfismo em complexos de núcleo metamórfico

As rochas da lapá de um complexo de núcleo metamórfico podem registrar uma ampla variedade de eventos metamórficos pré- a sin-extensionais. Dessa forma, é de suma importância a distinção desses eventos. A evolução das condições de *P-T* relacionadas com a exumação desses complexos segue uma trajetória *P-T*, em geral, isothermal decompressional horária seguida por resfriamento rápido ((Figura 6a; Whitney et al. 2013).

Ainda assim, em alguns casos, a exumação desses complexos não ocorre estritamente devido à formação do MCC. Como no caso do Complexo Nevado-Filabride na Cordilheira Bética no qual o modelo proposto envolve dois estágios de exumação. O primeiro estágio é relacionado a uma exumação rápida em canal de subducção e posteriormente, o segundo estágio de exumação mais lenta é associado com a captura do complexo por uma zona de cisalhamento extensional no período em que alcançou a crosta média. A partir disso a exumação final foi acomodada em uma geometria de complexo de núcleo metamórfico (Figura 6b; Behr e Platt, 2012).

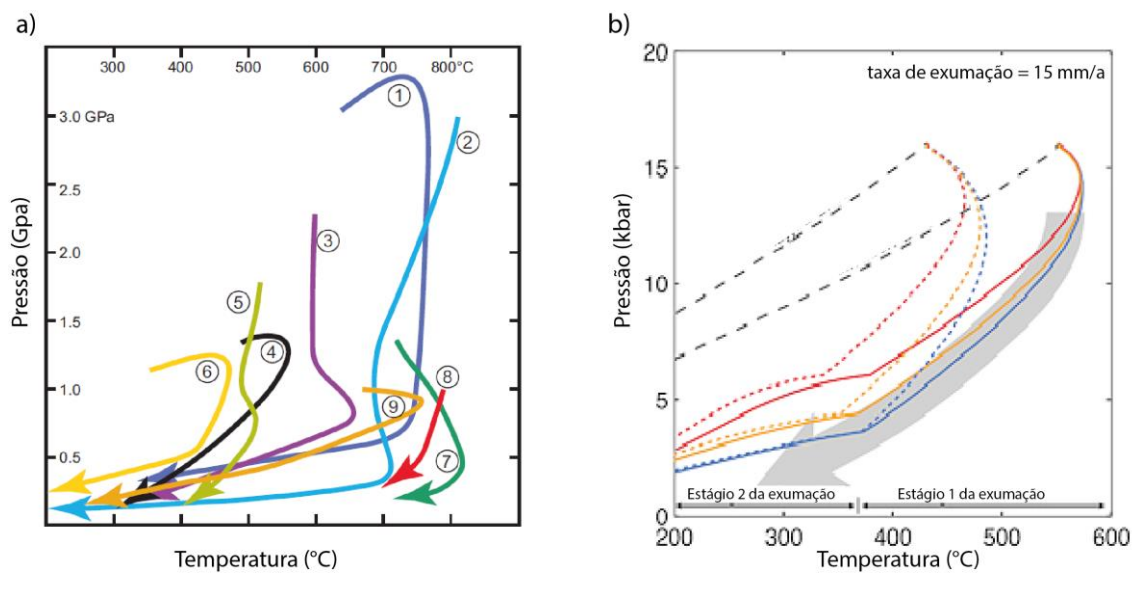


Figura 6.a) Compilação de trajetórias P-T de complexos de núcleo metamórfico (retirado de Platt et al., 2015. **b)** Trajetória P-T do Complexo Nevado-Filabride, observar a mudança de gradiente que marca a mudança do estágio de exumação (retirado de Behr e Platt, 2012)

Modelos numéricos demonstram que as trajetórias P - T são sensíveis à taxa de deformação, porém não são afetadas pela presença de fundido. Em taxas de deformação baixas, as trajetórias apresentam descompressão e resfriamento ao longo do gradiente geotérmico no intervalo de 20 a 35° C Km⁻¹ (Figura 7a). Por outro lado, uma taxa de deformação elevada exibe uma etapa de descompressão isotermal seguido por um período de descompressão e resfriamento ao longo do gradiente geotérmico no intervalo de 35 a 65° C Km⁻¹ (Figura 7b; Rey et al. 2009b).

Rey et al. (2009b) utilizam o MCC de *Ruby Mountain-East Humboldt Range* e o MCC de Shuswap da Cordilheira Norte-Americana como exemplos naturais para essas características encontradas nos modelos numéricos envolvendo diferentes taxas de deformação. O MCC de Shuswap exemplifica os MCCs com taxa de extensão elevada,

já que apresenta evolução de P-T e taxa de exumação similares com as definidas pelo modelo. A trajetória P-T desse domo registra decompressão isotermal de 1000 MPa para < 500 - 400 Mpa em temperatura fixa aproximada de 750°C (Rey et al. 2009b) (Figura 7b). Por outro lado, o MCC de *Ruby Mountain-East Humboldt Range* é o exemplo natural dos MCCs com taxa de extensão baixa. Esse complexo registra uma história de extensão e exumação prolongada a qual sua trajetória P-T é similar à trajetória proposta pelo modelo numérico (Figura 7a; Rey et al., 2009b).

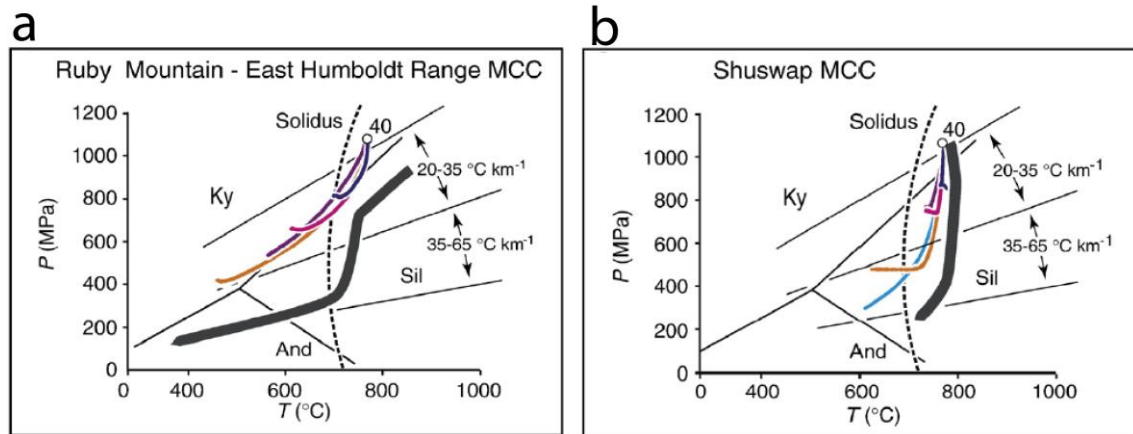


Figura 7. a) Comparação das trajetórias P-T estimadas pelo modelo de extensão lenta (linhas coloridas) com a evolução P-T do MCC de Ruby Mountain – East Humboldt Range (linha preta; retirado de Rey et al., 2009b). **b)** Comparação das trajetórias P-T estimadas pelo modelo de extensão rápida (linhas coloridas) com a evolução P-T do MCC de Shuswap (linha preta; retirado de Rey et al., 2009b).

1.3.4 Ambientes tectônicos de formação de complexos de núcleo metamórfico continentais

Complexos de núcleo metamórfico ocorrem em uma ampla variedade de ambientes tectônicos. A extensão litosférica que resulta na formação desses complexos ocorre em regimes convergentes, quando relacionada a colapsos orogênicos e regiões de retroarco, e em regimes transcorrentes. É importante salientar que Platt et al. (2015) não considera que complexos metamórficos exumados por meio de falhas transcorrentes se enquadrem na definição de complexo de núcleo metamórfico.

1.3.4.1 Margens convergentes

O colapso gravitacional da crosta continental ocorre quando há diminuição do contraste da energia potencial gravitacional que é acumulada durante a deformação litosférica (Rey et al. 2001). Isso é, quando há o decréscimo dos esforços tectônicos e da rigidez crustal a carga vertical de uma crosta espessa pode levá-la ao colapso. O regime

extensional é devido ao excesso de energia potencial gravitacional que afasta o material crustal da litosfera deformada (Rey et al., 2001).

O exemplo clássico de uma região que foi submetida a um regime extensional devido ao colapso orogênico é a Cordilheira Norte-Americana (Figura 8a). Tal região, mencionada nos tópicos anteriores, tem sido o maior laboratório natural para o entendimento da dinâmica dos MCCs. Esse orógeno é marcado pela ampla ocorrência de MCCs ao longo de sua extensão e é segmentado em três faixas distintas: setentrional, central e meridional (Figura 8b). Essas regiões apresentam variações quanto à idade de extensão (idades mais novas na região meridional), magnitude da exumação (ocorre mais exumação na faixa setentrional) e quantidade de material fundido (há aumento de fusão do sul para o norte; Whitney et al., 2013).

O regime extensional em regiões de retroarco é associado com a retração da placa subductante e com o movimento relativo entre as placas tectônicas. Os complexos de núcleo metamórfico formados nesse contexto tectônico ocorrem relacionados à rápida retração da placa em zonas de subducção.

A região do Mar Mediterrâneo possui domínios extensionais relacionados ao contexto de retroarco dos segmentos orogênicos do sistema Alpino (Figura 8b). Esse evento extensional é responsável pela abertura dos mares Tirreno, Egeu e Alborão. Nessas localidades há amplo registro de complexos metamórficos exumados por meio de zonas de cisalhamento regionais extensionais (e.g. Lister et al. 1984; Vignaroli et al. 2009; Behr e Platt, 2012).

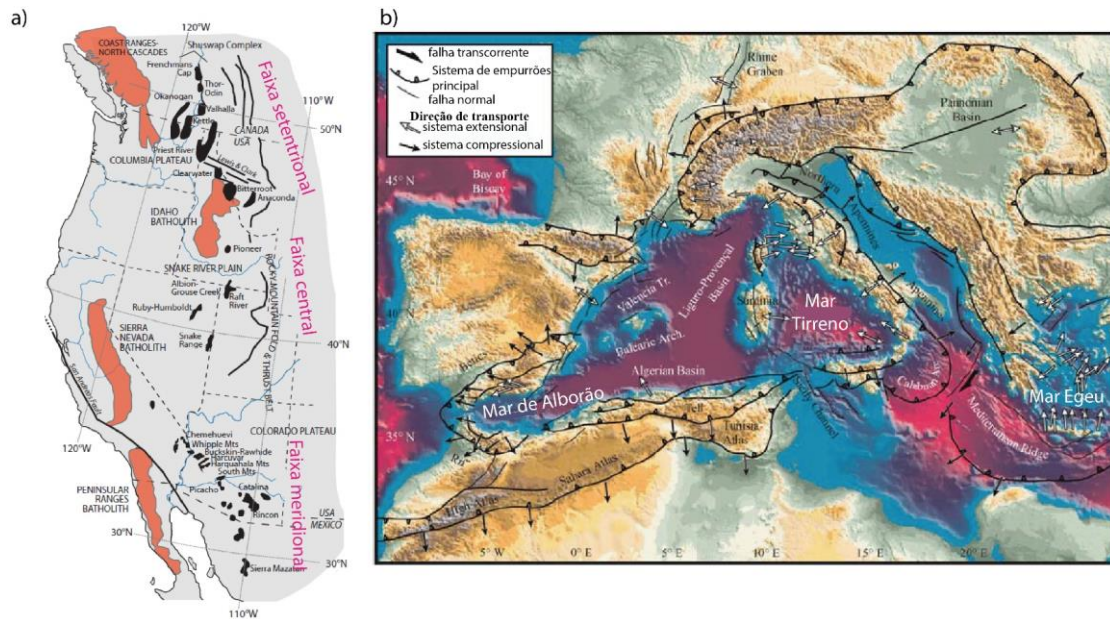


Figura 8. a) Mapa esquemático com os complexos de núcleo metamórfico da Cordilheira Norte-Americana (retirado de Whitney et al., 2013). **b)** Mapa tectônico do Mar Mediterrâneo mostrando os principais segmentos do sistema Alpino e suas direções de transporte tectônico (retirado de Vignaroli et al. 2009).

1.3.4.2 Regimes transcorrentes

Modelos tectônicos têm sido propostos para explicar a exumação de domos gnáissicos ao longo do sistema transcorrente de Négede no Escudo Árabe-Núbio (Figura 9a). Apesar de não se enquadrarem nos critérios propostos por Platt et al. (2015), a gênese desses domos tem sido atribuída a modelo de complexo de núcleo metamórfico transcorrente por diversos autores (e.g. Fritz et al., 1996; Neumayr et al., 1998; Meyer et al., 2014).

Meyer et al. (2014) propuseram um mecanismo pelo qual as rochas da crosta inferior podem ser exumadas ao longo de um sistema transcorrente de escala crustal sem a necessidade do afinamento crustal. Para tal, usou o Complexo Qazaz como objeto de estudo. O desenvolvimento desse complexo se daria por meio de uma curva de alívio na zona de cisalhamento transcorrente, o que permitiria o soerguimento da crosta média/inferior (Figura 9b).

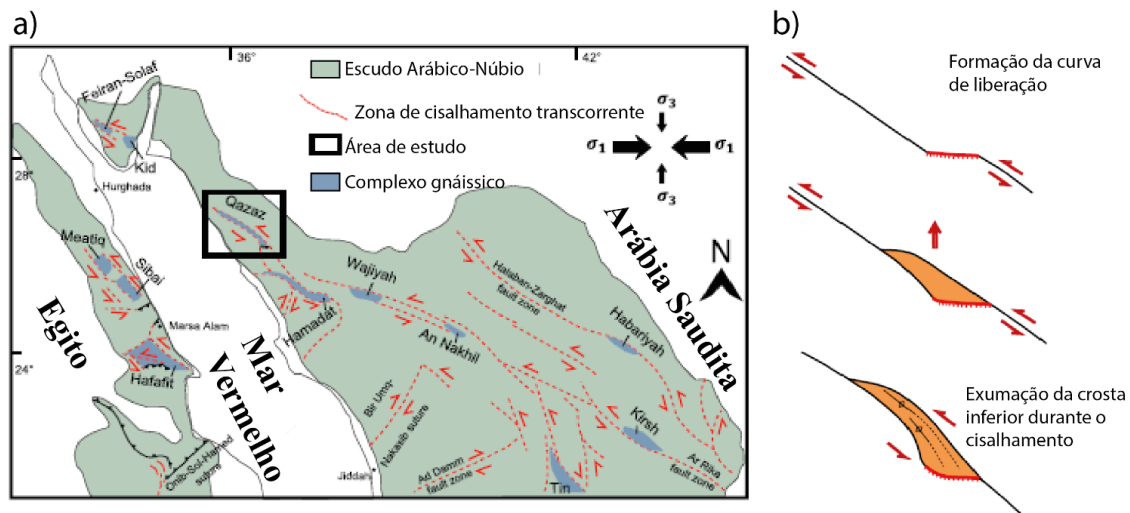


Figura 9. a) Mapa esquemático com os complexos gnáissicos do Escudo Árabe-Núbio (retirado de Meyer et al., 2014). **b)** Sequência de desenvolvimento do complexo Qazaz ao longo da zona de cisalhamento transcorrente de Qazaz (retirado de Meyer et al., 2014).

1.4 Evolução do conhecimento do Complexo Uruaçu e unidades adjacentes

As primeiras referências sobre a geologia da região centro-norte do estado de Goiás datam do século XIX. O naturalista Francis de Castelnau, em sua passagem pelo Brasil entre os anos 1842 e 1845, relata a ocorrência de granitos, itacolomitos, cangas e xistos no trajeto entre Goiás Velho e Porto Nacional (Castelnau, 1949). No final desse século Eugenio Hussak em Cruls (2012) desenvolve a primeira evolução geológica para o Planalto Central no estado de Goiás. O autor distingue duas formações geológicas: uma mais antiga composta por uma associação de quartzitos e xistos e outra, atribuída ao Paleozoico, composta por uma intercalação de arenito, xisto e calcário.

Os mapeamentos geológicos iniciais no contexto geológico do Complexo Uruaçu ocorreram nas décadas de 60 e 70. Barbosa et al. (1969) atribuíram todas as rochas desse contexto ao Grupo Araxá. Posteriormente, Ribeiro Filho et al. (1978) detalharam a geologia da região de Pilar-Uruaçu-Mara Rosa individualizando as rochas entre Grupo Araxá, Complexo Basal Goiano e Associação Metamórfica de Pilar de Goiás (Figura 10a). Esta é composta por uma sequência de paragneisses, xistos, quartzitos, mármore e rochas vulcânicas básicas e ultrabásicas; essa é a designação para o conjunto de gnaisses, granulitos e migmatitos; e aquela refere-se a uma sequência de rochas metassedimentares composta essencialmente por quartzitos e xistos.

O debate sobre o enquadramento geológico da região perdurou nos anos seguintes. As rochas de natureza vulcanossedimentar da região tiveram várias interpretações ao longo da década de 80. Tais rochas foram correlacionadas aos *greenstonebelts* de Goiás

(Machado e Oliveira, 1981); às sequências vulcanossedimentares de Juscelândia, Palmeirópolis e Indaianópolis (Ribeiro Filho e Lacerda Filho, 1985); e à sequência vulcanossedimentar de Mara Rosa (Ribeiro Filho, 1981; Cortês et al. 1987). Sendo a última hipótese a que perdurou nas décadas seguintes.

Já o conjunto de gnaisses e granulitos foi interpretado por Barreto Filho (1992) como fragmento dos complexos máficos-ultramáficos de Barro Alto, Niquelândia e Canabrava e recebeu a denominação de Maciço básico-ultrabásico Água Branca. Posteriormente, Lacerda Filho et al., (1999) delimitaram a unidade em mapa e a renomearam de Complexo Granulítico Uruaçu (Figura 10b). Oliveira et al. (2006) estabeleceram idade neoproterozoica para o complexo baseando-se na hipótese apresentada por Barreto Filho (1992).

O desenvolvimento de trabalhos geocronológicos proporcionou um grande avanço na contextualização geológica da região. Os dados isotópicos da Sequência Vulcanossedimentar Mara Rosa apresentados por Pimentel et al., (1997) e Oliveira et al., (2016) associam essa unidade a um sistema de arcos de ilha neoproterozoico formado entre 850 e 900 Ma. Kuyumjian et al., (2004) e Oliveira et al (2006) apresentaram uma nova sequência vulcanossedimentar paleoproterozoica denominada Sequência Campinorte, individualizando-a das sequências neoproterozoicas do Arco Magmático Mara Rosa (Figura 10c). Datações U-Pb em zircão revelam idades de cristalização em torno de 2.17 Ga para rochas metavulcânicas e graníticas dessa unidade (Pimentel et al. 1997; Giustina et al. 2009a).

Giustina et al. (2009b) apresentaram os primeiros dados isotópicos do Complexo Uruaçu. As idades U-Pb em zircão nos ortognaisses e anfibolitos estão entre 690 Ma e 650 Ma, sendo essas representativas da cristalização magmática. Já o sobrecrecimento metamórfico nos zircões indica idade próxima a 650 Ma. Esses dados reafirmam a inserção do complexo no Neoproterozoico proposta por Oliveira et al. (2006), entretanto descartam sua correlação com os complexos máficos-ultramáficos de Barro Alto, Niquelândia e Canabrava. Datações U-Pb em zircão em paragranelito e granulito máfico revelaram idades de pico metamórfico entre 2.08 Ga e 2.11 Ga, por conseguinte, associando o evento granulítico ao Arco Campinorte paleoproterozoico e não mais ao Complexo Uruaçu (Cordeiro et al. 2014; Cordeiro e Oliveira, 2017).

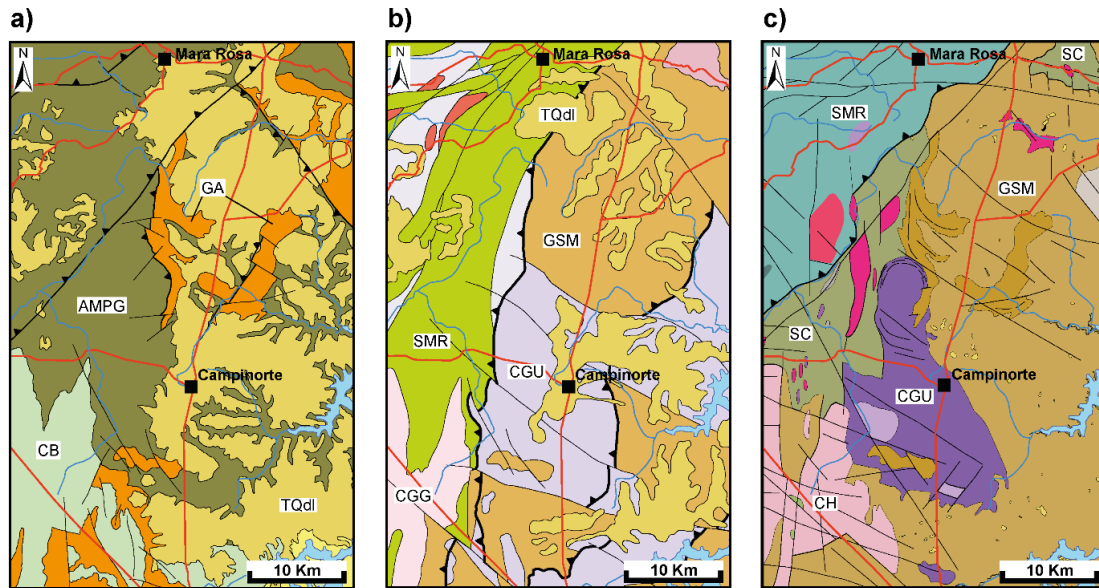


Figura 10. Evolução dos mapas geológicos na região de Campinorte-GO. **a)** Ribeiro Filho et al. 1978 (AMPG = Associação Metamórfica Pilar de Goiás, CB = Complexo Basal, GA = Grupo Araxá, TQdl = Coberturas detrito-lateríticas). **b)** Lacerda Filho et al. 1999 (CGG = C Complexo Granito-Gnáissico, CGU = Complexo Granulítico Uruaçu, GSM = Grupo Serra da Mesa, SMR = Sequência Mara Rosa). **c)** Oliveira et al. 2006 (CGU = Complexo Granulítico Uruaçu, CH = Complexo Hidrolina, GSM = Grupo Serra da Mesa, SC = Sequência Campinorte, SMR = Sequência Mara Rosa).

Atualmente, a geologia da região ainda é alvo de questionamentos em relação a sua gênese e natureza. O termo Maciço de Goiás tem sido empregado para nomear a área composta pelos Bloco Arqueano de Goiás e terrenos paleoproterozoicos exposta entre as falhas Rio dos Bois e Rio Maranhão (Valeriano, 2008; Fuck et al. 2017). O principal modelo, ilustrado na Figura 11a, considera esse compartimento como um microcontinente alóctone acrescido junto a borda oeste do Cráton São Francisco durante os últimos estágios da orogenia brasileira (Dardenne, 2000; Pimentel et al. 2000; Valeriano, 2008; Fuck et al. 2017). Dados gravimétricos e sísmicos sugerem que a Falha do Rio Maranhão seja uma zona de sutura entre o Maciço de Goiás e o cráton, reforçando tal hipótese (Assumpção et al. 2004; Berrocal et al. 2004).

Em contrapartida, Cordeiro e Oliveira (2017) apresentaram a hipótese na qual o Maciço de Goiás seria um terreno acrescido ao Cráton São Francisco durante o Paleoproterozoico (Figura 11b). Nessa proposta o maciço englobaria os domínios Crixás-Goiás; Campinorte, Cavalcante-Arrais e Almas-Conceição. O caráter intracontinental da Falha do Rio Maranhão sugerido por D'el Rey Silva et al. (2008) e Reis et al. (2020), bem como os dados geocronológicos apresentados por Cordeiro et al. (2014) e Cordeiro e Oliveira (2017) dão sustentação para esse argumento.

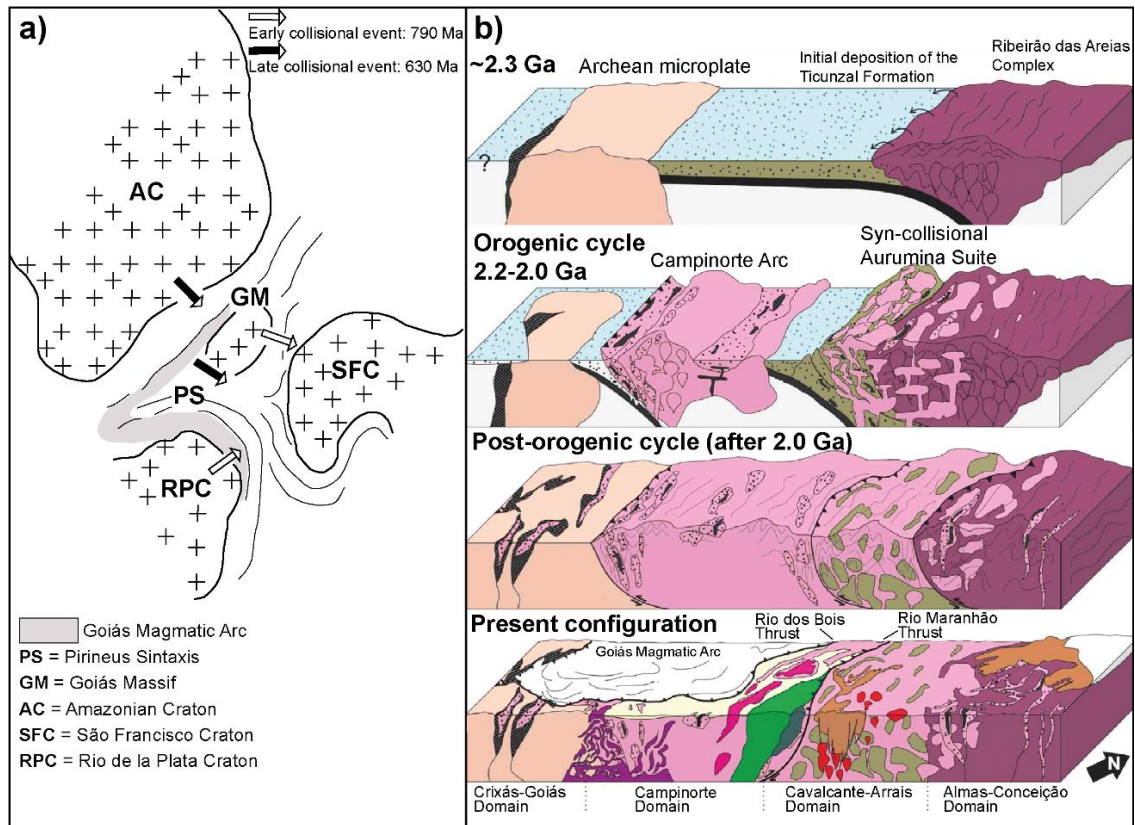


Figura 11. Diferentes modelos de evolução tectônica para o Maciço de Goiás. **a)** Modelo que considera o maciço como um microcontinente alóctone acrescido ao Cráton São Francisco durante o Neoproterozoico (retirado de Dardenne, 2000). **b)** Modelo no qual o maciço já fazia parte da margem ocidental do cráton durante a orogenia brasileira (retirado de Cordeiro e Oliveira, 2017).

1.5 Contexto geológico

A área de estudo está situada no Orógeno Brasília, um importante segmento neoproterozoico pertencente à Província Tocantis e localizado na margem oeste do Cráton São Francisco (Almeida et al., 1981; Brito Neves et al. 1999; figura 12a). Sua formação ocorreu em resposta à colisão dos crátons São Francisco, Paranapanema (Rio de La Plata) e Amazônico (Dardenne, 2000; Pimentel, 2016).

O orógeno é dividido de leste a oeste nos seguintes compartimentos tectônicos: (1) Zona Cratônica que corresponde à bacia de antepaís; (2) Zona Externa o qual compreende sequências de margem passivas empurradas sobre a zona cratônica; (3) Zona Interna constituída por sequências metassedimentares sin-orogênicas e por terrenos metamórficos de alto grau e (4) Arco Magmático de Goiás caracterizado por magmatismo calci-alcalino juvenil neoproterozoico que ocorreu entre 900-800 Ma, associado a um sistema de arcos de ilha e posteriormente entre 670-600 Ma, associado a um sistema de

arco continental (Figura 12b; Fuck et al. 1994; Valeriano et al. 2008; Pimentel, 2016; Fuck et al. 2017).

A Sintaxe dos Pirineus segmenta o orógeno em duas faixas com direções distintas denominadas Faixa Brasília Norte (FBN) e Faixa Brasília Sul (FBS; Araújo Filho, 2000; Figura 12b). Aquela apresenta direção NNE e possui vergência para sudeste enquanto essa possui direção SSE e tem vergência para leste.

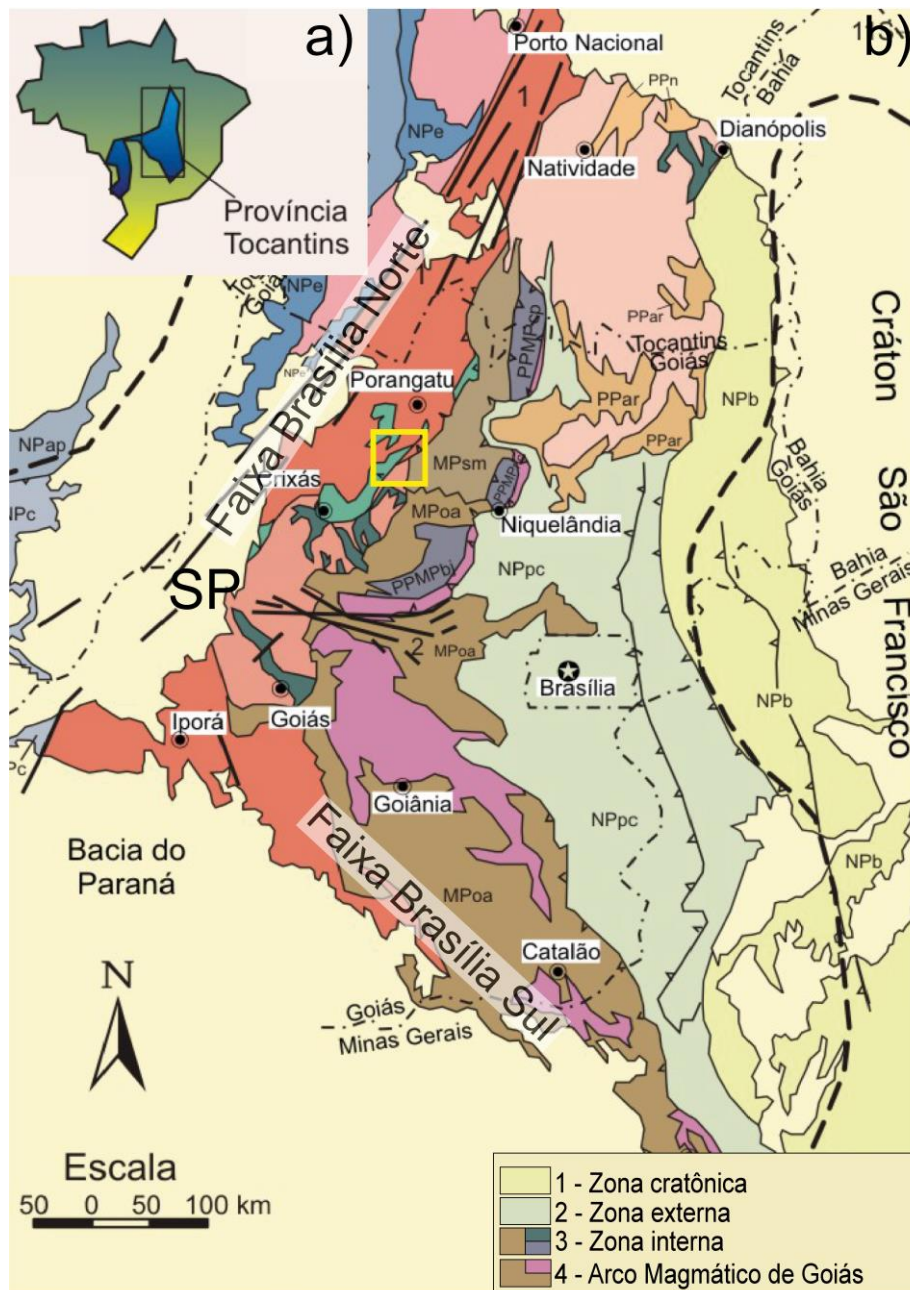


Figura 12. a) Mapa do Brasil com destaque para a Província Tocantins (modificado de Pimentel et al., 2004). **b)** Mapa geológico simplificado do Orógeno Brasília com destaque em amarelo para a área de estudo (modificado de Pimentel et al., 2004).

O Complexo Uruaçu é um terreno metamórfico neoproterozoico (690-650 Ma), exposto em meio a rochas metassedimentares do Grupo Serra da Mesa, localizado na porção centro-sul da Faixa Brasília Norte (Figura 13; Oliveira et al. 2006; Giustina et al. 2009b; Cordeiro et al. 2014, Cordeiro e Oliveira, 2017). As principais rochas encontradas no complexo são orto e paragnaisses. Os ortognaisses de composição quartzo diorítica são os litotipos mais comuns da área e, em geral, estão migmatizados e deformados. Associado aos ortognaisses ainda ocorrem rochas máficas e ultramáficas.

O embasamento desse terreno é formado pelas rochas paleoproterozoicas (2.19 a 2.07 Ga) do Arco Campinorte (Cordeiro et al. 2014, Cordeiro e Oliveira, 2017). Esse arco é constituído pelos metatonalitos e metagranitos da Suíte Pau de Mel, pela Sequência Metavulcanossedimentar Campinorte e por orto- e paragranulitos (Giustina et al., 2009a, Cordeiro et al. 2014, Cordeira e Oliveira, 2017).

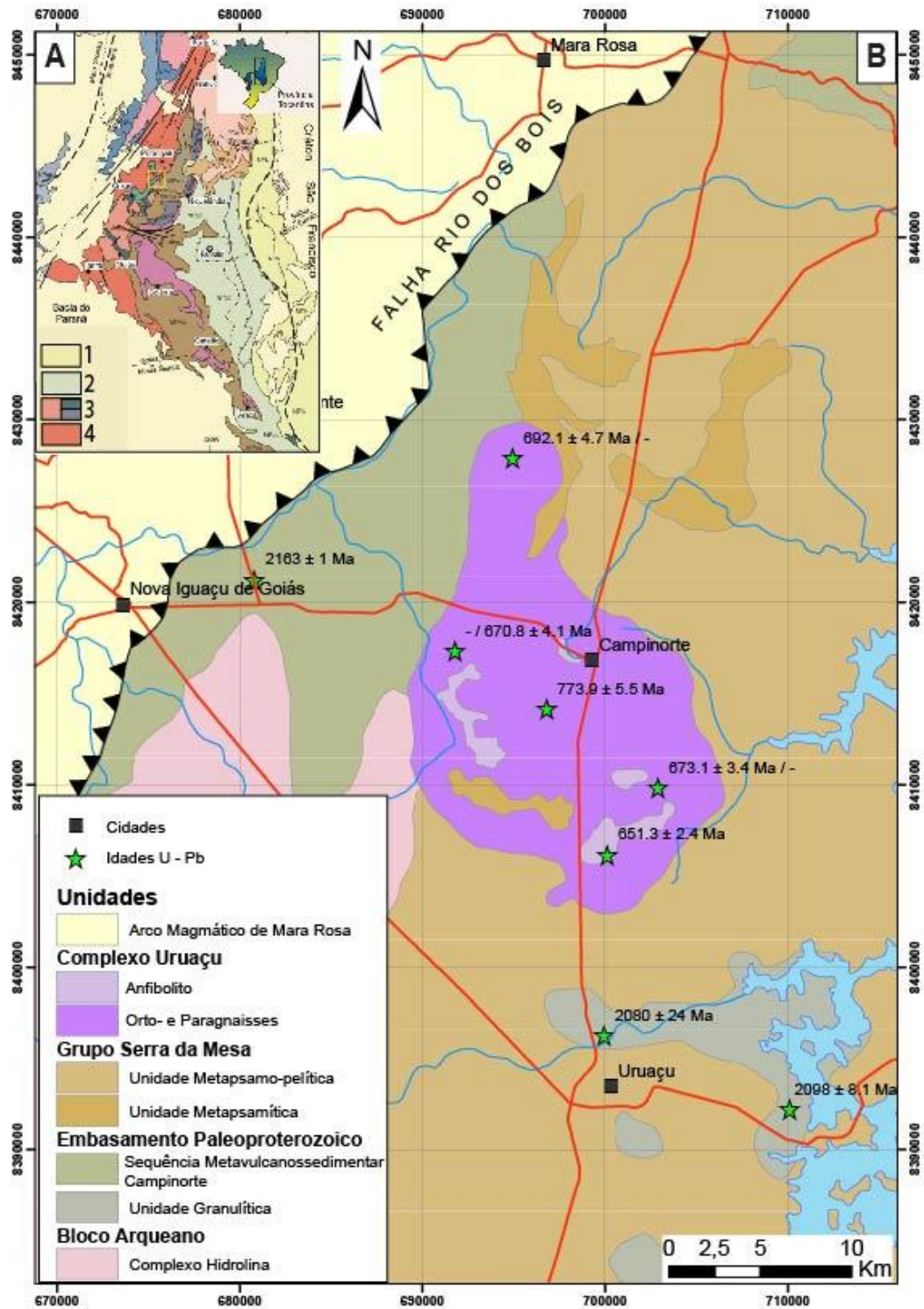


Figura 13. Mapa geológico do Complexo Uruaçu e unidades adjacentes com dados isotópicos U-Pb da área de estudo (compilado e modificado de Oliveira et al. 2006, Giustina et al. 2009b e Cordeiro et al. 2014)

1.6 Escopo do estudo

Conforme previsto no regulamento do Programa de Pós-Graduação em Geologia (Título VI, Art. 35) a dissertação de mestrado está estruturada em forma de artigo intitulado “TECTONIC SETTING AND EVOLUTION OF THE URUAÇU COMPLEX AND SERRA DA MESA GROUP, NORTHERN BRASÍLIA BELT: INSIGHTS FROM METAMORPHIC MODELLING AND U-PB DETRITAL ZIRCON PROVENANCE”. O manuscrito será submetido para publicação em periódico estrangeiro com corpo editorial.

CAPÍTULO 2

MANUSCRITO

2 TECTONIC SETTING AND EVOLUTION OF THE URUAÇU COMPLEX AND SERRA DA MESA GROUP, NORTHERN BRASÍLIA BELT: INSIGHTS FROM METAMORPHIC MODELLING AND U-PB DETRITAL ZIRCON PROVENANCE

ABSTRACT

The Uruaçu Complex is a Neoproterozoic domed-shaped metamorphic terrain (690-650 Ma) exposed underneath the supracrustal rocks of the Serra da Mesa Group in the central portion of the Northern Brasília Belt between the mafic-ultramafic complexes and the Mara Rosa Magmatic Arc. In this study, we combine field data, metamorphic modelling, and U-Pb detrital zircon provenance to constrain the tectonic setting and the evolution of the Uruaçu Complex and its surrounding rocks from the Serra da Mesa Group. The main rocks from the Uruaçu Complex are orthogneisses with tonalitic to granitic composition, and paragneisses. The amphibolites occur as scattered bodies through the complex. The pseudosection from the paragneiss and the amphibolite coupled with conventional geothermobarometers constrains the metamorphic peak at ~7 kbar and 700°C with retrogressive metamorphism at ~ 4.42 kbar and 551°C. The Serra da Mesa Group is mainly composed of quartzites and schist with minor occurrences of marble. The pseudosection modelling based on the garnet compositional profile predicts a *P-T* path from 4.3 kbar and 547°C to 5.9 kbar and 616°C for the garnet schist from the Serra da Mesa Group. In addition, normal structures were observed cross-cutting the regional foliation implying in preliminary evidence for extensional tectonics in the Northern Brasília Belt. The U-Pb detrital zircons collected from the Serra da Mesa Group suggest that the sediments were deposited in three different basins: (1) Paleo-Mesoproterozoic intracontinental extensional basin which can be the lateral correlative of the Traíras Group; (2) Neoproterozoic back-arc basin in the margins of the Mara Rosa Magmatic Arc, and (3) Neoproterozoic foreland basin also associated with the eastern portion of the Santa Terezinha Sequence. Combining these new data, we proposed that the Uruaçu Complex underwent a diapiric ascent during the collisional stage of the Brasília Orogen.

Keywords: Uruaçu Complex; Serra da Mesa Group; Metamorphic modelling; U-Pb detrital zircon provenance; Brasília Orogen

2.1 Introduction

A gneiss dome is a metamorphic terrain exhumed from the middle to lower continental crust which is mantled by supracrustal data (Eskola, 1948; Teyssier and Whitney, 2002). Such domes have a spatial and temporal distribution, occurring in various tectonic settings from Archean to present-day orogens (e.g., Liu and Wei, 2018; Chen et al., 2022). Furthermore, their formation can be explained by several mechanisms such as diapirism, superposition of two folding events, and thrust-duplex development (Makovsky et al. 1999; Folwer and Osman, 2001; Teyssier and Whitney, 2002; Yin, 2004). Specifically in extensional settings, many gneiss domes were later reinterpreted as metamorphic core complexes, since the recognition of the low-angle detachments faults in the role of their exhumation (Davis and Lister, 1988; Vanderhaeghe et al. 1999)

In this broad and complex context, the existence of a metamorphic core complex within the Precambrian Brasília Orogen was briefly discussed by Cordeiro et al. (2014) and Winge (1995), who associated this structure with the Uruaçu Complex and the Anápolis-Itaçu Complex, respectively. The Uruaçu Complex, the focus of this study, is a Neoproterozoic metamorphic terrain (690-650 Ma) exposed within the supracrustal rocks of the Serra da Mesa Group, located in the central portion of the Northern Brasília Belt.

In this way, this study presents a metamorphic and U-Pb on zircon provenance investigation of the Uruaçu Complex and its adjacent units, aiming to enhance the understanding of their genesis and evolution, as well as its regional implications within the tectonic evolution of the Northern Brasília Belt.

2.2 Regional geology and metamorphic record of Brasília Orogen

The Tocantins Province, located in central Brazil (Figure 14a), is a Neoproterozoic orogenic system formed during the collision of the Amazon, Paranapanema (Rio de La Plata), and São Francisco cratons during the assembly of the West Gondwana (Almeida et al., 1981; Brito Neves et al., 1999). It is comprised of three mobile belts, namely: Araguaia (northern branch, bordering the east margin of Amazon Craton), Paraguay (western branch alongside the south margin of Amazon Craton), and Brasília (eastern segment, developed on the west side of São Francisco Craton) (Figure 1a).

The Brasília Orogen extends along the entire western and southwestern margins of the São Francisco Craton, limited to the northwest and southwest by the Araguaia Belt

and the Paranapanema Craton (Figure 14b). The Pirineus Sintaxis, an important ENE lineament, structurally divides the orogen into two segments called the Northern Brasília Belt and the Southern Brasília Belt (Figure 14b; Araújo Filho, 2000). The former has an NNE direction and verges to SE, while the latter has an SSE direction and verges eastwards. Some authors (Brito Neves et al. 1999; Fuck et al. 2017) consider the southernmost part of the orogen, which surrounds the southern end of the São Francisco Craton, as a third segment (Figure 1c). Here, we consider the three segments subdivision, nominated here as northern, central, and southern belts (Figure 14b), agreeing with the proposal of Fuck et al. 2017).

Moreover, according to the intensity of metamorphism and deformation, the Brasília Belt is also subdivided into four tectonic domains (Figure 14b): (1) the Cratonic zone is the easternmost region which corresponds to the foreland basin of the orogen; (2) the External zone, comprising the passive margin sequences and the Paleo- to Mesoproterozoic rift-sag sequences; (3) the Internal zone which encompasses the syn-orogenic basins and the high-grade metamorphic terranes; and (4) the Goiás Magmatic Arc characterized by a Neoproterozoic juvenile calc-alkaline magmatism associated with volcano-sedimentary sequences (Dardenne, 2000; Valeriano et al., 2008; Pimentel, 2011).

The magmatic arc and, principally the internal zone, has been the spotlight of metamorphic studies in the Brasília Orogen. Overall, *P-T* estimates along these domains show that the orogen experienced two types of very distinct metamorphism: under high to ultra-high temperature conditions – mainly along the northern and central segments – and with occurrences of high-pressure rocks restricted to the southern segment (Junges et al., 2002; Moraes et al., 2002; Fumes et al., 2019). High-pressure conditions have also been reported in the Central Segment along the Araxá Group, where the geothermal gradient is below the Barrovian-type metamorphism (Silva et al., 2019; Sales et al., 2021).

Regarding the ages of metamorphism, three groups have been distinguished. To the south of Pirineus Sintaxis, the metamorphic ages only point out the continental collision episode (650-630 Ma, Moraes et al., 2002; Piuzana et al., 2003a; Baldwin et al., 2005; Baldwin & Brown, 2008). Ages of retrogressive metamorphism are found, in general, between 610-590 Ma (Cioffi et al., 2019; Simões et al., 2022). Older ages (750-790 Ma, Ferreira Filho et al., 1994; Junges et al., 2002) are registered on the rocks from the Northern Brasília Belt (Figure 15b) and related to the first accretionary phase, involving Mara Rosa island arc development and collision with the São Francisco Craton (Pimentel et al., 1997; Junges et al., 2002).

The northern segment

In the northern segment of the Brasília Orogen, two main metamorphic events are recognized. U-Pb zircon and Sm-Nd isochron ages from rocks of Barro Alto and Niquelândia mafic-ultramafic layered complexes constrain the first event between ca.750 Ma and ca.790 Ma (Figure 15b; Ferreira Filho et al., 1994; Pimentel et al., 2004; Moraes et al., 2006; Giustina et al., 2011). These complexes underwent amphibolite to granulite metamorphism with, locally, UHT assemblages in felsic granulites lenses within Barro Alto Complex which reached temperatures up to 1050°C (Figure 15a; Ferreira Filho et al., 1998; Moraes & Fuck, 2000). Adjacent to the Barro Alto Complex, the Juscelândia metavulcanosedimentary sequence rocks also record the same Neoproterozoic metamorphism, however under amphibolite facies peak conditions (Figure 15a, 15b; Moraes and Fuck, 1999; Moraes et al., 2006).

Westwards from the mafic-ultramafic complexes, Sm-Nd mineral isochrons ages from garnet-bearing metasedimentary rocks of Mara Rosa Arc indicate not only an older metamorphic event at ca. 730-760 Ma but also a younger one at ca. 600-610 Ma (Figure 15b; Junges et al., 2002). The former is characterized by a lower thermal gradient and is likely coeval to the high-grade metamorphism of the Barro Alto and Niquelândia complexes (Figure 15b; Junges et al., 2002). The latter is characterized by a higher thermal gradient and is associated with the ocean closure and the collisional event on the Brasília Belt (Figure 15; Junges et al., 2002).

In the region between the mafic-ultramafic complexes and the Mara Rosa Arc occur the metasedimentary rocks of the Serra da Mesa Group (Figure 14c). In this area, despite the lack of *P-T* quantitative estimations, a series of garnet-bearing schist are described in this group constraining the metamorphic imprint to greenschist facies (Oliveira et al, 2006). Still in this segment, the Neoproterozoic Uruaçu Complex outcrops among the rocks of the Serra da Mesa Group (Figure 16). It is formed by a set of gneisses and amphibolites and its metamorphic conditions remain unconstrained due to the lack of metamorphic investigations in the complex, but Giustina et al (2009a) interpreted the complex as a high-grade metamorphic terrain.

The Central Segment

In the central segment, ultra-high temperature assemblages constrain peak conditions for the granulitic units from Anápolis-Itaçu Complex up to 1050°C and 1 GPa around 630-650 Ma (Figure 15a, 15b). Surrounding the Anápolis-Itaçu Complex, the metapelitic rocks from the Araxá Group were affected by greenschist to amphibolite metamorphism with a peak at 610°C and 0.95 GPa (Figure 15a; Navarro et al., 2009; Silva et al., 2019; Sales et al., 2021). Despite the lack of metamorphic age constraints for this unit, tonalite intrusions in these rocks dated at ca. 638 Ma and maximum depositional age defined at ca. 643 Ma establish that deposition and metamorphism occurred between this period, which is consistent with the collisional event of the Brasília Orogen (Piuze et al., 2003b).

Still, in the central segment, gneisses from the Arenópolis Arc record amphibolite facies condition at 628°C and 0.86 GPa, and mafic-ultramafic intrusive bodies related to the Mangabal Complex indicate metamorphic conditions near granulite facies at 750°C and 0.85 GPa (Figure 15a; Navarro et al., 2009; Augustin & Giustina, 2019).

The Southern Segment

The southern segment of the Brasília belt (Figure 14c) comprises a series of eastward-verging Neoproterozoic nappe systems related to the convergence of the Paranapanema Craton against the São Francisco Craton passive margin (Campos Neto, 2000). The Socorro-Guaxupé Nappe is a Neoproterozoic allochthonous terrane associated with the Paranapanema plate arc magmatic (Campos Neto, 2000; Campos Neto & Caby, 2000). This domain consists of gneiss-migmatitic rocks that reached UHT and high-pressure granulite conditions between ca. 593 Ma and ca. 628 Ma (Figure 15a; Del Lama et al., 2000; Rocha et al., 2017; Motta et al., 2021).

Structurally below the Socorro-Guaxupé Nappe is the Andrelândia Nappe system (Figure 14c), consisting of metasedimentary rocks metamorphosed under amphibolite to high-P granulite conditions peaking at 871°C and 1.26 GPa at ca. 617 Ma (Campos Neto et al., 2010; Coelho et al., 2017). The Pouso Alegre Complex, a Paleoproterozoic terrain between the Socorro-Guaxupé and Andrelândia nappes, is reworked on this metamorphic event recording conditions of 720 °C and 1.34 GPa at ca. 603 Ma (Tedeschi et al., 2017). The lowest structural level is attributed to the Carrancas Nappe system, related to the São Francisco Craton passive margin (Campos Neto et al., 2010). This unit is mainly composed of metapelites metamorphosed under amphibolite to eclogite with a maximum pressure of 1.4 GPa at a temperature of 630 °C at ca. 632 Ma (Fumes et al., 2019).

This contribution aims to address the knowledge gap in metamorphic investigations in this segment of the Northern Brasília Orogen internal zone, particularly focusing on the Uruaçu Complex and its adjacent rocks. The objective is to provide new insights into the metamorphic evolution of these rocks and discuss the obtained results in the broader context of the Brasília Orogen.

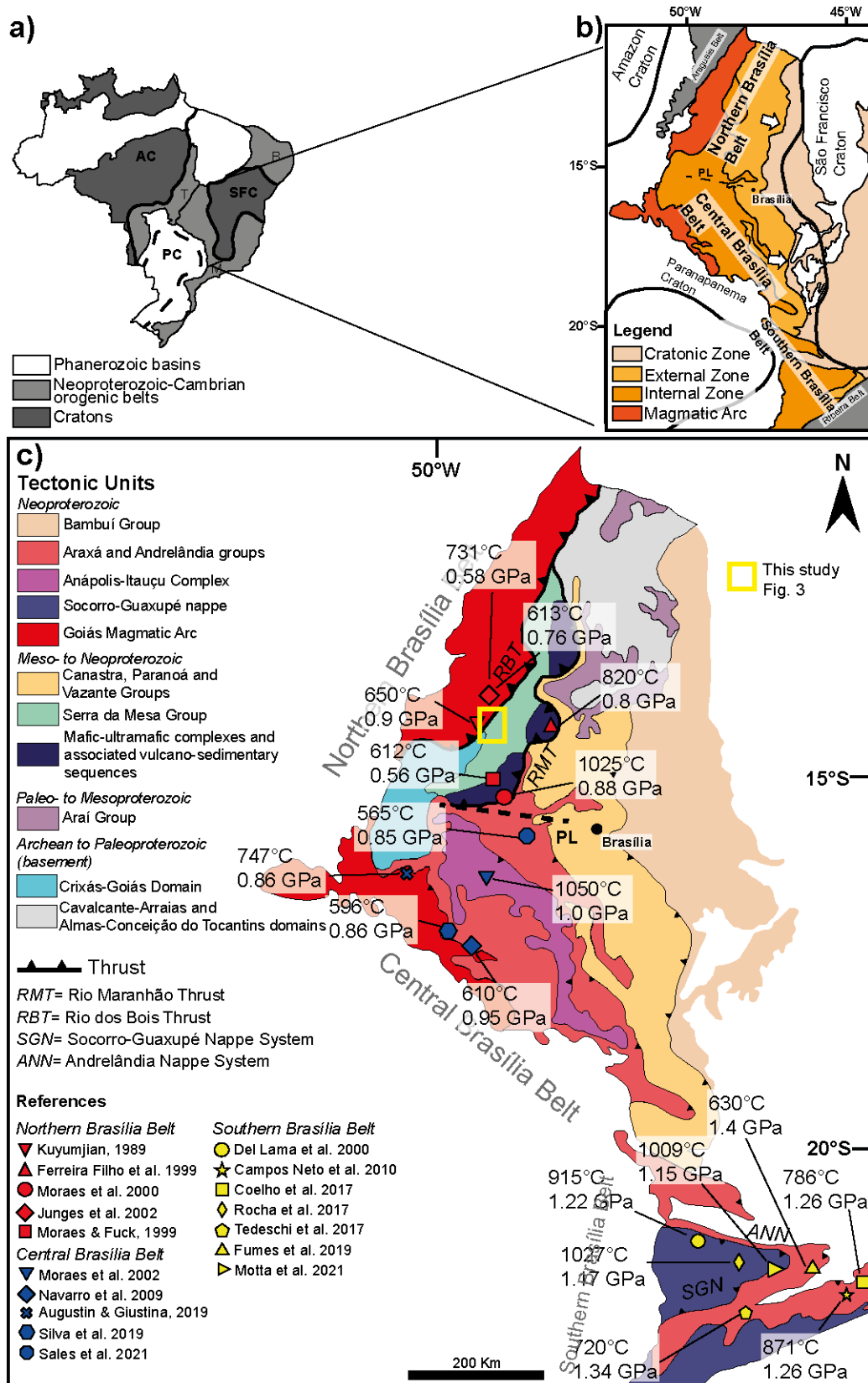


Figura 14. a) Brazilian Structural Provinces (T=Tocantins; B=Borborema; and M=Mantiqueira). **b)** Brasília Orogen tectonic domains. **c)** Geological map of Brasília Orogen with compiled P-T data (modified from Valeriano et al. 2008).

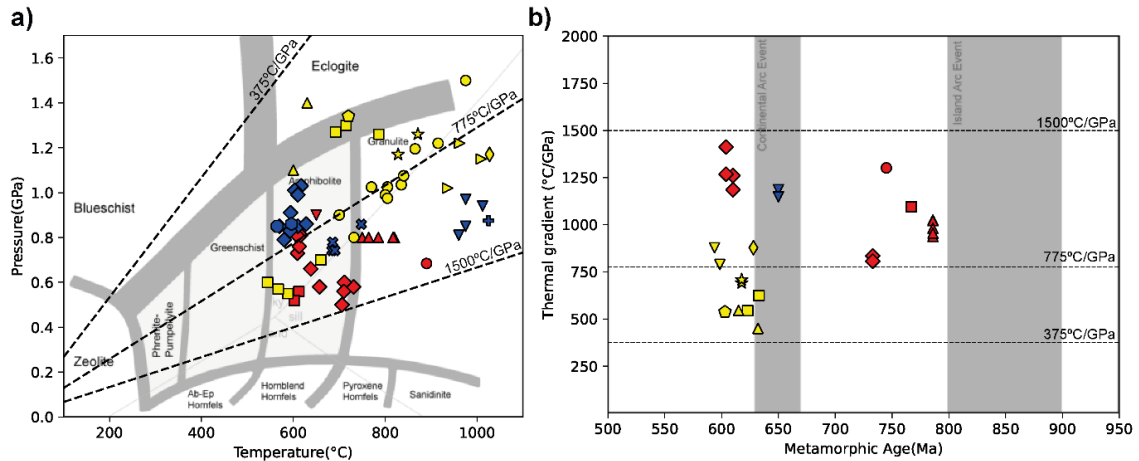


Figure 15. a) Metamorphic P-T conditions for Brasília Orogen. **b)** Thermal gradient (°C/GPa) vs. metamorphic age plot for Brasília Orogen metamorphic rocks.

2.3 Previous studies on the Uruaçu Complex and the surrounding area

Previous work on the Uruaçu Complex interpreted it as a western fragment of the mafic-ultramafic complexes of Barro Alto, Niquelândia, and Canabrava (Figure 14) based on magnetic similarities in airborne magnetic survey data (Barreto Filho, 1992). Subsequent isotopic data from Giustina et al. (2009a) established a crystallization age of ca. 690-650 Ma for the orthogneisses of the complex, distinguishing them from the Tonian mafic-ultramafic complexes.

Initially considered a granulitic terrain because of scattered occurrences of paragneisses with hercynite+quartz, the Uruaçu Complex (Figure 16) was interpreted as the Neoproterozoic metamorphic core of the orogen, along with the Anápolis-Itaçu Complex (Lacerda et al. 1999; Oliveira et al. 2006; Giustina et al., 2009a; Pimentel et al. 2016). However, geochronological data of the high-grade metamorphism resulting in 2100 Ma in the paragneiss unit indicated it as belonging to an older basement, the Campinorte Domain (Figure 16). The complex is then reduced to its current area, where occurs a variety of orthogneisses with tonalitic to granitic compositions, paragneisses, which are often migmatized, and banded amphibolites (Figure 16, Oliveira et al., 2006; Giustina et al., 2009a; Cordeiro et al., 2014).

The Campinorte Domain (Figure 16) is one of the Paleoproterozoic terrains that constitutes the Goiás Massif together with the Crixás-Goías, Cavalcante-Arrais, and Almas-Conceição do Tocantins domains (Cordeiro et al., 2014; Cordeiro and Oliveira, 2017). Rocks from the volcano-sedimentary Campinorte Sequence, Pau de Mel Suite, and a granulitic unit compound this domain which is representative of a Paleoproterozoic

crustal accretion episode in a magmatic arc system (Giustina et al., 2009b; Cordeiro et al., 2014).

The metasedimentary rocks covering the Campinorte Domain, and the Uruaçu Complex are currently attributed to the Serra da Mesa Group (Figure 16; Marini et al., 1984; Dardenne, 2000; Oliveira et al., 2006). Rocks from this group in the study region were first interpreted as belonging to the Araxá Group by Barbosa et al. (1969). However, after Marini et al. (1977), they were assigned to the Serra da Mesa Group principally due to occurrences of carbonate sediments. Nowadays, the group is correlated with the Araí Group post-rift phase represented by the Traíras Formation (Marini et al., 1984; Dardenne, 2000; Marques, 2009). This unit represents a Paleo- to Mesoproterozoic aborted rift that registers four main phases: (1) pre-rift phase; (2) rift phase; (3) transition phase, and (4) post-rift phase (Tanizaki et al., 2015). Martins-Ferreira et al. (2018) consider the Traíras Formation as an intracontinental sag-type basin and classify it as a distinct group apart from the Araí Group with maximum depositional age of ca. 1543 Ma.

2.4 Geology of the study area

The study area lies within the internal zone of the Northern Brasília Belt, situated between the mafic-ultramafic complexes and the Mara Rosa Magmatic Arc (Figure 14c). The region encompasses rocks from the Uruaçu Complex, the Campinorte Domain, and the metasedimentary cover associated with the Serra da Mesa Group (Figure 16).

The Uruaçu Complex is a Neoproterozoic small-domed-shaped terrain consisting of quartz-dioritic to granitic composition orthogneisses, paragneisses, and mafic to ultramafic rocks which are covered by the Serra da Mesa Group metasedimentary rocks (Figure 16). Giustina et al. (2009a) provided isotopic data from different rock types within the complex, summarized in Table 1 and described as follows. The U-Pb zircon dating suggests a magmatic event between ca. 690-650 Ma followed by a metamorphic imprint at ca. 650 Ma.

The orthogneisses with granitic composition present an *augen* texture characterized by mantled porphyroclasts of K-feldspar in a matrix of quartz, andesine, hornblende, and biotite (Figure 17a). U-Pb LA-ICP-MS zircon dating on this rock yielded a crystallization age of 673 ± 13 Ma and a metamorphic age of 652 ± 21 Ma (Giustina et al., 2009a). The paragneisses are often weakly migmatized, presenting isoclinal folded stromatic structures, drawn boudins in concordant leucosome layers, and asymmetrical boudins in oblique leucosome veins (Figure 17 b-c). The leucosome is characterized by

centimetric coarse-grained quartz-feldspathic layers, while the melanocratic domains are composed of fine- to medium grains of garnet, biotite, quartz, and muscovite. Detrital zircons from this rock indicate a maximum depositional age of 710 Ma for this unit, and a zircon overgrowth yielded a U-Pb age of 640 ± 22 Ma, which is interpreted as the metamorphic age (Giustina et al., 2009a).

The mafic to ultramafic rocks occur in scattered bodies throughout the complex. The main lithotype is a banded diopside-amphibolite which is well-exposed in a quarry located in the complex south portion. This amphibolite is characterized by mafic domains interlayered with calc-silicate layers (Figure 17d). The mafic layer is mainly composed of diopside, hornblende, and andesine, with minor occurrences of titanite and disseminated sulfides. Still, in the mafic domain, concordant greenish narrow stripes occur and are associated with the presence of epidote and garnet. On the other hand, the calc-silicate layer presents an association of medium-grained crystals of calcite, plagioclase, quartz, epidote, and titanite. U-Pb LA-ICPMS on zircon constrained a crystallization age of 651 ± 13 Ma for the amphibolite (Giustina et al., 2009a). U-Pb ID-TIMS on titanite yielded highly discordant ages with a lower intercept age of 635 ± 4 Ma (Giustina, 2007). Similar ages of ca. 630 Ma are reported in the Mara Rosa Arc, and the mafic-ultramafic complexes and it has been interpreted as the collisional episode age of the Northern Brasília Belt (Ferreira Filho et al., 1994; Pimentel et al., 1997; Junges et al., 2002).

In the study region, the Campinorte Domain occurs in a narrow segment between the Uruaçu Complex and the Mara Rosa Arc, and within structural windows in the Serra da Mesa Group (Figure 16). The investigated area was focused on these structural windows. South of the Uruaçu Complex, the Paleoproterozoic granulitic unit crops out near the Serra da Mesa Dam (Figure 16). This unit is mainly composed of a banded paragonulite with Grt+Sil+Hc+Crld+Kfs+Pl arranged in a grano- to nematoblastic texture. U-Pb LA-ICPMS on zircon yielded an age of 2.1 Ga which is interpreted as the age of the metamorphism (Cordeiro et al., 2014). Previous thermobarometric calculations on this rock constrained the *P-T* conditions at 782°C and 6.3 Kbar (Winge, 1995).

The Serra da Mesa Group overlays the rocks from Uruaçu Complex and the Campinorte Domain (Figure 16). After Lacerda et al. (1999), the group was subdivided into Unit A (psamitic) and Unit B (pelitic). The psamitic unit crops out mainly in inselbergs (Figure 17e) in the study region, with occasional occurrences in road cut exposures. It consists of fine- to medium-grained foliated quartzite with a variable amount

of mica. The pelitic unit is poorly exposed, with rare outcrops in natural drainages and road cuts. The principal rock of this unit is a Grt-mica schist with garnet porphyroblasts up to 1 cm wide (Figure 17f). Rare lenses of calc-schists and marbles occur interlayered within the Grt-mica schist layer.

Table 1. U-Pb data for the Uruaçu Complex from Giustina et al., 2009a

Sample	Description	Crystallization age (Ma)	Metamorphic Age (Ma)
CAMP26	Quartz-dioritic gneiss	690 ± 14	650 ± 18
CAMP12	Migmatite	673 ± 14	657 ± 13
CAMP04*	Amphibolite	651 ± 13	-
CN113A*	<i>Augen</i> gneiss	673 ± 13	652 ± 21
CN101*	Migmatitic paragneiss	-	640 ± 22

*Samples with *P-T* data from this study.

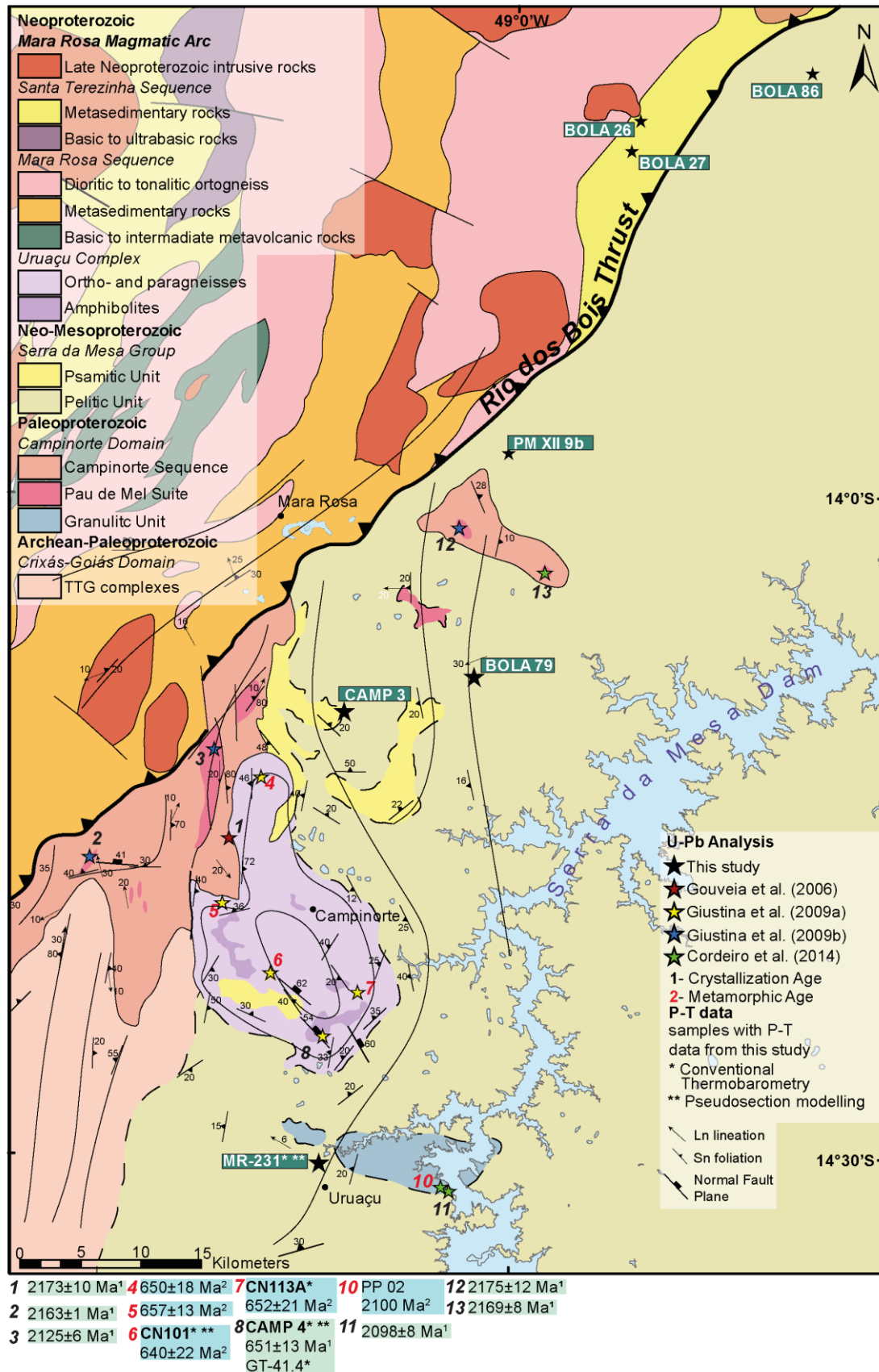


Figura 16. Geological map of the study area with samples location (compiled from Oliveira et al. 2006; Giustina et al. 2009a, Cordeiro et al. 2014 and Oliveira et al. 2016).

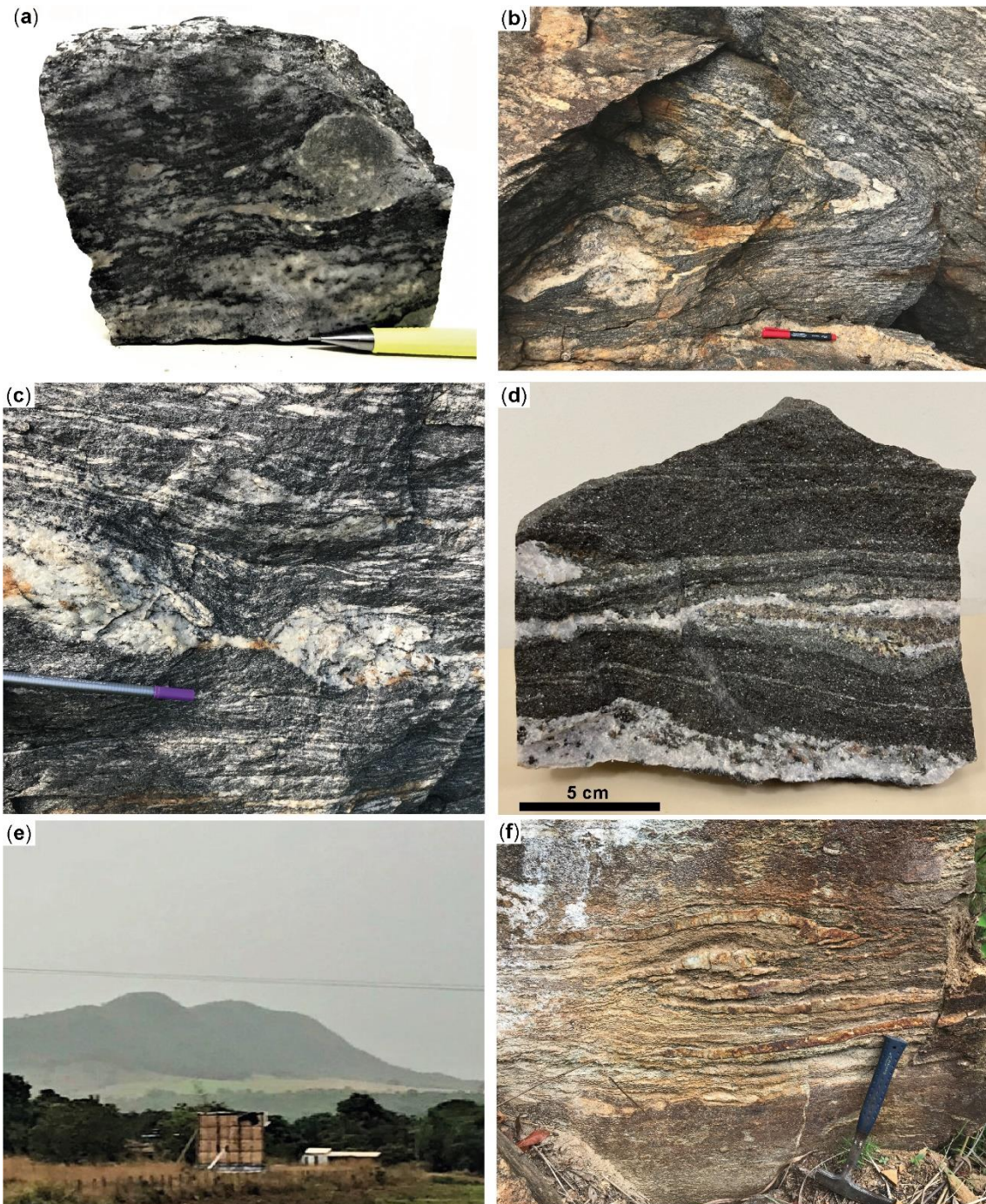


Figura 17. **a)** Hand specimen of *augen* gneiss (sample CN113A) from Uruaçu Complex with mantled delta porphyroblast; **b)** Folded stromatic structure and **c)** drawn-boudin in concordant leucosome layer of the paragneiss (sample CN101) from Uruaçu Complex; **d)** Hand specimen of banded diopside amphibolite (sample CAMP-04) with calc-silicate layers; **e)** Inselberg consisting of Serra da Mesa quartzites above Uruaçu Complex rocks; **f)** Garnet-mica schist (sample MR-231) from the pelitic unit of Serra da Mesa Group with garnet porphyroblasts and folded quartz segregations.

2.5 Structural framework

The region is tectonically bounded by two major thrust systems in Brasília Orogen: the Rio dos Bois Thrust to the west and the Rio Maranhão Thrust to the east (Figure 16). The main fabric element is a S_n regional foliation (Uhlein et al., 2013; Oliveira et al., 2016). The overall foliation has NE-SW trend and gently dips towards NW. The Serra da Mesa Group and the Uruaçu complex are strongly foliated and transposed, usually with overturned isoclinal folds, showing disrupted limbs. Stretching lineation plunges mainly to NW, and kinematic is top-up-to-southeast. Locally, it forms L-tectonites, observed mainly in Serra da Mesa Group. At the contact between the Uruaçu Complex and the Serra da Mesa Group, in both units, the foliation displays an approximately circular pattern, following the contact between those units (Figure 16). In the Paleoproterozoic Crixás-Goiás Domain, the TTGs exhibit predominantly moderate to high foliation, with primarily strike-slip kinematics. The Mara Rosa orthogneisses are commonly strongly foliated, locally with mylonitic textures.

N-S sinistral shear zones are also reported in the region cross-cutting rocks from the Uruaçu Complex and the Campinorte Domain (Figure 16; Oliveira et al. 2006).

According to Oliveira et al. (2016) at least 3 deformation phases can be observed in the Mara Rosa Magmatic Arc and are related to the Neoproterozoic Brasiliano orogeny. Phase D_n is associated with the earlier metamorphic event in the Northern Brasília Belt between ca. 760-730 Ma (Junges et al. 2002; Oliveira et al. 2016), related to the island arc accretion. It is characterized by a set of recumbent isoclinal and overturned folds that verge toward E/SE (Oliveira et al. 2016).

Phase D_{n+1} is characterized by the development of the Rio dos Bois Thrust System which defines the boundary between the Mara Rosa Magmatic Arc and the internal zone, occurred during collision. It consists of a series of reverse faults and folds, including drag, parasitic, isoclinal, and intrafolial folds. These structures were originated in response to NNW-SSE shortening between 630 and 580 Ma (Oliveira et al. 2016). Phase D_{n+2} presents dome and keel regional pattern which is formed by open to slight synclines and anticlines with E-W and N-S axis, respectively.

Field observation during this study recognized structural elements that can be related to phase D_{n+1} , considering the age of the Uruaçu Complex. Recumbent isoclinal folds on the Uruaçu Complex paragneiss and in the garnet schists of the Serra da Mesa Group depicted this deformational phase in the internal zone (Figure 17b, 17f).

2.5.1 *Extensional tectonics*

Normal faults in metatonalites from the Campinorte Domain with E-W direction were reported by Oliveira et al. (2006). These faults are characterized by decimetric shear zones with S-C structures and asymmetrical sigmoids with normal top to the NE movement. This structural style was ascribed to an earlier deformation phase prior to the Brasiliano event, as it was observed exclusively in Paleoproterozoic rocks (Oliveira et al., 2006).

However, our newly acquired field data reveal the presence of normal structures that cross-cut rocks from the Uruaçu Complex and the Serra da Mesa Group. Notably, in the diopside-amphibolite quarry (sample CAMP-04) well-exposed instances of this structure are observed. It is characterized by normal-sense mylonitic zones that cut all the amphibolite compositional layers throughout the outcrop (Figure 18a).

The development of S-C foliation and drag fold folds characterize the sense of movement along these shear/fault zones, separated from each other by centimeters to decimeters (Figure 18a-b). At the microscale, the shear zones display a protomylonitic fabric with S-C foliation and hornblende porphyroclasts with biotite in the pressure shadows (Figure 18c). These planes generally have an NW-SE direction, almost perpendicular to the regional S_n foliation, and dip between 40° and 60°, suggesting a top-to-the-NE extension. Normal faults with NW-SE direction are also found in the pelitic and psammitic rocks from the Serra da Mesa Group (Figure 18d-e). The normal-sense kinematic in these units is also attested by sigmoid porphyroclast and folds with top-down to the ENE movement.

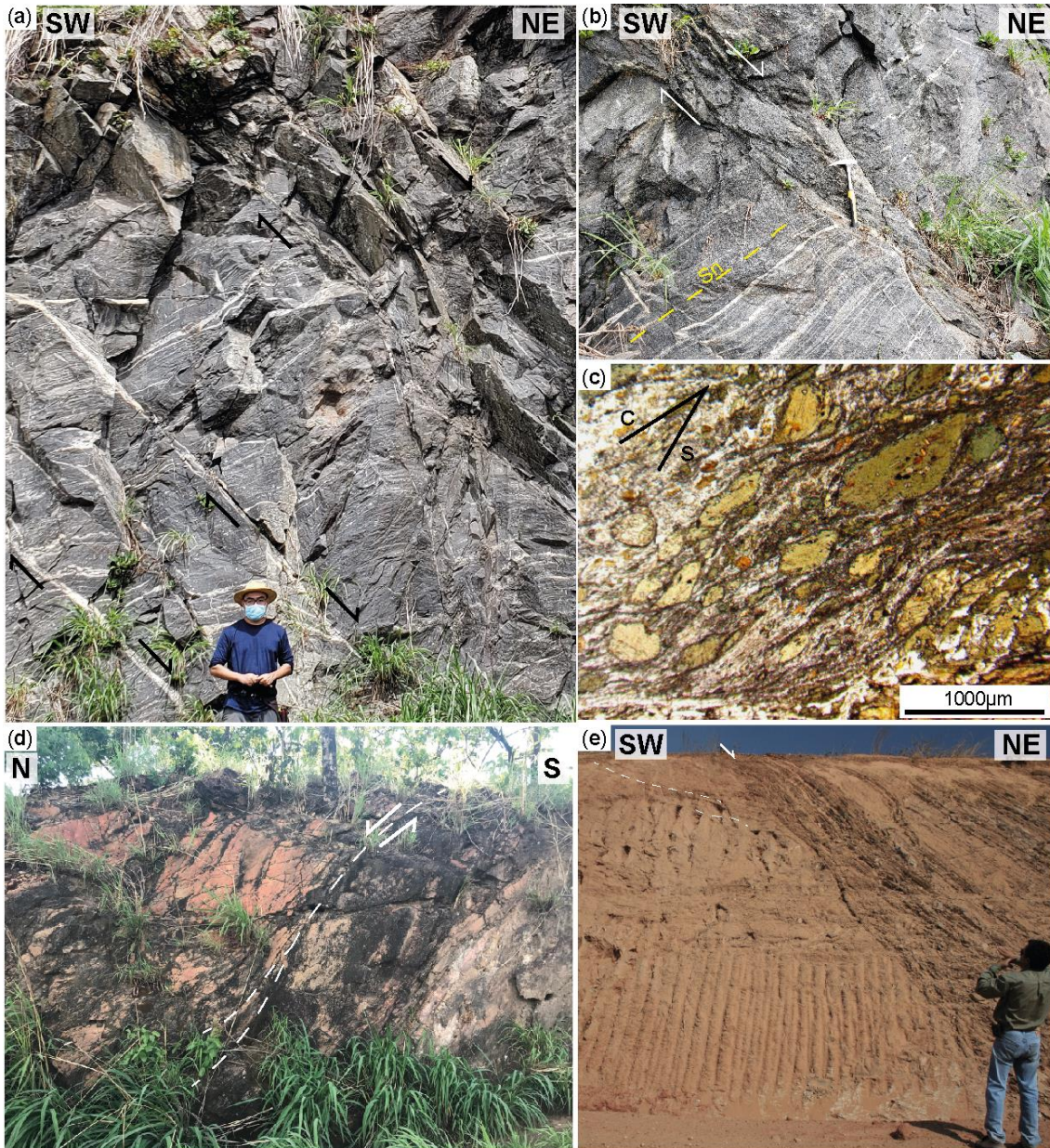


Figura 18. a-b) Set of centimetric to metric extensional faults with development of S-C foliation in diopside amphibolite quarry. **c)** Mylonitic fabric with porphyroclasts of hornblende. **d)** Normal fault on quartzites from Serra da Mesa Group at road cut exposures. **e)** Normal fault in weathered schists from Serra da Mesa Group.

2.6 Methods

2.6.1 Whole-rock composition

Whole-rock major element compositions of the collected samples were determined by an X-ray fluorescence spectrometer (Bruker S8 Tiger) at the Regional Center for Technological Development and Innovation (CRTI) of the University of Goiânia, Brazil. The results obtained from the analysis are listed in Table S1 and were used to perform *P-T* pseudosection modelling.

2.6.2 Mineral chemistry

Mineral compositions were determined by a JEOL JXA-8230 equipped with 5 WDS detectors at the Laboratory of Microscopy and Microanalysis (LMic) of the Federal University of Ouro Preto, Brazil. The operational conditions included 15-kV accelerating voltage, 20nA beam current, and a beam diameter of 5 nm. The results are listed in Tables S2-S7.

2.6.3 *P-T* determination

Pseudosection modelling was used to constrain the *P-T* conditions of the already dated samples by Giustina et al. (2009a) (samples CN101 and CAMP-4 from the Uruaçu Complex), and one sample (MR-231) from the Serra da Mesa Group with U-Pb zircon age determined in this study. Conventional geothermobarometry was also applied in the same samples with the addition of the samples CN113A (felsic gneiss) and GT-41.4 (retro-amphibolite). The location of the samples is shown in Figure 16. The *P-T* pseudosection calculations were performed using the THERIAK-DOMINO software (De Capitani & Petrakis, 2010). For geothermobarometry, the garnet-biotite thermometers from Thompson et al. (1976), Hodes and Spear (1982), and Bhattacharya et al. (1992), the amphibole-plagioclase thermometer from Holland and Blundy (1994), and the barometer Al-in-hornblende from Bhadra and Bhattacharya (2007) were applied to better constrain the *P-T* conditions.

The pseudosections of metapelites samples (CN101 – paragneiss and MR231 – Grt-mica schist) were calculated in the MnO-Na₂O-CaO-K₂O-FeO-MgO-Al₂O₃-SiO₂-H₂O-TiO₂ (MnNCKFMASHT) system with the Holland and Powell (1998) thermodynamic data set. The following *a-x* relationships were used: White et al. (2005) for garnet, biotite, and ilmenite; Coggon and Holland (2002) for white mica; Holland and Powell (2003) for feldspar; Mahar et al. (1997) for chloritoid; White et al. (2007) for melt and Holland and Powell (1998) for chlorite, epidote, staurolite, and cordierite. The diagram *T-H* was used to constrain the amount of H₂O in the bulk composition of the sample CN101, with the adjustments based on the garnet isopleths.

The *P-T* path of sample MR-231 (Grt-mica schist from Serra da Mesa Group) was constructed using the methodology proposed by Moynihan and Pattison (2013) and the software MP13 was provided online by Eric Kelly. This approach constructs the *P-T* path based on the compositional zoning of garnet, considering the fractionation of garnet

during its growth and the resultant impact on the changes in the effective bulk composition.

The pseudosection of the amphibolite sample (CAMP-04) was calculated in the $\text{Na}_2\text{O}-\text{CaO}-\text{FeO}-\text{MgO}-\text{Al}_2\text{O}_3-\text{SiO}_2-\text{H}_2\text{O}-\text{Fe}_2\text{O}_3$ (NCFMASHTO) system with the Holland and Powell (2011) thermodynamic data set. The following a - x relationships were used: White, Powell, and Johnson (2014) for garnet, ilmenite, orthopyroxene, and chlorite; Holland and Powell (2003) for feldspar; Green et al. (2016) for clinopyroxene, and amphibole. To evaluate the O contents in the bulk composition of the sample CAMP-04, the T - M_O diagram was calculated.

The mineral abbreviations follow the proposal of Whitney and Evans, (2010).

2.6.4 U-Pb LA-ICP-MS

U-Pb dating by LA-ICP-MS on zircon grains was carried out to investigate this area of the Serra da Mesa Group. The main objective was to ascertain whether these metasedimentary rocks form a continuous belt between the Magmatic Arc and the Mafic-ultramafic complexes or if they encompass other sequences beyond those already known. Additionally, we aimed to investigate the relationship between the Serra da Mesa Group and the overlying rocks of the Uruaçu Complex. Samples were collected from the southern portion of the Serra da Mesa Group (BOLA-79, BOLA-86, CAMP-03, MR-231, and PM XII 9b) and the easternmost region of the Mara Rosa Magmatic Arc attributed to the Santa Terezinha Sequence (BOLA-26 and BOLA-27). The location of the samples is shown in Figure 3. Sample preparation and isotopic analyses were performed in LEGGA-UnB (Laboratory for geodynamics, geochronology, and environmental studies of the University of Brasília).

The laboratory procedures and methods used for data acquisition followed the approach described by Buhn et al. (2009). The zircon standard GJ-1 (Jackson et al. 2004) was employed as the primary standard in a standard-sample bracketing method. The weighted mean age yielded from the standard zircon was 606.0 ± 2.7 Ma.

IsoplotR (Vermeesch, 2018) was used for the Wetherill Concordia diagram calculation while histograms, probability density plots (PDP), and kernel density estimates (KDE) were calculated with Density Plotter (Vermeesch, 2012). The histograms, PDP, and KDE were built based only on analysis with less than 10%

discordancy. Zircon grains younger than 1 Ga were selected by $^{206}\text{Pb}/^{238}\text{U}$ ratio while those older than 1 Ga were selected by $^{206}\text{Pb}/^{207}\text{Pb}$ ratio.

2.7 Petrography and mineral chemistry

Four samples from Uruaçu Complex, comprising one granitic gneiss (CN113A), one paragneiss (CN101), and two amphibolites (CAMP-04; GT-41.4), as well as one schist sample (MR-231) from the Serra da Mesa Group, were selected for a petrological study and subsequent calculation of their respective *P-T* conditions.

2.7.1 Uruaçu Complex

2.7.1.1 Felsic gneiss

The felsic gneiss CN113A presents an S-C planar fabric with coarse-grained K-feldspar porphyroclasts immersed in a fine- to medium-grained matrix of plagioclase, biotite, hornblende, and quartz (Figure 19a). The porphyroclasts have compositions ranging from $\text{An}_0\text{Ab}_{11}\text{Or}_{89}$ to $\text{An}_0\text{Ab}_{07}\text{Or}_{93}$ (Figure 20a) and are often surrounded by very fine-grained recrystallized plagioclase (Figure 6b). The composition of the plagioclase in the K-feldspar rims and the medium-grained crystals present in the matrix falls in the andesine field ranging from $\text{An}_{67}\text{Ab}_{32}\text{Or}_{01}$ to $\text{An}_{63}\text{Ab}_{36}\text{Or}_{01}$ (Figure 20a).

Biotite is the mineral that outlines the main foliation in this rock, occurring both as elongated fine-grained lamellas and as very fine-grained crystals in the matrix (Figure 19a, 19b). Most biotite compositions are plotted in the phlogopite field near the annite boundary with one falling into the eastonite field (Figure 20b). The $\text{Mg}/(\text{Mg}+\text{Fe}^{2+})$ ratio varies from 0.52 to 0.59 and the Al (VI) in phlogopite ranges from 0.23 to 0.36 a.p.f.u. while the eastonite has 0.65 a.p.f.u. (Figure 20b).

The subhedral greenish hornblende crystals constitute small aggregates with polygonal contacts in the matrix (Figure 19a). All the amphiboles in this sample are pargasites and do not show a significative compositional variation with contents of $\text{Ca}_B = 1.81\text{-}1.86$, $(\text{Na}+\text{K})_A = 0.67\text{-}0.79$, and $\text{Si} = 6.45\text{-}6.52$ a.p.f.u., with $\text{Mg}/(\text{Mg}+\text{Fe}^{2+}) = 0.56\text{-}0.57$ (Figure 20b; Leake et al., 1997).

2.7.1.2 Paragneiss

The paragneiss CN101 displays a gneissic foliation characterized by alternation layers of biotite-rich domains and quartz-feldspathic domains. The biotite occurs as elongated fine-grained lamellas parallel to the main foliation (Figure 19c). The biotite composition falls within the annite field with $\text{Mg}/(\text{Mg}+\text{Fe}^{2+})$ ratio ranging from 0.38 to

0.40 and Al (VI) content ranging from 0.28 to 0.41 a.p.f.u (Figure 20b). The garnet commonly occurs as fine-grained subhedral crystals within the biotite-rich domain and often presents inclusion of opaque minerals in their core (Figure 19c). Despite the textural differences in the garnet with an inclusion-rich core and an inclusion-poor rim, they show a flat compositional zoning and present values varying between $\text{Alm}_{70.8-74.5}\text{Sp}_{10.67-12.5}\text{Prp}_{9.1-10.6}\text{Gr}_{5.4-8.4}$ (Figures 20e, 21a).

The quartz-feldspathic domain exhibits a granoblastic texture characterized by equigranular grains of quartz and K-feldspar (Figure 19c). The feldspar also occurs as porphyroclasts up to 1mm and exhibits tartan twinning (Figure 19d). Its compositional falls within the sanidine field with values ranging from $\text{An}_{0.0-0.6}\text{Ab}_{5.8-7.7}\text{Or}_{71.8-94.2}$ (Figure 20a).

2.7.1.3 Amphibolite

The sample CAMP-04 is a typical representation of the unaltered portion of the amphibolite which preserves peak metamorphic assemblage, including $\text{Hbl}+\text{Di}+\text{Pl}\pm\text{Ttn}$. The rock exhibits a granonematoblastic texture determined by slightly oriented crystals of hornblende in polygonal contacts with diopside, and plagioclase (Figure 19e). Titanite and pyrite are present as accessory phases.

The dominant amphibole species is ferrohornblende with subordinated occurrences of magnesiohornblende and ferro-edenite (Figure 20c, d; Leake et al., 1997). The $\text{Mg}/(\text{Mg}+\text{Fe}^{2+})$ ratio varies between 0.45 and 0.52. The plagioclase crystals are subhedral and the composition falls into the andesine field ranging from $\text{An}_{39.8-43.32}\text{Ab}_{56.1-59.6}\text{Or}_{0.25-0.63}$ (Figure 20a). The diopside in this rock is commonly found as euhedral to subhedral grains and has a composition falling within the following range of values: $\text{Wo}_{45.7-46.8}\text{En}_{31.7-33.7}\text{Fs}_{20.6-21.5}$ (Figures 19a, 20f).

The sample GT-41.4 is representative of the concordant greenish stripes which are parallels to the main foliation and occur in the borders of calc-silicate layers (Figure 4d). The sample exhibits a retrometamorphic assemblage defined by $\text{Hbl}+\text{Pl}+\text{Ep}+\text{Grt}\pm\text{Ttn}\pm\text{Bt}$. In this domain, the amphibole composition is slightly different from that found in the unaltered portion. Although it has a similar $\text{Mg}/(\text{Mg}+\text{Fe}^{2+})$ ratio, its Si content is lower ranging from 6.37 to 6.56 a.p.f.u. (Figure 20d). On the other hand, plagioclase exhibits considerable variation in composition being classified as albite and oligoclase with values of $\text{An}_{0.8-17.9}\text{Ab}_{81.5-98.9}\text{Or}_{0.3-1.3}$ (Figure 20a).

The garnet occurs as rounded subhedral crystals (Figure 19f) and as coronas around epidote crystals (Figure 19g). In the subhedral garnet, there is a decrease in spessartine toward to the rim from 9.4 to 3.2 X_{sps} , while the concentration of almandine and grossular increases from 54.8 to 61.2 X_{alm} and 27.1 to 32.9 X_{grs} respectively (Figure 21b). The biotite is commonly observed in the garnet and amphibole borders (Figure 19e). The only biotite species found is annite with $\text{Mg}/(\text{Mg}+\text{Fe}^{2+})$ ratio varying from 0.43 to 0.46 and Al (VI) with 0.12 to 0.33 a.p.f.u. (Figure 20b).

2.7.2 *Serra da Mesa Group*

The sample MR231 is representative of the Grtmica schist from Serra da Mesa Group. The rock exhibits a porphyroblastic texture determined by medium-grained porphyroblasts of garnet crystals immersed in a matrix of $\text{Bt}+\text{Ms}+\text{Chl}+\text{Qtz}\pm\text{Pl}\pm\text{Ilm}$ (Figure 19h). The garnet occurs as intertectonic euhedral crystals up to 10 mm and has ilmenite inclusion in its core and a poor inclusion rim. The ilmenite inclusions define an internal foliation in the garnet crystal which is oblique with the foliation of the matrix and defines the intertectonic aspect (Figure 6h). This textural variation is also reflected in the major-element compositional zoning marked by a steep difference in the amounts of almandine, grossular, and pyrope (Figure 21c). In general, there is a soft decrease in spessartine and grossular towards the rim, until the inclusion-poor rim which presents a steep variation. The X_{sps} and X_{grs} decrease from 1.9 to 0.4 and 12.1 to 6.5, respectively (Figure 21c). On the other hand, there is an increase in almandine and pyrope from 79.6 to 84.3 X_{alm} and 6.3 to 8.8 X_{prp} (Figure 21c).

The biotite, chlorite, and muscovite constitute the rock matrix and define the foliation. The dominant biotite species found is annite with $\text{Mg}/(\text{Mg}+\text{Fe}^{2+})$ ratio varying from 0.39 to 0.44 and Al (VI) content ranging from 0.36 to 0.96 a.p.f.u (Figure 20b). The principal chlorite variety found in the sample is ripidolite with minor occurrences of daphnite (Table S7).

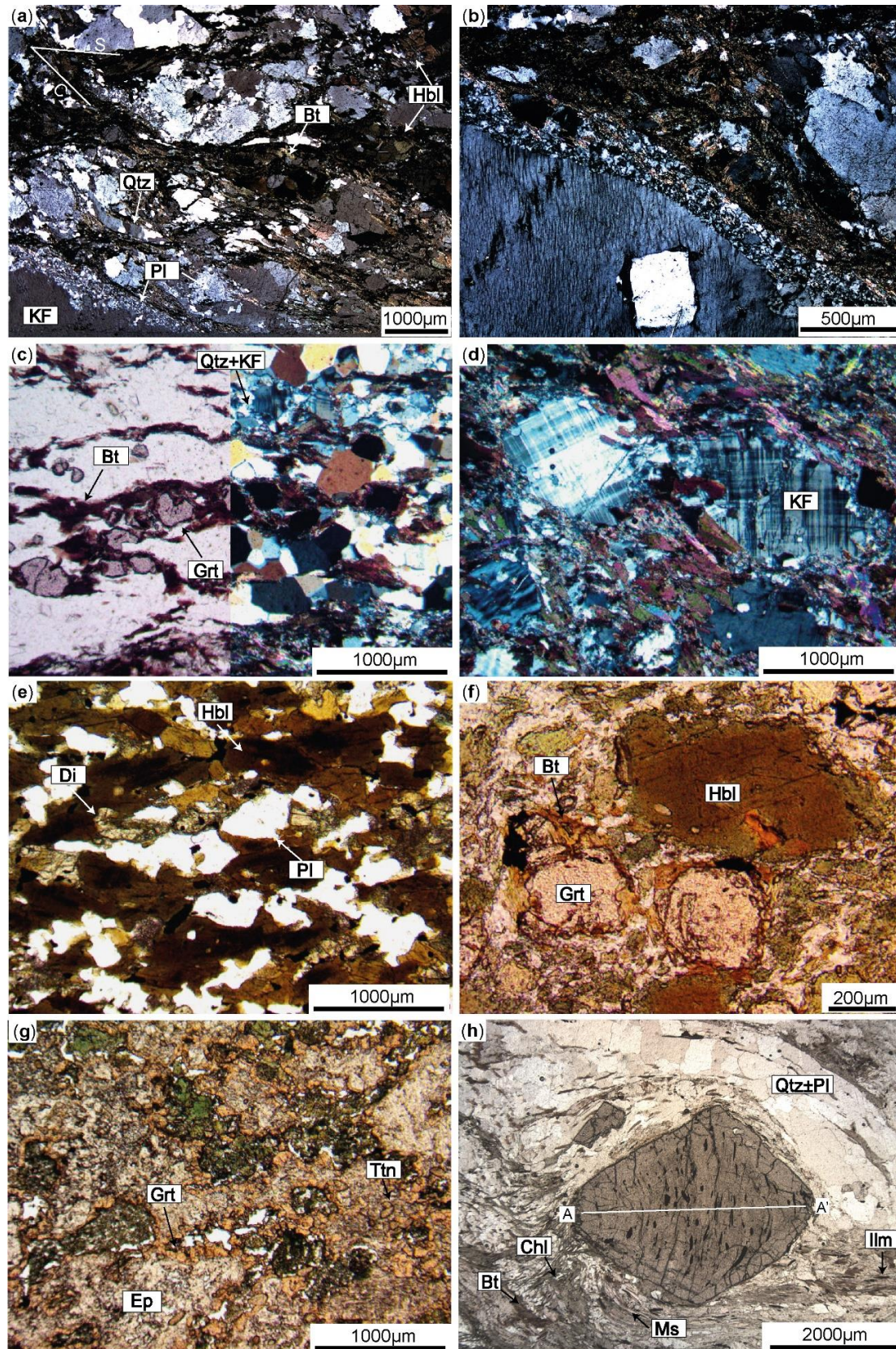


Figure 19. a) S-C foliation in orthogneiss with granitic composition. b) Recrystallized rim in K-feldspar porphyroblast in orthogneiss. c) Gneiss banding in paragneiss with alternating domains of Grt + Bt with Qtz + Pl. d) Kfs porphyroblast in a matrix of Ms + Bt in paragneiss. e) Diopside amphibolite with grano- to nematoblastic texture. f)

Rounded garnet rimmed with biotite in the calc-silicate layer of the amphibolite. **g)** Garnet corona around epidote in the greenish stripes of the amphibolite. **h)** Garnet porphyroblast with ilmenite inclusion and immersed in a matrix of Bt + Chl + Ms + Qtz + Pl.

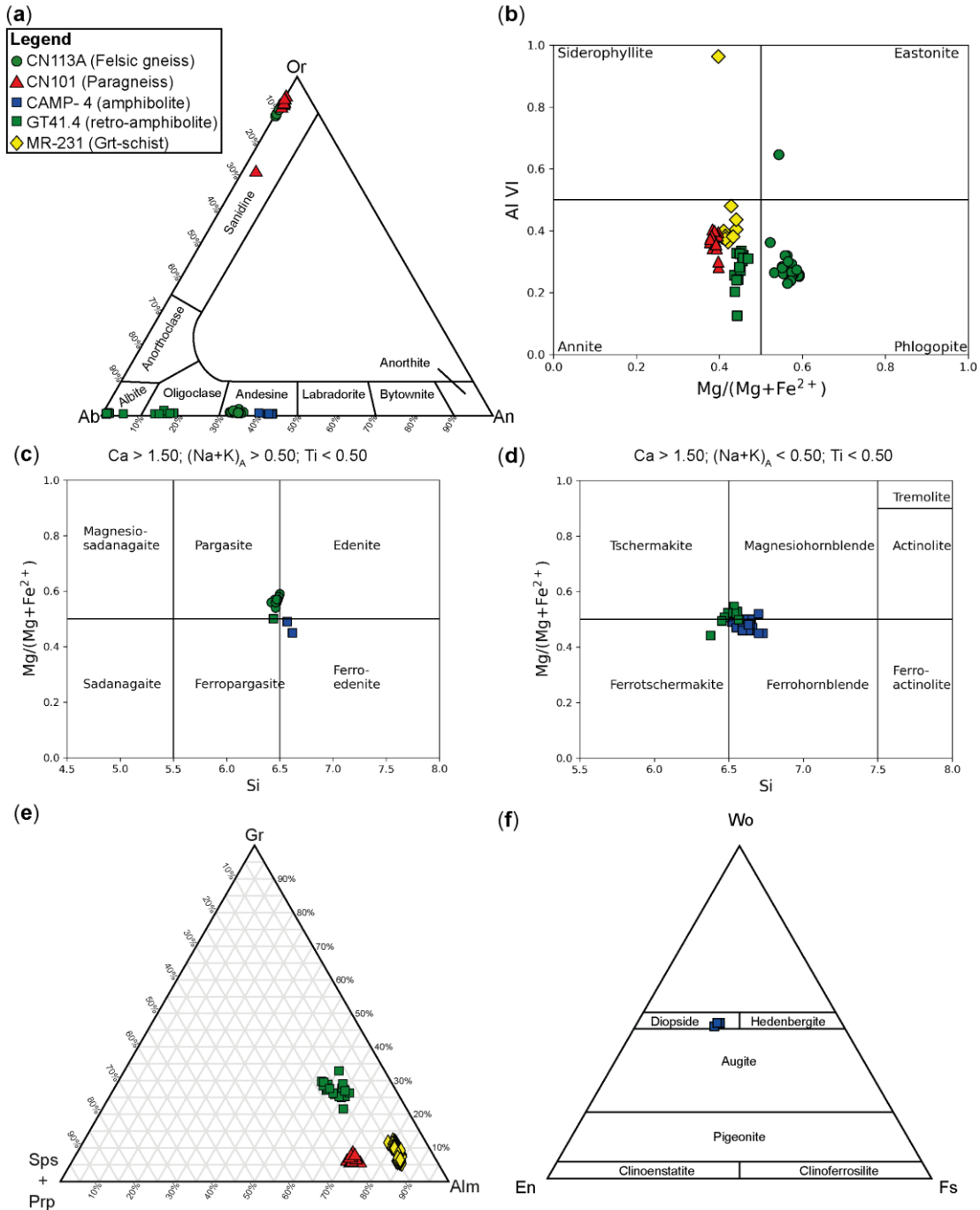


Figure 20. **a)** Ternary diagram showing feldspar composition. **b)** Plot of $Mg/(Mg+Fe)$ vs. Al (VI) per 11 oxygens in biotite. **c-d)** Classification of calcic-amphibolites (Leake et al., 1997). **e)** Ternary diagram showing garnet composition. **f)** Ternary diagram showing pyroxene composition.

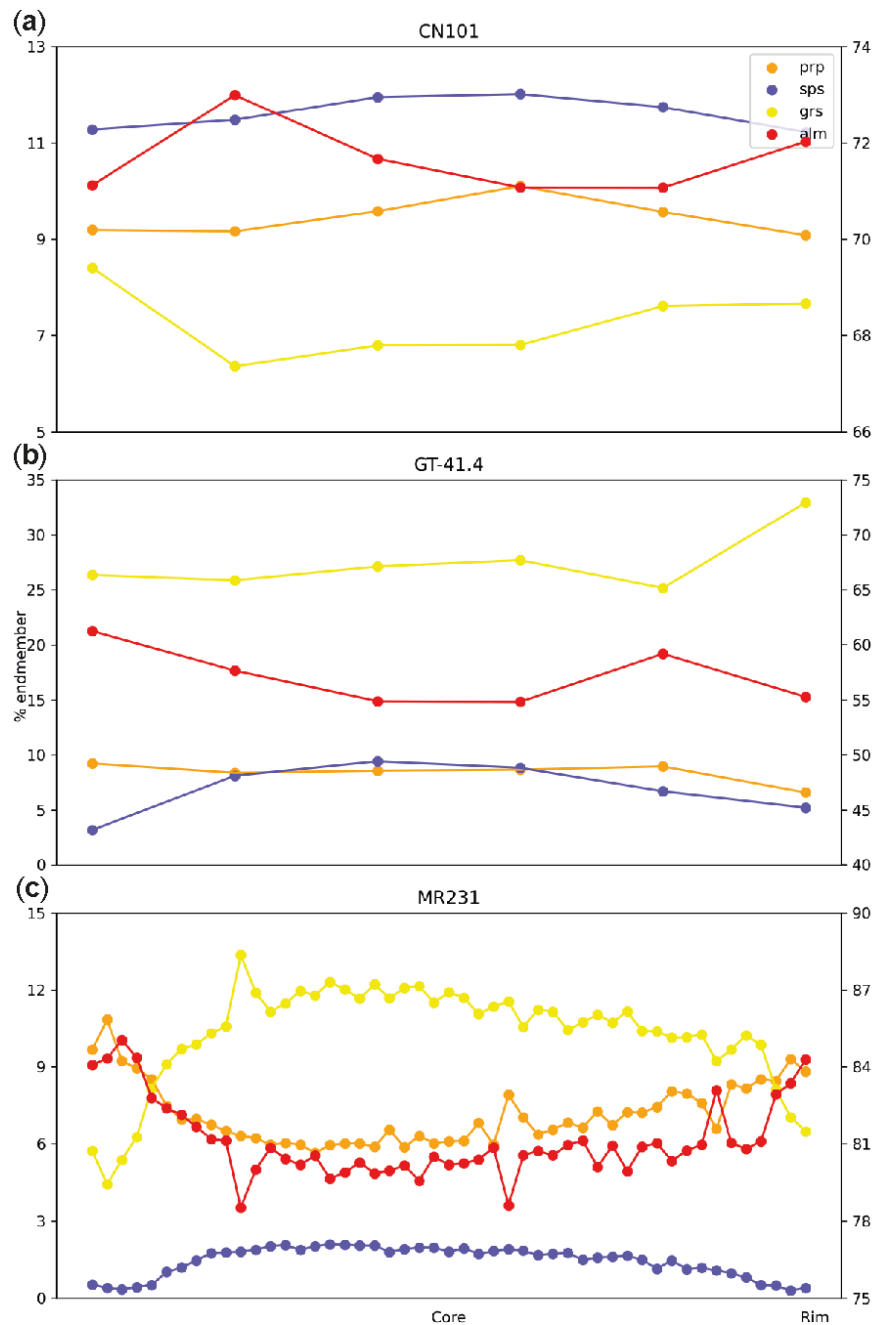


Figura 21. Garnet compositional profiles from samples a) CN101, b) GT-41.4 and c) MR231

2.8 Conventional geothermobarometers

Temperature conditions of the Uruaçu Complex and the Serra da Mesa Group were obtained using mineral chemical data in Table S2-5 and the results are summarized in Table 2. The Grt-Bt thermometers (Thompson et al., 1976; Hodes and Spear, 1982) were applied to the metapelite samples CN101 and MR231, while the Hbl-Pl thermometer (Holland and Blundy, 1994) and the Al-in-hornblende barometer (Bhadra and

Bhattacharya, 2007) were used for the felsic gneiss (CN113A) and amphibolite (CAMP04; GT-41.4) samples.

The results of the Grt-Bt and the Hbl-Pl thermometers yielded conditions between 695 and 745°C for the Uruaçu Complex with the altered amphibolite GT-41.4 providing a temperature of 551-591°C. The Al-in-hornblende yielded a pressure of 9.99 kbar and 7.13 kbar for the felsic gneiss and amphibolite, respectively, while the altered amphibolite provides a pressure of 4.47 kbar. For the Grt-schist, the Grt-Bt thermometers yielded a temperature of 583-585°C.

Table 2. Calculated thermobarometer data. The analyses column refers to the mineral chemistry data present in Table S2-S5.

Sample	Analyses	Temperature			Pressure (kbar)	
		P(kbar)	Grt-Bt		T (C°)	Al-in-hbl
		(Ref)	TH	HS	HB (ed-ri)	BB
CN113A (Felsic Gneiss, Uruaçu Complex)	amph-62, fsp-63	5	-	-	709	709 9.99
CN101 (Paragneiss, Uruaçu Complex)	grt-36, bt-49	5	695	734	-	- -
CAMP04 (Amphibolite, Uruaçu Complex)	amph-7, fsp-8	5	-	-	745	745 7.13
GT-41.4 (Retro-amphibolite, Uruaçu Complex)	amph-8, fsp-13	5	-	-	551	551 4.42
MR231 (Grt-schist, Serra da Mesa Group)	grt-2, bt-23	5	583	585	-	- -

2.9 Pseudosection modelling

Here, will be presented the results of the pseudosection modelling of the rocks from the Uruaçu Complex and the Serra da Mesa Group.

2.9.1 Uruaçu Complex

2.9.1.1 Sample CN0101 (Paragneiss)

The observed peak metamorphic assemblage Grt-Bt-Ms-Rt-Kf-Pl-Rt-Liq is stable just above the solidus curve at a narrow temperature range between ~650 and 675°C and at a wide H value above 5 mol in the T - H diagram (Figure 9). The X_{prp} and X_{grs} isopleths ($\text{Prp}_{9.1-10.6}$ $\text{Grs}_{5.4-6.9}$) constrain the H value at ~4.5-5.5 mol and an intermediate value of 5 mol was used in the P-T pseudosection modelling (Figure 22).

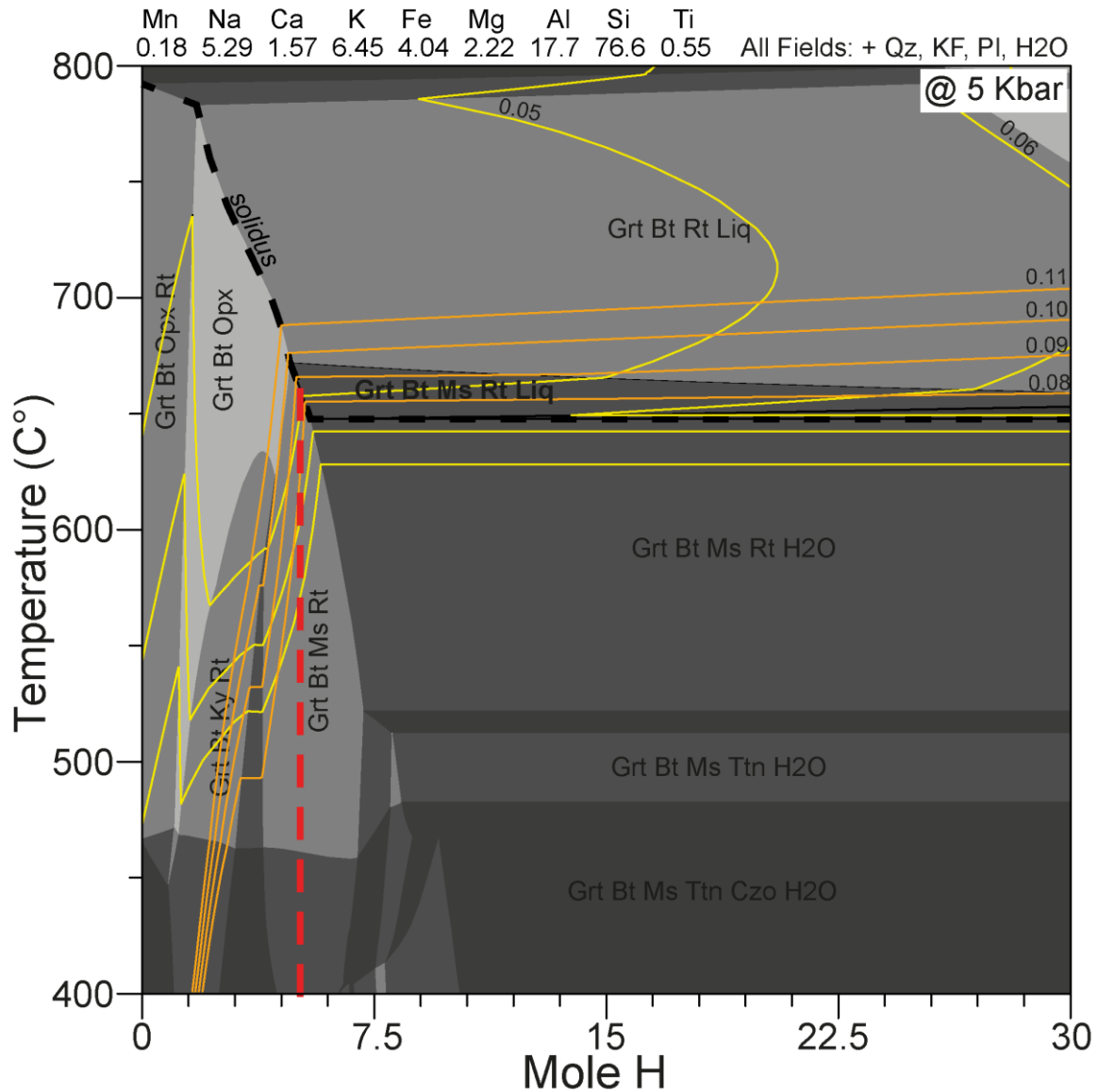


Figure 22. Calculated T - H diagram in the system $\text{MnO-Na}_2\text{O-CaO-K}_2\text{O-FeO-MgO-Al}_2\text{O}_3\text{-SiO}_2\text{-H}_2\text{O-TiO}_2$ (MnNCKFMASHT) for paragneiss CN101, Uruaçu Complex. The dashed red line indicates the estimated H value used in the P - T pseudosection. The orange and yellow lines indicate isopleths of X_{prp} and X_{grs} , respectively.

P - T pseudosection calculation for this sample set the peak mineral assemblage Grt-Bt-Ms-Rt-Kf-Pl-Rt-Liq at a very wide pressure range, higher than ~ 3.5 kbar, and temperature conditions between ~ 650 and 745°C (Figure 23). Compositional isopleths of X_{prp} (9.1-10.6) and X_{grs} (5.4-6.9) constrain the pressure at ~ 6 -6.9 kbar and the temperature at ~ 675 -685 $^\circ\text{C}$ (Figure 23). The temperature range is slightly below the conditions calculated with the garnet-biotite geothermometers (695-734 $^\circ\text{C}$)

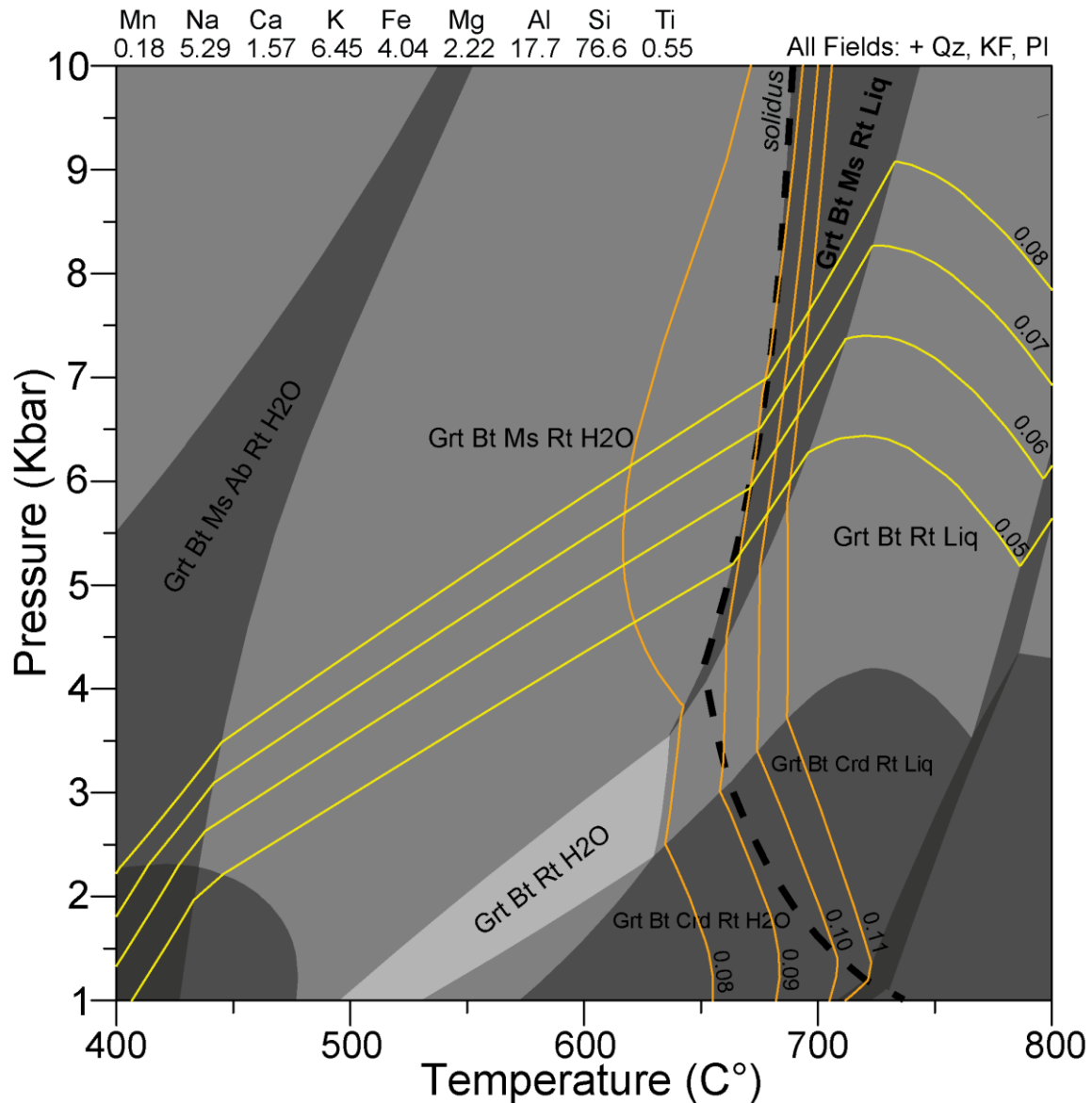


Figure 23. Calculated P-T pseudosection in the system MnO-Na₂O-CaO-K₂O-FeO-MgO-Al₂O₃-SiO₂-H₂O-TiO₂ (MnNCKFMASHT) for paragneiss CN101, Uruaçu Complex. The orange and yellow lines indicate isopleths of X_{prp} and X_{grs}, respectively.

2.9.1.2 Sample CAMP04 (Amphibolite)

The preserved peak-metamorphic assemblage Pl+Hbl+Cpx+Ilm+Ttn+Qrz is situated between 700 and 710°C, just below the solidus, in the $T-M_O$ diagram (Figure 24). The stable field occurs between 0.19 and 0.25 $Fe^{3+}/(Fe^{3+}+Fe^{2+})$ ratio and an intermediate value of 0.225 was used to construct the P-T pseudosection (Figure 24).

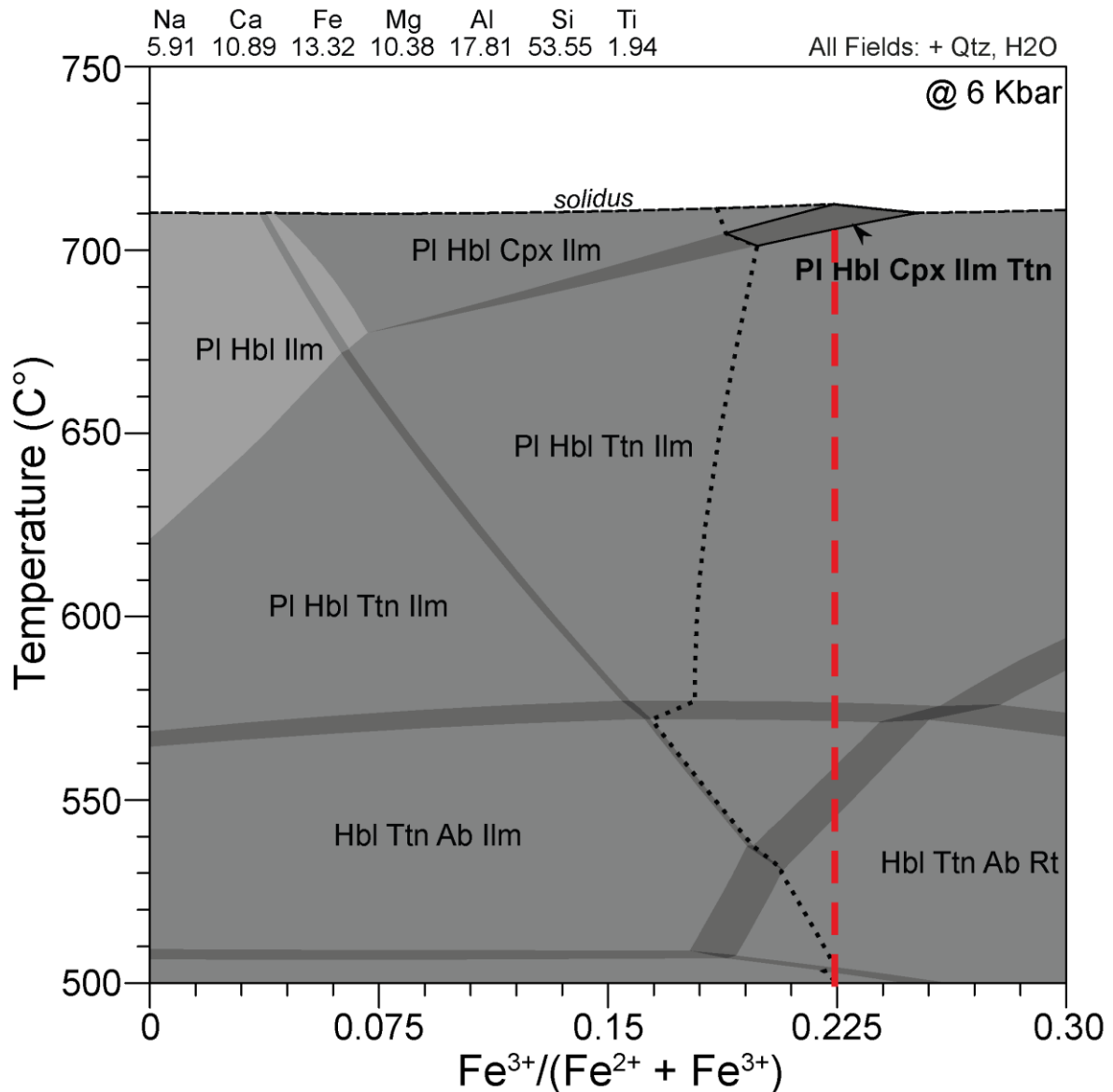


Figure 24. Calculated T - M_o diagram in the system Na_2O - CaO - FeO - MgO - Al_2O_3 - SiO_2 - H_2O - TiO_2 (NCFMASHT) for amphibolite CAMP-04, Uruaçu Complex. The stability field is indicated by the black arrow. The dashed red line indicates the estimated Fe^{3+} ($\text{Fe}^{3+}/\text{Fe}^{2+}$) ratio value used in the P - T pseudosection.

The stable field of the peak metamorphic assemblage $\text{Pl}+\text{Hbl}+\text{Cpx}+\text{Ilm}+\text{Ttn}+\text{Qtz}$ constrains the pressure and the temperature at ~ 5.1 - 6.1 kbar and 695 - 712°C (Figure 25). This field is congruent with the observed X_{An} (39.8-43-32) of the feldspar. The temperature conditions are consistent with those calculated with the Hbl - Pl geothermometer (709 - 745°C).

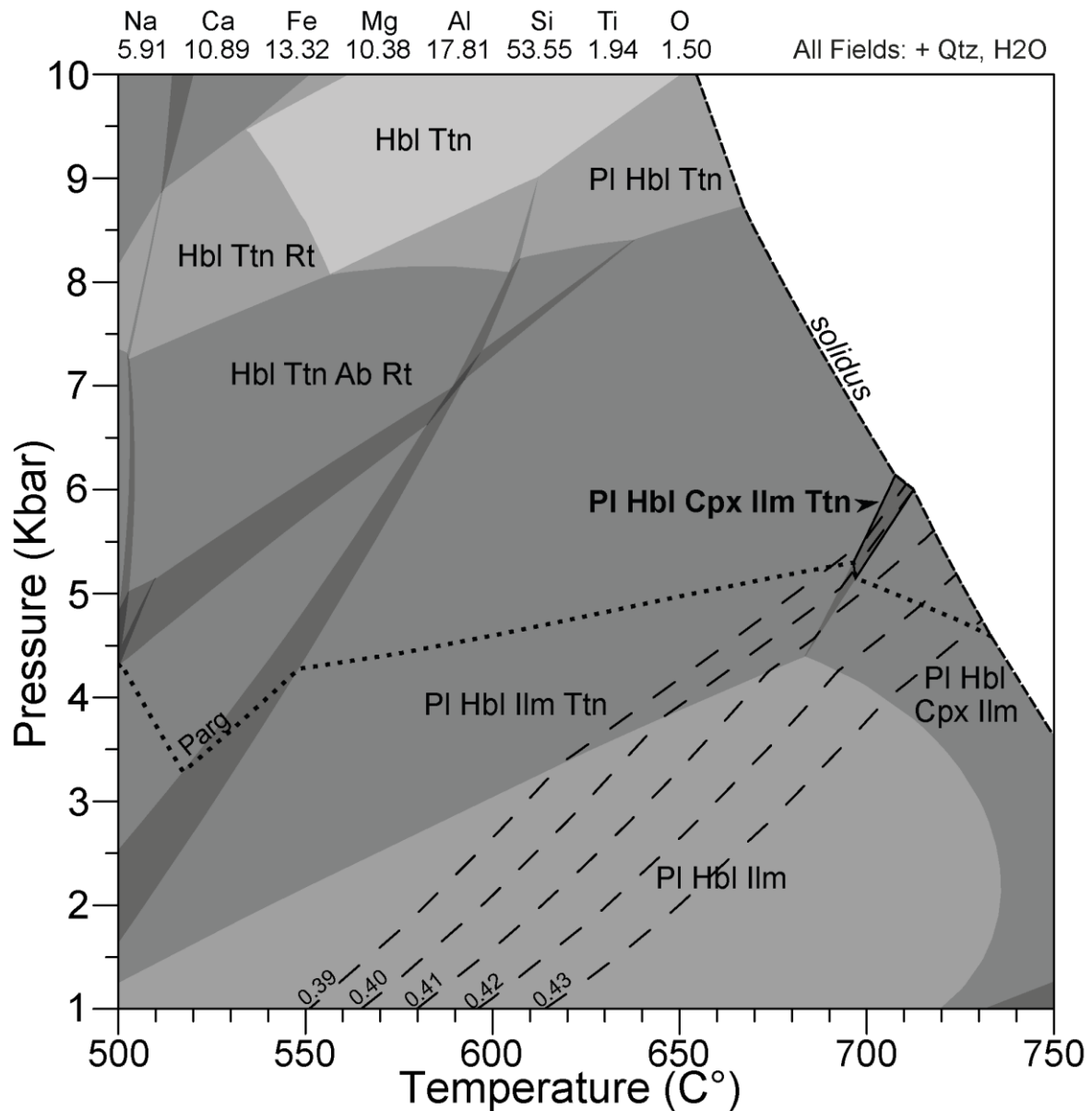


Figure 25. Calculated P-T pseudosection in the system $\text{Na}_2\text{O}-\text{CaO}-\text{FeO}-\text{MgO}-\text{Al}_2\text{O}_3-\text{SiO}_2-\text{H}_2\text{O}-\text{TiO}_2-\text{Fe}_2\text{O}_3$ (MnNCKFMASHTO) for amphibolite CAMP-04, Uruaçu Complex. The dashed black lines indicated the Xan isopleths.

2.9.2 Serra da mesa Group

2.9.2.1 Sample MR231 (Grt-schist)

The observed metamorphic assemblage $\text{Grt}+\text{Ms}+\text{Bt}+\text{Chl}+\text{Pl}+\text{Qtz}+\text{Ilm}$ occurs in a wide stable field in the P - T pseudosection at ~ 0.4 - 7.2 kbar and 470 - 590°C (Figure 26a). The X_{alm} , X_{grs} , and X_{prp} isopleths with core composition ($\text{Alm}_{79.6}\text{Gr}_{12.2}\text{Prp}_{6.3}$) constrain the P - T conditions to ~ 4 - 4.5 kbar and 550 - 560°C (Figure 26a).

The modelled garnet compositional profile corresponds well to the measured profile for X_{sps} (Figure 26b). However, the model adequately captures the major variation

for the values of X_{alm} , X_{prp} , and X_{grs} , but subtle changes are not reflected in the model (Figure 26b). The calculated P-T path based on the garnet compositional zoning indicates an initial condition at ~4.3 kbar and 547°C, as determined from the core composition (Figure 26c). This path then progresses to around 5.9 kbar and 616°C, as indicated by the rim composition (Figure 26d).

The constructed P-T path shows two distinct segments that are related to textural and compositional variations in the garnet profile. The first segment is representative of the garnet core with inclusions of ilmenite and presents an increase in both pressure and temperature from ~4.3 kbar and 547°C to ~5.09 kbar and 564°C (Figure 26d). The following segment is representative of the inclusion-poor rim marked by an increase of X_{prp} and a decrease of X_{grs} (Figure 26b). This segment is characterized by a near-isobaric increase in temperature from ~5.09 kbar and 564°C to ~5.9 kbar and 616°C, ending in a stable field with Pl+Grt+Bt+Ms+Ilm+St+Qtz (Figure 26d).

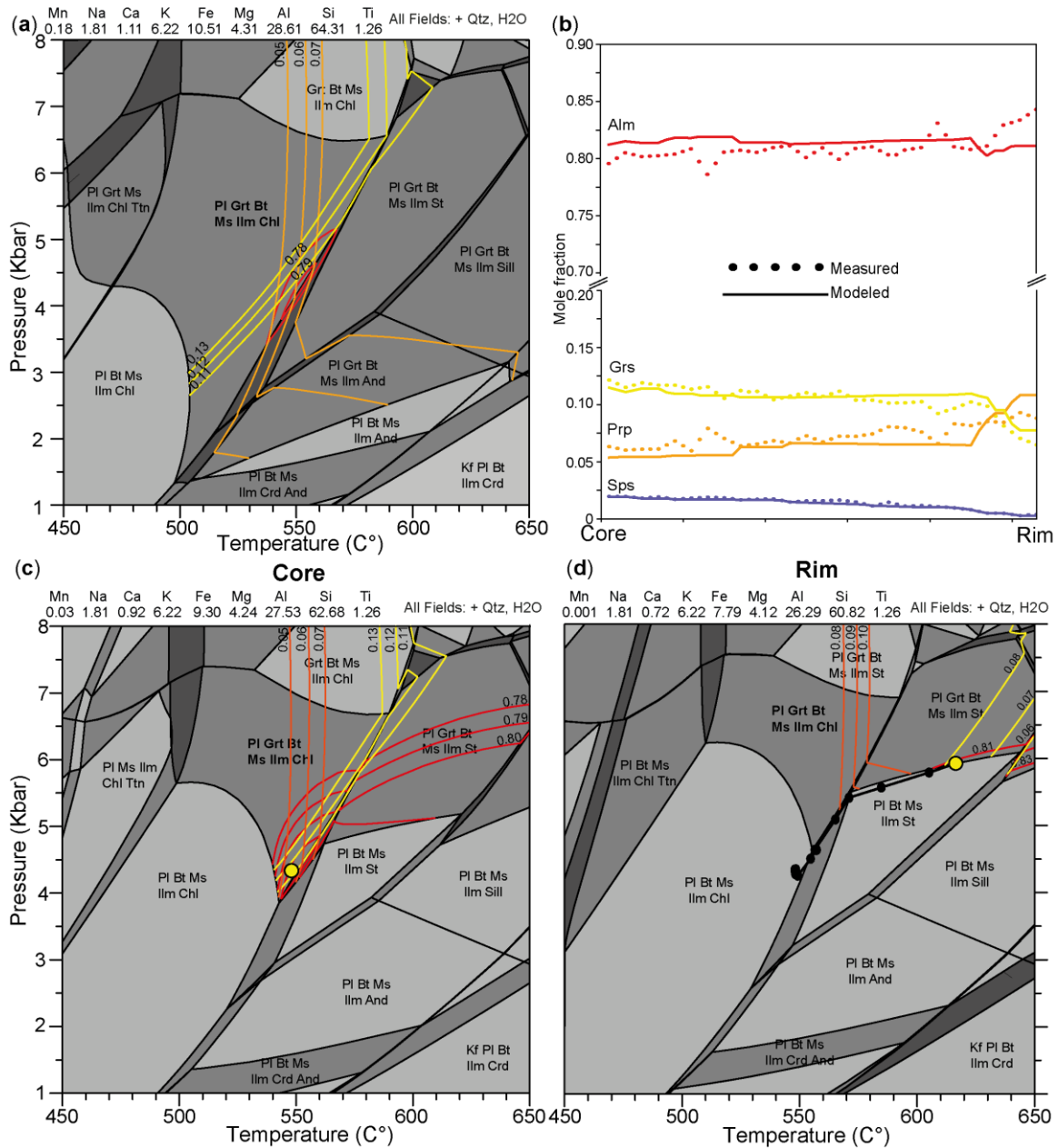


Figure 26. a) Calculated P-T pseudosection in the system MnO-Na₂O-CaO-K₂O-FeO-MgO-Al₂O₃-SiO₂-TiO₂-H₂O (MnNCKFMASHT) for the great-schist MR231, Serra da Mesa Group. **b)** Modeled garnet compositional profile vs. Measured garnet compositional profile. **c)** Calculated P-T pseudosection with initial garnet core composition. **d)** Calculated P-T pseudosection with garnet rim composition with the developed P-T path. The red, orange, and yellow lines indicate isopleths of X_{alm}, X_{prp}, and X_{grs}, respectively.

2.10 Zircon U-Pb geochronology

The analytical U-Pb data results are presented in Tables S8-S14 (Supplementary information). In total, 268 out of 330 spot analyses yielded concordant ages with less than 10% of discordance. Five samples of the Serra da Mesa Group were chosen for this study. Two from quartzites (samples BOLA-86 and CAMP-3) and three from schists (samples

PM-XII-9b, BOLA-79, and MR-231). Additionally, two samples from the Santa Terezinha Sequence were collected for this study, a quartzite (BOLA-26) and a paragneiss (BOLA-27). Their respective locations are shown in Figure 16. Under the BSE image, the zircon grains are rounded, homogeneous, and do not present a well-defined zoning pattern (Figure S1).

2.10.1 Serra da Mesa Group

U-Pb zircon data from pyrite schist BOLA-79 present a minimum age model (Galbraith, 2005; Vermeesch, 2021; MAM) of 1539 ± 16 Ma. The main population is between ca. 1700 and 2000 Ma with minor occurrences at ~ 1500 and 2300 Ma (Figure 27a). U-Pb zircon data from BOLA-86 have the MAM of 1536 ± 13 . The main population is between 1700 Ma and 2294 Ma with the principal peak at ca. 1975 Ma, and one Archean zircon grain (Figure 27b). Both samples have a high Th/U ratio (>0.1) varying from 0.184 to 1.174 (Figure 28).

The quartzite CAMP-03 presents a MAM of 802 ± 31 Ma. The U-Pb ages vary from 802 to 2980 Ma with two principal peaks at ca. 950 Ma and ca. 2150 Ma followed by older zircons grains until Mesoarchean (Figure 27c). The biotite-muscovite schist PM-XII-9b presents a MAM of 1454 ± 35 . U-Pb ages of the sample PM-XII-9b present a Paleoproterozoic main population between ~ 1700 and 2200 Ma with the principal peak at ca. 1900 Ma (Figure 27d). These samples have a high Th/U ratio (>0.1) varying from 0.106 to 3.001 with one Paleoproterozoic outlier with a 0.034 Th/U ratio (Figure 28).

The Grt schist MR-231 presents a MAM of 799 ± 3 Ma. U-Pb ages from sample MR-231 vary from 769 Ma to 2676 Ma with an important Neoproterozoic peak at ca. 800 Ma (Figure 27e). Zircons of sample MR-231 can be subdivided into two populations based on Th/U ratios. The population with a high Th/U ratio (>0.1) is characterized by a prominent Neoproterozoic peak followed by an equal age distribution until Paleoproterozoic (Figure 28). The other population with a low Th/U ratio (<0.1) has a restricted population at 800 Ma (Figure 28).

2.10.2 Santa Terezinha Sequence

Samples of quartzite (BOLA-26) and paragneiss (BOLA-27) from the easternmost margin of the Mara Rosa Magmatic Arc were chosen for U-Pb dating. Sample BOLA-26 presents a MAM of 835 ± 22 Ma. The U-Pb concordant ages from BOLA-26 range between 810 Ma and 2165 Ma with two prominent Meso-Paleoproterozoic clusters at 1800 Ma and 2000 Ma (Figure 27f). Sample BOLA-27 presents a MAM of 967 ± 18 Ma.

The U-Pb ages from sample BOLA-27 vary from 945 Ma to 2933 Ma with two prominent Meso-Paleoproterozoic clusters at 1300 Ma and 1900 Ma (Figure 27g). In general, spot analysis from both samples yielded high Th/U ratios (> 0.1) along with the age spectra (Figure 28).

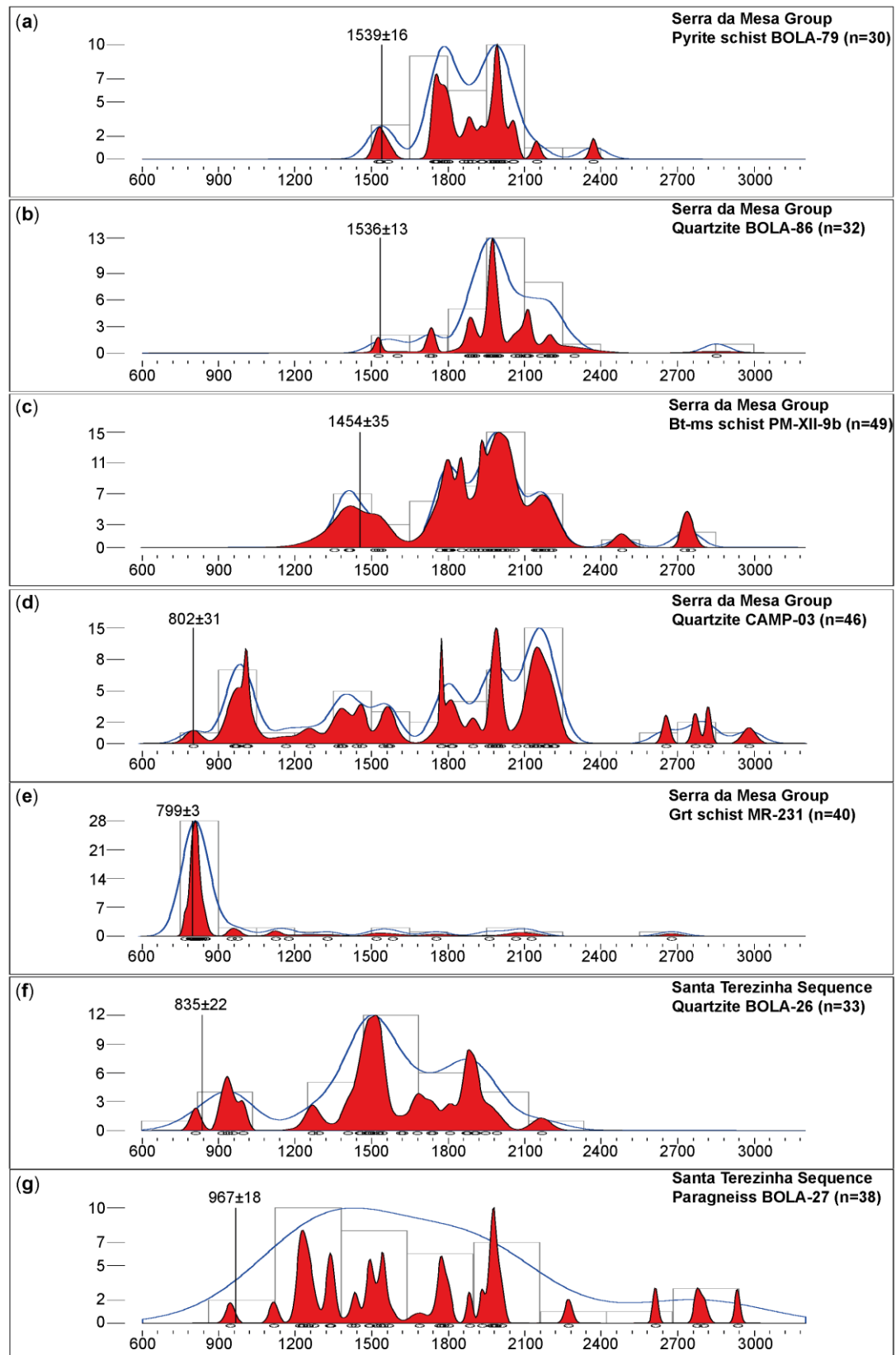


Figura 27. Histogram (white boxes), probability density plots (red filled curves), and kernel density estimate plots (blue lines) from samples (a) BOLA-79, (b) BOLA-86, (c) CAMP-03, (d) PM-XII-9b, and (e) MR-231 from Serra da Mesa Group. Samples (f) BOLA-26 and (g) BOLA-27 from Santa Terezinha sequence. The solid vertical line marks the minimum age model of each sample.

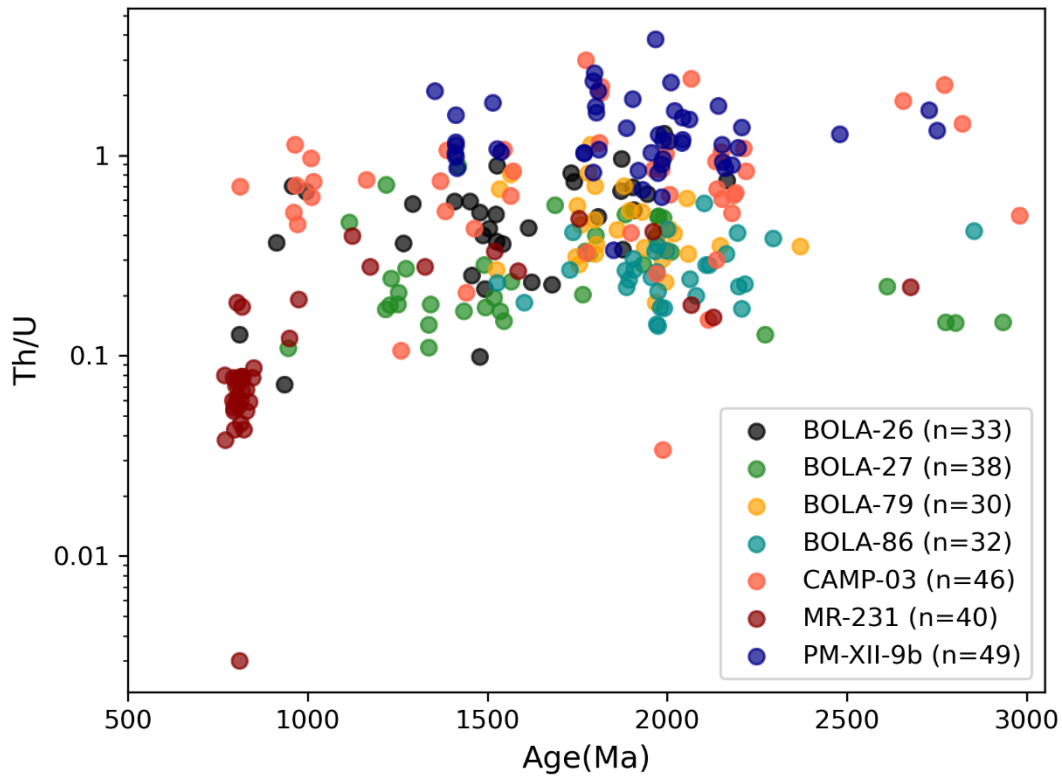


Figura 28. Concordia ages vs. Th/U ratio plot for zircon grains from metasedimentary rocks of the Santa Terezinha sequence (BOLA-26 and BOLA-27) and Serra da Mesa Group (BOLA-79, BOLA-86, CAMP-03, MR-231 and PM-XII-9b).

2.11 Discussion

2.11.1 Depositional age and tectonic setting of the Serra da Mesa Group

The scarcity of geochronological data in these metasedimentary rocks in the studied area led some authors (Dardenne, 2000; Oliveira et al., 2006; Valeriano et al., 2008) to establish correlations with the Mesoproterozoic Serra da Mesa Group, originally described to the north of the study area (Marini et al., 1984, Marques, 2009). In the present work, we collected five samples from the area where this unit was correlated only by lithological similarities with the region where the Serra da Mesa Group was originally proposed. Additionally, two samples from the Santa Terezinha Sequence were collected to establish some further correlation with the Serra da Mesa Group in the studied area.

Our results were analyzed through MDA, Cumulative proportion *versus* crystallization age minus deposition age diagram (Cawood et al., 2012), and Multidimensional Scaling plots to investigate its correlation. As discussed as follow, our proposition does not fully support the previous ones.

In order to constrain the tectonic setting of these metasedimentary rocks and make a first analysis of the tectonic environment of deposition, we used the cumulative

proportion vs. difference between crystallization age and depositional age (CA-DA) diagram proposed by Cawood et al., (2012). Here, we consider the minimum age model (Galbraith, 2005; Vermeesch, 2021) of each sample as its maximum depositional age (MDA; Figure 27) and use it as the possible depositional age (DA) in the diagram.

As shown in Figure 29, the quartzite BOLA-86, pyrite schist BOLA-79, and biotite-muscovite schist PM-XII-9b present cumulative probability curves that imply a collisional setting for their deposition. However, the CA-DA values less than 150 Ma are possibly related to a rift magmatic activity. Furthermore, this pattern resembles those from quartzites located at the north (Figure 29; samples PM-297 and PM 314 from Marques, 2009), where the Serra da Mesa Group was originally described, and from the Traíras Group (Figure 29; samples TFC02, TFC04, TFC05, and TFC06 from Martins-Ferreira et al. 2018). These metasedimentary rocks are correlated with the post-rift stage of the Araí Group represented by the Traíras Formation (Marini et al., 1984; Dardenne, 2000; Marques, 2009) or Traíras Group (Martins-Ferreira et al. 2018).

Thus, our samples may represent a southern expression of this Mesoproterozoic system, as indicated by their pattern similarities to those described by Marques (2009) and Martins-Ferreira et al. (2018) (Figure 29) and by the proximity of the samples in the MDS plot (Figure 30). Furthermore, the U-Pb ages obtained from our samples align with the proposed depositional interval of the Serra da Mesa Group as suggested by Dardenne (2000), ranging between 1.57 and 1.47 Ga. In this way, our data reinforces either the continuity of the Serra da Mesa Group to the region of this study and shows the Serra da Mesa Group as a lateral correlative of the Traíras Group (Martins-Ferreira et al. 2018) beyond the Rio Maranhão Thrust System.

The quartzite CAMP03 plots in the extensional setting but presents younger zircon grains reaching a younger age of 802 ± 31 Ma, with a secondary peak at ca. 960 Ma. Similar patterns are found in the samples from the Santa Terezinha Sequence which are plotted in the collisional field and present a uniform age distribution from ca. 900 Ma to 2100 Ma. These samples also form a cluster in the MDS plot (Figure 30) indicating a strong correlation between them. Although there are no reported ages of 960 Ma in the Goiás Magmatic Arc, the island arc event that took place between 900-800 Ma (Pimentel et al., 1991; Pimentel et al., 1997; Laux et al., 2005) is the closest possible magmatic source for this younger cluster of the samples BOLA-26, BOLA-27 and CAMP03. The oldest U-Pb zircon ages in the Goiás Magmatic Arc refer to a meta-rhyolite from the Arenópolis Arc that yielded an age of 929 ± 8 Ma (Pimentel et al., 1991). In the Mara

Rosa Arc segment, the older U-Pb age is from a metavolcanic rock that yielded an age of 916 ± 5 Ma (Matteini et al, 2010). Hence, these samples are most likely derived from a foreland basin formed during the collision of the island arc with the western margin of the São Francisco paleocontinent.

The Serra da Mesa garnet schist MR-231 and the Uruaçu Complex paragneiss CN101 fall within the convergent field (Figure 29), and both have a main Neoproterozoic population at ca. 770-800 Ma. This implies a strong influence of the island arc stage of the Goiás Magmatic Arc as a prominent source of these rocks. Nonetheless, this sample also presents zircon grains at ca. 2.7 Ga, 2.4-1.8 Ga, and 1.5-2.2 Ga, which may indicate cratonic (basement) sources and also possibly magmatic and sedimentary rift-related sources (Araí and Juscelândia rift systems) coming from São Francisco margin. The MDS plot (Figure 30) points out a strong similarity between the two samples suggesting that they both probably were deposited in the same basin.

Zircons of the garnet schist MR-231 have two populations with different Th/U rates (Figure 28). One with high rates (>0.1) and equal age distribution, from Archean to Neoproterozoic. The other has a lower rate (<0.1) and a population peak of around 800 Ma. In this way, the Th/U rate was changed at the source and there are two possibilities to interpret these ages. They can be related to a metamorphic age associated with the magmatic arc collision with the São Francisco craton or these zircons represent the erosion of these metamorphic rocks. Thereby this segment of the Serra da Mesa Group and the metasedimentary rocks of the Uruaçu Complex may have been deposited in a back-arc basin, fed by reworked arc/forearc and passive margin rocks.

Irrespective of the sedimentation model for the current Serra da Mesa Group, the geochronological data, including probability histograms, cumulative proportion diagram, and the multidimensional scaling plot, point out that the rocks within the same group originate from at least three distinct tectonic settings. The first one is related to Meso-Paleoproterozoic intracratonic extensional systems while the second is associated with a back/fore-arc setting peripheral to the island arc stage of Mara Rosa Magmatic Arc. Furthermore, the third tectonic setting is characterized by a sin-orogenic basin related to the island arc collision in the western margin of the São Francisco paleocontinent. These findings highlight a more complex geological history compared to the current model proposed for the group.

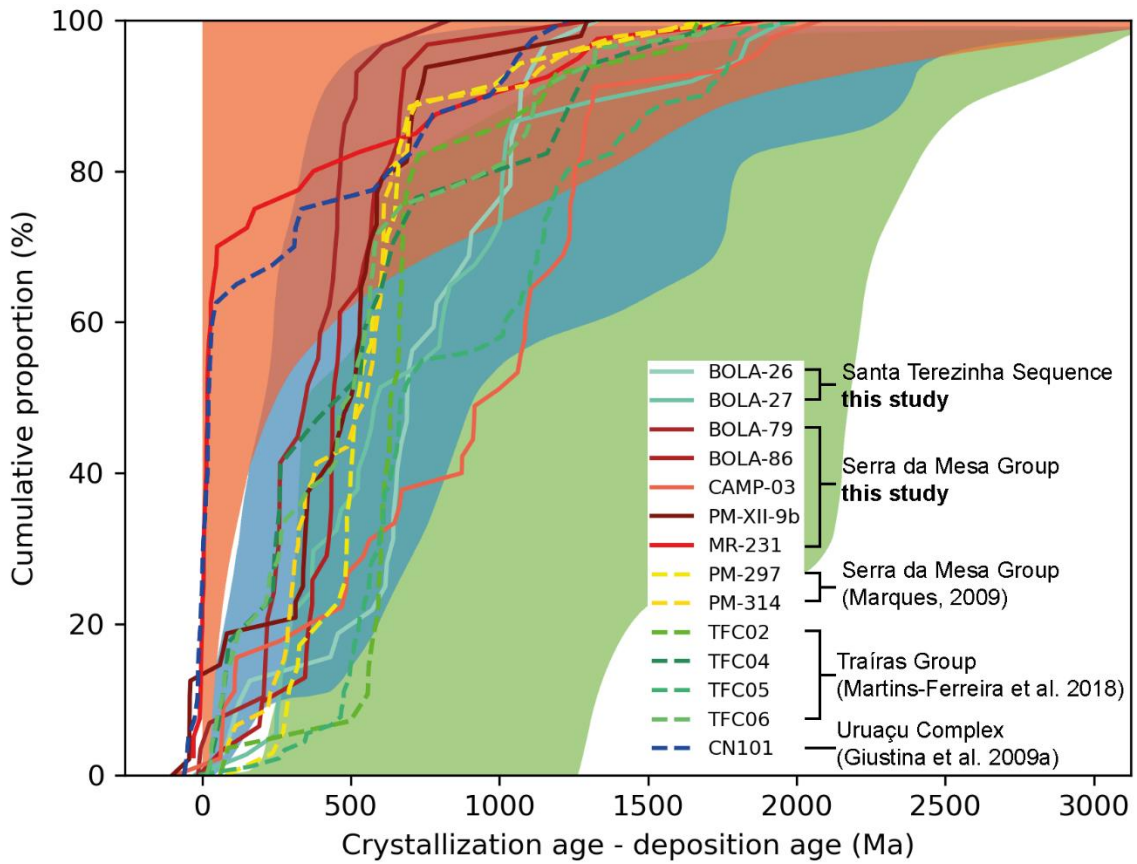


Figura 29. Cumulative proportion *versus* crystallization age minus deposition age diagram (Cawood et al., 2012) for the Serra da Mesa Group, Santa Terezinha Sequence and Uruaçu Complex. Fields for convergent (red), collisional (blue), and extensional (green) basins. Solid lines are samples from this study while the dashed lines are samples from Giustina et al. 2009a, Marques, 2009, and Martins-Ferreira et al. 2018.

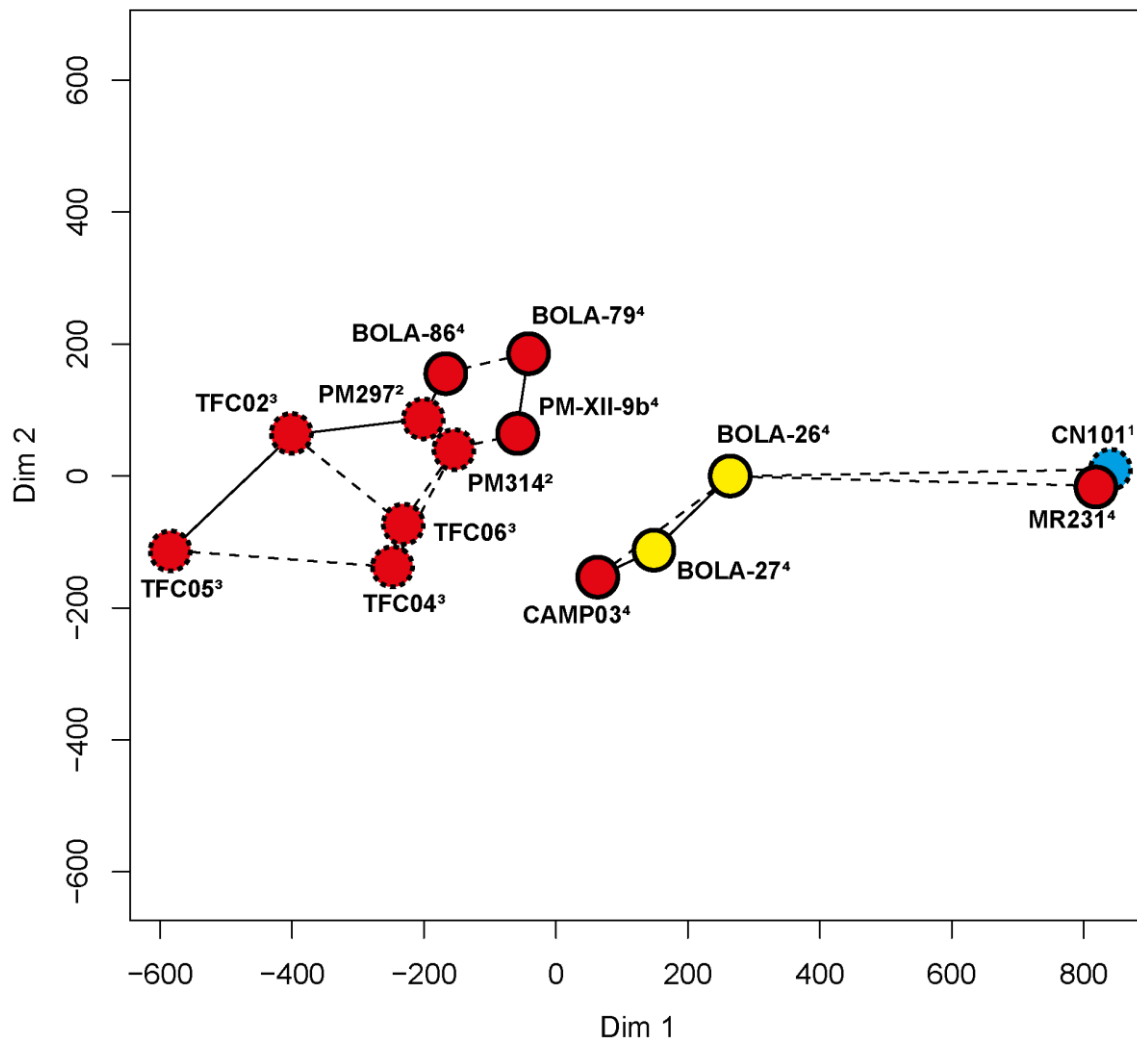


Figura 30. Multidimensional Scaling (MDS) plot of the Serra da Mesa Group (red circles), Uruaçu Complex (blue circle) and Santa Terezinha Sequence (yellow circles) U-Pb data. The nearest neighbor is connected with solid lines while the second-closest neighbor is connected with dashed lines (Vermeesch, 2013, 2018). The compiled samples are represented in dashed circles while the samples from this study are in solid lines. 1-Giustina et al. (2009a); 2-Marques (2009); 3-Martins-Ferreira et al. (2018); 4-This study.

2.11.2 Tectono-metamorphic evolution of the Uruaçu Complex and the Serra da Mesa Group

Based on pseudosection modelling and conventional thermobarometry, the rocks from Uruaçu Complex reached amphibolite facies peak metamorphism at $\sim 700^{\circ}\text{C}$ and ~ 7 kbar followed by cooling and decompression to $\sim 551^{\circ}\text{C}$ and ~ 4.4 kbar (Figure 31a). The surrounding rocks from the Serra da Mesa Group exhibit initial conditions at the transition of greenschist and amphibolite facies ($550\text{--}560^{\circ}\text{C}$ and $\sim 4\text{--}4.5$ kbar) and reached peak conditions within amphibolite facies (616°C and 5.9 kbar) (Figure 31a). This overall metamorphic evolution suggests a potential clockwise P - T path evolution for the rocks

from Uruaçu Complex and the Serra da Mesa Group, however under different crustal and metamorphic conditions (Figure 31a).

The clockwise P - T paths are a common feature in metamorphic rocks from modern collisional orogens being observed in natural examples and numerical models (Chowdhury et al., 2021). The occurrences of collisional orogens have been reported since the Neoproterozoic (Condie et al., 2015; Condie, 2018). Their style has evolved since its recognition due to the progressive cooling of the mantle over time (Holder et al., 2019; Brown et al., 2020; Chowdhury et al., 2021) with the Neoproterozoic marking the onset of the modern collisional orogen regime (Stern, 2018; Chowdhury et al., 2021).

The presence of normal faults cross-cutting the rocks from Uruaçu Complex, and the south portion of the Serra da Mesa Group may imply an extensional phase in the orogen. Following this hypothesis, the Uruaçu Complex could be interpreted as a metamorphic core complex, as suggested by Cordeiro et al. (2014). Nonetheless, according to Platt et al. (2015), a metamorphic core complex comprises three principal elements: (1) a core of ductile deformed metamorphic rocks from mid-crust or deeper; (2) a subhorizontal tectonic discontinuity and, (3) the lower-grade hanging-wall rocks that occur above the detachment zone. Additionally, the author suggests that intrusive or diapiric rock bodies such as plutons, salt domes, and gneiss domes should not be classified as metamorphic core complex.

In the Uruaçu Complex region, it is noted however the lack of two evidences. The first is the absence of a syn-extensional basin, which is not critical, once as a shallow basin it may have been eroded. The second is the lack of low-angle normal detachment fault, which, until now, rules out the structure in the classification of core complex defined by Platt et al. (2015). Alternatively, these normal faults can also be interpreted either as high-angle syn-orogenic detachments (Vanderhaeghe, 2012), generated to accommodate the vertical exhumation of the complex in response to crustal thickening or they may be associated with a later extensional event unrelated to the exhumation of the complex.

Considering:

(I) the structural framework of the Uruaçu Complex which can be described by a dome shape, with circular foliation (Figure 16), surrounded by lower-grade metamorphic rocks from the Serra da Mesa Group.

(II) the metamorphic conditions, where the Uruaçu Complex described a clockwise P - T path, coupled with the geochronological data present by Giustina et al. (2009a), that constrain the peak metamorphism at ca. 650 Ma.

(III) the maximum depositional age of the Uruaçu Complex and the Serra da Mesa Group which are constrained at 770 ± 5 Ma and 799 ± 3 Ma, respectively.

we propose the possibility that the exhumation of the Uruaçu Complex took place through diapiric ascent, driven by crustal thickening during the tardi-collisional phase of the Brasília Orogen. In this model, the U-Pb crystallization (~ 670 Ma) and metamorphic (~ 650 Ma) ages of the Uruaçu Complex (Table 1, Giustina et al. 2009a) are related to the collisional stage in the Brasília Orogen. During this time interval, it is likely that the crust in the Brasília Orogen experienced its most significant thickening, which favors the exhumation of the complex by diapirism.

Thus, numerical models point out that metamorphic phase transformations associated with amphibolite and granulite facies can induce gravitational instability leading to doming and diapirism in hot continental crust (Gerya et al., 2004). Also, a slightly density difference of $\sim 0.2 \text{ g.cm}^{-3}$ between the gneiss core and the surrounding rocks can trigger diapirism (Soula et al. 2001; Teyssier and Whitney, 2002).

The precise relationship between the normal faults and the Uruaçu Complex remains uncertain and further investigations are required to understand their significance in the complex exhumation process. Given that diapirism can induce normal faulting in the upper crust, and extensional tectonics can also lead to diapirism, with the possibility of these processes being coupled (Fayon et al. 2004), determining the timing of each mechanism becomes essential in assessing their individual contributions to the exhumation of the gneiss dome.

Regarding the geothermal gradient indicated by samples CN101, CAMP04, and MR-231, 1054°C/Gpa , 1257°C/Gpa , and 1044°C/Gpa respectively, we observe that they are consistent with the higher geothermal gradient observed in this segment of the Brasília Orogen (Figure 31a). In the Northern Brasília Belt thermal gradient is predominantly restricted to the high T/P ratio for both metamorphic events (Figures 2b and 18). Among others, high T/P ratios are associated with a back-arc setting where the lithosphere is hot and thin (De Yoreo et al. 1991; Hyndman et al. 2005; Liu et al. 2022). Considering the metamorphism in ca. 650 Ma (Giustina et al. 2009a), and possible subduction dipping eastward, this crustal setting could be suitable for the region of samples. Corroborating with this interpretation, seismic data of Soares et al. (2006) indicate a thinner crust beneath this terrane. This feature is typical of back-arc systems where extension takes place, usually accompanied by asthenosphere ascending.

In a broader context, this tectonic setting is suitable for the northern segment internal zone considering the metamorphic data together with the seismic data of Soares et al. (2006), which indicate a thinner crust beneath this terrane.

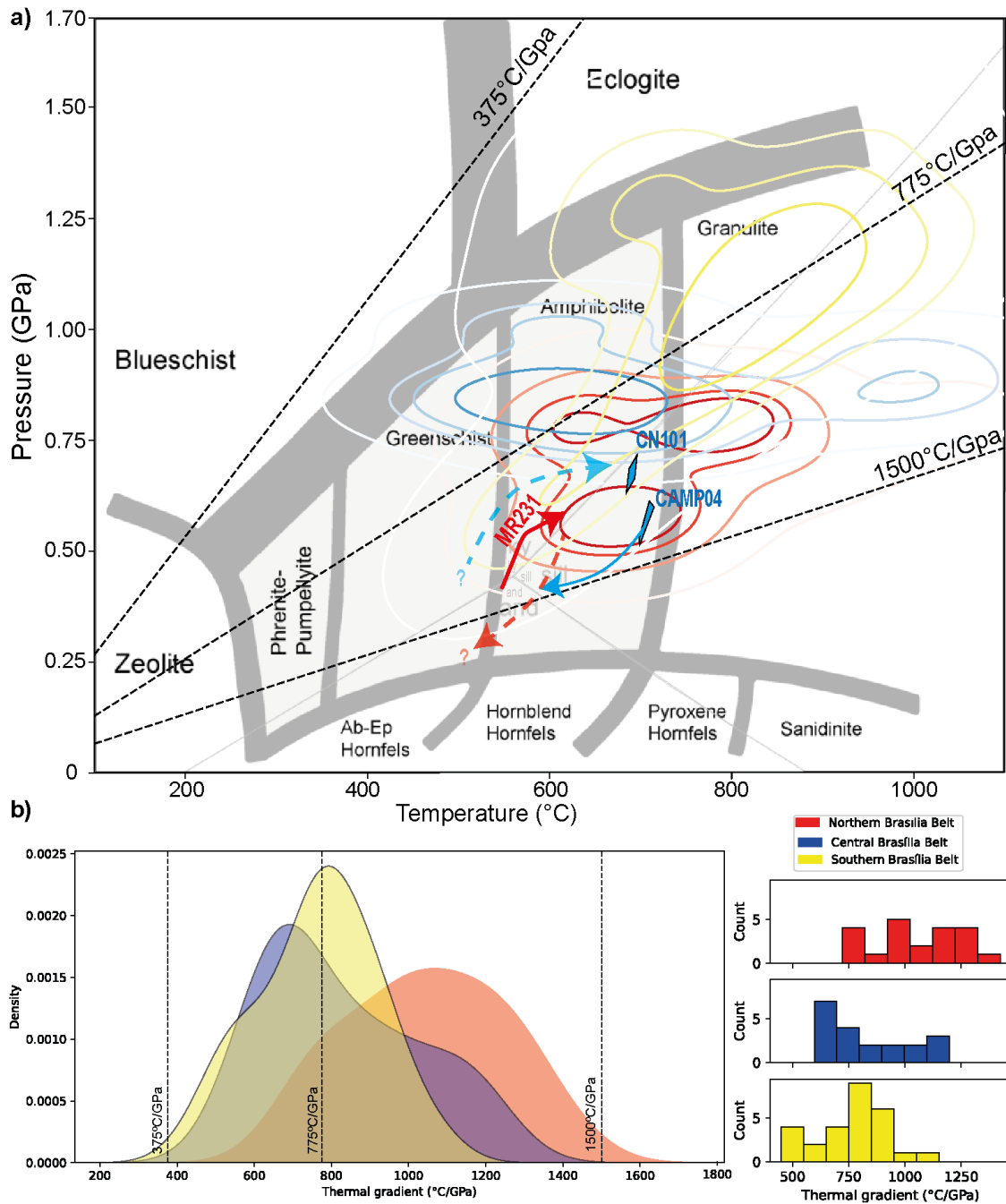


Figure 31. a) P-T diagram for the Uruaçu Complex (blue polygons) and the Serra da Mesa Group (red curve) with the kernel density estimates (KDE) of metamorphic conditions of the rocks from the Brasília Orogen. The red curve represents the constructed P-T path based on the garnet compositional profile for the garnet schist from the Serra da Mesa Group. **b)** KDE and histograms from the compiled thermal gradient from the different segments of the Brasília Orogen.

2.11.3 Implications on the Brasília Orogen

The Brasília Orogen preserves a protracted Neoproterozoic accretionary to collisional evolution from 900 Ma to 600 Ma (Dardenne, 2000; Valeriano et al. 2008; Pimentel, 2016; Fuck et al., 2017). This intricate geological history commenced with the formation of an intraoceanic island arc between 900 Ma and 800 Ma, followed by a second magmatic event associated with a continental arc setting between 670 Ma and 610 Ma (Pimentel et al., 1997; Junges et al., 2002, Laux et al., 2005). The closure of the Goiás-Pharusian Ocean marks the continental collision of the Amazon Craton and São Francisco Craton at ca. 650-630 Ma in the Northern Brasília Belt (Pimentel et al. 1997; Junges et al. 2002; Pimentel, 2016; Fuck et al. 2017).

The metamorphic rocks can be classified into three groups based on the thermal gradient, or thermobaric ratio (T/P), those with high T/P ($>775^{\circ}\text{C}/\text{GPa}$), intermediate T/P ($775\text{-}375^{\circ}\text{C}/\text{GPa}$), and low T/P ($<375^{\circ}\text{C}$) ratios (Brown & Johnson, 2018). The classification of the Brasília Orogen metamorphic rocks relying on these criteria constrains them within the high and intermediate ratios field (Figure 31). Furthermore, the three segments of the orogen present different thermal gradient distributions with decreasing ratios toward the south. The northern segment features high T/P conditions while the central and southern segments display intermediate T/P (Figures 14 and 31).

Regarding the tectonic setting of mafic-ultramafic complexes found in the Northern Brasília belt (Figure 14), two hypotheses are prevailing to explain their origin. The first one views these complexes as two distinct magmatic systems: one Mesoproterozoic (~ 1.25 Ga) and the other Neoproterozoic (~ 0.8 Ga), both associated with a continental rift opening and subsequently undergoing amphibolite to granulite metamorphism around ~ 0.76 Ga (Pimentel et al. 2004; Ferreira Filho et al. 2010; Giustina et al. 2011). Also, Pimentel et al. (2004) and Ferreira Filho et al. (2010) suggest that the complexes are part of an exotic block accreted onto the margins of the São Francisco craton during the Neoproterozoic. On the other hand, Correia et al. (2012) and Giovanardi et al. (2017) argues that the complexes are a product of a single igneous activity between ~ 810 and 770 Ma within a back-arc setting. Moreover, Giovanardi et al. (2018) attribute the ~ 1.25 Ga age to inherited zircons from the country rocks.

Although there is still no agreement about the tectonic setting of mafic-ultramafic complexes found in the Northern Brasilia system, here we consider the first hypothesis based on the metamorphic imprint at ~ 0.76 Ga. This proposition also aligns with the low

Th/U zircon signatures in the provenance data of the sample MR-231, which shows a metamorphic population peak at 800 Ma. However, considering the studies of Moraes et al. (2006), Del Rey et al. (2008), Cordeiro and Oliveira (2017), and Reis et al. (2020), which reevaluated the role of the Rio Maranhão Thrust System as an intracontinental structure rather than a suture zone, we interpreted that these igneous and metamorphic events occurred within the São Francisco paleocontinent instead of within an exotic block.

In this way, our sedimentary provenance, metamorphic data, and results combined with previously published works allow the elaboration of the following interpretative model for the Northern Brasília System and emplacement of Uruaçu Complex (Figure 32).

Island arc stage I: Development of the Mara Rosa island arc with the generation of juvenile calci-alkaline magmatic suites and volcano-sedimentary sequences between 0.9 and 0.8 Ga. On the margins of this island arc, the deposition of the metasedimentary rocks from the Uruaçu Complex and the Serra da Mesa Group occurs. Eastwards from the intraoceanic magmatic arc is located the São Francisco paleocontinent with the record of several rifting stages at ca. 1.7, 1.5, 1.2 Ga.

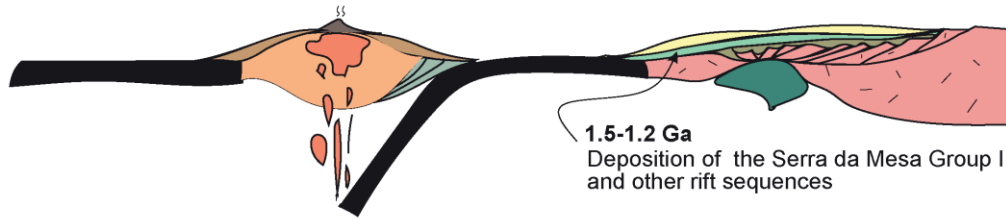
Island arc stage II: Collision of the island arc with the western margin of the São Francisco Craton marked by the metamorphic record in the Mara Rosa Magmatic Arc and in the mafic-ultramafic complexes. During the arc-continent collision occurs the deposition of sediments from the previously described Serra da Mesa Group and the Santa Terezinha Sequence, located in the east of the Magmatic Arc, in a foreland basin.

Continental arc stage: Development of a continental arc associated with the Santa Terezinha Sequence between 0.67 Ga and 0.65 Ga.

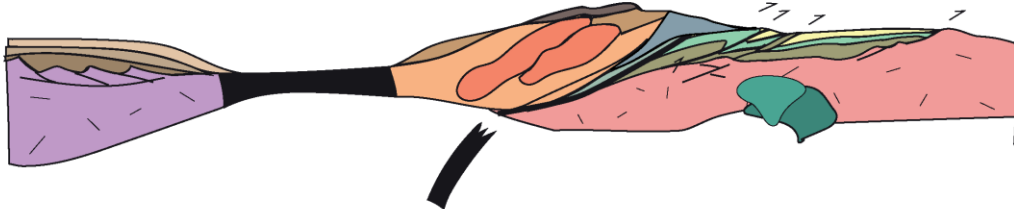
Collisional Stage: Closing of the Goiás-Pharusian Ocean and collision between the Amazon and São Francisco palaeocontinents. The second metamorphic event affecting rocks from the Mara Rosa Sequence, Serra da Mesa Group, and Uruaçu Complex under amphibolite facies. Formation and diapiric ascent of the Uruaçu Complex due to crustal overthickening.

Orogenic collapse: Onset of the extensional tectonics recorded by the normal faults.

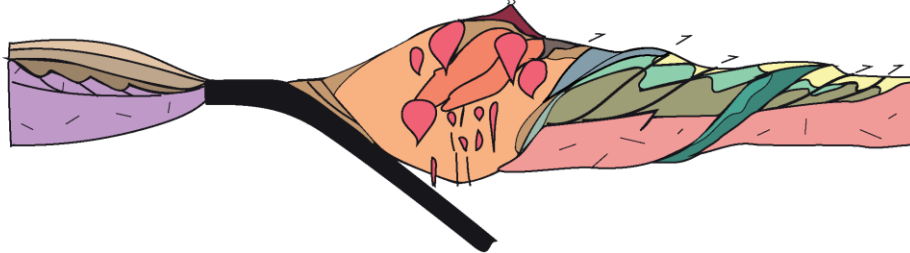
0.9-0.8 Ga: Island arc stage I: Development of the Mara Rosa magmatic arc



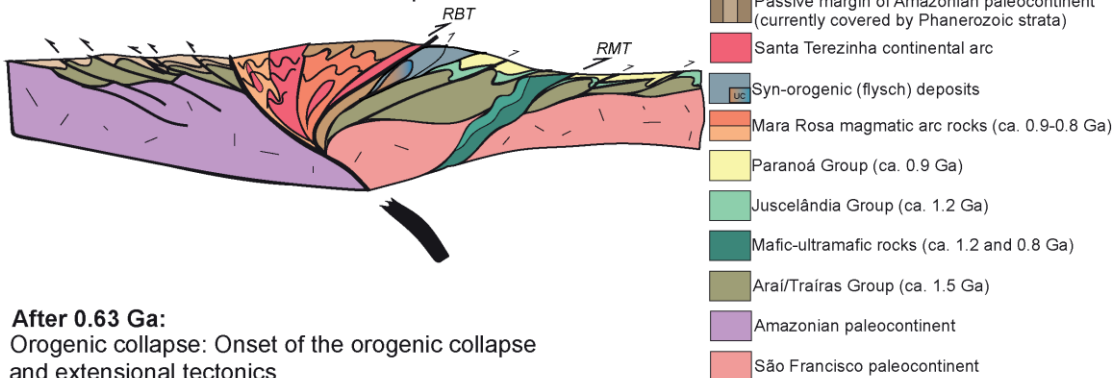
0.8-0.75 Ga: Island arc stage II: Collision of the Mara Rosa magmatic arc with the São Francisco paleocontinent



0.67-0.65 Ga: Continental arc stage: Development of the Stª Terezinha Sequence



0.65-0.63 Ga: Collisional stage: Collision between the Amazonian and the São Francisco paleocontinents



After 0.63 Ga:
Orogenic collapse: Onset of the orogenic collapse and extensional tectonics

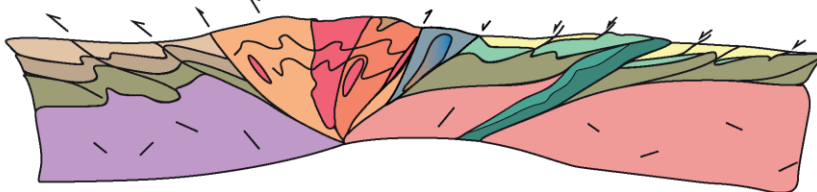


Figura 32. Tectonic evolution model for the Northern Brasília Belt.

2.12 Conclusions

The new field data, metamorphic modelling, and detrital zircon U-Pb data provides advances in the tectonic significance of the Uruaçu Complex and its metasedimentary cover on the Northern Brasília Belt. The metamorphic modelling by pseudosection coupled with previous geochronological studies (Giustina et al., 2009a)

constrain an amphibolite facies peak (7 kbar and 700°C) at ca. 650 Ma for the Uruaçu Complex, rather than a UHT condition previously postulated, with retrometamorphism in greenschist facies (4.42 kbar and 551°C). Also, the metamorphic modelling based on the garnet compositional profile predicts a *P-T* path from ~4.3 kbar and ~547°C to ~5.9 kbar and ~616°C for the garnet schist from the Serra da Mesa Group. Furthermore, the thermal gradient exhibited by both units aligns with the gradient observed in the compiled data from the Northern Brasília Belt.

The U-Pb detrital zircons from the metasedimentary cover analyzed through the Cumulative proportion *versus* crystallization age minus deposition age diagram and by the multidimensional scaling plot suggest that the sediments from the Serra da Mesa Group in the study region were deposited in three different basins: (1) Paleo- to Mesoproterozoic intracontinental extensional basin which can be the lateral correlative of the Traíras Group; (2) Neoproterozoic fore/ back-arc basin in the margins of the Mara Rosa Magmatic Arc, and (3) Neoproterozoic foreland basin also associated with the eastern portion of the Santa Terezinha Sequence.

The identified normal structures constitute preliminary evidence of Neoproterozoic extensional tectonics within the Northern Brasília Belt. Nevertheless, their precise role and timing in the orogenic evolution require further investigation.

2.13 Acknowledgments

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CAPÍTULO 3

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4 SUPPLEMENTARY INFORMATION

Table S 1. Whole rock composition of samples used in pseudosection modeling.

Sample	CN101	CAMP04	MR231
SiO ₂	69.89	47.98	54.49
TiO ₂	0.67	2.36	1.42
Al ₂ O ₃	13.7	13.54	20.57
Fe ₂ O ₃	4.9	15.387	11.83
MnO	b.d.l.	0.24	0.18
MgO	1.36	6.24	2.45
CaO	1.53	9.11	0.88
Na ₂ O	2.49	2.73	0.79
K ₂ O	4.61	0.38	4.13
P ₂ O ₅	0.15	0.23	0.22
LOI	0.6	0.58	2.62
Total	99.89	99.25	99.58

b.d.l.: below detection limit; LOI: loss on ignition

Table S 2. Microprobe analyses of feldspar from samples CN113A, CN101, CAMP04, and GT-41.4.

		Weight percent oxides											Atoms per 8 Oxygen											End-member			
Sample	Spot	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	FeO	MnO	MgO	CaO	BaO	Na ₂ O	K ₂ O	Total	Si	Ti	Al	Cr	Fe2	Mn	Mg	Ca	Ba	Na	K	An	Ab	Or
CN113A	1	64.19	0.00	19.17	0.00	0.00	0.00	0.00	0.02	1.15	1.18	14.46	100.18	2.97	0.00	1.05	0.00	0.00	0.00	0.00	0.00	0.02	0.11	0.85	0.11	11.03	88.86
CN113A	2	64.08	0.00	18.74	0.00	0.00	0.00	0.01	0.01	1.31	0.85	14.56	99.57	3.00	0.00	1.03	0.00	0.00	0.00	0.00	0.00	0.02	0.08	0.87	0.06	8.13	91.82
CN113A	3	64.69	0.00	18.98	0.00	0.00	0.01	0.01	0.01	1.21	0.94	14.77	100.62	2.99	0.00	1.03	0.00	0.00	0.00	0.00	0.00	0.02	0.08	0.87	0.06	8.79	91.15
CN113A	4	64.09	0.00	18.76	0.00	0.00	0.03	0.00	0.01	1.27	0.80	15.13	100.08	2.98	0.00	1.03	0.00	0.00	0.00	0.00	0.00	0.02	0.07	0.90	0.04	7.39	92.57
CN113A	5	64.53	0.00	18.71	0.00	0.03	0.00	0.00	0.04	1.59	0.82	14.70	100.41	3.00	0.00	1.02	0.00	0.00	0.00	0.00	0.00	0.03	0.07	0.87	0.23	7.76	92.01
CN113A	6	60.77	0.00	25.45	0.00	0.02	0.01	0.00	6.81	0.06	7.58	0.15	100.84	2.69	0.00	1.33	0.00	0.00	0.00	0.00	0.32	0.00	0.65	0.01	32.88	66.25	0.87
CN113A	7	60.21	0.00	25.46	0.00	0.05	0.03	0.00	6.95	0.00	7.27	0.11	100.07	2.69	0.00	1.34	0.00	0.00	0.00	0.00	0.33	0.00	0.63	0.01	34.36	65.01	0.63
CN113A	8	60.26	0.00	25.47	0.02	0.01	0.00	0.00	6.77	0.01	7.49	0.11	100.14	2.69	0.00	1.34	0.00	0.00	0.00	0.00	0.32	0.00	0.65	0.01	33.10	66.24	0.65
CN113A	9	60.38	0.02	25.56	0.00	0.07	0.02	0.00	6.74	0.01	7.47	0.12	100.41	2.68	0.00	1.34	0.00	0.00	0.00	0.00	0.32	0.00	0.64	0.01	33.01	66.26	0.72
CN113A	10	59.30	0.02	25.63	0.00	0.03	0.01	0.00	6.99	0.00	7.10	0.12	99.20	2.67	0.00	1.36	0.00	0.00	0.00	0.00	0.34	0.00	0.62	0.01	34.98	64.29	0.73
CN113A	11	60.74	0.02	25.75	0.00	0.05	0.01	0.00	7.00	0.02	7.25	0.11	100.95	2.69	0.00	1.34	0.00	0.00	0.00	0.00	0.33	0.00	0.62	0.01	34.57	64.76	0.66
CN113A	12	59.19	0.00	25.41	0.00	0.10	0.00	0.10	6.63	0.00	6.90	0.28	98.60	2.69	0.00	1.36	0.00	0.00	0.00	0.01	0.32	0.00	0.61	0.02	34.10	64.20	1.70
CN113A	13	61.61	0.00	25.49	0.00	0.02	0.03	0.01	6.65	0.03	7.64	0.15	101.61	2.71	0.00	1.32	0.00	0.00	0.00	0.00	0.31	0.00	0.65	0.01	32.22	66.94	0.84
CN113A	14	58.86	0.00	25.21	0.07	0.06	0.00	0.00	7.01	0.06	6.89	0.14	98.28	2.68	0.00	1.35	0.00	0.00	0.00	0.00	0.34	0.00	0.61	0.01	35.70	63.48	0.82
CN113A	21	59.85	0.06	25.47	0.01	0.10	0.00	0.01	7.17	0.04	7.30	0.09	100.10	2.67	0.00	1.34	0.00	0.00	0.00	0.00	0.34	0.00	0.63	0.01	35.00	64.45	0.55
CN113A	23	60.25	0.00	25.75	0.00	0.04	0.00	0.00	6.98	0.04	7.39	0.12	100.56	2.68	0.00	1.35	0.00	0.00	0.00	0.00	0.33	0.00	0.64	0.01	34.06	65.24	0.70
CN113A	25	60.10	0.03	25.69	0.00	0.13	0.01	0.00	6.75	0.04	7.43	0.18	100.35	2.67	0.00	1.35	0.00	0.00	0.00	0.00	0.32	0.00	0.64	0.01	33.09	65.89	1.02
CN113A	26	60.07	0.01	25.47	0.00	0.00	0.02	0.00	6.74	0.00	7.59	0.13	100.03	2.68	0.00	1.34	0.00	0.00	0.00	0.00	0.32	0.00	0.66	0.01	32.67	66.58	0.76
CN113A	27	60.40	0.00	25.64	0.00	0.10	0.03	0.00	6.93	0.00	7.55	0.11	100.77	2.67	0.00	1.34	0.00	0.00	0.00	0.00	0.33	0.00	0.65	0.01	33.46	65.90	0.64
CN113A	63	59.53	0.01	25.98	0.01	0.13	0.08	0.00	7.22	0.02	7.30	0.09	100.36	2.65	0.00	1.36	0.00	0.00	0.00	0.00	0.34	0.00	0.63	0.00	35.18	64.32	0.50
CN113A	64	60.32	0.02	25.97	0.00	0.08	0.02	0.00	7.04	0.04	7.38	0.11	100.97	2.67	0.00	1.35	0.00	0.00	0.00	0.00	0.33	0.00	0.63	0.01	34.30	65.06	0.64
CN113A	66	60.11	0.00	25.83	0.00	0.04	0.01	0.00	7.07	0.00	7.43	0.10	100.59	2.67	0.00	1.35	0.00	0.00	0.00	0.00	0.34	0.00	0.64	0.01	34.26	65.16	0.57
CN113A	67	60.36	0.00	25.91	0.00	0.06	0.02	0.00	7.11	0.03	7.34	0.11	100.92	2.67	0.00	1.35	0.00	0.00	0.00	0.00	0.34	0.00	0.63	0.01	34.66	64.72	0.62
CN113A	68	59.62	0.02	25.59	0.00	0.04	0.00	0.00	6.93	0.01	7.48	0.12	99.82	2.66	0.00	1.35	0.00	0.00	0.00	0.00	0.33	0.00	0.65	0.01	33.63	65.70	0.67
CN113A	69	60.06	0.00	25.49	0.00	0.07	0.00	0.01	7.08	0.00	7.44	0.14	100.27	2.67	0.00	1.34	0.00	0.00	0.00	0.00	0.34	0.00	0.64	0.01	34.20	65.01	0.79
CN113A	70	60.40	0.02	25.68	0.00	0.04	0.03	0.00	6.82	0.02	7.16	0.11	100.27	2.69	0.00	1.35	0.00	0.00	0.00	0.00	0.33	0.00	0.62	0.01	34.26	65.10	0.64
CN113A	71	60.42	0.02	25.73	0.00	0.04	0.02	0.00	6.91	0.00	7.30	0.12	100.56	2.68	0.00	1.35	0.00	0.00	0.00	0.00	0.33	0.00	0.63	0.01	34.11	65.20	0.69
CN113A	72	60.28	0.03	25.70	0.00	0.00	0.00	0.00	7.00	0.01	7.32	0.12	100.46	2.68	0.00	1.35	0.00	0.00	0.00	0.00	0.33	0.00	0.63	0.01	34.35	64.96	0.68
CN113A	73	60.24	0.00	25.89	0.00	0.04	0.00	0.00	7.06	0.06	7.58	0.12	100.98	2.66	0.00	1.35	0.00	0.00	0.00	0.00	0.33	0.00	0.65	0.01	33.75	65.59	0.66
CN113A	74	59.42	0.02	25.06	0.00	0.13	0.01	0.02	6.61	0.03	7.31	0.22	98.84	2.68	0.00	1.33	0.00	0.00	0.00	0.00	0.32	0.00	0.64	0.01	32.88	65.82	1.30
CN113A	76	60.54	0.01	25.93	0.02	0.03	0.00	0.02	7.04	0.06	7.35	0.12	101.11	2.68	0.00	1.35	0.00	0.00	0.00	0.00	0.33	0.00	0.63	0.01	34.39	64.90	0.71
CN113A	77	60.16	0.00	25.93	0.01	0.10	0.00	0.00	6.96	0.06	7.24	0.11	100.56	2.67	0.00	1.36	0.00	0.00	0.00	0.00	0.33	0.00	0.62	0.01	34.45	64.88	0.67
CN113A	78	63.27	0.00	18.73	0.00	0.06	0.02	0.01	0.02	1.34	1.21	14.36	99.03	2.97	0.00	1.03	0.00	0.00	0.00	0.00	0.00	0.02	0.11	0.86	0.10	11.36	88.55

CN113A	79	64.17	0.00	19.01	0.00	0.00	0.03	0.00	0.00	1.30	1.25	14.80	100.55	2.96	0.00	1.03	0.00	0.00	0.00	0.00	0.00	0.02	0.11	0.87	0.00	11.36	88.64
CN113A	80	64.66	0.00	19.10	0.00	0.01	0.00	0.00	0.01	1.33	1.17	14.73	101.02	2.97	0.00	1.03	0.00	0.00	0.00	0.00	0.00	0.02	0.10	0.86	0.05	10.77	89.18
CN113A	81	64.13	0.00	18.91	0.00	0.00	0.00	0.00	0.01	1.50	1.04	15.00	100.59	2.96	0.00	1.03	0.00	0.00	0.00	0.00	0.00	0.03	0.09	0.88	0.05	9.52	90.43
CN101	8	64.10	0.00	18.89	0.00	0.04	0.01	0.02	0.12	0.48	0.86	15.50	100.00	2.96	0.00	1.03	0.00	0.00	0.00	0.00	0.01	0.01	0.08	0.91	0.58	7.76	91.65
CN101	9	64.74	0.00	18.70	0.00	0.00	0.00	0.01	0.00	0.50	0.64	15.72	100.31	2.99	0.00	1.02	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.93	0.00	5.82	94.18
CN101	10	64.88	0.00	18.68	0.00	0.03	0.00	0.01	0.11	0.45	0.94	15.05	100.16	3.00	0.00	1.02	0.00	0.00	0.00	0.00	0.01	0.01	0.08	0.89	0.57	8.65	90.78
CN101	11	64.11	0.00	19.46	0.00	0.00	0.05	0.01	0.71	0.23	2.82	12.47	99.87	2.93	0.00	1.05	0.00	0.00	0.00	0.00	0.03	0.00	0.25	0.73	3.44	24.72	71.84
CN101	12	64.22	0.00	18.58	0.00	0.00	0.00	0.01	0.04	0.69	0.71	15.36	99.62	2.99	0.00	1.02	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.91	0.19	6.55	93.26
CN101	13	64.95	0.00	18.75	0.00	0.01	0.01	0.00	0.00	0.61	0.73	15.74	100.81	2.98	0.00	1.02	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.92	0.01	6.57	93.42
CN101	14	64.98	0.00	18.49	0.00	0.01	0.00	0.00	0.09	0.41	0.79	15.41	100.18	3.00	0.00	1.01	0.00	0.00	0.00	0.00	0.00	0.01	0.07	0.91	0.44	7.16	92.40
CN101	15	64.87	0.00	18.68	0.00	0.03	0.00	0.00	0.08	0.41	0.86	15.57	100.49	2.98	0.00	1.01	0.00	0.00	0.00	0.00	0.00	0.01	0.08	0.91	0.41	7.74	91.85
CN101	16	64.13	0.00	18.64	0.00	0.02	0.00	0.01	0.10	0.46	0.84	15.84	100.04	2.96	0.00	1.01	0.00	0.00	0.00	0.00	0.01	0.01	0.08	0.93	0.51	7.41	92.08
CN101	17	64.15	0.00	18.46	0.00	0.02	0.00	0.00	0.00	0.53	0.74	15.76	99.66	2.98	0.00	1.01	0.00	0.00	0.00	0.00	0.00	0.01	0.07	0.93	0.02	6.64	93.35
CAMP04	8	58.54	0.01	26.18	0.00	0.10	0.00	0.00	8.62	0.00	7.13	0.12	100.69	2.60	0.00	1.37	0.00	0.00	0.00	0.00	0.41	0.00	0.61	0.01	39.78	59.58	0.64
CAMP04	9	58.26	0.03	26.66	0.01	0.08	0.03	0.01	8.75	0.00	6.39	0.07	100.29	2.61	0.00	1.41	0.00	0.00	0.00	0.00	0.42	0.00	0.55	0.00	42.92	56.70	0.39
CAMP04	10	58.41	0.00	26.04	0.00	0.00	0.04	0.00	8.68	0.00	6.27	0.06	99.50	2.64	0.00	1.39	0.00	0.00	0.00	0.00	0.42	0.00	0.55	0.00	43.19	56.46	0.36
CAMP04	11	57.87	0.01	27.12	0.00	0.07	0.00	0.00	8.73	0.00	6.62	0.06	100.48	2.58	0.00	1.42	0.00	0.00	0.00	0.00	0.42	0.00	0.57	0.00	42.01	57.64	0.35
CAMP04	33	57.22	0.03	27.41	0.00	0.31	0.01	0.00	8.83	0.00	6.59	0.06	100.44	2.55	0.00	1.44	0.00	0.00	0.00	0.00	0.42	0.00	0.57	0.00	42.42	57.27	0.31
CAMP04	34	57.78	0.02	26.50	0.01	0.09	0.00	0.01	8.92	0.00	6.50	0.06	99.89	2.59	0.00	1.40	0.00	0.00	0.00	0.00	0.43	0.00	0.57	0.00	43.00	56.69	0.32
CAMP04	35	57.18	0.00	27.49	0.00	0.08	0.00	0.00	8.85	0.01	6.33	0.08	100.01	2.56	0.00	1.45	0.00	0.00	0.00	0.00	0.43	0.00	0.55	0.00	43.41	56.16	0.44
CAMP04	36	57.73	0.01	27.20	0.00	0.09	0.00	0.00	8.80	0.00	6.57	0.07	100.46	2.57	0.00	1.43	0.00	0.00	0.00	0.00	0.42	0.00	0.57	0.00	42.35	57.27	0.38
CAMP04	37	58.01	0.00	27.16	0.00	0.07	0.02	0.00	8.81	0.00	6.34	0.05	100.46	2.59	0.00	1.43	0.00	0.00	0.00	0.00	0.42	0.00	0.55	0.00	43.32	56.36	0.32
CAMP04	38	57.48	0.02	27.27	0.00	0.07	0.00	0.01	8.86	0.02	6.38	0.04	100.15	2.57	0.00	1.44	0.00	0.00	0.00	0.00	0.43	0.00	0.55	0.00	43.30	56.45	0.25
CAMP04	39	57.35	0.03	27.42	0.03	0.11	0.00	0.00	8.86	0.00	6.59	0.08	100.47	2.56	0.00	1.44	0.00	0.00	0.00	0.00	0.42	0.00	0.57	0.00	42.45	57.11	0.44
GT-41.4	13	65.55	0.03	21.02	0.00	0.09	0.00	0.00	2.79	0.03	10.03	0.06	99.60	2.90	0.00	1.10	0.00	0.00	0.00	0.00	0.13	0.00	0.86	0.00	13.26	86.40	0.34
GT-41.4	14	65.13	0.00	21.42	0.00	0.11	0.00	0.00	3.42	0.00	9.54	0.08	99.70	2.89	0.00	1.12	0.00	0.00	0.00	0.00	0.16	0.00	0.82	0.00	16.45	83.10	0.45
GT-41.4	15	64.06	0.00	22.24	0.00	0.20	0.00	0.00	3.57	0.03	9.01	0.11	99.22	2.86	0.00	1.17	0.00	0.01	0.00	0.00	0.17	0.00	0.78	0.01	17.87	81.49	0.65
GT-41.4	16	63.28	0.07	22.27	0.00	1.37	0.01	0.69	2.99	0.00	9.16	0.22	100.05	2.80	0.00	1.16	0.00	0.03	0.00	0.05	0.14	0.00	0.79	0.01	15.08	83.59	1.33
GT-41.4	17	66.75	0.01	20.52	0.00	0.22	0.01	0.00	1.07	0.00	10.91	0.06	99.55	2.94	0.00	1.07	0.00	0.01	0.00	0.00	0.05	0.00	0.93	0.00	5.12	94.53	0.35
GT-41.4	18	64.48	0.02	22.32	0.00	0.16	0.00	0.00	3.68	0.03	9.28	0.10	100.06	2.85	0.00	1.16	0.00	0.01	0.00	0.00	0.17	0.00	0.80	0.01	17.87	81.57	0.56
GT-41.4	19	64.92	0.01	21.85	0.02	0.35	0.00	0.00	2.97	0.00	9.79	0.06	99.97	2.87	0.00	1.14	0.00	0.01	0.00	0.00	0.14	0.00	0.84	0.00	14.30	85.34	0.36
GT-41.4	46	67.77	0.00	19.91	0.00	0.05	0.00	0.00	0.16	0.04	11.46	0.05	99.45	2.98	0.00	1.03	0.00	0.00	0.00	0.00	0.01	0.00	0.98	0.00	0.78	98.93	0.28
GT-41.4	47	67.46	0.00	20.04	0.00	0.00	0.04	0.00	0.30	0.00	11.27	0.08	99.18	2.97	0.00	1.04	0.00	0.00	0.00	0.00	0.01	0.00	0.96	0.00	1.44	98.09	0.48
GT-41.4	48	68.50	0.00	19.68	0.00	0.01	0.00	0.00	0.25	0.00	11.57	0.09	100.10	2.99	0.00	1.01	0.00	0.00	0.00	0.00	0.01	0.00	0.98	0.00	1.18	98.32	0.49
GT-41.4	49	64.14	0.00	22.47	0.01	0.12	0.00	0.00	3.54	0.00	9.48	0.08	99.84	2.84	0.00	1.17	0.00	0.00	0.00	0.00	0.17	0.00	0.81	0.00	17.04	82.48	0.48
GT-41.4	50	68.71	0.00	19.55	0.00	0.01	0.01	0.01	0.22	0.04	11.14	0.12	99.81	3.02	0.00	1.01	0.00	0.00	0.00	0.00	0.01	0.00	0.95	0.01	1.06	98.26	0.67
GT-41.4	51	67.95	0.00	20.00	0.00	0.02	0.00	0.00	0.17	0.04	11.31	0.08	99.56	2.99	0.00	1.04	0.00	0.00	0.00	0.00	0.01	0.00	0.96	0.00	0.82	98.71	0.47

Table S 3. Microprobe analyses of biotite from samples CN113A, CN101, GT-41.4, and MR231.

Sample	Spot	Weight percent oxides												OH			T		M					I		
		SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	F	Cl	Total	OH	Cl	F	Si	Al	Al	Ti	Mg	Fe ²⁺	Mn	Ca	Na	K
CN113A	15	37.22	2.13	16.38	16.41	0.27	11.85	0.07	0.06	9.51	0.37	0.09	94.78	1.90	0.01	0.09	2.84	1.16	0.32	0.12	1.35	1.05	0.02	0.01	0.01	0.93
CN113A	16	38.25	0.13	24.09	10.47	0.27	0.00	22.50	0.00	0.02	0.01	0.01	95.84	2.00	0.00	0.00	2.76	1.24	0.81	0.01	0.00	0.63	0.02	1.74	0.00	0.00
CN113A	17	36.26	1.89	17.28	15.48	0.27	9.49	4.58	0.04	7.64	0.21	0.07	93.58	1.94	0.01	0.05	2.79	1.21	0.36	0.11	1.09	1.00	0.02	0.38	0.01	0.75
CN113A	18	37.28	2.42	15.87	17.17	0.29	11.77	0.01	0.02	9.91	0.40	0.09	95.35	1.89	0.01	0.10	2.85	1.15	0.27	0.14	1.34	1.10	0.02	0.00	0.00	0.96
CN113A	19	36.72	2.43	16.10	17.96	0.29	11.46	0.00	0.04	9.84	0.36	0.08	95.44	1.90	0.01	0.09	2.81	1.19	0.26	0.14	1.31	1.15	0.02	0.00	0.01	0.96
CN113A	20	37.34	2.60	16.00	16.76	0.28	11.55	0.15	0.12	9.82	0.40	0.08	95.24	1.89	0.01	0.10	2.85	1.15	0.29	0.15	1.31	1.07	0.02	0.01	0.02	0.96
CN113A	38	36.62	2.26	15.71	16.11	0.27	11.88	0.00	0.06	9.77	0.49	0.08	93.51	1.87	0.01	0.12	2.85	1.15	0.29	0.13	1.38	1.05	0.02	0.00	0.01	0.97
CN113A	39	37.41	2.22	16.26	17.10	0.26	12.09	0.03	0.07	8.00	0.41	0.07	94.13	1.89	0.01	0.10	2.86	1.14	0.32	0.13	1.38	1.09	0.02	0.00	0.01	0.78
CN113A	40	36.72	2.37	15.64	16.69	0.21	11.84	0.02	0.09	9.57	0.49	0.06	93.78	1.87	0.01	0.12	2.85	1.15	0.28	0.14	1.37	1.08	0.01	0.00	0.01	0.95
CN113A	41	36.95	2.41	15.70	16.56	0.28	11.89	0.00	0.07	9.62	0.45	0.07	94.08	1.88	0.01	0.11	2.85	1.15	0.28	0.14	1.37	1.07	0.02	0.00	0.01	0.95
CN113A	43	36.50	2.54	15.58	16.80	0.22	11.69	0.01	0.08	9.64	0.37	0.07	93.59	1.90	0.01	0.09	2.83	1.17	0.26	0.15	1.35	1.09	0.01	0.00	0.01	0.96
CN113A	44	36.81	2.54	15.93	16.95	0.27	11.68	0.01	0.06	9.76	0.54	0.07	94.79	1.86	0.01	0.13	2.83	1.17	0.28	0.15	1.34	1.09	0.02	0.00	0.01	0.96
CN113A	45	37.21	2.37	16.19	16.18	0.25	12.23	0.00	0.07	9.76	0.40	0.06	94.82	1.89	0.01	0.10	2.84	1.16	0.29	0.14	1.39	1.03	0.02	0.00	0.01	0.95
CN113A	47	36.87	2.32	15.63	15.76	0.31	12.80	0.02	0.11	9.83	0.46	0.09	94.24	1.88	0.01	0.11	2.84	1.16	0.25	0.13	1.47	1.01	0.02	0.00	0.02	0.96
CN113A	48	37.32	2.55	15.67	15.68	0.27	12.77	0.01	0.06	9.86	0.52	0.09	94.94	1.86	0.01	0.13	2.85	1.15	0.26	0.15	1.45	1.00	0.02	0.00	0.01	0.96
CN113A	49	36.83	2.44	15.77	15.83	0.31	12.85	0.02	0.09	9.74	0.52	0.07	94.55	1.86	0.01	0.13	2.83	1.17	0.25	0.14	1.47	1.02	0.02	0.00	0.01	0.95
CN113A	50	36.96	2.44	15.60	15.83	0.29	12.78	0.02	0.06	9.71	0.54	0.08	94.31	1.86	0.01	0.13	2.84	1.16	0.26	0.14	1.47	1.02	0.02	0.00	0.01	0.95
CN113A	51	36.70	2.25	15.43	16.11	0.25	12.37	0.00	0.08	9.64	0.44	0.06	93.53	1.88	0.01	0.11	2.85	1.15	0.26	0.13	1.43	1.05	0.02	0.00	0.01	0.95
CN113A	52	36.92	2.29	15.46	16.39	0.29	12.40	0.00	0.11	9.72	0.53	0.07	94.38	1.86	0.01	0.13	2.85	1.15	0.25	0.13	1.43	1.06	0.02	0.00	0.02	0.96
CN113A	53	36.63	2.09	15.44	16.22	0.24	12.26	0.02	0.07	9.74	0.47	0.06	93.54	1.88	0.01	0.11	2.85	1.15	0.27	0.12	1.42	1.06	0.02	0.00	0.01	0.97
CN113A	54	36.76	2.39	15.53	16.46	0.24	12.37	0.01	0.12	9.78	0.31	0.06	94.20	1.92	0.01	0.07	2.83	1.17	0.24	0.14	1.42	1.06	0.02	0.00	0.02	0.96
CN113A	55	36.19	2.31	15.17	16.63	0.30	12.04	0.11	0.04	9.75	0.36	0.06	93.07	1.90	0.01	0.09	2.83	1.17	0.23	0.14	1.40	1.09	0.02	0.01	0.01	0.97
CN113A	89	36.05	2.22	16.92	16.34	0.27	12.97	0.09	0.07	9.69	0.53	0.07	95.33	1.86	0.01	0.13	2.75	1.25	0.27	0.13	1.48	1.04	0.02	0.01	0.01	0.94
CN113A	90	37.32	2.23	16.74	16.80	0.27	12.23	0.03	0.12	9.77	0.35	0.08	96.00	1.91	0.01	0.08	2.81	1.19	0.30	0.13	1.38	1.06	0.02	0.00	0.02	0.94
CN113A	91	43.21	1.70	17.29	12.93	0.24	8.62	0.65	2.23	8.04	0.51	0.06	95.52	1.87	0.01	0.12	3.16	0.84	0.65	0.09	0.94	0.79	0.01	0.05	0.32	0.75
CN101	18	36.06	2.91	16.04	21.62	0.17	8.01	0.03	0.06	9.98	0.25	0.01	95.23	1.94	0.00	0.06	2.81	1.19	0.28	0.17	0.93	1.41	0.01	0.00	0.01	0.99
CN101	19	35.36	2.81	16.58	21.67	0.20	8.02	0.00	0.08	10.04	0.38	0.02	95.21	1.90	0.00	0.09	2.77	1.23	0.30	0.17	0.94	1.42	0.01	0.00	0.01	1.00
CN101	20	36.28	1.80	16.70	21.57	0.29	7.58	0.00	0.05	9.96	0.26	0.10	94.60	1.92	0.01	0.07	2.84	1.16	0.39	0.11	0.89	1.41	0.02	0.00	0.01	1.00
CN101	21	35.51	1.79	16.98	21.91	0.26	7.54	0.05	0.06	9.87	0.37	0.04	94.44	1.90	0.01	0.09	2.80	1.20	0.38	0.11	0.89	1.45	0.02	0.00	0.01	0.99
CN101	22	35.58	1.78	17.50	21.47	0.25	7.48	0.02	0.12	10.76	0.41	0.09	95.46	1.89	0.01	0.10	2.79	1.21	0.40	0.10	0.87	1.41	0.02	0.00	0.02	1.08
CN101	23	36.39	1.85	16.88	22.07	0.25	7.90	0.01	0.04	9.98	0.30	0.07	95.80	1.92	0.01	0.07	2.82	1.18	0.37	0.11	0.91	1.43	0.02	0.00	0.01	0.99
CN101	24	36.30	1.69	16.83	21.49	0.21	7.94	0.02	0.10	9.94	0.51	0.10	95.17	1.86	0.01	0.13	2.84	1.16	0.40	0.10	0.93	1.41	0.01	0.00	0.02	0.99

CN101	25	36.35	1.88	16.94	21.44	0.25	7.62	0.02	0.07	10.89	0.35	0.08	95.96	1.90	0.01	0.09	2.83	1.17	0.38	0.11	0.88	1.39	0.02	0.00	0.01	1.08
CN101	26	36.37	1.81	16.96	21.37	0.22	7.85	0.01	0.08	10.46	0.37	0.07	95.63	1.90	0.01	0.09	2.83	1.17	0.38	0.11	0.91	1.39	0.01	0.00	0.01	1.04
CN101	27	35.81	1.82	16.98	22.16	0.27	7.66	0.05	0.09	9.78	0.39	0.09	95.30	1.89	0.01	0.10	2.81	1.19	0.37	0.11	0.89	1.45	0.02	0.00	0.01	0.98
CN101	28	35.79	1.85	17.06	21.98	0.29	7.64	0.03	0.08	9.91	0.33	0.04	95.10	1.91	0.00	0.08	2.80	1.20	0.38	0.11	0.89	1.44	0.02	0.00	0.01	0.99
CN101	29	35.34	1.92	17.48	21.52	0.24	7.66	0.01	0.07	9.86	0.38	0.11	94.65	1.89	0.01	0.09	2.78	1.22	0.40	0.11	0.90	1.42	0.02	0.00	0.01	0.99
CN101	47	35.86	1.80	16.36	21.28	0.25	7.61	0.00	0.05	10.89	0.50	0.11	94.83	1.86	0.02	0.13	2.84	1.16	0.37	0.11	0.90	1.41	0.02	0.00	0.01	1.10
CN101	48	35.59	1.79	16.68	21.93	0.23	7.44	0.00	0.05	10.80	0.40	0.08	95.06	1.89	0.01	0.10	2.81	1.19	0.36	0.11	0.88	1.45	0.02	0.00	0.01	1.09
CN101	49	35.54	1.79	17.05	21.83	0.22	7.52	0.02	0.06	9.93	0.28	0.05	94.40	1.92	0.01	0.07	2.80	1.20	0.38	0.11	0.88	1.44	0.01	0.00	0.01	1.00
CN101	50	35.20	1.79	16.73	21.90	0.17	7.65	0.01	0.05	10.90	0.32	0.10	94.92	1.91	0.01	0.08	2.78	1.22	0.34	0.11	0.90	1.45	0.01	0.00	0.01	1.10
CN101	51	35.45	1.78	16.64	21.59	0.27	7.85	0.01	0.05	10.79	0.29	0.11	94.91	1.91	0.01	0.07	2.80	1.20	0.34	0.11	0.92	1.42	0.02	0.00	0.01	1.09
CN101	52	35.73	1.73	16.80	21.81	0.24	7.44	0.00	0.07	10.84	0.41	0.08	95.21	1.89	0.01	0.10	2.81	1.19	0.37	0.10	0.87	1.44	0.02	0.00	0.01	1.09
CN101	53	35.45	1.86	16.82	21.48	0.21	7.76	0.01	0.06	10.87	0.40	0.09	95.13	1.89	0.01	0.10	2.79	1.21	0.36	0.11	0.91	1.42	0.01	0.00	0.01	1.09
GT-41.4	28	34.69	1.13	16.45	22.52	0.20	9.76	0.60	0.07	8.70	0.11	0.12	94.46	1.96	0.02	0.03	2.73	1.27	0.26	0.07	1.15	1.48	0.01	0.05	0.01	0.87
GT-41.4	29	36.65	1.22	16.18	21.37	0.21	10.03	0.22	0.08	8.82	0.07	0.17	95.11	1.96	0.02	0.02	2.83	1.17	0.30	0.07	1.15	1.38	0.01	0.02	0.01	0.87
GT-41.4	30	36.44	1.19	16.59	21.16	0.21	10.02	0.20	0.06	8.82	0.08	0.13	95.04	1.96	0.02	0.02	2.81	1.19	0.32	0.07	1.15	1.37	0.01	0.02	0.01	0.87
GT-41.4	31	36.66	1.16	16.70	21.26	0.24	9.88	0.23	0.13	8.45	0.00	0.15	94.98	1.98	0.02	0.00	2.82	1.18	0.33	0.07	1.13	1.37	0.02	0.02	0.02	0.83
GT-41.4	32	35.00	1.21	16.71	21.57	0.15	9.94	0.67	0.07	9.11	0.02	0.14	94.67	1.98	0.02	0.00	2.73	1.27	0.27	0.07	1.16	1.41	0.01	0.06	0.01	0.91
GT-41.4	33	36.24	1.23	16.35	21.27	0.19	9.43	0.04	0.06	9.19	0.02	0.15	94.28	1.97	0.02	0.01	2.83	1.17	0.33	0.07	1.10	1.39	0.01	0.00	0.01	0.91
GT-41.4	64	34.41	1.17	16.26	22.15	0.23	9.96	0.35	0.08	9.31	0.18	0.20	94.42	1.93	0.03	0.05	2.73	1.27	0.24	0.07	1.18	1.47	0.02	0.03	0.01	0.94
GT-41.4	65	36.56	1.04	16.15	21.23	0.21	9.69	0.07	0.10	9.18	0.11	0.19	94.62	1.95	0.02	0.03	2.85	1.15	0.33	0.06	1.12	1.38	0.01	0.01	0.02	0.91
GT-41.4	66	32.08	0.97	16.80	24.64	0.34	10.99	0.62	0.02	8.08	0.03	0.14	94.80	1.98	0.02	0.01	2.55	1.45	0.13	0.06	1.30	1.64	0.02	0.05	0.00	0.82
GT-41.4	67	35.04	1.13	16.31	22.82	0.23	10.13	0.31	0.01	8.58	0.00	0.12	94.76	1.98	0.02	0.00	2.74	1.26	0.24	0.07	1.18	1.49	0.02	0.03	0.00	0.86
GT-41.4	69	36.63	1.27	16.33	21.13	0.17	9.98	0.42	0.09	8.37	0.03	0.13	94.67	1.98	0.02	0.01	2.83	1.17	0.31	0.07	1.15	1.36	0.01	0.03	0.01	0.82
GT-41.4	70	35.89	1.19	16.38	21.91	0.25	9.98	0.44	0.16	8.72	0.15	0.16	95.29	1.94	0.02	0.04	2.78	1.22	0.28	0.07	1.15	1.42	0.02	0.04	0.02	0.86
GT-41.4	71	37.43	1.11	15.73	20.66	0.26	10.24	0.17	0.09	9.15	0.14	0.18	95.20	1.94	0.02	0.03	2.88	1.12	0.31	0.06	1.17	1.33	0.02	0.01	0.01	0.90
GT-41.4	72	33.94	1.03	16.43	23.53	0.28	10.26	0.50	0.04	8.64	0.11	0.14	94.95	1.95	0.02	0.03	2.68	1.32	0.20	0.06	1.21	1.55	0.02	0.04	0.01	0.87
MR231	22	35.41	1.50	17.31	19.99	0.02	8.80	0.05	0.18	10.33	0.42	0.46	94.49	1.84	0.06	0.10	2.79	1.21	0.41	0.09	1.04	1.32	0.00	0.00	0.03	1.04
MR231	23	35.89	1.51	17.11	21.50	0.00	8.27	0.01	0.19	10.41	0.18	0.53	95.73	1.89	0.07	0.04	2.80	1.20	0.38	0.09	0.96	1.40	0.00	0.00	0.03	1.04
MR231	24	36.01	1.59	17.09	20.93	0.02	8.65	0.00	0.22	10.65	0.46	0.25	95.95	1.86	0.03	0.11	2.81	1.19	0.37	0.09	1.00	1.36	0.00	0.00	0.03	1.06
MR231	32	36.87	1.45	17.45	21.91	0.00	8.55	0.02	0.16	9.64	0.38	0.20	96.83	1.88	0.03	0.09	2.82	1.18	0.40	0.08	0.98	1.40	0.00	0.00	0.02	0.94
MR231	33	34.31	1.50	17.95	21.16	0.00	8.39	0.04	0.11	10.48	0.24	0.25	94.55	1.91	0.03	0.06	2.71	1.29	0.38	0.09	0.99	1.40	0.00	0.00	0.02	1.06
MR231	34	35.21	1.50	18.05	21.72	0.03	8.86	0.01	0.18	10.58	0.29	0.21	96.71	1.90	0.03	0.07	2.72	1.28	0.36	0.09	1.02	1.40	0.00	0.00	0.03	1.04
MR231	35	35.45	1.60	17.53	21.95	0.02	8.69	0.13	0.13	9.64	0.53	0.23	96.00	1.84	0.03	0.13	2.76	1.24	0.37	0.09	1.01	1.43	0.00	0.01	0.02	0.96
MR231	36	37.85	0.96	23.62	14.69	0.03	5.42	0.01	0.47	9.91	0.24	0.27	93.56	1.91	0.03	0.06	2.86	1.14	0.96	0.05	0.61	0.93	0.00	0.00	0.07	0.96
MR231	71	36.06	1.78	18.75	19.99	0.00	8.40	0.00	0.15	9.69	0.35	0.30	95.58	1.88	0.04	0.09	2.78	1.22	0.48	0.10	0.96	1.29	0.00	0.00	0.02	0.95
MR231	72	35.76	1.86	17.09	20.50	0.04	8.79	0.00	0.16	9.67	0.42	0.29	94.70	1.86	0.04	0.10	2.80	1.20	0.38	0.11	1.03	1.34	0.00	0.00	0.02	0.97
MR231	73	36.73	1.73	17.72	20.01	0.00	8.81	0.00	0.15	9.70	0.44	0.25	95.68	1.86	0.03	0.11	2.83	1.17	0.44	0.10	1.01	1.29	0.00	0.00	0.02	0.95

Table S 4. Microprobe analyses of amphibole from samples CN113A, CAMP04, and GT-41.4.

		Weight percent oxides										T		C					B				A		
Sample	Spot	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	MnO	FeO	MgO	CaO	Na ₂ O	K ₂ O	Total	Si	Al	Ti	Al	Cr	Fe ²⁺	Mg	Mn ²⁺	Fe ²⁺	Ca	Na	Na	K
CN113A	28	42.63	1.49	11.43	0.05	0.54	15.10	10.36	11.38	1.59	1.63	96.50	6.49	1.51	0.17	0.54	0.01	1.92	2.35	0.00	0.00	1.86	0.08	0.39	0.32
CN113A	29	43.12	1.83	11.54	0.05	0.48	15.51	10.43	11.50	1.61	1.65	98.08	6.47	1.53	0.21	0.51	0.01	1.94	2.33	0.06	0.00	1.85	0.09	0.38	0.32
CN113A	31	42.76	1.59	11.37	0.02	0.52	15.76	10.47	11.12	1.64	1.57	97.10	6.48	1.52	0.18	0.51	0.00	1.94	2.37	0.07	0.06	1.81	0.07	0.41	0.30
CN113A	32	42.93	1.58	11.47	0.04	0.47	15.72	10.56	11.32	1.56	1.61	97.46	6.47	1.53	0.18	0.51	0.00	1.93	2.37	0.06	0.05	1.83	0.06	0.40	0.31
CN113A	33	42.75	1.61	11.37	0.05	0.51	15.56	10.40	11.29	1.64	1.57	97.20	6.48	1.52	0.18	0.51	0.01	1.95	2.35	0.07	0.03	1.83	0.07	0.41	0.30
CN113A	34	42.33	1.59	11.32	0.05	0.57	15.56	10.14	11.28	1.54	1.62	96.39	6.47	1.53	0.18	0.51	0.01	1.98	2.31	0.07	0.01	1.85	0.06	0.39	0.32
CN113A	35	41.68	2.30	10.55	0.03	0.58	15.75	10.23	11.00	1.47	1.55	95.60	6.45	1.55	0.27	0.37	0.00	1.99	2.36	0.08	0.05	1.82	0.05	0.39	0.31
CN113A	56	42.20	1.52	11.32	0.06	0.51	15.83	9.90	11.26	1.64	1.58	96.24	6.47	1.53	0.18	0.52	0.01	2.02	2.26	0.07	0.01	1.85	0.07	0.42	0.31
CN113A	57	43.38	1.43	11.41	0.04	0.47	15.09	10.87	11.37	1.51	1.58	97.52	6.52	1.48	0.16	0.54	0.01	1.86	2.44	0.06	0.04	1.83	0.07	0.37	0.30
CN113A	58	43.31	1.41	11.38	0.05	0.59	15.35	10.77	11.26	1.53	1.58	97.61	6.52	1.48	0.16	0.53	0.01	1.89	2.42	0.08	0.05	1.82	0.06	0.38	0.30
CN113A	59	42.31	1.47	11.43	0.05	0.51	15.46	10.11	11.21	1.62	1.61	96.13	6.48	1.52	0.17	0.54	0.01	1.97	2.31	0.07	0.02	1.84	0.08	0.40	0.31
CN113A	60	43.85	1.42	11.97	0.04	0.45	15.70	10.60	11.38	1.62	1.60	98.98	6.50	1.50	0.16	0.59	0.01	1.90	2.34	0.06	0.05	1.81	0.09	0.38	0.30
CN113A	62	42.37	1.11	12.32	0.03	0.47	15.46	10.28	11.23	1.64	1.64	97.01	6.45	1.48	0.00	0.73	0.00	1.92	2.33	0.06	0.04	1.83	0.06	0.42	0.32
CAMP04	1	44.16	1.95	11.01	0.02	0.32	18.03	8.77	10.64	1.74	0.67	97.37	6.65	1.35	0.22	0.61	0.00	2.20	1.97	0.04	0.07	1.72	0.17	0.34	0.13
CAMP04	2	43.92	2.19	11.31	0.00	0.33	18.58	8.97	10.68	1.96	0.66	98.74	6.56	1.44	0.25	0.54	0.00	2.21	2.00	0.04	0.11	1.71	0.14	0.43	0.13
CAMP04	3	42.08	11.20	7.60	0.01	0.30	17.32	9.32	8.64	1.10	0.49	98.36	6.29	1.34	0.89	0.00	0.00	2.02	2.08	0.04	0.15	1.38	0.32	0.00	0.09
CAMP04	4	44.73	1.97	10.74	0.02	0.30	18.18	9.08	10.57	1.74	0.61	98.07	6.69	1.31	0.22	0.58	0.00	2.17	2.02	0.04	0.10	1.69	0.17	0.34	0.12
CAMP04	5	44.34	2.13	11.03	0.01	0.29	18.13	9.04	10.51	1.89	0.64	98.05	6.63	1.37	0.24	0.58	0.00	2.17	2.02	0.04	0.10	1.68	0.18	0.37	0.12
CAMP04	6	44.26	1.69	11.04	0.02	0.33	18.98	8.53	10.51	1.73	0.67	97.85	6.66	1.34	0.19	0.62	0.00	2.27	1.91	0.04	0.12	1.69	0.15	0.36	0.13
CAMP04	7	43.66	2.06	11.18	0.00	0.32	18.34	8.53	10.46	2.04	0.65	97.39	6.60	1.40	0.24	0.59	0.00	2.25	1.92	0.04	0.07	1.69	0.19	0.41	0.13
CAMP04	15	44.24	1.62	11.31	0.04	0.23	17.47	8.52	11.39	1.65	0.65	97.30	6.66	1.34	0.18	0.67	0.01	2.20	1.91	0.00	0.00	1.84	0.16	0.32	0.13
CAMP04	16	43.79	1.59	11.54	0.04	0.28	17.57	8.53	11.35	1.67	0.67	97.16	6.61	1.39	0.18	0.67	0.00	2.22	1.92	0.03	0.00	1.84	0.13	0.36	0.13
CAMP04	17	44.29	1.76	11.52	0.03	0.23	17.77	8.72	11.37	1.55	0.65	97.93	6.62	1.38	0.20	0.65	0.00	2.20	1.94	0.03	0.03	1.82	0.12	0.33	0.12
CAMP04	18	44.76	1.71	11.08	0.04	0.28	17.80	8.16	11.16	1.70	0.69	97.51	6.72	1.28	0.19	0.68	0.00	2.24	1.83	0.00	0.00	1.80	0.20	0.29	0.13
CAMP04	19	44.00	1.50	11.79	0.02	0.26	17.44	8.30	11.32	1.71	0.69	97.16	6.63	1.37	0.17	0.73	0.00	2.20	1.87	0.00	0.00	1.83	0.17	0.33	0.13
CAMP04	20	43.97	1.46	11.74	0.02	0.27	17.49	9.03	11.17	1.93	0.65	97.87	6.59	1.41	0.16	0.66	0.00	2.15	2.02	0.04	0.04	1.79	0.13	0.43	0.12
CAMP04	21	44.03	1.51	11.13	0.03	0.19	17.80	8.08	11.31	1.39	0.71	96.37	6.70	1.30	0.17	0.70	0.00	2.27	1.83	0.01	0.00	1.84	0.15	0.26	0.14
CAMP04	22	43.65	1.33	12.42	0.01	0.16	17.70	9.11	10.98	1.87	0.67	98.08	6.53	1.47	0.15	0.72	0.00	2.10	2.03	0.02	0.11	1.76	0.11	0.43	0.13
CAMP04	23	43.96	1.60	11.55	0.03	0.20	17.81	8.55	11.23	1.76	0.62	97.38	6.62	1.38	0.18	0.67	0.00	2.23	1.92	0.03	0.02	1.81	0.15	0.37	0.12
CAMP04	24	43.41	1.50	12.13	0.02	0.23	17.67	8.38	11.44	1.62	0.72	97.30	6.55	1.45	0.17	0.71	0.00	2.22	1.89	0.03	0.01	1.85	0.11	0.36	0.14
CAMP04	25	45.18	1.31	10.84	0.01	0.24	17.17	9.70	11.17	1.56	0.57	97.93	6.73	1.27	0.15	0.63	0.00	2.05	2.15	0.03	0.08	1.78	0.10	0.35	0.11
CAMP04	26	43.67	1.46	11.42	0.00	0.20	17.71	8.39	11.37	1.68	0.66	96.61	6.63	1.37	0.17	0.68	0.00	2.25	1.90	0.02	0.00	1.85	0.13	0.36	0.13
CAMP04	27	43.58	1.45	11.65	0.01	0.23	17.79	8.48	11.36	1.60	0.65	97.06	6.60	1.40	0.17	0.68	0.00	2.23	1.91	0.03	0.02	1.84	0.10	0.36	0.13
CAMP04	28	43.58	1.51	11.53	0.04	0.22	18.02	8.42	11.30	1.74	0.64	97.12	6.60	1.40	0.17	0.66	0.00	2.26	1.90	0.03	0.02	1.83	0.12	0.39	0.12

CAMP04	29	44.19	1.56	11.54	0.01	0.26	17.34	8.63	11.27	1.64	0.68	97.22	6.65	1.35	0.18	0.70	0.00	2.18	1.94	0.03	0.00	1.82	0.16	0.32	0.13
CAMP04	30	44.41	1.73	11.63	0.02	0.25	17.65	8.65	11.03	1.75	0.67	97.93	6.64	1.36	0.20	0.69	0.00	2.18	1.93	0.03	0.02	1.77	0.18	0.33	0.13
CAMP04	31	43.91	1.59	11.32	0.02	0.28	17.67	8.44	12.19	1.66	0.67	97.91	6.60	1.40	0.18	0.61	0.00	2.22	1.89	0.00	0.00	1.96	0.04	0.45	0.13
CAMP04	32	44.06	1.86	11.34	0.01	0.22	17.77	9.21	11.18	1.50	0.67	97.99	6.60	1.40	0.21	0.60	0.00	2.14	2.06	0.03	0.09	1.79	0.09	0.35	0.13
GT-41.4	1	42.96	0.61	15.05	0.06	0.38	18.15	7.50	11.19	1.74	0.89	98.52	6.38	1.62	0.07	1.01	0.01	2.10	1.66	0.04	0.00	1.78	0.18	0.33	0.17
GT-41.4	2	43.33	1.21	12.40	0.05	0.32	16.83	9.24	11.41	1.42	1.01	97.22	6.50	1.50	0.14	0.69	0.01	1.94	2.06	0.04	0.01	1.83	0.12	0.29	0.19
GT-41.4	3	43.86	1.37	11.80	0.04	0.31	17.00	9.60	11.34	1.38	1.08	97.78	6.54	1.46	0.15	0.61	0.00	1.90	2.13	0.04	0.02	1.81	0.13	0.27	0.20
GT-41.4	4	43.83	1.62	11.16	0.02	0.30	17.18	9.71	11.31	1.41	0.96	97.50	6.56	1.44	0.18	0.52	0.00	1.91	2.17	0.04	0.02	1.81	0.13	0.28	0.18
GT-41.4	5	43.51	1.57	11.78	0.03	0.28	17.04	9.35	11.25	1.38	1.12	97.31	6.53	1.47	0.18	0.61	0.00	1.95	2.09	0.04	0.01	1.81	0.14	0.26	0.21
GT-41.4	6	43.40	1.54	12.02	0.04	0.39	16.96	9.26	11.27	1.34	1.04	97.27	6.51	1.49	0.17	0.63	0.00	1.93	2.07	0.05	0.01	1.81	0.13	0.25	0.20
GT-41.4	7	43.74	1.37	11.54	0.04	0.35	17.19	9.78	10.78	1.25	1.26	97.30	6.53	1.47	0.15	0.57	0.00	1.76	2.18	0.04	0.05	1.73	0.18	0.18	0.24
GT-41.4	8	43.86	0.99	12.85	0.01	0.28	16.23	9.30	11.42	1.44	0.98	97.36	6.54	1.46	0.11	0.80	0.00	1.90	2.07	0.03	0.00	1.82	0.14	0.27	0.19
GT-41.4	38	43.30	1.43	12.12	0.01	0.18	16.90	9.47	11.51	1.21	1.01	97.13	6.49	1.51	0.16	0.64	0.00	1.89	2.12	0.02	0.03	1.85	0.10	0.26	0.19
GT-41.4	39	43.02	1.47	12.22	0.03	0.19	17.37	9.12	11.31	1.39	1.02	97.14	6.47	1.53	0.17	0.64	0.00	1.95	2.04	0.02	0.03	1.82	0.12	0.28	0.20
GT-41.4	40	43.63	1.49	11.91	0.03	0.15	17.03	9.01	11.31	1.38	1.03	96.97	6.56	1.44	0.17	0.68	0.00	2.02	2.02	0.02	0.01	1.82	0.15	0.26	0.20
GT-41.4	41	43.23	0.76	13.75	0.01	0.23	17.10	8.65	11.34	1.60	0.83	97.49	6.45	1.55	0.09	0.87	0.00	1.95	1.92	0.03	0.02	1.81	0.14	0.32	0.16
GT-41.4	42	42.84	1.06	13.34	0.01	0.17	16.76	8.90	11.34	1.50	1.07	96.99	6.44	1.56	0.12	0.80	0.00	1.94	1.99	0.02	0.02	1.83	0.13	0.30	0.21

Table S 5. Microprobe analyses of garnet from samples CN101, GT-41.4, and MR-231.

Sample	Spot	Weight percent oxides									Atoms per 12 Oxygen								End-member			
		SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	FeO	MnO	MgO	CaO	Total	Si	Ti	Al	Cr	Fe ²⁺	Mn	Mg	Ca	Alm	Prp	Grs	Sps
MR231	1	38.19	0.05	20.70	0.03	35.92	0.18	2.42	2.06	99.54	3.10	0.00	1.98	0.00	2.44	0.01	0.29	0.18	83.45	10.01	6.12	0.43
MR231	2	38.39	0.00	21.28	0.03	35.71	0.19	2.32	1.94	99.86	3.10	0.00	2.03	0.00	2.41	0.01	0.28	0.17	83.97	9.74	5.84	0.45
MR231	3	38.19	0.04	20.26	0.02	36.59	0.22	2.21	1.91	99.43	3.11	0.00	1.94	0.00	2.49	0.02	0.27	0.17	84.70	9.13	5.65	0.52
MR231	4	38.09	0.06	20.24	0.02	35.83	0.16	2.22	2.39	99.00	3.11	0.00	1.95	0.00	2.45	0.01	0.27	0.21	83.32	9.18	7.12	0.38
MR231	5	38.28	0.05	20.49	0.01	36.27	0.20	2.25	2.00	99.53	3.11	0.00	1.96	0.00	2.46	0.01	0.27	0.17	84.28	9.31	5.95	0.47
MR231	6	38.47	0.06	20.41	0.02	35.47	0.20	2.19	2.10	98.92	3.14	0.00	1.96	0.00	2.42	0.01	0.27	0.18	83.93	9.23	6.37	0.47
MR231	7	38.46	0.00	20.55	0.03	36.19	0.13	2.31	2.04	99.72	3.12	0.00	1.96	0.00	2.45	0.01	0.28	0.18	84.06	9.55	6.08	0.31
MR231	8	38.33	0.02	20.51	0.02	35.80	0.19	2.34	2.04	99.24	3.12	0.00	1.97	0.00	2.44	0.01	0.28	0.18	83.69	9.77	6.10	0.44
MR231	9	39.00	0.04	20.34	0.00	36.67	0.20	2.16	1.80	100.21	3.15	0.00	1.94	0.00	2.48	0.01	0.26	0.16	85.24	8.95	5.35	0.46
MR231	24 (core)	36.74	0.12	20.91	0.03	35.04	0.85	1.56	4.18	100.23	2.97	0.01	1.99	0.00	2.37	0.06	0.19	0.36	79.57	6.32	12.15	1.96
MR231	25	36.85	0.11	20.79	0.02	35.56	0.86	1.49	3.97	100.05	2.99	0.01	1.99	0.00	2.41	0.06	0.18	0.34	80.51	6.02	11.51	1.96
MR231	26	37.02	0.09	20.19	0.03	35.56	0.79	1.52	4.12	100.51	2.99	0.01	1.93	0.00	2.41	0.05	0.18	0.36	80.18	6.10	11.91	1.81
MR231	27	37.34	0.05	20.66	0.04	35.49	0.84	1.52	4.04	99.98	3.03	0.00	1.97	0.00	2.40	0.06	0.18	0.35	80.25	6.12	11.70	1.93
MR231	28	37.48	0.18	20.40	0.24	35.41	0.75	1.69	3.81	99.95	3.04	0.01	1.95	0.02	2.40	0.05	0.20	0.33	80.39	6.82	11.07	1.72
MR231	29	36.78	0.12	20.07	0.34	35.65	0.79	1.48	3.91	99.67	3.00	0.01	1.93	0.02	2.43	0.05	0.18	0.34	80.85	5.97	11.35	1.82
MR231	30	36.03	0.11	20.49	0.05	33.94	0.81	1.92	3.90	99.50	2.94	0.01	1.97	0.00	2.31	0.06	0.23	0.34	78.62	7.92	11.56	1.90
MR231	31	37.26	0.44	20.77	0.02	35.24	0.80	1.73	3.61	99.86	3.02	0.03	1.98	0.00	2.39	0.05	0.21	0.31	80.56	7.04	10.56	1.84
MR231	32	37.32	0.06	20.97	0.03	36.07	0.74	1.60	3.92	100.83	3.00	0.00	1.99	0.00	2.42	0.05	0.19	0.34	80.73	6.38	11.23	1.67
MR231	33	37.05	0.08	20.28	0.02	35.75	0.75	1.63	3.87	100.01	3.01	0.01	1.94	0.00	2.43	0.05	0.20	0.34	80.55	6.56	11.16	1.72
MR231	34	36.99	0.25	20.07	0.00	35.99	0.77	1.71	3.62	100.18	3.00	0.02	1.92	0.00	2.44	0.05	0.21	0.31	80.96	6.84	10.44	1.75
MR231	35	36.59	0.16	20.32	0.18	35.61	0.64	1.64	3.68	99.73	2.98	0.01	1.95	0.01	2.43	0.04	0.20	0.32	81.13	6.64	10.74	1.48
MR231	36	36.63	0.07	20.04	0.04	35.14	0.68	1.79	3.78	99.65	2.99	0.00	1.93	0.00	2.40	0.05	0.22	0.33	80.10	7.27	11.04	1.58
MR231	37	36.88	0.06	20.07	0.02	35.73	0.70	1.67	3.70	99.56	3.01	0.00	1.93	0.00	2.44	0.05	0.20	0.32	80.94	6.74	10.73	1.60
MR231	38	36.61	0.08	20.87	0.01	35.05	0.71	1.78	3.82	100.59	2.95	0.00	1.98	0.00	2.36	0.05	0.21	0.33	79.94	7.24	11.17	1.65
MR231	39	36.99	0.07	20.29	0.03	35.83	0.65	1.79	3.60	100.07	3.00	0.00	1.94	0.00	2.43	0.04	0.22	0.31	80.89	7.22	10.40	1.49
MR231	40	36.88	0.07	20.11	0.02	35.78	0.50	1.84	3.58	99.68	3.00	0.00	1.93	0.00	2.44	0.03	0.22	0.31	81.03	7.44	10.39	1.14
MR231	41	36.46	0.06	20.87	0.02	35.07	0.63	1.97	3.46	100.75	2.94	0.00	1.98	0.00	2.36	0.04	0.24	0.30	80.34	8.06	10.14	1.46
MR231	42	36.91	0.10	20.76	0.02	35.71	0.49	1.98	3.51	100.36	2.98	0.01	1.97	0.00	2.41	0.03	0.24	0.30	80.75	7.97	10.16	1.12
MR231	43	36.53	0.05	21.32	0.03	35.40	0.51	1.87	3.50	100.15	2.95	0.00	2.03	0.00	2.39	0.03	0.22	0.30	80.97	7.60	10.26	1.17
MR231	44	37.27	0.08	20.49	0.25	36.67	0.47	1.64	3.18	100.04	3.02	0.00	1.96	0.02	2.49	0.03	0.20	0.28	83.10	6.60	9.23	1.07

MR231	45	36.76	0.05	20.72	0.10	35.66	0.42	2.05	3.32	99.76	2.98	0.00	1.98	0.01	2.42	0.03	0.25	0.29	81.04	8.32	9.68	0.97
MR231	46	36.58	0.02	20.11	0.65	35.36	0.35	2.01	3.49	99.47	2.98	0.00	1.93	0.04	2.41	0.02	0.24	0.31	80.80	8.17	10.23	0.80
MR231	47	36.90	0.06	20.99	0.06	35.82	0.22	2.11	3.40	100.23	2.98	0.00	2.00	0.00	2.42	0.02	0.25	0.29	81.10	8.52	9.86	0.51
MR231	48	36.74	0.08	20.71	0.14	36.49	0.21	2.09	2.79	99.63	2.99	0.01	1.98	0.01	2.48	0.01	0.25	0.24	82.93	8.45	8.13	0.49
MR231	49	37.02	0.03	20.85	0.02	36.93	0.13	2.31	2.44	100.23	2.99	0.00	1.98	0.00	2.49	0.01	0.28	0.21	83.37	9.30	7.05	0.29
MR231	50 (rim)	37.07	0.02	20.50	0.06	37.36	0.17	2.19	2.25	99.62	3.01	0.00	1.97	0.00	2.54	0.01	0.27	0.20	84.29	8.82	6.49	0.40
CN101	1	38.30	0.08	20.49	0.00	32.21	4.56	2.28	1.84	99.75	3.11	0.00	1.96	0.00	2.18	0.31	0.27	0.16	74.51	9.38	5.44	10.67
CN101	2	38.34	0.02	20.27	0.00	31.46	4.86	2.51	2.26	99.71	3.10	0.00	1.93	0.00	2.13	0.33	0.30	0.20	71.91	10.21	6.62	11.26
CN101	3	37.52	0.00	20.76	0.02	31.65	4.97	2.56	2.28	99.74	3.03	0.00	1.98	0.00	2.14	0.34	0.31	0.20	71.68	10.32	6.60	11.40
CN101	4	38.61	0.02	20.40	0.00	31.44	4.93	2.61	2.09	100.10	3.11	0.00	1.94	0.00	2.12	0.34	0.31	0.18	71.85	10.61	6.12	11.41
CN101	5	38.20	0.03	20.58	0.00	31.08	5.05	2.54	2.25	99.73	3.09	0.00	1.96	0.00	2.10	0.35	0.31	0.19	71.28	10.40	6.60	11.72
CN101	6	37.95	0.06	20.73	0.01	31.25	4.74	2.20	2.28	99.22	3.09	0.00	1.99	0.00	2.13	0.33	0.27	0.20	72.87	9.13	6.81	11.20
CN101	7	38.16	0.01	20.41	0.00	31.04	4.76	2.40	2.32	99.09	3.11	0.00	1.96	0.00	2.11	0.33	0.29	0.20	72.01	9.91	6.88	11.20
CN101	35	37.59	0.04	20.79	0.00	30.70	5.21	2.57	2.06	98.95	3.06	0.00	2.00	0.00	2.09	0.36	0.31	0.18	71.08	10.60	6.12	12.21
CN101	36	38.85	0.00	20.54	0.01	30.44	5.34	2.53	2.05	99.77	3.14	0.00	1.96	0.00	2.06	0.37	0.30	0.18	70.82	10.49	6.11	12.58
CN101	37	37.95	0.02	20.34	0.00	30.82	5.32	2.64	2.01	99.10	3.09	0.00	1.95	0.00	2.10	0.37	0.32	0.17	70.87	10.82	5.91	12.40
CN101	38	37.76	0.02	20.23	0.00	31.53	5.36	2.52	1.87	99.28	3.07	0.00	1.94	0.00	2.15	0.37	0.31	0.16	71.93	10.24	5.46	12.37
CN101	39	38.61	0.01	20.64	0.01	31.05	5.08	2.44	1.91	99.74	3.12	0.00	1.97	0.00	2.10	0.35	0.29	0.17	72.24	10.10	5.69	11.96
GT-41.1	20	37.16	0.06	21.24	0.01	26.45	1.39	2.50	9.50	100.21	2.95	0.00	1.99	0.00	1.75	0.09	0.30	0.81	59.45	10.02	27.36	3.17
GT-41.1	21	37.08	0.15	21.26	0.04	27.03	2.06	2.32	8.76	100.18	2.95	0.01	1.99	0.00	1.80	0.14	0.28	0.75	60.78	9.31	25.22	4.69
GT-41.1	22	37.49	0.02	21.19	0.01	27.82	3.25	2.27	7.58	100.22	2.99	0.00	1.99	0.00	1.85	0.22	0.27	0.65	62.02	9.00	21.64	7.33
GT-41.1	23	37.39	0.20	20.28	0.01	24.44	3.94	1.95	10.12	100.16	2.98	0.01	1.91	0.00	1.63	0.27	0.23	0.86	54.47	7.75	28.88	8.90
GT-41.1	24	37.28	0.13	21.00	0.00	26.75	2.58	2.33	8.73	100.19	2.97	0.01	1.97	0.00	1.78	0.17	0.28	0.74	59.86	9.29	25.01	5.84
GT-41.1	25	37.62	0.08	20.33	0.00	27.30	1.95	2.44	8.93	99.90	3.00	0.00	1.91	0.00	1.82	0.13	0.29	0.76	60.60	9.64	25.39	4.37
GT-41.1	26	37.13	0.11	21.25	0.00	26.08	1.78	2.39	9.64	100.14	2.95	0.01	1.99	0.00	1.73	0.12	0.28	0.82	58.61	9.58	27.75	4.05
GT-41.1	27	37.60	0.19	20.49	0.02	26.29	1.94	2.12	10.22	99.46	3.01	0.01	1.93	0.00	1.76	0.13	0.25	0.87	58.25	8.38	29.00	4.36

Table S 6. Microprobe analyses of pyroxene from sample CAMP04.

Sample	Spot	Weight percent oxides										Atoms per 6 Oxygen										End-member		
		SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	Total	Si	Ti	Al	Cr	Fe ³⁺	Fe ²⁺	Mn	Mg	Ca	Na	Wo	En	Fs
CAMP04	12	52.06	0.14	1.62	0.01	12.53	0.39	11.52	21.74	0.43	100.45	1.96	0.00	0.07	0.00	0.03	0.36	0.01	0.65	0.88	0.03	45.72	33.72	20.56
CAMP04	13	52.27	0.13	1.62	0.02	12.81	0.40	10.58	21.73	0.47	100.03	1.99	0.00	0.07	0.00	0.00	0.41	0.01	0.60	0.88	0.03	46.79	31.69	21.52
CAMP04	14	52.84	0.45	0.93	0.00	12.14	0.42	10.63	21.33	0.35	99.10	2.03	0.01	0.04	0.00	0.00	0.39	0.01	0.61	0.88	0.03	46.78	32.43	20.79

Table S 7. Microprobe analyses of chlorite from sample MR231.

		Weight percent oxides													Atoms per 28 Oxygen																
Sample	Spot	SiO2	TiO2	Al2O3	FeO	MnO	MgO	CaO	Na2O	K2O	ZnO	F	Cl	NiO	Total	Si	Al iv	Al vi	Ti	Fe3+	Fe2+	Mn	Mg	Ni	Zn	Ca	Na	K	F	Cl	OH*
MR231	10	25.03	0.02	21.12	26.05	0.00	14.25	0.04	0.05	0.08	0.20	0.00	0.05	0.03	86.93	5.35	2.65	2.68	0.00	0.01	4.64	0.00	4.54	0.01	0.03	0.01	0.04	0.04	0.00	0.04	15.96
MR231	11	25.01	0.04	21.05	25.95	0.00	13.83	0.05	0.05	0.02	0.20	0.00	0.03	0.01	86.25	5.60	2.40	2.53	0.02	0.12	6.61	0.21	2.25	0.00	0.02	0.02	0.02	0.06	0.11	0.01	15.88
MR231	12	25.66	0.05	21.50	25.84	0.03	13.79	0.03	0.02	0.02	0.11	0.03	0.02	0.00	87.12	5.48	2.52	3.07	0.02	0.39	6.01	0.17	1.73	0.00	0.02	0.00	0.03	0.09	0.26	0.01	15.73
MR231	13	25.54	0.09	21.99	25.94	0.01	13.56	0.05	0.03	0.18	0.12	0.11	0.05	0.01	87.70	5.83	2.17	2.33	0.02	0.23	3.82	0.21	4.94	0.00	0.02	0.02	0.00	0.07	0.42	0.01	15.57
MR231	14	25.15	0.05	21.15	26.19	0.00	14.07	0.00	0.00	0.01	0.17	0.12	0.03	0.05	86.99	5.89	2.11	2.34	0.02	0.18	3.89	0.21	5.01	0.00	0.02	0.02	0.03	0.07	0.16	0.01	15.83
MR231	15	25.78	0.07	21.48	25.82	0.03	13.08	0.02	0.01	0.04	0.10	0.03	0.05	0.00	86.56	5.40	2.60	2.67	0.01	0.10	7.27	0.32	1.40	0.00	0.04	0.01	0.02	0.02	0.16	0.01	15.83
MR231	16	25.81	0.13	21.67	26.04	0.00	12.74	0.03	0.09	0.19	0.10	0.00	0.07	0.02	86.89	5.89	2.11	3.01	0.02	0.41	6.03	0.26	1.29	0.00	0.03	0.02	0.03	0.58	0.06	0.01	15.94
MR231	17	25.83	0.09	21.18	25.71	0.03	14.04	0.02	0.05	0.07	0.13	0.13	0.03	0.06	87.41	5.35	2.65	2.64	0.01	0.05	7.23	0.36	1.55	0.00	0.02	0.01	0.02	0.03	0.18	0.01	15.82
MR231	25	25.44	0.06	21.35	25.68	0.03	13.24	0.03	0.07	0.12	0.21	0.07	0.02	0.01	86.39	5.43	2.57	2.84	0.01	0.17	4.42	0.00	4.21	0.00	0.03	0.01	0.05	0.06	0.09	0.02	15.89
MR231	26	26.12	0.10	21.02	25.12	0.00	13.91	0.02	0.03	0.09	0.07	0.10	0.02	0.02	86.61	5.52	2.48	2.79	0.02	0.22	4.22	0.00	4.38	0.00	0.01	0.00	0.02	0.05	0.14	0.01	15.85
MR231	27	25.70	0.10	21.36	25.28	0.01	13.85	0.05	0.08	0.13	0.12	0.00	0.02	0.05	86.78	5.45	2.55	2.81	0.02	0.14	4.34	0.00	4.38	0.01	0.02	0.01	0.06	0.07	0.00	0.02	15.98
MR231	28	25.64	0.05	21.14	25.35	0.07	13.83	0.06	0.11	0.16	0.13	0.02	0.04	0.00	86.60	5.46	2.54	2.78	0.01	0.12	4.39	0.01	4.39	0.00	0.02	0.01	0.09	0.08	0.02	0.03	15.95
MR231	29	25.50	0.18	21.54	25.20	0.07	13.62	0.01	0.07	0.14	0.02	0.02	0.05	0.09	86.52	5.42	2.58	2.84	0.03	0.17	4.31	0.01	4.31	0.02	0.00	0.00	0.06	0.07	0.02	0.04	15.94
MR231	30	25.65	0.09	21.64	25.09	0.00	13.87	0.01	0.05	0.08	0.06	0.07	0.02	0.04	86.69	5.43	2.57	2.85	0.01	0.18	4.25	0.00	4.37	0.01	0.01	0.00	0.04	0.05	0.10	0.01	15.89
MR231	31	25.20	0.05	21.50	25.39	0.05	13.67	0.02	0.03	0.05	0.12	0.10	0.03	0.00	86.22	5.38	2.62	2.82	0.01	0.16	4.37	0.01	4.35	0.00	0.02	0.01	0.02	0.03	0.14	0.02	15.85
MR231	81	25.25	0.05	21.35	26.15	0.01	13.27	0.03	0.04	0.04	0.12	0.10	0.03	0.05	86.53	5.39	2.61	2.80	0.01	0.16	4.51	0.00	4.23	0.01	0.02	0.01	0.03	0.02	0.14	0.02	15.84
MR231	82	25.06	0.06	21.38	26.08	0.01	13.99	0.03	0.00	0.10	0.08	0.00	0.08	0.04	86.90	5.35	2.65	2.74	0.01	0.06	4.59	0.00	4.45	0.01	0.01	0.01	0.00	0.05	0.01	0.05	15.94
MR231	83	24.99	0.10	21.53	26.48	0.00	12.97	0.03	0.04	0.08	0.06	0.03	0.03	0.05	86.39	5.36	2.64	2.83	0.02	0.13	4.62	0.00	4.15	0.01	0.01	0.01	0.03	0.04	0.04	0.02	15.94
MR231	84	25.71	0.10	21.31	25.47	0.01	13.09	0.02	0.06	0.10	0.06	0.00	0.03	0.03	86.02	5.50	2.50	2.89	0.02	0.22	4.33	0.00	4.17	0.01	0.01	0.01	0.05	0.05	0.00	0.02	15.98
MR231	85	25.45	0.06	21.14	25.92	0.00	13.07	0.02	0.05	0.05	0.16	0.19	0.03	0.05	86.21	5.44	2.56	2.80	0.01	0.22	4.41	0.00	4.16	0.01	0.02	0.00	0.04	0.03	0.26	0.02	15.72
MR231	86	25.38	0.03	21.13	25.78	0.01	13.28	0.02	0.03	0.11	0.12	0.00	0.04	0.02	85.99	5.45	2.55	2.82	0.00	0.15	4.48	0.00	4.25	0.00	0.02	0.01	0.03	0.06	0.00	0.03	15.97

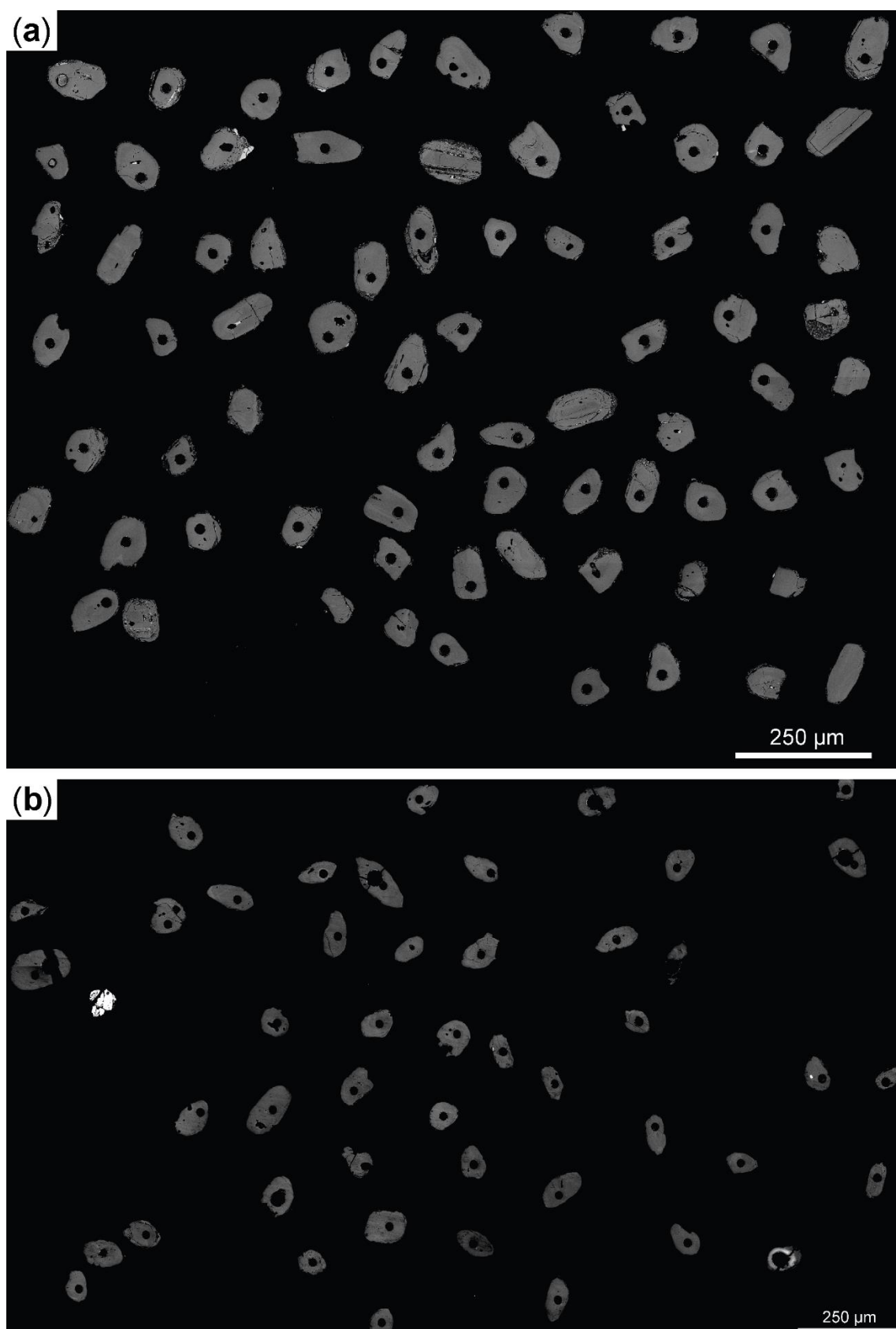


Figure S 1. (a) and (b) backscattered (BSE) images of zircon grains from samples BOLA-79 and BOLA-86, respectively.

Table S 8. U-Pb zircon data from sample BOLA-26.

Spot	U (ppm)	Th (ppm)	Th/U	Rho	Isotopic ratios						Ages						Discordancy (%)
					$^{206}\text{Pb}/^{238}\text{U}$	1 σ (%)	$^{207}\text{Pb}/^{235}\text{U}$	1 σ (%)	$^{207}\text{Pb}/^{206}\text{Pb}$	1 σ (%)	$^{206}\text{Pb}/^{238}\text{U}$	2 σ (Abs.)	$^{207}\text{Pb}/^{235}\text{U}$	2 σ (Abs.)	$^{207}\text{Pb}/^{206}\text{Pb}$	2 σ (Abs.)	
045-Z35	1072.33	137.57	0.13	0.940	0.134	1.328	1.312	1.409	0.071	0.469	810.64	20.23	851.01	16.24	957.74	19.65	10.0
004-Z2	1500.67	170.36	0.11	0.858	0.137	1.682	1.433	1.952	0.076	0.989	827.68	26.13	902.80	23.35	1091.43	39.90	12.5
023-Z16	160.91	59.21	0.37	0.814	0.152	0.953	1.524	1.149	0.073	0.643	912.16	16.21	940.09	14.09	1006.10	27.36	4.4
042-Z31	1070.27	77.48	0.07	0.687	0.156	0.815	1.574	1.139	0.073	0.796	934.51	14.18	960.01	14.14	1018.88	33.41	3.8
014-Z9	274.60	193.41	0.70	0.808	0.160	0.966	1.589	1.173	0.072	0.666	956.78	17.18	965.91	14.62	986.74	28.00	1.4
045-Z34	73.03	37.02	0.51	0.782	0.164	0.948	1.846	1.656	0.081	1.358	978.97	17.22	1062.00	21.81	1236.82	42.82	13.4
047-Z37	129.22	85.19	0.66	0.788	0.167	0.899	1.782	1.115	0.077	0.660	995.56	16.59	1038.91	14.50	1131.28	27.23	6.2
018-Z13	395.85	25.87	0.07	0.929	0.216	1.609	2.253	1.728	0.076	0.629	1260.70	36.85	1197.72	24.30	1085.81	25.47	-10.8
043-Z32	62.94	51.89	0.82	0.950	0.328	3.061	3.498	3.887	0.077	0.997	1828.68	97.47	1526.76	61.39	1130.16	54.50	-42.7
057-Z45	252.43	92.15	0.37	0.897	0.186	1.319	2.126	1.463	0.083	0.632	1099.67	26.67	1157.29	20.21	1266.84	24.90	9.3
053-Z41	48.22	27.65	0.57	0.722	0.196	1.572	2.269	2.158	0.084	1.478	1153.80	33.21	1202.71	30.42	1291.65	58.28	6.2
035-Z27	59.08	14.15	0.24	0.756	0.187	2.341	2.223	4.620	0.086	3.983	1105.10	47.55	1188.32	64.71	1343.07	124.50	12.8
017-Z12	167.55	98.71	0.59	0.753	0.219	0.730	2.692	0.931	0.089	0.578	1276.59	16.91	1326.26	13.79	1407.42	23.61	5.8
026-Z19	41.82	10.55	0.25	0.805	0.237	1.228	2.989	2.050	0.091	1.641	1371.08	30.33	1404.82	31.19	1456.40	49.34	3.9
051-Z39	185.60	109.42	0.59	0.707	0.284	0.718	3.572	0.966	0.091	0.647	1611.48	20.48	1543.33	15.33	1451.21	25.92	-6.8
055-Z43	263.00	26.05	0.10	0.812	0.251	0.866	3.202	1.043	0.093	0.581	1443.63	22.40	1457.64	16.14	1478.13	23.21	1.6
013-Z8	82.33	42.66	0.52	0.830	0.240	1.103	3.061	1.313	0.093	0.712	1386.70	27.52	1422.99	20.10	1477.71	27.78	4.3
029-Z22	238.93	95.37	0.40	0.914	0.225	1.348	2.883	1.468	0.093	0.583	1308.24	31.92	1377.48	22.13	1486.48	23.06	10.0
048-Z38	224.86	48.56	0.22	0.864	0.239	0.975	3.071	1.402	0.093	1.007	1381.50	24.25	1425.48	21.48	1491.80	28.46	4.9
006-Z4	225.73	97.29	0.43	0.743	0.262	1.049	3.388	1.706	0.094	1.345	1500.07	28.08	1501.62	26.75	1503.82	44.11	0.2
034-Z26	111.40	99.03	0.89	0.795	0.242	0.759	3.168	0.924	0.095	0.528	1397.09	19.07	1449.39	14.26	1526.97	20.90	5.9
037-Z29	96.83	36.12	0.37	0.935	0.254	1.881	3.321	2.008	0.095	0.704	1459.07	49.12	1486.00	31.34	1524.65	25.82	4.0
027-Z20	144.39	73.34	0.51	0.827	0.259	0.889	3.384	1.055	0.095	0.568	1484.72	23.58	1500.70	16.54	1523.33	22.19	1.8
015-Z10	112.29	40.63	0.36	0.807	0.244	0.741	3.219	0.890	0.096	0.492	1407.46	18.74	1461.74	13.79	1541.53	19.64	6.1
016-Z11	171.28	59.79	0.35	0.950	0.223	1.916	3.033	2.224	0.099	1.129	1297.71	45.04	1415.96	33.97	1598.63	26.94	20.2
058-Z46	163.28	70.91	0.43	0.820	0.267	1.478	3.661	2.453	0.099	1.958	1525.56	40.16	1562.91	39.13	1613.74	55.95	3.9
054-Z42	139.44	32.64	0.23	0.560	0.261	0.899	3.597	2.628	0.100	2.469	1494.96	23.99	1548.87	41.76	1623.22	83.76	6.9
024-Z17	200.06	45.21	0.23	0.958	0.280	1.951	3.978	2.035	0.103	0.577	1591.36	55.02	1629.72	33.02	1679.59	21.05	5.4
028-Z21	189.68	155.04	0.82	0.859	0.269	1.230	3.932	1.420	0.106	0.710	1535.72	33.62	1620.29	22.99	1731.95	26.59	9.4
003-Z1	53.81	39.99	0.74	0.695	0.299	1.339	4.392	1.900	0.107	1.348	1686.35	39.74	1710.84	31.43	1740.95	50.42	2.3
005-Z3	115.86	75.75	0.65	0.801	0.238	2.735	3.516	3.406	0.107	2.031	1376.29	67.79	1530.82	53.85	1751.41	74.81	16.7
033-Z25	127.31	63.10	0.50	0.808	0.292	0.852	4.448	1.031	0.110	0.580	1651.52	24.83	1721.33	17.09	1807.31	21.99	6.9
046-Z36	174.97	116.79	0.67	0.966	0.318	2.787	5.019	2.884	0.114	0.741	1779.95	86.70	1822.53	48.84	1871.55	25.29	5.4

009-Z7	228.31	220.29	0.96	0.889	0.307	1.489	4.850	1.669	0.115	0.752	1725.93	45.09	1793.61	28.10	1873.26	27.44	7.3
056-Z44	645.30	218.90	0.34	0.866	0.322	0.745	5.095	0.842	0.115	0.392	1799.49	23.40	1835.27	14.29	1876.10	14.97	3.5
044-Z33	193.23	86.00	0.45	0.665	0.283	0.844	4.478	1.220	0.115	0.881	1606.45	24.00	1726.90	20.25	1876.14	32.66	11.7
019-Z14	139.59	96.76	0.69	0.803	0.331	1.139	5.317	1.399	0.117	0.814	1843.23	36.52	1871.60	23.91	1903.25	30.17	2.6
052-Z40	374.39	200.24	0.53	0.921	0.316	0.979	5.087	1.055	0.117	0.394	1770.16	30.31	1833.94	17.90	1907.12	14.85	7.0
038-Z30	598.84	558.42	0.93	0.928	0.228	2.325	3.703	2.501	0.118	0.923	1324.01	55.66	1572.02	39.99	1923.00	32.96	35.4
007-Z5	204.11	174.47	0.85	0.892	0.299	2.086	4.874	2.334	0.118	1.047	1686.35	61.90	1797.77	39.33	1929.58	38.12	12.1
036-Z28	106.12	68.32	0.64	0.775	0.323	0.993	5.311	1.256	0.119	0.769	1804.36	31.26	1870.63	21.46	1945.07	28.11	6.0
032-Z24	87.04	112.00	1.29	0.866	0.331	1.567	5.582	1.800	0.122	0.886	1843.23	50.24	1913.33	31.00	1990.19	31.57	6.8
020-Z15	48.32	36.33	0.75	0.764	0.374	0.929	6.968	1.580	0.135	1.278	2048.19	32.60	2107.36	28.06	2165.63	37.04	4.9
025-Z18	40.14	20.89	0.52	0.695	0.201	2.249	5.271	3.220	0.190	2.304	1180.69	48.53	1864.18	54.96	2743.84	76.66	102.0
008-Z6	316.81	200.23	0.63	0.846	0.611	1.225	16.468	1.434	0.195	0.746	3074.01	59.90	2904.37	27.45	2788.81	24.74	-10.4

Table S 9. U-Pb zircon data from sample BOLA-27.

Spot	U (ppm)	Th (ppm)	Th/U	Rho	Isotopic ratios						Ages						Discordancy (%)
					$^{206}\text{Pb}/^{238}\text{U}$	1 σ (%)	$^{207}\text{Pb}/^{235}\text{U}$	1 σ (%)	$^{207}\text{Pb}/^{206}\text{Pb}$	1 σ (%)	$^{206}\text{Pb}/^{238}\text{U}$	2 σ (Abs.)	$^{207}\text{Pb}/^{235}\text{U}$	2 σ (Abs.)	$^{207}\text{Pb}/^{206}\text{Pb}$	2 σ (Abs.)	
018 Z14	71.9	12.0	0.167	0.828	0.243	0.704	3.196	0.823	0.095	0.428	1402.27	17.74	1456.19	12.73	1535.77	17.29	6.2
023 Z16	61.8	6.8	0.109	0.861	0.158	0.988	1.601	1.134	0.074	0.555	945.65	17.38	970.60	14.18	1027.52	23.41	4.1
010 Z08	73.2	14.3	0.196	0.962	0.245	1.916	3.192	2.170	0.095	1.019	1412.64	48.61	1455.23	33.56	1517.97	23.77	7.2
037 Z28	10.4	5.9	0.567	0.847	0.277	1.536	3.952	1.804	0.104	0.946	1576.24	42.96	1624.40	29.24	1687.37	35.07	5.2
024 Z17	59.6	8.8	0.147	0.921	0.503	0.874	13.439	0.940	0.194	0.347	2626.68	37.71	2711.01	17.77	2774.47	12.09	6.0
044 Z33	305.2	33.7	0.110	0.931	0.218	0.998	2.583	1.066	0.086	0.374	1271.30	23.03	1295.83	15.61	1336.71	15.15	3.9
019 Z15	49.4	24.2	0.489	0.914	0.341	0.910	5.746	0.986	0.122	0.382	1891.48	29.83	1938.32	17.06	1988.75	14.55	4.7
048 Z37	64.0	17.5	0.273	0.856	0.206	0.855	2.362	0.982	0.083	0.483	1207.47	18.83	1231.19	14.01	1272.96	19.56	3.3
054 Z40	48.7	9.9	0.203	0.822	0.301	0.751	4.478	0.888	0.108	0.475	1696.27	22.40	1726.90	14.74	1764.23	18.59	3.0
043 Z32	136.7	20.1	0.147	0.942	0.551	0.884	16.232	0.933	0.214	0.298	2829.33	40.49	2890.56	17.85	2933.50	10.30	4.1
008 Z06	186.4	27.8	0.149	0.989	0.259	1.893	3.423	1.914	0.096	0.281	1484.72	50.21	1509.69	30.08	1544.89	10.15	4.3
026 Z19	133.4	52.0	0.390	0.873	0.343	0.640	5.713	0.817	0.121	0.508	1901.09	21.07	1933.34	14.12	1968.08	14.59	3.0
015 Z11	55.9	10.1	0.181	0.834	0.208	0.796	2.357	0.933	0.082	0.486	1218.15	17.67	1229.68	13.30	1249.94	20.39	1.5
045 Z34	83.9	35.5	0.423	0.864	0.349	0.741	5.857	0.838	0.122	0.393	1929.82	24.72	1954.89	14.54	1981.54	15.24	2.3
057 Z43	145.1	24.2	0.167	0.883	0.241	0.691	3.005	0.765	0.090	0.329	1391.89	17.30	1408.89	11.66	1434.69	13.88	2.2
014 Z10	31.5	10.2	0.325	0.952	0.309	1.710	4.646	1.795	0.109	0.544	1735.78	52.04	1757.58	30.00	1783.58	20.44	2.7
040 Z31	46.0	10.8	0.235	0.864	0.268	0.866	3.583	1.208	0.097	0.842	1530.64	23.60	1545.77	19.18	1566.52	24.00	1.6
038 Z29	162.7	29.4	0.181	0.865	0.226	0.665	2.684	0.748	0.086	0.342	1313.50	15.81	1324.06	11.07	1341.18	14.26	1.4
049 Z38	38.1	5.6	0.146	0.913	0.530	1.041	14.396	1.132	0.197	0.446	2741.45	46.49	2776.17	21.50	2801.50	15.36	2.4
065 Z49	23.9	3.1	0.128	0.963	0.413	1.458	8.179	1.512	0.143	0.399	2228.62	54.94	2251.02	27.36	2271.45	14.60	2.1
039 Z30	132.4	43.6	0.329	0.895	0.361	0.700	6.154	0.767	0.124	0.315	1986.91	23.94	1997.94	13.40	2009.37	12.43	1.0
017 Z13	107.4	76.9	0.716	0.851	0.207	0.705	2.308	0.806	0.081	0.392	1212.82	15.59	1214.75	11.42	1218.18	16.72	0.3
060 Z46	284.9	132.1	0.464	0.953	0.189	1.219	2.001	1.331	0.077	0.534	1115.96	24.98	1115.85	18.02	1115.65	16.69	0.0
063 Z47	586.3	105.1	0.179	0.865	0.210	1.055	2.353	1.207	0.081	0.586	1228.82	23.61	1228.47	17.20	1227.85	24.20	0.0
033 Z24	128.3	18.3	0.143	0.887	0.231	0.895	2.736	0.996	0.086	0.437	1339.74	21.65	1338.29	14.81	1335.98	17.57	-0.2
047 Z36	156.2	44.8	0.287	0.887	0.351	0.613	5.731	0.673	0.119	0.277	1939.37	20.53	1936.06	11.64	1932.51	11.00	-0.3
027 Z20	118.9	47.5	0.399	0.929	0.322	1.013	4.887	1.084	0.110	0.385	1799.49	31.81	1800.02	18.27	1800.63	14.50	0.1
055 Z41	70.2	35.0	0.499	0.919	0.363	0.826	6.071	0.889	0.121	0.330	1996.38	28.36	1986.09	15.50	1975.40	12.42	-1.0
058 Z44	356.7	60.9	0.171	0.954	0.212	1.079	2.362	1.127	0.081	0.327	1239.46	24.33	1231.19	16.08	1216.73	13.85	-1.5
046 Z35	205.8	42.6	0.207	0.904	0.221	0.721	2.507	0.861	0.082	0.471	1287.16	16.83	1274.06	12.50	1252.04	14.84	-1.8
035 Z26	74.7	16.6	0.222	0.981	0.515	1.460	12.472	1.487	0.176	0.283	2677.94	63.99	2640.62	27.96	2612.14	9.85	-4.0
029 Z22	114.9	28.1	0.244	0.967	0.216	1.377	2.425	1.422	0.081	0.356	1260.70	31.54	1250.04	20.45	1231.72	13.57	-2.1
066 Z50	124.8	35.5	0.284	0.947	0.268	1.171	3.440	1.332	0.093	0.634	1530.64	31.91	1513.59	20.96	1489.80	16.15	-2.5

053 Z39	63.4	56.1	0.885	0.484	0.254	0.975	3.141	1.934	0.090	1.670	1459.07	25.46	1442.80	29.79	1418.89	64.89	-1.9
034 Z25	269.0	46.9	0.175	0.928	0.269	0.793	3.459	0.846	0.093	0.295	1535.72	21.67	1517.92	13.33	1493.18	11.77	-2.4
030 Z23	131.5	67.0	0.509	0.961	0.353	1.034	5.608	1.122	0.115	0.435	1948.91	34.78	1917.33	19.34	1883.34	11.42	-3.6
036 Z27	220.9	73.3	0.332	0.948	0.329	0.889	4.914	0.983	0.108	0.420	1833.53	28.37	1804.66	16.59	1771.48	11.33	-3.4
059 Z45	232.8	114.8	0.493	0.903	0.380	0.733	6.349	0.799	0.121	0.318	2076.28	26.02	2025.25	14.02	1973.63	12.42	-4.7
064 Z48	167.6	75.3	0.449	0.960	0.406	0.961	6.866	0.997	0.123	0.267	2196.61	35.78	2094.28	17.67	1995.17	9.92	-10.1

Table S 10. U-Pb zircon data from sample BOLA-79.

Spot	U (ppm)	Th (ppm)	Th/U	Rho	Isotopic ratios						Ages						Discordancy (%)
					²⁰⁶ Pb/ ²³⁸ U	1σ (%)	²⁰⁷ Pb/ ²³⁵ U	1σ (%)	²⁰⁷ Pb/ ²⁰⁶ Pb	1σ (%)	²⁰⁶ Pb/ ²³⁸ U	2σ (Abs.)	²⁰⁷ Pb/ ²³⁵ U	2σ (Abs.)	²⁰⁷ Pb/ ²⁰⁶ Pb	2σ (Abs.)	
049-Z36	458.2	336.5	0.734	0.905	0.026	1.672	0.043	2.036	0.012	0.772	165.46	5.46	42.75	1.70	0.00	10.97	-3200.0
020-Z15	99.1	41.4	0.418	0.878	0.323	1.572	4.015	2.141	0.090	1.454	1804.36	49.48	1637.24	34.81	1428.78	40.85	-18.0
014-Z9	311.0	83.6	0.269	0.881	0.297	0.883	3.885	0.989	0.095	0.445	1676.42	26.07	1610.57	15.97	1525.51	17.64	-7.4
046-Z33	124.3	84.7	0.681	0.838	0.294	0.948	3.862	1.113	0.095	0.584	1661.49	27.77	1605.78	17.95	1533.45	22.87	-5.9
039-Z29	231.0	123.8	0.536	0.980	0.394	1.692	5.243	1.751	0.096	0.341	2141.35	61.66	1859.63	29.86	1557.76	13.11	-34.0
056-Z41	370.0	298.6	0.807	0.925	0.292	1.466	3.899	1.613	0.097	0.592	1651.52	42.72	1613.48	26.07	1564.18	23.00	-4.8
047-Z34	394.6	247.6	0.628	0.941	0.410	1.065	6.021	1.169	0.107	0.482	2214.92	39.93	1978.89	20.36	1740.50	14.56	-24.0
038-Z28	419.3	130.7	0.312	0.931	0.337	0.843	4.963	0.898	0.107	0.310	1872.22	27.40	1813.04	15.18	1745.69	12.01	-6.5
013-Z8	314.1	176.2	0.561	0.950	0.350	1.185	5.167	1.243	0.107	0.377	1934.60	39.61	1847.20	21.15	1750.14	14.21	-9.9
016-Z11	471.9	135.0	0.286	0.910	0.345	0.899	5.105	1.033	0.107	0.509	1910.68	29.73	1836.94	17.54	1754.38	15.74	-7.7
024-Z17	470.4	212.0	0.451	0.887	0.324	1.359	4.806	1.524	0.108	0.689	1809.23	42.88	1785.95	25.62	1758.85	25.74	-2.4
058-Z43	236.3	192.9	0.816	0.842	0.367	0.697	5.507	0.804	0.109	0.401	2015.27	24.13	1901.69	13.82	1779.92	15.84	-10.0
025-Z18	194.1	219.5	1.131	0.863	0.353	1.209	5.320	1.389	0.109	0.684	1948.91	40.67	1872.08	23.74	1787.84	25.57	-7.4
044-Z31	204.1	151.7	0.743	0.911	0.386	1.061	5.848	1.158	0.110	0.462	2104.25	38.10	1953.55	20.08	1797.42	17.38	-15.0
023-Z16	107.9	51.6	0.478	0.876	0.369	1.493	5.592	1.696	0.110	0.804	2024.69	51.88	1914.87	29.22	1797.92	29.77	-10.0
027-Z20	223.2	72.0	0.323	0.866	0.347	1.197	5.262	1.370	0.110	0.667	1920.26	39.76	1862.72	23.38	1799.10	24.93	-5.6
030-Z23	265.5	187.0	0.704	0.937	0.349	2.425	5.294	2.835	0.110	1.468	1929.82	80.89	1867.90	48.43	1799.67	37.01	-7.1
019-Z14	1015.8	365.4	0.360	0.904	0.295	1.064	4.480	1.168	0.110	0.481	1666.47	31.25	1727.27	19.39	1801.76	18.17	6.9
015-Z10	430.4	183.0	0.425	0.872	0.348	1.013	5.459	1.148	0.114	0.542	1925.04	33.72	1894.17	19.70	1860.51	20.30	-3.0
040-Z30	438.0	309.8	0.707	0.951	0.351	1.233	5.563	1.294	0.115	0.391	1939.37	41.30	1910.39	22.27	1879.07	14.42	-3.2
005-Z2	296.7	157.5	0.531	0.950	0.343	1.202	5.484	1.262	0.116	0.384	1901.09	39.58	1898.09	21.68	1894.82	14.17	-0.3
057-Z42	569.6	412.8	0.725	0.936	0.280	1.248	4.487	1.440	0.116	0.719	1591.36	35.20	1728.57	23.91	1898.94	18.57	17.0
055-Z40	504.6	263.3	0.522	0.932	0.332	1.124	5.411	1.200	0.118	0.420	1848.07	36.12	1886.60	20.57	1929.27	15.58	4.2
018-Z13	140.3	48.7	0.347	0.837	0.376	0.926	6.150	1.087	0.119	0.570	2057.57	32.62	1997.37	18.99	1935.66	21.30	-5.3
009-Z6	394.2	169.1	0.429	0.988	0.398	2.683	6.567	2.715	0.120	0.412	2159.82	98.48	2054.93	47.85	1951.29	14.98	-11.0
028-Z21	355.6	113.1	0.318	0.938	0.270	1.982	4.461	2.110	0.120	0.724	1540.80	54.33	1723.75	35.00	1953.69	26.13	23.0
050-Z37	267.4	100.0	0.374	0.933	0.412	1.057	6.805	1.127	0.120	0.392	2224.06	39.76	2086.37	19.95	1953.13	14.49	-13.0
060-Z45	435.0	80.0	0.184	0.867	0.371	0.750	6.174	0.847	0.121	0.394	2034.10	26.17	2000.78	14.80	1966.53	15.06	-3.0
007-Z4	436.3	188.2	0.431	0.964	0.403	1.141	6.718	1.182	0.121	0.307	2182.84	42.26	2074.99	20.89	1969.58	11.21	-11.0
010-Z7	199.2	82.6	0.415	0.933	0.396	1.055	6.636	1.188	0.122	0.548	2150.59	38.58	2064.15	20.97	1978.92	15.34	-8.5
029-Z22	276.9	189.8	0.685	0.919	0.446	1.484	7.507	1.611	0.122	0.625	2377.44	59.01	2173.82	28.87	1986.79	22.60	-18.0
004-Z1	242.6	73.6	0.303	0.961	0.375	1.377	6.307	1.430	0.122	0.386	2052.88	48.42	2019.43	25.07	1985.39	14.07	-3.5
048-Z35	204.7	166.7	0.814	0.910	0.551	1.168	9.287	1.276	0.122	0.514	2829.33	53.50	2366.74	23.39	1989.21	18.82	-35.0

037-Z27	61.6	21.1	0.343	0.948	0.389	0.966	6.571	1.057	0.123	0.429	2118.19	34.88	2055.47	18.63	1993.14	12.03	-6.3
035-Z25	176.6	41.4	0.234	0.963	0.386	1.113	6.525	1.153	0.123	0.302	2104.25	39.96	2049.28	20.30	1994.41	11.05	-5.7
059-Z44	54.7	64.2	1.174	0.885	0.414	0.993	7.030	1.110	0.123	0.497	2233.18	37.48	2115.23	19.73	2002.44	18.36	-10.0
017-Z12	617.9	266.0	0.430	0.909	0.410	1.000	6.979	1.091	0.123	0.437	2214.92	37.49	2108.76	19.38	2006.75	16.15	-9.6
051-Z38	175.4	71.4	0.407	0.893	0.414	0.949	7.092	1.146	0.124	0.641	2233.18	35.82	2123.04	20.40	2018.02	18.47	-9.7
034-Z24	268.5	164.5	0.612	0.940	0.422	1.266	7.382	1.343	0.127	0.447	2269.55	48.44	2158.79	24.02	2055.05	16.18	-10.0
006-Z3	120.5	39.0	0.324	0.954	0.392	1.248	6.870	1.371	0.127	0.566	2132.10	45.31	2094.79	24.30	2058.34	14.66	-3.8
026-Z19	113.5	44.6	0.393	0.925	0.465	1.730	8.462	1.972	0.132	0.947	2461.60	70.80	2281.85	35.81	2124.52	26.45	-16.0
008-Z5	154.8	54.8	0.354	0.963	0.405	1.596	7.465	1.656	0.134	0.440	2192.02	59.31	2168.80	29.66	2146.89	15.59	-2.3
054-Z39	516.4	174.8	0.338	0.924	0.469	1.075	8.824	1.156	0.136	0.427	2479.17	44.25	2319.98	21.09	2182.69	15.39	-13.0
045-Z32	250.6	88.5	0.353	0.925	0.458	0.989	9.609	1.062	0.152	0.388	2430.72	40.05	2398.03	19.53	2370.39	13.77	-2.6
036-Z26	55.9	61.1	1.094	0.706	0.228	1.619	11.153	2.273	0.355	1.595	1324.01	38.76	2536.00	42.36	3727.64	48.98	170.0

Table S 11. U-Pb zircon data from sample BOLA-86.

Spot	U (ppm)	Th (ppm)	Th/U	Rho	Isotopic ratios						Ages						Discordancy (%)
					$^{206}\text{Pb}/^{238}\text{U}$	1 σ (%)	$^{207}\text{Pb}/^{235}\text{U}$	1 σ (%)	$^{207}\text{Pb}/^{206}\text{Pb}$	1 σ (%)	$^{206}\text{Pb}/^{238}\text{U}$	2 σ (Abs.)	$^{207}\text{Pb}/^{235}\text{U}$	2 σ (Abs.)	$^{207}\text{Pb}/^{206}\text{Pb}$	2 σ (Abs.)	
044 Z32	35.2	6.1	0.172	0.663	0.146	1.164	2.136	1.721	0.106	1.268	878.50	19.12	1160.53	23.80	1733.59	47.27	45.0
028 Z21	410.5	86.8	0.211	0.933	0.191	0.963	2.743	1.032	0.104	0.353	1126.79	19.91	1340.19	15.36	1699.49	13.68	35.0
053 Z39	731.7	166.8	0.228	0.746	0.199	3.745	2.725	5.015	0.100	3.336	1169.95	80.14	1335.30	74.50	1611.28	124.45	20.0
009 Z07	393.3	116.7	0.297	0.764	0.178	1.725	2.199	2.243	0.089	1.434	1056.04	33.61	1180.73	31.31	1417.00	55.34	17.0
019 Z15	328.4	109.7	0.334	0.748	0.239	1.877	3.549	2.494	0.108	1.642	1381.50	46.68	1538.21	39.51	1760.83	60.52	17.0
048 Z36	40.5	16.6	0.410	0.344	0.375	1.563	9.069	4.466	0.175	4.184	2052.88	54.96	2344.99	81.69	2609.84	139.67	31.0
016 Z12	181.1	34.6	0.191	0.381	0.262	1.383	4.182	6.532	0.116	6.384	1500.07	37.02	1670.50	107.05	1891.84	220.93	22.0
007 Z05	312.6	79.1	0.253	0.857	0.205	1.749	2.643	2.033	0.094	1.037	1202.12	38.36	1312.69	29.95	1498.17	39.63	14.0
036 Z27	241.2	68.8	0.285	0.965	0.290	1.455	4.874	1.584	0.122	0.625	1641.53	42.17	1797.77	26.69	1984.15	15.02	20.0
060 Z46	395.0	86.1	0.218	0.988	0.250	2.804	3.650	2.909	0.106	0.772	1438.48	72.30	1560.51	46.37	1729.81	16.69	20.0
034 Z25	132.4	33.0	0.250	0.939	0.304	1.161	5.296	1.231	0.126	0.410	1711.11	34.90	1868.22	21.03	2047.79	14.96	18.0
024 Z17	386.0	65.3	0.169	0.928	0.279	0.914	4.384	0.977	0.114	0.346	1586.32	25.71	1709.33	16.16	1863.55	13.15	15.0
004 Z02	178.7	84.1	0.471	0.961	0.304	2.075	5.177	2.158	0.124	0.590	1711.11	62.37	1848.84	36.73	2007.54	21.18	17.0
006 Z04	140.8	22.1	0.157	0.827	0.305	1.272	5.173	1.558	0.123	0.899	1716.06	38.33	1848.18	26.51	2000.34	31.12	13.0
013 Z09	155.8	37.3	0.240	0.918	0.314	1.001	5.017	1.083	0.116	0.412	1760.36	30.84	1822.20	18.34	1893.63	15.45	6.8
033 Z24	38.5	15.8	0.410	0.679	0.374	2.976	7.085	4.370	0.137	3.200	2048.19	104.44	2122.16	77.77	2194.61	111.51	5.9
057 Z43	99.6	18.3	0.184	0.724	0.266	3.334	3.624	4.597	0.099	3.165	1520.47	90.32	1554.82	73.17	1601.80	118.31	3.5
010 Z08	217.3	66.5	0.306	0.753	0.329	1.861	5.293	2.494	0.117	1.660	1833.53	59.40	1867.73	42.60	1906.01	58.96	3.0
027 Z20	189.7	73.1	0.386	0.734	0.407	3.412	8.164	4.642	0.145	3.148	2201.19	127.25	2249.36	83.98	2293.48	108.41	3.6
040 Z31	83.6	20.2	0.242	0.866	0.361	0.797	6.345	1.034	0.127	0.659	1986.91	27.26	2024.69	18.14	2063.43	18.56	3.3
046 Z34	264.8	46.2	0.175	0.896	0.347	0.672	5.820	0.773	0.122	0.383	1920.26	22.32	1949.39	13.40	1980.48	12.24	2.8
014 Z10	54.2	15.5	0.285	0.833	0.376	0.852	6.777	1.001	0.131	0.526	2057.57	30.02	2082.72	17.71	2107.69	19.45	2.1
015 Z11	32.9	11.0	0.334	0.794	0.355	1.083	6.011	1.343	0.123	0.795	1958.43	36.58	1977.44	23.38	1997.38	29.02	1.6
055 Z41	87.2	29.1	0.333	0.966	0.350	1.507	5.820	1.558	0.121	0.394	1934.60	50.37	1949.39	27.00	1965.14	14.37	1.7
003 Z01	166.3	44.0	0.264	0.887	0.354	0.872	5.904	0.970	0.121	0.425	1953.67	29.39	1961.82	16.85	1970.43	15.97	0.8
045 Z33	105.6	14.9	0.141	0.946	0.359	1.095	6.000	1.153	0.121	0.363	1977.43	37.29	1975.84	20.07	1974.18	13.32	-0.2
037 Z28	136.4	23.4	0.172	0.688	0.411	2.987	7.840	4.329	0.138	3.133	2219.49	112.18	2212.81	77.97	2206.63	109.05	-0.5
008 Z06	149.6	29.9	0.200	0.760	0.384	1.441	6.814	1.877	0.129	1.202	2094.94	51.55	2087.54	33.24	2080.25	42.95	-0.6
059 Z45	67.1	28.9	0.430	0.990	0.366	2.390	6.203	2.414	0.123	0.341	2010.55	82.56	2004.87	42.22	1999.02	12.10	-0.7
035 Z26	139.8	37.4	0.267	0.886	0.342	0.770	5.430	0.854	0.115	0.370	1896.28	25.30	1889.60	14.65	1882.27	14.27	-0.7
038 Z29	166.3	44.5	0.268	0.967	0.311	1.682	4.536	1.738	0.106	0.435	1745.63	51.44	1737.60	28.92	1727.95	16.26	-1.0
055 Z41	120.3	25.3	0.210	0.979	0.365	1.597	6.100	1.680	0.121	0.519	2005.83	55.06	1990.25	29.31	1974.10	12.32	-1.8
018 Z14	236.3	52.3	0.221	0.726	0.347	1.437	5.522	1.956	0.116	1.327	1920.26	47.73	1904.03	33.63	1886.39	48.44	-1.4

054 Z40	316.1	73.2	0.232	0.963	0.271	1.204	3.546	1.248	0.095	0.329	1545.88	33.10	1537.54	19.77	1526.10	12.67	-1.2
005 Z03	133.6	36.0	0.269	0.815	0.351	0.993	5.649	1.197	0.117	0.670	1939.37	33.26	1923.61	20.65	1906.66	24.92	-1.4
047 Z35	134.1	43.3	0.323	0.696	0.408	3.427	7.598	4.911	0.135	3.517	2205.77	128.03	2184.63	88.13	2164.83	122.97	-1.6
023 Z16	103.9	23.8	0.229	0.708	0.422	3.169	8.093	4.468	0.139	3.150	2269.55	121.25	2241.46	80.76	2215.91	109.42	-2.1
058 Z44	157.5	44.9	0.285	0.989	0.402	1.912	7.280	1.932	0.131	0.280	2178.24	70.68	2146.36	34.50	2115.99	10.02	-3.6
026 Z19	32.1	7.1	0.222	0.921	0.424	0.990	8.053	1.210	0.138	0.695	2278.61	38.00	2236.99	21.86	2199.10	16.94	-3.7
017 Z13	158.8	66.7	0.420	0.717	0.587	3.432	16.454	4.775	0.203	3.320	2977.25	163.67	2903.56	91.41	2852.85	108.39	-4.3
030 Z23	189.5	46.6	0.246	0.834	0.375	0.596	6.200	0.735	0.120	0.430	2052.88	20.96	2004.45	12.85	1954.89	14.50	-4.1
050 Z38	124.2	44.2	0.356	0.967	0.379	1.295	6.324	1.371	0.121	0.451	2071.61	45.89	2021.79	24.04	1971.29	12.50	-5.4
025 Z18	108.0	15.5	0.144	0.910	0.379	0.710	6.323	0.768	0.121	0.293	2071.61	25.16	2021.65	13.47	1971.01	11.36	-4.7
039 Z30	273.5	113.2	0.414	0.913	0.331	0.783	4.854	0.847	0.106	0.323	1843.23	25.10	1794.31	14.26	1737.91	12.68	-5.2
029 Z22	31.3	18.1	0.577	0.887	0.414	1.010	7.438	1.127	0.130	0.501	2233.18	38.13	2165.55	20.17	2102.05	18.28	-5.8
049 Z37	286.7	49.6	0.173	0.937	0.392	0.899	6.616	0.954	0.122	0.318	2132.10	32.64	2061.48	16.83	1991.61	11.85	-6.8

Table S . U-Pb zircon data from sample CAMP-03.

Spot	U (ppm)	Th (ppm)	Th/U	Rho	Isotopic ratios						Ages						Discordancy (%)
					²⁰⁶ Pb/ ²³⁸ U	1σ (%)	²⁰⁷ Pb/ ²³⁵ U	1σ (%)	²⁰⁷ Pb/ ²⁰⁶ Pb	1σ (%)	²⁰⁶ Pb/ ²³⁸ U	2σ (Abs.)	²⁰⁷ Pb/ ²³⁵ U	2σ (Abs.)	²⁰⁷ Pb/ ²⁰⁶ Pb	2σ (Abs.)	
004-Z1	97.7	182.6	1.869	0.978	0.516	2.048	12.814	2.073	0.180	0.314	2680.52	89.83	2666.1	39.04	2655.17	14.49	-1.5
005-Z2	571.3	259.1	0.454	0.972	0.163	2.010	1.610	2.012	0.072	0.315	971.37	36.26	974.27	25.2	980.81	19.47	0.8
006-Z3	592.9	142.9	0.241	0.998	0.224	3.153	2.730	4.060	0.087	1.161	1305.4	74.52	1336.72	60.34	1387.23	35.93	11.0
009-Z4	213.0	69.9	0.328	0.998	0.333	2.063	4.978	2.095	0.108	0.311	1851.3	66.41	1815.54	35.43	1774.74	5.26	-4.2
010-Z5	539.6	284.9	0.528	0.963	0.230	2.287	2.788	2.596	0.087	0.690	1332.6	55.07	1352.22	38.8	1383.39	28.03	3.7
011-Z6	94.2	69.7	0.741	0.923	0.166	2.032	1.673	2.081	0.072	0.380	990.39	37.32	998.21	26.45	1015.43	32.8	1.6
012-Z7	117.9	72.9	0.619	0.996	0.169	2.078	1.701	2.110	0.072	0.404	1008.52	38.8	1008.96	26.98	1009.92	7.94	0.1
015-Z8	96.2	80.1	0.833	0.889	0.279	1.988	3.736	2.029	0.096	0.383	1585.04	55.87	1579.04	32.51	1571.04	35.55	-0.7
016-Z9	174.7	386.3	2.211	0.913	0.334	1.966	5.115	1.988	0.110	0.329	1858.12	63.47	1838.66	33.77	1816.7	29.93	-2.1
017-Z10	190.2	162.9	0.856	0.966	0.360	1.985	6.046	2.016	0.121	0.321	1980.29	67.7	1982.5	35.14	1984.79	18.57	0.2
018-Z11	625.7	256.5	0.410	0.964	0.315	2.034	5.041	2.088	0.115	0.383	1764.14	62.79	1826.19	35.38	1897.7	19.87	7.6
021-Z12	270.5	276.6	1.022	0.988	0.366	2.031	6.202	2.041	0.122	0.342	2012.84	70.22	2004.78	35.69	1996.5	11.38	-0.9
022-Z13	179.6	125.6	0.699	0.898	0.133	2.070	1.210	2.089	0.066	0.446	802.39	31.24	805.08	23.23	812.53	39.22	0.6
023-Z14	123.7	119.8	0.968	0.880	0.164	2.003	1.643	2.041	0.073	0.406	977.16	36.33	986.93	25.76	1008.74	40.27	1.8
024-Z15	98.5	201.8	2.049	0.941	0.322	2.011	4.931	2.047	0.110	0.352	1801.65	63.22	1807.58	34.56	1814.43	25.43	0.7
027-Z16	156.9	100.1	0.638	0.973	0.360	1.983	6.127	2.002	0.123	0.320	1982.95	67.71	1994.11	34.96	2005.69	16.47	1.2
028-Z17	114.9	122.0	1.061	0.752	0.243	1.990	2.956	2.024	0.088	0.462	1402.36	50.16	1396.36	30.71	1387.21	54.25	-0.7
029-Z18	187.2	6.4	0.034	0.985	0.325	2.128	5.474	2.128	0.122	0.333	1814.85	67.32	1896.56	36.54	1987.21	12.97	10.0
030-Z19	16.8	19.0	1.131	0.816	0.162	2.279	1.602	2.412	0.072	0.858	965.19	40.85	971.16	30.17	984.67	58.16	1.0
033-Z20	84.9	42.8	0.503	0.919	0.571	1.948	17.323	1.980	0.219	0.327	2912.9	91.3	2952.92	38.01	2980.29	25.52	2.6
034-Z21	58.3	49.6	0.851	0.858	0.355	2.002	5.887	2.030	0.120	0.401	1957.52	67.61	1959.38	35.24	1961.35	38.41	0.2
035-Z22	106.2	72.3	0.681	0.925	0.370	1.976	6.778	2.003	0.132	0.342	2027.7	68.74	2082.9	35.45	2137.93	26.92	5.3
036-Z23	71.4	37.0	0.518	0.548	0.161	1.951	1.607	2.055	0.072	0.573	961.72	34.86	973.06	25.72	998.73	77.44	1.7
039-Z24	169.1	106.8	0.632	0.889	0.406	1.907	7.649	1.932	0.136	0.311	2197.53	71.02	2190.69	34.71	2184.29	31.53	-0.6
040-Z25	42.9	22.2	0.517	0.879	0.387	1.982	7.269	2.027	0.135	0.388	2109.59	71.32	2144.98	36.19	2179.06	34.32	3.1
041-Z26	270.9	41.0	0.151	0.903	0.375	1.948	6.778	1.969	0.130	0.313	2051.49	68.45	2082.89	34.84	2114.08	30.21	2.9
042-Z17	348.4	218.3	0.627	0.950	0.273	1.974	3.650	1.994	0.096	0.311	1558.02	54.63	1560.45	31.78	1563.74	23.57	0.3
045-Z28	117.8	98.2	0.834	0.876	0.385	1.978	7.389	2.002	0.139	0.336	2098.67	70.88	2159.59	35.82	2218.01	34.32	5.3
046-Z29	110.9	120.8	1.089	0.929	0.401	1.986	7.670	2.020	0.138	0.322	2172.4	73.25	2193.13	36.29	2212.58	26.14	1.9
047-Z30	76.0	49.7	0.654	0.898	0.396	1.960	7.480	2.006	0.136	0.334	2149.86	71.67	2170.64	35.93	2190.34	31.16	1.8
048-Z31	157.8	169.3	1.073	0.810	0.242	1.912	3.198	1.936	0.096	0.393	1396.19	48.01	1456.59	29.94	1545.85	44.63	7.2
051-Z32	315.1	315.1	1.000	0.980	0.190	2.040	2.521	2.084	0.096	0.357	1119.09	41.92	1278.22	30.3	1556.74	15.45	34.0
052-Z33	153.5	31.7	0.207	0.920	0.250	1.959	3.132	1.997	0.090	0.352	1440.24	50.57	1440.57	30.75	1441.05	30.24	0.0

053-Z34	137.9	143.5	1.041	0.938	0.377	2.000	6.969	2.011	0.134	0.330	2063.56	70.64	2107.5	35.71	2150.66	24.63	4.2
054-Z35	206.1	52.9	0.257	0.989	0.360	2.004	6.012	2.020	0.121	0.323	1984.12	68.44	1977.65	35.18	1970.89	10.82	-0.7
057-Z36	241.0	104.2	0.432	0.974	0.231	2.002	2.927	2.053	0.091	0.340	1341.69	48.51	1389.04	31.08	1462.55	17.6	8.5
058-Z37	116.5	262.9	2.257	0.980	0.537	2.009	14.311	2.038	0.192	0.316	2771.44	90.52	2770.56	38.68	2769.92	13.44	-0.1
059-Z38	156.5	143.8	0.919	0.819	0.316	2.014	5.876	2.103	0.134	0.527	1771.94	62.39	1957.71	36.5	2160.28	43.26	17.0
060-Z39	54.8	164.5	3.001	0.896	0.296	2.018	4.431	2.073	0.108	0.428	1673.47	59.49	1718.21	34.34	1773.16	34.17	5.0
063-Z40	131.4	93.3	0.710	0.793	0.162	1.993	1.603	2.049	0.071	0.475	968.21	35.83	971.2	25.63	977.98	53.01	0.5
064-Z41	122.3	91.0	0.744	0.915	0.222	2.135	2.675	2.166	0.087	0.406	1292.53	50.01	1321.64	32.02	1369.14	34.18	4.4
065-Z42	77.3	23.4	0.302	0.795	0.374	1.970	6.860	2.033	0.132	0.408	2049.17	69.18	2093.52	36.04	2137.41	44.87	3.7
069-Z43	254.8	284.9	1.118	0.763	0.214	2.206	2.783	2.425	0.094	0.843	1248.16	50.07	1351.09	36.23	1517.98	60.67	12.0
070-Z44	46.0	43.2	0.938	0.939	0.388	2.058	7.096	2.099	0.132	0.388	2111.63	74.11	2123.58	37.36	2135.17	25.46	1.1
071-Z45	107.0	154.7	1.446	0.986	0.532	2.023	14.610	2.031	0.199	0.318	2748.09	90.52	2790.17	38.61	2820.74	10.91	3.1
072-Z46	41.8	101.4	2.423	0.808	0.380	2.004	6.689	2.041	0.127	0.442	2075.65	71.13	2071.15	36.06	2066.69	44.24	-0.4
075-Z47	225.5	23.9	0.106	0.918	0.214	1.987	2.437	2.014	0.082	0.350	1250.09	45.17	1253.51	29	1259.39	31.62	0.6
076-Z48	94.7	71.6	0.757	0.725	0.196	1.969	2.126	2.042	0.078	0.509	1153.85	41.6	1157.15	28.19	1163.34	59.02	0.5
077-Z49	91.8	55.8	0.607	0.892	0.386	1.955	7.136	1.992	0.133	0.356	2104.24	70.2	2128.57	35.48	2152.15	32.12	2.2
078-Z50	94.8	109.7	1.157	0.751	0.317	1.951	4.845	2.001	0.110	0.415	1777.36	60.62	1792.83	33.68	1810.87	50.72	1.5

Table S 12. U-Pb zircon data from sample PM-XII-9b.

Spot	U (ppm)	Th (ppm)	Th/U	Rho	Isotopic ratios						Ages						Discordancy (%)
					$^{206}\text{Pb}/^{238}\text{U}$	1 σ (%)	$^{207}\text{Pb}/^{235}\text{U}$	1 σ (%)	$^{207}\text{Pb}/^{206}\text{Pb}$	1 σ (%)	$^{206}\text{Pb}/^{238}\text{U}$	2 σ (Abs.)	$^{207}\text{Pb}/^{235}\text{U}$	2 σ (Abs.)	$^{207}\text{Pb}/^{206}\text{Pb}$	2 σ (Abs.)	
04 Z2	22.9	21.3	0.929	0.913	0.386	3.014	7.141	3.112	0.134	0.391	2103.56	108.21	2129.14	55.43	2153.93	44.7	2.3
05 Z3	27.1	30.5	1.129	0.818	0.239	2.990	2.940	3.107	0.089	0.483	1380.13	74.29	1392.31	47.08	1411.02	70.5	1.5
06 Z4	29.4	61.8	2.101	0.895	0.323	3.004	4.925	3.097	0.110	0.368	1806.1	94.63	1806.53	52.28	1807.01	51.03	0.0
09 Z5	51.6	58.4	1.132	0.893	0.385	3.033	7.105	3.115	0.133	0.299	2097.3	108.59	2124.66	55.45	2151.24	49.81	2.4
10 Z7	26.5	29.1	1.097	0.894	0.390	3.016	7.386	3.082	0.137	0.346	2120.84	109	2159.23	55.13	2195.93	48.77	3.4
11 Z7	61.1	112.2	1.836	0.898	0.269	2.991	3.503	3.053	0.094	0.299	1538.12	81.85	1527.92	48.23	1513.82	51.56	-1.3
12 Z8	83.3	99.5	1.195	0.987	0.338	3.346	5.874	3.349	0.126	0.523	1878.4	109.06	1957.38	58.11	2041.97	19.29	9.3
15 Z9	15.2	13.6	0.895	0.925	0.393	3.058	7.381	3.139	0.136	0.420	2136.28	111.19	2158.69	56.14	2180.08	41.99	2.1
16 Z10	51.4	54.9	1.069	0.923	0.321	2.979	4.894	3.181	0.110	0.601	1794.08	93.3	1801.22	53.65	1809.5	44.44	0.8
17 Z11	49.3	50.8	1.030	0.905	0.308	2.980	4.584	3.066	0.108	0.309	1728.52	90.35	1746.45	51.12	1767.98	48.34	2.0
18 Z12	50.2	42.3	0.844	0.849	0.346	2.964	5.601	3.036	0.117	0.268	1913.31	98.14	1916.23	52.32	1919.4	59.17	0.3
21 Z13	62.2	109.6	1.762	0.898	0.291	2.977	4.415	3.059	0.110	0.290	1646.51	86.52	1715.08	50.64	1799.85	49.76	7.8
22 Z14	99.5	176.1	1.771	0.899	0.396	2.972	7.287	3.048	0.133	0.257	2152.82	108.78	2147.18	54.43	2141.78	47.3	-0.5
23 Z15	55.0	56.2	1.023	0.688	0.248	2.957	3.059	3.037	0.089	0.315	1430.73	75.88	1422.55	46.48	1410.32	90.66	-0.9
24 Z16	95.7	113.8	1.190	0.940	0.359	2.969	6.046	3.052	0.122	0.271	1978.29	101.16	1982.53	53.18	1986.95	37.13	0.4
27 Z17	49.2	72.3	1.469	0.799	0.342	2.916	6.286	3.024	0.133	0.319	1895.94	95.8	2016.45	52.98	2142.21	65.92	11.0
28 Z18	70.7	118.9	1.683	0.984	0.530	2.979	13.774	3.074	0.188	0.259	2742.84	133.08	2734.26	58.19	2727.93	17.93	-0.9
29 Z19	107.6	72.5	0.674	0.996	0.344	2.995	5.608	3.079	0.118	0.268	1904.13	98.75	1917.34	53.07	1931.66	10.57	1.7
30 Z20	59.4	51.3	0.863	0.733	0.398	2.986	7.388	3.075	0.134	0.309	2158.43	109.54	2159.58	55.01	2160.67	77.28	0.1
33 Z21	39.4	40.8	1.036	0.843	0.354	2.985	5.852	3.073	0.119	0.329	1953.91	100.64	1954.19	53.3	1954.48	60.76	0.0
34 Z22	42.9	44.1	1.027	0.758	0.314	2.947	4.676	3.003	0.108	0.412	1759.01	90.72	1762.93	50.24	1767.58	75.64	0.4
35 Z23	49.6	47.8	0.963	0.840	0.368	2.994	6.201	3.053	0.121	0.276	2020.43	103.87	2004.58	53.39	1988.28	60.82	-1.4
36 Z24	54.1	47.0	0.868	0.574	0.240	2.983	2.956	3.059	0.089	0.338	1384.32	74.33	1396.32	46.42	1414.7	106.75	1.3
39 Z25	94.6	199.2	2.106	0.689	0.235	2.938	2.810	3.011	0.086	0.318	1360.68	72.07	1358.14	45.09	1354.15	90.56	-0.3
40 Z26	84.1	52.0	0.619	0.947	0.323	2.947	5.425	3.037	0.121	0.283	1802.91	92.69	1888.78	52.08	1984.53	34.9	9.8
41 Z27	93.7	71.4	0.762	0.922	0.187	2.980	2.560	3.062	0.099	0.322	1104.96	60.51	1289.36	44.71	1611.22	44.64	31.0
42 Z28	88.3	207.4	2.349	0.903	0.294	2.996	4.438	3.058	0.109	0.318	1659.02	87.65	1719.54	50.68	1794.03	48.49	6.9
45 Z29	12.2	46.5	3.802	0.903	0.362	3.127	6.019	3.207	0.120	0.537	1989.86	107.06	1978.56	55.86	1966.77	49.76	-1.1
46 Z30	62.0	143.9	2.322	0.908	0.368	2.949	6.272	3.034	0.123	0.282	2019.36	102.24	2014.58	53.14	2009.69	45.57	-0.5
47 Z31	96.9	32.8	0.338	0.995	0.337	2.990	5.265	3.073	0.113	0.276	1874.44	97.26	1863.19	52.45	1850.67	10.91	-1.3
48 Z32	33.1	42.1	1.270	0.891	0.365	2.979	6.099	3.081	0.121	0.380	2004.7	102.66	1990.05	53.76	1974.88	50.5	-1.4
51 Z33	40.2	46.4	1.154	0.888	0.374	2.995	6.485	3.075	0.125	0.322	2046.97	105.06	2043.81	54.1	2040.62	50.96	-0.3
52 Z34	27.9	38.3	1.369	0.899	0.339	3.015	5.395	3.098	0.115	0.339	1881.38	98.4	1884.01	53.07	1886.91	49.52	0.3

53 Z35	21.7	25.6	1.181	0.970	0.367	3.111	6.232	3.186	0.123	0.326	2013.64	107.62	2008.97	55.75	2004.18	27.29	-0.5
54 Z36	45.7	47.5	1.040	0.944	0.271	2.982	3.569	3.060	0.095	0.291	1546.7	82.02	1542.61	48.53	1537	38.21	-0.6
57 Z37	36.3	57.9	1.594	0.898	0.247	2.981	3.041	3.079	0.089	0.374	1422.01	76.08	1418.02	47.05	1412.03	52.47	-0.5
58 Z38	41.3	52.6	1.275	0.959	0.463	3.015	10.358	3.083	0.162	0.290	2451.71	122.96	2467.26	57.1	2480.09	29.66	1.3
59 Z39	35.7	54.3	1.518	0.961	0.389	3.024	6.825	3.095	0.127	0.303	2117.21	109.13	2088.93	54.82	2061.17	30.43	-2.9
60 Z40	42.8	55.5	1.295	0.909	0.250	3.010	4.154	3.168	0.120	0.513	1439.03	77.65	1664.95	51.85	1962.91	47.36	28.0
63 Z41	19.3	25.7	1.335	0.979	0.539	3.041	14.198	3.119	0.190	0.281	2780.4	137.34	2763.02	59.18	2750.34	20.67	-1.8
64 Z42	52.4	81.3	1.552	0.912	0.383	2.943	6.644	3.027	0.125	0.289	2088.96	105.01	2065.19	53.42	2041.55	44.44	-2.2
65 Z43	88.9	80.6	0.906	0.989	0.278	3.046	4.130	3.145	0.107	0.275	1583.29	85.53	1660.24	51.43	1758.99	17.19	12.0
66 Z44	35.2	20.0	0.568	0.998	0.307	3.804	7.308	4.264	0.171	0.755	1724.55	115.12	2149.75	76.16	2584.93	17.81	51.0
69 Z45	34.8	66.5	1.912	0.883	0.347	2.930	5.572	3.012	0.116	0.311	1919.9	97.29	1911.85	51.86	1903.12	51.76	-0.8
70 Z46	20.6	28.3	1.377	0.909	0.410	2.934	7.817	3.023	0.138	0.324	2214.46	109.97	2210.12	54.42	2206.11	44.14	-0.4
72 Z48	36.8	61.5	1.673	0.898	0.341	2.976	5.853	3.071	0.123	0.314	1892.98	97.65	1954.31	53.26	2019.92	48.59	6.1
75 Z49	6.4	19.8	3.074	0.975	0.605	3.258	11.432	3.369	0.136	0.529	3049.17	158.29	2559.02	62.9	2190.71	25.88	-39.0
76 Z50	16.6	14.9	0.900	0.909	0.362	2.996	6.082	3.077	0.121	0.354	1991.66	102.65	1987.73	53.67	1983.64	46.14	-0.4
77 Z51	11.2	11.0	0.981	0.981	0.259	5.359	3.185	5.693	0.089	1.015	1482.79	141.98	1453.63	87.99	1411.26	43.18	-5.3
78 Z52	40.3	38.0	0.943	0.917	0.293	3.073	4.828	3.179	0.119	0.487	1656.28	89.76	1789.72	53.48	1949.01	45.77	15.0
81 Z53	25.4	20.8	0.818	0.930	0.352	2.980	5.873	3.064	0.120	0.313	1942.26	99.96	1957.23	53.17	1973.11	40.53	1.5
82 Z54	17.3	18.6	1.080	0.716	0.269	3.014	3.520	3.095	0.094	0.528	1536.16	82.38	1531.82	48.95	1525.83	86.86	-0.5
83 Z55	7.1	12.4	1.755	0.985	0.837	3.142	25.567	3.232	0.221	0.335	3918.72	184.53	3330.13	63.16	2992.8	18.25	-34.0
84 Z58	49.8	40.9	0.822	0.825	0.300	2.951	4.533	3.051	0.109	0.318	1690.86	87.77	1737.1	50.76	1793.23	64.7	4.7
87 Z57	25.3	65.4	2.585	0.990	0.333	2.987	5.037	3.063	0.110	0.338	1850.49	96.11	1825.57	51.9	1797.26	15.94	-2.9
88 Z58	27.5	45.0	1.634	0.868	0.332	2.993	5.043	3.070	0.110	0.326	1847.18	96.13	1826.63	52.03	1803.27	56.61	-2.1
89 Z59	24.4	28.5	1.169	0.392	0.260	2.987	3.205	3.066	0.089	0.418	1490.02	79.48	1458.28	47.45	1412.36	127.75	-3.4

Table S 13. U-Pb zircon data from sample MR231.

Spot	Th/U	Rho	Isotopic ratios						Ages						Discordancy (%)
			$^{206}\text{Pb}/^{238}\text{U}$	2 σ (%)	$^{207}\text{Pb}/^{235}\text{U}$	2 σ (%)	$^{207}\text{Pb}/^{206}\text{Pb}$	2 σ (%)	$^{206}\text{Pb}/^{238}\text{U}$	2 σ (Abs.)	$^{207}\text{Pb}/^{235}\text{U}$	2 σ (Abs.)	$^{207}\text{Pb}/^{206}\text{Pb}$	2 σ (Abs.)	
03 Z1	0.279	0.890	0.185	2.011	2.019	5.837	0.076	3.082	1095.74	20.27	1122.06	39.64	1173.39	82.09	4.8
04 Z2	0.078	0.941	0.122	3.408	1.202	6.902	0.066	2.596	739.26	23.8	801.5	38.26	978.66	78.9	16.0
06Z4	0.078	0.847	0.140	1.244	1.261	3.629	0.066	2.563	846.21	9.87	828.31	20.55	780.57	55.86	-3.6
09 Z5	0.043	0.367	0.136	1.032	1.219	3.123	0.066	2.592	822.18	7.96	809.38	17.42	774.36	61.15	-2.3
10 Z6	0.056	0.915	0.133	1.751	1.228	3.784	0.066	2.423	807.56	13.29	813.39	21.18	829.38	47.84	1.4
11 Z7	0.077	0.757	0.135	1.228	1.272	3.318	0.066	2.571	817.15	9.42	833.18	18.86	876.19	52.14	3.1
12 Z12	0.418	0.917	0.379	3.059	6.294	10.118	0.123	2.910	2073.86	54.25	2017.62	88.65	1960.55	132.28	-8.9
12 Z8	0.046	0.884	0.135	1.481	1.232	4.149	0.066	2.867	813.58	11.32	815.43	23.26	820.48	61.05	0.4
15 Z9	0.179	0.951	0.395	2.251	6.944	4.215	0.125	2.311	2143.8	41.05	2104.32	37.41	2065.94	38.56	-3.2
16 Z10	0.397	0.682	0.190	1.897	1.888	5.755	0.073	4.235	1123.03	19.55	1076.87	38.2	984.6	95.13	-7.2
21 Z13	0.456	0.771	0.124	1.906	1.343	3.712	0.081	2.642	753.05	13.54	864.41	21.6	1161.84	50.53	22.0
22 Z14	0.188	0.888	0.117	3.779	1.122	6.649	0.065	3.229	715.33	25.58	764.04	35.7	909.27	76.7	11.0
24 Z16	0.056	0.957	0.158	2.275	1.408	5.656	0.066	2.404	946.14	20.02	892.24	33.58	760.92	74.67	-13.0
27 Z17	0.221	0.897	0.514	1.409	12.932	3.328	0.189	2.283	2671.87	30.81	2674.74	31.37	2676.91	35.7	0.2
28 Z18	0.062	0.833	0.133	1.653	1.208	3.761	0.066	2.534	804.05	12.49	804.2	20.89	804.62	53.48	0.0
29 Z19	0.077	0.850	0.133	1.995	1.186	5.289	0.066	4.028	803.46	15.07	794.09	29.14	767.87	78.83	-2.0
30 Z20	0.185	0.709	0.133	1.544	1.207	4.017	0.066	2.885	803.97	11.67	804.04	22.31	804.23	65.31	0.0
33 Z21	0.060	0.802	0.134	1.567	1.200	3.873	0.066	2.696	813.4	11.98	800.6	21.45	765.14	58.52	-2.5
34 Z22	0.484	0.939	0.311	1.822	4.595	4.402	0.107	2.406	1743.45	27.83	1748.44	36.71	1754.41	50.53	0.9
36 Z24	0.278	0.809	0.227	1.605	2.673	4.728	0.086	3.001	1318.5	19.14	1321.16	34.94	1325.47	68.88	0.4
39 Z25	0.058	0.733	0.132	1.049	1.190	3.616	0.067	2.511	799.25	7.88	796.06	19.95	787.12	61.64	-0.6
40 Z26	0.080	0.814	0.127	1.305	1.159	4.962	0.066	2.847	769.68	9.47	781.59	27.05	815.75	83.04	2.4
41 Z27	0.038	0.833	0.127	1.157	1.155	4.103	0.066	2.440	770.1	8.39	779.44	22.33	806.29	67.07	1.9
42 Z28	0.078	0.840	0.131	1.126	1.165	4.041	0.066	2.606	792.86	8.4	784.15	22.07	759.45	66.51	-1.8
45 Z29	0.003	0.749	0.134	1.008	1.199	3.541	0.066	2.522	810.96	7.68	800.33	19.61	770.84	60.3	-2.1
46 Z30	0.053	0.759	0.131	1.031	1.191	3.845	0.066	2.720	794.86	7.71	796.39	21.22	800.67	65.7	0.3
47 Z31	0.055	0.818	0.131	1.169	1.189	3.891	0.066	2.565	795.29	8.75	795.26	21.46	795.2	63.16	0.0
48 Z32	0.079	0.841	0.135	1.263	1.219	4.658	0.066	2.618	814.62	9.66	809.16	25.98	794.17	76.77	-1.1
51 Z33	0.071	0.684	0.132	1.422	1.221	4.354	0.066	2.973	799.54	10.69	810.39	24.3	840.32	73.63	2.1
52 Z34	0.067	0.708	0.135	1.299	1.203	4.103	0.066	2.880	816.63	9.96	801.75	22.74	760.62	69.85	-2.8
53 Z35	0.283	0.739	0.135	1.426	1.464	4.355	0.069	2.954	819.05	10.96	915.71	26.27	1156.51	68.23	18.0
54 Z36	0.043	0.951	0.132	2.901	1.125	6.513	0.067	2.752	797.04	21.75	765.21	35.01	673.37	82.55	-8.4
57 Z37	0.059	0.908	0.139	1.451	1.278	3.879	0.066	2.248	837.06	11.39	836.09	22.1	833.54	54.89	-0.2

59 Z39	0.087	0.807	0.141	2.601	1.225	5.836	0.068	3.179	849.2	20.7	812.09	32.62	711.7	85.83	-7.1
60 Z40	0.076	0.939	0.218	2.086	2.257	4.638	0.081	2.360	1272.92	24.1	1198.93	32.63	1067.93	55.77	-13.0
63 Z41	0.176	0.695	0.135	1.834	1.202	4.433	0.066	3.127	816.73	14.07	801.45	24.57	759.21	72.22	-2.8
64 Z42	0.053	0.926	0.137	2.005	1.245	4.321	0.066	2.302	828.37	15.59	821.18	24.33	801.75	53.97	-1.7
65 Z43	0.068	0.795	0.137	2.035	1.187	4.269	0.066	2.710	828.38	15.82	794.34	23.52	699.98	62.27	-6.4
66 Z44	0.060	0.695	0.131	1.773	1.186	3.943	0.067	2.762	791.29	13.21	794.06	21.72	801.83	62.76	0.5
69 Z45	0.122	0.574	0.159	1.854	1.632	3.932	0.075	2.800	949.81	16.37	982.59	24.75	1056.56	65.32	5.2
70 Z46	0.464	0.948	0.374	2.956	7.259	4.765	0.134	2.360	2049.26	51.89	2143.75	42.52	2235.57	37.65	11.0
72 Z48	0.265	0.944	0.274	2.548	3.695	4.767	0.095	2.354	1560.18	35.31	1570.32	38.09	1583.98	46.89	1.4
75 Z49	0.332	0.794	0.300	1.817	3.911	3.093	0.097	2.209	1691.3	27.03	1615.89	25.01	1518.98	37.45	-7.3
76 Z50	0.155	0.788	0.161	1.949	1.778	3.750	0.082	2.417	963.75	17.45	1037.33	24.37	1195.84	49.65	13.0
78 Z52	0.156	0.905	0.412	1.968	7.517	4.049	0.136	2.327	2225.54	37.03	2175.07	36.29	2127.79	42.36	-4.1
79 Z53	0.079	0.804	0.135	2.142	1.153	4.084	0.066	2.504	818.92	16.47	778.57	22.21	664.59	57.52	-7.4
80 Z54	0.191	0.799	0.163	2.005	1.630	4.332	0.073	3.071	975.35	18.15	981.77	27.26	996.16	60.62	1.1
83 Z55	0.073	0.733	0.133	2.078	1.204	4.302	0.066	2.892	805.55	15.73	802.5	23.86	794.03	65.36	-0.6