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**FORMAÇÃO EXU: REGISTRO FLUVIAL DA CONTINENTALIZAÇÃO DA
BACIA DO ARARIPE DURANTE A FASE PÓS-RIFTE**

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Dissertação de Mestrado apresentada ao Instituto de Geociências e Ciências Exatas do Câmpus de Rio Claro, da Universidade Estadual Paulista Júlio de Mesquita Filho, como parte dos requisitos para obtenção do título de Mestre em Geociências e Meio Ambiente.

Orientador: Prof. Dr. Mario Luis Assine

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RESUMO

A sequência pós-rifte II da Bacia do Araripe registra uma importante fase de rearranjo do mergulho deposicional da bacia e do padrão das paleodrenagens continentais no interior do Nordeste brasileiro, após a abertura do Oceano Atlântico Sul. Enquanto nas bacias marginais brasileiras a transição entre Cretáceo Inferior e Cretáceo Superior é caracterizada por condições marinhas transgressivas que perduram até o final do Cretáceo, no interior do continente depósitos exclusivamente continentais indicam uma mudança paleogeográfica que implicou a perda de conexão com o recém formado Oceano Atlântico Sul. O último ciclo deposicional da Bacia do Araripe, representado pela Formação Exu, registra esta mudança paleogeográfica e, portanto, representa uma unidade-chave para o entendimento da evolução deposicional e do relevo no Nordeste brasileiro durante a fase pós-rifte. A fim de integrar o registro continental da Formação Exu ao contexto paleogeográfico regional, a presente pesquisa centrou-se na identificação do sistema deposicional e das principais áreas-fonte desta unidade. As análises estratigráfica e sedimentológica da Formação Exu indicam que a unidade, com espessura máxima de ~200 metros, é constituída por seis associações de fácies depositadas principalmente nas porções proximal e central de um sistema fluvial distributivo. Dados de paleocorrentes fluviais indicam paleodrenagens para oeste, o que é corroborado por idades U-Pb de zircões detríticos que sugerem bacia de captação localizada na porção leste do Domínio Transversal da Província Borborema. Variações de arquitetura deposicional e dispersão sedimentar entre as unidades subjacentes (Grupo Santana e Formação Araripina) e a Formação Exu reiteram a relação entre o soerguimento da região leste da Província Borborema e a inversão da pendente da bacia, com o aumento do suprimento sedimentar para a área deposicional e o estabelecimento de um leque fluvial de grande escala. Com base no empilhamento estratigráfico, foi possível discutir a influência de fatores alogênicos, principalmente soerguimento e quiescência na área-fonte, tanto para o estabelecimento do sistema, como para sua evolução estratigráfica. Por fim, a completa continentalização das drenagens da Bacia do Araripe revela uma nova paleogeografia para a região, após a abertura do Oceano Atlântico Sul, e o fim das periódicas ingressões marinhas na bacia, características do Aptiano.

Palavras-chave: sistema fluvial distributivo; proveniência sedimentar por datação U-Pb de zircões detríticos; soerguimento pós-rifte; Província Borborema; Bacia do Araripe; rifteamento do Gondwana

ABSTRACT

Following the final breakup of Gondwana and the formation of the South Atlantic Ocean, the continental drainage network of Northeast Brazil underwent a complete rearrangement, resulting in the continentalization of the Araripe Basin. The last depositional cycle of the Araripe Basin (Exu Formation) records this key event and represents a unique opportunity to understand the Albian-Cenomanian depositional and paleogeographic evolutions in the interior of Northeast Brazil. Employing a combination of facies analysis and detrital zircon geochronology, this work investigates the depositional and paleogeographic histories of the Exu Formation emphasizing possible implications for the post-rift landscape evolution of northeastern Brazil. Stratigraphic and sedimentological analyses indicate that the Exu Formation is composed of six facies associations deposited in proximal to medial zones of a distributive fluvial system. Provenance analysis based on U-Pb zircon dating and paleocurrent data revealed that this west-flowing fluvial system drained a highland located in the eastern part of the Borborema Province, with most of its source area placed in the Transversal Domain. The contrasting dispersion pattern, in relation to the underlying Santana Group and Araripina Formation, suggest a post-Albian uplift close to the NE Brazilian margin resulting in: (1) high amount of sediment supply delivered to the depositional site; (2) a reconfiguration of basin paleoslope; and (3) the establishment of a distributive fluvial system in the Araripe Basin. Based on stratigraphic trends and relations between channelized and non-channelized elements, it was possible to extend the discussion on the influence of allogenic forcing mechanisms, such as source area tectonism, to the stratigraphic evolution of the distributive fluvial system. The development of this drainage system, driven by geodynamic processes related to the opening of the South Atlantic Ocean, represented the return to continental deposition in the interior of Northeast Brazil and the cessation of the temporary connections between the Araripe Basin and the newly formed South Atlantic Ocean, typical of the Aptian period.

Keywords: Cretaceous distributive fluvial system, detrital zircon provenance, Borborema Province, post-rift uplift, Gondwana rifting.

ORGANIZAÇÃO DA DISSERTAÇÃO

Nesta dissertação de mestrado, os resultados são apresentados e discutidos sob a forma de um manuscrito de artigo científico, redigido em inglês, que será submetido a uma revista científica internacional da área. O manuscrito possui uma lista de referências bibliográficas própria cuja formatação atende aos padrões dos principais periódicos internacionais da área. Desta forma, a dissertação foi organizada em três capítulos principais que têm como objetivos: introduzir e contextualizar a pesquisa desenvolvida; expor e discutir detalhadamente os resultados; e, por fim, apontar as considerações finais referentes à pesquisa.

O Capítulo I, redigido em português, se inicia com a introdução do tema da dissertação, seguida da apresentação dos objetivos do trabalho, da descrição do contexto geológico regional no qual a área de estudo se insere, e do detalhamento dos métodos utilizados. Por fim, são listadas as referências bibliográficas referentes a esta seção do trabalho.

O Capítulo II contém o manuscrito do artigo científico no qual os dados obtidos na pesquisa são apresentados e discutidos detalhadamente.

Por fim, no Capítulo III constam as considerações finais da pesquisa de mestrado, seguidas de um apêndice com tabelas suplementares.

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I. CONSIDERAÇÕES INICIAIS

I.1. Introdução

As bacias das margens leste e equatorial brasileira, bem como as bacias cretáceas do Nordeste do Brasil, tiveram seu desenvolvimento relacionado aos eventos tectônicos responsáveis pela fragmentação do supercontinente Gondwana. Neste contexto, a reativação de estruturas do embasamento pré-cambriano no Nordeste do Brasil promoveu a formação de uma série de bacias interiores (Matos, 1992; Ponte & Ponte Filho, 1996; Brito Neves et al., 2000; Assine, 2007), dentre as quais se destaca a Bacia do Araripe (Figura 1).

O registro pós-rifte da Bacia do Araripe corresponde aos estágios finais da separação entre América do Sul e África, com a formação dos oceanos Atlântico Sul e Equatorial (Assine, 2007). A megasequência pós-rifte I, composta por sequências transicionais transgressivas-regressivas, registra condições marinhas epicontinentais na bacia (Assine *et al.*, 2016; Custódio *et al.*, 2017; Varejão *et al.*, 2021), as quais se relacionam em termos litológicos, paleontológicos e genéticos às sequências das bacias da margem leste brasileira (Assine, 2007). Sobre esta megasequência, a sequência pós-rifte II representa o último ciclo deposicional na Bacia do Araripe. De caráter exclusivamente continental, seu registro não possui correlação com sequências coevas das bacias marginais, caracterizadas por condições marinhas transgressivas até o final do Cretáceo (Assine, 2007).

Na sequência pós-rifte I, paleodrenagens fluviais para sul e sudeste em direção às bacias Tucano e Jatobá, e ingressões marinhas na direção oposta, demonstram a conexão destas bacias com o recém formado Oceano Atlântico Sul (Assine, 1994; Assine *et al.*, 2016; Custódio *et al.*, 2017; Varejão *et al.*, 2021). De maneira oposta, depósitos fluviais da Formação Exu (pós-rifte II) com paleofluxo para oeste e oeste-sudoeste (Assine, 1994; Warren et al., 2021) demonstram a completa continentalização da Bacia do Araripe, com o estabelecimento de um sistema fluvial de grande extensão.

Alguns indícios da literatura, como: (1) eventos tectono-magmáticos na Bacia do Pernambuco, que culminaram no alojamento em nível crustal raso do plúton granítico do Cabo (Long *et al.*, 1986; Nascimento, 2003); (2) dados de traço de fissão em apatita indicativos de intervalos de resfriamento entre ~110 e 90 Ma (Morais-Neto *et al.*, 2009; Turner *et al.* 2008; Japsen et al., 2012; Jelinek et al., 2014) e (3) dados de paleocorrentes da Formação Exu (Assine, 1994; Warren et al., 2021 e presente trabalho) sugerem o soerguimento do leste da Província Borborema, após a abertura do Oceano Atlântico Sul, como responsável pela reorganização da paleodrenagem continental no nordeste brasileiro.

No entanto, pouco foi feito no sentido de associar os eventos supracitados à inversão da pendente da Bacia do Araripe e ao estabelecimento de sistemas fluviais que abrangiam, ao menos, a região entre a Chapada do Araripe e a Serra Negra, na Bacia do Jatobá (Figura 1). Da mesma forma, o registro sedimentar destes sistemas é pouco conhecido, já que poucos trabalhos discorrem sobre a Formação Exu e seu contexto paleogeográfico.

Ante ao panorama exposto, este estudo propõe um modelo deposicional para a Formação Exu, com base nas análises sedimentológica, estratigráfica e de proveniência sedimentar, associando dados de paleocorrentes e idades de zircão detrítico. A integração destes resultados é fundamental, tanto para interpretação do sistema deposicional de uma unidade com registro fragmentado, como para o aperfeiçoamento do contexto paleogeográfico da Bacia do Araripe e do Nordeste brasileiro, após a abertura do Oceano Atlântico Sul.

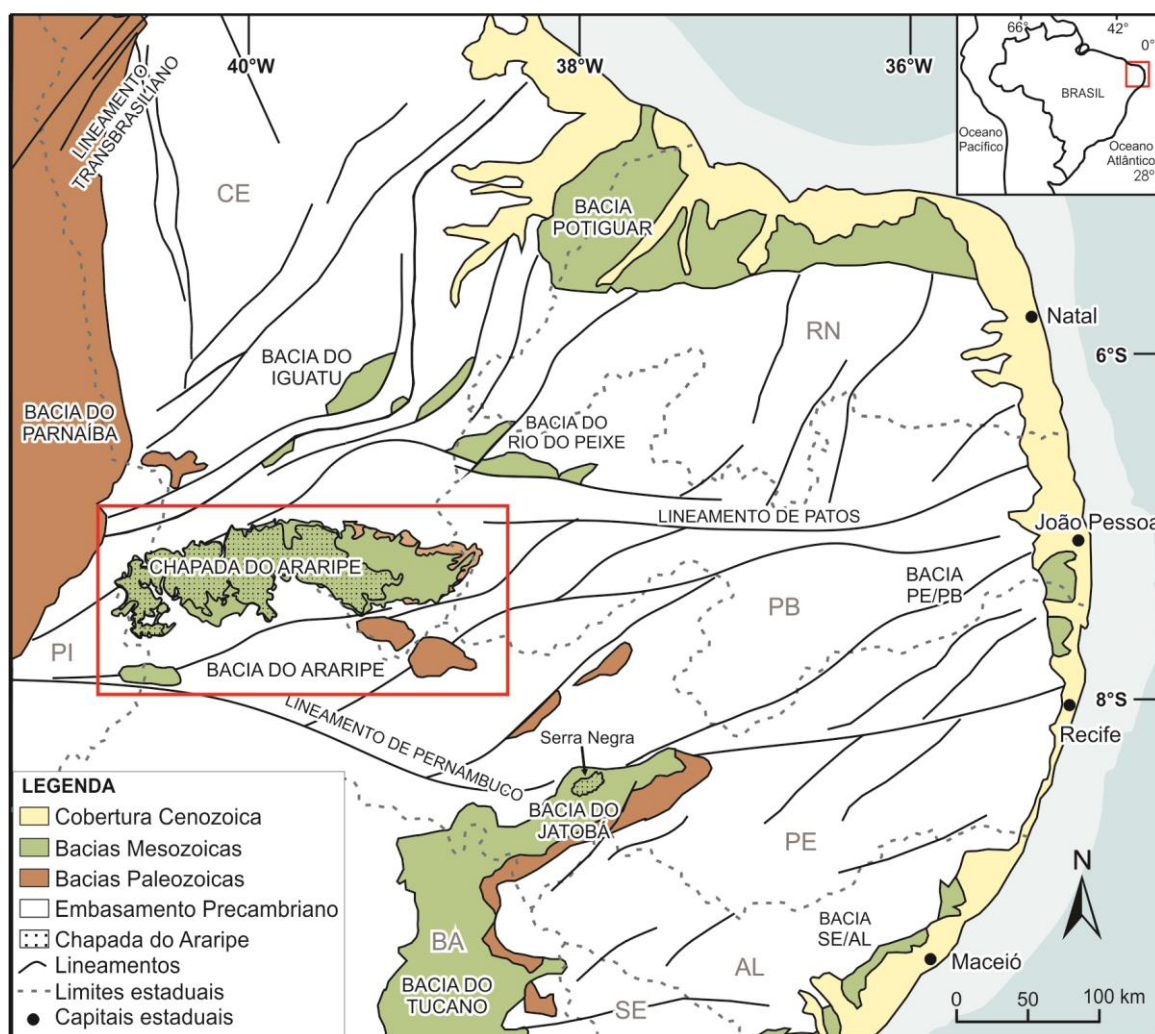


Figura 1. Localização das bacias interiores do Nordeste brasileiro, com destaque para a Bacia do Araripe. Modificado de Assine (1990).

I.2. Objetivos

O objetivo principal desta pesquisa foi estabelecer um modelo para a evolução sedimentar da Formação Exu. Para isso, buscou-se elucidar o sistema deposicional da unidade com base na descrição e interpretação de suas fácies sedimentares e associações de fácies, bem como na identificação de suas principais áreas-fonte. A combinação destas abordagens permitiu integrar o registro continental pós-rifte da Bacia do Araripe ao contexto paleogeográfico regional. Ademais, procurou-se comparar dados da Formação Exu com dados de unidades subjacentes da fase pós-rifte, com o intuito de identificar as principais mudanças regionais que influenciaram a sedimentação da Formação Exu e, assim, aperfeiçoar o modelo paleogeográfico da bacia no contexto pós abertura do Oceano Atlântico Sul.

I.3. Contextualização regional

I.3.1. Bacia do Araripe

O processo de fragmentação do supercontinente Gondwana, que culminou na abertura do Oceano Atlântico Sul, gerou uma série de bacias rifte tanto nas margens continentais como no interior do Nordeste do Brasil. Durante a ruptura, a propagação de esforços tectônicos continente adentro acarretou na reativação de estruturas do embasamento pré-cambriano da Província Borborema e na consequente formação de pequenas bacias interiores (Matos, 1992; Ponte & Ponte Filho, 1996; Brito Neves *et al.*, 2000; Assine, 2007); dentre as quais a Bacia do Araripe se destaca por ser a mais extensa e com o mais complexo registro geológico (Assine, 2007).

A Bacia do Araripe abrange uma área de aproximadamente 9000 km², com espessura total máxima de cerca de 1700 metros (Assine, 1992). Encontra-se entre os estados do Ceará, Pernambuco, Piauí e Paraíba (Figura 1), sobre os terrenos da Zona Transversal da Província Borborema (Brito Neves *et al.*, 2000), delimitados a norte pelo Lineamento de Patos e a sul pelo Lineamento de Pernambuco.

De acordo com Matos (1992), sua origem resulta da reativação de falhas transpressivas NE-SW que compõe o *splay* da extremidade oeste do Lineamento de Patos. Uma distensão de direção NW-SE atuante durante o Eocretáceo teria sido responsável por reativar este pequeno segmento da Zona de Cisalhamento de Patos e criar as falhas normais geradoras da bacia. Trabalhos mais recentes descrevem falhas direcionais e oblíquas com movimentação sinistral e dextral como indicativas de regime tectônico *strike-slip* ao longo da evolução da fase rifte na bacia (Rosa *et al.*, 2019). Dados gravimétricos e magnetométricos demonstram que a Bacia do

Araripe se divide em duas sub-bacias rifte (Feira Nova e Cariri) separadas pelo Alto de Dom Leme (Castro & Castelo Branco, 1999), embora, na fase pós-rifte, a deposição tenha ultrapassado os limites destas sub-bacias, recobrando diretamente o embasamento pré-cambriano (Assine, 2007; Assine *et al.*, 2014; Varejão *et al.*, 2021).

O registro estratigráfico da Bacia do Araripe é representado por quatro sequências deposicionais limitadas por discordâncias regionais, associadas às distintas fases tectônicas da bacia (Ponte, 1992): sequência paleozoica, supersequência pré-rifte, supersequência rifte e supersequência pós-rifte, subdivida nas sequências pós-rifte I e pós-rifte II (Assine, 2007; Figura 2).

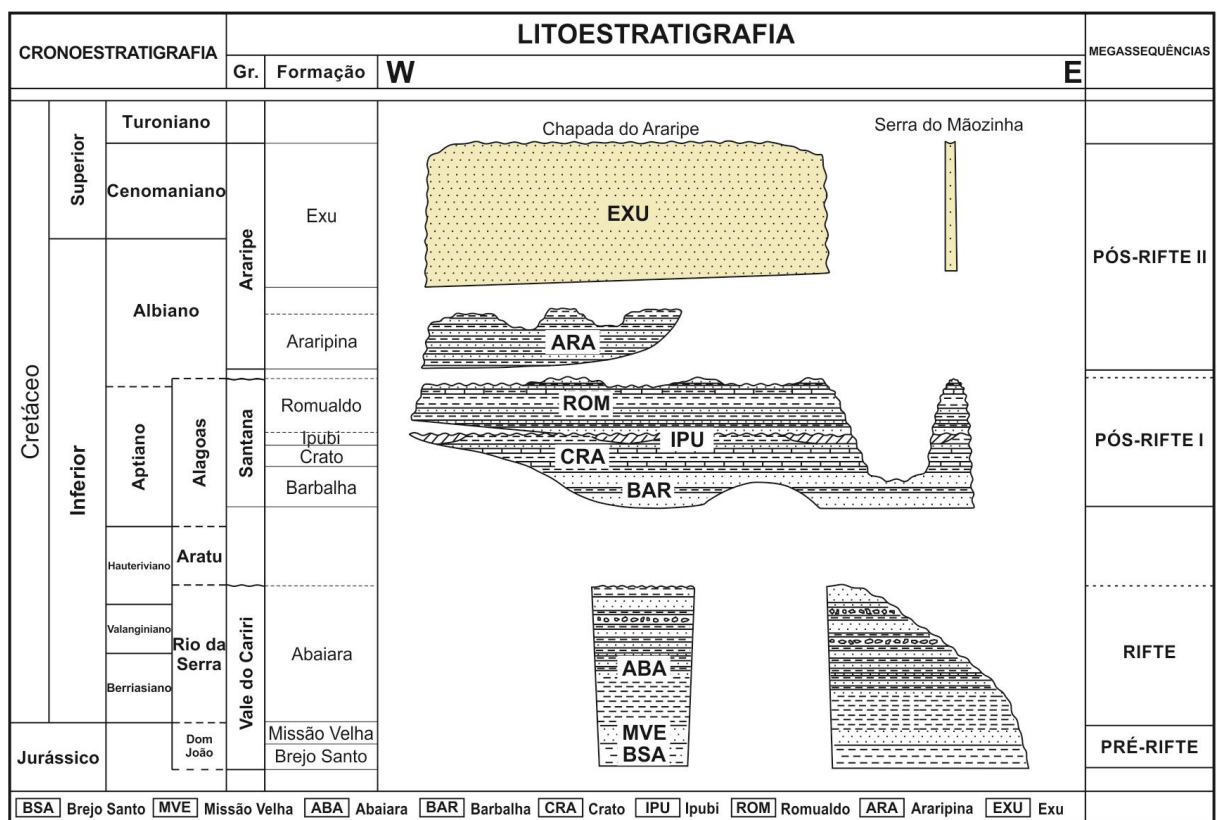


Figura 2. Carta estratigráfica da Bacia do Araripe, com destaque para a Formação Exu (modificada de Assine, 2007).

A sequência paleozoica é constituída apenas pela Formação Cariri, definida por Beurlen (1962). Tal unidade aflora na região leste da Bacia do Araripe, definindo os contornos do Vale do Cariri. Em sua porção oeste, ocorre somente em subsuperfície, como na sub-bacia de Feira Nova. Sua espessura é reduzida, atingindo cerca de uma centena de metros (Assine, 2007). É composta por arenitos imaturos, de granulação média a muito grossa, interpretados como depósitos de sistemas fluviais entrelaçados (Assine, 2007). Por meio de correlação com o Grupo

Serra Grande da Bacia do Parnaíba e com a Formação Tacaratu da Bacia do Jatobá, a Formação Cariri foi posicionada no intervalo Neo-Ordoviciano/Eo-Devoniano (Assine, 2007).

A supersequência pré-rifte compreende as formações Brejo Santo e Missão Velha (Assine, 2007). A Formação Brejo Santo apresenta espessura máxima de 450 metros e é composta por folhelhos e lamitos avermelhados, entre os quais se intercalam camadas decimétricas a métricas de arenito e lâminas de calcário argiloso rico em ostracodes (Assine, 1992). Com base na presença de organismos exclusivamente não marinhos, interpreta-se sedimentação continental em ambiente lacustre caracterizado por condições oxidantes (Assine, 1992; Assine, 2007). Em contato concordante com a Formação Brejo Santo, a Formação Missão Velha, com espessura máxima próxima a 200 metros, apresenta arenitos quartzosos, por vezes feldspáticos e/ou caoliníticos, localmente conglomeráticos e portadores de fósseis de troncos silicificados, atribuídos à conífera *Dadoxylon benderi* (Assine, 2007). Segundo este autor, a associação de fácies da unidade sugere deposição em planícies fluviais de sistemas entrelaçados caracterizados por canais rasos de alta energia. A partir de associações palinológicas descritas por Coimbra *et al.* (2002), a unidade foi posicionada no Andar Dom João (Neojurássico).

O início do estágio rifte na Bacia do Araripe é marcado pela deposição da Formação Abaiara, no Neocomiano, em contato basal discordante com a Formação Missão Velha (Ponte & Ponte-Filho, 1996). Essa unidade, de grande variação faciológica lateral e vertical, é constituída por folhelhos e siltitos vermelhos, na base, e lentes métricas de arenito interestratificadas com folhelho siltoso esverdeado, associadas a níveis conglomeráticos com fragmentos de madeira silicificada, em sua porção superior (Assine, 1992). O conteúdo fóssilífero da Formação Abaiara permite posicioná-la entre os andares Rio da Serra e Aratu (Ponte & Appi, 1990; Assine, 1992). Sua associação de fácies indica sedimentação em ambientes continentais, com gradual substituição de lagos rasos por planícies fluviais de canais entrelaçados (Assine, 2007).

A supersequência pós-rifte, subdividida em sequência pós-rifte I – de idade neoaptiana-eoalbiana – e sequência pós-rifte II – de idade albiana-cenomaniana – recobre as sequências sotopostas a partir de uma discordância angular regional (pré-Alagoas), reconhecida em todas as bacias da margem leste brasileira (Assine, 2007). Depósitos da supersequência pós-rifte ocorrem também em não-conformidade com o embasamento pré-cambriano, demonstrando que sua área de deposição ultrapassava os limites atuais da Bacia do Araripe (Assine, 2007; Assine *et al.*, 2014; Varejão *et al.*, 2019a). Esta observação é reforçada pela presença de seções incompletas da supersequência em morros testemunhos das bacias Tucano Norte e Jatobá (Neumann & Rocha, 2014; Varejão *et al.*, 2016; Varejão *et al.*, 2021).

A sequência pós-rifte I é composta pelo Grupo Santana (Neumann, 1999), o qual inclui as formações Barbalha, Crato, Ipubi e Romualdo (Neumann & Assine, 2015).

O registro da Formação Barbalha compreende dois grandes ciclos fluviais granodecrescente ascendentes, cujos topos são marcados por intervalos pelítico-carbonáticos lacustres, por vezes betuminosos (Assine, 1992; 2007; Chagas *et al.*, 2007). O nível de folhelho betuminoso é papiráceo e fossilífero, com ostracodes pertencentes à biozona RT-011 (Andar Alagoas), conchostráceos e palinomorfos (Assine, 1992).

Sobrepostas à Formação Barbalha, ocorrem, respectivamente, as formações Crato, Ipubi e Romualdo; as unidades mais estudadas da Bacia do Araripe devido a seu diversificado conteúdo fossilífero e a sua complexidade litológica.

A Formação Crato é composta por calcários micríticos laminados, com registro fossilífero abundante, interdigitados lateralmente com folhelhos verdes. Considerado como um dos mais importantes *fossilagerstätte* do Cretáceo mundial, esta unidade registra diversa assembleia fossilífera, constituída por pequenos peixes, insetos, crustáceos, aracnídeos, quelônios, lagartos, pterossauros, ostracodes e fósseis vegetais em excelente estado de preservação (Silva Santos & Valença, 1968; Mabesoone & Tinoco, 1973; Neumann, 1999; Varejão *et al.*, 2019b). A rica associação fossilífera em seus calcários laminados indica ambiente de sedimentação lacustre (Neumann, 1999). Adicionalmente, fácies de planície de maré associadas a icnoassembleia característica de condições de água salobra, permitiram a interpretação de, ao menos, uma ingressão marinha na unidade (Varejão *et al.*, 2021).

Sobreposta à Formação Crato, a Formação Ipubi caracteriza-se por depósitos evaporíticos compostos majoritariamente por gipsita, intercalados a folhelhos verdes calcíferos, níveis dolomíticos e camadas de anidrita subordinadas (Assine, 1990).

A Formação Romualdo recobre de maneira discordante as formações Crato e Ipubi (Assine, 2007). Na porção leste da bacia, compreende depósitos aluviais e de planície de maré, seguidos por fácies marinhas transgressivas (tempestitos e folhelhos negros com concreções carbonáticas fossilíferas e coquinas) e, por fim, fácies carbonáticas de ambientes marinhos marginais que caracterizam um ciclo regressivo incompleto e o retorno à sedimentação continental na bacia (Custódio *et al.*, 2017; Fürsich *et al.*, 2019).

Sobre uma discordância regional, a sequência pós-rifte II particulariza-se por depósitos aluviais que destoam do registro das bacias marginais do Nordeste, caracterizadas por condições marinhas transgressivas até o fim do Cretáceo (Assine, 2007). É composta pelas formações Araripina e Exu, anteriormente nomeadas como membros inferior e superior da Formação Exu (Mabesoone & Tinoco, 1973).

A Formação Araripina restringe-se à porção oeste da bacia e é composta por ritmitos e rochas heterolíticas às quais se intercalam corpos lenticulares de arenito médio a grosso (Assine, 2007). Nesta unidade são comuns estruturas de sobrecarga, truncamentos de estratificação, dobramentos convolutos e brechas intraformacionais (Assine, 2007; Warren *et al.*, 2021). As fácies sedimentares da Formação Araripina são interpretadas como depósitos das porções média e distal de leques fluviais, sob influência de tectonismo sindeposicional (Assine, 2007; Warren *et al.*, 2021). De acordo com Lima (1978), a associação palinológica da unidade permite datá-la como mesoalbianana.

Em contato erosivo com as rochas da Formação Araripina, os depósitos da Formação Exu apresentam mergulho deposicional sub-horizontal para oeste, denotando um novo evento tectono-sedimentar na bacia (Assine, 2007). Sua associação de fácies é interpretada como resultado de deposição em sistemas fluviais entrelaçados e meandantes psamíticos (Assine, 1992; 2007) e a ausência de fósseis com valor bio e cronoestratigráfico impede a definição exata da idade da unidade até o momento.

O relevo atual da Chapada do Araripe, bem como de outros *plateaus* localizados na Província Borborema, reflete a complexa evolução geomorfológica da região, associada a diferentes fases de soerguimento e denudação ocorridas entre o Cretáceo Superior e o Mioceno (Moraes-Neto *et al.*, 2009; Japsen *et al.*, 2012). Por meio destes eventos, houve a inversão topográfica da Bacia do Araripe, com a elevação de seus depósitos pós-rifte a altitudes de até 1000 metros e a formação da chapada. Sequências coevas à fase pós-rifte da Bacia do Araripe, preservadas como morros testemunhos das bacias Tucano e Jatobá, também foram afetadas por eventos de soerguimento e denudação. Nestes casos, a exumação e a erosão resultaram em um registro pós-rifte delgado, incompleto e geograficamente restrito que sugere a interconexão dos depósitos da supersequência pós-rifte ao longo destas bacias (Varejão *et al.*, 2021).

I.3.2. Formação Exu

Litoestratigrafia, relações de contato, ambientes de deposição e cronoestratigrafia

A primeira menção aos arenitos do topo da Chapada do Araripe foi feita por Small (1913), o qual intitulou-os como "Arenito Superior". Posteriormente, Beurlen (1962) definiu formalmente a unidade que os compreendia e nomeou-a Exu. Outras terminações, como Formação Arajara e Formação Feira Nova, foram propostas posteriormente por Barros (1963) e Anjos (1964), respectivamente.

Em consonância à proposição de Beurlen (1962), Mabesoone & Tinoco (1973) subdividiram a formação em dois membros (Inferior e Superior), de acordo com suas distintas características litológicas. Ponte & Appi (1990) utilizaram a nomenclatura de Formação Exu apenas para o membro superior da unidade, ao passo que seu membro inferior foi designado de Formação Arajara e correlacionado à seção superior da Formação Romualdo nos arredores da cidade homônima.

Assine (2007), ao notar a inexistência de correlação estratigráfica entre o topo da Formação Romualdo, na região do Vale do Cariri, e a seção da Formação Arajara, na porção oeste da Bacia do Araripe, decidiu abandonar o termo Arajara como unidade litoestratigráfica formal. Em seu lugar, definiu a unidade restrita à porção oeste da bacia como Formação Araripina, visto que sua melhor área de exposição se situa nos arredores da cidade homônima. Deste modo, os antigos membros Inferior e Superior tornaram-se Formação Araripina e Exu, ambas pertencentes ao Grupo Araripe (Assine, 2007).

As relações de contato com as unidades subjacentes variam ao longo da Bacia do Araripe (Figura 3). Na região oeste da Chapada, a Formação Exu recobre a Formação Araripina a partir de uma discordância erosiva (Assine, 2007), a qual é facilmente observada ao longo das escarpas (Figuras 3A e 3B). Na maior parte das porções leste e central da bacia, sobrepõe a Formação Romualdo também sobre uma desconformidade (Assine, 1992). No entanto, este contato dificilmente é observado, pois encontra-se quase sempre encoberto por depósitos de tálus associados ao recuo das escarpas (Assine, 1992; Figura 3C). Na borda sul do *plateau*, nas proximidades de Timorante (PE) e Jardim (CE), os depósitos da Formação Exu ultrapassam os limites das unidades sedimentares sotopostas, recobrando diretamente o embasamento cristalino (Figura 3D).

Quanto ao empilhamento de fácies sedimentares da Formação Exu, são descritos dois padrões principais, referentes às regiões oeste e leste da bacia. Na região oeste, os depósitos se organizam em ciclos granodecrescente ascendentes compostos por níveis delgados de conglomerados e/ou arenitos conglomeráticos na base, superpostos por arenitos grossos com estratificação cruzada planar e acanalada de dimensão decimétrica a métrica, em meio aos quais ocasionalmente ocorrem fácies pelíticas de planície de inundação (Assine, 1992; 2007). Esta associação de fácies foi interpretada como produto de rios meandrantess psamíticos (Assine, 1992). Na porção leste da bacia, arenitos mais grossos e imaturos, com maior frequência de níveis conglomeráticos e estratificações cruzadas planares e/ou acanaladas, foram considerados depósitos de sistemas fluviais entrelaçados (Assine, 2007).

Nenhum registro paleontológico com valor bio e cronoestratigráfico foi identificado na unidade, de maneira que a sua idade permanece indeterminada. Somente Lima (1978) descreveu formas distintas de palinomorfos provenientes da Formação Exu. Contudo, de acordo com a redefinição litoestratográfica realizada no Grupo Araripe, estes palinomorfos passaram a pertencer à Formação Araripina. Em vista da ausência de marcadores bioestratigráficos, o posicionamento cronoestratigráfico da Formação Exu no intervalo Albiano-Cenomaniano foi definido a partir de sua correlação com as formações Açú, da Bacia Potiguar, e Itapecuru, da Bacia do Parnaíba (Assine, 2007).

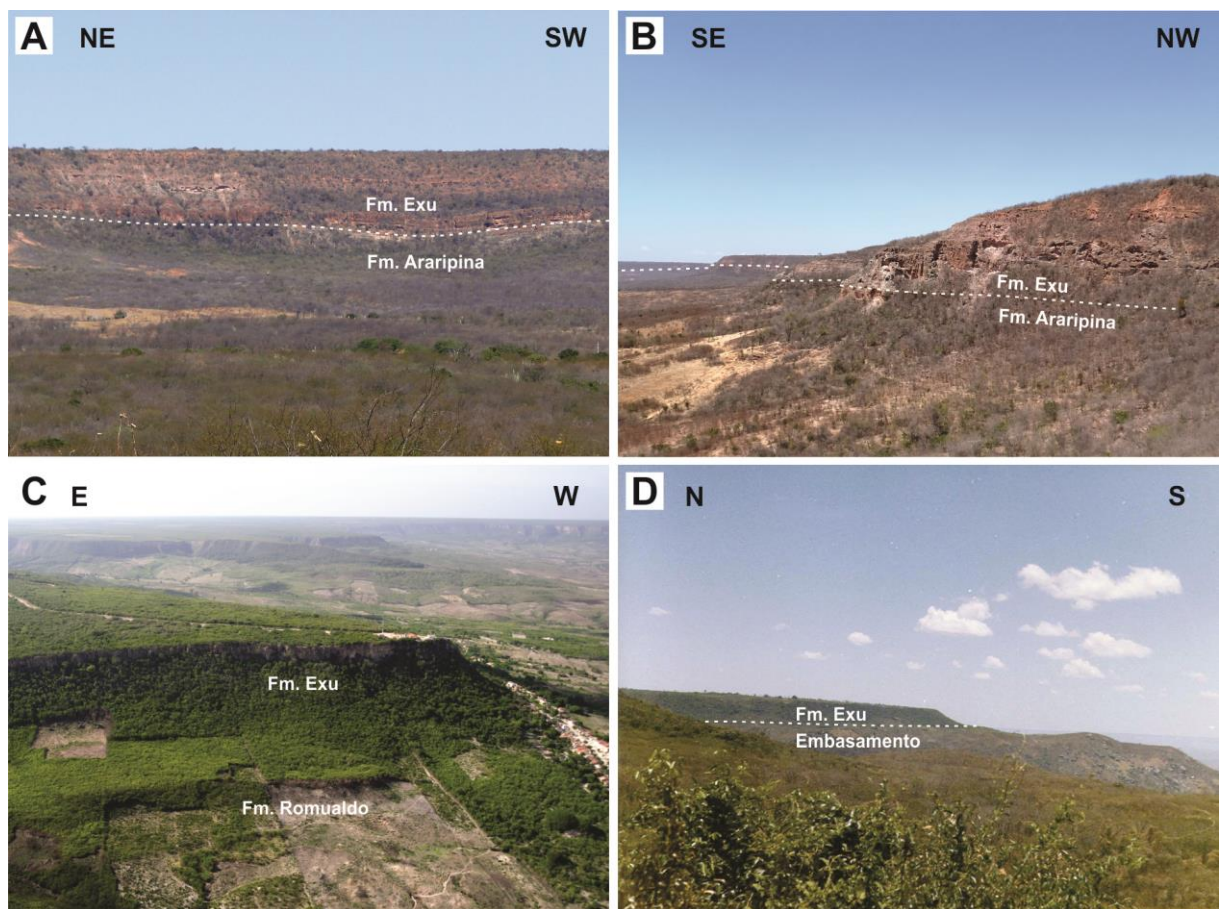


Figura 3. Relações de contato entre a Formação Exu e as unidades subjacentes. A e B) Desconformidade Araripina/Exu na região oeste da Bacia do Araripe. C) Formação Exu na região do Pontal de Santa Cruz. O contato com a Formação Romualdo encontra-se encoberto, aproximadamente na quebra de base da escarpa. D) Depósitos da Formação Exu sobre o embasamento próximo a Timorante-PE.

Relevo e clima

A Formação Exu constitui a sucessão sedimentar que majoritariamente sustenta a Chapada do Araripe: um *plateau* com extensão lateral de aproximadamente 200 km e elevação máxima de 1000 m, topo plano, escarpas geralmente íngremes e cornijas sub-verticais de dezenas de metros (Morales & Assine, 2015). Sua superfície de topo é descrita como erosiva, marcada por um intenso processo de laterização. Ao longo do *plateau*, esta superfície apresenta níveis de silcrete e ferricrete que tornam as rochas aflorantes no topo mais resistentes à erosão (Morales & Assine, 2015).

Na porção leste da chapada, as altitudes atingem os 1000 m, ao passo que a oeste não ultrapassam os 800 m, o que resulta em um gradiente topográfico de aproximadamente 1m/km. Apesar de tanto os depósitos da Formação Exu como a superfície de topo da chapada apresentarem certa sub-horizontalidade, o caráter erosivo desta implica uma superfície irregular que intercepta os depósitos da unidade em diferentes intervalos estratigráficos ao longo da chapada.

As maiores espessuras registradas para a Formação Exu encontram-se na sub-bacia de Feira Nova (Figuras 4B e 4C) e na margem leste da chapada. Principalmente nas regiões norte e oeste da bacia, observa-se a diminuição da espessura da unidade em direção às bordas do *plateau* (Figura 4A), o que resulta em escarpas aflorantes menos espessas do que os poços perfurados em regiões centrais da chapada (e.g. Poço 2-AP-1- CE; Figura 4C; e Bodocó). A variação em espessura, associada à frequente existência de depósitos de tálus sobre os metros basais da unidade (Assine, 1992), limita o acesso ao registro estratigráfico da Formação Exu ao longo de toda a bacia. Por esta razão, as seções-colunares descritas apresentam espessura máxima de ~100 metros. As onze seções-colunares adquiridas neste trabalho situam-se nas bordas oeste, leste, norte e sul da Chapada do Araripe (Figura 3B).

Apesar da grande espessura da unidade na margem leste da chapada, o clima nesta porção da Chapada favorece o intemperismo das rochas aflorantes. Chuvas orográficas na região do Vale do Cariri geram clima mais úmido (pluviosidade de 1200mm/ano) do que o presente na porção oeste do *plateau* e no restante do interior do Nordeste brasileiro (300 a 800mm/ano - Morales & Assine, 2015). Consequentemente, os afloramentos da Formação Exu encontram-se mais intemperizados e encobertos por extensa vegetação de cerrado na margem leste da Chapada, o que acarreta seções estratigráficas menos completas do que aquelas descritas em sua porção oeste.

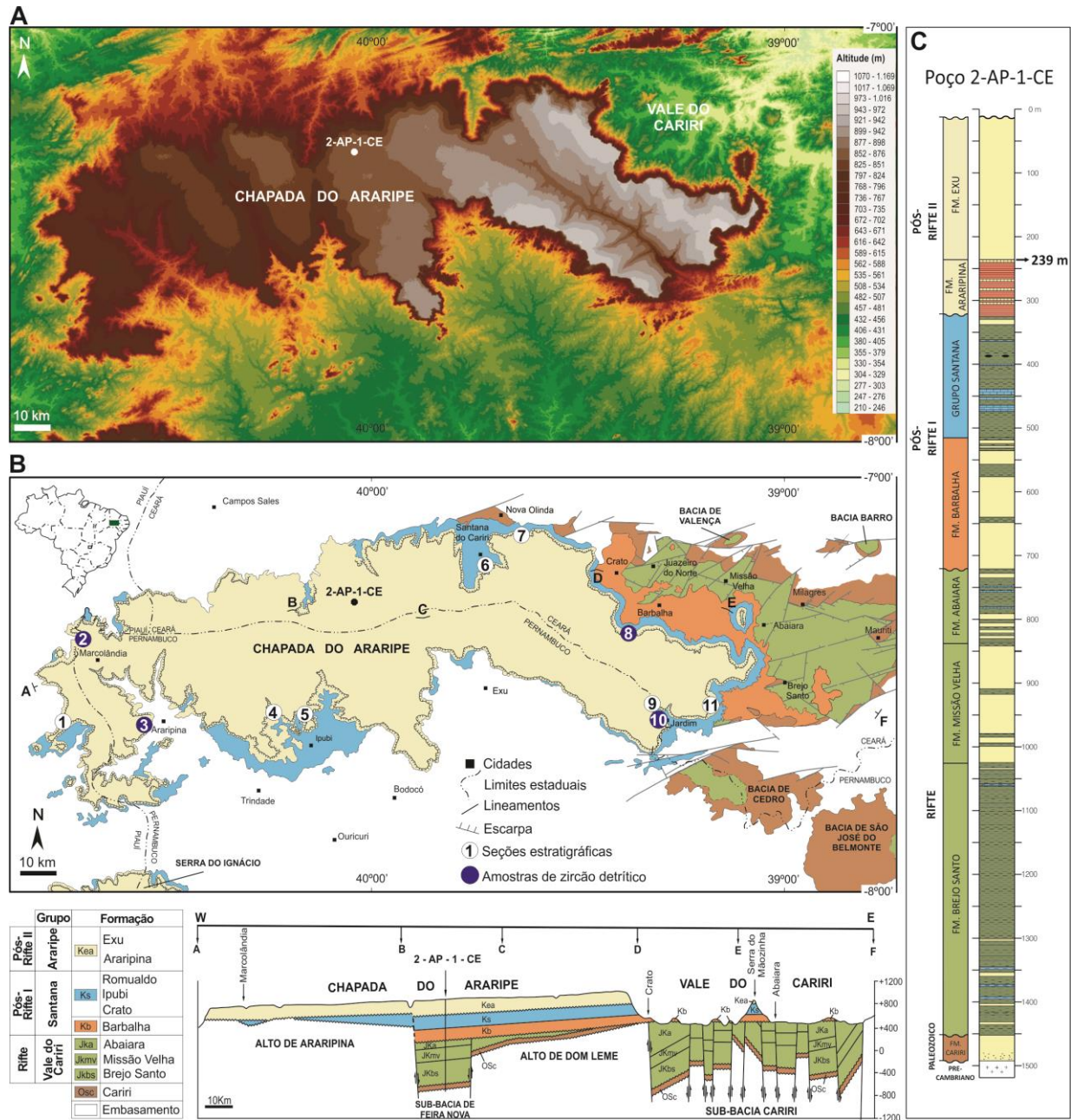


Figura 4. A) Modelo digital de elevação com base em dados altimétricos SRTM/NASA, 2000. B) Mapa e seção geológica da Baía do Araripe (Assine, 2007), com a localização das seções colunares levantadas e estações de coletas de amostras para análise de zircão detritico. 1) Simões, 2) Alagoinha, 3) Sítio Torre Grande, 4) Serra Branca, 5) Gameleira, 6) Pontal da Santa Cruz, 7) Ponte de Pedra, 8) Sítio Santa Rita, 9) Gravatá, 10) Jardim e 11) Sobradinho. C) Perfil litológico do Poço 2-AP-1-CE, com destaque para a espessura de 239m da Formação Exu (modificado de Assine, 2007).

I.4. Materiais e Métodos

I.4.1. Leitura e análise da bibliografia

A pesquisa bibliográfica centrou-se na literatura relativa à sedimentologia, estratigrafia e paleopedologia de sistemas fluviais; geocronologia U-Pb aplicada às unidades do embasamento da Província Borborema; bem como à restrita bibliografia disponível sobre a Formação Exu. Neste caso, com ênfase em seus aspectos paleoambientais, paleogeográficos e deposicionais.

I.4.2. Trabalhos de campo

As etapas de trabalho de campo incluíram a descrição de fácies sedimentares da Formação Exu, a partir do levantamento de onze seções-colunares em escala de semi-detallhe (1:50); a aquisição de medidas de paleocorrentes; e a coleta de amostras destinadas à análise geocronológica. Foram também realizados o registro fotográfico dos diferentes litotipos e feições sedimentares e o georreferenciamento, por meio de GPS, de cada ocorrência analisada.

I.4.3. Descrição de seções-colunares e análise de fácies sedimentares

Onze seções-colunares na escala 1:50 foram descritas a fim de se identificar e compreender os padrões de empilhamento das fácies sedimentares da Formação Exu e suas variações ao longo da Bacia do Araripe.

A análise de fácies sedimentares foi realizada de acordo com a metodologia proposta por Walker & James (1992), segundo a qual uma fácies sedimentar é compreendida como um corpo de rocha individual caracterizado por seus atributos físicos, não confinado a uma posição estratigráfica, e definido a partir de critérios descritivos, como granulação, textura, estruturas sedimentares, geometria dos estratos e conteúdo fossilífero. Para a caracterização das fácies sedimentares identificadas, foi utilizada a nomenclatura do código de fácies de depósitos aluviais proposto por Miall (1978). Fácies não abordadas no trabalho de Miall (1978) foram adicionadas ao código como uma adequação ao protocolo original.

Para a interpretação paleoambiental, fácies geneticamente relacionadas foram agrupadas em associações de fácies, as quais, relacionadas aos elementos arquiteturais reconhecidos, permitiram a identificação do sistema deposicional da unidade.

Os dados obtidos em campo foram organizados e representados através de: (1) documentação fotográfica para cada fácies identificada; (2) confecção de fotomosaicos de afloramentos e esquemas interpretativos, e (3) montagem de perfis estratigráficos verticais, os quais foram correlacionados segundo o padrão das associações de fácies e as superfícies com

significado estratigráfico identificadas. As seções colunares descritas foram representadas no *software* CorelDRAW® versão 18, o qual foi também utilizado para o tratamento das fotografias e confecção das ilustrações presentes neste trabalho.

I.4.4. Análise macromorfológica dos perfis de paleossolos

A identificação de paleossolos em campo foi feita a partir da observação de um conjunto de características diagnósticas, como rizólitos, mosqueamento, estruturas e horizontes (Retallack, 2001). Uma vez distinguidos dos depósitos inalterados, os perfis de paleossolo tiveram sua descrição macromorfológica baseada nas recomendações de Schoeneberger et al., (2012). Neste sentido, os principais parâmetros observados foram a espessura de cada horizonte, o tipo de contato entre os horizontes, cores (de acordo com a Carta de Cores Munsell), cor do mosqueamento, textura, forma e tamanho das estruturas, intensidade e tamanho das bioturbações (rizólitos e escavações) e feições de oxidação e oxirredução.

I.4.5. Análise de paleocorrentes

Dez estações de paleocorrentes foram definidas ao longo da bacia, a fim de se adquirir um número representativo de medidas que possibilitassem interpretar os padrões de fluxo e dispersão sedimentar atuantes durante a sedimentação da Formação Exu. No total, 390 dados foram adquiridos medindo-se planos de estratificação cruzada acanalada e planar, já que estas constituem as estruturas indicativas de fluxo mais comuns na unidade.

Os dados de paleocorrentes coletados foram apresentados sob a forma de histogramas circulares de frequência (rosetas), distribuídos em classes de 30°. Para cada roseta foram também calculados o vetor médio, dado pela média aritmética dos azimutes medidos, e o fator de consistência, ou magnitude do vetor, que indica o grau de dispersão dos azimutes, sendo 0 a máxima dispersão e 1 a mínima dispersão (Rao and Sengupta, 1972).

A definição dos padrões das paleocorrentes foi fundamental para a determinação do mergulho deposicional da unidade, para definição de suas possíveis áreas-fonte e para caracterização de seus ambientes deposicionais.

I.4.6. Análise geocronológica: datação de zircões detríticos pelo método LA-ICPMS

A análise de zircões detríticos, associada aos dados de paleocorrente, teve como objetivo a determinação das principais áreas-fonte para os sedimentos da Formação Exu.

Seis amostras de arenito médio a grosso foram coletadas em quatro seções-colunares (Alagoinha, Sítio Torre Grande, Sítio Santa Rita e Jardim – Figura 3B), localizadas nas porções

oeste e leste da Bacia, a fim de obter dados representativos da unidade e possivelmente detectar variações de idade em área e ao longo da sucessão sedimentar.

Após a coleta das amostras em campo, as mesmas foram preparadas no Laboratório de Preparação de Amostras do antigo Departamento de Petrologia e Metalogenia (atualmente Departamento de Geologia, UNESP), de acordo com a metodologia padrão aplicada na separação de minerais pesados.

As amostras, secas e livres de impurezas, foram fragmentadas, britadas e posteriormente processadas em moinho de discos. O material resultante foi peneirado em um agitador de peneiras e, em seguida, destinado a separação por gravidade em bateia mecânica, com objetivo de separar minerais leves e pesados. Após esta etapa, o concentrado de minerais pesados foi submetido à separação magnética com imã de mão, e então processado no separador eletromagnético *Frantz* sucessivas vezes, com correntes de 0,4A, 0,6A, 1A e 1,7 A. A fração de minerais pesados não-magnéticos resultante foi submetida à elutriação por líquido denso (bromofórmio), a fim de segregar cristais de quartzo e feldspato restantes, e seca em uma estufa simples. O concentrado resultante foi, por fim, destinado à catação manual em lupa para a separação dos grãos de zircão detríticos.

No intuito de avaliar a estrutura interna dos cristais de zircão, foi realizado o imageamento dos grãos por catodoluminescência, por meio do Microscópio Eletrônico de Varredura (MEV), modelo JEOL 6510. Este método possibilitou separar as zonas dos grãos afetadas por processos de alteração hidrotermal, recristalização metamórfica ou fraturamento, que naturalmente constituem regiões de menor confiabilidade para a aquisição de idades pelo método LA-ICPMS.

A obtenção das razões isotópicas U/Pb em zircão detrítico foi realizada no Laboratório de Geoquímica Isotópica da Universidade Federal de Ouro Preto, sob coordenação do Prof. Dr. Cristiano Lana. As análises foram feitas em um espectrômetro de massa LA-SF-ICP-MS (Element 2 Thermo Finnigan) acoplado a um sistema de ablação à laser (Photon-Machines) com comprimento de onda de 193 nm. Os dados foram adquiridos a partir da intercalação entre medição do *background* e ablação, com diâmetro do feixe de 25 μm . As análises foram realizadas com fluência de 3.06 J/cm² a uma frequência de 10 Hz, *shot count* de 280 e *output* de 15%.

Os materiais empregados como referência e para controle de qualidade das análises geocronológicas foram os zircões BB-1 (562.58 ± 0.26 Ma; Santos et al., 2017), GJ-1 (608 ± 0.4 Ma, Jackson et al. 2004) e Plešovice (337.1 ± 0.4 Ma, Sláma et al., 2008). As razões isotópicas relevantes ($^{207}\text{Pb}/^{206}\text{Pb}$, $^{208}\text{Pb}/^{206}\text{Pb}$, $^{208}\text{Pb}/^{232}\text{Th}$, $^{206}\text{Pb}/^{238}\text{U}$ e $^{207}\text{Pb}/^{235}\text{U}$) foram

reduzidas utilizando-se o *software* Glitter, desenvolvido pela ARC *National Key Centre for Geochemical Evolution and Metallogeny of Continents* em conjunto com CSIRO *Exploration and Mining*. O limite mínimo de 95% de concordância foi estabelecido para validação dos dados obtidos, os quais somaram 267 dados de idade para toda a unidade. A correção do Pb comum foi aplicada com base no modelo de composição de Pb de Stacey & Kramers (1975). Grãos de zircão mais jovens que 1300 Ma foram reportados a partir da razão $^{206}\text{Pb}/^{238}\text{U}$, ao passo que grãos mais velhos que 1300 Ma foram associados às idades obtidas pela razão $^{207}\text{Pb}/^{206}\text{Pb}$. Os erros encontram-se apresentados em 2a.

Com o objetivo de melhor ilustrar os resultados obtidos, todos os dados foram representados graficamente a partir de diagramas de pizza e histogramas de frequência relativa acompanhados da função densidade de probabilidade, por meio dos programas Isoplot (Ludwig, 2001) e Density Plotter (Vermeesh, 2012). Esse procedimento foi aplicado ao estudo de proveniência sedimentar (Kosler *et al.*, 2002), a partir da comparação entre as classes de idade obtidas neste estudo e as idades presentes na literatura para as unidades do embasamento adjacente à Bacia do Araripe.

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II. RESULTADOS

Apesar de se destacar na geomorfologia do Nordeste brasileiro por sustentar o relevo da Chapada do Araripe, a Formação Exu permanece pouco conhecida dos pontos de vista sedimentológico e estratigráfico. O estudo de sua sucessão sedimentar é relevante tanto para uma classificação mais precisa de seu sistema deposicional, quanto para a compreensão de seu contexto paleogeográfico na complexa evolução pós-rifte da Bacia do Araripe e do Nordeste brasileiro. Este manuscrito, apresentado como o capítulo de resultados desta dissertação, busca responder a estas questões por meio de um estudo que integra dados estratigráficos, sedimentológicos e de proveniência sedimentar da Formação Exu, obtidos ao longo de toda a Bacia do Araripe. Para alcançar estes objetivos, foram utilizadas análise de fácies sedimentares, análise de paleocorrentes, o estudo de proveniência sedimentar por meio de idades de zircões detríticos e dados macromorfológicos de alguns perfis de paleossolo. Os dados adquiridos permitiram desenvolver um modelo de evolução sedimentar para a Formação Exu compatível com a paleogeografia do Nordeste brasileiro à época da deposição da unidade, que leva em conta as limitações de se interpretar um sistema fluvial de escala regional com base em um registro descontínuo. Com este estudo, esperou-se discutir as interações entre área-fonte e arquitetura da bacia sedimentar, tanto para a inversão da pendente e geração de um novo sistema deposicional de grande escala, quanto para a evolução estratigráfica deste sistema ao longo dos ~100 metros analisados. Finalmente, espera-se que este manuscrito, a ser submetido para um periódico internacional da área, contribua não somente para o conhecimento acerca da Formação Exu, mas para a reconstituição paleogeográfica do Nordeste brasileiro no período pós-rifte.

The post-rift shift of the continental paleodrainage pattern in the Araripe Basin: provenance and sedimentary evolution of the Exu Formation and their implications for the Albian-Cenomanian paleogeography of Northeastern Brazil

ABSTRACT

Following the final breakup of Gondwana and the formation of the South Atlantic Ocean, the continental drainage network of Northeast Brazil underwent a complete rearrangement, resulting in the continentalization of the Araripe Basin. The last depositional cycle of the Araripe Basin (Exu Formation) records this key event and represents a unique opportunity to understand the Albian-Cenomanian depositional and paleogeographic evolutions in the interior of Northeast Brazil. Employing a combination of facies analysis and detrital zircon geochronology, this work investigates the depositional and paleogeographic histories of the Exu Formation emphasizing possible implications for the post-rift landscape evolution of northeastern Brazil. Stratigraphic and sedimentological analyses indicate that the Exu Formation is composed of six facies associations deposited in proximal to medial zones of a distributive fluvial system. Provenance analysis based on U-Pb zircon dating and paleocurrent data revealed that this west-flowing fluvial system drained a highland located in the eastern part of the Borborema Province, with most of its source area placed in the Transversal Domain. The contrasting dispersion pattern, in relation to the underlying Santana Group and Araripina Formation, suggest a post-Albian uplift close to the NE Brazilian margin resulting in: (1) high amount of sediment supply delivered to the depositional site; (2) a reconfiguration of basin paleoslope, and (3) the establishment of a distributive fluvial system in the Araripe Basin. Based on stratigraphic trends and relations between channelized and non-channelized elements, it was possible to extend the discussion on the influence of allogenic forcing mechanisms, such as source area tectonism, to the stratigraphic evolution of the distributive fluvial system. The development of this drainage system, driven by geodynamic processes related to the opening of the South Atlantic Ocean, represented the return to continental deposition in the interior of Northeast Brazil and the cessation of the temporary connections between the Araripe Basin and the newly formed South Atlantic Ocean, typical of the Aptian period.

Keywords: Cretaceous distributive fluvial system, detrital zircon provenance, Borborema Province, post-rift uplift, Gondwana rifting.

INTRODUCTION

The Mesozoic Araripe Basin, located in northeastern Brazil, is an interior basin whose genesis and sedimentary infill are related to the breakup of Gondwana and the opening of the South Atlantic Ocean (Assine, 1992, 2007; Matos, 1992; Ponte and Ponte Filho, 1996). Its geological evolution is represented by four distinct tectonostratigraphic phases: (1) the continental pre-rift; (2) the fluvio-lacustrine syn-rift; (3) the transitional post-rift I, and (4) the continental post-rift II. Unlike the post-rift I sequence (Santana Group), characterized by marine incursions progressing from south to north throughout the Aptian (Assine et al., 2016; Custódio et al., 2017; Rodrigues et al., 2020; Varejão, 2021), the post-rift II sequence shows no connection with the newly formed South Atlantic Ocean. Instead, this sequence portrays the definitive return to continental sedimentation in the Araripe Basin, as its sedimentary record reveals a regional drainage rearrangement after the breakup of Gondwana and the opening of the South Atlantic Ocean (Assine, 1994; Assine 2007).

The breakup of supercontinents is often followed by vertical movements that can lead to drainage reorganization at the continental scale (Hurtado et al., 2018). In the interior of Northeast Brazil, the Albian-Cenomanian record of a fluvial system (Exu Formation) shows evidence for such a shift. With an original depositional area that exceeded the current limits of the Araripe Basin (Assine, 2007; Neumann and Rocha, 2014), the Exu Formation is described as a ~200 meters thick, siliciclastic fluvial unit deposited in erosive contact over the Romualdo and Araripina formations (Assine, 1994; Assine 2007). Previous paleocurrent data from the Exu Formation indicate paleoflow towards the west, suggesting a catchment area located to the east of the Araripe Basin (Assine, 1994; Warren et al., 2021) and the consequent reorganization of the continental paleodrainage during the post-rift II phase (Assine, 1994; 2007). Nevertheless, the lack of studies dealing with facies analysis, stratigraphy, and sedimentary provenance prevented the elaboration of a depositional model for this unit and further investigations on the post-rift paleogeography of the Araripe Basin.

Using detailed stratigraphic profiles, facies association and paleosol descriptions, as well as paleocurrent and detrital zircon data, this study aims to characterize the basin-scale fluvial system responsible for the deposition of the Exu Formation. Furthermore, through the definition of paleogeographic elements, such as depositional dip and main sources for the sediments, coupled with basin-wide stratigraphic observations, we intent to discuss the possible influence of allogenic upstream controls, especially source area tectonism, on the deposition of this continental sequence. Combined, our data lead to regional paleogeographic interpretations

that provide new insights on the post-rift evolution of the Araripe Basin and on the Mid-Cretaceous landscape evolution of northeastern Brazil after the Gondwana breakup.

GEOLOGICAL SETTINGS

The Araripe Basin is an interior rift basin generated by strike-slip reactivation of Precambrian basement structures, in response to the Late Jurassic-Early Cretaceous break-up of Gondwana and the subsequent opening of the South Atlantic Ocean (Rosa et al., 2019; Celestino et al., 2020). The basin is located within the Transversal Domain of the Borborema Province, bounded by two major shear zones; the Patos Lineament in the north and the Pernambuco Lineament in the south (Brito Neves et al., 2000). Its Mesozoic sedimentary record encompasses four stratigraphic mega sequences related to different tectonostratigraphic phases (Fig. 1): (1) continental pre-rift, (2) fluvio-lacustrine syn-rift; (3) transitional evaporite post-rift I, and (4) continental post-rift II (Assine, 2007; Assine et al., 2014b).

The syn-rift phase was deposited in two depocenters (Feira Nova and Cariri sub-basins) separated by the Dom Leme High (Matos, 1992), while post-rift deposits exceeded the original basin limits, overlapping Precambrian basement rocks at some localities (Assine et al., 2014b; Varejão et al., 2016; Varejão et al., 2021). The post-rift sequences crop out as a ~900 m high plateau, with steep, erosional escarpments and a flat, erosional summit that slightly deepens into the west (Morales and Assine, 2015). Transitional and continental post-rift deposits are respectively represented by the Aptian continental-marine Santana Group (Barbalha, Crato, Ipubi, and Romualdo formations) and the continental Albian-Cenomanian Araripe Group (Araripina and Exu formations) (Assine, 2007). The post-rift stratigraphy is also preserved as scattered plateaus located as far as 200 km southeast of the Araripe Basin, where thin successions of the Santana Group and Exu Formation occur (Varejão et al., 2016).

The Araripina Formation is a 40-m-thick succession of rhythmically interbedded mudstone and sandstone, with evidence of synsedimentary tectonics, deposited by a fluvial system restricted to the western part of the basin (Warren et al., 2021). Its paleocurrent data indicate paleoflow towards the east and southeast, similar to those observed in the fluvial deposits of the Santana Group (Warren et al., 2021). The Exu Formation comprises a siliciclastic succession of up to 200-m that crops out on the upper part of the Araripe Plateau. It is disconformably underlain by the Araripina and Romualdo formations, respectively at the western (Araripina Formation; Fig. 2A and B) and eastern to central (Romualdo Formation;

Fig. 2C) parts of the Araripe Basin, and by Precambrian basement rocks at some localities from the southern part of the basin (Fig. 2D – Assine, 1992).

In terms of its deposits, the Exu Formation is mainly composed of pebbly, very coarse- to coarse-grained sandstone, conglomerate, and mudstone deposited in a basin-scale fluvial setting (Assine, 2007). The few works that mentioned sedimentological and stratigraphic aspects of this unit describe fining upwards cycles of pebbly- to coarse-grained cross-bedded sandstone occasionally interbedded with fine layers of mudstone in the western part of the Araripe Basin (Assine, 1994, 2007). Conglomerate beds that normally grade into immature pebbly- to coarse-grained cross-bedded sandstone (Assine, 1994, 2007) are more common in the eastern part of the outcrop area. Contrarily to the paleoflow data from the underlain Santana Group and Araripina Formation, paleocurrents from the Exu Formation deposits reveal a consistent depositional dip towards the west (Assine, 1994; Warren et al., 2021).

The absence of a paleontological record with biostratigraphic relevance in the Exu Formation hinders the definition of a precise depositional age for this unit. Despite the lack of biostratigraphic markers, regional correlations with the putatively coeval Açú and Itapecuru formations, from Potiguar and Parnaíba basins, suggest depositional ages between the Albian and Cenomanian (Assine, 2007).

MATERIALS AND METHODS

Eleven detailed columnar sections (i.e., Simões, Alagoinha, Sítio Torre Grande, Serra Branca, Gameleira, Pontal da Santa Cruz, Ponte de Pedra, Sítio Santa Rita, Gravatá, Jardim and Sobradinho, see Fig. 1 for location) were measured along the western, eastern, northern and southern escarpments of the Araripe Plateau. Sedimentary facies were described in terms of their lithology, grain properties, geometry, sedimentary structures, and trace fossil content. 390 paleoflow measurements were taken from trough and planar cross-stratification at 10 different stations from distinct parts of the outcrop area. These paleocurrent indicators were presented in the form of iso-frequency rose diagrams to provide information regarding the sediment source areas and the main depositional dip of the basin. Panoramic outcrop images were taken to better describe the external geometries and internal structures of the deposits. Paleosol preliminary recognition followed the NRCS protocol (Schoeneberger et al. 2012), based on the identification of macromorphological features such as color, texture, mottlings, bioturbation, horizons, transitions, and pedogenic structures.

Six samples of medium- to coarse-grained sandstone were collected along four different columnar sections (Alagoinha, Sítio Torre Grande, Sítio Santa Rita, and Jardim, see Fig. 1 for location and Fig. 3 for stratigraphic position) as a mean to compare detrital zircon ages from distinct areas and throughout the sedimentary succession. The samples (AL-1, AL-2, STG-1, STG-2, SSR-1, JD-2) were processed by standard methods for zircon grain separation, including crushing, sieving, Frantz isodynamic magnetic separator, and heavy liquids. The zircon grains retained in the heavy minerals concentrate were handpicked under a binocular stereo microscope, arranged on adhesive tape, and enclosed in epoxy mounts. All samples were prepared in the Sample Preparation Laboratory from the São Paulo State University (UNESP, Rio Claro, Brazil). After this first preparation stage, cathodoluminescence (CL) images were acquired using a Scanning Electron Microscope (SEM) JEOL 6510 at the Isotopic Geochemistry Laboratory in the Federal University of Ouro Preto (UFOP).

U-Pb geochronology of zircon grains was conducted by a laser ablation microprobe (Photon-machines Excimer Laser 193) coupled with a sector field inductively coupled plasma mass spectrometry LA-SF-ICP-MS (Element 2), at the Isotopic Geochemistry Laboratory. Data were obtained using a spot diameter of 25µm, with a laser energy density of ca. 3.06 J/cm² at a repetition rate of 10 Hz, shot count of 280, and laser output of 15%. BB-1 (562.58 ± 0.26 Ma; Santos et al., 2017), GJ-1 (608 ± 0.4 Ma; Jackson et al., 2004), and Plešovice zircons (337.1 ± 0.4 Ma; Sláma et al., 2008) were used as standard materials to assure quality and precision of the obtained ages. GJ-1 zircon was also applied to correct the laser-induced elemental fractionation and instrumental mass discrimination (Jackson et al. 2004). Common lead correction was done according to Stacey and Kramers (1975) model. The relevant isotope ratios (²⁰⁷Pb/²⁰⁶Pb, ²⁰⁸Pb/²⁰⁶Pb, ²⁰⁸Pb/²³²Th, ²⁰⁶Pb/²³⁸U, and ²⁰⁷Pb/²³⁵U) were reduced using Glitter software (Van Achterbergh et al., 2001), and a threshold of 95% concordance was established for filtering data. The best age was determined from ²⁰⁶Pb/²³⁸U ages for analyses with ²⁰⁶Pb/²³⁸U ages younger than 1300 Ma, and from ²⁰⁷Pb/²⁰⁶Pb ages for analyses with ²⁰⁶Pb/²³⁸U ages older than 1300 Ma. In order to evaluate U-Pb age variations and most probable source areas for the Exu Formation sediments, ages with concordance ≥ 95% (266 of 336 analyzed grains) were graphically presented in the form of histograms, probability density plots (using Density Plotter – Vermeesch, 2012), and pie charts.

FACIES AND FACIES ASSOCIATIONS

Detailed description of the Exu Formation deposits allowed the recognition of twelve siliciclastic facies, summarized in Table 1 and illustrated in Figs. 4 to 9. These facies are interpreted as products of fluvial, pedogenic and eolian processes and, thus, are grouped in six facies associations (Fig. 10): (1) gravelly channels; (2) sand-bed channels; (3) poorly confined channels; (4) splays; (5) floodplain; and (6) eolian dunes facies association.

Table 1. Summary facies description and interpretation for the Exu Formation

Code	Facies	Description	Depositional processes
Gt	Trough cross-bedded conglomerate	Clast-supported, trough cross-bedded conglomerate, composed of sub-angular to sub-rounded granules and pebbles mostly of igneous and metamorphic origin (quartz veins, gneiss and granite). Occasional sparse pebble to cobble-sized sand and mudclasts. Sets are 0.1 to 1.0 m (generally 0.1 to 0.3 m) thick. Basal surfaces are usually erosional, while upper ones are either erosional or gradational to facies St .	3-D gravel dune and bar migration. Mudclasts and sandclasts indicate reworking of pre-deposited fluvial sediments by high-energy flows.
Gp	Planar cross-bedded conglomerate	Clast-supported, planar cross-bedded conglomerate, disposed in 0.1-0.3 m thick sets. Clasts are predominantly sub-angular to sub-rounded quartz veins granules and pebbles. Basal and upper surfaces are erosional or gradational to facies Sp .	Transverse (2D) gravel dune and gravel bar migration
Gm	Massive conglomerate	Clast-supported, structureless conglomerate, in 0.1 to 0.5 thick beds, bounded by basal erosional surfaces. Clasts are sub-angular to sub-rounded quartz vein granules and pebbles and pebble- to cobble-sized intraformational mudclasts.	Bedload deposition as gravel sheet or channel lag deposits by high-magnitude flows, capable of eroding and excavating the underlying deposits.
St	Trough cross-bedded sandstone	Fine- to very coarse-grained/pebbly sandstone with trough cross-stratification. Sets are 0.1m to 1.0 m thick (generally 0.2 to 0.3 m). Quartz vein granules and pebbles are parallel to foresets and set bounding surfaces, or on the front of cross beds; mud and paleosol clasts are sparsely distributed or over basal surfaces. Meniscate burrows (i.e. <i>Taenidium barretti</i> and <i>Beaconites coronus</i>) and root traces are present in the topmost part or throughout beds.	3-D dune migration by unidirectional currents under lower flow regime. Mudclasts and sandclasts indicate erosion and reworking of pre-deposited sediments. Later modification by bioturbation.
Sp	Planar cross-bedded sandstone	Fine- to very coarse-grained/pebbly sandstone with plane-parallel to low-angle cross-stratification. Sets are 0.1m to 1.0m thick (typically 0.1 to 0.5m). Quartz vein granules and pebbles are either concentrated at basal contacts or on the foresets. Sparse bioturbation includes menicaste burrows and root traces.	Transverse (2-D) dune migration by unidirectional currents under lower flow regime.
Sh	Horizontally bedded sandstone	Fine- to coarse-grained sandstone with horizontal stratification. Cm- to dm-scale thick, tabular or lenticular beds, generally interbedded to Sr or St .	Planar bed generated under upper flow regime.
Sm	Massive sandstone	Fine- to coarse-grained, structureless sandstone organized in dm- to m-scale thick tabular or undulated beds. Common bioturbation by roots.	Deceleration of high-energy sheet-floods or complete obliteration of original structures by post-depositional processes, such as pedogenesis and intense bioturbation.

Table 1. (Continued)

Code	Facies	Description	Depositional processes
Stg	Trough cross-bedded sandstone with grain size segregation	Fine- to medium-grained, well-sorted sandstone with 0.8-1.5 m thick cross-stratification. Well-rounded quartz grains. Foresets characterized by grain size segregation.	Eolian dune migration, grainflow and grainfall processes.
Sr	Ripple cross-laminated sandstone	Very fine- to medium-grained sandstone with ripple cross-lamination, disposed in cm-thick sets. Generally interbedded with Sh , Fm and Fl , or overlaying St . Common burrows and root traces. Occasional cm-scale soft-sediment deformation (load structures).	Subaqueous migration of unidirectional current-ripples by suspension and traction, under lower flow regime. Soft-sediment deformation caused by loading over an unconsolidated liquefied fine-grained bed.
Fl	Horizontally laminated siltstone/mudstone	Reddish-brown to grayish-brown laminated siltstone and mudstone organized in cm- to dm-scale tabular or lenticular beds. Very-fine sand dispersed in the fine matrix is frequent.	Mud and silt settling in standing waters, combined with wind-blown sand grains.
Fm	Massive mudstone/siltstone	Reddish-brown, medium-brown and purplish-brown siltstone and mudstone, generally with very-fine sand dispersed in the matrix. Cm- to dm-thick tabular or lenticular beds usually interbedded with Sr . Frequent invertebrate burrows and root traces. Occasional cm- to dm-scale soft-sediment deformation features.	Suspension settling in standing waters or deposition from weak currents, combined with wind-blown sand grains. Soft-sediment deformation caused by loading over unconsolidated liquefied fine-grained sediments.
P	Paleosol	Muddy to coarse-grained sandstones, organized in dm- to m-thick tabular or irregular beds. Dominance of poorly developed C and C(r) horizons with colors that range between 10R and 10YR and eventually G1 (Munsell chart). Main pedogenic features include mottling and variegated colors (10R, 10YR, G2 and white); clay-sandy to sandy-clay textures; root marks and invertebrate traces filled by clay or sand, frequently surrounded by oxidation or redox halos. Root traces and relicts of the primary stratification are common. B and A horizons are rarely preserved. The former displays 10R colours, wedge-shaped structures, slickensides, gilgai microrelief, root marks and desiccation cracks, whereas A horizons are characterized by rizoliths organized in laterally spreading systems.	Pedogenesis of previously deposited sandstone and mudstone. Purplish colours, mottling, variegated colours and abundant root traces disposed in laterally spreading systems are indicative of hydromorphy (Kraus and Aslan, 1993; Kraus, 1999). Red colours, oxidation halos and a lack of mottlings suggest more well-drained conditions, generally associated to coarse-grained parent material. Slickenside structures, gilgai microrelief, wedge-shaped peds and filled desiccation cracks figure as evidence of wetting and drying episodes (Retallack, 2001).

Facies Association 1 – Gravelly channels

Description

Gravelly channel deposits are found chiefly in the northeastern cropping out area of the Exu Formation, totalizing up to 30 m-thick continuous successions (Fig. 3). This facies association comprises clast-supported granule- to pebble- conglomerate (facies **Gt**, **Gp** and **Gm** – Fig. 4A and 4B) and pebbly- to medium-grained sandstone (facies **St**, **Sp**), organized in dm- to m-thick and 10s of m-wide lenticular, tabular and wedge-shaped amalgamated bodies, or filling small channelized bodies up to 1.5 m thick and 10 meters wide (Fig. 5).

The general stacking pattern of FA1 is represented by 0.1-1.0 m-thick sets of cross-bedded granule-to pebble-conglomerate (**Gt** and **Gp**) that grade into pebbly-to coarse-grained cross-bedded sandstone (**St** and **Sp**) (Fig. 10). Occasionally, these deposits are overlaid by dm- to m-thick sets of pebbly- to medium-grained cross-bedded sandstone (**St** and **Sp**), forming poorly defined fining-upward successions. Locally, cm-thick granule and pebble lag deposits (**Gm**; Fig. 4A) occur at the base of the succession.

Gravel and sand bodies show varying internal and external bed geometries. Commonly, cm- to dm-thick sets of planar and trough cross-stratified conglomerate (**Gp** and **Gt**) are organized in dm to m-thick cosets, whose erosional bounding surfaces define lenticular to wedge-shaped external morphologies (Fig. 4A). Stacked dm-thick sets of cross-strata can be bounded by horizontal or low angle to convex upward accretion surfaces that dip concordantly to the internal cross-sets. Locally, dm- to m-thick cosets are overlaid by single m-thick sets of planar cross-stratification that rest on erosional surfaces with higher angles (Fig. 5). Finally, minor concave scours are composed of up to 1.0 m-thick sets of trough cross-bedded conglomerate (**Gt**) grading into **St**, with festoon truncations as set bounding surfaces (Fig. 5).

Outcrop observations suggest that the above-mentioned geometries form amalgamated tabular and lenticular bodies of 2-3 m-thick and more than tens of meters wide. However, the lack of laterally continuous outcrops precludes the recognition of major bounding surfaces and macroforms. Paleocurrent data acquired in facies **Gt**, **Gp**, **St**, and **Sp** demonstrate mean paleoflow towards SSW and WSW (Figs. 3 and 11).

Interpretation

Amalgamated lenticular, tabular, wedge-shaped and minor channelized bodies composed of trough and planar cross-bedded conglomerate with normal grading suggest deposition in fluvial channels dominated by bedload transport. The prevalence of dm-thick

cross-sets indicates migration of sinuous-crested (3D) and linguoid (2D) subaqueous dunes, under lower flow regime, as the main depositional process.

Sets of trough and planar cross-bedding sandstone limited by horizontal to slightly dipping surfaces are interpreted as sandy bedforms generated by the aggradation of downstream-migrating dunes on channel thalwegs or on top of bars (Miall, 1996). Lenticular and wedge-shaped geometries composed of stacked sets of cross-bedded conglomerate (**Gt** and **Gp**) were produced by the migration of gravel bars (Miall, 1996). Cosets of dm-scale cross-stratified sets bounded by planar and convex-upward surfaces that dip concordantly to the internal cross bedding indicate the downstream accretion of sand bars, probably mid-channel bars (Allen, 1983; Miall, 1996; Bridge, 2006). Single, larger (i.e., m-thick) sets of planar cross-stratification resting on high-angle surfaces are interpreted as unit bar or bar-margin slipface deposits (Wooldridge and Hickin, 2005; Sambrook Smith et al., 2006; Reesink and Bridge, 2007; Herbert et al., 2020). The lack of muddy overbank deposits coupled with sparse intraformational mudclasts in conglomerate facies indicate erosion and reworking of overbank areas by avulsive, perennial channels, resulting in cannibalized floodplains.

Facies Association 2 – Sand-bed channels

Description

Sand-bed channel deposits are the most common facies association in the Exu Formation succession, especially in the western region of the Araripe Basin (Fig. 3). FA2 deposits occur as single or multistory/multilateral sand bodies with minimal dimensions of 1-3 m-thick and 100 meters wide, limited by slightly concave-upward erosive base and flat top (Figs. 6 and 10). Larger dimensions are normally difficult to track in the analyzed outcrops. These elements occur interbedded with paleosol beds or suspension settling deposits from floodplain facies association (FA5), although lateral and vertical amalgamation are commonly present.

Generally, FA2 sand bodies are composed of single or multiple fining upward successions with erosional basal surfaces marked by quartz granules and pebbles and/or pebble-to cobble-sized angular mudclasts (Figs. 4C and 4D – facies **Gm** and **Gt**), followed by coarse-grained trough cross-bedded sandstone with scattered granules, mudclasts and paleosol fragments (facies **St** – Fig. 7A). The fining upward pattern finishes with cross sets of medium-to fine-grained sandstone (facies **St** and **Sp**; Fig. 4D). In cases where upward trends are not recognizable, sand-bed channels are composed of amalgamated lenticular or tabular bodies

filled by stacked dm-scale sets of trough and planar cross-bedded sandstone with scattered granules and/or mudclasts (Fig. 4E).

Meniscate burrows and root traces are common features in FA2 deposits (Figs. 8A and B). Locally, intensely bioturbated sand sheets present 0.8-1.0 m-thick and 3-6 m-wide mud-filled ribbons encased at their top (Figs. 6 and 7C). Paleocurrent measurements in FA2 deposits (facies **St**, **Sp** and **Gt**) show sedimentary transport towards W, SW and NNW (Figs. 3 and 11), revealing greater variation in transport direction than FA1.

Interpretation

Sand bodies with basal erosional surfaces, composed of fining upward successions dominated by cosets of trough and planar cross-bedded sandstone (**St** and **Sp**) indicate deposition of sandy bars and bedforms in fluvial channels (Miall, 1996). Frequent intraformational mudclasts and paleosol fragments, generated by the rework of dissected overbank fines and paleosols, suggest avulsion and erosion of adjacent abandoned areas by channelized flows (Cain and Mountney, 2009). Amalgamated lenticular and tabular bodies filled by cosets of trough and planar cross-bedding are interpreted as sandy bar deposits. Cosets of planar and trough cross-bedded sandstone with horizontal or gently inclined set boundaries may also represent dune aggradation on channel thalwegs (Miall, 1996), although larger macroforms cannot be ruled out in the case of laterally restricted outcrops.

The increasing preservation of associated abandoned channels and overbank deposits (FA5) compared to FA1 imply a reduction in channel mobility (Nichols and Fisher, 2007). Local mud-filled ribbons encased at the top of bioturbated sand bodies points to the gradual abandonment of the FA2 channels, which were latter filled through mud suspension after flood events (Bridge, 2003; Nichols and Fisher, 2007).

Facies Association 3 – Poorly confined channels

Description

FA3 is present in central areas of the Araripe Basin (Feira Nova sub-basin) and, together with FA4, it corresponds to the most distal preserved deposits of the upper part of the Exu Formation (Fig. 3). FA3 deposits occurs as isolated or amalgamated lenticular and tabular sand bodies up to ~2 m thick and, at least, 30 m wide, interbedded with floodplain and splay deposits (FA4 and FA5) (Figs. 8C and 10). Most sandstone bodies lack internal accretion surfaces, with the exception of laterally accreted beds. Internally, FA3 deposits are characterized by monotonous successions of well-sorted medium-to very fine-grained sandstone with 0.1-0.4 m-

thick sets of trough and planar cross-bedding (**St** and **Sp**), or by fining upward successions from medium-grained trough cross-bedded to very fine-grained ripple cross-laminated sandstone (**Sr**).

Compared to FA1 and FA2, FA3 channels are distinguished by: (1) considerable finer-grained and texturally mature fill; (2) reduced occurrence of amalgamated geometries; (3) dominance of thinner cross-sets, and (4) its association with floodplain (paleosol) and splay elements (FA4 and FA5). Root traces are also frequently observed in these deposits. Common obliteration of primary structures by pedoturbation and weathering can make these elements almost texturally indistinct from adjacent overbank deposits, especially if composed of very fine-grained sand. Paleocurrent measurements obtained in facies **St** and **Sp** reveal main transport direction towards W.

Interpretation

Lenticular and tabular sand bodies composed of well-sorted sediment, displaying small scale cross sets and ripple-cross lamination, represent the transport of medium and fine-grained sand under lower-flow regime in poorly confined channels. These channels are interpreted as relatively fixed channels with local evidence of lateral accretion prior to aggradation (Gibbling, 2006). Frequent root traces in the sand bodies, combined with FA3 relation to floodplain and splay deposits (FA4 and FA5), particularly to paleosol with abundant rootlets (Fig. 8C and 8D), indicate recurring events of deposition and abandonment. In this way, FA3 elements could be produced by successive events of avulsion and abandonment of non-coeval channels and/or by the downstream bifurcation of channels. In the last case, coeval channels could represent either a distributary network, or segments of an anabranching planform if there was channel rejoin (Kelly and Olsen, 1993; Nichols and Fisher, 2007; Cain and Mountney, 2009; Nanson & Knighton, 1996; North et al., 2007).

Facies Association 4 – Splays

Description

FA4 is made up of thin, tabular and lenticular sandstone sheets that exceed 20 m in lateral extent. Their thickness ranges from 0.05 to 0.8 m, with sharp flat or undulating basal surfaces that occasionally present centimeter-scale load structures (Figs. 7D). Upper contacts are flat to slightly convex-up, and occasionally diffuse (Fig. 9). FA4 occurs as isolated or amalgamated sand bodies interspersed with floodplain (FA5), poorly confined channel (FA3) and sand-bed channel (FA 2) deposits (Fig. 10). These bodies are filled by very-fine- to

medium-grained, horizontally laminated sandstone (**Sh**), through cross-bedded sandstone (**St**), ripple cross-laminated sandstone (**Sr**), or massive sandstone (**Sm**) (Fig. 7), sometimes organized in fining upward trends. Bioturbation produced by invertebrate organisms and roots is frequent, especially at the topmost part of the splay deposits. Thicker successions of FA4 are present in the central areas of the Araripe Basin (Feira Nova sub-basin), where they correspond to the most distal preserved deposits of the upper part of the unit (Fig. 3). Isolated, thin successions of crevasse splay deposits occur typically in the western and, more rarely, at the eastern part of the outcrop area (Fig. 3).

Interpretation

Thin, laterally extensive geometries composed of fine-grained sediments with horizontal and ripple cross-lamination are interpreted as deposits of shallow, unconfined flows across the alluvial plain. Splays were sourced either from a breach point in the bank of their feeder channel at times of peak flood discharge, or from channel terminations via distributary/splay channels (Coleman, 1969; Bridge and Leeder, 1979; Nanson and Crooke, 1992; Cain and Mountney, 2009). Sheet-like sandstone beds with upward transitions from **Sh** to **Sr** and **Sm**, or from **St** to **Sr**, sometimes presenting fining upward trends, represent downstream waning flow conditions until the return of settling deposition in the floodplain area (Burns et al., 2017). Bioturbation features, such as root and invertebrate traces from the Scoyenia Ichnofacies are representative of periodically exposed/periodically inundated environments (Frey and Pemberton, 1984; Buatois and Mángano, 2004).

Facies Association 5 – Floodplain

Description

Floodplain facies association is represented by massive sandy mudstone (**Fm**), laminated siltstone (**Fl**), and paleosols (**P**). Proportion of floodplain deposits vary vertically and laterally throughout the entire Exu Formation, although there is an overall downstream and upward increase in FA5 (Fig. 3).

The eastern part of the Araripe Basin is characterized by few overbank deposits, represented by dm-thick massive and laminated sandy mudstone (**Fm** and **Fl**; Fig. 7). Paleosols are dm- to m-thick poorly developed profiles composed of C horizons with 10R and 10YR hues, showing sandy or sandy-clayed texture, occasional mottling, root traces, and invertebrate burrows (**P**).

Floodplain elements are most prevalent in the medial area of the basin, especially in the upper part of the unit (Fig. 3). Overbank deposits from the medial region consist of paleosol beds (**P**) and cm-to m-thick beds of massive or laminated mudstone/siltstone (**Fm** and **Fl**), which are frequently interbedded with splay (FA4) and poorly confined channel (FA3) deposits, and sometimes present infilled desiccation cracks (Fig. 8F, 9 and 10). Simple and meniscate invertebrate burrows are observed in both mudstone and sandstone facies (Figs. 8A, 8B, and 8E). Paleosol profiles are mainly composed of poorly developed C, with rarely preserved A (Fig. 8D) and Bss horizons (Figs. 8F). C horizons share similar pedogenic features with the formerly described paleosols, except for G1 and G2 Munsell hues, whereas A horizons are characterized by 10R and 10YR colors and abundant shallow rhizoliths, frequently filled by sand (Fig. 8C and 8D) and surrounded by redox haloes. Bss horizons display 10R colors, root marks, wedge-shaped structures, slickenside planes, gilgai microrelief, and infilled desiccation cracks (Fig. 8F).

In the western part of the basin, FA5 is represented by thin layers of massive mudstone/siltstone (**Fm**) interbedded with current rippled (**Sr**), horizontally laminated (**Sh**), or massive very fine-grained sandstone (**Sm**) (Figs. 7B, C, and D). These deposits generally present cm- to dm-scale soft-sediment deformation, such as load structures (pillow and flame, attached and detached pseudo-nodules – Figs. 7D and 7E) and convolute lamination. Channel scours of 0.8-1m thick and 3-6 m wide entirely filled by mudstone (**Fm** – Figs. 6 and 7C) are also observed. Paleosol levels are composed of m-thick C horizons with 10R, 10YR, and G1 Munsell hues. Variegated colors and mottlings (10R, 10YR, G1, G2, and white), relict structures, root marks, and invertebrate burrows occasionally surrounded by oxidation and redox haloes are all observed to varying degrees in these profiles (Figs. 8G and 8H). Root traces are either vertical to oblique thin tubes or laterally spreading root systems (Fig. 8H).

Interpretation

FA5 is composed of overbank and abandoned bar and channel deposits, often modified by pedogenic processes. The fine-grained overbank facies are products of unconfined flows generated when discharge exceeded the bank-full capacity (Bridge and Leeder, 1979; Nanson and Croke, 1992). Deposition of massive and laminated fine-grained facies occurred as flow deceleration allowed settling from suspension, which could be increased by the presence of vegetation (North and Davidson, 2012).

Paleosol profiles characterized by reddish colors (10R and 10YR), sandy textures, relict structures, and root marks with oxidation features suggest well-drained soils developed over

sandy abandoned channels and bar-tops. These profiles indicate good drainage conditions, primarily influenced by its physiographic position close to the main channels (Krauss, 1999; Retallack, 2001).

Alternatively, profiles with purple and grey colors, relict structures, intense mottling, as well as burrows and root traces evidenced by redoximorphic features, suggest relatively saturated soils, either due to stagnant surface water or to suspended water table (Krauss, 1999; Retallack, 2001). Most of these profiles are located in the central and western areas of the basin and represent moderately poorly-drained paleosols, in which texture, distance from main channels, and topography acted as key factors for hydromorphy intensity variations (Besly and Fielding, 1989; Kraus and Aslan, 1993). In this sense, A and C horizons containing abundant rhizoliths organized in shallow tabular systems indicate waterlogged environments (Retallack, 2001), interspersed with channel deposits. Finally, Bss horizons showing prismatic peds, slickenside surfaces, infilled desiccation cracks, and gilgai microrelief were formed by the shrinking and swelling of floodplain clays, in a context of wetting and drying episodes (Retallack, 2001).

Eolian facies association

Facies Association 6 – Eolian dunes

Description

This facies association is composed of fine- to medium-grained, well-sorted, m-scale trough cross-bedded sandstone (facies **Stg**), with foresets marked by grain-size segregation (Fig. 4F). At the top of these deposits, a poorly-developed sandy paleosol shows mottlings and relicts of the original metric-scale trough cross-stratification (**Stg**). FA6 is restricted to one of the studied columnar sections (Sítio Santa Rita – Fig. 3), and occurs interbedded with the dominant fluvial deposits of FA2 (Fig. 10). Paleocurrent measurements obtained in facies **Stg** indicate dune migration towards W (Fig. 3 and 11).

Interpretation

Well-sorted, m-scale trough cross-bedded sandstone with foresets marked by grain size segregation is interpreted as a product of the migration of eolian dunes through grain-flow and grain-fall processes (Kocurek 1991, Fryberger and Schenk, 1988). The occurrence of eolian dune facies between thick deposits of fluvial origin implies fluvio-eolian interaction and deposition of dunes in the exposed areas of the channel belt, or the rework of fluvial bar tops. The establishment of scarce vegetation over the dune deposits was probably responsible for the

incipient soil formation and obliteration of primary sedimentary structures. The restricted occurrence of FA6 and its limited number of paleocurrent measurements preclude further interpretations about the morphology of the dunes and the extension of fluvio-eolian interactions throughout the basin.

EXU FORMATION DETRITAL ZIRCON U-PB AGE ANALYSIS

Detrital Zircon U-Pb Age Analysis and Sedimentary Provenance

Detrital zircon grain analysis was conducted on six samples (AL-1, AL-2, STG-1, STG-2, SSR-1, and JD-2) of medium- to coarse-grained sandstone collected from the eastern and western parts of the Araripe Plateau (Figs. 1 and 3). The concordant data are grouped into four age populations, based on probability density plots distribution and their correlation with the main source units in the Borborema Province, located east of the Araripe Basin (Figs. 12 and 13). Table 2 summarizes the four age populations described in this work, showing their age ranges and the likeliest sources for primary and reworked detrital zircons.

Table 2. Detrital zircon age populations and their first-order and recycled sources.

Population	Age ranges	First-order sources	Recycled sources
A- Neoproterozoic	545-650 Ma	Brazilian/Pan-African plutons	Seridó, Cachoeirinha, and Sertânia supracrustal sequences
	920-1000 Ma	Alto Pajeú Domain (Cariris Velhos related rocks)	Seridó, Sertânia, Surubim, Rio Una, and Cachoeirinha supracrustal sequences
B – Statherian-Calymmian	1.5-1.7 Ga	Passira Complex, Taquaritinga intrusion, Serra da Barra, Carnoió and Coloete Suites (all located in the Central Zone)	Surubim and Rio Una supracrustal sequences
	1.7-1.8 Ga	No primary sources recognized in the Northern, Central, and Southern zones of the BP	Seridó, Sertânia, Surubim, and Rio Una supracrustal sequences
C – Rhyacian-Orosian	1.9-2.3 Ga	Paleoproterozoic basement, pervasive throughout all Borborema Province	Seridó, Sertânia, Surubim, and Rio Una supracrustal sequences
D – Archean-Siderian	2.3-2.5 Ga	Tonalitic orthogneiss from the Alto Moxotó domain.	Seridó, Sertânia, Surubim, and Rio Una supracrustal sequences
	2.5-3.6 Ga	São José do Campestre Massif, Granjeiro Complex, and Riacho das Lages Suite.	Seridó, Sertânia, Surubim, and Rio Una supracrustal sequences

Population A: 1000-540 Ma. Neoproterozoic detrital zircon grains from population A occur in all analyzed samples and correspond to 39% of the concordant data (Fig. 12). They range in relative abundance from 28 to 57% per sample and belong almost entirely to the Ediacaran period, with the main peak at 585 Ma (Fig. 12).

Late Cryogenian to Ediacaran ages from Population A are mostly related to the Brazilian/Pan-African orogeny, which included multiple stages of pluton emplacement throughout the tectonic zones of the Borborema Province (BP), from 640 Ma to 530 Ma (Van Schmus et al., 2011, Caxito et al., 2020 and references therein). Neoproterozoic grains older than 610 Ma may also correspond to recycled zircon grains sourced from supracrustal units metamorphosed during the Brazilian/Pan-African orogenic cycle. In this sense, the Seridó Group, of the Northern Zone (NZ), the Cachoeirinha Group and the Sertânia Complex, both from the Transversal Zone (TZ), represent the most probable metasedimentary sources. The Seridó Group, deposited between 650 Ma and 610 Ma (Van Schmus et al., 2003), shows major clusters at 1000-950 Ga, 800-750 Ma and 650 Ma (Van Schmus et al., 2003, Kalsbeek et al., 2013, Hollanda et al., 2015). In the TZ, the Cachoeirinha Group of the Piancó-Alto Brígida Domain has a maximum depositional age of 620-600 Ma and sources ranging from 980 Ma to 630 Ma (Van Schmus et al., 2008, 2011). Finally, the Sertânia Complex of the Alto Moxotó Domain (AM) has a maximum depositional age of 642 ± 42 Ma and Neoproterozoic zircon populations of 875-810 Ma and 775-700 Ma (Neves et al., 2009).

The two zircon grains that yielded Early Tonian ages (962 Ma and 970 Ma) are either first-order grains from units related to the Cariris Velhos event (*ca.* 1000-920 Ma), or recycled grains from Neoproterozoic supracrustal sequences. In the former case, source areas would be related to Early Tonian magmatism and sedimentation in the Alto-Pajeú Domain of the TZ, and to secondary occurrences in the Southern Zone (SZ) of the BP (Jardim de Sá et al., 1988, 1992, Silvo Filho et al., 2002, 2014, Van Schmus et al., 2008, 2011, Santos et al., 2010, Oliveira et al., 2010, Guimarães et al., 2012, 2016, Caxito et al., 2014).

Population B: 1.8-1.5 Ga. Detrital zircon grains from population B comprise 27% of total concordant data, encompassing 4 to 55% of each sample (Fig. 12). U-Pb ages are primarily concentrated in the 1.79-1.71 Ga interval, with a major peak at 1.74 Ga. Samples AL-1, AL-2, and STG-1 also present detrital zircon ages between 1.69 Ga and 1.58 Ga (Fig. 12).

Few Statherian-Calymmian units have been recognized in the Borborema Province. Within the analyzed area, *ca.* 1.7-1.5 Ga is associated with metaigneous rocks from the Rio Capibaribe (RC) and Alto Moxotó (AM) domains of the Transversal Zone. In the RC, 1.7-1.5

Ga units include the Taquaritinga granitic intrusion (*ca.* 1.54 Ga; Sá et al., 2002) and the Passira Complex, characterized by 1.7 Ga meta-anorthosite associated with 1.68-1.58 Ga type-A metagranite (Accioly, 2000). In the AM, Statherian-Calymmian units comprise the Serra da Barra Suite, with orthogneiss and rare mafic rocks of 1.64-1.63 Ga (Santos et al., 2015); the Carnaió Suite (*ca.* 1638 Ma), considered to be an extension of the aforementioned Serra da Barra Suite (Lages et al., 2019); and the Coloete Suite, composed of 1652 Ma granite gneisses with granitic-granodioritic chemical composition (Lages et al., 2019). Additionally, 1.7-1.6 Ga ages were obtained on zircon grains from the Neoproterozoic supracrustal sequences of Surubim, in the TZ, and Rio Una, in the SZ (Neves et al., 2009).

Thus far, the Orós-Jaguaribeano Belt, from the Ceará Central Domain (Fig. 13), is the only source of primary Late Orosian-Early Statherian (*ca.* 1.7-1.8 Ga) zircon grains that has been identified throughout the BP. It consists of a metavolcano-sedimentary belt, formed between 1.8 and 1.75 Ga, in response to intracrustal rifting (Sá et al., 1995, 1997). In the Central and Southern zones, however, Paleoproterozoic metasedimentary sequences have not yet been recognized and the indication of rift-related events is only given by 1.7-1.6 Ga A-type metagranites associated with a discrete continental break-up attempt (Lages et al., 2019). Nevertheless, Late Orosian-Early Statherian ages were also obtained on zircon grains from the Neoproterozoic supracrustal sequences of Sertânia, Surubim, and Rio Una, in the TZ and SZ (Neves et al., 2009), as well as from the supracrustal Seridó Belt, in the NZ (Van Schmus et al., 2003). Therefore, given the location of the Orós-Jaguabariano belt, far from the catchment area indicated by the paleocurrents from the Exu Formation (Fig. 13), it is more reasonable to assume a recycled origin for the 1.7-1.8 Ga zircon population.

Population C: 2.3-1.8 Ga. Rhyacian-Orosian ages represent 31% of all concordant data and comprise 11 to 60% of each sample (Fig. 12). Detrital zircon grains from population C are mainly placed in 2.18-2.08 Ga and 2.05-1.99 Ga age intervals, with secondary contributions of 2.28-2.20 Ga and 1.97-1.92 Ga age ranges (Fig. 12).

Rhyacian-Early Orosian zircon grains are ubiquitous in the BP as its basement mostly consists of 2.2-2.0 Ga rocks related to the Transamazonian/Eburnean orogeny (Brito Neves et al., 2000, Neves, 2003, Caxito et al., 2020 and references therein). Likewise, all the above-mentioned Neoproterozoic metasedimentary sequences inherited detrital zircon populations spanning the Late-Orosian through Rhyacian, to a greater or lesser extent. Consequently, no particular source can be assigned to Population C.

Population D: 3.6-2.29 Ga. Archean and Siderian grains comprise 3% of all concordant data (Fig. 12). This population occurs in samples AL-1, AL-2, STG-1, and SSR-1, with sparse ages of 2.3 Ga, 2.46 Ga, 2.61 Ga, 2.66 Ga, 2.75 Ga, 3.09 Ga and 3.36 Ga (Fig. 12).

Although scarce in the entire Exu Formation, Archean-Siderian ages could indicate more specific source areas in the BP, as rocks within the 3.6-2.3 Ga age range are restricted to a few basement blocks. Most Siderian rocks of the BP are related to the granulitic basement of the Médio Coreaú domain (Fetter et al., 2000, Santos et al., 2008), located in northwestern NZ and, therefore, an improbable direct source of sediments for the Exu Formation. Apart from the Médio Coreaú domain, 2.4 Ga orthogneiss and migmatite were also found in the basement of the Alto Moxotó Domain, in the TZ (Brito Neves et al., 2001, Melo et al., 2002, Santos et al., 2015).

First-order Archean sources are located in the NZ and TZ of the BP, and include: (1) the São José do Campestre Massif (with several episodes of magma generation between 3.45-3.0 Ga and at 2.7 Ga; Dantas et al., 1998; 2004; 2013), and mafic-ultramafic rocks from the Rio Grande do Norte Domain which yielded ages of 3.7-3.5 Ga (Santos et al., 2020); (2) the Granjeiro Complex, bounded to the north by the Farias Brito Shear Zone and to the south by the Patos Lineament, with gneissic rocks crystallized between 3.5 and 2.7 Ga and BIF sedimentation related to basaltic volcanism at 2.6 Ga (Arthaud et al., 1998; Pitarello et al., 2019), and (3) the Neoproterozoic Riacho das Lages Suite, (*ca.* 2.6 Ga), located in the Alto Moxotó Domain (Santos et al., 2017) (Fig. 13). Once again, metasedimentary units seemingly acted as sources for the Exu Formation sediments, as recycled grains from Seridó, Sertânia, Surubim and Rio Una Neoproterozoic supracrustal sequences exhibit Archean age ranges (Hollanda et al., 2015; Neves et al., 2009).

Source area trends and catchment basin

Geochronological data from the Exu Formation reveal an outstanding homogeneity in the distribution of detrital zircon ages, with three (A, B, and C) of the four main populations identified in all analyzed samples. Minor stratigraphic and spatial variations are represented by a much-reduced *n* limited to one or two samples. The only exception is the 1.7-1.58 Ga population of 13 detrital zircon grains, identified in three of the four samples from the basal interval of the unit, all located in the western part of the basin (Fig. 12).

This difference could be considered an evidence of variable source regions for the west and east parts of the Exu Formation depositional system. Accordingly, the Statherian-

Calymmian (*ca.* 1.7-1.5 Ga) ages found in samples AL-1, AL-2 and STG-1 would imply that rocks from Rio Capibaribe and Alto Moxotó domains yielded sediments only to the western part of the fluvial system. On the other hand, intrinsic sorting processes (e.g. the variability to sampling multimodal populations, potential biases created by preferential sampling, and grain fractionation) could also create statistically significant differences amongst detrital zircon samples derived from the same sources, especially in small-*n* populations (Ibañez-Mejia et al., 2018). Consequently, the overall uniformity of the dataset seems to support the interpretation of a constant catchment region for the Exu Formation.

In summary, the entire unit reveals contributions from source areas located between ESE and ENE of the basin, in agreement with the paleocurrent data (Figs. 3, 11). Therefore, based on: (1) the prevalence of age populations A and C, in line with ages obtained for the BP basement; (2) the existence of secondary age groups (populations B and D), related to very specific sources east of the Araripe Basin, and (3) solid evidence of supracrustal units as dominant sources, especially regarding population B, we define the region from south of the Pernambuco Shear Zone (close to the boundary between the SZ and the TZ) to North of the Patos Shear Zone (at the eastern part of the Rio Grande do Norte Domain) as the catchment area for the drainage system of the Exu Formation (Fig. 13).

DEPOSITIONAL MODEL

Fluvial successions can be particularly difficult to correlate due to their high degree of lateral variability and lack of biostratigraphic markers, especially in highly avulsive systems. In the absence of a clear regional datum within the Exu Formation, and of an upper basin-scale unconformity, the basal contact with the Romualdo and Araripina Formations was used as the stratigraphic datum for sedimentary log correlation (see Fig. 3). Regardless of this choice, internal changes in facies associations and paleosol frequency can be analyzed in order to track long-term tendencies and their possible driven forces.

The analyzed successions of the Exu Formation record a regional-scale west-flowing fluvial system that entered the Araripe Basin at its eastern margin (Fig. 14). Like the underlying Santana Group (Custodio et al., 2017; Varejão et al., 2016; 2021), a thin succession of Exu Formation' deposits has been described in isolated buttes located in the Jatobá Basin (Neumann & Rocha, 2014), at distances of ~200 km from the Araripe Basin. Even though this work does not present data directly obtained from these sparse occurrences, their existence suggests that similar west-flowing fluvial systems covered an area far larger than the present limits of the

Araripe Plateau. Despite the intrinsic limitations of recognizing large fluvial systems based on discontinuous outcrop exposures, the vertical and downstream trends identified through the stratigraphic logs allowed us to interpret the Exu Formation deposits as fragments of a large distributive fluvial system (DFS) with a minimal length of 200 km (Fig. 14).

Sedimentary data from the Exu Formation reveal downstream decreases in channel size, confinement, and interconnectivity (Figs. 3 and 14). The distribution of facies and facies associations throughout the basin also indicate a downstream reduction in grain size, with gravelly facies concentrated in the proximal areas, and higher proportions of floodplain (FA5), splay (FA4), and poorly confined channel (FA 3) deposits at the most distal preserved parts of the system (Figs. 3 and 14). Abandonment deposits are almost ubiquitous across the basin, although their frequency also increases downstream. All the above-mentioned trends are also observed vertically, especially in thicker continuous successions (sections 4, 5, and 7 from figure 3), resulting in a slight retrogradational stacking pattern that reflects an overall upward decrease in fluvial energy and channel capacity (Figs. 3 and 14).

Paleocurrent indicators obtained in the studied successions show main sediment transport towards WSW and ENE (Fig. 11). Equivalent stratigraphic intervals usually demonstrate deviation from a mean westward vector, but do not form the typical radial pattern expected for distributive systems (Fig. 11). The regional distribution of facies, facies associations, and paleocurrents over the basin enables the recognition of proximal and medial/distal zones of the megafan (Nichols and Fisher, 2007; Cain and Mountney, 2009; Weissmann et al., 2013). As the system likely exceed the present limits of the basin, its proximal, medial and distal zones were presumably larger than the recorded.

The deposits from FA1, located at the NE border of the basin, represent the most proximal preserved part of the DFS. With measured vertical extensions of up to 30 meters and mean paleoflow towards SSW and WSW (Figs. 3 and 11), these amalgamated bodies are mostly interpreted as downstream migrating gravel and sand bars organized in multistory sheets deposited by braided channel belts (Bristow and Best, 1993; Weissmann et al., 2013). The high degree of interconnectivity between coarse-grained facies (almost 100%) is suggestive of laterally mobile channels that repeatedly migrated to new positions, eroding and reworking sediments from the adjacent floodplain area and preventing weathering for significant periods (Nichols and Fisher, 2007). The few paleosol profiles observed in the proximal area are well-drained, immature profiles composed of stacked, structureless, C(r) and C horizons. These features reflect the coarse-grained parent material in which paleosols were developed, their

proximity to active channel belts, and a rather mobile environment that precluded significant soil formation (Hartley et al., 2013).

A significant increase in the proportion of overbank facies (FA4 and FA5), chiefly as abandoned channels (paleosols) and fine-grained suspension settling deposits mark the medial region of the DFS. These occur interspersed with sand-bed channels (FA2), splay deposits (FA4), and sparse eolian dunes (FA6), totalizing up to 50 m-thick measured in vertical profiles (Fig. 3). Channel facies are finer than the ones observed in the proximal zone (FA1), reflecting major distances from the source area. The increasing proportion of preserved floodplain material from the proximal to the medial zone (0-20% to 30-50%, respectively) indicate a tendency of FA2 channels to become more laterally stable when compared to channels from FA1 (Nichols and Fisher, 2007).

Nevertheless, lateral shifting and channel abandonment were still crucial processes, as suggested by the high frequency of paleosol profiles developed over sandy paleochannel deposits. Local mud-filled ribbons encased at the top of major sheet sand bodies also attest to the gradual infilling and abandonment of FA2 channels (Fig. 6). During these avulsion events, fluvial progradation over adjacent alluvial plain would lead to the erosion and reworking of the fan surface, producing abundant intraformational mudclasts and paleosol fragments disposed as basal lag deposits or scattered in sandstone facies from FA2.

The described paleosols from the medial zone are poorly developed profiles composed of stacked C horizons, occasionally separated by layers of unmodified sediments. Compared to paleosols from the proximal zone, these profiles reveal a significant increase in the density of mottling, rhizoliths and invertebrate burrows, as well as a greater variety of colors and textures (Figs. 8G and 8H). Sandy profiles formed over abandoned channel and bar deposits vary from well-drained to relatively poorly-drained. Well-drained paleosols are dominated by reddish colors and present occasional oxidation halos around root and invertebrate traces. On the other hand, redoximorphic features such as redox halos, intense mottling, purple and grey colors (Fig. 8G), and eventual tabular root systems suggest saturated soils, either due to stagnant surface water or to suspended water table (Krauss, 1999; Retallack, 2001). Low-diversity assemblages dominated by meniscate trace fossils (*Taenidium* sp. and *Beaconites* sp., Figs. 8A and 8B), typical of periodically inundated low energy environments, also corroborate the interpretation of paleochannel deposits forming sand-rich floodplains (Buatois and Mangano, 2004). Finally, clayey profiles developed over settling deposits locally reveal features of waterlogging caused by a perched water table above an impermeable layer (Retallack, 2001).

The medial to distal zone of the DFS differs significantly from other parts of the system (Fig. 14). Successions dominated by poorly confined channel (FA3), splay (FA4), and floodplain (FA5) deposits suggests downstream reductions in fluvial discharge and sediment supply. The inferred downstream reduction in transport capacity could be related to infiltration through gravelly and sandy channel deposits from proximal and medial zones (Weissmann et al., 2013), or channel bifurcation. Likewise, sand-rich floodplains composed of paleochannel deposits probably increased interconnectivity and infiltration compared to fluvial fans dominated by settling deposition (Alexander and Fielding, 2006; Assine et al., 2014a). Infiltration and/or channel bifurcation reduced fluvial discharge and the amount of sediment sourced from the catchment basin that would reach the medial/distal part of the DFS, resulting in successions dominated by finer-grained sediments, in both confined and unconfined settings (Cain and Mountney, 2009).

FA3 sand bodies are separated by overbank facies (FA5) and sparse thin sheets interpreted as splay deposits (FA4). Despite the high proportion of cross-bedded deposits indicating channelized flows over the fan surface, erosion and rework of the alluvial plain were not so significant, as channel bases can be poorly defined and few evidence of floodplain cannibalization were observed. Shallow horizontal to oblique roots extend from the interspersed overbank into channel deposits revealing recurring conditions of waterlogging (Retallack, 2001). Upward in the succession, vertisol profiles, characterized by Bss horizons with slickenside planes, wedge-shaped structures, infilled desiccation cracks, and gilgai microrelief (Fig. 8F), attest to the shrinking and swelling of clays in a context of seasonal wetting and drying episodes (Retallack, 2001; Tabor and Myers, 2015). Together, these features suggest a periodically wet alluvial plain, with a high amount of fine-grained sand, over which channels with low flow competency would move until being abandoned and pedogenized.

Towards the west, suspension settling facies from floodplain (FA5) and thin sheet sand bodies interpreted as splay deposits (FA4) become dominant, with few minor channels representing the final extents of the feeding distributary network (see Fig. 14; Lang et al., 2004; Nichols and Fisher, 2007). Reddish mudrock with simple and meniscate burrows suggests oxidized soils formed in better drainage conditions (Retallack, 2001). The spatial relationship between confined and unconfined deposits from the medial-distal reach of the fluvial fan suggests that FA3 elements worked as a channel network that fed splay deposits (FA4).

BASIN EVOLUTION AND IMPLICATIONS FOR THE ALBIAN-CENOMANIAN PALEOGEOGRAPHY

During the Aptian, distinct events of marine ingression progressing from south to north influenced the deposition of post-rift transgressive-regressive successions from the Santana Group in the Araripe Basin (Assine et al., 2016; Custódio et al., 2017; Fursich et al., 2019; Varejão et al., 2019a; Rodrigues et al., 2020; Varejão et al., 2021). Periods of regression were marked by continental-scale fluvial systems (Barbalha Formation) that flowed towards southeast through the Recôncavo-Tucano-Jatobá basins (Marizal Formation; Assine et al., 2016; Varejão et al., 2016; Freitas et al., 2017). Conversely, during intervals of high sea level, marine waters would migrate from the Sergipe-Alagoas through the fluvial valleys of the Recôncavo-Tucano-Jatobá basins until finally reaching the Araripe Basin (Fig. 15; Assine et al., 2016).

In the early Albian, sedimentation became continental in the Araripe Basin, with the development of a fluvial system (Araripina Formation) confined to the western part of the basin, where subsidence and syndepositional tectonic activity were controlled by the reactivation of regional basement faults (Warren et al., 2021). Even though related to different basin geometries, the fluvial systems of Araripina Formation and Santana Group shared similar paleoflow pattern towards southeast (Assine, 1994; Warren et al., 2021), revealing a relatively constant depositional dip throughout most of the post-rift phase in the Araripe Basin.

However, after the deposition of the Araripina Formation, this pattern suffered a major shift. At some point between Albian and Cenomanian, a regional-scale reversal of basin paleoslope lead to the establishment of a new depositional style in the Araripe Basin. Sedimentological, paleocurrent and U-Pb detrital zircon data from the Exu Formation reveal significant changes in sediment texture, source areas, syndepositional tectonics and basin architecture compared to the underlying deposits. Modifications in sediment dispersion routes and basin geometry were directly related to the uplift of areas located east of the Araripe basin (Assine, 1994). These elevated areas acted as new sources, providing large sediment supply to the depositional site and inverting paleoslope orientation, which, in turn, resulted in the complete continentalization of the Araripe Basin (Fig. 15). Paleocurrent and geochronological data from basal deposits of the Exu Formation (Figs. 11 and 12) indicate that this reconfiguration had already happened when sedimentation started, suggesting source area tectonism, related to the opening of the South Atlantic Ocean (e.g. formation of rift shoulders/flanks), as a primary control for the establishment of the Exu fluvial system.

Fluvial fans are built through recurring progradation of avulsion belts across the alluvial plain (Shukla et al., 2001; Assine, 2005; Nichols and Fisher, 2007; Weissmann et al., 2010; Assine et al., 2014a). As each avulsion cycle occurs, a self-driven topographic gradient is created between channel belts and the adjacent floodplain, resulting in the infilling of the topographic lows by the next cycle. Over longer periods, and under circumstances of stable or forward migrating apex and declining accommodation space in relation to sediment supply, this autocyclic mechanism tends to create a prograding stacking pattern (Weissmann et al., 2013). Indeed, upward increases in grain size, sand body thickness and channel-belt amalgamation have been reported in several examples of large fluvial fans (Weissmann et al., 2013; Wilson et al., 2014; Owen et al., 2017a, b; Batezelli et al., 2019; Ventra and Clarke, 2018; Wang and Plink-Bjorklund, 2019).

Contrarily to these examples, the vertical succession observed in the most continuous columnar sections of the Exu Formation (sections 4, 5 and 7 from figure 3) do not indicate a prograding architecture. Overall up-section decreases in channel capacity and sand body amalgamation are demonstrated by facies from the medial to distal zone overlying facies from the proximal to medial part of the system. In the aforementioned logs, this upward transition is also marked by paleosol profiles that, although not well developed to represent a clear stratigraphic marker (see Fig. 3; Kraus, 1999; Retallack 2001; Atchley et al., 2013), might endorse the vertical changes of facies associations in the stacking pattern.

Towards the upper part of some of the sedimentary logs (section 4 from fig. 3), there is an increase in grain size, with sets of cross-bedded sandstone indicating the return of channelized flows in medial to distal parts of the system. Nevertheless, pervasive evidences of recurring channel abandonment also increase up section, with intense bio and pedoturbation obliterating primary structures and forming multiple overlapped paleosol profiles. Even though the continuous interaction between sedimentation and pedogenesis prevented the development of mature paleosols (Kraus, 1999; Fedoroff et al., 2010), the frequency of paleosol occurrence suggests a persistent influence of pedogenetic processes throughout the basin. In this sense, the local return to channelized deposition in the medial-to distal part of the system might reflect avulsion processes, while the slight backstepping of the DFS observed in the 100 m-thick stratigraphic interval could be related to one or multiple allocyclic controls (Owen et al., 2017b).

The three main allocyclic controls to which fluvial systems respond are eustasy, climate and tectonics (Allen, 1971; Shanley and McCabe, 1994; Miall, 2006; Catuneanu, 2006). Paleocurrent data towards west hinder any downstream connection between the Exu fluvial

system and the South Atlantic Ocean. At the estimated period of deposition of the Exu Formation, the distance between the newly formed Equatorial Atlantic Ocean and the study area exceed the < 200-km-width buffer zone in which eustasy normally influences base-level changes (Blum and Törnqvist, 2000; Blum et al., 2013). Therefore, eustatic sea level changes were not a key factor. Since no evidence of a lacustrine terminal system was observed, the Exu fluvial system was likely controlled by upstream mechanisms such as climate shifts, source area tectonism, and basin subsidence, rather than downstream eustatic or lake level variations (Catuneanu, 2006).

In turn, climatic conditions in the Araripe Basin during the Albian-Cenomanian interval are not very clear. Paleoclimatic interpretations based on palynological content from the underlying Araripina Formation suggest warm and arid climate during the Albian (Lima, 1978), in agreement with the arid zones and evaporite belts described for tropical regions at this period (Chumakov et al., 1995; Hay and Floegel, 2012). Despite the lack of paleoclimate studies in the Exu Formation, global paleoclimate models indicate temperatures continued increasing from the Albian through the Cenomanian (Huber et al., 2018). Palynological analysis performed in the chrono-correlated Itapecuru Formation (Parnaíba Basin) suggest arid to tropical climate (Pedrão et al., 1993), or wet equatorial climate for the Albian-Cenomanian (Ferreira et al., 2020), while paleosol profiles indicate climate seasonality (Menezes et al., 2019). In this case, moisture would be related to the development of the equatorial humid belt after the opening of the Equatorial Atlantic Ocean (Chumakov et al., 1995; Hay and Floegel, 2012).

Whether this humidity increase reached the interior of Northeast Brazil or not remains uncertain, but widespread well-drained, reddish paleosols with oxidation and reduction features suggest tropical conditions influenced by seasonality (Kraus and Hasiotis, 2006), which are reinforced by the presence of vertisols (Tabor and Myers, 2015). Still, varying degrees of hydromorphy observed throughout the basin were not necessarily climatic driven, but rather a consequence of specific hydrological conditions related to physiographic position in the depositional system (Kraus, 1999; Retallack, 2000). Consequently, careful paleoclimatic interpretations demand further studies focused on detailed micromorphological and geochemical analysis of the paleosol profiles throughout the basin.

As previously observed, tectonic activity in the catchment area was crucial for the continentalization of the drainages and the development of the Exu Formation fluvial system. Apatite fission-track data from basement rocks of the Borborema Plateau and adjacent coastal areas indicate cooling episodes between 110-95 Ma (Turner et al., 2008), 100-90 Ma (Moraes-Neto et al., 2009), 110-105 Ma (Japsen et al., 2012), and ~140-90 Ma (Jelinek et al., 2014). The

regional basement uplift related to the cooling episodes is reinforced by the exhumation of the Cabo granite (102 ± 1 Ma; Nascimento et al., 2003), for about 1-2 km before the deposition of the Cenomanian-Turonian carbonates of the Estiva Formation (Nascimento, 2003; Almeida et al., 2005). Usually, the Early-Mid Cretaceous cooling is associated with unconformities produced during the transition from syn- to post-rift sedimentation in the Recôncavo-Tucano-Jatobá and Sergipe Alagoas basins (Turner et al., 2008; Japsen et al., 2012; Jelinek et al., 2014), although the spatial and temporal extents of this event are still uncertain. Some works interpret it as a regional event reflecting the uplift and exhumation of rift margins and hinterland up to 200 km west of the rift (Moraes-Neto et al., 2009; Japsen et al., 2012).

The rise of hinterland was crucial for the establishment of the Exu Formation fluvial system. Likewise, minimal variations in paleocurrent and detrital zircon data throughout the sedimentary succession reveal a persistent catchment basin for the entire unit (Fig. 15). In this way, the slight retrograding stacking pattern observed through the logs could be a consequence of decreasing uplift rates in hinterland (Quirk, 1996; Fig. 14) and/or increasing accommodation space in relation to sediment supply. Since no significant changes in paleoslope direction and sediment provenance were identified in this study, backstepping of proximal-to-medial facies zones towards the source may be related to a reduction in sediment yield caused by a period of tectonic quiescence, after the major uplift pulses (Cain and Mountney, 2009; Bordy and Paiva, 2021).

Finally, despite the stratigraphic and provenance data point to an important influence of source area tectonics in controlling paleoslope, sediment input, and longitudinal profile, paleoclimatic studies are needed to understand how climate influenced the deposition of the Exu Formation.

CONCLUSIONS

The ~200 m-thick Albian-Cenomanian Exu Formation is a siliciclastic succession that represents the last depositional cycle in the Araripe Basin and the complete return to continental deposition in the basin. The unit rests over an unconformity with the Araripina and Romualdo Formations and rocks from the Precambrian basement, while its upper surface corresponds to the summit of the Araripe Plateau. Sedimentological and stratigraphic analysis of the Exu Formation deposits allowed recognizing six facies associations that reflect laterally and temporally associated environments of a distributive fluvial system, probably developed under tropical climate, during the final stages of post-rift sedimentation in the Araripe Basin.

Evidences of coeval deposits outside the Araripe Plateau suggest that the original depositional site of the Exu Formation exceeded the present limits of the basin, meaning that the preserved outcrops represent only a fragment of the original fluvial systems. Proximal to medial/distal zones of the DFS were recognized based on basin-wide trends and stratigraphic relations between channel and overbank facies associations. Paleosol profiles indicate well-drained to poorly-drained conditions, which are mostly associated to their physiographic position in the depositional system. Seasonality probably affected the basin's climate, although detailed paleoclimatic studies are required for further conclusions.

Mean paleoflow towards W indicates the inversion of basin paleoslope during the post-rift II phase, compared to the underlying post-rift sequences (Santana Group and Araripina Formation). This inversion is reinforced by U-Pb detrital zircon ages from basal and medial stratigraphic intervals of the Exu Formation, which suggest a catchment-area extending from south of the Pernambuco Shear Zone to North of the Patos Shear Zone. In this way, the onset of the Exu fluvial system was driven by the uplift of areas located east from the Araripe Basin, after the South Atlantic Ocean opening. The consequence was the complete rearrangement of the continental drainage in Northeast Brazil, creating new source areas that lead to high sediment yield and the progradation of a regional-scale, west-flowing DFS across the Araripe Basin. Small variations in paleocurrent and detrital zircon data throughout the succession reveal a persistent catchment area for the entire unit. In this context, source-area uplift might have influenced the deposition of the entire succession, not just determining the establishment of this continental fluvial system, but inducing a slight backstepping towards the source as uplift rates decreased.

The last depositional cycle in the Araripe Basin is a key-unit for the reconstruction of the post-rift landscape of Northeastern Brazil, as it demonstrates the complete reorganization of the continental drainages in response to a regional uplift. Accordingly, this contribution might help improving geodynamic models for the post-rift evolution of the Borborema Province in two ways: (1) by indirectly demonstrating a regional post-rift event of basement uplift in the east part of the Borborema Province; (2) by rejecting the hypothesis of accommodation controlled by eustasy during the deposition of the post-rift II sequences (Sacek et al., 2019), since there was no connection between these continental systems and the South Atlantic Ocean.

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FIGURE CAPTIONS

Figure 1.

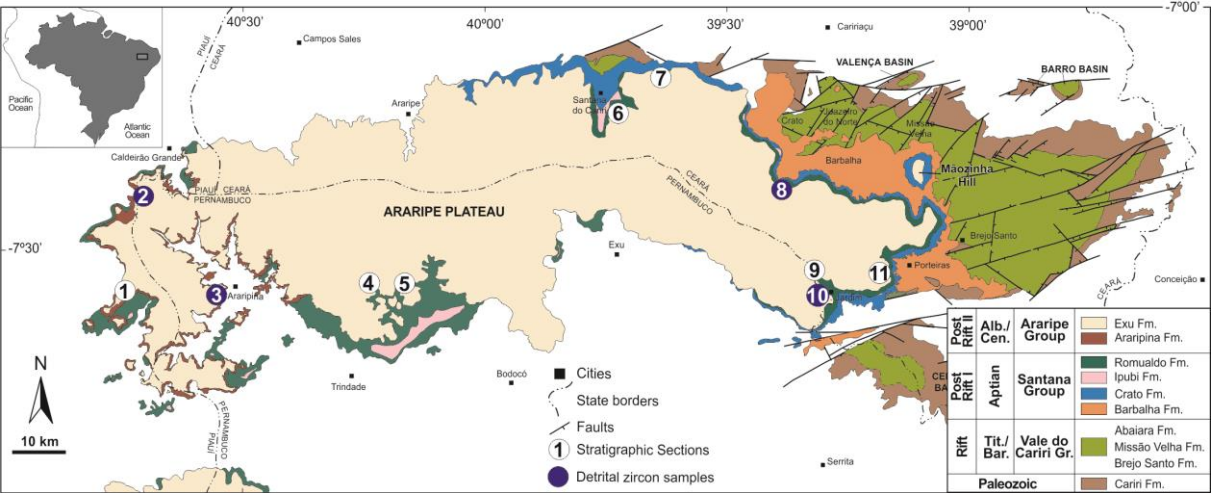


Fig. 1. Geologic map of the Araripe Basin with the location of the sedimentary logs and detrital zircon samples. (1) Simões; (2) Alagoinha; (3) Sítio Torre Grande; (4) Serra Branca; (5) Gameleira; (6) Pontal da Santa Cruz; (7) Ponte de Pedra; (8) Sítio Santa Rita; (9) Gravatá; (10) Jardim and (11) Sobradinho.

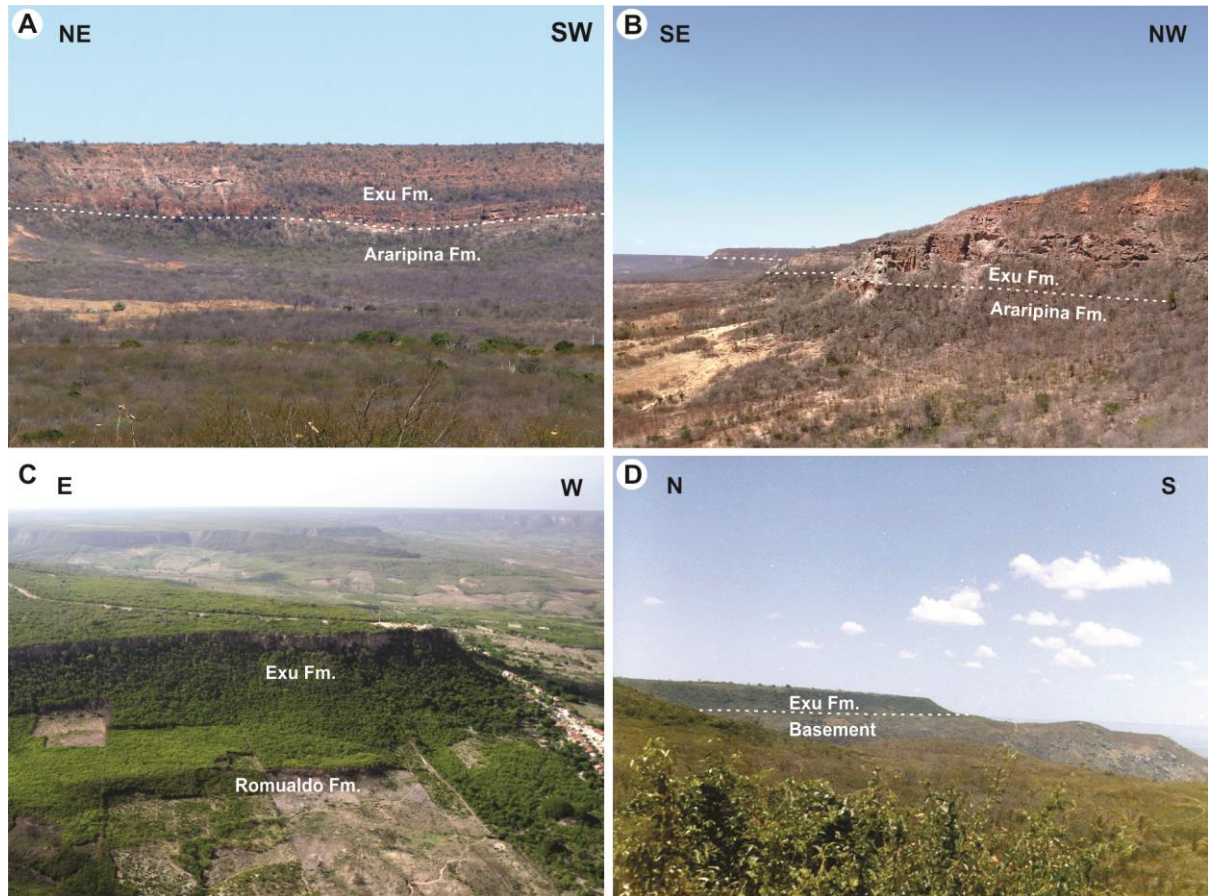
Figure 2.

Fig. 2. Lower boundaries of the Exu Formation throughout the Araripe Plateau. (A, B) Unconformity with the Araripina Formation, at the western part of the Araripe Basin. (C) Unconformity with the Romualdo Formation, at the northeast part of the Araripe plateau. Talus deposits generally cover this contact. (D) Nonconformity with the Precambrian basement, at the southern margin of the plateau.

Figure 3.

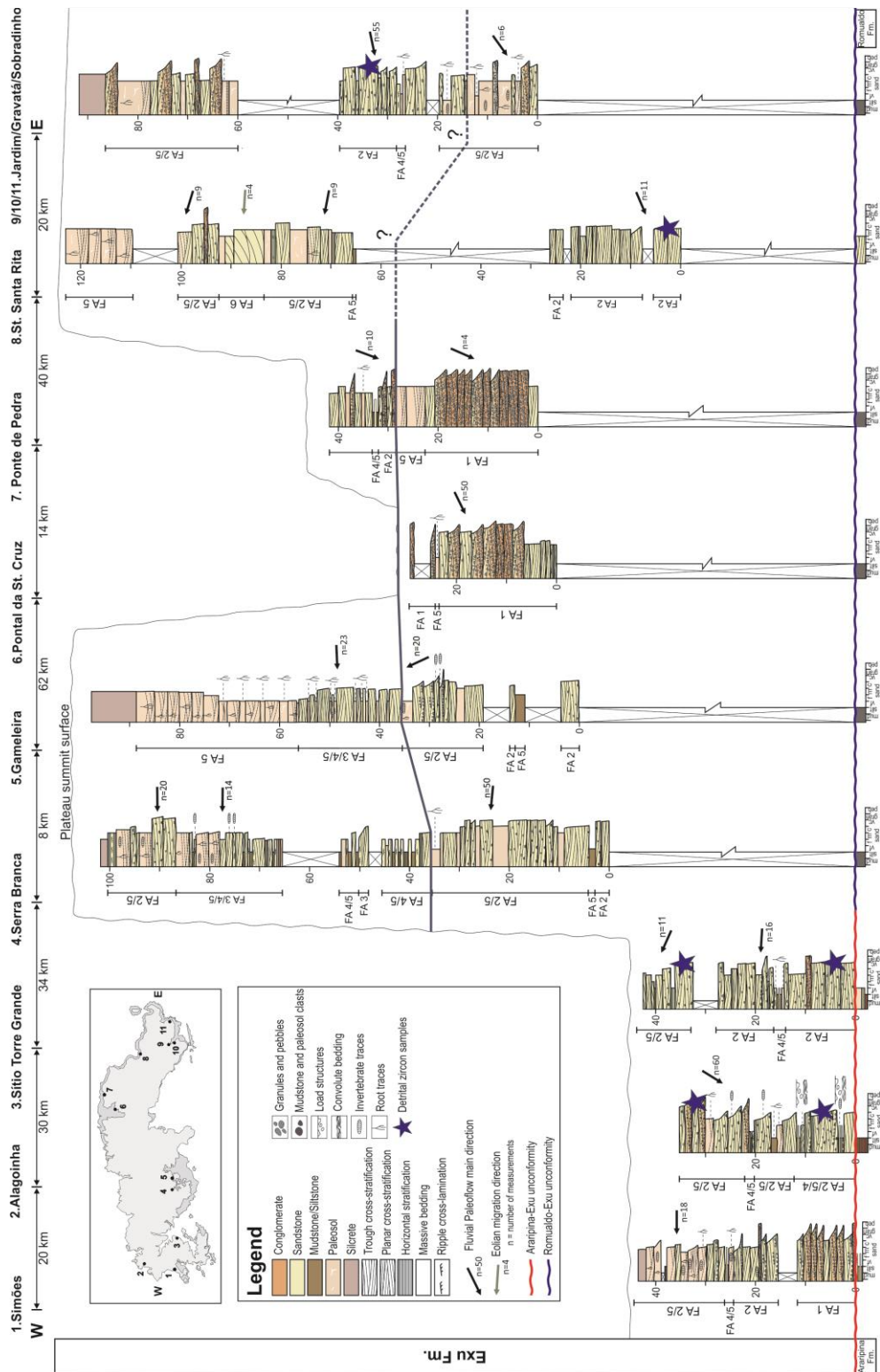


Fig. 3. E-W correlation of the measured sedimentary logs from Exu Formation. Facies associations, paleocurrents and sample locations are also indicated in the sections.

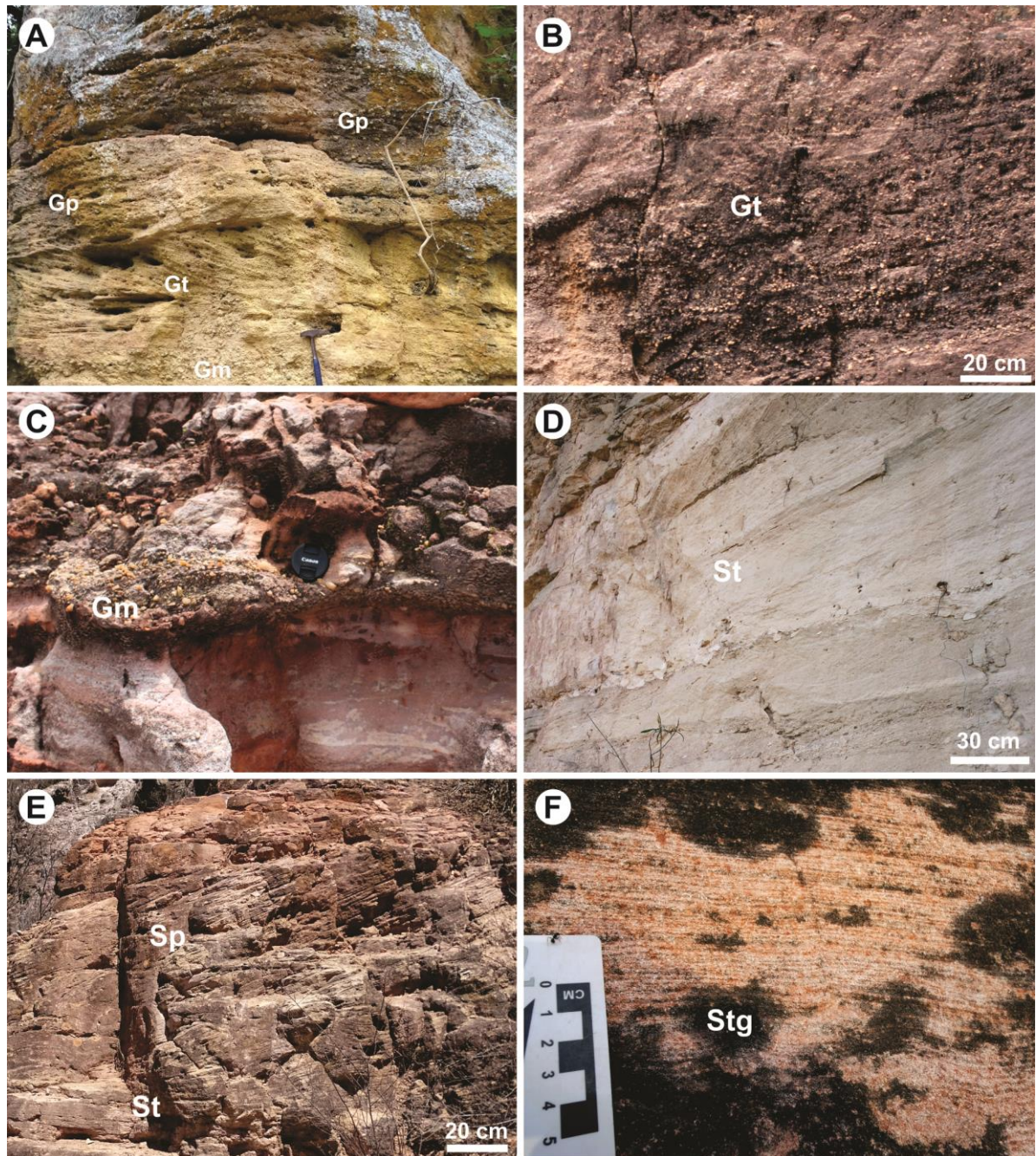
Figure 4.

Fig. 4. Conglomerate and sandstone facies from Exu Formation. (A) Conglomerate lag (Gm) overlaid by through cross-bedded granule conglomerate and wedge-shaped bodies composed of cm- to dm-thick sets of planar cross-bedded conglomerate (Gp). (B) Trough cross-bedded conglomerate (Gt). (C) Conglomerate lag (Gm). (D) Medium-grained trough cross-bedded sandstone with intraclasts (St), organized in thinning upward sets, overlying a laterally continuous erosive surface. (E) Cosets of coarse-grained trough and planar cross-bedded sandstone with sparse granules. (F) Medium- to fine-grained trough cross-bedded sandstone, showing grain size segregation. Lens caps in A and E have diameter of 58mm. Hammer in D is 25 cm long.

Figure 5.

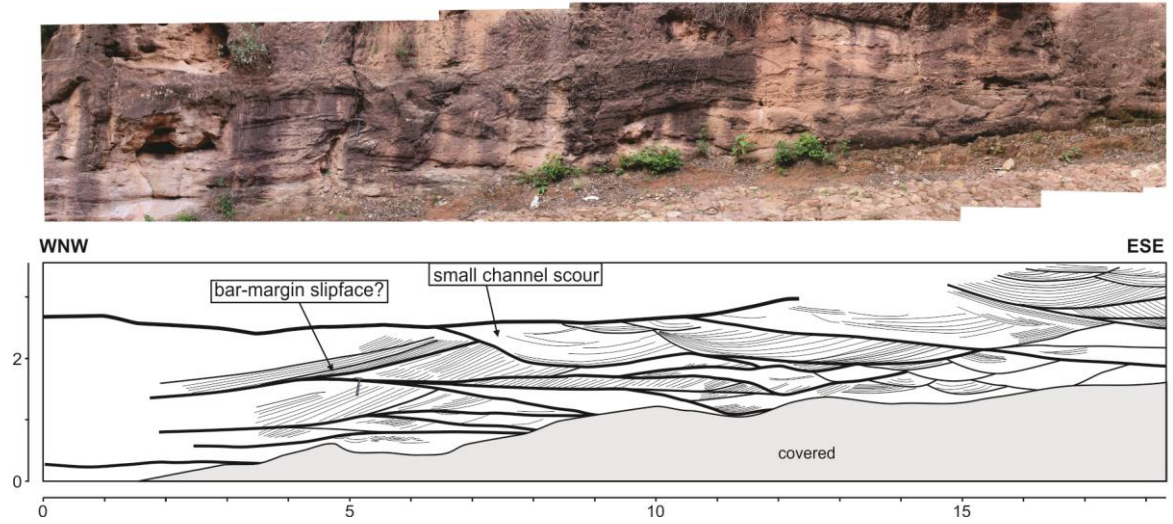


Fig. 5. Outcrop and line drawing interpretation of FA1 deposits, presenting lenticular, tabular and channelized geometries composed of trough cross-bedded conglomerate and sandstone (facies Gt and St).

Figure 6.

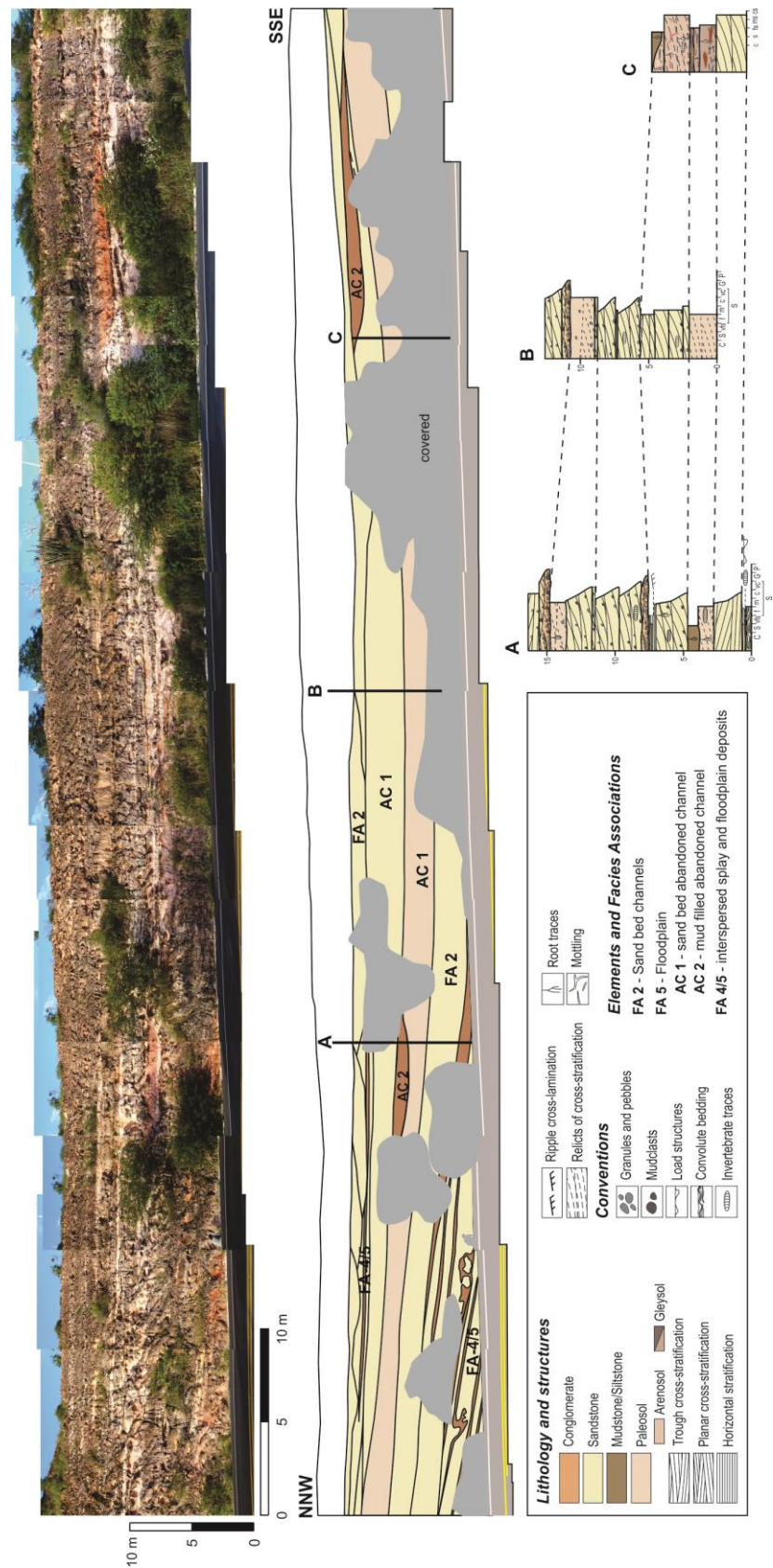


Fig. 6. Outcrop and drawing interpretation of sand bed channel deposits (FA2), interbedded with overbank, paleosols (FA5), and crevasse splay deposits (FA4).

Figure 7.

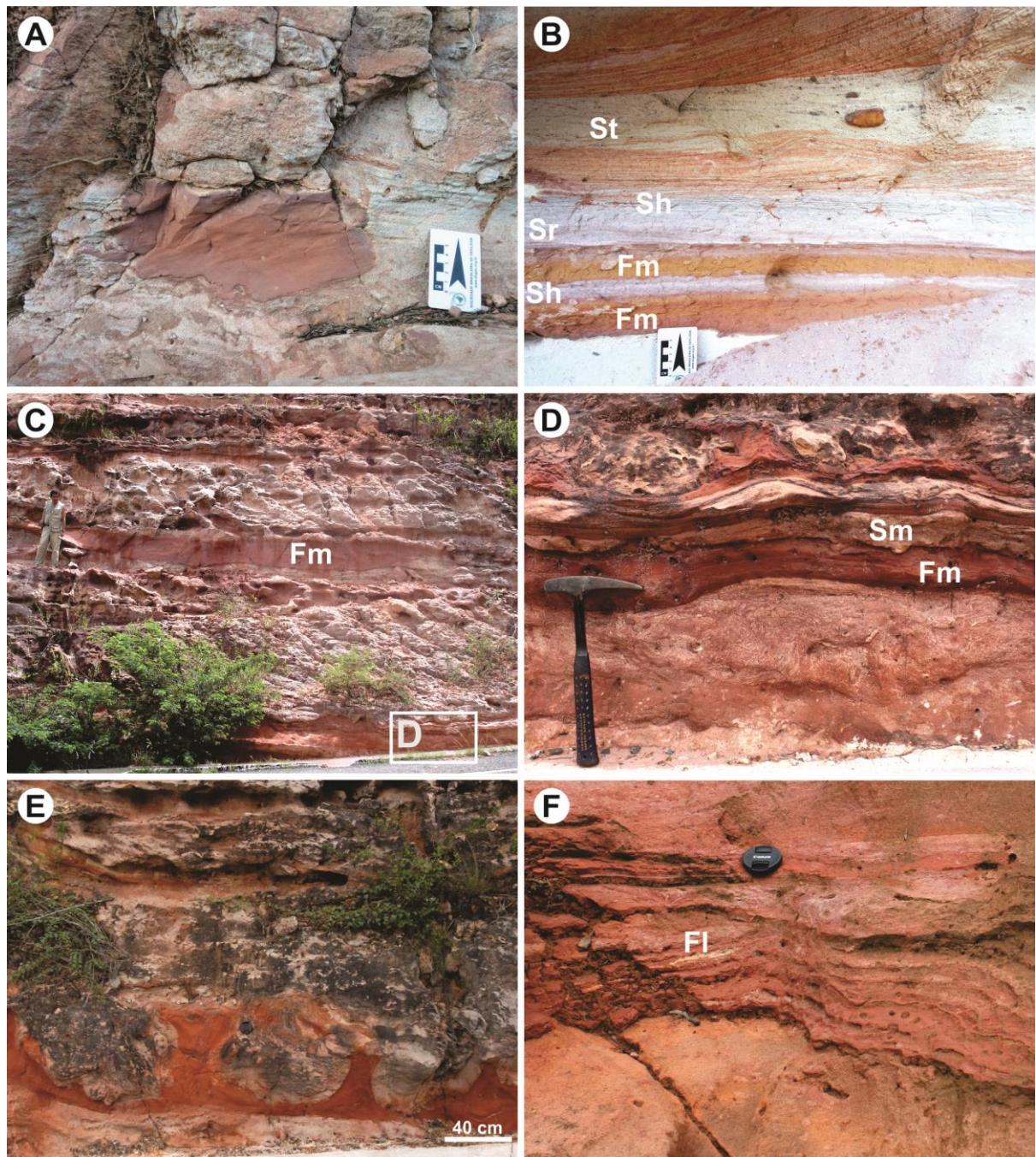


Fig. 7. Fine-grained facies and soft-sediment deformation from the Exu Formation. (A) Large intraformational mudclast in fine-grained trough cross-bedded sandstone (St). (B) Massive mudstone (Fm) interbedded with very fine-grained sandstone displaying horizontal (Sh) and ripple crosslamination (Sr), overlaid by trough cross-bedded sandstone with intraformational mudclasts in the foresets. (C) Intercalation of FA2 and FA5 deposits. Note the abandoned channel filled with massive mudstone (Fm). (D) Massive mudstone (Fm) interbedded with massive fine-grained sandstone (Sm) presenting cm- to dm-scale load structures. (E) Dm-scale attached and detached pseudonodules. (F) Horizontally laminated sandy mudstone (Fl). Hammer in B is 33 cm long. Lens caps in D and E have diameter of 58mm.

Figure 8.

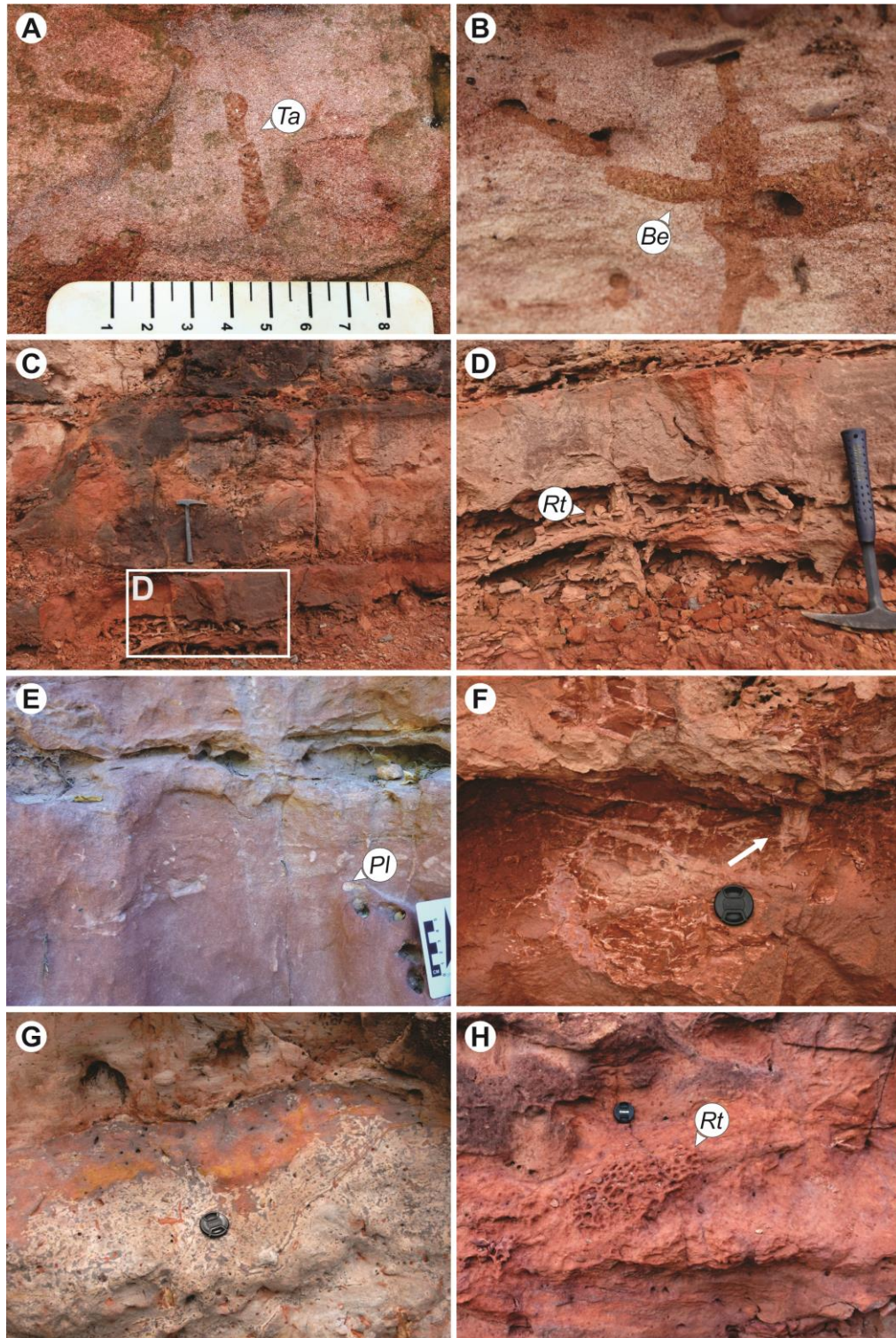


Fig. 8. Paleosols and trace fossils from Exu Formation. (A) *Taenidium barreti* in abandoned channel deposits. (B) *Beaconites capronus* in abandoned channel deposits. (C) Poorly channelized elements associated to intensely biotubated levels. (D) Abundant root traces filled by sand, organized in laterally spreading systems that indicate poorly-drained soils. (E) Simple, cylindrical burrows filled by sand (*Planolites* sp.) and root traces in floodplain deposits. (F) Bss horizon showing slickenside planes and infilled desiccation crack (arrow). (G) Intensely mottled paleosol showing purple, red and grey/white colours, developed over paleochannel and eroded by a subsequent channelized flow. (H) Rhizoliths surrounded by redox halos.

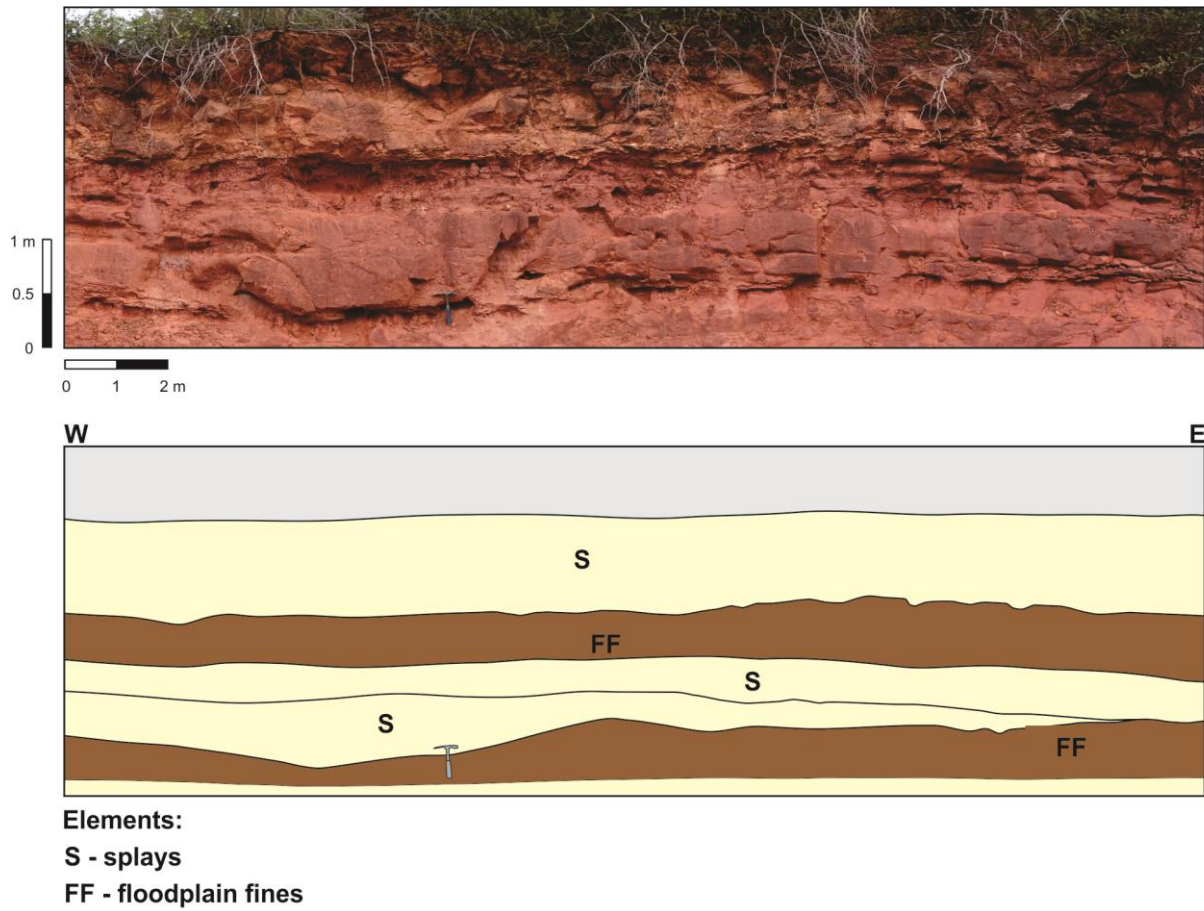
Figure 9.

Fig. 9. Outcrop and drawing interpretation of crevasse splay deposits presenting lenticular geometry (Sr, Sm and Sh facies) from FA4 interbedded with floodplain fines (Fm and Fl facies) from FA5.

Figure 10

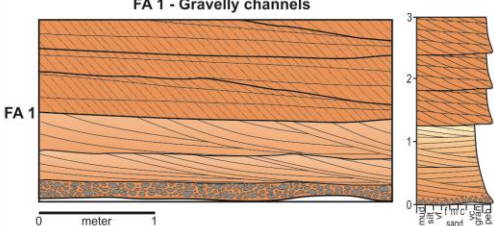
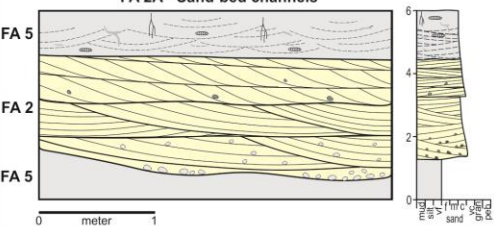
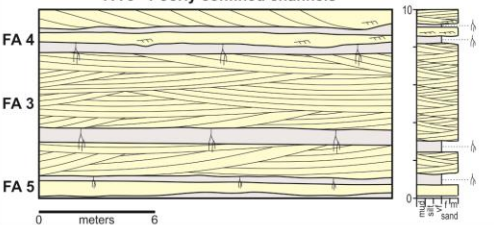
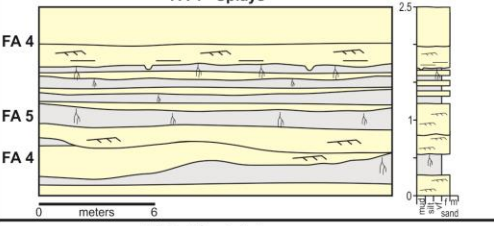
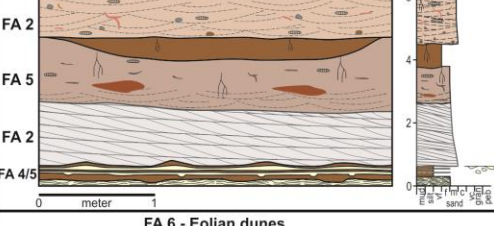
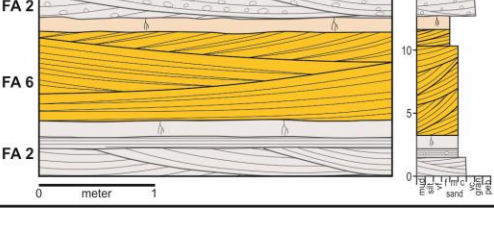
Facies associations and vertical successions		Facies	Interpretation
FA 1 - Gravelly channels 		Gt, Gp, Gm, St, Sp, Sh	Gravel and sand bars deposited in low sinuosity braided channels
FA 2A - Sand-bed channels 		Gm, Gt, St, Sp, Sh	Amalgamated sand bars and bedforms
FA 3 - Poorly confined channels 		St, Sp, Sr, Sm	Isolated sand bodies mainly filled by aggradation and lateral accretion
FA 4 - Splays 		Sr, Sh, Sm, St	Thin sandstone sheets formed by shallow, unconfined flows across the alluvial plain
FA 5 - Floodplain 		Fm, Fl, P	Pedogenized paleochannels and settling deposits from floodplain areas
FA 6 - Eolian dunes 		St, P	Sinuus crested eolian dunes

Fig. 10. Description and interpretation of the six facies associations described for the Exu Formation.

Figure 12.

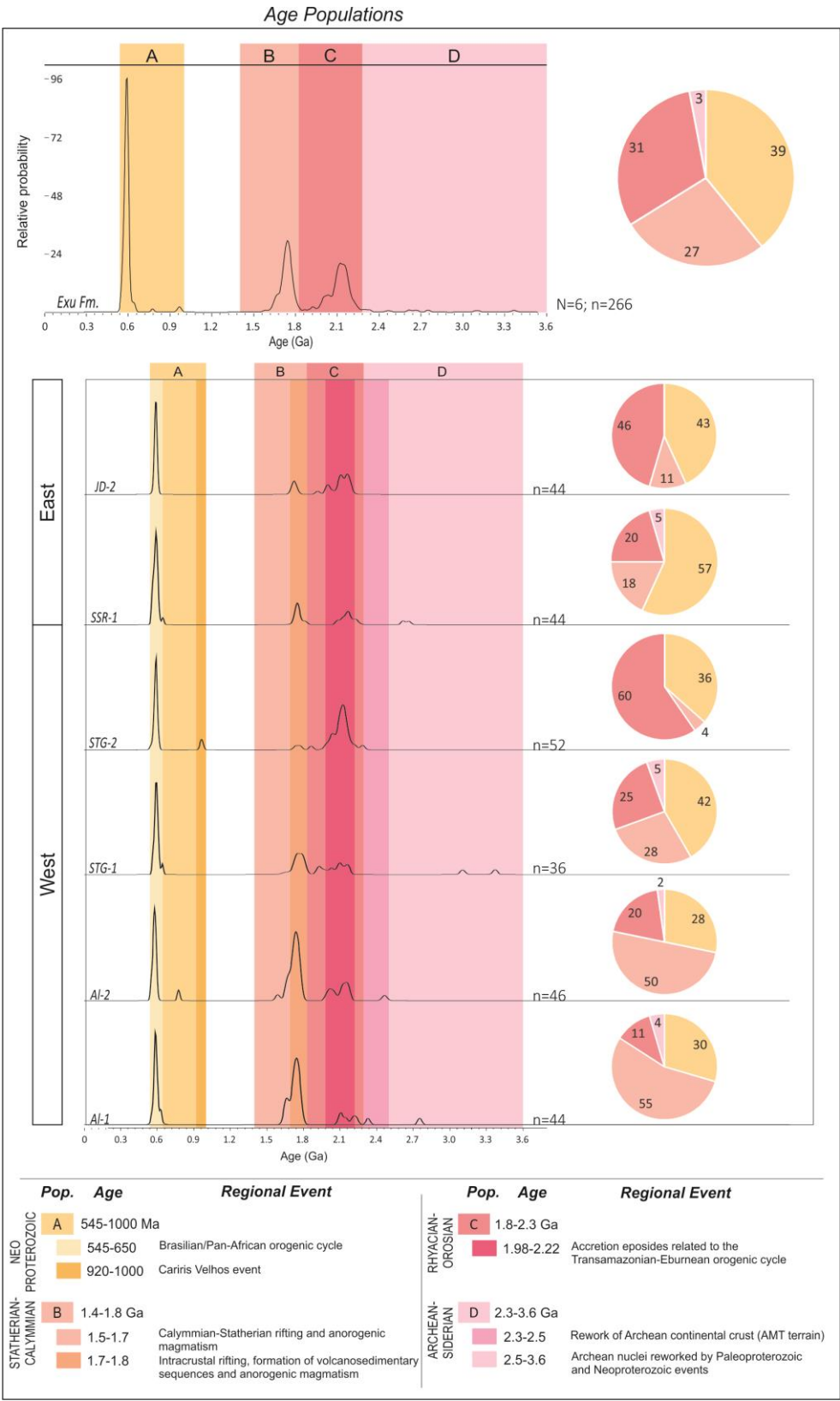


Fig. 12. Pie charts and age probability density plots presented for each sample collect along the Exu Formation, and for the total data. Colored bars indicate the main regional geologic events found in the Borborema Province. N: number of samples; n: number of detrital zircon grains analyzed in each sample. Ages according to the International Chronostratigraphic Chart 2020/03.

Figure 13.

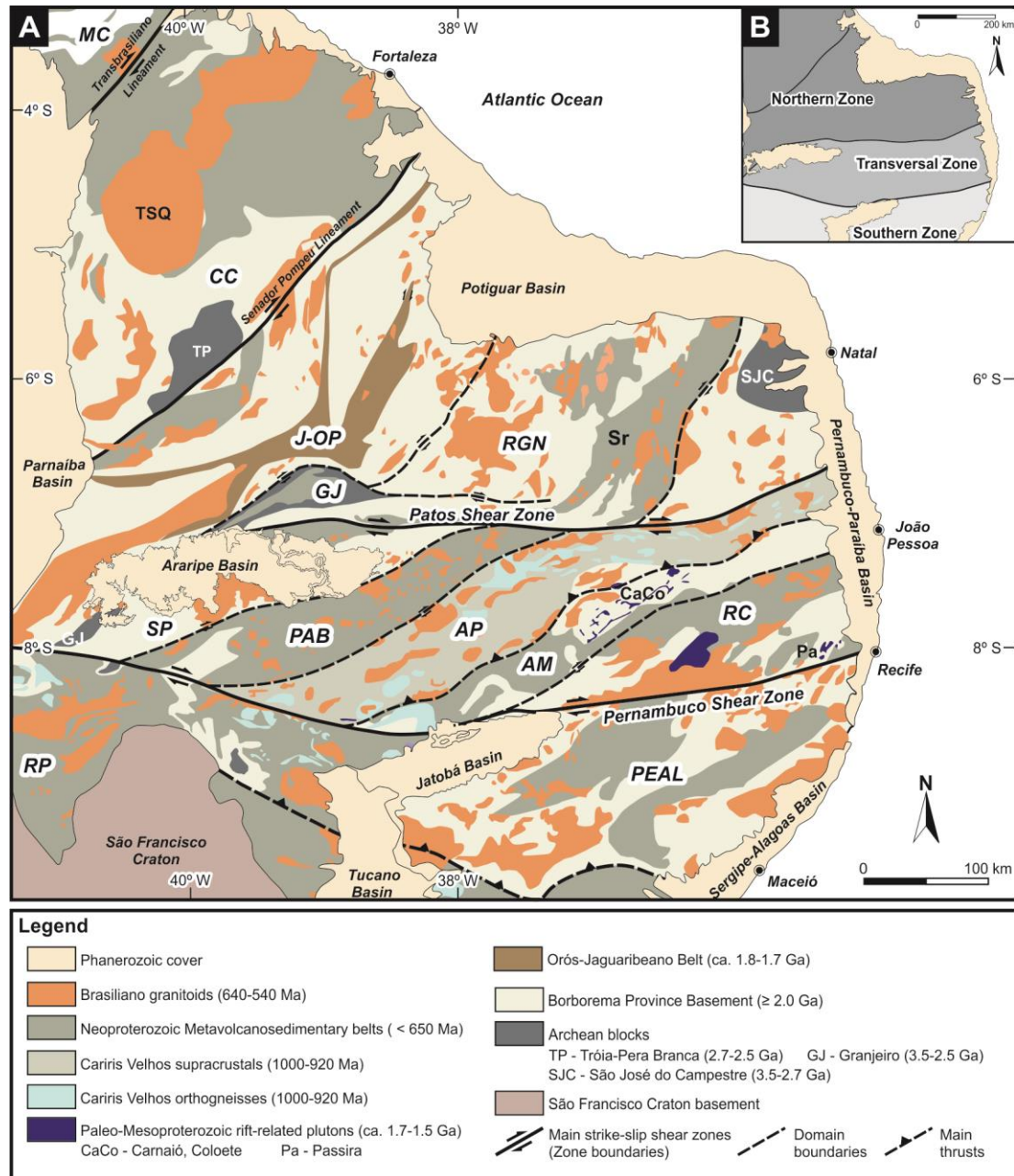


Fig. 13. Tectonic framework of the Borborema Province. (A) Domains and subdomains: RP – Riacho do Pontal, PEAL – Pernambuco – Alagoas, RC – Rio Capibaribe, AM – Alto Moxotó, AP – Alto Pajeú, PAB – Piancó-Alto Brígida, SP – São Pedro, Sr – Seridó, RGN - Rio Grande do Norte, CC - Ceará Central, MC – Medio Coreau. (B) Zones/Subprovinces.

Figure 14.

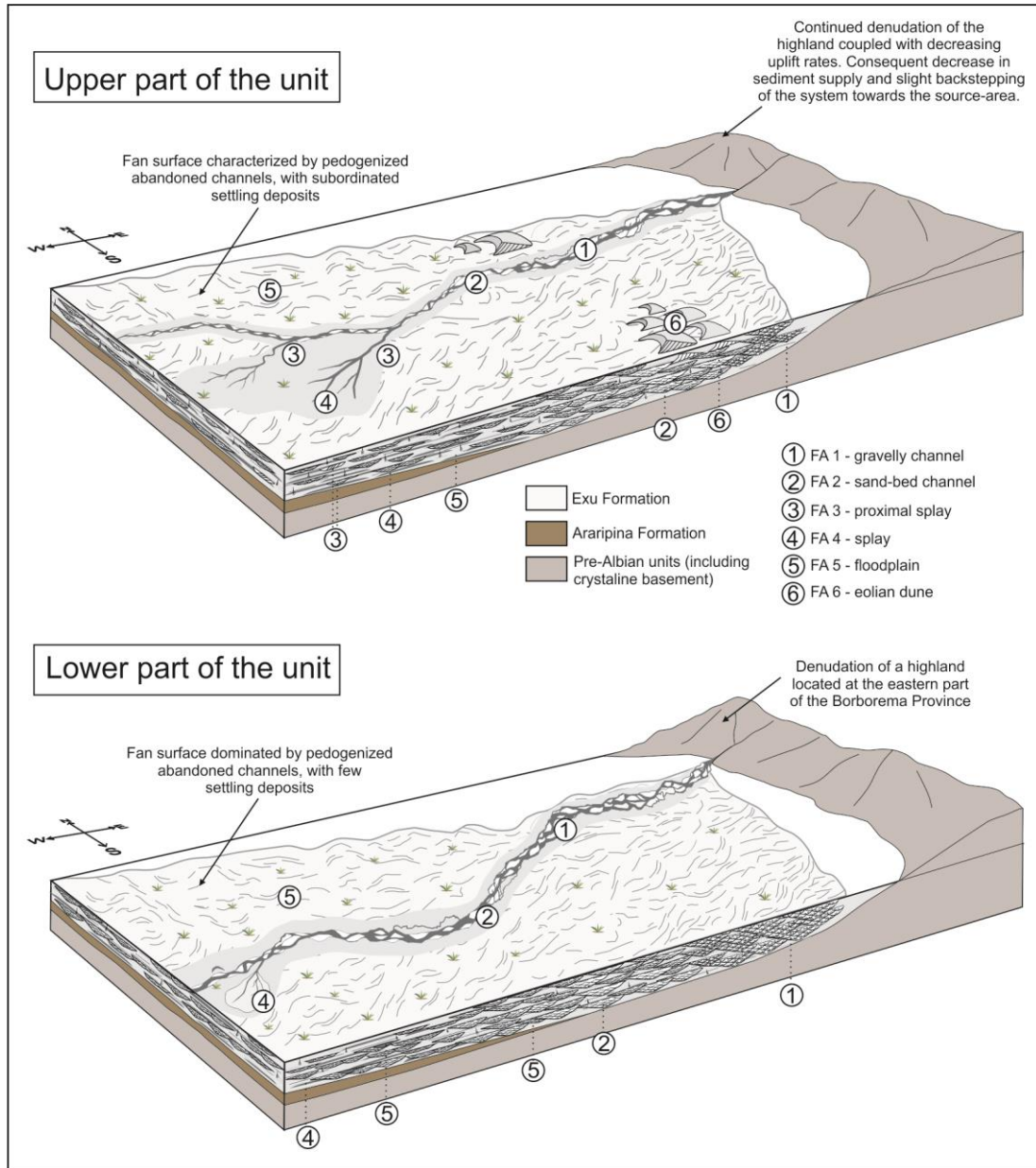


Fig. 14. Depositional model of the Exu Formation

Figure 15.

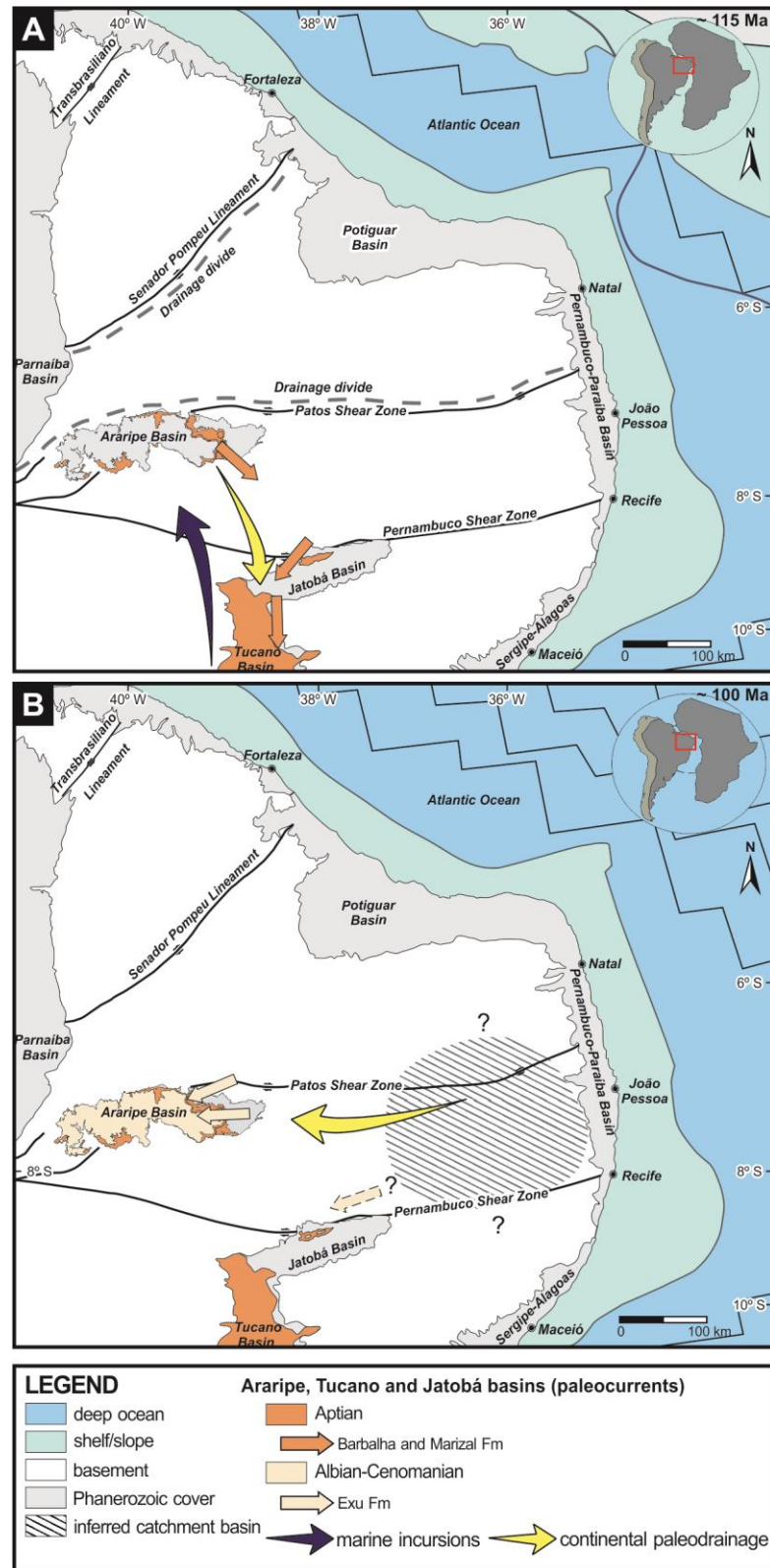


Fig. 15. Paleogeographic scenario of Northeast Brazil during Late Aptian (A) and Albian-Cenomanian (B), focusing on Araripe, Tucano and Jatobá basins. (A) Probable path of marine ingressions along the fluvial valleys, based on Assine et al. (2016) and Custódio et al. (2017); (B) Reorganization of the continental paleodrainage, after the uplift of the eastern part of the Borborema Province. Plate tectonic reconstruction based on Heine et al. (2013), and Pérez-Díaz and Eagles (2017).

III. CONSIDERAÇÕES FINAIS

1) A Formação Exu corresponde à unidade de topo Chapada do Araripe, com altitudes máximas que variam entre 800 m e 1000 m, e níveis de silcrete e ferricrete responsáveis por sustentar seu relevo. Constitui a unidade superior do Grupo Araripe e, conseqüentemente, o último ciclo deposicional da Bacia homônima. Encontra-se delimitada na base por uma discordância erosiva de expressão regional com as formações Araripina (Grupo Araripe, porção oeste da Bacia do Araripe) e Romualdo (Grupo Santana, porção leste da Bacia do Araripe) e, localmente (porção sul da bacia), em desconformidade sobre rochas do embasamento Pré-cambriano. Apresenta considerável variação de espessura, com valores menores nas porções norte e oeste e tendência de aumento à leste e na sub-bacia de Feira Nova. Depósitos de tálus que recobrem a seção basal da Formação Exu impedem a descrição desta porção da unidade nas regiões leste e central da bacia. Deste modo, apesar de espessura máxima aferida de 239 m, a partir do poço 2-AP-1-CE, as seções aflorantes da Formação Exu nas escarpas da chapada dificilmente ultrapassam os 100 m.

2) É essencialmente siliciclástica, inteiramente constituída por depósitos continentais com ampla predominância de fácies fluviais e subordinada ocorrência de fácies eólicas. De maneira geral, predominam depósitos de fácies de arenitos finos a muito grossos com estratificações cruzadas acanalada, tabular e horizontal (facies **St**, **Sp**, **Sh**) intercalados a níveis de paleosolos (**P**). Secundariamente, facies conglomeráticas (facies **Gm**, **Gp** e **Gt**) ocorrem principalmente na porção NE da área aflorante. Depósitos pelíticos (facies **Fl** e **Fm**) tendem a se concentrar nas porções central e oeste da bacia. Os perfis de paleosolos são elementos frequentes do registro sedimentar da Formação Exu. Estes apresentam características que sugerem desde boa drenagem até condições de hidromorfia. Os depósitos eólicos ocorrem localmente na porção leste da bacia e são representados por arenitos bem selecionados com estratificação cruzada acanalada de porte métrico e segregação granular nos *foresets* (facies **Stg**);

4) As fácies sedimentares descritas foram agrupadas em seis associações de fácies: depósitos de preenchimento de canais fluviais cascalhosos (FA1 – facies **Gt**, **Gp**, **Gm**, **St**, **Sp** e **Sh**), depósitos de preenchimento de canais de leito arenoso (FA2 – facies **Gm**, **Gt**, **St**, **Sp**, **Sh** e **P**), depósitos de preenchimento de canais pouco confinados (FA3 – facies **St**, **Sp**, **Sm** e **Sr**), *splays* (FA4 – fácies **St**, **Sh**, **Sr** e **Sm**), planície de inundação (FA5 – facies **P**, **Fm** e **Fl**) e dunas eólicas (FA6 – fácies **Stg** e **P**). A partir das tendências observadas de montante à jusante no registro deste sistema, como: (1) diminuição do grau de amalgamação dos depósitos de preenchimento

de canal; (2) diminuição da granulação; (3) diminuição do grau de confinamento e do tamanho dos canais, e (4) aumento da recorrência das fácies de planície de inundação (principalmente paleossolos), splay e canais pouco confinados, interpreta-se um sistema fluvial distributivo dominado por carga de fundo arenosa e com áreas intercanais compostas principalmente por depósitos de paleocanais submetidos à pedogênese. Depósitos eólicos localizados relacionam-se a áreas expostas nas quais os sedimentos fluviais foram retrabalhados pelo vento.

5) A caracterização macromorfológica de alguns perfis de paleossolo da Formação Exu permitiu classificá-los em três grupos principais: (1) perfis vermelhos, arenosos, com pouco mosqueamento e raízes, sugestivos de reações de oxidação e relativamente bem drenados; (2) perfis de colorações avermelhada, arroxeada e acinzentada, com mosqueamento e abundantes raízes organizadas em tramas horizontais, gerados sob condição de hidromorfia associada a nível alto do freático local ou à água estagnada sobre camadas impermeáveis, e (3) perfis com estruturas em forma de paralelepípedo, planos de *slickenside*, microrelevo *gilgae* e gretas de contração preenchidas por areia.

6) Os dados de paleocorrentes, adquiridos ao longo das seções-colunares descritas, coadunam com as informações apresentadas em Assine (1994) e, portanto, reafirmam a inversão de polaridade sedimentar da Bacia do Araripe, durante o Albiano-Cenomaniano. Com paleofluxo para oeste e oeste-sudoeste, concluiu-se proveniência sedimentar oriunda de áreas-fonte a leste da bacia. Estes dados indicam a mudança brusca da pendente da Bacia do Araripe no intervalo entre a deposição do Grupo Santana e da Formação Araripina e a deposição da Formação Exu, no Albiano-Cenomaniano.

7) Os dados U-Pb em grãos de zircão detrítico da Formação Exu foram organizados em quatro populações principais. População A, correspondente a 39% dos dados totais, com idades entre 545 e 1000 Ma e principal pico a 585 Ma. População B, referente a 27% dos dados totais, com idades entre 1,4 e 1,8 Ga e principal intervalo de 1,71 a 1,79 Ga. População C, que totaliza 31% dos dados, com idades de 1,8 a 2,3 Ga e principais intervalos de 1,99 a 2,05 Ga e de 2,08 a 2,18 Ga. Por último, a população D que compõe 3% dos dados e apresenta idades de 2,3 Ga, 2,46 Ga, 2,61 Ga, 2,66 Ga, 2,75 Ga, 3,09 Ga e 3,36 Ga.

8) Os conjuntos de idade obtidos sugerem áreas-fonte localizadas a leste da Bacia do Araripe, nas Zonas Norte, Central e Sul da Província Borborema, relacionadas primordialmente aos ciclos orogênicos Transamazônico e Brasileiro/Pan-Africano. A definição das possíveis áreas-

fonte se baseia em: (1) predomínio das populações A e C, em concordância com os principais ciclos geotectônicos atuantes na Província Borborema; (2) intervalos de idade secundários (nas populações B e D) relacionados a áreas-fonte restritas à região a leste da Bacia do Araripe, e (3) indicação de sequências metassedimentares como principais fontes para os sedimentos da Formação Exu, principalmente no caso de grãos da população B. Deste modo, define-se a área de captação do sistema de drenagens da Formação Exu como uma região de topografia elevada que incluía desde o limite entre os domínios Sul e Central da Província Borborema (a sul da Zona de Cisalhamento de Pernambuco) até, possivelmente, a região leste do Domínio Rio Grande do Norte (a norte do Lineamento de Patos).

10) Os dados adquiridos permitiram constatar que a inversão da pendente da bacia e a instalação do sistema fluvial distributivo foram condicionadas pelo soerguimento de uma nova área-fonte, à leste, e pela consequente geração de suprimento sedimentar para a bacia. Aventa-se que o padrão de empilhamento observado para a Formação Exu possa ter sido também influenciado por fatores alogênicos. Na ausência de controle eustático, sugere-se que a redução das taxas de soerguimento na área-fonte possa ter influenciado a sutil retração do sistema distributivo em direção à bacia de captação, gerando um empilhamento caracterizado por fácies da zona média/distal sobre fácies das zonas proximal à média.

APÊNDICE – Dados geocronológicos

Table 1. U-Pb Geochronological Analyses for DZ Grains - Sample AL-1

Analysis	U ($\mu\text{g g}^{-1}$) a	Th/U	$^{206}\text{Pb}/^{204}\text{Pb}$	$^{207}\text{Pb}/^{206}\text{Pb}$ b	2s (%)	Isotope Ratios					Ages						
						$^{207}\text{Pb}/^{235}\text{U}$	2s (%)	$^{206}\text{Pb}/^{238}\text{U}$	2s (%)	Rho	$^{207}\text{Pb}/^{206}\text{Pb}$	2s	$^{206}\text{Pb}/^{238}\text{U}$	2s	$^{207}\text{Pb}/^{235}\text{U}$	2s	Conc
						Data for Wetherill plot c						abs		abs		abs	(%)
1.sMPABC167	50.3640	0.0835	4385.6716	0.0630	1.3022	0.8208	2.0162	0.0945	1.5393	0.7635	707.2177	27.6977	582.3417	8.4943	608.5169	9.2173	95.4935
1.sMPABC168	118.3849	0.0860	56418.2808	0.1055	0.9957	4.4923	1.7393	0.3090	1.4261	0.8199	1722.1746	18.2916	1735.6414	21.5614	1729.5438	14.5207	99.9341
1.sMPABC169	27.4567	0.1002	2278.1605	0.0596	1.6281	0.7821	2.2921	0.0952	1.6134	0.7039	588.3554	35.3179	586.2689	8.9611	586.6973	10.2049	99.7209
1.sMPABC170	42.8849	0.1146	20193.2832	0.1048	1.0210	4.4386	1.7768	0.3072	1.4542	0.8184	1710.8080	18.7825	1726.7762	21.8885	1719.5702	14.8029	100.0015
1.sMPABC171	105.0313	0.0628	384.6461	0.1013	1.0036	3.9699	1.7526	0.2843	1.4368	0.8198	1647.7410	18.6115	1612.8919	20.3662	1628.0708	14.2845	98.6650
1.sMPABC172	196.6412	0.0933	387.5324	0.1336	0.9802	7.1336	1.7428	0.3871	1.4410	0.8268	2146.3858	17.1261	2109.5087	25.7799	2128.2427	15.6197	98.6668
1.sMPABC173	27.8812	0.1351	14105.5030	0.1082	1.0442	4.7689	1.8008	0.3196	1.4672	0.8147	1769.6654	19.0681	1787.7879	22.7648	1779.4416	15.2011	100.0447
1.sMPABC174	105.9538	0.0820	10.9270	0.0601	1.0814	0.7855	1.8090	0.0948	1.4502	0.8017	607.5366	23.3826	583.7105	8.0204	588.6076	8.0649	98.9627
~~1.sMPABC175~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~
1.sMPABC176	69.4042	0.1164	29458.1005	0.1015	1.0147	4.0009	1.7693	0.2859	1.4495	0.8192	1651.9109	18.8067	1620.8004	20.6356	1634.3856	14.4450	98.7650
~~1.sMPABC177~~	~~268.9160~~	~~0.0849~~	~~106236.1869~~	~~0.1185~~	~~0.9871~~	~~3.7239~~	~~1.7288~~	~~0.2279~~	~~1.4193~~	~~0.8210~~	~~1934.1819~~	~~17.6702~~	~~1323.2747~~	~~16.8552~~	~~1576.5191~~	~~13.9015~~	~~83.5868~~
1.sMPABC178	445.1195	0.0404	40438.5597	0.0606	1.0074	0.8564	1.7400	0.1026	1.4187	0.8153	623.2864	21.7270	629.4876	8.4330	628.1390	8.1367	99.9968
1.sMPABC179	83.2345	0.0814	6789.5208	0.0592	1.1323	0.7689	1.8463	0.0942	1.4583	0.7898	573.3567	24.6260	580.6154	8.0242	579.1400	8.1329	100.0503
1.sMPABC180	254.0006	0.0840	357.5042	0.0594	3.5147	0.7828	4.3399	0.0956	2.5459	0.5866	582.1161	76.3256	588.3505	14.1940	587.0688	19.4189	100.0117
1.sMPABC187	8.4914	0.0892	678.5590	0.0602	3.5038	0.7533	4.0820	0.0907	2.0942	0.5130	611.4887	75.7148	559.8037	11.1305	570.1222	17.8566	97.9915
1.sMPABC188	38.6725	0.0991	252.1538	0.1078	1.0856	4.7326	1.8242	0.3185	1.4660	0.8036	1762.0525	19.8442	1782.3551	22.6855	1773.0236	15.3791	100.1025
1.sMPABC189	45.9468	0.1204	1201.2709	0.1061	1.0277	4.4361	1.7793	0.3034	1.4525	0.8163	1732.7635	18.8542	1707.9097	21.6538	1719.1036	14.8224	98.9346
1.sMPABC190	33.3164	0.0866	16385.6234	0.1068	1.0483	4.6360	1.7956	0.3147	1.4579	0.8119	1746.1948	19.1994	1763.8489	22.3557	1755.7823	15.0810	100.0377
~~1.sMPABC191~~	~~139.2620~~	~~0.0967~~	~~90078.0827~~	~~0.1305~~	~~0.9959~~	~~6.0972~~	~~1.7393~~	~~0.2388~~	~~1.4260~~	~~0.8199~~	~~2105.2414~~	~~17.4791~~	~~1880.6699~~	~~23.1195~~	~~1989.8428~~	~~15.2639~~	~~94.0871~~
1.sMPABC192	100.9549	0.0702	2702.3230	0.1381	0.9993	7.8219	1.7420	0.4108	1.4269	0.8191	2203.5153	17.3491	2218.5282	26.6385	2210.7331	15.7862	99.8893
1.sMPABC193	26.1673	0.1005	12624.0633	0.1063	1.0443	4.5476	1.8049	0.3103	1.4721	0.8156	1736.7366	19.1491	1742.2077	22.3314	1739.7227	15.1061	99.7238
1.sMPABC194	49.6922	0.0996	477.8129	0.1020	1.0493	3.9881	1.8102	0.2837	1.4750	0.8148	1660.2865	19.4280	1609.7461	20.8728	1631.7743	14.7710	98.2481
1.sMPABC195	55.7041	0.0765	26027.8184	0.1047	1.0221	4.4045	1.7691	0.3051	1.4440	0.8162	1708.8759	18.8068	1716.7009	21.6245	1713.1788	14.7172	99.7894
1.sMPABC196	78.6793	0.0355	4.4762	0.0578	11.3213	0.7781	13.2521	0.0977	6.8882	0.5198	520.9643	248.4137	600.8854	39.2609	584.4223	60.2914	102.6070
1.sMPABC197	46.2759	0.1079	18.5347	0.1047	2.6468	4.4815	3.1334	0.3105	1.6771	0.5352	1708.5220	48.7050	1743.3014	25.4626	1727.5501	26.2993	100.4919
1.sMPABC198	54.1804	0.0868	26648.0490	0.1072	1.0258	4.6362	1.7764	0.3136	1.4503	0.8164	1752.8654	18.7724	1758.2966	22.1774	1755.8162	14.9182	99.7205
1.sMPABC199	24.5906	0.0938	10696.1125	0.1023	1.0951	4.1001	1.8640	0.2908	1.5084	0.8092	1665.7237	20.2621	1645.3765	21.7630	1654.3323	15.2991	99.0516
~~1.sMPABC200~~	~~73.9060~~	~~0.0970~~	~~680.5490~~	~~0.1196~~	~~1.0120~~	~~3.8192~~	~~1.7597~~	~~0.2317~~	~~1.4396~~	~~0.8181~~	~~1949.8058~~	~~18.0820~~	~~1343.1936~~	~~17.3294~~	~~1596.8037~~	~~14.2282~~	~~83.7650~~
1.sMPABC207	34.4814	0.0687	16401.2245	0.1061	1.0560	4.4837	1.8100	0.3066	1.4701	0.8122	1732.7635	19.3731	1723.9846	22.0965	1727.9535	15.1101	99.3538

1.sMPABC208	144.6097	0.0756	188.1233	0.1053	1.0518	4.4514	1.7737	0.3065	1.4282	0.8052	1719.9120	19.3278	1723.6356	21.4623	1721.9548	14.7848	99.6808
1.sMPABC209	100.2821	0.1854	22.5238	0.0595	3.5369	0.7749	4.3814	0.0945	2.5859	0.5902	583.9007	76.7845	582.2227	14.2735	582.5652	19.4934	99.7363
1.sMPABC210	48.8375	0.0857	21997.7276	0.1052	1.0360	4.2459	1.7879	0.2927	1.4571	0.8150	1717.9878	19.0418	1654.9590	21.1291	1682.9374	14.7703	97.9305
1.sMPABC211	187.9420	0.0409	157.1336	0.1483	0.9978	8.9687	1.7389	0.4385	1.4242	0.8190	2326.7625	17.0959	2344.0569	27.8430	2334.8231	15.9940	99.9232
1.sMPABC212	19.0779	0.1033	1561.9057	0.0592	1.8246	0.7717	2.4861	0.0946	1.6886	0.6792	574.0917	39.6773	582.4608	9.3206	580.7555	10.9893	100.0886
1.sMPABC213	1649.9853	0.2000	13.6542	0.1502	3.5396	0.2995	35.7163	0.0145	35.5405	0.9951	2348.0266	60.5131	92.5584	32.4042	265.9819	86.4792	34.7575
1.sMPABC214	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1.sMPABC215	40.9427	0.0735	20441.9111	0.1073	1.0437	4.7064	1.7856	0.3181	1.4488	0.8114	1754.2300	19.0962	1780.3783	22.3972	1768.3756	15.0362	100.2550
1.sMPABC216	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1.sMPABC217	-0.0438	-0.0021	—	—	—	—	—	—	—	—	—	—	4130.0435	—	—	—	—
1.sMPABC218	99.4679	0.0711	44406.3981	0.1028	1.0218	4.2083	1.7623	0.2970	1.4359	0.8148	1674.5623	18.8839	1676.4929	21.0591	1675.6356	14.5327	99.6398
1.sMPABC219	185.5458	0.1067	16085.3644	0.0601	1.0488	0.8172	1.7766	0.0987	1.4340	0.8072	606.0970	22.6837	606.5804	8.2275	606.4783	8.0973	99.8052
1.sMPABC220	70.8514	0.1045	105.1902	0.1403	1.0491	7.8371	1.7897	0.4050	1.4499	0.8101	2231.4495	18.1598	2192.0601	26.7965	2212.4817	16.2253	98.6176
1.sMPABC227	54.7446	0.1065	27.3411	0.1115	2.1639	4.3547	2.7108	0.2832	1.6327	0.6023	1824.1843	39.2524	1607.6141	23.0812	1703.7885	22.5895	93.9580
1.sMPABC228	140.3250	0.0918	43.2902	0.0596	1.0731	0.7997	1.7911	0.0973	1.4341	0.8007	590.5385	23.2705	598.2735	8.1202	596.6615	8.0659	100.0608
1.sMPABC229	1343.1435	0.5664	22.1519	0.1376	2.1256	0.7043	7.4254	0.0371	7.1146	0.9582	2196.7758	36.9312	235.0155	16.2738	541.3279	31.4454	43.3203
1.sMPABC230	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1.sMPABC231	53.1914	0.0905	172.2972	0.1072	1.0445	4.5801	1.7964	0.3098	1.4615	0.8136	1752.8654	19.1137	1739.6217	22.1423	1745.6444	15.0540	99.2368
1.sMPABC232	25.7356	0.1270	12028.5823	0.1059	1.0959	4.4058	1.8575	0.3019	1.4998	0.8074	1729.1266	20.1140	1700.6078	22.2758	1713.4249	15.4588	98.8386
1.sMPABC233	228.9203	0.1131	165544.3395	0.1305	1.0268	6.8167	1.7821	0.3788	1.4565	0.8173	2104.7035	18.0235	2070.8813	25.6515	2087.8900	15.8821	98.7355
1.sMPABC234	808.7214	0.2826	235.5386	0.1347	1.0125	3.1380	1.7477	0.1690	1.4245	0.8151	2159.7908	17.6634	1006.5588	13.1692	1442.0574	13.5122	69.5127
1.sMPABC235	109.7635	0.1077	9215.1453	0.0600	1.1161	0.7914	1.8366	0.0956	1.4586	0.7942	604.6561	24.1458	588.6478	8.1323	591.9557	8.2233	99.2345
1.sMPABC236	20.1926	0.0800	248.5367	0.1081	1.1934	4.6409	2.0039	0.3114	1.6097	0.8033	1767.4702	21.8001	1747.5751	24.4891	1756.6537	16.8475	99.0643
1.sMPABC237	36.9345	0.0957	17891.6392	0.1073	1.0622	4.5662	1.8113	0.3086	1.4672	0.8100	1754.4005	19.4350	1733.7498	22.1623	1743.1298	15.1719	99.0446
1.sMPABC238	181.3385	0.0534	132666.5325	0.1301	1.0149	6.8963	1.7489	0.3846	1.4243	0.8144	2098.7733	17.8265	2097.5683	25.3586	2098.1766	15.6080	99.5178
1.sMPABC239	246.2907	0.0748	2422.4897	0.1909	1.0160	14.0929	1.7489	0.5353	1.4235	0.8139	2750.2752	16.6974	2763.7661	31.8536	2755.9760	16.7063	99.7875
1.sMPABC240	60.6958	0.0920	30887.5630	0.1085	1.0415	4.7970	1.7749	0.3207	1.4372	0.8097	1774.3828	19.0077	1792.9203	22.3540	1784.3688	14.9958	100.0543

Concordance calculated as (206Pb-238U age/207Pb-206Pb age)*100

Table 2. U-Pb Geochronological Analyses for DZ Grains - Sample AL-2

Analysis	U (µg g ⁻¹) a	Th/U	206Pb/204Pb	207Pb/206Pb b	2s (%)	Isotope ratios					Ages						
						207Pb/235U	2s (%)	206Pb/238U	2s (%)	Rho	207Pb/206Pb	2s	206Pb/238U	2s	207Pb/235U	2s	Conc
						Data for Wetherill plot c						abs		abs		abs	(%)
1.sSMPABC007	129.6435	0.1167	226.5923	0.0605	3.4713	0.7954	4.3163	0.0954	2.5652	0.5943	621.2573	74.8901	587.1405	14.3861	594.2025	19.5820	98.7730
1.sSMPABC008	38.2495	0.1097	16915.5132	0.1066	1.0226	4.5737	1.7945	0.3112	1.4746	0.8217	1741.9031	18.7390	1746.6569	22.5670	1744.4943	15.0574	100.0458
1.sSMPABC009	233.2340	0.0578	140481.5445	0.1241	0.9832	6.2293	1.7408	0.3641	1.4366	0.8252	2015.8509	17.4327	2001.4996	24.7291	2008.5712	15.3417	99.5651
1.sSMPABC010	197.4509	0.0788	251.4897	0.1054	0.9868	4.4260	1.7409	0.3046	1.4343	0.8238	1721.1290	18.1301	1714.0133	21.5902	1717.2186	14.5175	99.7359
1.sSMPABC011	78.7238	0.0684	56315.6308	0.1349	0.9934	7.3983	1.7542	0.3978	1.4458	0.8242	2162.5916	17.3248	2158.8522	26.5414	2160.7695	15.8097	99.8259
1.sSMPABC012	347.8421	0.0450	67.2544	0.1036	0.9886	4.2452	1.7389	0.2971	1.4305	0.8227	1690.4706	18.2335	1676.6735	21.1227	1682.8114	14.3864	99.5587
1.sSMPABC013	89.6402	0.1137	307.2661	0.1079	1.0105	4.6795	1.7587	0.3146	1.4394	0.8185	1763.7477	18.4663	1763.4329	22.2129	1763.5770	14.8159	99.9133
1.sSMPABC014	87.0716	0.1785	39523.2076	0.1080	0.9997	4.6945	1.7557	0.3152	1.4433	0.8221	1766.4559	18.2637	1766.0855	22.3022	1766.2552	14.7992	99.9118
1.sSMPABC015	50.4484	0.0690	48.9108	0.1065	1.0159	4.4720	1.7788	0.3047	1.4602	0.8209	1739.5094	18.6208	1714.5084	21.9871	1725.7948	14.8639	99.2687
1.sSMPABC016	78.8671	0.0770	55223.1806	0.1337	0.9948	7.2416	1.7574	0.3928	1.4488	0.8244	2147.1247	17.3783	2135.9380	26.3570	2141.6452	15.7977	99.6485
1.sSMPABC017	83.3670	0.0854	59.5055	0.1054	1.0056	4.4587	1.7647	0.3068	1.4501	0.8218	1721.4776	18.4745	1724.8470	21.9501	1723.3253	14.7369	100.0106
1.sSMPABC018	40.0780	0.1085	29.3579	0.1068	1.0397	4.5834	1.7984	0.3114	1.4674	0.8159	1744.8228	19.0455	1747.4451	22.4655	1746.2515	15.0964	99.9902
1.sSMPABC019	51.4880	0.1160	84.8680	0.1077	1.0120	4.6709	1.7704	0.3145	1.4527	0.8205	1761.0345	18.5000	1762.8924	22.4117	1762.0423	14.9105	99.9697
1.sSMPABC020	41.2774	0.0859	36.2837	0.1083	1.0344	4.5637	1.8016	0.3057	1.4750	0.8188	1770.6776	18.8865	1719.4077	22.2661	1742.6606	15.1114	98.5883
~~1.sSMPABC027~~	~~513.9605~~	~~0.0436~~	~~67.4663~~	~~0.1544~~	~~1.1972~~	~~4.6850~~	~~1.9170~~	~~0.2201~~	~~1.4972~~	~~0.7810~~	~~2395.3982~~	~~20.3676~~	~~1282.1451~~	~~17.4027~~	~~1764.5715~~	~~16.1633~~	~~72.5988~~
1.sSMPABC028	78.8195	0.0968	57.9396	0.0596	3.5457	0.7678	4.4068	0.0935	2.6169	0.5938	588.2850	76.9177	576.0451	14.4109	578.5269	19.6014	99.5331
1.sSMPABC029	80.8314	0.1128	873.0280	0.1314	0.9967	6.9255	1.7529	0.3822	1.4420	0.8226	2117.1593	17.4709	2086.4065	25.7170	2101.9293	15.6696	99.1774
~~1.sSMPABC030~~	~~456.4076~~	~~0.1310~~	~~119.7086~~	~~0.0696~~	~~1.0063~~	~~0.8111~~	~~1.7419~~	~~0.0846~~	~~1.4218~~	~~0.8162~~	~~915.2927~~	~~20.7049~~	~~523.2174~~	~~7.1376~~	~~603.0506~~	~~7.9433~~	~~86.7433~~
1.sSMPABC031	94.5895	0.0468	40967.6629	0.1057	1.0026	4.4793	1.7557	0.3073	1.4412	0.8209	1726.8708	18.4078	1727.3673	21.8426	1727.1428	14.6735	99.9352
~~1.sSMPABC032~~	~~675.8428~~	~~0.1112~~	~~648.0978~~	~~0.1836~~	~~0.9881~~	~~5.5043~~	~~1.7303~~	~~0.2174~~	~~1.4204~~	~~0.8209~~	~~2685.6375~~	~~16.3366~~	~~1268.3127~~	~~16.3482~~	~~1901.2620~~	~~14.9734~~	~~66.6494~~
1.sSMPABC033	62.6325	0.1669	27957.6528	0.1072	1.0354	4.6165	1.7818	0.3123	1.4500	0.8138	1752.3533	18.9495	1752.1718	22.2518	1752.2546	14.9753	99.9170
~~1.sSMPABC034~~	~~209.9732~~	~~0.0418~~	~~124506.3335~~	~~0.1288~~	~~0.9936~~	~~6.1325~~	~~1.7395~~	~~0.3453~~	~~1.4278~~	~~0.8208~~	~~2081.9309~~	~~17.4859~~	~~1911.9555~~	~~23.6314~~	~~1994.8871~~	~~15.2967~~	~~95.7624~~
1.sSMPABC035	65.4249	0.0998	7.4463	0.0592	1.1822	0.7604	1.9146	0.0931	1.5060	0.7866	574.8263	25.7049	574.0955	8.2627	574.2429	8.4229	99.9365
1.sSMPABC036	36.9910	0.1790	15.1265	0.0606	1.4029	0.7824	2.1315	0.0937	1.6048	0.7529	624.7105	30.2481	577.1082	8.8491	586.8488	9.5346	98.3022
1.sSMPABC037	80.3737	0.2063	5.8548	0.0607	1.1045	0.7443	1.8336	0.0890	1.4636	0.7982	627.1996	23.8052	549.5869	7.7013	564.9298	7.9669	97.2476
1.sSMPABC038	39.6816	0.0805	17188.5382	0.1058	1.0401	4.4798	1.7988	0.3072	1.4677	0.8159	1727.5652	19.0936	1726.9720	22.2399	1727.2403	15.0374	99.9067
1.sSMPABC039	60.5375	0.0750	56.8659	0.1608	1.2605	10.3950	1.9445	0.4688	1.4806	0.7614	2464.1363	21.2950	2478.4656	30.4964	2470.6002	18.1700	100.2288
~~1.sSMPABC040~~	~~94.4743~~	~~0.0319~~	~~89.1449~~	~~0.1321~~	~~0.9995~~	~~6.1383~~	~~1.7517~~	~~0.3371~~	~~1.4385~~	~~0.8212~~	~~2125.5373~~	~~17.5039~~	~~1872.7537~~	~~23.3883~~	~~1995.7030~~	~~15.4070~~	~~93.7601~~
1.sSMPABC047	80.4494	0.0789	33944.5737	0.1047	1.0219	4.3637	1.7701	0.3023	1.4453	0.8165	1709.2274	18.8024	1702.4671	21.6290	1705.4998	14.7232	99.7450
~~1.sSMPABC048~~	~~895.3336~~	~~0.5593~~	~~38.3283~~	~~0.1584~~	~~1.5369~~	~~1.6873~~	~~3.1790~~	~~0.0773~~	~~2.7828~~	~~0.8754~~	~~2438.3030~~	~~26.0308~~	~~479.8153~~	~~12.8568~~	~~1003.7337~~	~~20.4569~~	~~47.7723~~

1.sSMPABC049	176.0121	0.0621	76441.3265	0.1058	1.0016	4.4916	1.7477	0.3078	1.4322	0.8195	1728.7798	18.3843	1729.9360	21.7349	1729.4128	14.6141	99.9524
~~1.sSMPABC050~~	~~188.4305~~	~~0.0517~~	~~39.9630~~	~~0.1023~~	~~1.0269~~	~~1.4345~~	~~1.7668~~	~~0.1017~~	~~1.4377~~	~~0.8137~~	~~1665.3619~~	~~19.0004~~	~~624.6526~~	~~8.5498~~	~~903.4224~~	~~10.6175~~	~~69.1035~~
1.sSMPABC051	90.3054	0.0751	36171.4243	0.1023	1.0266	4.1425	1.8015	0.2937	1.4804	0.8217	1665.9046	18.9935	1660.2192	21.6712	1662.7310	14.8373	99.7727
1.sSMPABC052	49.2837	0.0849	46.7019	0.1037	1.0319	4.2730	1.7892	0.2989	1.4617	0.8169	1691.1952	19.0307	1685.7304	21.6852	1688.1671	14.8243	99.7788
1.sSMPABC053	131.6398	0.0409	94662.3531	0.1356	1.0028	7.4371	1.7515	0.3977	1.4360	0.8199	2171.9995	17.4706	2158.5287	26.3574	2165.4409	15.7949	99.5955
1.sSMPABC054	280.6788	0.0939	116.3281	0.1225	1.1104	6.1252	1.8181	0.3628	1.4396	0.7918	1992.2864	19.7435	1995.3411	24.7163	1993.8410	15.9907	99.9924
1.sSMPABC055	76.0343	0.1180	34405.9770	0.1082	1.0259	4.6799	1.7867	0.3137	1.4629	0.8187	1769.3279	18.7348	1758.8620	22.5243	1763.6510	15.0541	99.6501
1.sSMPABC056	186.4778	0.0755	71.9481	0.0601	1.0477	0.7941	1.7838	0.0958	1.4437	0.8093	608.2559	22.6529	589.6167	8.1250	593.4757	8.0396	99.3111
1.sSMPABC057	46.1826	0.0956	80.9694	0.1026	1.0531	4.0798	1.8159	0.2885	1.4793	0.8146	1670.7807	19.4726	1634.2056	21.3571	1650.2679	14.9119	98.9511
1.sSMPABC058	39.6282	0.1349	2915.3455	0.0591	1.3530	0.7608	2.0707	0.0933	1.5675	0.7570	571.8858	29.4313	575.1590	8.6156	574.4983	9.1155	100.0771
1.sSMPABC059	145.1421	0.0907	42.4865	0.0597	1.0819	0.7901	1.8197	0.0960	1.4631	0.8040	591.4423	23.4578	591.2080	8.2557	591.2564	8.1793	99.9531
1.sSMPABC060	34.7788	0.0916	21.5376	0.0599	3.5894	0.7686	4.4566	0.0930	2.6414	0.5927	600.2980	77.7092	573.5046	14.4847	578.9342	19.8353	99.0244
1.sSMPABC067	486.1639	0.0906	239.0524	0.1019	1.0243	4.1395	1.7532	0.2946	1.4229	0.8116	1659.2578	18.9674	1664.4115	20.8746	1662.1340	14.4350	100.0606
1.sSMPABC068	50.8855	0.0815	21893.9925	0.1055	1.0518	4.4498	1.8271	0.3058	1.4940	0.8177	1723.5676	19.3188	1720.1002	22.5610	1721.6648	15.2567	99.8315
1.sSMPABC069	559.8216	0.1125	289.5822	0.0981	1.0199	3.7127	1.7519	0.2745	1.4244	0.8131	1588.1126	19.0608	1563.6934	19.7780	1574.1146	14.1059	99.2640
1.sSMPABC070	84.4568	0.0806	37326.4622	0.1066	1.0228	4.5708	1.7687	0.3111	1.4430	0.8158	1741.5592	18.7433	1745.9673	22.0758	1743.9623	14.8383	100.0368
1.sSMPABC071	123.1640	0.0252	13630.6867	0.0650	1.0776	1.1446	1.8133	0.1278	1.4584	0.8043	773.0412	22.6765	775.2476	10.6428	774.6792	9.8653	100.0258
~~1.sSMPABC072~~	~~301.8260~~	~~0.0704~~	~~109.3289~~	~~0.1172~~	~~1.1302~~	~~3.8698~~	~~1.8397~~	~~0.2395~~	~~1.4516~~	~~0.7891~~	~~1914.0804~~	~~20.2794~~	~~1383.8847~~	~~18.0751~~	~~1607.4079~~	~~14.9473~~	~~86.0270~~
1.sSMPABC073	76.7320	0.0724	17.3163	0.0594	1.1608	0.7795	1.8768	0.0951	1.4748	0.7858	583.2498	25.2038	585.7251	8.2478	585.2178	8.3732	100.0483
1.sSMPABC074	84.9778	0.0763	1772.2729	0.1261	1.0311	6.4708	1.7821	0.3722	1.4536	0.8156	2044.0148	18.2235	2039.8815	25.4315	2041.9375	15.7914	99.8158
1.sSMPABC075	118.9190	0.1643	8756.9130	0.0593	1.1139	0.7616	1.8378	0.0932	1.4617	0.7954	576.2944	24.2137	574.5682	8.0259	574.9166	8.0907	99.9016
1.sSMPABC076	98.4335	0.0425	66092.7867	0.1320	1.0302	6.9442	1.7785	0.3815	1.4497	0.8151	2124.8742	18.0425	2083.3683	25.8229	2104.3232	15.9052	98.9202
1.sSMPABC077	233.7929	0.0937	629.7237	0.1283	1.8632	6.7135	2.4080	0.3794	1.5255	0.6335	2075.1026	32.8132	2073.6831	27.0695	2074.3953	21.5016	99.8816
~~1.sSMPABC078~~	~~127.8251~~	~~0.0806~~	~~43934.9491~~	~~0.1015~~	~~1.0245~~	~~3.5547~~	~~1.7640~~	~~0.2540~~	~~1.4360~~	~~0.8141~~	~~1651.9109~~	~~18.9892~~	~~1458.9561~~	~~18.7471~~	~~1539.4875~~	~~14.0701~~	~~94.6982~~
1.sSMPABC079	56.2566	0.1408	4013.3238	0.0588	1.2749	0.7378	1.9840	0.0910	1.5202	0.7662	560.8106	27.7845	561.2016	8.1608	561.1243	8.5793	99.9767
~~1.sSMPABC080~~	~~0.0000~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~

Concordance calculated as (206Pb-238U age/207Pb-206Pb age)*100

Table 3. U-Pb Geochronological Analyses for DZ Grains - Sample STG-1

Analysis	U ($\mu\text{g g}^{-1}$) a	Th/U	206Pb/204Pb	207Pb/206Pb	2s (%)	Isotope ratios					Ages						
						207Pb/235U	2s (%)	206Pb/238U	2s (%)	Rho	207Pb/206Pb	2s	206Pb/238U	2s	207Pb/235U	2s	Conc
						Data for Wetherill plot c						abs		abs		abs	(%)
1.sSMPABC007	93.4133	0.1893	210.2448	0.1214	1.9300	6.0389	2.4560	0.3608	1.5189	0.6185	1976.7082	34.3768	1986.0326	25.9412	1981.4682	21.6117	100.0683
1.sSMPABC008	120.5100	0.1569	246.1395	0.1301	1.8330	6.6913	2.3747	0.3729	1.5098	0.6358	2099.8312	32.1910	2043.0822	26.4169	2071.4747	21.1865	98.4663
1.sSMPABC009	385.9217	0.0644	330.2658	0.1020	2.2008	4.1039	2.7031	0.2918	1.5695	0.5806	1661.0165	40.7442	1650.4155	22.8250	1655.0849	22.2958	99.5689
1.sSMPABC010	~~244.7685~~	~~0.0399~~	~~246.3113~~	~~0.1229~~	~~1.0147~~	~~7.8231~~	~~1.7332~~	~~0.4618~~	~~1.4051~~	~~0.8107~~	~~1998.3794~~	~~18.0284~~	~~2447.3317~~	~~28.6009~~	~~2210.8722~~	~~15.7179~~	~~110.5147~~
1.sSMPABC011	89.4608	0.0683	12.1839	0.0602	1.0969	0.7934	1.8170	0.0956	1.4485	0.7972	609.6935	23.7101	588.7888	8.1274	593.1139	8.1774	99.1952
1.sSMPABC012	~~0.0194~~	~~79.3376~~	~~88.4520~~	~~0.3510~~	~~21.3875~~	~~33.7418~~	~~72.3397~~	~~0.6972~~	~~69.1057~~	~~0.9553~~	~~3711.3442~~	~~325.7382~~	~~3410.0421~~	~~2146.7546~~	~~3602.5232~~	~~1230.9789~~	~~94.4742~~
1.sSMPABC013	~~603.5175~~	~~0.0408~~	~~782.7503~~	~~0.3411~~	~~0.9984~~	~~5.6525~~	~~1.7298~~	~~0.1202~~	~~1.4127~~	~~0.8166~~	~~3667.7844~~	~~15.2503~~	~~721.6059~~	~~9.7441~~	~~1924.1458~~	~~15.0262~~	~~37.9498~~
1.sSMPABC014	~~257.1153~~	~~0.0120~~	~~90.7386~~	~~0.1045~~	~~1.0046~~	~~2.5477~~	~~1.7298~~	~~0.1768~~	~~1.4082~~	~~0.8141~~	~~1705.8849~~	~~18.4923~~	~~1049.4049~~	~~13.6076~~	~~1285.7889~~	~~12.6786~~	~~81.5042~~
1.sSMPABC015	56.6344	0.1016	35.3793	0.1068	1.0209	4.7367	1.7561	0.3218	1.4289	0.8137	1744.9944	18.7002	1798.2918	22.3972	1773.7551	14.8210	101.2276
1.sSMPABC016	46.9662	0.0938	30956.3142	0.1104	1.0235	4.8853	1.7607	0.3209	1.4327	0.8137	1806.1690	18.6059	1794.1779	22.4114	1799.7301	14.9398	99.5366
1.sSMPABC017	105.2731	0.1147	11266.1014	0.0607	1.0717	0.7932	1.7945	0.0949	1.4393	0.8021	626.8442	23.0998	584.1802	8.0152	592.9903	8.0746	98.4392
1.sSMPABC018	124.5744	0.0806	13314.4765	0.0597	1.0562	0.7922	1.7844	0.0963	1.4382	0.8060	590.9021	22.9017	592.8039	8.1223	592.4101	8.0231	99.9905
1.sSMPABC019	98.8210	0.0365	325.0769	0.1305	1.0192	6.6806	1.7584	0.3713	1.4330	0.8149	2104.7035	17.8890	2035.4418	24.9896	2070.0655	15.6423	98.1647
1.sSMPABC020	~~98.0079~~	~~0.0672~~	~~12610.7138~~	~~0.2675~~	~~1.2470~~	~~20.5864~~	~~1.9191~~	~~0.5581~~	~~1.4588~~	~~0.7601~~	~~3291.5275~~	~~19.5772~~	~~2858.8612~~	~~23.6895~~	~~3119.3225~~	~~18.7526~~	~~91.4750~~
1.sSMPABC027	328.3063	0.0427	339.7238	0.1288	0.9983	6.6650	1.7296	0.3754	1.4124	0.8166	2081.2888	17.5696	2054.6671	24.8274	2067.9892	15.3787	99.1920
1.sSMPABC028	33.4601	0.0989	131.8934	0.1094	1.0333	4.9084	1.7750	0.3255	1.4432	0.8131	1788.7790	18.8248	1816.6255	22.8221	1803.6935	15.0742	100.5608
1.sSMPABC029	100.6361	0.1826	49.5975	0.0596	3.5219	0.7927	4.3363	0.0964	2.5298	0.5834	589.9942	76.3792	593.3942	14.3073	592.6898	19.6155	100.0428
1.sSMPABC030	73.2943	0.0741	7978.0734	0.0594	1.0943	0.8068	1.8142	0.0985	1.4471	0.7976	581.7880	23.7646	605.6590	8.3413	600.6501	8.2416	100.7567
1.sSMPABC031	53.5200	0.1008	32929.6804	0.1065	1.0238	4.5604	1.7626	0.3107	1.4348	0.8140	1739.8387	18.7650	1743.9139	21.8951	1742.0615	14.7749	99.9533
1.sSMPABC032	~~64.0827~~	~~0.0938~~	~~7122.4924~~	~~0.0623~~	~~1.1240~~	~~0.8250~~	~~1.8448~~	~~0.0961~~	~~1.4629~~	~~0.7930~~	~~683.7374~~	~~23.9986~~	~~591.3281~~	~~8.2420~~	~~610.8102~~	~~8.4852~~	~~96.7346~~
1.sSMPABC033	114.7793	0.0680	4198.4761	0.2369	1.3061	20.3339	1.9552	0.6226	1.4549	0.7441	3098.9336	20.8219	3120.4510	36.0052	3107.3730	19.0970	100.2352
1.sSMPABC034	92.5042	0.0813	9844.3438	0.0596	1.0742	0.7888	1.7987	0.0960	1.4428	0.8021	588.3554	23.3025	591.0329	8.1245	590.4799	8.0684	100.0179
1.sSMPABC035	—	—	~~0.1773~~	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1.sSMPABC036	74.1341	0.0481	72303.4472	0.1337	1.0101	7.2289	1.7491	0.3923	1.4279	0.8164	2146.4712	17.6475	2133.4172	25.9159	2140.0741	15.7152	99.5226
1.sSMPABC037	325.4933	0.0702	560.1980	0.1090	2.0937	4.9750	2.6046	0.3310	1.5492	0.5948	1783.1011	38.1704	1843.0806	24.8106	1815.0867	22.2478	101.3848
1.sSMPABC038	142.8822	0.0865	140570.4377	0.1352	0.9987	7.2920	1.7372	0.3912	1.4215	0.8183	2166.3363	17.4095	2128.5351	25.7493	2147.8316	15.6247	98.9357
1.sSMPABC039	35.6125	0.1306	3887.2806	0.0609	1.2818	0.8090	1.9883	0.0964	1.5199	0.7644	633.9360	27.5961	593.4532	8.5926	601.9194	9.0497	98.5174
1.sSMPABC040	~~50.9491~~	~~0.0594~~	~~89.9861~~	~~0.2732~~	~~1.1714~~	~~23.8778~~	~~1.8653~~	~~0.6338~~	~~1.4515~~	~~0.7782~~	~~3324.7021~~	~~18.3437~~	~~3164.6069~~	~~36.3159~~	~~3263.4176~~	~~18.3400~~	~~96.7890~~

1.sMPABC047	83.1978	0.0662	8712.2161	0.0594	1.1113	0.7762	1.8361	0.0948	1.4616	0.7960	581.4224	24.1357	583.7665	8.1337	583.2873	8.1618	100.0071
~~1.sMPABC048~~	~~-0.0816~~	~~-0.0405~~	~~0.0000~~	~~0.0000~~	~~—~~	~~—~~	~~—~~	~~0.3323~~	~~685.9364~~	~~—~~	~~—~~	~~—~~	~~1849.3496~~	~~—~~	~~—~~	~~—~~	~~—~~
1.sMPABC049	109.6167	0.0907	509.2067	0.1071	2.1221	4.6137	2.6366	0.3124	1.5648	0.5935	1750.8122	38.8435	1752.5486	23.9857	1751.7568	22.2292	99.8918
~~1.sMPABC050~~	~~0.0105~~	~~0.7991~~	~~0.1996~~	~~1.3661~~	~~74.9694~~	~~16.4128~~	~~229.8408~~	~~0.0871~~	~~217.2703~~	~~0.9453~~	~~5672.0815~~	~~1036.2599~~	~~538.5667~~	~~1228.6199~~	~~2901.1596~~	~~—~~	~~18.5190~~
1.sMPABC051	367.7126	0.0958	171.3245	0.0590	1.0178	0.7459	1.7487	0.0918	1.4220	0.8132	565.2500	22.1657	566.0091	7.6830	565.8579	7.5978	99.9535
1.sMPABC052	49.5571	0.0869	39.4259	0.0612	1.1594	0.8845	1.8767	0.1048	1.4758	0.7864	647.6743	24.9026	642.1969	8.9957	643.4108	8.9653	99.7304
1.sMPABC053	138.0481	0.0799	128.3226	0.1054	1.0802	4.4852	1.7932	0.3086	1.4313	0.7982	1721.6565	19.8439	1733.6853	21.7305	1728.2417	14.9877	100.1623
1.sMPABC054	48.9234	0.1063	40890.2383	0.1249	1.0245	6.1949	1.7721	0.3596	1.4460	0.8160	2027.9467	18.1403	1980.3236	24.6323	2003.7287	15.6041	98.6707
1.sMPABC055	40.1288	0.1151	9.4692	0.0593	5.0818	0.7923	6.1015	0.0970	3.3769	0.5535	576.7688	110.4562	596.5805	19.2031	592.4720	27.7028	100.6171
1.sMPABC056	23.5607	0.1124	84.9946	0.1078	1.0576	4.6257	1.8168	0.3112	1.4772	0.8131	1762.3917	19.3310	1746.8263	22.5765	1753.9240	15.2719	99.4424
1.sMPABC057	120.7078	0.0892	57.2587	0.0603	1.0622	0.8087	1.7924	0.0973	1.4437	0.8055	612.5649	22.9501	598.8219	8.2324	601.7012	8.1526	99.4449
~~1.sMPABC058~~	~~0.0000~~	~~—~~	~~0.0000~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~
1.sMPABC059	87.1872	0.0813	9283.3425	0.0598	1.1031	0.7892	1.8371	0.0957	1.4690	0.7996	597.4320	23.8939	588.9660	8.2450	590.7134	8.2436	99.6286
~~1.sMPABC060~~	~~136.8233~~	~~0.0452~~	~~58.2949~~	~~0.0643~~	~~1.0572~~	~~0.8432~~	~~1.7832~~	~~0.0951~~	~~1.4360~~	~~0.8053~~	~~752.1705~~	~~22.3229~~	~~585.4804~~	~~8.0136~~	~~620.8908~~	~~8.2992~~	~~94.2216~~
1.sMPABC067	322.9221	0.1411	1713.6895	0.1191	1.9581	5.9787	2.4857	0.3640	1.5312	0.6160	1942.9742	35.0163	2001.2794	26.3225	1972.7541	21.8442	101.2828
~~1.sMPABC068~~	~~529.3910~~	~~0.0412~~	~~656.7240~~	~~0.5040~~	~~1.0060~~	~~7.2178~~	~~1.7776~~	~~0.1039~~	~~1.4655~~	~~0.8244~~	~~4253.0634~~	~~14.8191~~	~~636.9815~~	~~8.8638~~	~~2138.7083~~	~~15.9703~~	~~29.7223~~
1.sMPABC069	255.5018	0.0478	320.5242	0.1176	1.0177	5.6161	1.7574	0.3464	1.4327	0.8153	1919.8087	18.2494	1917.4286	23.7382	1918.5723	15.2523	99.7808
1.sMPABC070	40.7232	0.0973	301.8308	0.2804	1.2361	26.5887	1.9303	0.6878	1.4826	0.7681	3364.8909	19.2970	3374.4077	38.9780	3368.4394	19.0645	99.9894
~~1.sMPABC071~~	~~513.4613~~	~~0.1008~~	~~81.7458~~	~~0.1115~~	~~1.1680~~	~~2.4533~~	~~1.8962~~	~~0.1596~~	~~1.4938~~	~~0.7878~~	~~1823.8207~~	~~21.1880~~	~~954.5108~~	~~13.2226~~	~~1258.3824~~	~~13.7558~~	~~75.7485~~
1.sMPABC072	142.5478	0.0933	321.2117	0.1091	1.0082	4.7099	1.7549	0.3131	1.4364	0.8185	1784.4413	18.3785	1755.9499	22.0515	1769.0003	14.7956	99.1091
1.sMPABC073	282.5434	0.0686	48.0653	0.0624	1.0584	0.7855	1.7955	0.0914	1.4504	0.8078	686.4777	22.5880	563.5784	7.8042	588.6364	8.0351	95.6701
1.sMPABC074	131.9251	0.1080	14548.0623	0.0600	1.0505	0.8174	1.7841	0.0988	1.4421	0.8083	602.4923	22.7352	607.6616	8.3387	606.5696	8.1631	100.1026

Concordance calculated as (206Pb-238U age/207Pb-206Pb age)*100

Table 4. U-Pb Geochronological Analyses for DZ Grains - Sample STG-2

Analysis	U (µg g ⁻¹) a	Th/U	206Pb/204Pb	207Pb/206Pb	2s (%)	Isotope ratios					Ages						
						207Pb/235U	2s (%)	206Pb/238U	2s (%)	Rho	207Pb/206Pb	2s	206Pb/238U	2s	207Pb/235U	2s	Conc
						Data for Wetherill plot c						abs		abs		abs	(%)
1.sSMPABC075	134.5319	0.0817	26.4908	0.0608	2.2057	0.7968	2.9241	0.0951	1.9196	0.6565	631.4533	47.5056	585.5129	10.6953	595.0243	13.2087	98.2859
1.sSMPABC076	107.2734	0.0673	934.1270	0.1343	1.7932	7.2772	2.3548	0.3931	1.5264	0.6482	2154.3496	31.3012	2137.3125	27.7085	2146.0121	21.2273	99.3388
~~1.sSMPABC077~~	~~642.5566~~	~~0.0901~~	~~596.6979~~	~~0.2546~~	~~0.9912~~	~~5.5631~~	~~1.7458~~	~~0.1585~~	~~1.4371~~	~~0.8232~~	~~3213.5888~~	~~15.6563~~	~~948.2901~~	~~12.6208~~	~~1910.4014~~	~~15.1239~~	~~49.4979~~
1.sSMPABC078	444.3754	0.1976	24.7920	0.0589	2.2518	0.7602	2.9591	0.0936	1.9197	0.6488	562.6562	49.0616	577.0394	10.5476	574.1355	13.0159	100.3916
1.sSMPABC079	89.9735	0.0837	66590.1163	0.1302	0.9988	6.5106	1.7540	0.3628	1.4419	0.8220	2100.1232	17.5402	1995.3271	24.6837	2047.3294	15.5449	97.2126
1.sSMPABC080	30.5837	0.0658	2730.2790	0.0597	1.3563	0.7853	2.0679	0.0954	1.5610	0.7549	593.4447	29.3980	587.2299	8.7204	588.5089	9.2477	99.6668
1.sSMPABC087	104.3863	0.1201	74605.6784	0.1252	1.0064	6.2871	1.7992	0.3642	1.4915	0.8289	2031.6269	17.8122	2002.0805	25.6081	2016.6633	15.8728	99.0277
1.sSMPABC088	31.0193	0.0649	22614.5153	0.1264	1.0837	6.4133	1.9162	0.3679	1.5803	0.8247	2048.7733	19.1427	2019.6441	27.3396	2034.0892	16.9592	99.0398
1.sSMPABC089	71.8076	0.0772	6534.2357	0.0598	1.1210	0.8005	1.8491	0.0971	1.4706	0.7953	595.2583	24.2891	597.5817	8.3533	597.0974	8.3543	99.9637
1.sSMPABC090	407.4311	0.0151	667.5336	0.1141	1.0166	5.3183	1.7727	0.3380	1.4523	0.8192	1865.8744	18.3468	1877.1464	23.5894	1871.8022	15.2505	100.0423
1.sSMPABC091	70.5287	0.0703	13.9542	0.1389	4.2113	8.1018	4.6487	0.4232	1.9684	0.4234	2212.9439	73.0412	2274.9167	37.6846	2242.4497	42.8813	101.1846
1.sSMPABC092	52.7258	0.0629	39995.7288	0.1299	1.0085	6.6729	1.7639	0.3726	1.4471	0.8204	2096.4757	17.7192	2041.6025	25.2631	2069.0409	15.6843	98.4232
1.sSMPABC093	30.8449	0.0611	25169.3692	0.1338	1.0241	7.1782	1.7943	0.3892	1.4734	0.8211	2148.1696	17.8882	2118.9001	26.5494	2133.7941	16.1070	99.0473
1.sSMPABC094	264.5190	0.0806	197.1865	0.1254	1.0032	6.2559	1.7462	0.3619	1.4293	0.8185	2034.2019	17.7499	1991.0431	24.4235	2012.3079	15.3909	98.6949
1.sSMPABC095	120.5777	0.1849	18.4328	0.0596	1.0742	0.7867	1.8042	0.0958	1.4496	0.8034	588.3554	23.3025	589.5383	8.1279	589.2945	8.0716	99.9252
~~1.sSMPABC096~~	~~323.7408~~	~~0.1216~~	~~196.5746~~	~~0.1271~~	~~1.0181~~	~~5.1438~~	~~1.7537~~	~~0.2936~~	~~1.4279~~	~~0.8142~~	~~2057.8678~~	~~17.9663~~	~~1659.3946~~	~~20.8288~~	~~1843.3639~~	~~15.0045~~	~~89.7965~~
1.sSMPABC097	57.1790	0.0881	45788.4766	0.1317	1.0096	7.0444	1.7604	0.3878	1.4422	0.8192	2121.2878	17.6877	2112.6886	25.9209	2117.0493	15.7632	99.5392
1.sSMPABC098	124.0130	0.0841	92615.4570	0.1265	1.0277	6.5696	1.7535	0.3767	1.4208	0.8103	2049.8907	18.1508	2060.6607	25.0003	2055.2816	15.5591	100.0089
1.sSMPABC099	96.2525	0.0658	261.8384	0.1310	1.8249	7.0355	2.3758	0.3895	1.5212	0.6403	2111.5325	32.0082	2120.4403	27.4295	2115.9215	21.3283	99.9580
1.sSMPABC100	34.8045	0.1062	56.7019	0.1086	1.0309	4.7867	1.7878	0.3196	1.4606	0.8170	1776.7359	18.8098	1787.5462	22.7403	1782.5639	15.1126	100.0415
1.sSMPABC107	189.1179	0.1054	17060.3330	0.0599	1.0345	0.7936	1.7776	0.0960	1.4455	0.8132	601.0482	22.3947	591.1360	8.1259	593.1888	7.9908	99.5375
~~1.sSMPABC108~~	~~1090.6220~~	~~0.4712~~	~~16.9696~~	~~0.3518~~	~~3.3077~~	~~3.5535~~	~~15.5745~~	~~0.0733~~	~~15.2192~~	~~0.9772~~	~~3714.9685~~	~~50.3644~~	~~455.7162~~	~~66.9400~~	~~1539.2211~~	~~131.3974~~	~~29.5282~~
1.sSMPABC109	327.8034	0.1743	33.6342	0.0608	1.0196	0.8349	1.7599	0.0996	1.4345	0.8151	632.5202	21.9549	611.9283	8.3348	616.3273	8.1373	99.1666
1.sSMPABC110	90.9607	0.1607	29.8911	0.0603	1.0945	0.8094	1.8305	0.0974	1.4672	0.8015	614.3568	23.6406	598.8818	8.3516	602.1255	8.3214	99.3436
1.sSMPABC111	30.8011	0.1322	20.3497	0.1064	1.0530	4.5449	1.8165	0.3099	1.4801	0.8148	1737.9437	19.3059	1740.2948	22.5115	1739.2273	15.2150	99.8264
1.sSMPABC112	92.3529	0.0858	58.9530	0.0600	3.5078	0.7918	4.3400	0.0956	2.5556	0.5889	605.0199	75.8829	588.8281	14.3200	592.1750	19.5970	99.3187
1.sSMPABC113	77.4347	0.1525	6891.5556	0.0601	1.1311	0.7829	1.8546	0.0944	1.4698	0.7925	607.8963	24.4563	581.7812	8.1376	587.1365	8.2755	98.9729
1.sSMPABC114	92.9805	0.0859	234.1107	0.0600	1.1202	0.7974	1.8453	0.0964	1.4663	0.7946	602.5762	24.2438	593.4430	8.2739	595.3403	8.3188	99.5645
1.sSMPABC115	83.7630	0.0946	103.0645	0.1318	1.0942	7.1221	1.8081	0.3919	1.4394	0.7961	2122.1052	19.1688	2131.6778	26.0674	2126.8084	16.2154	99.9729

1.sSMPABC116	122.5289	0.0758	99302.7997	0.1320	0.9998	7.1293	1.7433	0.3916	1.4281	0.8192	2125.1395	17.5086	2130.3732	25.8500	2127.7107	15.6321	99.8692
~~1.sSMPABC117~~	~~0.0000~~	~~—~~	~~0.0000~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~
1.sSMPABC118	134.3871	0.0832	163.6772	0.1288	1.0404	6.8034	1.7691	0.3831	1.4309	0.8088	2081.5290	18.3096	2090.8777	25.4915	2086.1709	15.7713	99.9714
~~1.sSMPABC119~~	~~390.1626~~	~~0.0599~~	~~299566.5123~~	~~0.1393~~	~~0.9978~~	~~6.7542~~	~~1.7346~~	~~0.3516~~	~~1.4189~~	~~0.8180~~	~~2218.6485~~	~~17.2946~~	~~1942.3874~~	~~23.7360~~	~~2079.7390~~	~~15.4468~~	~~93.1542~~
1.sSMPABC120	10.5618	0.0576	9582.0726	0.1397	1.0955	7.9808	1.8850	0.4145	1.5339	0.8138	2222.9968	18.9798	2235.2451	28.9182	2228.8591	17.1412	100.0259
1.sSMPABC127	80.6981	0.0874	141.1592	0.1365	1.0552	7.6476	1.7762	0.4064	1.4288	0.8044	2183.0380	18.3604	2198.4179	26.5579	2190.4703	16.0649	100.1037
1.sSMPABC128	315.7226	0.1658	54.6180	0.0606	1.2636	0.8172	1.9801	0.0977	1.5245	0.7699	626.5579	27.2378	601.1270	8.7089	606.4855	9.0526	98.9985
1.sSMPABC129	363.7857	0.1678	117.2810	0.0607	3.4539	0.7544	4.3537	0.0901	2.6504	0.6088	628.9763	74.4191	556.2531	14.0639	570.7605	19.1236	97.3473
1.sSMPABC130	54.6699	0.0749	44999.8071	0.1329	1.0233	7.2408	1.7714	0.3951	1.4460	0.8163	2136.6340	17.8982	2146.6617	26.3426	2141.5420	15.9169	99.9823
1.sSMPABC131	95.6964	0.0794	8623.1983	0.0596	1.1070	0.7927	1.8326	0.0964	1.4605	0.7969	589.8112	24.0087	593.4430	8.2408	592.6905	8.2341	100.0101
1.sSMPABC132	97.6120	0.0944	17642.0664	0.0716	1.0469	1.5899	1.7782	0.1610	1.4374	0.8083	975.7310	21.3399	962.1013	12.7943	966.2595	11.1197	99.4029
1.sSMPABC133	209.6036	0.1563	199516.1781	0.1452	1.0058	8.3734	1.7390	0.4184	1.4186	0.8158	2289.6755	17.3009	2253.0544	26.9181	2272.3057	15.8873	98.8925
~~1.sSMPABC134~~	~~0.0132~~	~~0.0000~~	~~70.4928~~	~~5.0352~~	~~191.4871~~	~~46.9513~~	~~439.5584~~	~~0.0676~~	~~395.6567~~	~~0.9001~~	~~7428.8247~~	~~2523.7043~~	~~421.8524~~	~~1848.0177~~	~~3929.7219~~	~~—~~	~~10.6897~~
~~1.sSMPABC135~~	~~322.4442~~	~~0.1700~~	~~34.3349~~	~~0.0821~~	~~1.0108~~	~~1.1943~~	~~1.7359~~	~~0.1055~~	~~1.4113~~	~~0.8130~~	~~1248.1416~~	~~19.7896~~	~~646.5119~~	~~8.6409~~	~~797.9546~~	~~9.6131~~	~~80.8974~~
1.sSMPABC136	153.1654	0.0563	327.2769	0.1306	1.0108	6.6728	1.7538	0.3706	1.4331	0.8172	2105.8582	17.7408	2032.2415	24.9214	2069.0261	15.5938	97.9723
1.sSMPABC137	34.0601	0.0967	3055.7027	0.0596	1.3262	0.7892	2.0236	0.0961	1.5285	0.7553	587.9913	28.7706	591.4318	8.5969	590.7210	9.0738	100.0038
1.sSMPABC138	182.7657	0.1108	124.0312	0.1304	1.0569	6.9429	1.7746	0.3863	1.4255	0.8033	2102.7149	18.5563	2105.6292	25.5482	2104.1555	15.8619	99.8153
1.sSMPABC139	158.2202	0.0657	243.0941	0.1329	1.0176	6.9470	1.7790	0.3792	1.4591	0.8202	2136.2327	17.7995	2072.5670	25.8028	2104.6863	15.9024	98.2220
~~1.sSMPABC140~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~	~~—~~
~~1.sSMPABC147~~	~~1024.8845~~	~~0.3058~~	~~29.1909~~	~~0.1365~~	~~1.9566~~	~~2.2161~~	~~3.1039~~	~~0.1178~~	~~2.4096~~	~~0.7763~~	~~2183.2058~~	~~34.0454~~	~~717.6228~~	~~16.2981~~	~~1186.1495~~	~~21.9118~~	~~60.3730~~
~~1.sSMPABC148~~	~~379.2618~~	~~0.2554~~	~~45.9933~~	~~0.1317~~	~~1.4268~~	~~3.1524~~	~~2.1493~~	~~0.1736~~	~~1.6074~~	~~0.7479~~	~~2121.2350~~	~~24.9982~~	~~1031.6562~~	~~15.2651~~	~~1445.5799~~	~~16.6807~~	~~71.2017~~
1.sSMPABC149	71.6124	0.1656	50313.5317	0.1227	1.0185	6.1805	1.7529	0.3652	1.4267	0.8139	1996.2883	18.1002	2006.9271	24.5444	2001.6897	15.4241	100.0115
1.sSMPABC150	45.3421	0.0897	135.6785	0.1350	1.0523	7.3967	1.8107	0.3975	1.4735	0.8138	2163.5612	18.3501	2157.4360	26.9598	2160.5761	16.3148	99.5978
1.sSMPABC151	112.6305	0.0787	163.8472	0.0598	1.1044	0.7806	1.8180	0.0947	1.4440	0.7943	594.8958	23.9320	583.4992	8.0175	585.8347	8.0979	99.4861
1.sSMPABC152	100.0304	0.1282	8676.5335	0.0594	1.1109	0.7630	1.8243	0.0931	1.4471	0.7932	582.1536	24.1246	574.1334	7.9109	575.7536	8.0218	99.6048
1.sSMPABC153	76.4238	0.0659	57.8773	0.0726	1.2199	1.6255	1.9045	0.1624	1.4625	0.7679	1002.8314	24.7628	970.0279	13.1173	980.1301	12.0162	98.8017
1.sSMPABC154	58.4100	0.0535	48301.6446	0.1337	1.0251	7.2744	1.7612	0.3948	1.4321	0.8132	2146.4712	17.9090	2144.8488	26.0711	2145.6776	15.8329	99.7049
1.sSMPABC155	43.3930	0.1052	42.4146	0.1292	1.5390	6.8100	2.1540	0.3823	1.5070	0.6996	2087.1936	27.0678	2086.8444	26.8072	2087.0202	19.2376	99.7378
1.sSMPABC156	259.7341	0.0482	324.4384	0.1225	1.9291	6.2193	2.4480	0.3681	1.5072	0.6157	1993.4868	34.2935	2020.4974	26.0820	2007.1719	21.6249	100.4128
1.sSMPABC157	109.4540	0.1542	98.0603	0.1314	1.1246	7.0220	1.8242	0.3876	1.4363	0.7874	2116.4916	19.7130	2111.8942	25.8077	2114.2243	16.3323	99.6349
1.sSMPABC158	36.0191	0.0770	9822.3899	0.1326	1.0479	7.1966	1.7907	0.3935	1.4520	0.8109	2133.2083	18.3358	2139.0811	26.3735	2136.0872	16.0789	99.8838
1.sSMPABC159	39.2744	0.0425	32906.7181	0.1341	1.0367	7.3706	1.7770	0.3987	1.4432	0.8122	2152.0815	18.1009	2163.0019	26.4615	2157.4045	16.0016	100.0020
1.sSMPABC160	103.4143	0.0490	286.3990	0.1329	1.8193	7.0163	2.3696	0.3828	1.5182	0.6407	2137.1403	31.8187	2089.2834	27.0335	2113.4955	21.2645	98.6014

Concordance calculated as (206Pb-238U age/207Pb-206Pb age)*100

Table 5. U-Pb Geochronological Analyses for DZ Grains - Sample SSR-1

Analysis	U (μg g ⁻¹) a	Th/U	206Pb/204Pb	207Pb/206Pb b	2s (%)	Isotope ratios					Ages						
						207Pb/235U	2s (%)	206Pb/238U	2s (%)	Rho	207Pb/206Pb b	2s	206Pb/238U	2s	207Pb/235U	2s	Conc
						Data for Wetherill plot c						abs		abs		abs	(%)
1.sMPABC087	108.9675	0.1078	7651.8418	0.0595	1.0926	0.7465	1.8103	0.0910	1.4434	0.7973	585.0751	23.7155	561.4792	7.8010	566.1732	7.9093	99.2635
1.sMPABC088	237.1047	0.0346	145660.4257	0.1284	0.9655	6.5305	1.7256	0.3688	1.4302	0.8288	2076.5935	17.0012	2023.6924	24.9763	2050.0141	15.3191	98.9226
1.sMPABC089	47.1214	0.1108	20150.3677	0.1070	1.0092	4.5458	1.7590	0.3081	1.4407	0.8191	1749.2773	18.4755	1731.1741	21.9920	1739.3873	14.7595	99.7214
1.sMPABC090	67.4846	0.0830	5001.0890	0.0600	1.1510	0.7878	1.8770	0.0953	1.4827	0.7899	601.7704	24.9118	586.8307	8.3593	589.9092	8.4562	99.5741
1.sMPABC091	138.2394	0.0987	39.6793	0.0594	3.5254	0.7476	4.3878	0.0913	2.6124	0.5954	581.5829	76.5646	563.1254	14.1653	566.8022	19.2939	99.4441
1.sMPABC092	79.9904	0.1828	24.3474	0.0592	1.1310	0.7539	1.8518	0.0923	1.4663	0.7918	575.9275	24.5862	569.1186	8.0280	570.4837	8.1373	99.8543
1.sMPABC093	404.2727	0.0563	65.5616	0.0595	1.1907	0.7844	1.8941	0.0956	1.4730	0.7777	585.1894	25.8448	588.7046	8.3297	587.9812	8.5129	100.2192
1.sMPABC094	28.4111	0.1288	11353.6059	0.1069	1.2250	4.2480	2.0337	0.2881	1.6234	0.7982	1747.9081	22.4307	1632.0366	23.5388	1683.3554	16.8703	97.1385
1.sMPABC095	207.3410	0.0792	378.1499	0.1315	0.9752	6.8438	1.7212	0.3775	1.4183	0.8240	2117.8295	17.0928	2064.6640	25.1950	2091.4052	15.3744	98.9296
1.sMPABC096	56.9416	0.0747	25.0289	0.1035	1.0141	3.1820	1.7666	0.2229	1.4466	0.8188	1688.5249	18.7084	1297.1305	17.0869	1452.8012	13.7573	89.4478
1.sMPABC097	138.3401	0.0553	425.5622	0.1326	1.8120	7.1288	2.3540	0.3900	1.5027	0.6384	2132.1011	31.7074	2123.0304	27.3355	2127.6424	21.1940	99.9944
1.sMPABC098	19.0720	0.0940	1412.0726	0.0603	1.7756	0.7871	2.4888	0.0947	1.7439	0.7007	612.9234	38.3610	583.4328	9.7784	589.4990	11.2218	99.0664
1.sMPABC099	—	—	0.2459	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1.sMPABC100	124.4567	0.1453	8985.7175	0.0596	1.0576	0.7675	1.7934	0.0934	1.4483	0.8076	587.9913	22.9437	575.8690	8.0195	578.3263	7.9601	99.6696
1.sMPABC107	583.8932	0.0236	111.0057	0.0836	0.9926	1.6915	1.7361	0.1467	1.4244	0.8204	1283.7269	19.3340	882.5109	11.8089	1005.3408	11.1600	87.9108
1.sMPABC108	26.6822	0.1828	18.1965	0.0590	1.5437	0.7394	2.2528	0.0910	1.6408	0.7283	565.2500	33.6180	561.3028	8.8658	562.0845	9.7985	99.9535
1.sMPABC109	108.5608	0.1768	9.6110	0.0595	1.0917	0.7604	1.8239	0.0926	1.4611	0.8011	586.8983	23.6883	571.0564	8.0256	574.2477	8.0536	99.5381
1.sMPABC110	501.4928	0.4434	41.0565	0.0818	1.3482	0.8990	2.1650	0.0797	1.6940	0.7824	1230.9570	26.4256	494.5721	8.1062	651.1938	10.4877	76.0318
1.sMPABC111	147.3582	0.0769	290.7383	0.1067	1.0024	4.5932	1.7451	0.3121	1.4285	0.8186	1744.4796	18.3634	1751.0057	22.0226	1748.0330	14.6697	100.3650
1.sMPABC112	51.6799	0.1964	3988.8384	0.0655	1.2975	0.8205	2.0596	0.0908	1.5995	0.7766	790.7582	27.2269	560.4795	8.6303	608.3151	9.4947	92.2289
1.sMPABC113	36.5901	0.1455	3835.5624	0.0804	1.1816	1.1171	1.9259	0.1008	1.5208	0.7897	1206.8173	23.2704	618.9050	9.0210	761.5675	10.3951	81.3665
1.sMPABC114	214.7725	0.1405	60.3588	0.0607	1.1960	0.8305	1.8971	0.0992	1.4727	0.7763	629.4578	25.7665	609.6905	8.6111	613.8998	8.8011	99.4132
1.sMPABC115	161.4328	0.0560	12055.0505	0.0600	1.0502	0.7938	1.7917	0.0960	1.4517	0.8102	603.2139	22.7249	590.7536	8.2364	593.3341	8.1050	99.6615
1.sMPABC116	91.4798	0.1163	39534.9212	0.1072	1.0079	4.5941	1.7630	0.3110	1.4465	0.8205	1751.4995	18.4479	1745.4296	22.2389	1748.1932	14.8219	100.0364
1.sMPABC117	88.3989	0.0783	99497.5732	0.1759	1.0178	11.9649	1.8165	0.4934	1.5045	0.8283	2614.3042	16.9419	2585.4482	32.2300	2601.6592	17.1723	99.6018
1.sMPABC118	41.7161	0.1666	3085.8414	0.0600	1.3009	0.7863	2.0224	0.0951	1.5484	0.7657	602.1314	28.1548	585.7178	8.7142	589.0957	9.1047	99.5224
1.sMPABC119	50.5467	0.1600	39.5216	0.1066	1.0316	4.5381	1.7960	0.3087	1.4701	0.8186	1742.5906	18.9022	1734.1650	22.4755	1737.9874	15.0674	99.9740
1.sMPABC120	77.9004	0.0734	5735.4358	0.0596	1.1575	0.7827	1.8985	0.0952	1.5049	0.7926	589.4473	25.1058	586.3621	8.4777	586.9958	8.5224	99.9879
1.sMPABC127	131.3253	0.1532	44.4103	0.0763	1.2938	1.0173	2.0364	0.0967	1.5725	0.7722	1103.0598	25.8705	595.0251	8.9842	712.5724	10.5066	83.6003

1.sMPABC128	1305.8197	0.1284	55.6476	0.0822	1.0099	0.6392	1.7643	0.0564	1.4467	0.8200	1250.0478	19.7650	353.7211	5.0045	501.8069	7.0307	70.5529
1.sMPABC129	114.5331	0.0600	217.1643	0.1065	2.1426	4.5149	2.6778	0.3074	1.6061	0.5998	1740.8810	39.2678	1727.7893	24.4801	1733.7186	22.5271	99.8515
1.sMPABC130	48.9501	0.0425	7488.3840	0.0891	1.1106	1.6262	1.8698	0.1323	1.5042	0.8045	1407.1697	21.2639	801.0488	11.3898	980.3958	11.8469	81.8260
1.sMPABC131	294.0301	0.0204	119553.3738	0.1071	1.0177	4.3223	1.7702	0.2927	1.4483	0.8182	1750.6452	18.6294	1655.0044	21.2552	1697.6200	14.7163	97.6783
1.sMPABC132	141.7328	0.0797	545.7254	0.1546	1.0159	8.5954	1.7713	0.4033	1.4511	0.8192	2397.3250	17.2794	2184.0281	27.0314	2296.0684	16.2490	95.3302
1.sMPABC133	65.7805	0.0586	4806.0785	0.0598	1.2550	0.7767	1.9877	0.0943	1.5414	0.7755	594.8958	27.1955	580.6780	8.6032	583.5816	8.8859	99.5976
1.sMPABC134	59.1325	0.1096	75.5837	0.1095	1.0505	3.9132	1.8225	0.2593	1.4893	0.8172	1790.6104	19.1344	1486.0690	19.8731	1616.4226	14.8618	92.1120
1.sMPABC135	337.5629	0.0646	2124.5188	0.1404	1.7548	7.9615	2.3317	0.4112	1.5354	0.6585	2232.6504	30.3702	2220.1789	29.0024	2226.6724	21.2661	99.9229
1.sMPABC136	143.1722	0.0661	217.5686	0.1354	1.0263	7.4147	1.7835	0.3970	1.4587	0.8179	2169.6854	17.8843	2155.4384	26.8740	2162.7439	16.0937	99.8745
1.sMPABC137	46.4308	0.1312	10.8896	0.0601	1.3320	0.8053	2.0634	0.0972	1.5759	0.7637	605.7369	28.8112	598.2415	9.0501	599.8085	9.4148	99.8361
1.sMPABC138	211.7257	0.0285	412.5095	0.1348	1.8240	7.1246	2.4312	0.3833	1.6074	0.6612	2161.3882	31.8139	2091.8499	28.8801	2127.1242	21.8946	98.5507
1.sMPABC139	110.7255	0.1469	8363.4162	0.0600	1.1506	0.8029	1.9037	0.0971	1.5167	0.7967	602.4923	24.9005	597.4229	8.6983	598.4810	8.6689	99.9205
1.sMPABC140	103.7425	0.1808	7954.4817	0.0603	1.1279	0.8151	1.8784	0.0981	1.5021	0.7997	613.9986	24.3624	602.9754	8.6908	605.2969	8.6244	99.7145
1.sMPABC147	42.4086	0.1987	3163.4009	0.0600	1.3327	0.7929	2.0661	0.0958	1.5789	0.7642	604.6561	28.8308	589.7585	8.9443	592.8410	9.3463	99.5763
1.sMPABC148	69.4192	0.1106	5430.8198	0.0629	1.2405	0.8316	1.9901	0.0959	1.5562	0.7820	704.1748	26.3974	590.4609	8.8255	614.5142	9.2411	96.1822
1.sMPABC149	37.9742	0.1525	29.4119	0.1107	1.0841	4.9235	1.8601	0.3226	1.5115	0.8126	1810.7721	19.6974	1802.4297	23.8986	1806.3013	15.8343	99.9830
1.sMPABC150	74.0737	0.1901	78.1477	0.0603	1.3108	0.8299	2.0480	0.0999	1.5735	0.7683	612.7554	28.3188	613.7745	9.2601	613.5572	9.5003	100.1348
1.sMPABC151	88.6508	0.0510	37.3812	0.0597	1.3915	0.7889	2.1819	0.0959	1.6807	0.7703	590.9021	30.1721	590.4609	9.5321	590.5520	9.8445	100.0809
1.sMPABC152	17.0298	0.1263	12646.7759	0.1396	1.1243	7.8943	1.9372	0.4100	1.5776	0.8144	2222.7486	19.4793	2214.9944	29.7435	2219.0252	17.6204	100.0328
1.sMPABC153	145.6862	0.1284	100035.1919	0.1352	1.1099	7.2992	1.9144	0.3917	1.5599	0.8148	2165.9493	19.3490	2130.7328	28.4643	2148.7155	17.2524	99.3741
1.sMPABC154	143.2891	0.1097	387.5308	0.1345	1.0796	7.1875	1.8486	0.3875	1.5005	0.8117	2157.8361	18.8385	2111.2514	27.1673	2134.9483	16.6226	99.1001
1.sMPABC155	321.6110	0.0813	27725.4852	0.0631	1.0775	0.9164	1.8259	0.1053	1.4741	0.8073	711.9395	22.9002	645.4832	9.1004	660.4606	8.9272	97.8356
1.sMPABC156	70.2170	0.0866	368.3199	0.1092	1.0713	4.2935	1.8439	0.2851	1.5007	0.8139	1786.2781	19.5239	1617.1784	21.5821	1692.1242	15.3145	95.7565
1.sMPABC157	57.3073	0.4439	11006.7043	0.1744	1.0664	10.2085	1.8407	0.4245	1.5004	0.8151	2600.5143	17.7744	2280.8090	28.9857	2453.8444	17.1748	93.1595
1.sMPABC158	98.2610	0.0826	204.4242	0.1810	1.0838	12.7163	1.8461	0.5094	1.4944	0.8095	2662.3602	17.9584	2654.2808	32.7028	2658.8683	17.5350	100.0543
1.sMPABC159	331.4880	0.0868	25050.1722	0.0603	1.0776	0.8033	1.8337	0.0966	1.4836	0.8091	615.0730	23.2719	594.3816	8.4671	598.6963	8.3507	99.3762
1.sMPABC160	79.5475	0.1285	6114.0588	0.0602	1.2118	0.8170	1.9578	0.0984	1.5377	0.7854	612.2062	26.1833	604.8447	8.9233	606.3978	9.0026	99.8421

Concordance calculated as (206Pb-238U age/207Pb-206Pb age)*100

Table 6. U-Pb Geochronological Analyses for DZ Grains - Sample JD-2

Analysis	U (μg g-1) a	Th/U	206Pb/204Pb	207Pb/206Pb	2s (%)	Isotope ratios					Ages						
						207Pb/235U	2s (%)	206Pb/238U	2s (%)	Rho	207Pb/206Pb	2s	206Pb/238U	2s	207Pb/235U	2s	Conc
						Data for Wetherill plot c						abs		abs		abs	(%)
1-sSMPABC007	204.0985	0.0488	1088.4629	0.1347	1.7784	4.9930	2.3422	0.2687	1.5243	0.6508	2160.7564	21.0210	1534.4316	20.7946	1818.1444	19.9993	84.2813
1.sSMPABC008	207.3838	0.1526	12609.9596	0.0601	1.0146	0.8018	1.6874	0.0967	1.3483	0.7990	607.8963	21.9387	595.2049	7.6479	597.8499	7.6397	99.4943
1.sSMPABC009	246.6055	0.0406	258798.6605	0.1315	0.9809	6.9193	1.6528	0.3816	1.3302	0.8048	2118.2258	17.1917	2083.7295	23.6738	2101.1359	14.7640	99.0350
1.sSMPABC010	147.7059	0.1154	212.4329	0.1362	1.7675	7.5766	2.2689	0.4034	1.4226	0.6270	2179.4792	30.7678	2184.8801	26.3559	2182.0957	20.5506	99.9881
1.sSMPABC011	45.2491	0.0794	47610.6038	0.1304	0.9971	6.9374	1.6839	0.3859	1.3570	0.8058	2103.0886	17.5048	2103.8257	24.3478	2103.4530	15.0490	99.8803
1.sSMPABC012	221.7311	0.0553	225.2032	0.1234	1.0216	6.1943	1.6901	0.3642	1.3464	0.7966	2005.3911	18.1357	2001.9539	23.1580	2003.6460	14.8774	99.7808
1-sSMPABC013	365.8705	0.0542	534.0542	0.2130	0.9833	6.5348	1.6590	0.2225	1.3362	0.8054	2928.7429	15.9032	1294.9569	15.6543	2050.5963	14.7094	63.0544
1.sSMPABC014	123.6174	0.0769	172.5539	0.1346	0.9954	7.3719	1.6642	0.3972	1.3337	0.8014	2159.0967	17.3663	2155.9696	24.4298	2157.5717	14.9837	99.7871
1.sSMPABC015	263.7589	0.1040	437.5174	0.1341	0.9810	7.3277	1.6748	0.3962	1.3574	0.8105	2152.6933	17.1278	2151.6635	24.8239	2152.1904	15.0693	99.8369
1.sSMPABC016	49.0579	0.1400	6003.0647	0.0616	1.1530	0.8068	1.8250	0.0950	1.4147	0.7752	659.5548	24.7165	585.1728	7.8956	600.6590	8.2939	97.3594
1.sSMPABC017	95.4532	0.0051	1827.4154	0.1232	0.9906	6.1851	1.6697	0.3642	1.3441	0.8050	2002.5017	17.5915	2002.1909	23.1206	2002.3439	14.6934	99.8576
1.sSMPABC018	157.3781	0.0510	363.8503	0.1342	1.0032	7.3626	1.6720	0.3978	1.3376	0.8000	2154.0146	17.5121	2158.9775	24.5305	2156.4348	15.0522	99.9791
1.sSMPABC019	62.6848	0.0685	382.3245	0.0602	1.1340	0.8043	1.7928	0.0969	1.3885	0.7745	610.4889	24.5090	596.2662	7.8898	599.2357	8.1324	99.4411
1.sSMPABC020	96.7980	0.0913	18.7098	0.0595	2.8629	0.7901	3.5770	0.0964	2.1445	0.5995	584.1992	62.1485	593.0817	12.1275	591.2445	16.1301	100.2477
1.sSMPABC027	210.1226	0.0818	24794.3984	0.0597	1.0049	0.7780	1.6900	0.0945	1.3588	0.8040	593.0817	21.7813	582.1010	7.5455	584.3465	7.5231	99.5536
1.sSMPABC028	90.8917	0.0674	166.1317	0.1316	0.9804	6.9536	1.7072	0.3833	1.3977	0.8187	2119.1584	17.1807	2091.5885	24.9559	2105.5190	15.2636	99.2015
1.sSMPABC029	292.9933	0.0574	547.7354	0.0599	1.0177	0.8135	1.6869	0.0984	1.3453	0.7975	601.4093	22.0285	605.2214	7.7536	604.4186	7.6989	100.0687
1-sSMPABC030	97.2133	0.0515	76941.2448	0.1272	0.9906	5.2130	1.6745	0.2972	1.3500	0.8062	2059.6318	17.4761	1677.5896	19.9226	1854.7482	14.3593	90.2270
1.sSMPABC031	54.8824	0.0718	46164.0244	0.1176	1.0206	5.5459	1.7103	0.3421	1.3724	0.8024	1919.7642	18.3010	1896.7119	22.5369	1907.7450	14.8136	99.2901
1.sSMPABC032	205.0824	0.0540	214888.4449	0.1292	1.0063	6.9086	1.6756	0.3878	1.3399	0.7996	2086.9768	17.6981	2112.8253	24.1272	2099.7582	14.9666	100.4844
1.sSMPABC033	56.2701	0.0257	55467.3764	0.1259	1.0164	6.4993	1.6905	0.3743	1.3509	0.7991	2042.0510	17.9672	2049.5156	23.7054	2045.7972	14.9800	100.0456
1.sSMPABC034	134.3548	0.0701	27.7327	0.0598	1.0370	0.7907	1.7100	0.0959	1.3597	0.7951	595.9832	22.4662	590.4268	7.6536	591.5753	7.6821	99.7430
1.sSMPABC035	151.0633	0.0843	1247.4283	0.1348	0.9870	7.4046	1.6722	0.3984	1.3498	0.8072	2161.4756	17.2161	2161.5678	24.7798	2161.5205	15.0643	99.8633
1.sSMPABC036	59.5910	0.0792	62421.4048	0.1316	1.0413	6.9065	1.7378	0.3807	1.3912	0.8006	2118.8920	18.2495	2079.7496	24.7203	2099.4886	15.5251	98.9234
1-sSMPABC037	63.0538	0.1181	7.3449	0.6100	4.5962	93.5875	5.3811	1.1126	2.7984	0.5201	4532.1035	66.6977	4821.5274	95.5703	4619.5106	55.5514	104.2112
1.sSMPABC038	52.1337	0.0655	34985.3352	0.1048	1.0112	4.4246	1.7026	0.3061	1.3699	0.8046	1711.3346	18.6004	1721.5584	20.6792	1716.9500	14.1917	100.1421
1.sSMPABC039	67.2970	0.1176	189.8974	0.1298	0.9938	6.9024	1.6911	0.3857	1.3682	0.8091	2095.2579	17.4631	2102.7524	24.5388	2098.9670	15.1035	100.0428
1.sSMPABC040	18.8114	0.0707	89.4576	0.1357	1.0316	7.5878	1.7432	0.4055	1.4052	0.8061	2173.1552	17.9703	2194.3655	26.1283	2183.4212	15.7548	100.3614
1.sSMPABC047	54.1391	0.0719	1288.5042	0.0597	1.1392	0.7846	1.8128	0.0953	1.4101	0.7779	592.3555	24.6967	587.0033	7.8934	588.1042	8.1103	99.7503

1.sMPABC048	~~118.0759~~	~~0.0605~~	~~49116.6216~~	~~0.0982~~	~~1.0068~~	~~2.7427~~	~~1.6991~~	~~0.2023~~	~~1.3687~~	~~0.8055~~	~~1592.6933~~	~~18.8043~~	~~1187.6321~~	~~14.8234~~	~~1340.0964~~	~~12.7114~~	~~88.5218~~
1.sMPABC049	44.4564	0.0619	5368.8989	0.0599	1.1688	0.7963	1.8513	0.0964	1.4357	0.7755	599.6027	25.3074	593.4356	8.1211	594.7160	8.3524	99.7216
1.sMPABC050	70.8995	0.1418	8348.5593	0.0596	1.1072	0.7764	1.7864	0.0945	1.4019	0.7848	589.4473	24.0142	581.8647	7.7817	583.4137	7.9443	99.6724
1.sMPABC051	39.2252	0.0944	4794.9391	0.0605	1.1566	0.8060	1.8418	0.0966	1.4333	0.7782	622.2175	24.9494	594.3793	8.1199	600.1931	8.3657	98.9682
1.sMPABC052	151.2051	0.0997	34.4309	0.0600	1.0333	0.7807	1.7256	0.0944	1.3819	0.8009	603.5746	22.3591	581.3329	7.6643	585.8871	7.6970	99.1606
1.sMPABC053	75.1148	0.1350	9.9546	0.0601	4.6572	0.7803	5.6638	0.0941	3.2232	0.5691	607.9235	100.6989	579.9145	17.8483	585.6450	25.4777	98.9595
1.sMPABC054	~~493.0921~~	~~0.0741~~	~~547.6280~~	~~0.1312~~	~~0.9914~~	~~3.5807~~	~~1.6820~~	~~0.1979~~	~~1.3588~~	~~0.8078~~	~~2114.4472~~	~~17.3828~~	~~1164.0294~~	~~14.4486~~	~~1545.2660~~	~~12.4296~~	~~75.2324~~
1.sMPABC055	~~407.6035~~	~~0.0989~~	~~722.5816~~	~~0.2288~~	~~0.9933~~	~~5.8091~~	~~1.6872~~	~~0.1841~~	~~1.3638~~	~~0.8083~~	~~3043.9794~~	~~15.9080~~	~~1089.3678~~	~~13.6469~~	~~1947.7685~~	~~14.7146~~	~~55.8443~~
1.sMPABC056	92.9623	0.0557	209.1822	0.1364	1.0240	7.6109	1.7017	0.4046	1.3591	0.7987	2182.2966	17.8204	2190.2692	25.2308	2186.1546	15.3827	100.0486
1.sMPABC057	~~268.0181~~	~~0.0603~~	~~62.3661~~	~~0.0770~~	~~1.0134~~	~~0.8147~~	~~1.7164~~	~~0.0768~~	~~1.3853~~	~~0.8071~~	~~1120.4125~~	~~20.2114~~	~~476.7807~~	~~6.3506~~	~~605.0713~~	~~7.8403~~	~~78.7446~~
1.sMPABC058	32.1376	0.1134	3827.3105	0.0599	1.2521	0.7852	1.9204	0.0951	1.4562	0.7582	599.9642	27.1089	585.4681	8.1311	588.4490	8.5978	99.4310
1.sMPABC059	27.5425	0.1174	23.2670	0.1057	1.0412	4.4948	1.7588	0.3086	1.4175	0.8060	1725.6547	19.1180	1733.6284	21.5309	1730.0183	14.7060	100.0820
1.sMPABC060	95.8201	0.0848	80.0074	0.0598	1.2375	0.8038	1.9079	0.0974	1.4521	0.7611	597.7337	26.8040	599.2723	8.2908	598.9508	8.6539	99.9901
1.sMPABC067	~~420.6806~~	~~0.1469~~	~~1678.2921~~	~~0.4156~~	~~1.1042~~	~~7.4177~~	~~2.3413~~	~~0.1295~~	~~2.0646~~	~~0.8818~~	~~3966.4346~~	~~16.5424~~	~~784.7393~~	~~15.2292~~	~~2163.1041~~	~~21.1600~~	~~36.2174~~
1.sMPABC068	6.7301	0.1333	3.9574	0.0587	4.4530	0.7676	5.3560	0.0949	2.9760	0.5556	555.3655	97.1397	584.2869	16.5968	578.4044	23.8526	100.9547
1.sMPABC069	30.8610	0.0611	2227.6969	0.1370	1.0290	7.6150	1.7445	0.4031	1.4087	0.8075	2189.8742	17.8927	2183.1749	26.0813	2186.6309	15.7735	99.7027
1.sMPABC070	~~285.0468~~	~~0.0731~~	~~113927.8722~~	~~0.1022~~	~~0.9978~~	~~2.6352~~	~~1.6978~~	~~0.1870~~	~~1.3737~~	~~0.8091~~	~~1664.9999~~	~~18.4620~~	~~1104.8598~~	~~13.9255~~	~~1310.5246~~	~~12.5633~~	~~84.2107~~
1.sMPABC071	26.2474	0.1470	17924.0755	0.1068	1.0579	4.5025	1.7899	0.3057	1.4439	0.8067	1745.8520	19.3753	1719.5281	21.7763	1731.4341	14.9730	99.1865
1.sMPABC072	~~32.1984~~	~~0.1171~~	~~5284.5984~~	~~0.0784~~	~~1.1485~~	~~1.0825~~	~~1.8591~~	~~0.1002~~	~~1.4619~~	~~0.7863~~	~~1156.0153~~	~~22.7875~~	~~615.5162~~	~~8.5628~~	~~744.8387~~	~~9.8449~~	~~82.5730~~
1.sMPABC073	66.8703	0.0759	11.4148	0.0594	1.1115	0.7653	1.8006	0.0935	1.4166	0.7867	581.0567	24.1413	576.0714	7.7887	577.0807	7.9430	99.7635
1.sMPABC074	~~199.5878~~	~~0.0429~~	~~182424.6600~~	~~0.1320~~	~~1.0000~~	~~6.0263~~	~~1.7006~~	~~0.3311~~	~~1.3755~~	~~0.8088~~	~~2124.7415~~	~~17.5134~~	~~1843.7796~~	~~22.0417~~	~~1979.6564~~	~~14.9122~~	~~93.0088~~
1.sMPABC075	56.2073	0.0811	107.6720	0.0597	1.1400	0.7957	1.8295	0.0967	1.4309	0.7821	590.9021	24.7193	595.3228	8.1187	594.4047	8.2504	100.0912
1.sMPABC076	59.7452	0.0881	400.9862	0.1054	1.0148	4.4694	1.7264	0.3074	1.3966	0.8090	1722.0004	18.6422	1728.0414	21.1535	1725.3110	14.4180	100.0318
1.sMPABC077	234.5042	0.0198	1521.0390	0.1226	1.0199	6.1155	1.7119	0.3619	1.3750	0.8032	1993.8246	18.1305	1991.1363	23.5406	1992.4557	15.0439	99.7993
1.sMPABC078	39.9792	0.1324	18.6937	0.0597	1.2232	0.7831	1.9169	0.0952	1.4759	0.7699	591.9923	26.5187	585.9996	8.2483	587.2306	8.5685	99.7279
1.sMPABC079	186.1299	0.1833	907.1390	0.1308	1.0032	6.9730	1.7025	0.3866	1.3755	0.8079	2108.9767	17.6008	2106.9980	24.7122	2107.9993	15.2260	99.8150
1.sMPABC080	70.4197	0.0962	47455.8742	0.1059	1.0199	4.4432	1.7302	0.3043	1.3977	0.8078	1729.8201	18.7181	1712.7390	21.0052	1720.4384	14.4347	99.4267

Concordance calculated as (206Pb-238U age/207Pb-206Pb age)*100