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CORRELAÇÕES BIOESTRATIGRÁFICAS E FACIOLÓGICAS DA FASE PÓS-RIFTE DAS BACIAS DE ARARIPE, TUCANO NORTE E JATOBÁ, NORDESTE DO BRASIL

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Tese apresentada ao Programa de Pós-Graduação em Geociências da Universidade Federal de Pernambuco, Centro de Tecnologia e Geociências, como requisito para obtenção do título de Doutora em Geociências. Área de Concentração: Geologia Sedimentar e Ambiental

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RESUMO

As bacias mesozoicas interiores de Araripe, Tucano Norte e Jatobá representam um ramo do Rifte Sul-Atlântico abortado no Eoaptiano. A seção pós-rifte, correspondente ao Andar Local Alagoas, Biozona Ostracoda 011 (Aptiano), é registrada na Bacia do Araripe pelo Grupo Santana, que é constituído, da base para topo, pelas formações Barbalha, Crato, Ipubi e Romualdo. Nas bacias de Tucano Norte e Jatobá, a Formação Marizal é correlata à Formação Barbalha e, com exceção da Formação Ipubi, as demais unidades litoestratigráficas de mesmo nome e correlatas às do Grupo Santana são registradas. Seis testemunhos de sondagem e quinze afloramentos foram litologicamente caracterizados e amostrados, resultando em mais de 100.000 espécimes de ostracodes e mais de 9.300 espécimes de foraminíferos recuperados ao longo da sequência pós-rifte das três bacias estudadas. Os microfósseis recuperados da Bacia do Araripe se apresentaram melhor preservados, abundantes e diversos em comparação com as bacias de Tucano Norte e Jatobá, proporcionando uma taxonomia de Ostracoda mais detalhada, que, integrada à ocorrência de foraminíferos, permitiu o refinamento bioestratigráfico e paleoambiental do Grupo Santana, base para a posterior correlação com as demais bacias. Vinte e cinco táxons de ostracodes foram identificados, incluindo a proposição de cinco espécies novas: *Damonella pumila*, *Pattersoncypris cucurves*, *Pattersoncypris kroemmelbeini*, *Ilyocypris coimbrai* e *Rhinocypris spinata*. A Zona *Pattersoncypris micropapillosa* (OST-011), foi descrita e dividida nas subzonas *Pattersoncypris cucurves* (OST-011.1) (Camadas Batateira, Formação Barbalha), *Pattersoncypris cucurves-Neuquenocypris berthoui* (OST-011.2) (sequência superior da Formação Barbalha), *Damonella grandiensis* (OST-011.3) (Formação Crato) e *Pattersoncypris crepata* (OST-011.4) (formações Ipubi e Romualdo). Dois intervalos bioestratigráficos de foraminíferos planctônicos foram identificados permitindo a calibração internacional das subzonas de ostracodes, a Zona *Leupoldina cabri* do Aptiano inferior contém as subzonas OST-011.1 a OST-011.2 e a zona composta *Hedbergella infracretacea*–*Microhedbergella miniglobularis* do Aptiano superior correlacionada com a subzona OST-011.4. Durante o Aptiano, a Bacia do Araripe evoluiu de um ambiente transicional a marinho, registrando o “Sistema Estuarino Batateira” no Eoaptiano, seguido de uma progradação continental representada pelo “Sistema Fluvial Barbalha” até uma nova transgressão que originou um delta de cabeceira. No início do Neoaptiano, desenvolveu-se a “Baía Crato”, que posteriormente retrogradou gerando uma rampa restrita sob aridez extrema e a precipitação do “Evaporito Ipubi”. A última fase deposicional aconteceu no final do Aptiano com a completa instalação do mar na “Rampa Externa Romualdo”. Litologicamente e bioestratigraficamente é possível correlacionar os estratos do Grupo Santana da Bacia do Araripe e as unidades pós-rift das bacias Tucano Norte e Jatobá, a partir da análise de associações de fácies tanto macro como microscópica e das ocorrências de ostracodes e foraminíferos.

Palavras-chave: Aptiano; Andar Alagoas; Nordeste do Brasil; ostracodes; foraminíferos; ambiente transicional.

ABSTRACT

The Araripe, Tucano Norte and Jatobá Mesozoic basins represent a branch of the South Atlantic Rift aborted in the early Aptian. The post-rift phase, which corresponds to the Alagoas Local Stage, Ostracoda Biozone 011 (Aptian), is recorded in the Araripe Basin by the Santana Group, constituted from base to top by the Barbalha, Crato, Ipubi and Romualdo formations. In the Tucano Norte and Jatobá basins, the Marizal Formation is correlated with the Barbalha Formation, and excepting the Ipubi Formation the other units with same name and correlated to those of the Santana Group are recorded. Six well cores and fifteen outcrops were lithologically characterized and sampled, resulting in more than 100,000 ostracod specimens and more than 9,300 foraminifer specimens along the post-rift sequence from the three studied basins. The microfossils recovered from the Araripe Basin presented better preservation, abundance and diversity compared with the Tucano Norte and Jatobá basins, providing a more detailed Ostracoda taxonomy that, integrated to the Foraminifera occurrence allowed the biostratigraphic and palaeoenvironmental refinement of the Santana Group, base for the posterior correlation with the other basins. Twenty-five ostracod taxa were identified, including the proposal of five new species: *Damonella pumila*, *Pattersoncypris cucurves*, *Pattersoncypris kroemmelbeini*, *Ilyocypris coimbrai* e *Rhinocypris spinata*. The *Pattersoncypris micropapillosa* Zone (OST-011) was described and divided into the subzones *Pattersoncypris cucurves* (OST-011.1), *Pattersoncypris cucurves-Neuquenocypris berthoui* (OST-011.2), *Damonella grandiensis* (OST-011.3) and *Pattersoncypris crepata* (OST-011.4). Two biostratigraphic intervals of planktic foraminifers were identified allowing the international calibration of the ostracod subzones, the lower Aptian *Leupoldina cabri* Zone contents the OST-011.1 to OST-011.2 subzones, and the upper Aptian *Hedbergella infracretacea–Microhedbergella miniglobularis* composite zone correlated to the OST-011.4 subzone. During the Aptian, the Araripe Basin evolved from a transitional to a marine environment, recording the early Aptian “Batateira Estuarine System”, followed by a continental progradation represented by the “Barbalha Fluvial System” up to a new transgression originating a bayhead delta. In the beginning of the late Aptian, the “Crato Bay” developed, that posteriorly retrograded forming a restricted marine ramp under extreme aridity and the precipitation of the “Ipubi Evaporite”. The last depositional phase took place during the latest Aptian with the full installation of the sea on the “Romualdo Outer Ramp”. Lithologically and biostratigraphically it is possible to correlate the Santana Group strata and the post-ritf units of the Tucano Norte and Jatobá basins, from the analyses of macro and microfacies and of the ostracods and foraminifera occurrence.

Keywords: Aptian; Alagoas Stage; Northeast Brazil; ostracods; foraminifera; transitional environment.

SUMÁRIO

1 INTRODUÇÃO

As bacias da margem continental do Brasil registram a evolução do segmento norte do Sistema Rifte Sul-Atlântico, o qual se desenvolveu durante o Mesozoico com a separação de América do Sul e África (CHANG; KOWSMANN; FIGUEREIDO, 1988). O desenvolvimento do rifte Sul-Atlântico teve início pelo extremo sul no Berriasiano com velocidades baixas até o Hauteriviano, quando a atividade rifte aumentou no Atlântico Equatorial com rotação NE-SW (HEINE; ZOETHOUT; MÜLLER, 2013). A partir do Eoaptiano, o rompimento litosférico foi diacrônico, e o final da quebra continental entre América do Sul e África aconteceu no segmento Santos-Benguela há aproximadamente 113 Ma e no segmento Atlântico equatorial entre Gana e a margem Piauí-Ceará há 103 Ma (HEINE; ZOETHOUT; MÜLLER, 2013). Ao contrário das bacias da margem leste do Brasil que evoluíram ao estágio de deposição drifte, as bacias mesozoicas interiores do Araripe e do subsistema Tucano Norte-Jatobá registram a interrupção do processo de estiramento crustal no início do Aptiano. Dados paleontológicos sugerem que águas vindas do Mar de Tétis teriam atravessado o interior do Nordeste do Brasil durante o Aptiano (ARAI, 2009, 2014, 2016; ARAI et al., 2000; MELO et al., 2020). A ingressão marinha registrada nas bacias interiores do Nordeste do Brasil é o reflexo da subsidência térmica e de eventos eustáticos globais de elevação do nível do mar, que criaram espaço de acomodação para a deposição dos sedimentos (ASSINE, 2007; VAZ et al., 2007). Durante o Aptiano e Eoalbiano, o nível eustático do mar permaneceu em um período de estase, no qual apenas variou numa amplitude moderada, entre 25 e 75 m (HAQ, 2014).

Na fase pós-rifte, a megassequência transicional evaporítica é composta de sedimentos depositados em ambiente continental a marinho durante o Aptiano (Andar Local Alagoas) (CHANG; KOWSMANN; FIGUEREIDO, 1988). Nas bacias interiores tipo rifte do Nordeste do Brasil, as rochas sedimentarias aptianas são extensas embora menos espessas em relação às bacias marginais, e têm sido comumente caraterizadas como depósitos aluviais e flúvio-lacustres associados a *sabkhas* costeiros locais, originados em condições de clima árido a semiárido (ASSINE, 1992; BUENO, 1996; CHANG et al., 1992; NEUMANN et al., 2009; NEUMANN; ROCHA, 2014; VAREJÃO et al., 2021; VAZ et al., 2007). Para o topo da sequência transicional evaporítica, o empilhamento é transgressivo e os arenitos costeiros cedem lugar a uma seção com influência marinha (ASSINE, 2007; CUSTÓDIO et al., 2017; VAREJÃO et al., 2019; VAZ et al., 2007). Na Bacia do Araripe, o Grupo Santana é a unidade litoestratigráfica que registra a fase transicional pós-rifte, este é constituído de base para topo pelas formações Barbalha, Crato, Ipubi e Romualdo (ASSINE et al., 2014; NEUMANN; CABRERA, 1999). Nas bacias do subsistema Tucano Norte-Jatobá, a Formação Marizal é correlata à Formação Barbalha e, com exceção da Formação Ipubi, as demais unidades do Grupo Santana são registradas (NEUMANN; ROCHA, 2014; VAREJÃO et al., 2016). Estas unidades da fase pós-rifte são associadas à biozona RT-011, caracterizada inicialmente pela ocorrência de ostracodes agrupados como *Cytheridea*? spp. 201–218 (SCHALLER, 1969). Posteriormente vários destes táxons foram identificados em espécies pertencentes aos gêneros *Pattersoncypris* Bate, 1972 e *Damonella* Anderson, 1966 (BERTHOU et al., 1994; COIMBRA; ARAI; CARREÑO, 2002; COLIN; DÉPÊCHE, 1997; SILVA-TELLES JR.; VIANA, 1990; TOMÉ; LIMA FILHO; NEUMANN, 2014). Além de ostracodes, nas rochas aptianas das bacias de Araripe, Tucano Norte e Jatobá, fósseis mixohalinos e/ou marinhos como dinoflagelados, foraminíferos, peixes, equinoides e moluscos foram encontrados (ARAI et al., 2000; ARARIPE et al., 2021; BRITO; NASCIMENTO; MEUNIER, 2021; BRITO; YABUMOTO, 2011; GOLDBERG et al., 2019; MELO et al., 2020; PRADO; CALADO; BARRETO, 2019; PRADO; FAMBRINI; BARRETO, 2018; PRADO et al., 2018; VAREJÃO et al., 2021).

Em paleoambientes aquáticos continentais, representantes da Classe Ostracoda normalmente são os microfósseis calcários mais frequentes e abundantes. Em paleoambientes marinhos, os ostracodes também ocorrem possuindo grande aplicação paleoecológica e paleoceanográfica, porém, nestes ambientes, o Filo Foraminifera apresenta maior aplicação bioestratigráfica. O alto potencial de fossilização, frequência de ocorrência, diversidade e abundância destes grupos, os caracterizam como excelentes ferramentas para muitas aplicações, como interpretações paleoecológicas, paleobiogeográficas, bioestratigráficas e quimioestratigráficas.

Novas metodologias de recuperação e análise microfossilífera nas bacias do Araripe, Tucano Norte e Jatobá têm permitido avanços na taxonomia dos representantes da Classe Ostracoda e evidenciado a ocorrência de outros grupos, como foraminíferos planctônicos e bentônicos. À luz destas descobertas será possível a atualização da bioestratigrafia da sequência pós-rifte da margem continental brasileira. A integração dos dados bioestratigráficos à caracterização faciológica dos estratos, permitirá propor modelos deposicionais da evolução da sequência pós-rifte na região das bacias de Araripe, Tucano Norte e Jatobá durante o Aptiano.

1.1 OBJETIVOS

1.1.1 Objetivo geral

O objetivo geral desta pesquisa é caracterizar a faciologia e refinar a bioestratigrafia dos depósitos sedimentares da fase pós-rifte, Andar Alagoas das bacias de Araripe, Tucano Norte e Jatobá, NE do Brasil. A integração destes dados visa à interpretação dos paleoambientes de deposição e a correlação cronoestratigráfica e litoestratigráfica dos sedimentos da fase pós-rifte das referidas bacias e com os eventos regionais e/ou globais.

1.1.2 Objetivos específicos

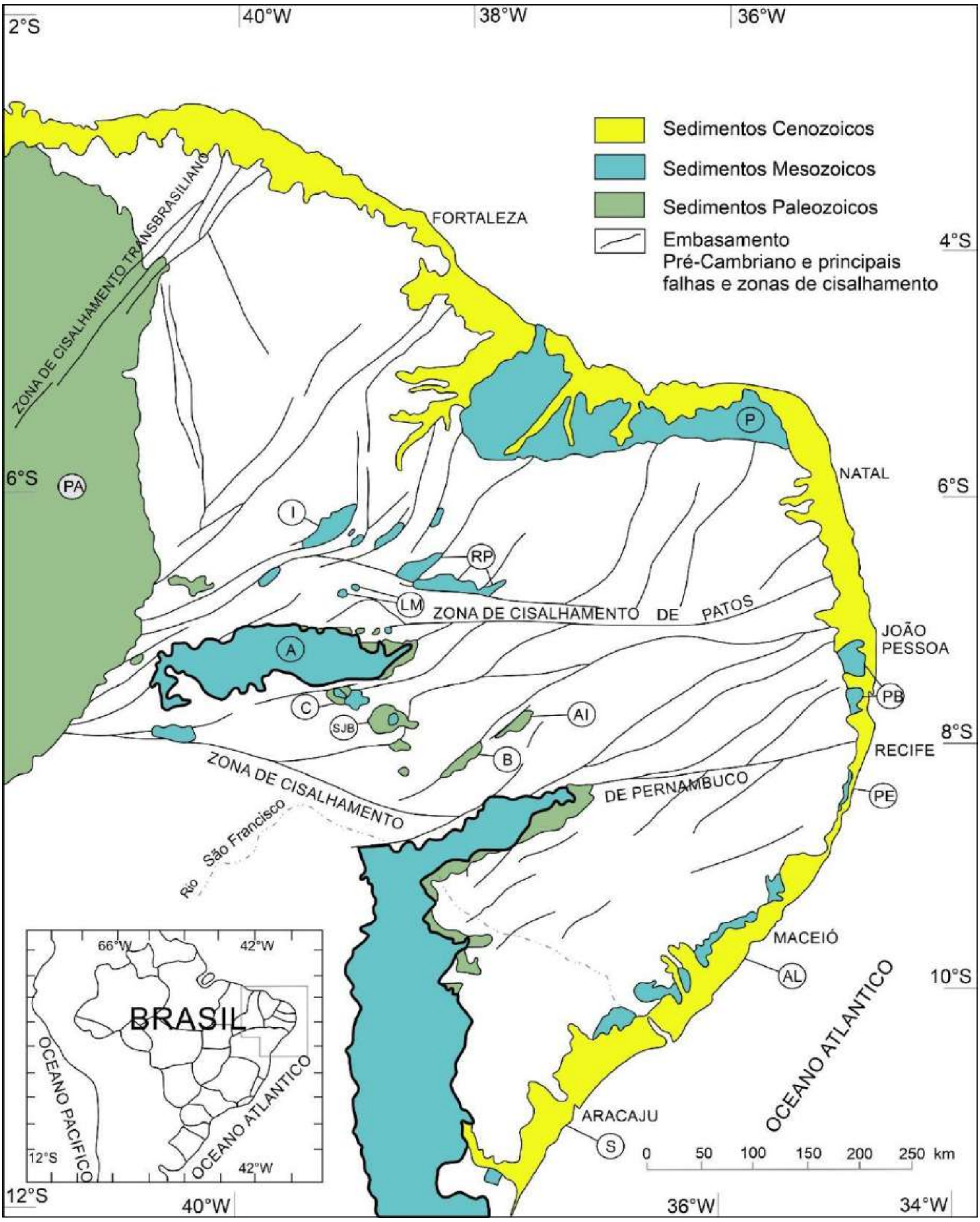
- Elaborar perfis sedimentológicos de testemunhos de sondagem e afloramentos das bacias de Araripe, Tucano Norte e Jatobá e identificar suas litofácies macroscópicas.
- Caracterizar as microfácies carbonáticas a partir do estudo petrográfico.
- Identificar e classificar os microfósseis carbonáticos recuperados, com ênfase na fauna de ostracodes.
- Refinar o arcabouço bioestratigráfico do Andar Alagoas, com base em microfósseis carbonáticos.
- Integrar a bioestratigrafia de ostracodes às ocorrências de foraminíferos visando interpretar os paleoambientes de deposição das unidades litoestratigráficas das sequências estudadas.
- Correlacionar eventos atuantes regional e/ou globalmente a fim de estabelecer a possível conexão das bacias de Araripe, Tucano Norte e Jatobá, na região centro-norte de Gondwana durante o Aptiano.

2 CONTEXTO GEOLÓGICO-ESTRATIGRÁFICO

As bacias de Araripe, Jatobá e Tucano Norte representam bacias interiores tipo rifte abortado localizadas na região Nordeste do Brasil que foram implantadas sobre terrenos cristalinos Pré-Cambrianos que constituem a Província Borborema. A Província Borborema (PB) engloba o conjunto de unidades geológicas estabilizadas ao final da Orogênese Brasiliana/Pan-Africana (600 ± 50 Ma) e representa um segmento crustal de uma extensa faixa fortemente afetada pela deformação, resultante da colisão entre os crátons do Oeste Africano/São Luís e Congo-Kasai/São Francisco, que constituíam massas continentais consolidadas em tempos anteriores à articulação de Gondwana (BRITO NEVES; SANTOS; VAN SCHMUS, 2000). Os limites desta província são marcados a norte e leste por bacias sedimentares costeiras, a oeste pela Bacia do Parnaíba e a sul pelo Cráton São Francisco. A Província Borborema é dividida em cinco grandes domínios tectônicos Médio Coreaú, Ceará, Rio Grande do Norte, da Zona Transversal ou Central e Sul ou Externo (NEVES, 2003; VAN SCHMUS et al., 2008). Os domínios tectônicos da PB são separados por zonas de sutura, tais como: a Zona de Cisalhamento de Pernambuco limite tectônico do Domínio Sul com o Transversal, e a Zona de Cisalhamento de Patos como o limite do Domínio Transversal com o Domínio Rio Grande do Norte (Figura 1).

O registro estratigráfico do Mesozoico das bacias da margem continental brasileira foi consolidado por Ponte, Dauzacker e Porto (1978) que estabeleceram cinco megassequências: continental, transicional evaporitica, de plataforma carbonática rasa, marinha transgressiva e marinha regressiva. Segundo Chang, Kowsmann e Figuereido (1988) e Chang et al. (1992), a megasequência continental compreende três sequencias de estágios sin-rifte baseados nas suas associações de fácies e estilos estruturais: (1) sin-rifte I do final do Jurássico (Andar Local Dom João) corresponde ao estágio inicial de subsidência relacionada ao estiramento litosférico inicial (GARCIA, 1991), que resultou na formação da “Depressão Afro-brasileira” (CESERO; PONTE, 1972); (2) sin-rifte II, depositada durante o Eocretáceo (andares locais Rio da Serra–Aratu) quando o rifteamento alcança o seu clímax e a extensão acelerada da crosta provocou o rápido aprofundamento dos grábens, nos quais lagos de água doce e permanentemente estratificados foram estabelecido; (3) sin-rifte III com uma taxa de subsidência maior, a sedimentação dos lagos foi sucedida pela deposição de sedimentos aluvio-fluviais no Barremiano (andares locais Buracica–Jiquiá). Seguindo o modelo de Prosser (1993) e a modificação de Kuchle e Scherer (2010), a estratigrafia das bacias interiores de Araripe, Tucano Norte e Jatobá, do tipo rifte abortado, é subdividida nas sequências sinéclise paleozoica, início de rifte, desenvolvimento do hemi-gráben e clímax de rifte e pós-rifte (GUZMÁN et al., 2015; KUCHLE et al., 2011; SCHERER et al., 2014).

Figura 1 – Mapa da Provincia Borborema, Nordeste do Brasil, apresentando as bacias fanerozoicas da região: Destacam-se as bacias rifte de Araripe, e do sistema Recôncavo-Tucano-Jatobá. Legenda: AI = Afogados da Ingazeira; AL = Alagoas; B = Betânia; C = Cedro; I = Iguatu; LM = Lavras da Mangabeira; P = Potiguar; PA = Parnaíba; PB = Paraíba; PE = Pernambuco; RP = Rio do Peixe; S = Sergipe; SJB = São José do Belmonte; R = Recôncavo



Fonte: modificada de Assine (1992).

A sequência pós-rifte cobre a megassequência continental, assentada sobre uma discordância angular regional responsável pela peneplanação geral da topografia rifte, esta discordância é reconhecida na maioria das bacias do Sistema Rifte do leste do Brasil (ASSINE, 2007; CHANG; KOWSMANN; FIGUEREIDO, 1988). Nas bacias de Araripe e Jatobá, a sequência pós-rifte é dividida em duas unidades, pós-rifte I e pós-rifte II (ASSINE, 2007; NEUMANN; ROCHA, 2014). A unidade pós-rifte I, corresponde a sequência transicional evaporítica caracterizada por rochas do Aptiano (Andar Local Alagoas), de pouca espessura, mas de grande extensão, e compostas por sedimentos siliciclásticos de ambiente flúvio-lacustre e aluvial, substituídos por carbonatos e folhelhos associados localmente com evaporitos depositados em ambientes costeiros de supramaré. Para o topo da unidade é marcada a transgressão marinha no interior do nordeste do Brasil (ASSINE, 2007; ASSINE et al., 2014; CHANG et al., 1992; VAZ et al., 2007). A sequência pós-rifte II, de deposição aluvio-fluvial registra o retorno das condições continentais nas bacias interiores (ASSINE, 2007; NEUMANN; ROCHA, 2014), esta diverge do registro pós-Aptiano das bacias marginais de deposição marinha drifte.

Implantada nos terrenos pré-cambrianos São José do Caiano da Zona Transversal da Província Borborema (BRITO NEVES; SANTOS; VAN SCHMUS, 2000) ao norte da Zona de Cisalhamento de Pernambuco e sul da Zona de Cisalhamento de Patos, a Bacia do Araripe é a mais extensa das bacias mesozoicas interiores do Nordeste abarcando território dos estados de Pernambuco, Piauí e principalmente Ceará. Esta bacia apresenta duas fisionomias distintas, o Vale do Cariri e a Chapada do Araripe. As sub-bacias do Cariri e da Chapada do Araripe são estruturadas por falhas de direção NE e WNW. Tal estruturação foi consequência da propagação continente adentro dos eventos tectônicos relacionados à fase rifte das bacias da margem atlântica brasileira (ASSINE, 1992; MATOS, 1992; PONTE; PONTE FILHO, 1996). O Vale do Cariri se estende para leste onde, segundo Assine (2007), afloram a Formação Cariri (Paleozoico) da sequência sinéclise, as formações Brejo Santo e Missão Velha (Jurássico Superior) da sequência início do rifte e a Formação Abaiara (Berriasiano–Hauteriviano inferior) da sequência clímax do rifte. A Chapada do Araripe de maior extensão para o oeste é formada pela sequência pós-rifte (Aptiano–Albiano), as formações Barbalha, Crato, Ibupi e Romualdo do Grupo Santana integram a sequência pós-rifte I, esta é separada por uma discordância erosiva regional da sequência pós-rifte II conformada pelas formações Araripina e Exu (ASSINE et al., 2014).

As bacias de Tucano Norte e de Jatobá representam a extremidade setentrional do Sistema Rifte Recôncavo-Tucano-Jatobá. Estas bacias situadas principalmente nos estados de Bahia, Sergipe e Pernambuco, são formadas por um sistema de grábens de direção S–N (Recôncavo–Tucano), que muda abruptamente de direção para W–E constituindo a Bacia de Jatobá. O sistema compreende estas três bacias, separadas por altos/arcos do embasamento (COSTA et al., 2007). O embasamento da Sub-bacia de Tucano Norte é representado pelos terrenos Canindé-Marancó e Pernambuco-Alagoas a noroeste e leste-nordeste, pelos metassedimentos da Faixa de Dobramentos Sergipana a oeste-sudoeste e sudeste, e pelas rochas sedimentares da Bacia Juá, a sudeste. A Bacia de Jatobá instalou-se integralmente sobre o terreno Pernambuco-Alagoas. A configuração estrutural destas bacias reflete a atuação dos esforços extensionais em um embasamento heterogêneo (MAGNAVITA, 1996). A mudança no sentido de abertura do rifte, que passa de S–N, no Tucano Norte, para SW–NE, na Bacia de Jatobá, é talvez o exemplo mais claro do controle exercido por estruturas pretéritas do embasamento (COSTA et al., 2007). Esta inflexão está condicionada à Zona de Cisalhamento de Pernambuco, cuja reativação durante o Eocretáceo deu origem à Falha de Ibimirim, limite norte da Bacia de Jatobá (COSTA et al., 2007; SANTOS; CUPERTINO; BRAGA, 1990). Tanto a Sub-bacia de Tucano Norte, como a Bacia de Jatobá, apresenta uma geometria típica de meio-gráben, com falhas de borda a oeste e noroeste, respectivamente. A estratigrafia das bacias Tucano Norte e Jatobá apresenta diferenças no seu registro sedimentar e tectono-estrutural (GUZMÁN et al., 2015). As diferenças fundamentais encontram-se na fase rifte, que é menos pronunciada na Bacia de Jatobá do que na Bacia de Tucano Norte. Rochas sedimentares pertencentes ao Grupo Jatobá (formações Tacaratu e Inajá) caracterizam a sequência sinéclise siluro-devoniana, que aflora a S–SE da Bacia de Jatobá e a leste da Sub-bacia de Tucano Norte, no Gráben de Santa Brígida. A Formação Inajá restringe-se à Bacia de Jatobá. As formações Curituba e Santa Brígida, de idade Carbonífero e Permiano, respetivamente, só são registradas na bacia de Tucano Norte. A área abrangida pela Sub-bacia de Tucano Norte e pela Bacia de Jatobá representa a porção distal dos sistemas aluviais do Jurássico Superior (Andar Dom João), e rochas das formações Aliança e Sergi foram depositadas no início do rifte sob paleoclima árido. As sequências clímax e fase final do rifte (Berriasiano–Eoaptiano), compreendem depósitos relacionáveis à Formação Candeias, ao Grupo Ilhas e à Formação São Sebastião; da Formação Salvador somente se tem registro de subsuperfície na Bacia de Tucano Norte. A tectono-sequência pós-rifte I do Andar Alagoas (Aptiano) para ambas as bacias é representada pela Formação Marizal, cronocorrelata à Formação Barbalha na Bacia do Araripe, e pelas demais formações que compõem o Grupo Santana.A litologia das unidades da sequência pós-rifte I das bacias de Araripe, Tucano Norte e Jatoba é mista, apresentando tanto rochas clásticas como carbonáticas. As formações Barbalha e Marizal são essencialmente compostas por arenitos abrangendo o intervalo de folhelhos com abundante matéria orgânica das Camadas Batateira/Camadas Amargosa (ASSINE, 2007; ASSINE et al., 2014; VAREJÃO et al., 2016). A Formação Crato, é caraterizada por bancos de ritmitos calcário-argilito intercalados com folhelhos (BUENO, 1996; NEUMANN; CABRERA, 1999; NEUMANN; ROCHA, 2014; VAREJÃO et al., 2016). Sobrepostos aos sedimentos da Formação Crato, lentes de evaporito em associação com folhelhos compõem a Formação Ipubi (ASSINE et al., 2014; NEUMANN; ROCHA, 2014). A unidade superior, a Formação Romualdo, compreende conglomerados estratificados, arenitos, calcários, margas e folhelhos (ASSINE et al., 2014; NEUMANN; ROCHA, 2014).

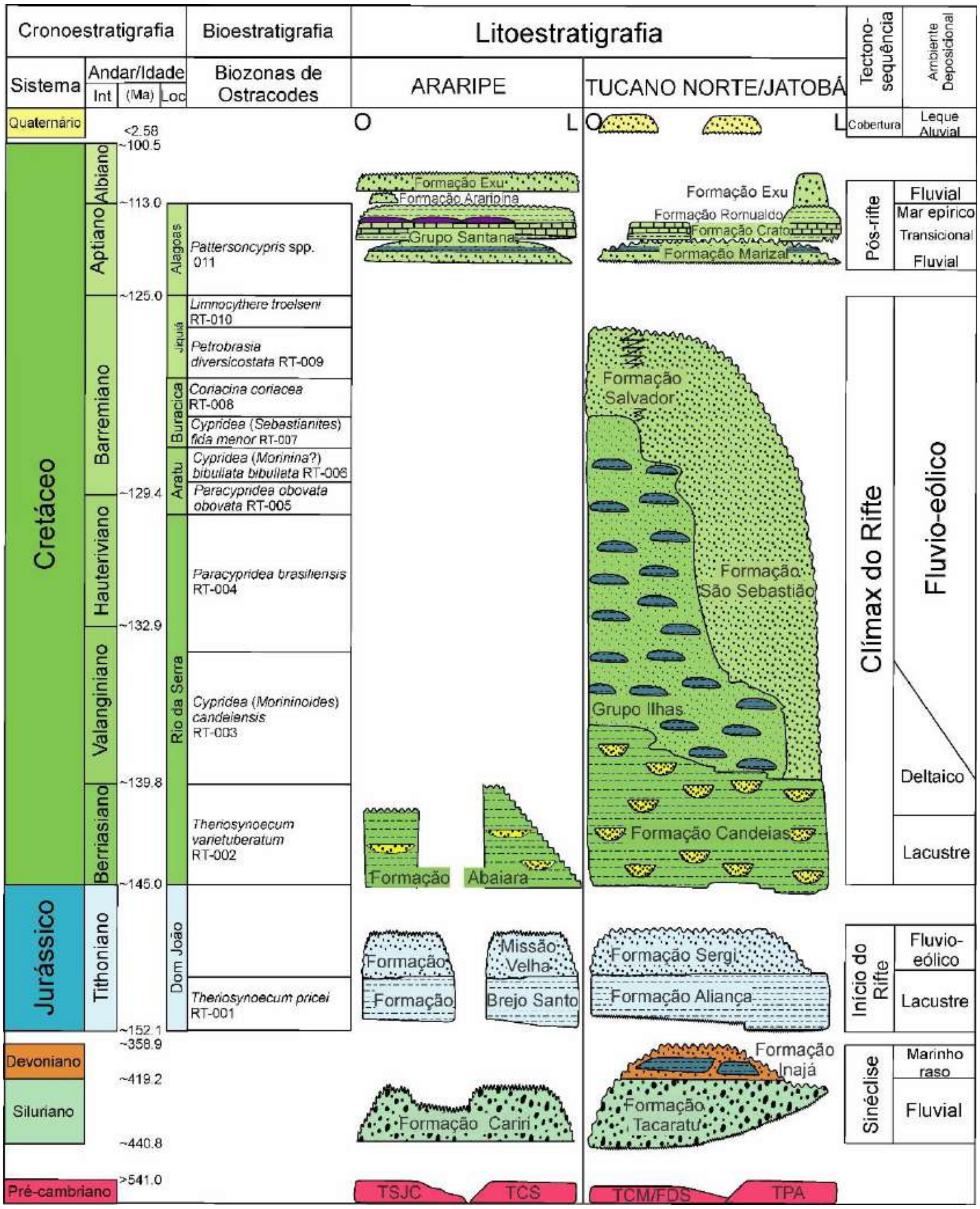
2.1 BIOESTRATIGRAFIA E PALEOAMBIENTES

Os depósitos sedimentares de idade mesozoica nas bacias de Araripe, Tucano Norte e Jatobá representam as fases rifte (início de rifte e clímax de rifte) e pós-rifte que se desenvolveram do final do Jurássico ao final do Eocretáceo durante o processo de quebra continental do Supercontinente Gondwana, resultando na separação dos continentes América do Sul e África. O arcabouço bioestratigráfico das bacias de Araripe, Tucano Norte e Jatobá foi estabelecido a partir da identificação de ostracodes como marcadores dos andares locais, permitindo datar a deposição das sequências tectono-estratigráficas de evolução rifte. As biozonas de Ostracoda RT-001 a RT-011, abrangem, na estratigrafia local, os andares Dom João (Jurássico Superior), Rio da Serra (Berriasiano – Hauteriviano inferior), Aratu (Hauteriviano – Barremiano), Buracica (Barremiano), Jiquiá (Barremiano – Aptiano) e Alagoas (Aptiano) (Figura 2) (ALMEIDA-LIMA et al., 2022a; COIMBRA; ARAI; CARREÑO, 2002; CUNHA; MOURA, 1979; GUZMÁN et al., 2015; KUCHLE et al., 2011; MELO et al., 2020; MENDES et al., 2020; REGALI; VIANA, 1989; SCHALLER, 1969; VIANA et al., 1971).

O trato tectônico de início do rifte, composto pelas formações Aliança e Sergi (Grupo Brotas, bacias de Tucano Norte e Jatobá) e pelas formações Brejo Santo e Missão Velha (Bacia do Araripe), registra sedimentação continental composta por sistemas fluviais, eólicos e lacustres (KUCHLE; SCHERER, 2010). O primeiro ciclo lacustre desenvolvido durante esta fase (Neojurássico, Andar Dom João), denominado Lago Capianga, é caracterizado como uma bacia endorreica de grande extensão, cujo registro nestas bacias corresponde às formações Brejo Santo e Aliança, relacionada a biozona de ostracodes RT-001 *Theriosynoecum pricei*

(ALMEIDA-LIMA et al., 2022a, 2022b; COIMBRA; ARAI; CARREÑO, 2002; GUZMÁN-GONZÁLEZ et al., 2016; GUZMÁN et al., 2015; KUCHLE et al., 2011). Estas formações são constituídas principalmente por lamitos maciços ou laminados, vermelhos, com alguns estratos cinza esverdeados, intercalados com arenitos e coquinas de ostracodes de laminação cruzada.

Figura 2 – Carta estratigráfica atualizada da Bacia do Araripe e do sistema de bacias Tucano Norte-Jatobá ilustrando andares locais, biozonas de ostracodes e tectono-sequências estratigráficas



Fonte: Piovesan et al. (2021), baseada em Arai e Assine (2020), Assine (2007), Caixeta et al. (1994), Costa et al. (2007), Guzmán et al. (2015), Melo et al. (2020), Mendes et al. (2020), Moura e Praça (1985), Moura (1988), Neumann e Rocha (2014), Regali e Viana (1989) e Schaller (1969), Varejão et al. (2021).

Durante o desenvolvimento tectônico do hemi-gráben e clímax do rifte (Andar Rio da Serra no intervalo Berriasiano–Hauteriviano), foram depositadas as formações Abaiara na Bacia do Araripe, Candeias e a base do Grupo Ilhas nas bacias de Jatobá e Tucano Norte. Estas unidades representam a segunda fase flúvio-lacustre e deltaica que se instalou no sistema, com caraterísticas de maior profundidade que evidenciam tectonismo mais intenso, aumento progressivo na taxa da subsidência e maior umidade (KUCHLE; SCHERER, 2010). O Andar Rio da Serra nestas bacias é registrado como folhelhos e siltitos vermelhos, com intercalações lateralmente descontínuas de arenitos deltaicos (ASSINE, 2007; COSTA et al., 2007; SCHERER et al., 2014). A fauna de ostracodes representativa corresponde às biozonas *Theriosynoecum varietuberatum* (RT-002), *Cypridea* (*Morininoides*) *candeiensis* (RT-003) e *Paracypridea brasiliensis* (RT-004) (CUNHA; MOURA, 1979). O estágio final do rifte é marcado por uma diminuição da atividade tectônica e o recuo do sistema lacustre (KUCHLE; SCHERER, 2010). O total preenchimento do rifte com a deposição da porção média e superior do Grupo Ilhas e as formações Salvador e São Sebastião nas bacias de Tucano Norte e Jatobá representa esta fase final do rifteamento. Na Bacia do Recôncavo, estas unidades registram associações de ostracodes dos andares Aratu, biozonas *Paracypridea obovata obovata* (RT-005), *Cypridea* (*Morinina*?) *bibullata bibullata* (RT-006), Buracica, biozonas *Coriacina coriacea* (RT-007) e *Cypridea* (*Sebastianites*) *fida minor* (RT-008) e Jiquiá, biozona *Petrobrasia diversicostata* (RT-009) (CUNHA; MOURA, 1979). Almeida-Lima et al. (2022a), só reconheceram a Biozona RT-002 na Bacia de Tucano Norte, enquanto na Bacia de Jatobá o registro foi mais amplo, da Biozona RT-003 a Biozona RT-007. Na Bacia do Araripe, ocorrem depósitos das bizonas RT-002 a RT-004 (COIMBRA; ARAI; CARREÑO, 2002), embora, não haja registro de seções pertencentes aos andares Buracica e Jiquiá, devido, provavelmente, a estruturação rúptil, não criando espaço de acomodação e basculamento das unidades mais antigas (ASSINE, 2007).

A sequência pós-rifte I ocorre através de todo o subsistema rifte Tucano Norte-Jatobá e na Bacia do Araripe. O Grupo Santana conformado pelas formações Barbalha, Crato, Ipubi e Romualdo, é registrado em sua totalidade na Bacia do Araripe (ASSINE et al., 2014; NEUMANN; ASSINE, 2015). Nas bacias de Tucano Norte e Jatobá, a base da sequência pós-rifte I é denominada Formação Marizal, correlata à Formação Barbalha, a Formação Crato é registrada nas duas bacias, enquanto a Formação Ipubi é ausente, e a Formação Romualdo só ocorre na Bacia de Jatobá (NEUMANN; ROCHA, 2014; VAREJÃO et al., 2016). Os depósitos sedimentares da sequência pós-rifte I registram a evolução de um ambiente transicional para rampa marinha (CUSTÓDIO et al., 2017; MELO et al., 2020; VAREJÃO et al., 2019, 2021).

A fauna de ostracodes presente na sequência pós-rifte I tem sido associada à Biozona 011 que caracteriza o Andar Alagoas. Esta biozona apresenta duas propostas de denominação: 1. Poropat e Colin (2012), propõem os táxons *Pattersoncypris* e *Kroemmelbeincypris* como espécies-guia deste intervalo, entretanto, a proposta está sendo criteriosamente analisada sob o ponto de vista taxonômico, uma vez que apresenta divergências; 2. Tomé et al. (2014), na qual descrevem a espécie *Damonella grandiensis* e consideraram este táxon como o guia da biozona. A revisão taxonômica detalhada dos ostracodes deste intervalo poderá com maior critério definir qual é a espécie mais apropriada para formalmente nomear a biozona. Devido a sua ampla distribuição geográfica e calibração com biozonas de foraminíferos, representantes do gênero *Pattersoncypris* são mais adequados para caracterização da Biozona 011.

Muitos trabalhos abordaram a idade e a direção de entrada da água do mar nas bacias interiores brasileiras (ARAI; ASSINE, 2020 e referências citadas naquele trabalho). Modelos tectônicos e geodinâmicos indicaram a abertura do Oceano Atlântico Sul se iniciando no Sul, mas evidências estratigráficas e paleontológicas recentes, incluindo dados produzidos no âmbito deste projeto, indicam que a ingressão marinha cretácea nas bacias mesozoicas do Brasil chegou do Oceano Tétis, ao Norte. A diferenciação paleobiogeográfica é sustentada pela associação de microfósseis aptianos do Atlântico Sul em decorrência da barreira física no segmento Santos–Benguela que impediu a livre circulação e mistura da água do mar entre o Atlântico Sul e o Atlântico central-equatorial (MELO et al., 2020).

3 MATERIAL E MÉTODOS

O presente estudo de doutorado está inserido no projeto “ARTUNJA: Correlações Bioestratigráficas dos Sistemas Flúvio-Lacustres das fases Rifte e Pós-Rifte das Bacias do Araripe, Tucano Norte e Jatobá, NE do Brasil”, um projeto de pesquisa concluído (2018–2021), coordenado pela Profª. Drª. Enelise Katia Piovesan e financiado pela Petrobras (2017/00263-2). Todos os processos laboratoriais deste estudo foram completamente desenvolvidos no Laboratório de Micropaleontologia Aplicada (LMA), Instituto de Pesquisa em Petróleo e Energia (LITPEG), Universidade Federal de Pernambuco (UFPE).

O material é constituído por seções estratigráficas de afloramentos e seis testemunhos de sondagem provenientes das bacias de Araripe, Tucano Norte e Jatobá (Figuras 3, 4). Os testemunhos 2-AR-SR-1A-CE e 2-AR-SR-1B-CE foram perfurados no Sítio Romualdo, Município de Crato, Ceará, Bacia do Araripe (Projeto Três Furos e Projeto Santana/Petrobras); os testemunhos 2-TN-SM-BA e 2-TN-ST-3A-BA, na base e topo da Serra de Tonã, Município de Macururé, Bahia, Bacia de Tucano Norte (Projeto Três Furos) e os testemunhos 2-JB-SN-2A-PE e 2-JB-SN-2B-PE, no topo e base da Serra Negra, Município de Ibimirim, Pernambuco, Bacia de Jatobá (Projeto Três Furos e Projeto FINEP/UFPE). As amostragens superficiais foram realizadas nas três bacias e os afloramentos foram identificados com as siglas BAr (Bacia do Araripe), BTN (Bacia de Tucano Norte) e BJ (Bacia de Jatobá), precedidos e sucedidos por numeração. Foram coletadas um total de 1880 amostras, 1825 obtidas dos testemunhos e 55 dos afloramentos (Tabela 1).

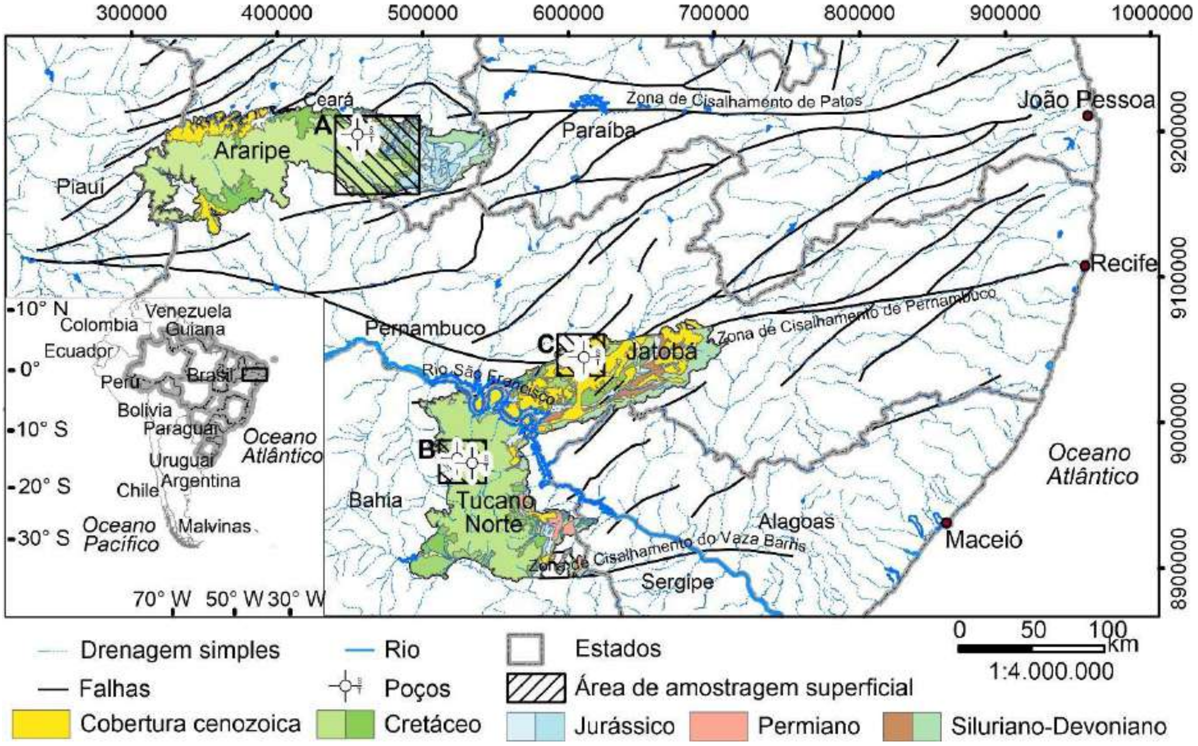
Tabela 1 – Relação de seções estratigráficas estudadas e amostras coletadas. Coordenadas SIRGAS 2000 24S

Seção estratigráfica	# amostras	Tipo	Coordenadas		Profundidade
2-AR-SR-1A-CE	476	Testemunho	N9193984	E456617	140 m
2-AR-SR-1B-CE	259	Testemunho	N9197712	E455205	105 m
1BAr11	6	Afloramento	N9204540	E420538	–
1BAr17	8	Afloramento	N9213217	E422963	–
2BAr04	1	Afloramento	N9186698	E489927	–
2BAr05	7	Afloramento	N9186456	E490069	–
3BAr01	1	Afloramento	N9200385	E451227	–
3BAr02	1	Afloramento	N9200279	E450993	–
3BAr03	1	Afloramento	N9200254	E450933	–
3BAr04	1	Afloramento	N9199182	E450365	–
3BAr05	2	Afloramento	N9198829	E450069	–

3BAr06	5	Afloramento	N9198774	E449987	–
4BAr01	13	Afloramento	N9163029	E481969	–
2-TN-SM-BA	285	Testemunho	N8972138	E533826	100,3 m
2-TN-ST-3A-BA	362	Testemunho	N8975078	E523634	138 m
4BTN02	1	Afloramento	N8971572	E535131	–
4BTN04	1	Afloramento	N8972977	E527105	–
4BTN05	1	Afloramento	N8974338	E532000	–
2-JB-SN-2A-PE	251	Testemunho	N9042782	E607985	105 m
2-JB-SN-2B-PE	192	Testemunho	N9044544	E610733	72,50 m
4BJ01	0	Afloramento	N9047395	E623375	
4BJ02	1	Afloramento	N9045977	E611992	–
4BJ03	2	Afloramento	N9044334	E610029	–
4BJ04	3	Afloramento	N9042058	E607987	–

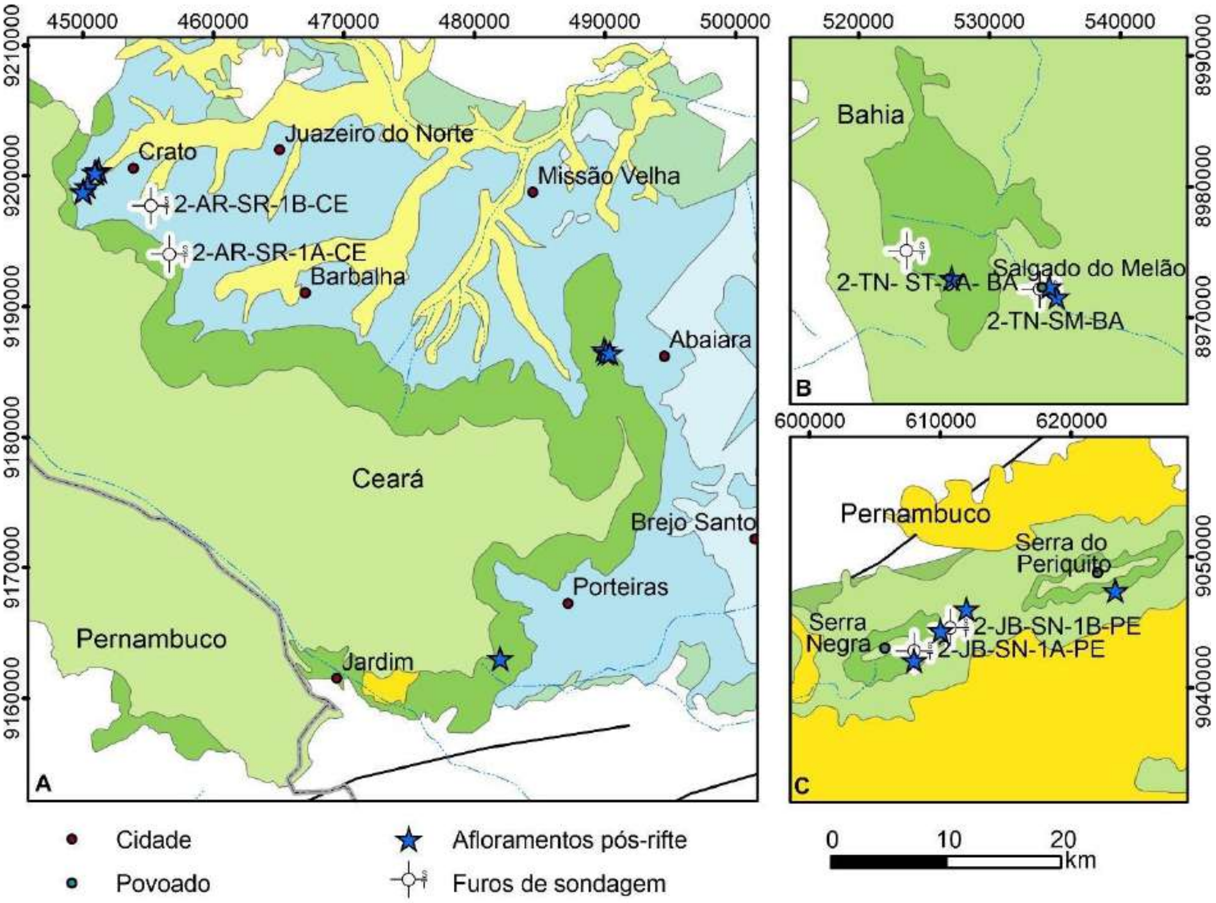
Fonte: Piovesan et al. (2021).

Figura 3 – Mapa regional de localização das bacias de Araripe, Tucano Norte e Jatobá, nos domínios tectônicos Transversal e Sul da Província Borborema, nordeste do Brasil: Os quadrantes A, B e C correspondem as áreas de amostragem de afloramentos e testemunhos perfurados da fase pós-rifte e são detalhadas para cada bacia na Figura 4



Fonte: Piovesan et al. (2021), metadados escala 1:1.000.000 disponibilizados pelo Sistema de Geociências do Serviço Geológico do Brasil – CPRM.

Figura 4 – Localização de afloramentos e testemunhos de sondagem da fase pós-rifte amostrados: A. Bacia do Araripe; B. Bacia de Tucano Norte; C. Bacia de Jatobá



Fonte: Piovesan et al. (2021), metadados escala 1:1.000.000 disponibilizados pelo Sistema de Geociências do Serviço Geológico do Brasil – CPRM.

3.1 PREPARAÇÃO E ANÁLISE DE MICROFÓSSEIS CALCÁRIOS

As amostras utilizadas nesse estudo são provenientes de seis testemunhos de sondagem e 18 afloramentos, de três bacias sedimentares: Araripe, Tucano Norte e Jatobá. Foi preparado um total de 1880 amostras para recuperação e análise de microfósseis calcários, 1825 obtidas dos testemunhos e 55 dos afloramentos (Tabela 1). A etapa de preparação foi desenvolvida pelos integrantes da equipe do projeto ARTUNJA, supervisionados pela autora da presente tese e pelo pesquisador Dr. Robbyson Mendes Melo.

Aproximadamente 60 g de sedimento foram separados para os estudos da fauna de ostracodes. A etapa de preparação das amostras tem como finalidade a separação das carapaças dos microfósseis da matriz sedimentar, sendo constituída basicamente por quatro fases: pesagem, trituração, ataque químico e lavagem. Todos os procedimentos são realizados com o devido cuidado para evitar possíveis contaminações ou erros de etiquetagem. Após a etapa de pesagem, cada amostra é triturada para melhor desagregação da rocha, para facilitar o ataque químico e separação dos microfósseis da matriz.

Na etapa de preparação química a metodologia convencional envolve o ataque com peróxido de oxigênio. Nesta fase, foram testados diferentes métodos para obtenção de resultados mais satisfatórios e recuperação das carapaças. Em algumas amostras não foi necessário o ataque químico e o material foi lavado em água corrente, para limpeza dos microfósseis. Do testemunho 2-TN-SM-BA, Bacia de Tucano Norte, todas as amostras foram submetidas ao ataque químico, seguindo o procedimento padrão para preparação de microfósseis carbonáticos. Dessa forma, cada amostra foi acondicionada em copos de Becker devidamente identificados e cobertas com uma solução de peróxido de hidrogênio (H_2O_2), com concentração de 35%, deixando-as em repouso por um período variável entre uma e doze horas. O uso de H_2O_2 tem como função eliminar a matéria orgânica, bem como separar a argila dos demais materiais presentes na amostra, agindo como defloculante de sedimento argiloso, contribuindo para a recuperação das carapaças. Do testemunho 2-JB-SN-2A-PE, Bacia de Jatobá, a preparação das amostras envolveu três diferentes metodologias. Para aplicação destes métodos foi realizado uma análise prévia das amostras onde foram observados aspectos litológicos, ocorrência de microfósseis, bem como o modo e estado de preservação das carapaças. Através da análise prévia, em algumas amostras foi possível constatar a presença de microfósseis antes da preparação com método convencional. No entanto, após a preparação, as amostras apresentavam-se estéreis. Devido a isso, adotou-se os métodos abaixo, na tentativa de uma melhor recuperação das carapaças, tentando evitar ao máximo sua perda.

Método 1: as amostras foram submetidas ao ataque químico com uso do H_2O_2 a 35%.

Método 2: as amostras foram submetidas ao ataque químico com uso do H_2O_2 a 10-20%.

Método 3: as amostras foram imersas em água, durante 24 horas, sendo posteriormente apenas lavadas com água corrente.

Dos três métodos aplicados, para o material analisado neste projeto, a imersão das amostras em água, mostrou-se mais eficiente na recuperação das carapaças, uma vez que evitou a dissolução. Destaca-se que, durante a descrição litológica do testemunho, já foram observadas as amostras que contém ostracofauna abundante.

Para o material dos testemunhos 2-AR-SR-1A-CE e 2-AR-SR-1B-CE da Bacia do Araripe, e dos testemunhos 2-TN-ST-3A-BA da Bacia de Tucano Norte e 2-JB-SN-2B-PE da Bacia de

Jatobá, além dos afloramentos das três bacias objeto de estudo, em todas as amostras que foram preparadas, foi aplicado o método 3. Imersão em água e posteriormente sua lavagem utilizando água corrente e peneiras de malha maior que (>) 500 µm, > 250 µm, > 180 µm, > 63 µm e > 45 µm. Posteriormente, o resíduo retido nas peneiras foi colocado em recipientes, sendo em seguida levado à estufa a 60 °C, para secagem.

A separação dos microfósseis dos fragmentos de rocha após a preparação química corresponde à etapa de triagem sob estereomicroscópio. A etapa de triagem foi desenvolvida por estudantes de graduação bolsistas vinculados ao projeto ARTUNJA. Para esta etapa utilizam-se, uma bandeja metálica, pincel e células porta-microfósseis. A triagem da microfauna é realizada espalhando sobre a bandeja metálica uma fina camada do material a ser observado na lupa. Com o auxílio de um pincel úmido, os microfósseis presentes são transferidos para a célula porta-microfóssil, devidamente identificada, para posteriormente serem estudados. Para as análises pretendidas, foram selecionados os espécimes de ostracodes e foraminíferos de cada amostra. Amostras com abundância de microfósseis foram quarteadas, a quantidade desejada foi de 300 espécimes por cada grupo para cada fração de amostra.

A identificação de ostracodes foi realizada pela autora da presente tese e a identificação de foraminíferos foi realizada pelo especialista Dr. Robbyson Mendes Melo, que é coautor de dois dos artigos resultantes da pesquisa. Os exemplares melhor preservados foram fotografados por meio de microscopia eletrônica de varredura. Os espécimes foram selecionados das células porta-microfóssil, e sobre *stubs* de alumínio com fita adesiva de carbono, estes foram posicionados e inseridos no microscópio eletrônico de varredura *Phenom XL* instalado no Laboratório de Micropaleontologia Aplicada.

3.2 PREPARAÇÃO E ANÁLISE DE LÂMINAS PETROGRÁFICAS

Para os estudos petrográficos foram coletados cerca de 5 cm das fácies calcárias dos testemunhos estudados. As lâminas foram confeccionadas pela empresa prestadora de serviço terceirizado GEOLAB – Soluções em Geologia, Olinda, Pernambuco, Brasil (conforme previsto no projeto ARTUNJA), seguindo a metodologia padrão, que consta basicamente de três etapas:

1. Colagem da amostra na lâmina;

2. Corte e desbaste;

3. Polimento ou cobertura com lamínula.

Algumas análises petrográficas e de catodoluminescência (CL) foram realizadas utilizando o microscópio Leica DM 2550 P com câmera acoplada (Leica DFC 310 FX), câmara de cátodo quente CITL MK5 - 2 e uma unidade de controle montada. Tensões de aceleração de 15 kV e uma corrente de feixe de elétrons entre 500 e 600 µA foram usadas. Outras análises petrográficas foram realizadas usando o microscopio Zeiss Axio Scope.A1 equipado com câmera Zeiss AxioCam MRc.

4 RESULTADOS E DISCUSSÕES

Os resultados e as interpretações da presente pesquisa serão apresentados em quatro partes. Na primeira, são apresentados a descrição da litologia das seções estratigráficas de amostragem totalmente realizada pela autora da presente tese, seguida de dois artigos, um publicado e um submetido e atualmente em revisão, com os quais se cumprem os requisitos para a defesa de doutorado. A quarta parte desta seção, apresenta dados bioestratigráficos e faciológicos das unidades pós-rifte das bacias de Tucano Norte e Jatobá e a sua correlação com o Grupo Santana da Bacia do Araripe, esta informação constituirá um manuscrito a ser posteriormente organizado e submetido para publicação.

4.1 CARACTERIZAÇÃO E AMOSTRAGEM DE AFLORAMENTOS E TESTEMUNHOS DE SONDAGEM

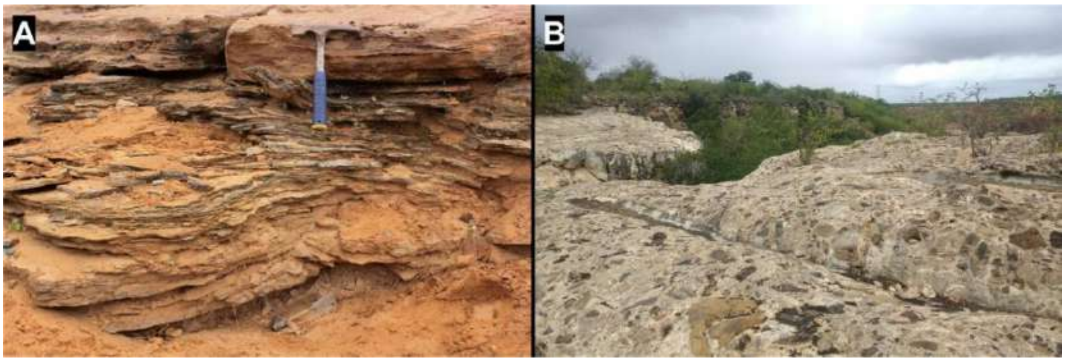
4.1.1 Afloramentos

Na Bacia de Tucano Norte, a Formação Marizal é caracterizada por um espesso pacote de arenitos que, em sua parte média, encontram-se intercalados por siltitos, argilitos, folhelhos e calcários laminados denominados informalmente de “Camadas Amargosa”. No leito do Rio Riacho Grande, povoado Salgado do Melão, Bahia, afloram os calcários laminados das Camadas Amargosa fortemente silicificados, afloramento 4BTN02 (Figura 5a), de onde foi coletada uma amostra. A Serra do Tonã, a leste do Povoado Salgado do Melão registra a continuação dos depósitos pós-rifte da Bacia de Tucano Norte, onde estratos predominantemente pelíticos são encontrados interestratificados com calcários e quartzoarenitos de granulação fina a média da Formação Crato, afloramentos 4BTN04 e 4BTN05, calcário laminado e brecha calcária (Figura 5B) respetivamente.

Na Bacia de Jatobá, na Serra do Periquito e na Serra Negra afloram estratos correspondentes às formações Marizal, Crato e Romualdo. Arenitos de granulação fina a média da Formação Marizal, afloram na base da Serra Negra, afloramento 4BJ02. Carbonatos laminados típicos da Formação Crato são encontrados nas porções medias de ambas as serras. Na Serra do Periquito, do afloramento 4BJ01 (Figura 6A), caracterizado por calcários laminados fortemente silicificados, foi recuperado um peixe fóssil do gênero *Dastilbe* (Figura 6B), sendo o primeiro registro para a Bacia de Jatobá deste gênero de peixes que é muito abundante na Formação Crato da Bacia do Araripe. Em direção ao topo da Serra Negra, o afloramento 4BJ03 (Figura 6C) apresenta uma seção de ritmitos calcários-argilitos intemperizados que correspondem à

Formação Crato, e mais próximo ao topo no afloramento 4BJ04 (Figura 6D) são encontrados argilitos vermelhos e arenitos muito finos esbranquiçados que caracterizam a Formação Romualdo.

Figura 5 – Fotografias dos afloramentos da fase pós-rifte na Bacia de Tucano Norte. A. Calcários laminados das Camadas Amargosa da Formação Marizal na margem do Rio Riacho Grande, afloramento 4BTN02. B. Vista geral do afloramento 4BTN05 no topo da Serra do Tonã



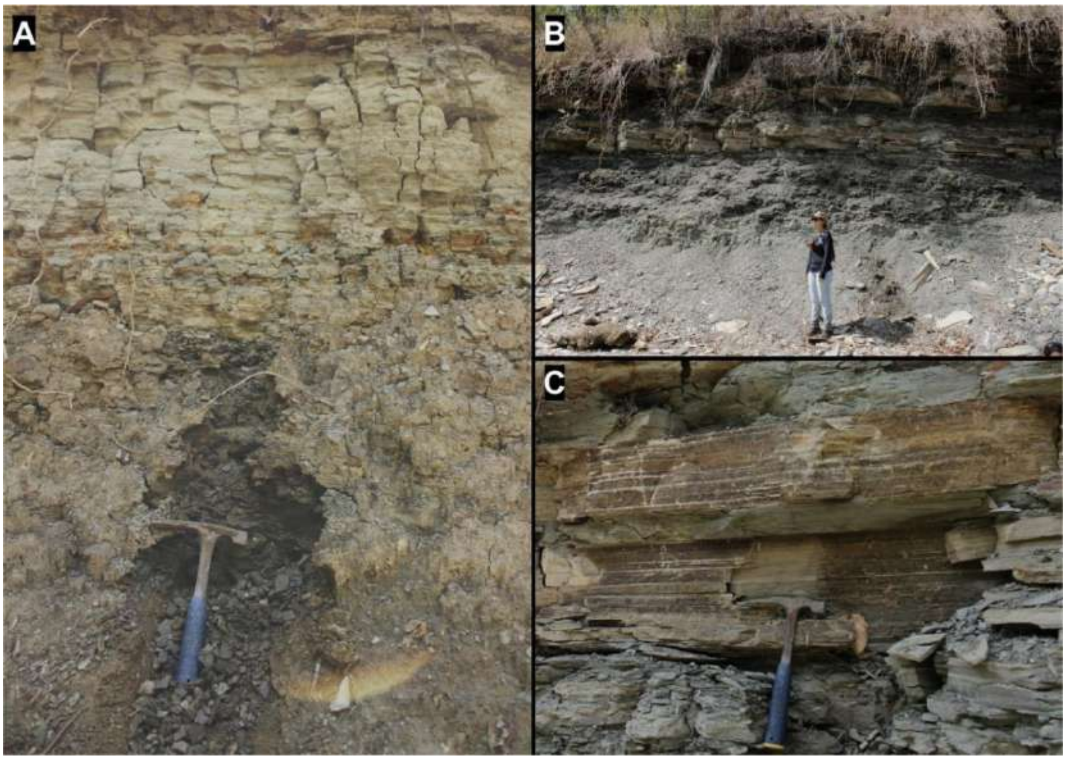
Fonte: A autora (2023).

Figura 6 – Fotografias dos afloramentos da fase pós-rifte na Bacia de Jatobá. A–C. Calcários laminados da Formação Crato, na Serra do Periquito o afloramento 4BJ01 (A) onde foi recuperado o peixe fóssil do gênero *Dastilbe* (B), e na Serra Negra, afloramento 4BJ03 (C). D. Afloramento 4BJ04 na Serra Negra, a seção está conformada por argilitos vermelhos e arenitos finos da Formação Romualdo

Fonte: A autora (2023).

A sequência pós-rifte foi estudada em detalhe nos afloramentos localizados nas encostas da Chapada do Araripe, Bacia do Araripe. O Grupo Santana que, da base para o topo, é composto pelas formações Barbalha, Crato, Ipubi e Romualdo, foi amostrado em afloramentos nas bordas nordeste, leste e sudeste da bacia. A Formação Barbalha, correlacionada crono e litologicamente com a Formação Marizal das bacias de Tucano Norte e Jatobá, aflora ao longo do Rio da Batateira, correspondendo ao Geossítio Batateiras na área do Parque Estadual Sítio Fundão, Crato, Ceará (Figura 7).

Figura 7 – Fotografias dos afloramentos ao longo do Rio Batateira, formações Barbalha e Crato, fase pós-rifte na Bacia do Araripe. A. Na base, folhelho preto, no topo, arenito de grão muito fino a fino da Formação Barbalha, afloramento 3BAr05. B. Afloramento 3BA r06, base da Formação Crato apresentando intercalação de folhelhos e calcários laminados. C. Vista de detalhe das camadas basais de calcário laminado da Formação Crato no afloramento 3BAr06 (B)

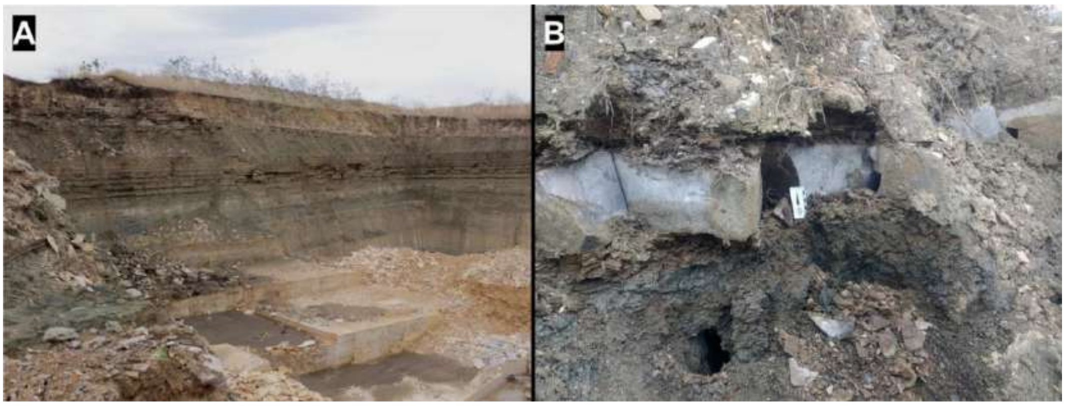


Fonte: A autora (2023).

O afloramento 3BAr01 corresponde às “Camadas Batateira” (correlacionadas com as Camadas Amargosa da Formação Marizal) e possui 1,70 m de altura de folhelhos pretos bioclásticos, onde uma amostra foi coletada no nível que apresentava menor alteração. Percorrendo o rio em sentido sudoeste, mais cinco amostras dos afloramentos 3BAr02, 3BAr03, 3BAr04 e 3BAr05 (Figura 7A) de argilitos e folhelhos cinza intercalados aos arenitos da Formação Barbalha foram coletadas. Próximo à Cascata do Lameiro e à Avenida José Ribeiro de Andrade, Crato, Ceará, a Formação Barbalha é sobreposta pela Formação Crato. O afloramento 3BAr06 apresentou-se constituído por folhelhos pretos e calcários laminados da base da Formação Crato (Figura 7B–C).

Nas cidades de Nova Olinda e Santana do Cariri, Ceará, abundantes minas de exploração de calcário da Formação Crato, para cimento ou lajes, e de gipsita da Formação Ipubi são encontradas. Do lajeiro Mina Três Irmãos, afloramento 1BAr17, calcário laminado intercalado por siltitos, folhelhos e finos níveis de gipsita da Formação Crato foram amostrados (Figura 8A). A Mina Conceição Preta, afloramento 1BAr11 (Figura 8B), apresenta uma sucessão de gipsita/anhidrita, folhelho, siltito e calcário de 16 m de altura.

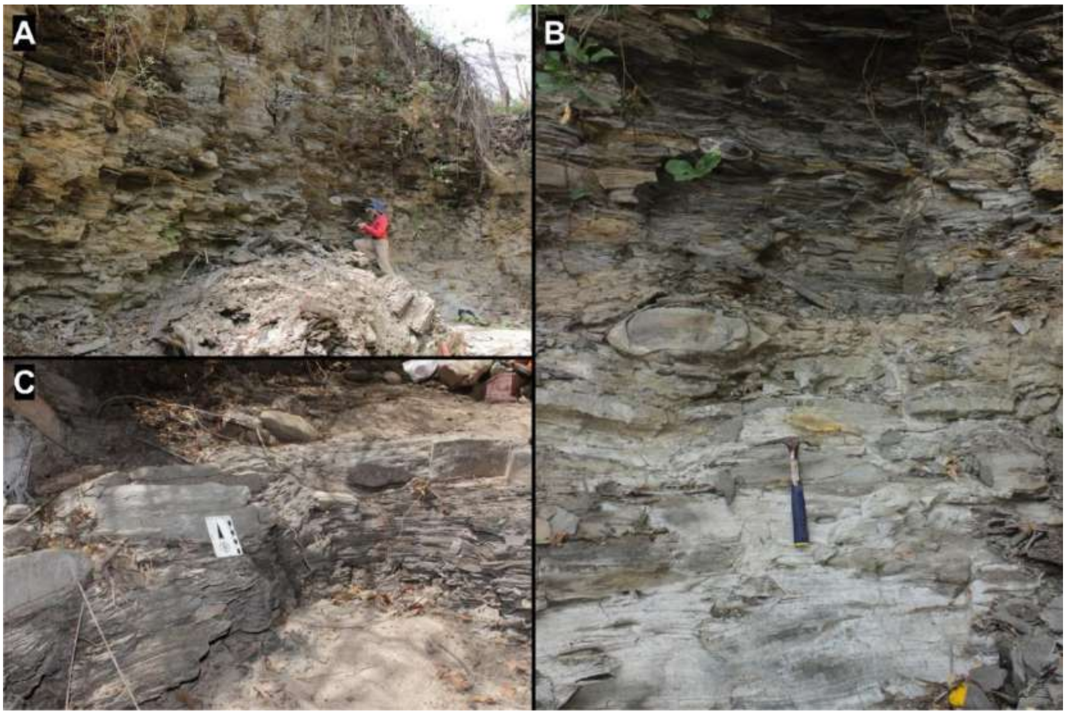
Figura 8 – Fotografias dos afloramentos das formações Crato e Ipubi, fase pós-rifte na Bacia do Araripe: A. Vista geral da frente de explotação de lajes da Mina Três Irmãos (1BAr17). B. Vista de detalhe de nível de 10 cm de espessura de calcário maciço (amostra 1BAr11f) intercalado nos estratos de folhelho e evaporito da Mina Conceição Preta.



Fonte: A autora (2023).

O Sítio Sobradinho, afloramento 4BAr01 (Figura 9), localizado a sudeste da Chapada do Araripe, corresponde a um afloramento com aproximadamente 100 m de altura que registra a seção estratigráfica mais espessa e completa da Formação Romualdo, Grupo Santana. Nesta seção, depósitos costeiros transicionais, quartzoarenitos finos, argilitos, siltitos e folhelhos, e calcários como níveis interestratificados e como concreções (Figura 9A–C), repousam discordantemente sobre as fácies carbonáticas-siliciclásticas da Formação Crato. Quatro associações de fácies estão relacionadas a um padrão de empilhamento retrogradacional de trato de sistema transgressivo e trato de sistema de mar alto (CUSTÓDIO et al. 2017). Um intervalo de 8 m de espessura no Sítio Sobradinho (Figura 9) foi analisado através de um estudo faciológico e bioestratigráfico de ostracodes e foraminíferos, visando atribuir para a maior precisão na idade, paleoambiente, paleoecologia e paleogeografia do mar que é registrado no Cretáceo na Bacia do Araripe. Treze amostras foram coletadas, a cada mudança de litologia, cinco destas amostras resultaram estéreis. O estudo desta seção da Formação Romualdo foi publicado pela equipe do Projeto ARTUNJA, com minha participação como coautora e, tendo como primeiro autor, o especialista em foraminíferos Dr. Robbyson Mendes Melo, na revista Scientific Reports, do Grupo Nature (Ver MELO et al. 2020 na lista de referências).

Figura 9 – Fotografias do afloramento Sítio Sobradinho (4BAr01), Formação Romualdo da Bacia o Araripe: A. Vista geral da porção superior do intervalo estudado, deposito de folhelho com abundantes concreções calcárias; B. Vista de detalhe de nível de calcário cinza maciço sobrepondo folhelho preto; C. Vista de detalhe do pacote de folhelhos contendo concreções calcárias e intercalado por nível centimétrico de calcário cinza.

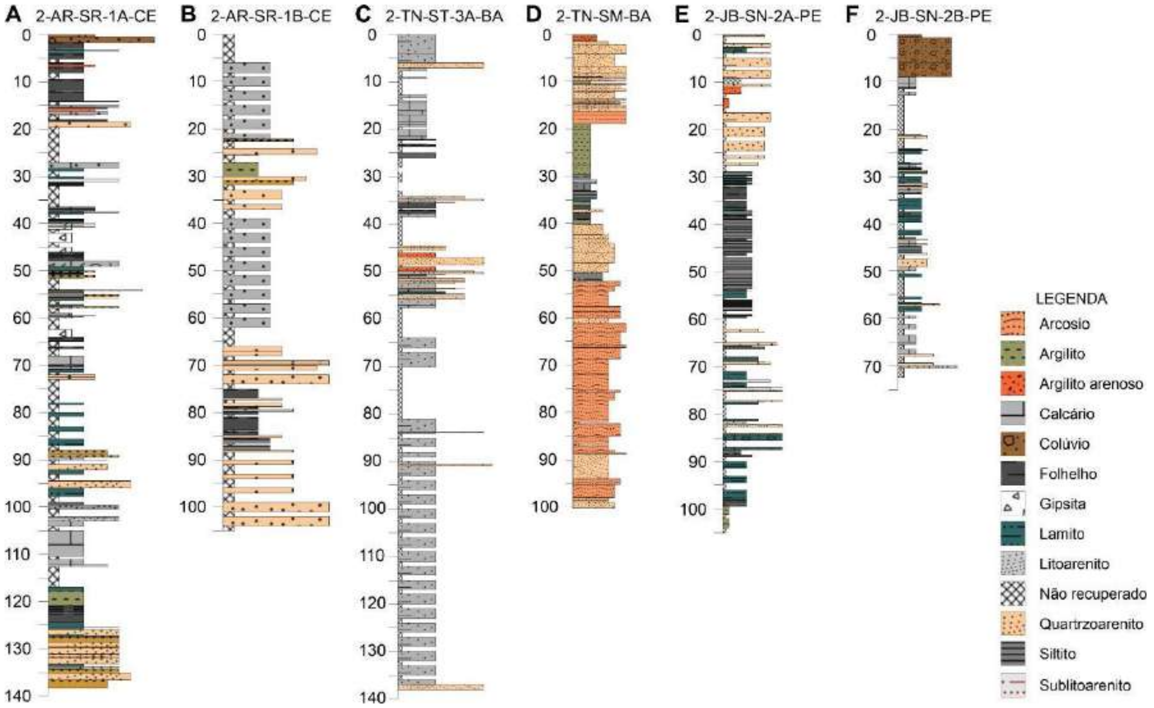


Fonte: A autora (2023).

4.1.2 Testemunhos

O testemunho de sondagem AR-SR-1A-CE (Figura 10A), com uma profundidade de 140 m, foi recuperado na localidade do Sítio Romualdo, Município do Crato, Ceará. O testemunho apresenta uma ampla variedade litológica, a porção superior predominantemente pelítica, registra calcários laminados intercalados. No intervalo 40–70 m, ocorrem evaporitos e folhelhos escuros, seguidos por calcilutitos e calcários bioclásticos contendo ostracodes e lamitos. Para a base, o tamanho de grão aumenta de siltito a arenito de granulação média. Os estratos registrados neste furo são associados às formações Romualdo, Ipubi e Crato do Grupo Santana.

Figura 10 – Colunas estratigráficas dos testemunhos das bacias de Araripe (A–B), Tucano Norte (C–D) e Jatobá (E–F). Profundidade em metros



Fonte: A autora (2023).

O furo estratigráfico 2-AR-SR-1B-CE (Figura 10B), com uma profundidade de 105 m, foi perfurado na localidade do Sítio Romualdo, Município de Crato, Ceará. Duas litologias predominam no testemunho, a porção superior até aproximadamente 20 m e o intervalo entre 40 e 62 m apresenta lamito arenoso pouco consolidado a inconsolidado. A porção média, entre os intervalos de lamito arenoso e a porção inferior por baixo destes corresponde a um pacote de quartzoarenito fino a conglomerático intercalado por argilitos, siltitos, folhelhos ricos em matéria orgânica e um nível centimétrico de calcário apresentando estruturas de indução microbiana. Este furo atravessou a base da Formação Crato e a Formação Barbalha.

O testemunho de sondagem 2-TN-ST-3A-BA (Figura 10C), com uma profundidade de 138 m, foi obtido da Serra do Tonã, Município de Macururé, Bahia. A seção é predominantemente pelítica. Na parte mediana da seção, um nível fino de calcário laminado foi observado. Na porção superior do testemunho (7 – 31 m) a litologia corresponde a calcário de lama carbonática, para a base passa a se intercalar com folhelhos de coloração castanho a cinza. Abaixo da porção carbonática o pacote sedimentar corresponde a um lamito arenoso com intercalações de quartzoarenito de granulação fina a grossa. Os sedimentos registrados neste testemunho correspondem à Formação Crato e possivelmente o topo da Formação Marizal.

O furo estratigráfico 2-TN-SM-BA (Figura 10D), com uma profundidade de 100,3 m, foi perfurado no povoado de Salgado de Melão, Município de Macururé, Bahia. A seção é predominantemente psamítica apresentando arcosios e quarzoarenitos. Na porção superior (18,8 – 40,2 m) a litologia é pelítica com intercalações de carbonato e sílica. A litologia identificada é associada à Formação Marizal contendo as Camadas Amargosa.

O testemunho de sondagem 2-JB-SN-2A-PE (Figura 10E), com uma profundidade de 105 m, foi recuperado da localidade de Serra Negra, Município de Ibimirim, Pernambuco. A seção é predominantemente pelítica com abundante muscovita de tamanho silte. Na parte mediana da seção, um nível fino de calcário laminado foi observado. Na porção inferior do testemunho (84,4–87,4 m) a litologia corresponde a um calcário brechoide. Em direção ao topo do testemunho, o tamanho de grão é maior representado por quartzoarenitos conglomeráticos. Está seção registra a ocorrência das Formações Crato e Romualdo.

O furo estratigráfico 2-JB-SN-2B-PE, com uma profundidade de 72,5 m, foi perfurado na localidade de Serra Negra, município de Ibimirim, Pernambuco. No topo ocorrem solo e colúvio cobrindo a seção autóctone. A seção é predominantemente pelítico-carbonática (Figura 10F), caracterizada por uma intercalação de calcários laminados e lamitos a arenitos finos em acamamento plano paralelo a cruzado do tipo linsen e ondulado. Estes sedimentos podem ser associados à Formação Crato.

4.2 ARTIGO 1

Neste artigo, é apresentada a sistemática da Classe Ostracoda da fase pós-rifte I, recuperada da Bacia do Araripe. O artigo intitulado "*Aptian ostracods from the Santana Group, Araripe Basin, Brazil*" (Ostracodes aptianos do Grupo Santana da Bacia do Araripe, Brasil), foi publicado o dia 11 de outubro de 2022 na *Revue de Micropaléontologie*, volume 77, https://doi.org/10.1016/j.revmic.2022.100694. O artigo publicado corresponde ao APÊNDICE A desta tese.

4.3 ARTIGO 2

Neste artigo, é apresentada a distribuição estratigráfica de ostracodes e foraminiferos ao longo do Grupo Santana, Bacia do Araripe, permitindo propor quatro subzonas dentro da comumente denominada biozona 011, sua calibração estratigráfica internacional e a interpretação da evolução paleoambiental. O artigo intitulado "*Ostracoda and Foraminifera biostratigraphy and palaeoenvironmental evolution of the Aptian Santana Group, post-rift of* *the Araripe Basin, Brazil*" (Bioestratigrafia de Ostracoda e Foraminifera e evolução paleoambiental do Grupo Santana, pós-rifte da Bacia do Araripe, Brasil), foi submetido à revista Gondwana Research, no dia 15 de fevereiro de 2023.

Ostracoda and Foraminifera biostratigraphy and palaeoenvironmental evolution of the Aptian Santana Group, post-rift of the Araripe Basin, Brazil

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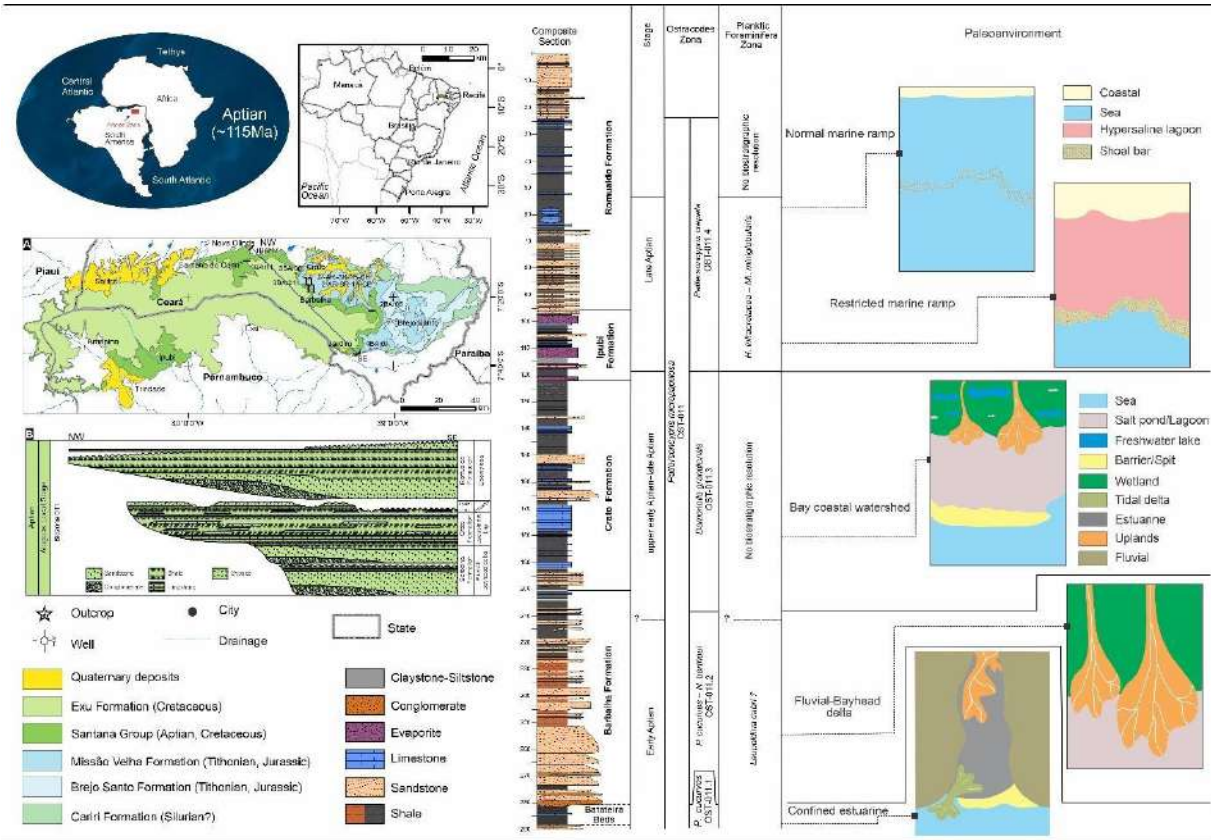
ABSTRACT

The Santana Group, consisting of the Barbalha, Crato, Ipubi and Romualdo formations, records the post-rift sequence of the Gondwana break-up in the Araripe Basin. The post-rift phase of the South Atlantic rifting is dated as the Alagoas Stage, which corresponds to the ostracod biozone 011. A detailed ostracod stratigraphical distribution along the Santana Group, allowed to standardise a common ostracod for the biozone name and a code, the *Pattersoncypris micropapillosa* Biozone (OST-011). Four different ostracod associations were recognized establishing the subzones: *Pattersoncypris cucurves* (OST-011.1), *Pattersoncypris cucurves-Neuquenocypris berthoui* (OST-011.2), *Damonella grandiensis* (OST-011.3) and *Pattersoncypris crepata* (OST-011.4). Planktic foraminifers were also recovered in different associations, leading to identify two international biostratigraphic intervals and calibrate the ostracod subzones, the Early Aptian *Leupoldina cabri* Zone contents the OST-011.1 and OST-011.2 subzones, and the upper Late Aptian *Hedbergella infracretacea–Microhedbergella miniglobularis* composite zone correlated to the OST-011.4 subzone. Between these zones there is an interval without foraminiferal biostratigraphy resolution, the OST-011.3 subzone which is assigned to the lower Late Aptian. The palaeoenvironmental evolution of the Santana Group was reconstituted from the integrated study of ostracods, planktic and benthic foraminifers. Through the Aptian, the Araripe Basin evolved from a transitional to a marine environment, recording estuarine, fluvial to bayhead deltas, a bay coastal watershed that reached better-marine conditions under extreme aridity and the full installation of an epeiric sea flooding the area.

Keywords: Microfossils; Biozonation; Post-rift; Salt deposition; Transitional palaeoenvironment; Seaway



1. Introduction

The biostratigraphic framework of the late Jurassic–Aptian rift-related sequences of Brazil was established from the identification of ostracods delimiting eleven biozones in six local stages: Dom João, Rio da Serra, Aratu, Buracica, Jiquiá and Alagoas. The ostracod biozonation was first recognized for the Sergipe/Alagoas and Recôncavo/Tucano basins in internal reports of Petrobras company during the 1960’s and openly formalised by Schaller (1969) and Viana et al. (1971), respectively. Viana (1965), proposed eight zones and ten subzones for the Bahia Supergroup in the Recôncavo and Tucano basins, not all of them recovered by the time in the correlated units of the Sergipe/Alagoas, Jatobá and Almada basins. The Viana’s proposals included in the biozone code the letters R and T (R, RT) in reference to the Recôncavo and Tucano basins. For the Sergipe/Alagoas basin biostratigraphy, Schaller (1969) correlated with the Recôncavo Basin proposal of Viana (1965), numbering the zones from oldest to youngest and starting the code with 0, in reference to the Ostracoda group, more two digits from the zone 01 to the zone 10/11, without the usage of letters.

The Alagoas Stage dates the post-rift phase of the South Atlantic rifting and corresponds to the ostracod biozone code 011. The term Alagoas was introduced by Branner (1963) in reference to the bituminous shales outcropping along the Alagoas State coast. The term was formally assigned as a chronostratigraphic term by Schaller (1969) in view of the palaeontological determinations in sediments from south Bahia State and north Espírito Santo State, in the Sergipe/Alagoas Basin the stage comprises the upper part of the Coqueiro Seco and Morro de Chaves formations, the Ponta Verde and Muribeca formations and the lower portion of the Riachuelo Formation. According to Moura and Praça (1985), the biozone 011 was informally defined in the Sergipe/Alagoas Basin by Troelsen and Beurlen in an internal Petrobras report of 1965, naming it as "*Cytheridea*"? spp. 201/218, by that time a group of non-identified species possessing a smooth or subtle ornamented carapaces and similar outlines. In the 1965 internal Petrobras reports of Weber in the Piaçabuçu area, Alagoas Sub-basin, the Zone 011 was characterised by the "Ostracod 207" and separated from the zone 010 with the species *Cytheridea*? sp. 215 (Schaller, 1969). According to Moura and Praça (1985) and Moura (1988) the Zone 010, characterised by the *Limnocythere troelseni* ostracod species correspond to the upper zone of the Jiquiá Stage and can also be separated from the Zone 011 in the Campos Basin.

The Zone 011 has been also recognized in other Brazilian basins, both along the northeast-southeast coast and in several interior basins in northeast Brazil. The occurrence of species of the *Cytheridea*? 201/218 group as *Pattersoncypris* (= *Hourqcia angulata*, *Harbinia*, *Kroemmelbeincypris*) and *Damonella* (= "Ostracod 207", *Candona*) species have been being reported from the Codó (de Lima Barros et al., 2022) and Itapecuru formations (Vicalvi and Carvalho, 2002), Parnaíba Basin; Codó Formation, Grajaú Basin (Ramos et al., 2006); Alagamar Formation, Potiguar Basin (Viviers and Regali, 1987; Viviers et al., 2000; Do Carmo et al., 2013, 2018); Guarujá and São Mateus formations, Santos and Espírito Santo basins, respectively (Piovesan et al., 2013). Besides, several West and Northcentral African basins record species of the *Cytheridea*? 201/218 group and other associated genera as *Theriosynoecum*, *Neuquenocypris*, *Alicenula* (e.g., Bate, 1972; Grosdidier et al., 1996; Colin and Dépêche, 1997). In the Araripe Basin, Coimbra et al. (2002) biostratigraphically characterised the complete Mesozoic succession identifying several species that led to assign the Santana Group to the Zone 011. In the taxonomic studies that Tomé et al. (2014) carried out in the post-rift sequence from Jatobá and Araripe Basin, the "Ostracode 207" were described as *Damonella grandiensis*, and an associated diversified Ostracoda fauna were also reported, including the genera *Pattersoncypris*, *Alicenula*, *Ilyocypris*, *Neuquenocypris*, *Rhinocypris*, some of these were already reported for the Crato Formation in the Araripe Basin by Berthou et al. (1994). Recently, a more complete Ostracoda taxonomy of the Santana Group (from base to top: Barbalha, Crato, Ipubi and Romualdo formations), Araripe Basin, have been presented, the works of Araripe et al. (2021, 2022) and Tomé et al. (2022) focused on the top of the Romualdo Formation fauna, whilst Guzmán et al. (2022) reported 25 taxa for the complete group.

Clearly marine microfossil biota has also been found in strata bearing ostracods of the *Cytheridea*? 201/218 group. Since the first stratigraphic works in the Sergipe/Alagoas Basin, the upper part of the Alagoas Stage was dated as upper Aptian, to the top of the sequence (base of the Riachuelo Formation) facies with ammonoids, foraminifers and nannofossils allowed the relative dating and evidenced the marine influence in the depositional environment (Schaller, 1969). Further northeast, in the Potiguar Basin the occurrences of the agglutinated foraminifer, *Gaudryinella* aff. *G. sherlocki* and foraminiferal organic linings indicate that the Alagamar Formation was deposited under a transitional (paralic) palaeoenvironment during the late Aptian (Do Carmo et al., 2018); in the Parnaiba Basin (de Lima Barros et al., 2022) also reported both benthic and planktic foraminifera from the Codó Formation, for which Antonioli and Arai (2002) had already indicated the marine influence evidenced by *Subtilisphaera* dinocyst. To the southeast, Sanjinés et al. (2022) reassessed the planktic foraminifer biostratigraphic framework of the Santos, Campos and Espírito Santo basins, pointing out to a late Aptian age for the post-salt marine section deposited immediately above the evaporitic sequence, traditionally dated as Albian. In the Araripe Basin (Fig. 1), evidence of well-established marine conditions during the deposition of the Romualdo Formation, top of the Santana Group, is confirmed by the presence of microfossils such as dinoflagellates (Arai and Coimbra, 1990; Arai and Assine, 2020; Vallejo et al., 2023), foraminiferal linings (Arai and Coimbra, 1990; Arai and Assine, 2020), benthic and planktic foraminifers (Melo et al., 2020; Araripe et al., 2021, 2022), calcareous nannofossils (Araripe et al., 2022). Moreover, from the lower units of the Santana Group also typical marine microfossils have been recovered, the upper strata of the Crato Formation record foraminiferal linings (Goldberg et al., 2019; Vallejo et al., 2023), and in the upper part of the Barbalha Formation Varejão et al. (2021a) documented the presence of dinoflagellate cysts, suggesting that the marine ingression in the Araripe Basin should had occurred even earlier.

The biostratigraphic refinement of the Alagoas Stage is crucial to better understand the depositional phases of the Santana Group, Araripe Basin. The present study aims to formalise a common ostracod species for the name of the Biozone 011, dividing it into four subzones. The species identified in Guzmán et al. (2022) from the Santana Group of the Araripe Basin constitute the base for the ostracod biostratigraphy proposal here presented. Besides ostracods, foraminifers both benthic and planktic were recovered along the complete Santana Group. Integrating the Ostracoda fauna to the Foraminifera occurrences allow the accurate dating and interpretating of depositional palaeoenvironments of the Barbalha, Crato, Ipubi and Romualdo formations, documenting the evolution of the Araripe Basin during the deposition of the Santana Group since the earliest marine influence.

2. Geologic and stratigraphic context

The South Atlantic Ocean began to form when new basins were created, and old ones were restructured along the newly forming continental margin and interior of South America and Africa. In the Brazilian continental interior, besides the complete restructuring of the syneclises, siliciclastic sedimentation occurred because of the formation of new rift systems, deepening of older depocenters and intensification of some linear zones of uplift (arcs), that led to the fragmentation of a large part of the original Paleozoic cover (Brito Neves, 2002). The evolution of the rift-related Brazilian basins has been better understood in terms of stratigraphic megasequences, namely the continental syn-rift, the transitional evaporitic, the shallow marine carbonate platform of the early drift stage, and the open marine-transgressive and regressive cycles of the passive margin stage (Ponte et al., 1978). The Araripe Basin (Fig. 1A) contain sections that include sediments deposited during the extensional process of the Gondwana break-up and the South Atlantic Ocean opening.

The Araripe Basin (Fig. 1A) is embedded in the Precambrian São José do Caiano Terrane in the Transversal Zone Domain of the Borborema Province (Brito Neves et al., 2000), between the Pernambuco Shear Zone to the south and the Patos Shear Zone to the north. Following the model of Prosser (1993) and the adaptation of Kuchle and Scherer (2010) to the Brazilian basins, the stratigraphy of the Araripe Basin is divided in syneclise, early rift, rift climax and post-rift. The syneclise sequence is represented by the Paleozoic Cariri Formation (Assine, 2007), which outcrops to the east in the Cariri Valley. Overlying the syneclise deposits, occur the sedimentary record of the Mesozoic rifting (Fambrini et al., 2011). The early rift sequence is represented by the Tithonian Brejo Santo and Missão Velha formations deposited in the called fluvio-lacustrine “Afro-Brazilian Depression” (Cesero and Ponte, 1972; Kuchle et al., 2011; Scherer et al., 2014). The Berriasian Abaiara Formation constitutes the rift climax sequence, recording fluvio-deltaic-lacustrine strata of the half-grabens development (Scherer et al., 2014). The Araripe Plateau and the Serra do Mãozinha hill constitutes remarkable geographic features where the post-rift sequence is exposed. The post-rift sequence resulted from the thermal flexural subsidence, differing structurally and stratigraphically from the underlying rift sequences on which it overlays in angular unconformity, to the west of the basin the post-rift sequence overlays directly above the Precambrian basement rocks (Assine, 2007). The post-rift sequence is divided into a lower post-rift I sequence that corresponds to the Alagoas-Stage Santana Group outcropping along the slopes, and the upper post-rift II sequence constituted by the alluvial units of the Araripe Group, namely, the Araripina and Exu formations (Assine et al., 2014).

The Santana Group is composed by fluvial to bayhead delta, and coastal to marine deposits including from base to top the Barbalha, Crato, Ipubi and Romualdo formations (Assine et al., 2014; Custódio et al., 2017; Varejão et al., 2019, 2021a, 2021b). According to Assine et al. (2014), two disconformities led to separate the Alagoas Santana Group in three depositional sequences, the first corresponds to the lower half of the Barbalha Formation up to the top of the Batateira Beds, the second sequence consists of the upper half of the Barbalha Formation and the Crato and Ipubi formations, and the third being the Romualdo Formation (Fig. 1B). Essentially composed of fluvial sandstones, the Barbalha Formation also encompasses the interbedded lacustrine pelitic interval known as Batateira Beds, marking the division between two-fining upward cycles (Assine, 2007; Assine et al., 2014). Scherer et al. (2015) interpreted these cycles as reflecting the variation in the accommodation-sediment supply ratio in the early post-rift sag basin, with amalgamated channel-fill beds (low-accommodation system tract) at the base passing upwards into floodplain-dominated and lacustrine successions (high-accommodation system tract) in each sequence. The Barbalha Formation is well exposed along the Batateira River (section 3BAr01–3BAr05, Fig. 2B) in the municipality of Crato, Ceará, sampled by the present study from the Batateira Beds upwards the river, this interval was also sampled along the well-core 2-AR-SR-1B-CE (Fig. 2E). To the top of the upper sequence the sandstone strata progressively become thinner, interpreted by Assine et al. (2014) as delta systems that prograde to unstable shallow lakes, but the recently recovered of dinoflagellates and marine ichnotaxa, led (Varejão et al., 2021a) interpreted the Barbalha Formation as deposited in a bayhead delta environment.

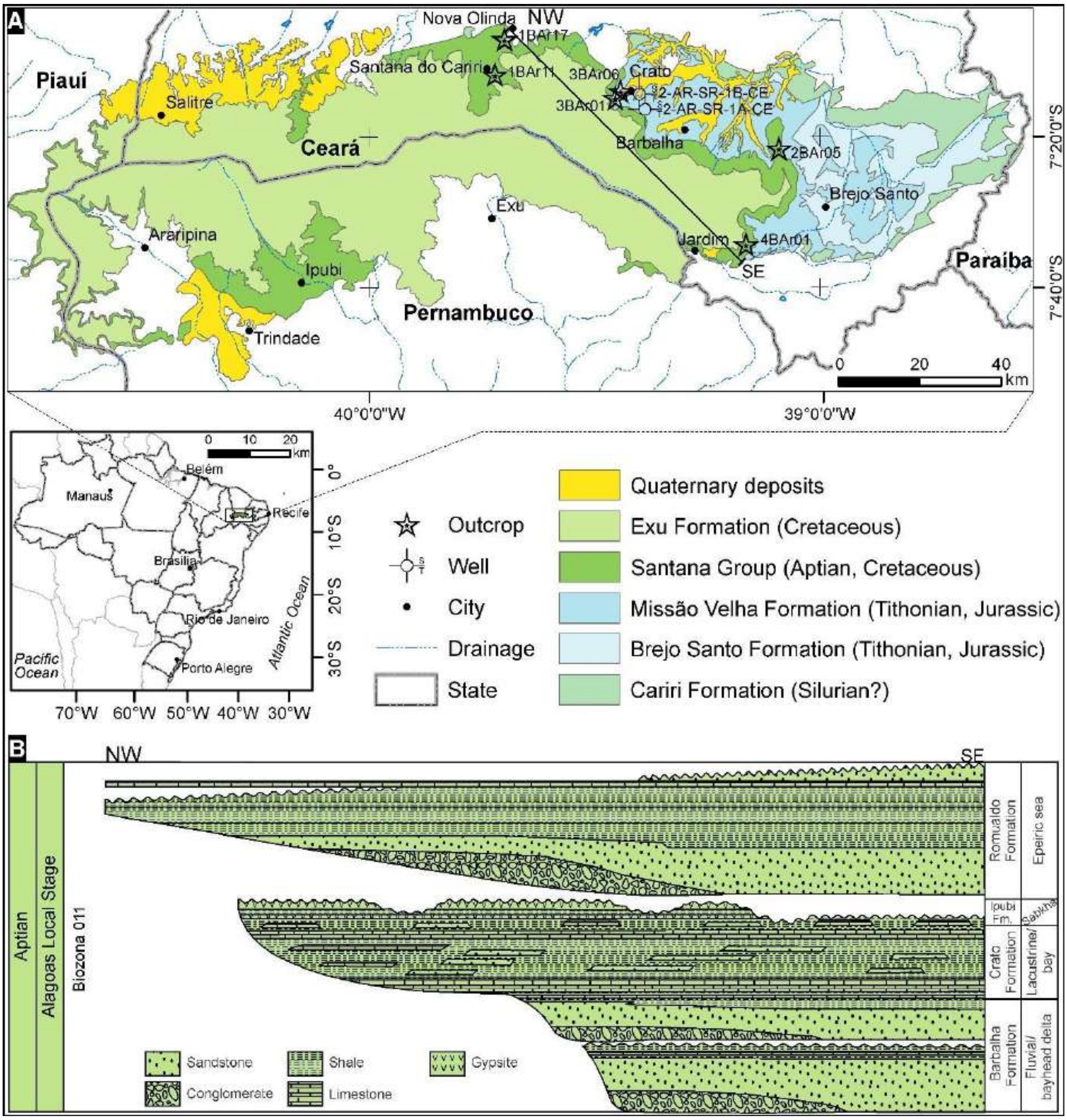


Fig. 1. Study area location. **A,** Geological map of the Araripe Basin with outrops and wells located, created using ESRI ArcMap v.10.3 software (https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview) with metadata acquired from the online Geosciences Service of the Geological Service of Brazil-CPRM. **B,** Stratigraphic framework of the Aptian Santana Group composed of three depositional sequences bounded by disconformities (Modified from Assine et al., 2014 and Varejão et al. 2021a).

Constituted by 50–70 m-thick rhythmite limestone-claystone shoals interspersed with shales and sandstones, the Crato Formation has been usually interpreted as deposited in a lacustrine environment with a carbonate depocenter in expansion (Neumann and Cabrera, 1999). According to Neumann et al. (2003), the lacustrine system was relatively shallow, closed meromictic, which evolved in a palaeoequatorial location and under warm, semiarid palaeoclimatic conditions. Well exposures of the unit were characterised and sampled by the present study at the Três Irmãos Quarry (section 1BAr17, Fig. 2A), "Cascatinha" (small waterfall) point at the Batateira River (outcrop 3BAr06, Fig. 2C), and Serra do Mãozinha hill (section 2BAr05, Fig. 2F), also the unit was completely recorded by the well-core 2-AR-SR-1A-CE (Fig. 2D) from 62.40 m depth down to the base. The basal strata of the Crato Formation constitute *Konservat-Laggerstätte* carbonates considered by Martill et al. (2007) as deposited in a protected lagoonal system, with probably fluctuating salinities and reducing conditions attested by the presence of sulphide minerals (Heimhofer and Martill, 2007). Intermittent connection of the Crato lagoon with the sea perhaps through restricted channels is suggested by the presence of certain fish marine taxa which could entered to the lagoon for reproduction and to use as a nursery (Brito, 2007; Brito and Yabumoto, 2011). Aside from marine fishes, other aquatic non-marine and non-aquatic fossils like insects, reptiles, birds, plants (Martill et al., 2007), have been recovered from the Crato Formation *Laggerstätte* and from other strata along the entire unit, which evidenced the terrestrial proximity and the freshwater influence into the complex Crato lacustrine system. Overlying the *Laggerstätte* strata, a short-term isochronous regional freshening event, a crucial shift from a closed system to an open one, is registered by the Caldas Bed benthic palaeocommunities; above this bed the record of heterolithic facies, tidal bundles and marine ichnotaxa points to yet another change marine related (Varejão et al., 2021b). The presence of microforaminiferal linings to the upper strata of the unit confirmed its deposition in a marine environment (Goldberg et al., 2019). According to Varejão et al. (2021a), the Crato Formation sedimentation fluctuating between continental and marine conditions resulted from an allocyclic process associated with combined climatic, tectonic and eustatic variations.

Evaporite strata associated with shales and occasionally thin levels of limestone and fine-grained sandstone constitute the ~30 m thick Ipubi Formation, which overlies the Crato Formation and records extreme aridity in the Araripe Basin (Assine et al., 2014). In the present study, the Ipubi Formation was recorded at the Conceição Preta Quarry (section 1BAr11, Fig. 2B) and with the well-core 2-AR-SR-1A-CE (Fig. 2D) interval between 36.98 and 62.40 m depth. From petrographic and geochemistry characterisation, the Ipubi Formation evaporites were interpreted as deposited in a hypersaline lagoon of a coastal *sabkha* (Bobco et al., 2017). According to Moura et al. (2020), the organic matter contained in the bituminous shales intercalated between the evaporites of the Ipubi Formation, are mostly of marine algae origin and evidenced anoxic conditions in a transitional to restricted marine palaeoenvironment. The top of the Ipubi Formation is marked by a disconformity which is cover by conglomerates and sandstones of the lower portion of the Romualdo Formation (Assine et al., 2014). Heterolithic facies represented by black and calcareous shale with limestone concretions and interstratified with siltstone, claystone and limestone levels occur over the basal coarse-grained facies of the Romualdo Formation (Assine et al., 2014). The black shales level bearing abundant early diagenetic carbonate concretions with well-preserved fossils, represents another *Konservat-Lagerstätte* (Maisey, 1991; Martill et al., 2007) of the Santana Group. As well as ostracods and other marine microfossils, a diverse macrofossil invertebrate and vertebrate fauna like echinoids, decapod crustaceans, molluscs, fishes, dinosaurs, pterosaurs are recovered (Kellner and Campos, 2002; Brito and Yabumoto, 2011; Prado et al., 2018a, 2018b, 2019; Melo et al., 2020; Sayão et al., 2020; Araripe et al., 2022; Guzmán et al., 2022; Pereira et al., 2022; Tomé et al., 2022). To the southeast of the basin and along a slope of the plateau, the Sítio Sobradinho, section 4BAr01 (Fig. 2G), corresponds to the most representative outcrop of the Romualdo Formation, which was also recorded by the present study through the upper part of the well-core 2-AR-SR-1A-CE (Fig. 2D) from top down to 36.98 m depth. With the deposition of the Romualdo Formation clearly marine conditions were well established in the Araripe Basin. According to Custódio et al. (2017), the Romualdo depositional sequence comprises a transgressive-regressive cycle with depositional dip towards the southeast, decreasing in thickness towards northwest, and with source areas located at the northern side of the basin. To the east of the basin, the facies associations recorded are related to a deepening-upward sequence on a mixed siliciclastic-carbonate marine ramp (Melo et al., 2020), whereas to the west, the facies associations indicate a rocky-protected lagoon (Varejão et al., 2019), thus corroborating a low-gradient ramp marine environment, that deepens to the east of the Araripe Basin (Melo et al., 2020).

3. Material and methods

Two well cores and ten outcrops from the Santana Group (Fig. 2, Table 1), Araripe Basin, Brazil, were sampled and prepared for calcareous microfossil analysis at the Applied

Micropalaeontology Laboratory (LMA) of the Federal University of Pernambuco (UFPE), Brazil. An average of 60 g of each rock sample were broken into millimetre-sized fragments and immersed in water for 24 h. Posteriorly, the samples were washed through a set of sieves with opening of 500, 250, 180 and 63 μm and each fraction dried in an oven at 50 °C for 24 h. Both ostracods and foraminifers were picked out using a Zeiss Stemi-305 stereomicroscope and transferred to micropalaentological slides. A total of 88,862 ostracods were recovered from 218 samples and 7,777 foraminifers from 87 samples. Each micropalaentological slide was detailly analysed under a Zeiss SteREO Discovery.V8 stereomicroscope for identification and the best-preserved specimens were selected for image acquisition in the SEM (Scanning Electron Microscope) Phenom XL. Figured ostracods and foraminifers are housed in the calcareous microfossils collection of the LMA. The list of identified taxa and their full names can be found in Appendix A.

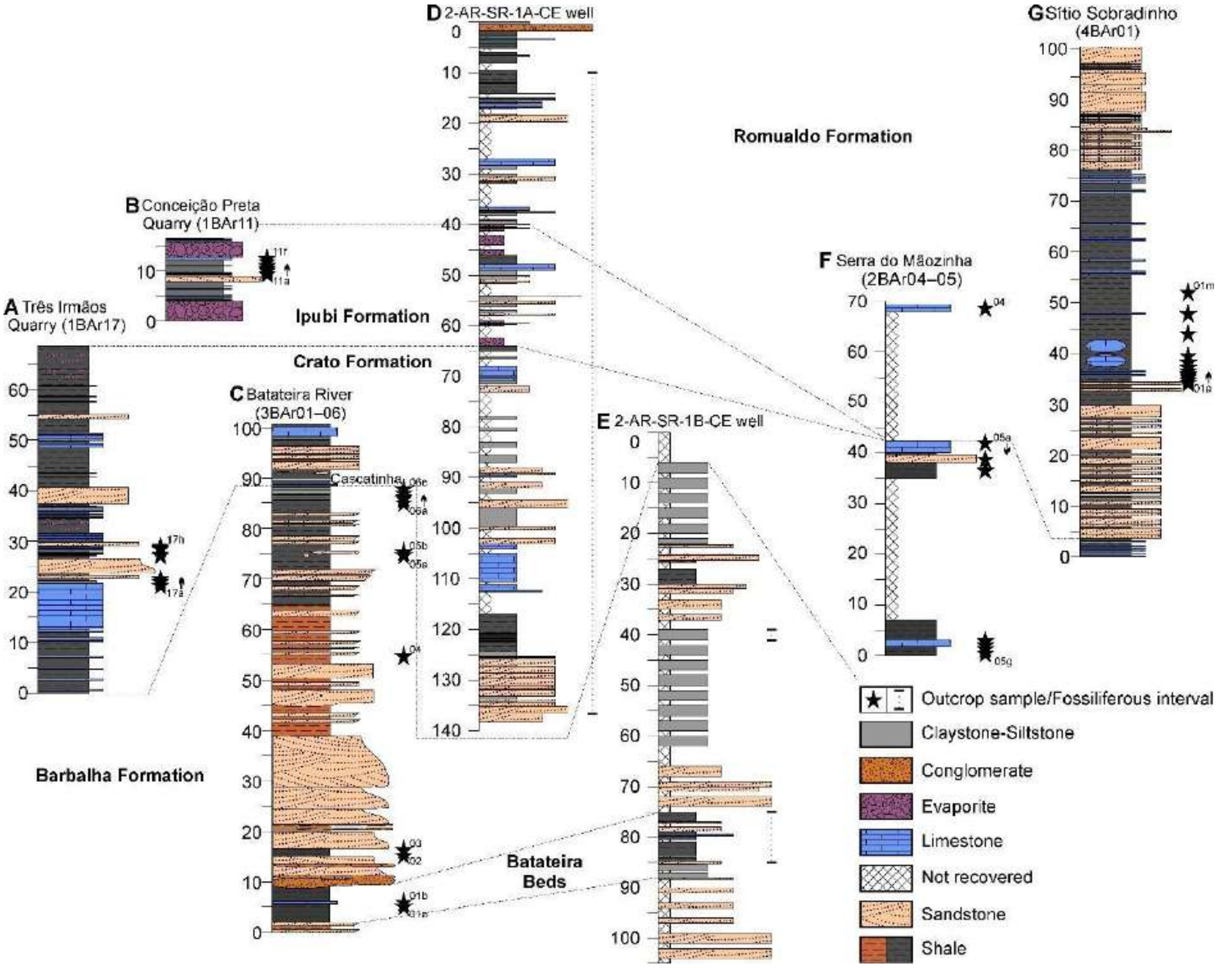


Fig. 2. Lithological profiles of well cores and outcrops (in meters) of the Santana Group, Araripe Basin, Brazil showing the fossiliferous intervals from cores and the samples collected from outcrops. **A,** Três Irmãos Quarry, 1BAr17 outcrop, Crato Formation. **B,** Conceição Preta Quarry, 1BAr11 outcrop, Ipubi Formation. **C,** Composite profile containing the 3BAr01–3BAr06 outcrops along the Batateira River, Barbalha Formation up to the contact with the Crato

Formation. **D,** 2-AR-SR-1A-CE well core. **E,** 2-AR-SR-1B-CE well core. **F,** Composite profile containing the 2BAr04 and 2BAr05 outcrops at Serra do Mãozinha hill, Crato Formation and to the top the Romualdo Formation. **G,** Sítio Sobradinho section, 4BAr01 outcrop, Romualdo Formation. (A–C, F–G) Outcrop profiles adapted from Assine et al. (2014), Custodio et al. (2017) and Varejão et al. (2021a; 2021b). The black arrow indicates the vertical direction of sampling in each outcrop.

4. Ostracoda biozonation

A total of 25 Ostracoda taxa were identified from the Santana Group, Araripe Basin, Brazil (Guzmán et al., 2022). Several of the identified taxa correspond to the *Cytheridea*? spp. 201/218 group which characterised the Biozone 011, Alagoas Local Stage. Improvements of the taxonomy of this group up to the current day, has led to name the Biozone 011 as *Pattersoncypris* ex. gr. *angulata* Zone (Viviers et al., 2000), *Harbinia* spp. 201–218 Zone (Do Carmo et al., 2008, 2013, 2018), *Pattersoncypris* and *Kroemmelbeincypris* Zone (Poropat and Colin, 2012), *Harbinia sinuata*? Zone (Antonietto et al., 2015) and *Damonella grandiensis* Zone (Nascimento et al., 2017). The species *Pattersoncypris micropapillosa* is the appropriate taxon to characterise the Biozone 011, it presents abundance, diversity, wide geographic distribution, and calibration with foraminifer biozones. Also, the new code acronym OST (in reference to ostracod) is proposed considering the wide geographic record of the Mesozoic ostracod fauna in the Brazilian Basins and avoiding the use of basin names acronyms (e.g., R /RT for Recôncavo/Recôncavo-Tucano Basin; OP for ostracods from Potiguar Basin; OSE for ostracods from Sergipe Basin, MSA for marine of the Sergipe/Alagoas) or digits codifying different micro-fossiliferous groups (e.g., Schaller, 1969). This proposal can be extended to other interior and marginal basins for which ostracods define their biostratigraphic frameworks, the comparative chronostratigraphy providing the local stages and Ostracoda biostratigraphy correlation between the Recôncavo, Tucano, Jatobá, Sergipe/Alagoas, Campos and Araripe basins is presented in Fig. 3. The stratigraphical distribution of the ostracods recorded along the Santana Group of the Araripe Basin allow to establish four subzones. The stratigraphic ranges and the abundance of each ostracod species recorded by this study are presented in Fig. 4.

4.1. *Pattersoncypris micropapillosa* Taxon-range Biozone (OST-011)

A zone defined by the stratigraphic interval recording *Pattersoncypris micropapillosa* (Fig. 5A–B), which presents a wide palaeogeographic distribution making it a good index species for correlation. In Brazil, it is recorded in Alagoas Strata from Campos (Moura and Praça, 1985;

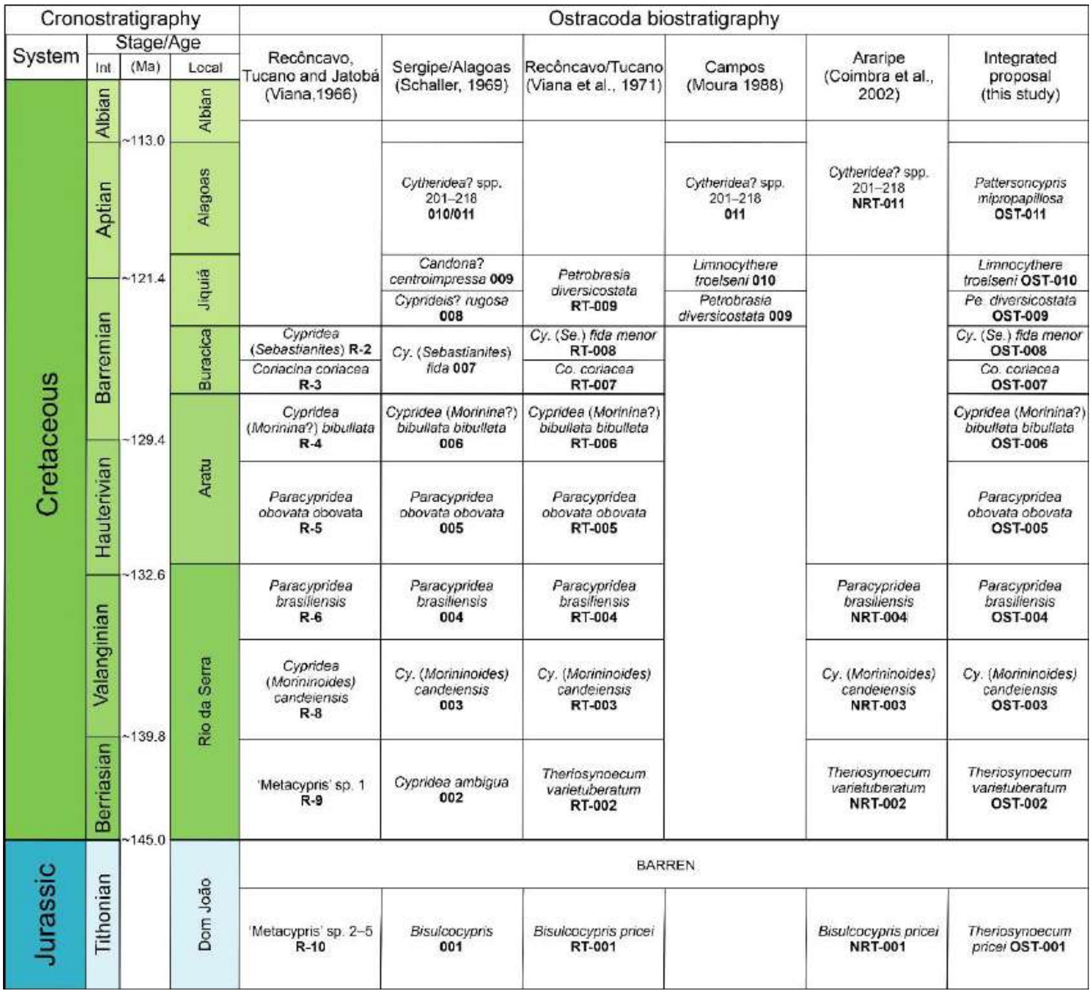
Moura, 1988), Espírito Santo (Piovesan et al., 2013), Sergipe-Alagoas (Smith, 2000), Potiguar (= *Harbinia sinuata*, Do Carmo et al., 2013), Grajaú (Ramos et al., 2006), Parnaíba (de Lima Barros et al., 2022), Jatobá (Tomé et al., 2014) and Araripe (Coimbra et al., 2002; Tomé et al., 2014, 2022; Araripe et al., 2021, 2022; Guzmán et al., 2022) basins. In West and Northcentral Africa this species has also been reported from several Aptian–Albian basins (Bate, 1972; Colin and Dépêche, 1997). The two well cores 2-AR-SR-1A-CE (Fig. 2D) and 2-AR-SR-1B-CE (Fig. 2E) from the Araripe Basin constitute reference sections for the establishment of the *Pattersoncypris micropapillosa* Zone, these were drilled at the Sítio Romualdo, Crato Municipality, Ceará State, recording the Santana Group from the base of the Batateira Beds, Barbalha Formation to the Romualdo Formation. The *Pattersoncypris micropapillosa* stratigraphic range covers the Santana Group throughout, associated to a diversified ostracod fauna that led to recognized four subzones: *Pattersoncypris cucurves*, *P. cucurves-Neuquenocypris berthoui*, *Damonella grandiensis* and *Pattersoncypris crepata* (Fig. 4). This zone also presents abundant benthic and planktic foraminifera co-occurring in different associations with Aptian index species (see Section 5).

4.1.1. *Pattersoncypris cucurves* Taxon-range Subzone (OST-011.1)

The local range of *Pattersoncypris cucurves* (Fig. 4, Fig. 5C–D) is restricted to the organic-rich shales and carbonate levels of the Batateira Beds, Barbalha Formation. In association, *Candonopsis*? *alagoensis* (Fig. 4, Fig. 5A–B) also occurs restricted to the Batateira Beds, both species are abundant. Other ostracod species associated are *Damonella grandiensis* (Fig. 4, Fig. 5E–F), *Damonella pumila* (Fig. 4, Fig. 6E–F), *Pattersoncypris micropapillosa* and *Theriosynoecum silvai* (Fig. 4, Fig. 6Q–R). The boundaries of this subzone correspond to the base and top of the Batateira Beds of the Barbalha Formation, the establishment of lithostratigraphic boundaries is due to chemical compounds controlling the preservation/recovering of ostracods along the complete interval. The reference section for the *Pattersoncypris cucurves* Subzone correspond to the interval between 78 and 80 m depth of the well-core 2-AR-SR-1B-CE (Fig. 2E). Benthic foraminifera are also present in this stratigraphic interval. An early Aptian age for this interval is inferred from the integrated biostratigraphy with planktic foraminifera (see Section 5).

4.1.2. *Pattersoncypris cucurves-Neuquenocypris berthoui* Interval Subzone (OST-011.2)

The subzone is defined by the stratigraphical interval between the top of the Batateira Beds that corresponds to the local highest occurrence of *Pattersoncypris cucurves* (lower boundary) and the local lowest occurrence of *Neuquenocypris berthoui* (Fig. 5I–J) in the upper portion of the Barbalha Formation (upper boundary). A low diversity characterised this subzone presenting as associated species *Theriosynoecum silvai*, *Alicenula martinsi* (Fig. 4, Fig. 6S–T) and *Pattersoncypris micropapillosa*, besides a planktic foraminifer recovered to the top of the stratigraphic interval. The Batateira River section (Fig. 2C), ascending along the river from the top of the Batateira Beds up to the base of the "Cascatinha" point, and the well-core 2-AR-SR-1B-CE (Fig. 2E) interval between 0 and 78 m depth, correspond to the reference sections of the *P. cucurves-N. berthoui* Subzone. An early Aptian age for this interval is inferred from the integrated biostratigraphy with planktic foraminifers (see Section 5).



Cronostratigraphy				Ostracoda biostratigraphy					
System	Stage/Age			Recôncavo, Tucano and Jatobá (Viana,1966)	Sergipe/Alagoas (Schaller, 1969)	Recôncavo/Tucano (Viana et al., 1971)	Campos (Moura 1988)	Araripe (Coimbra et al., 2002)	Integrated proposal (this study)
	Int.	(Ma)	Local						
Cretaceous	Albian		Albian					*Cytheridea?* spp. 201–218 **NRT-011**	
	Aptian	~113.0	Alagoas		*Cytheridea?* spp. 201–218 **010/011**		*Cytheridea?* spp. 201–218 **011**		*Pattersoncypris mipropapillosa* **OST-011**
	Barremian	~121.4	Jiquiá		*Candona? centroimpressa* **009**	*Petrobrasia diversicostata* **RT-009**	*Limnocythere troelseni* **010**		*Limnocythere troelseni* **OST-010**
					Cyprideis? rugosa **008**		*Petrobrasia diversicostata* **009**		*Pe. diversicostata* **OST-009**
			Buracica	*Cypridea* (*Sebastianites*) **R-2**	*Cy.* (*Sebastianites*) *fida* **007**	*Cy.* (*Se.*) *fida menor* **RT-008**			*Cy.* (*Se.*) *fida menor* **OST-008**
				Coriacina coriacea **R-3**		*Co. coriacea* **RT-007**			*Co. coriacea* **OST-007**
			Aratu	*Cypridea* (*Morinina?*) *bibullata* **R-4**	*Cypridea* (*Morinina?*) *bibullata bibulleta* **006**	*Cypridea* (*Morinina?*) *bibullata bibulleta* **RT-006**			*Cypridea* (*Morinina?*) *bibulleta bibullata* **OST-006**
	Hauterivian	~129.4		*Paracypridea obovata obovata* **R-5**	*Paracypridea obovata obovata* **005**	*Paracypridea obovata obovata* **RT-005**			*Paracypridea obovata obovata* **OST-005**
	Valanginian	~132.6	Rio da Serra	*Paracypridea brasiliensis* **R-6**	*Paracypridea brasiliensis* **004**	*Paracypridea brasiliensis* **RT-004**		*Paracypridea brasiliensis* **NRT-004**	*Paracypridea brasiliensis* **OST-004**
				Cypridea (*Morininoides*) *candeiensis* **R-8**	*Cy.* (*Morininoides*) *candeiensis* **003**	*Cy.* (*Morininoides*) *candeiensis* **RT-003**		*Cy.* (*Morininoides*) *candeiensis* **NRT-003**	*Cy.* (*Morininoides*) *candeiensis* **OST-003**
	Berriasian	~139.8		'Metacypris' sp. 1 **R-9**	*Cypridea ambigua* **002**	*Theriosynoecum varietuberatum* **RT-002**		*Theriosynoecum varietuberatum* **NRT-002**	*Theriosynoecum varietuberatum* **OST-002**
Jurassic	Tithonian	~145.0	Dom João	BARREN					
				'Metacypris' sp. 2–5 **R-10**	*Bisulcocypris* **001**	*Bisulcocypris pricei* **RT-001**		*Bisulcocypris pricei* **NRT-001**	*Theriosynoecum pricei* **OST-001**

Fig. 3. Upper Jurassic–Lower Cretaceous international chronostratigraphy, local stages and Ostracoda biostratigraphy correlation between the Recôncavo, Tucano, Jatobá, Sergipe/Alagoas, Campos and Araripe basins.

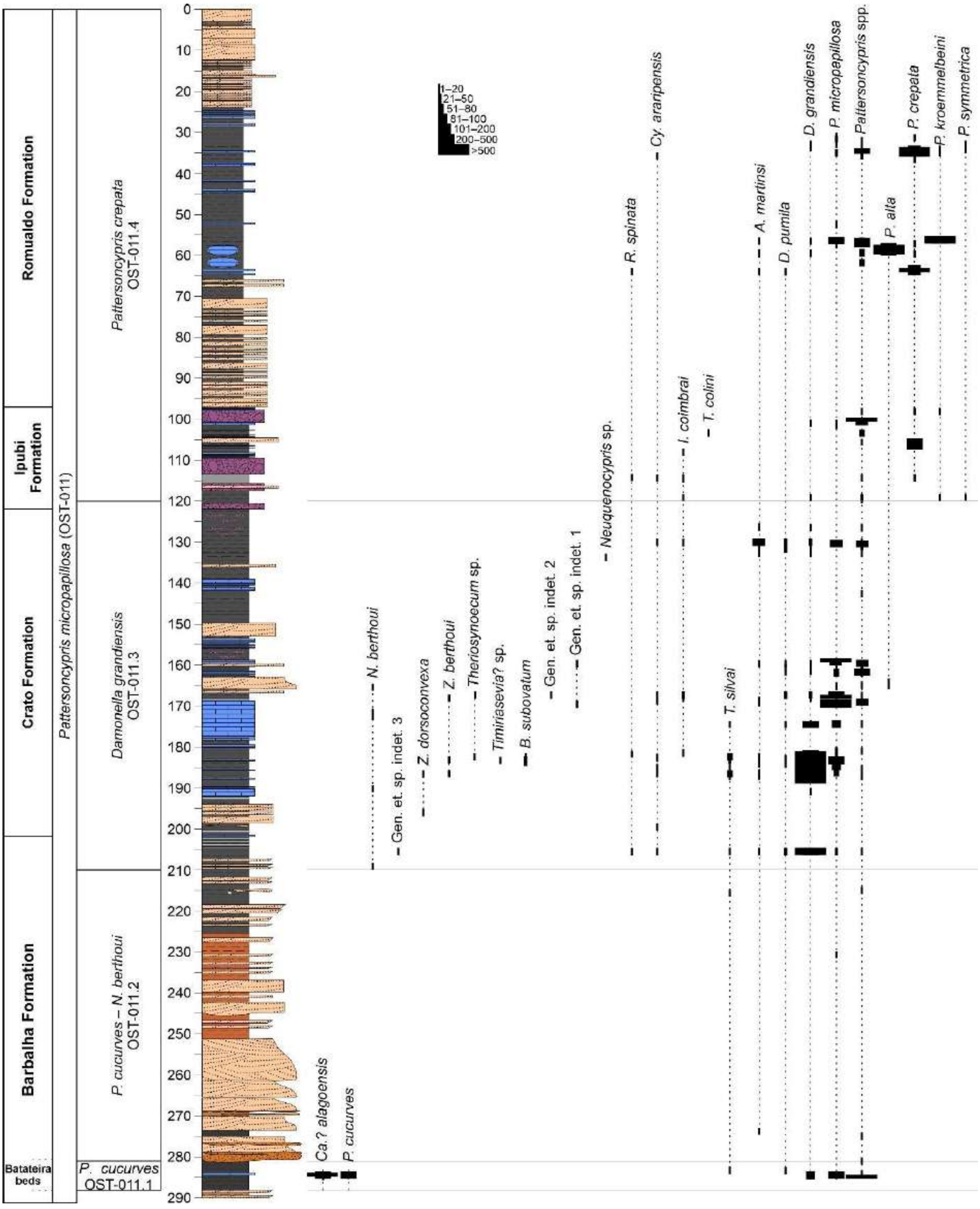


Fig. 4. Stratigraphical ranges and abundances of ostracod species recovered from the Santana Group, Araripe Basin showing the biozonation.

4.1.3. *Damonella grandiensis* Assemblage Subzone (OST-011.3)

Lower and upper boundaries are defined by the local lowest occurrences of *Neuquenocypris berthoui* and *Pattersoncypris kroemmelbeini* (Fig. 4, Fig. 6I–J), respectively. A subzone characterised by a high diversity of the ostracod fauna and conspicuous abundance of

Damonella grandiensis and *Pattersoncypris micropapillosa*. The ostracod association is constituted by *Alicenula martinsi*, *Brasacypris subovatum* (Fig. 4, Fig. 6C–D), *Cypridea araripensis* (Fig. 4, Fig. 6G–H), *Damonella pumila*, Gen. et. sp. indet. 1 (Fig. 4, Fig. 7A–B), Gen. et. sp. indet. 2 (Fig. 4, Fig. 7C–D), Gen. et. sp. indet. 3 (Fig. 4, Fig. 7E–F), *Ilyocypris coimbrai* (Fig. 4, Fig. 7G–H), *Neuquenocypris berthoui*, *Neuquenocypris* sp. (Fig. 4, Fig. 7I–J), *Pattersoncypris alta* (Fig. 4, Fig. 6M–N), *Rhinocypris spinata* (Fig. 4, Fig. 7K–L), *Theriosynoecum silvai*, *Theriosynoecum* sp. (Fig. 4, Fig. 7M–N), *Timiriasevia*? sp. (Fig. 4, Fig. 7O–P), *Zonocypris berthoui* (Fig. 4, Fig. 7Q–R) and *Zonocypris dorsoconvexa* (Fig. 4, Fig. 7S–T). As *Pattersoncypris micropapillosa*, *Damonella grandiensis* occurs throughout the Santana Group and presents a wide palaeogeographic distribution, it has been identified as Ostracod 207/*Candona*? sp. in Alagoas Stage strata from Campos (Moura and Praça, 1985; Moura, 1988), Sergipe/Alagoas (Schaller, 1969), Potiguar (Do Carmo et al., 2013), Cedro and Jatobá (Tomé et al., 2014), Grajaú (Ramos et al., 2006) and Parnaíba (de Lima Barros et al., 2022) basins. The *Damonella grandiensis* Subzone can be referenced in the well-core 2-AR-SR-1A-CE (Fig. 2D) interval between the base (lower portion of Crato Formation) and the top of the lower evaporite level of the Ipubi Formation (62.40 m depth). Also, this subzone can be referenced in the Três Irmãos Quarry (Fig. 2A) which is a well representative section of the Crato Formation corresponding to a *Konservat-Laggerstätte* and the “Cascatinha” outcrop of the Batateira River Section (Fig. 2C), where is exposed the transition between the Barbalha and Crato formations. Along this stratigraphical interval occurs a high diversity of benthic foraminifera associated. A late early Aptian–late Aptian age for this interval is inferred from the integrated biostratigraphy with planktic foraminifera (see Section 5).

4.1.4. *Pattersoncypris crepata* Interval Subzone (OST-011.4)

Stratigraphic interval defined by the highest occurrences of *Pattersoncypris crepata* (Fig. 4, Fig. 5G–H) and *Pattersoncypris micropapillosa* marking the upper boundary; the lower boundary corresponds to the local lowest occurrences of *Pattersoncypris kroemmelbeini* and *Pattersoncypris symmetrica* (Fig. 4, Fig. 6K–L). The subzone is characterised by high abundance of *Pattersoncypris crepata*, which has been recorded in Alagoas Stage strata from Sergipe-Alagoas (Antonietto et al., 2016) and Potiguar (Do Carmo et al., 2013) basins. In the Araripe Basin this subzone is recorded by the Ipubi and Romualdo formations with the ostracod associated species *Alicenula martinsi*, *Cyrpidea araripensis*, *Damonella grandiensis*, *Damonella pumila*, *Ilyocypris coimbrai*, *Pattersoncypris alta*, *Rhinocypris spinata* and

Theriosynoecum colini (Fig. 4, Fig. 6Q–R), also in this subzone are recorded foraminifera both benthic and planktic in high diversity. The presence of planktic foraminifera associated to the *Microhedbergella miniglobularis* Zone indicates that the age of *Pattersoncypris crepata* is late Aptian (Melo et al., 2020), thus dating this subzone. The reference sections of the *Pattersoncypris crepata* Subzone are the well-core 2-AR-SR-1A-CE (Fig. 2D) interval from the top of the well core down to the top of the lower evaporite level of the Ipubi Formation (62.40 m depth). The Sítio Sobradinho section (Fig. 2G), as the most representative of the Romualdo Formation, also correspond to a reference section of this subzone.

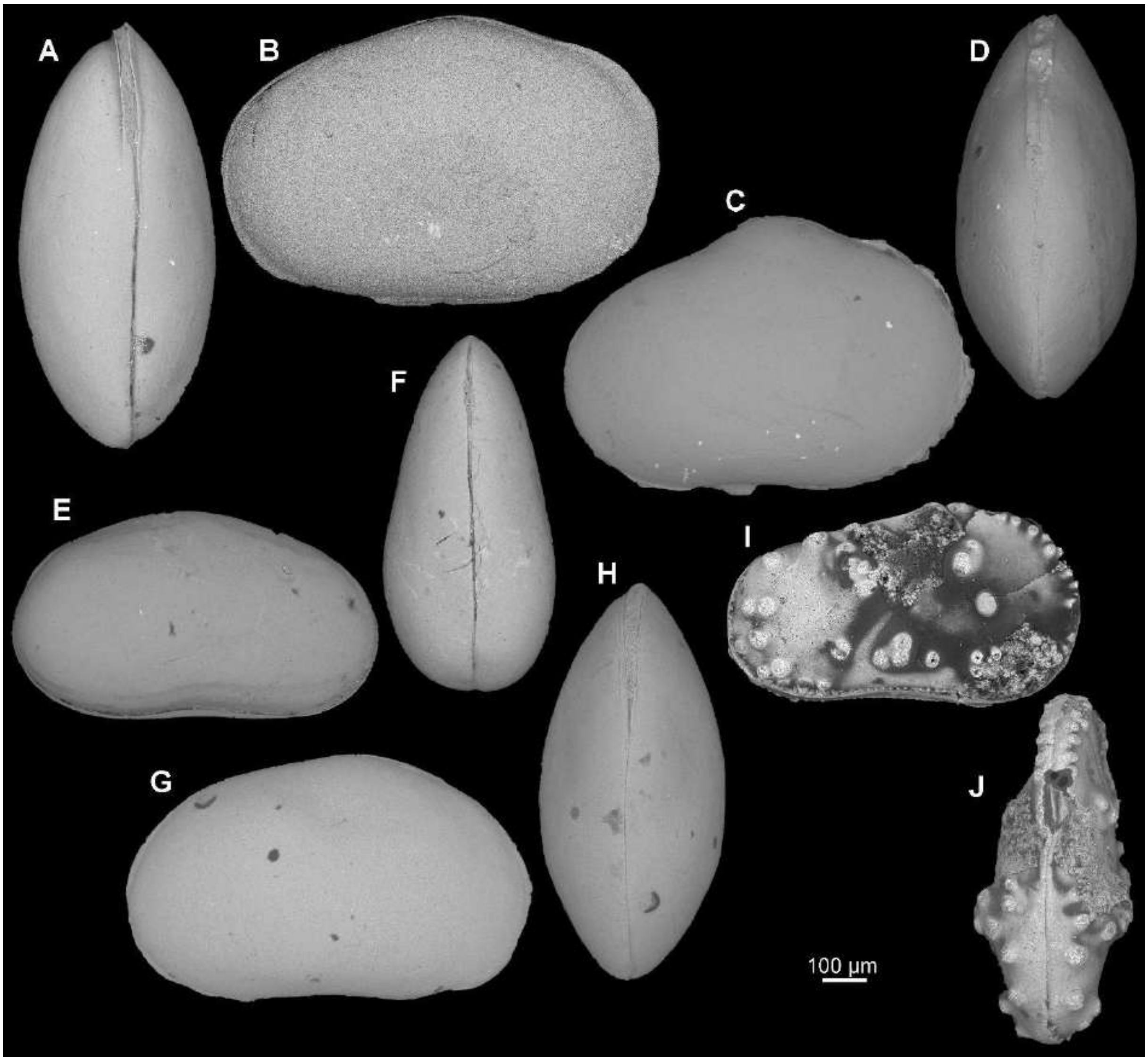


Fig. 5. Ostracod index species. **A–B,** *Pattersoncypris micropapillosa*, right (A) and left (B) views. **C–D,** *Pattersoncypris cucurves*, right (C) and left (D) views. **E–F,** *Damonella grandiensis*, right (E) and left (F) views. **G–H,** *Pattersoncypris crepata*, right (G) and left (H) views. **I–J,** *Neuquenocypris berthoui*, right (I) and left (J) views. (A–J) scale bar: 100 µm.

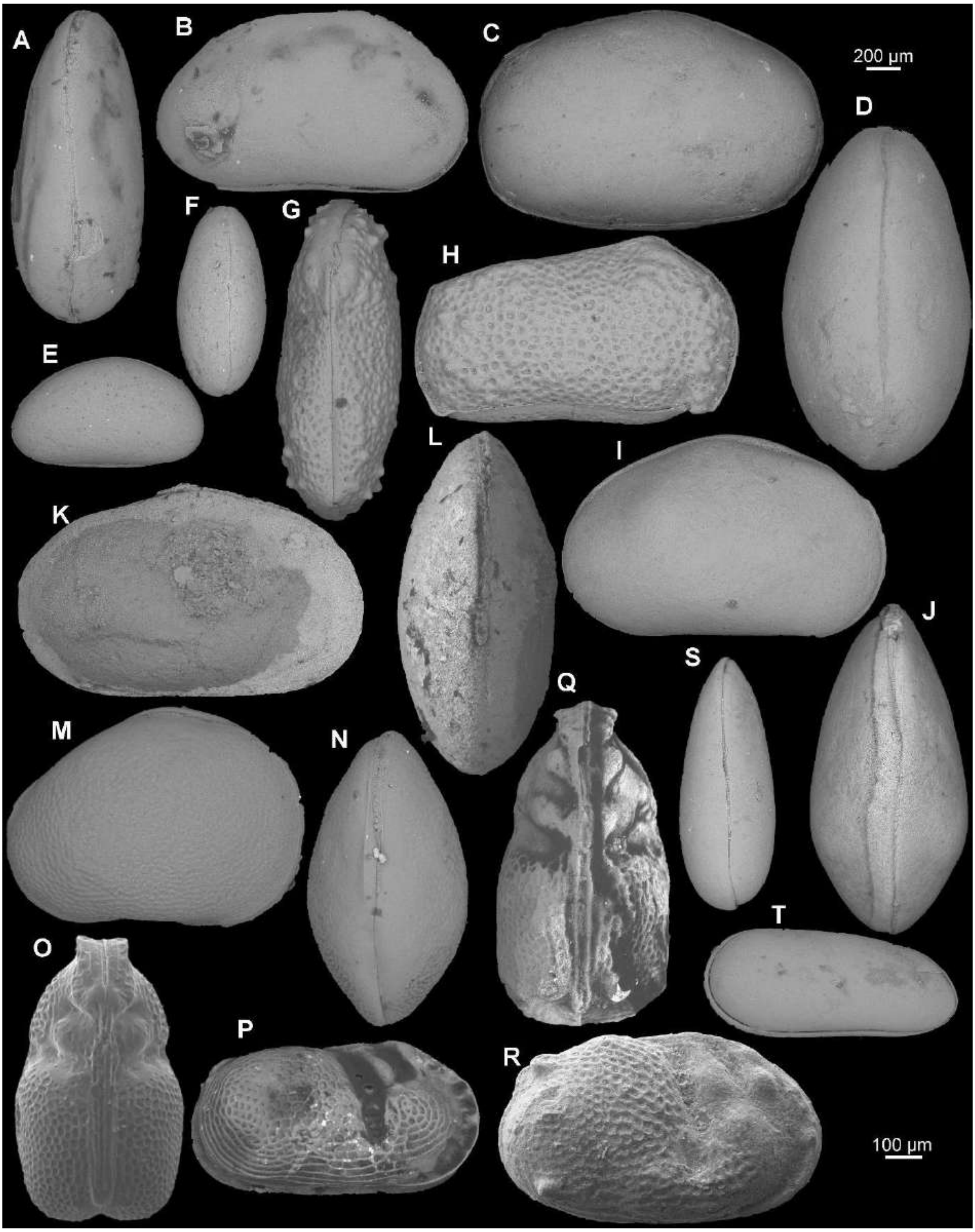


Fig. 6. Ostracod associated species. **A–B,** *Candonopsis*? *alagoensis*, right (A) and left (B) views. **C–D,** *Brasacypris subovatum*, right (C) and left (D) views. **E–F,** *Damonella pumila*, right (E) and left (F) views. **G–H,** *Cypridea araripensis*, right (G) and left (H) views. **I–J,** *Pattersoncypris kroemmelbeini*, right (I) and left (J) views. **K–L,** *Pattersoncypris symmetrica*, right (K) and left (L) views. **M–N,** *Pattersoncypris alta*, right (M) and left (N) views. **O–P,** *Theriosynoecum silvai*, right (O) and left (P) views. **Q–R,** *Theriosynoecum colini*, right (Q) and left (R) views. **S–T,** *Alicenula martinsi*, right (S) and left (T) views. (A–B, E–T) scale bar: 100 µm, (C–D) scale bar: 100 µm.

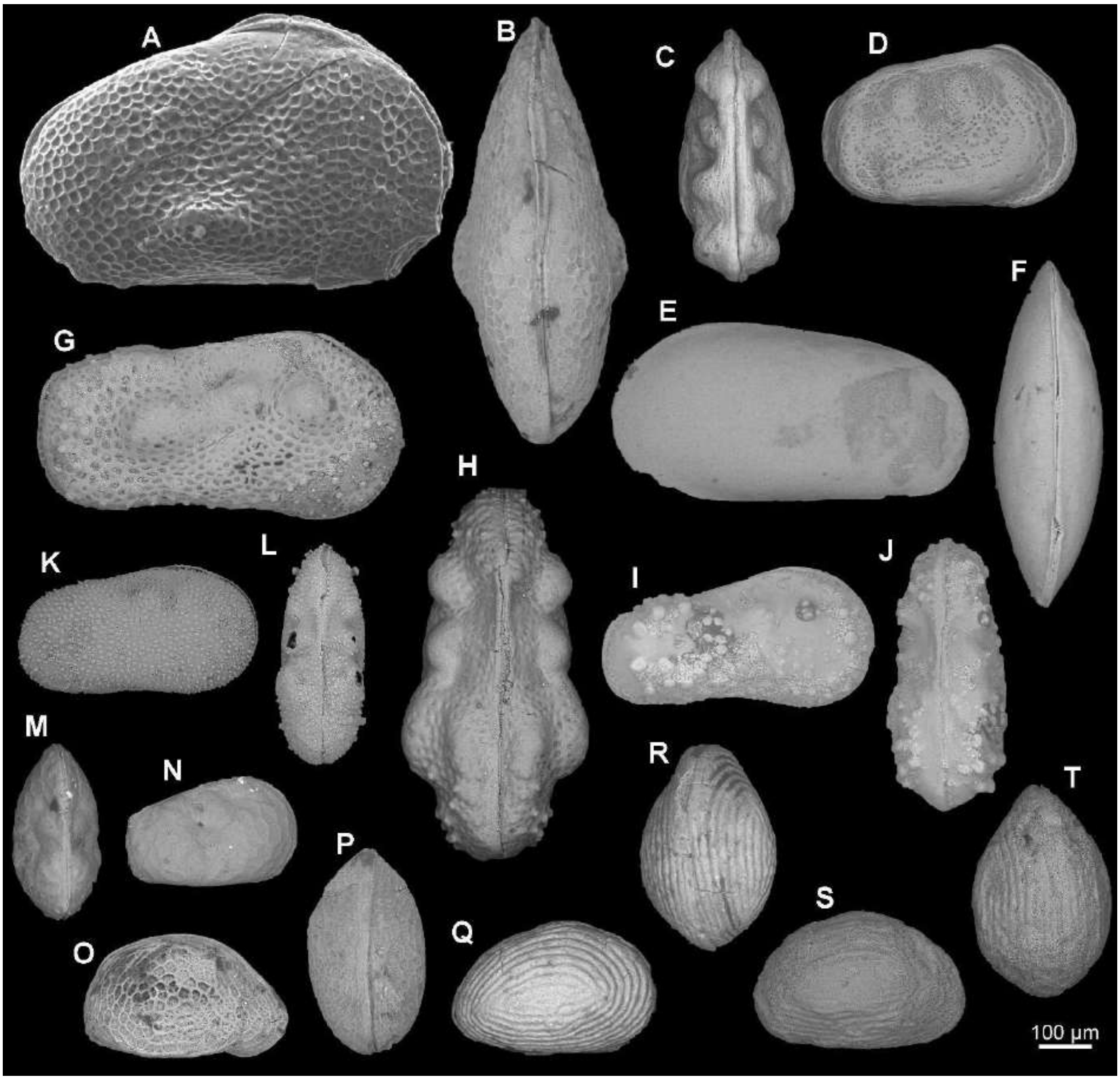


Fig. 7. Ostracod associated species. **A–B,** Gen et. sp. indet. 1, right (A) and left (B) views. **C–D,** Gen et. sp. indet. 2, right (C) and left (D) views. **E–F,** Gen et. sp. indet. 3, right (E) and left (F) views. **G–H,** *Ilyocypris coimbrai*, right (G) and left (H) views. **I–J,** *Neuquenocypris* sp., right (I) and left (J) views. **K–L,** *Rhinocypris spinata* right (K) and left (L) views. **M–N,** *Theriosynoecum* sp., right (M) and left (N) views. **O–P,** *Timiriasevia*? sp., right (O) and left (P) views. **Q–R,** *Zonocypris berthoui*, right (Q) and left (R) views. **S–T,** *Zonocypris dorsoconvexa*, right (S) and left (T) views. (A–T) scale bar: 100 µm.

5. Foraminifera assemblages

A total of 89 Foraminifera taxa were identified from the Santana Group, Araripe Basin, Brazil. The stratigraphical distribution of each foraminifer species recorded are presented in Fig. 8.

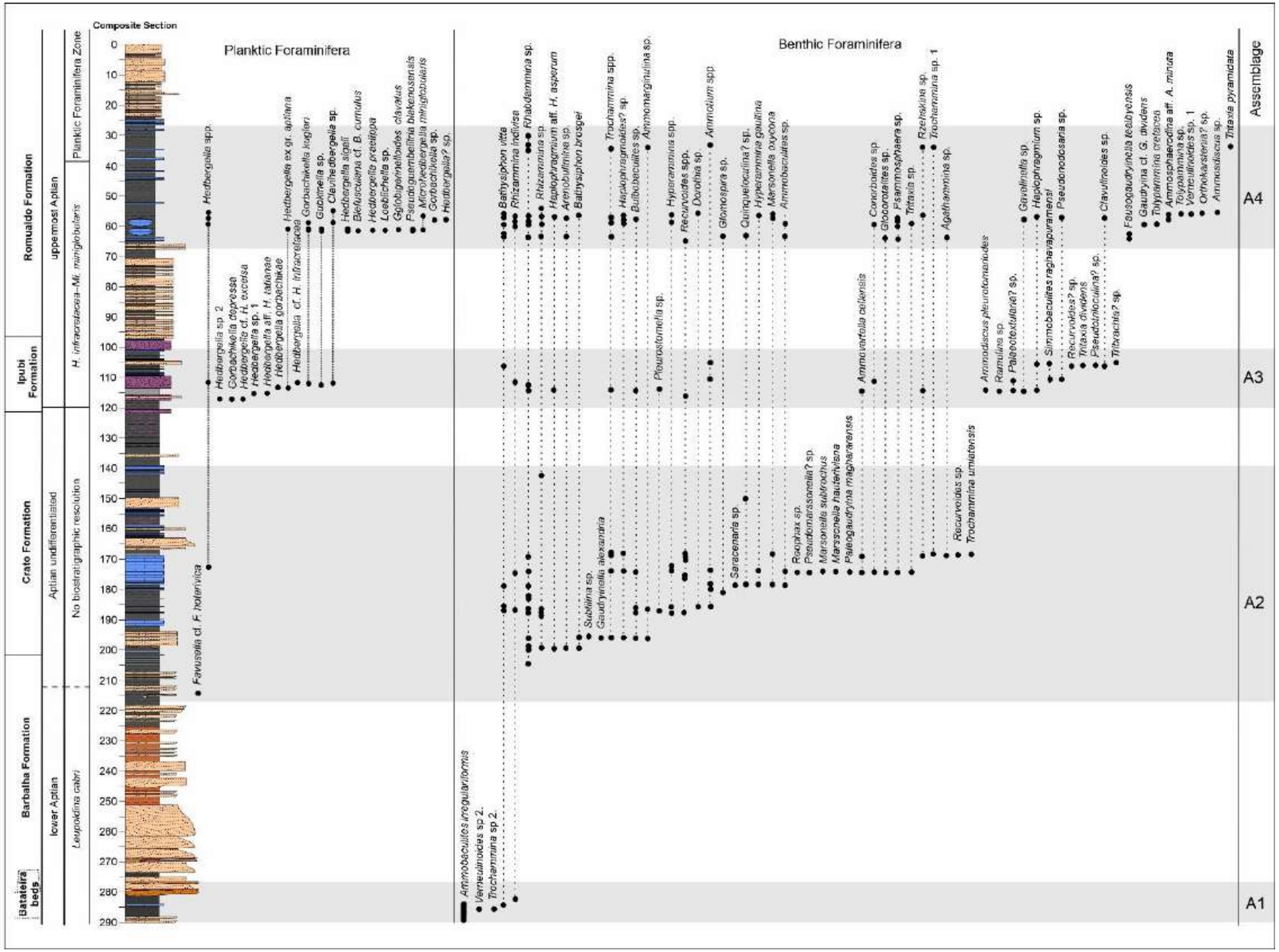


Fig. 8. Foraminifer species stratigraphic distribution showing the planktic foraminiferal zones and the assemblages with the benthic species.

A total of 68 benthic and 21 planktic taxa have recovered found. Based on the abundance, diversity, and distribution of benthic foraminifer taxa throughout the Santana Group it is possible to characterize four main assemblages (Fig. 8). Selected foraminifer specimens are illustrated in Fig. 9 and Fig. 10. The foraminiferal assemblages are dominated by benthic taxa represented by the genera *Agathammina*, *Ammobaculites*, *Ammomarginulina*, *Ammotium*, *Bathysiphon*, *Fausogaudryinella*, *Hyperammina*, *Marssonella*, *Rhabdammina*, *Rhizammina*, *Tritaxia* and *Trochammina*.

Assemblage 1 presents extremely high abundance and low diversity, it is characterised by *Ammobaculites irregulaliformis* (Fig. 9V–Y) which is the most abundant, *Trochammina* sp. 2 (Fig. 9''–D'') and *Verneuilinoides* sp. 2 (Fig. 9U') occurring restricted to the Batateira Beds, Barbalha Formation.

With high diversity the assemblage 2 is dominated by *Agathammina* sp. (Fig. 9I'–K'), *Ammovertella cellensis*, *Marssonella subtrochus* (Fig. 9M–N), *Marssonella hauteriviana* (Fig. 9K–L), *Paleogaudryina maghararensis, Reophax* sp. (Fig. 9P), *Recurvoides* spp. and abundant agglutinated tubular as bathysiphonids, rhabdamminids, and rhizammids. *Gaudryinella alexandria*, *Pseudomarssonella*? sp., *Recurvoides* sp. (Fig. 9Q'–R'), *Saracenaria* sp. (Fig. 9O'–P'), *Subtilina* sp., and *Trochammina umiatensis* (Fig. 9A''–B'') occur exclusively in this assemblage. In this interval is recorded the first occurrences of planktic foraminifers represented by *Favusella* cf. *F. hoterivica* (Fig. 10C'–E') and mainly small hedbergilinids. This assemblage is found from the top of the Barbalha Formation to the upper part of the Crato Formation, mainly in limestone and shale levels.

Assemblage 3 displays lower diversity of benthic foraminifera compared with Assemblage 2; however, it has a more diverse record of planktic foraminifera. The benthic foraminifera composing the assemblage, include the species *Ammodiscus pleurotomariodes* (Fig. 9F'), *Ammovertella cellensis* (Fig. 9E'), *Ramulina* sp. (Fig. 9I), *Palaeotextularia*? sp., *Pleurostomella* sp., *Pseudonodosaria* sp. (Fig. 9N'), *Pseudotriloculina*? sp., *Simmobaculites raghavapuramensi*, *Recurvoides*? sp. (Fig. 9F''–G''), *Tribrachia*? sp. (Fig. 9Z) and *Tritaxia dividens* (Fig. 9Q), which occur restricted to the Ipubi Formation. Planktic foraminifers as *Gorbachikella depressa* (Fig. 10B'), *Hedbergella* sp. 1 (Fig. 10P–Q), *Hedbergella* sp. 2 (Fig. 10R–S), *Hedbergella gorbachikae* (Fig. 10V), *Hedbergella* cf. *H. excelsa* (Fig. 10T–U), *Hedbergella* cf. *H. infracretacea* (Fig. 10I–K) and *Hedbergella* aff. *H. tatianae* (Fig. 10N–O) are exclusively of the assemblage 3, also characterising the Ipubi Formation. Other associated planktic species are *Clavihedbergella* sp. (Fig. 10Y, F'), *Hedbergella* ex gr. *H. aptiana* (Fig. 10G–H), *Gorbachikella kugleri* (Fig. 10Z–A') and *Gubkinella* sp (Fig. 10A–B).

Assemblage 4 is marked by high abundance and high diversity of benthic foraminifera bearing in strata of the Romualdo Formation, upper unit of the Santana Group. The benthic foraminifera are represented by *Ammosdiscus* sp., *Ammosphaerodina* aff. *A. minuta* (Fig. 9H''–K''), *Falsogaudryinella tealbyensis* (Fig. 9C'–D'), *Gaudryina* cf. *G. dividens*, *Orthokarstenia*? sp. (Fig. 9S), *Tolypammina* sp. (Fig. 9L''), *Tolypammina cretacea*, *Tritaxia pyramidata* (Fig. 9R) and *Verneuilinoides* sp. 1 (Fig. 9O). The planktic foraminifera are represented by *Blefuscuiana* cf. *B. cumulus*, *Hedbergella sigali* (Fig. 10L–M), *Hedbergella praelippa*, *Loeblichella* sp., *Globigerinelloides clavatus*, *Pseudoguembelitria blakenosensis* (Fig. 10C–D), *Microhedbergella miniglobularis* (Fig. 10E–F), *Gorbachikella* sp. and *Hedbergella*? sp. (Fig. 10W–X) that only constitute the assemblage 4. The hedbergilinids and *Gubkinella* sp. are abundant, also associated were recovered *Gorbachikella kugleri and Clavihedbergella* sp.

Along the entire group the benthic species *Bathysiphon vitta* (Fig. 9A) and *Rhizammina indivisa* (Fig. 9D–E) occur associated with the different assemblages. *Pleurostomella* sp. and *Ammovertella cellensis* have record in Crato and Ipubi formations. From the Crato Formation to the Romualdo Formation, *Agathammina* sp., *Ammobaculites* sp., *Ammomarginulina* sp., *Ammotium* spp. (Fig. 9S'–T'), *Arenobulimina* sp. (Fig. 9M'), *Bathysiphon brosgei* (Fig. 9B–C), *Bulbobaculites* sp. (Fig. 9A'–B'), *Conorboides* sp., *Dorothia* sp., *Globorotalites* sp., *Glomospira* sp. (Fig. 9L'), *Haplophragmium* aff. *H. asperum*, *Haplophragmoides*? sp., *Hyperammina gaultina* (Fig. 9F–G), *Hyperammina* spp., *Marsonella oxycona* (Fig. 9J), *Psammosphaera* sp. (Fig. 9H'), *Quinqueloculina*? sp., *Recurvoides* spp., *Rhabdammina* sp. (Fig. 9H), *Rhizammina* sp., *Rzehakina* sp. (Fig. 9G'), *Tritaxia* sp. (Fig. 9T–U), *Trochammina* spp. and *Trochammina* sp. 1 (Fig. 9X'–Z') had been recorded. *Clavulinoides* sp., *Gavelinella* sp. (Fig. 9V'–W'), *Haplophragmium* sp. (Fig. 9E''). and *Pseudonodosaria* sp. were just registered for the Ipubi and Romualdo formations.

6. Integrated biostratigraphy

Two international Aptian biostratigraphic intervals were recognized from the Santana Group, characterised by the planktic foraminiferal assemblages. From the determined planktic foraminiferal biozones, the ostracod biozones proposed in Section 3 were dated, the bioevents and biostratigraphy integration are presented in Fig. 11.

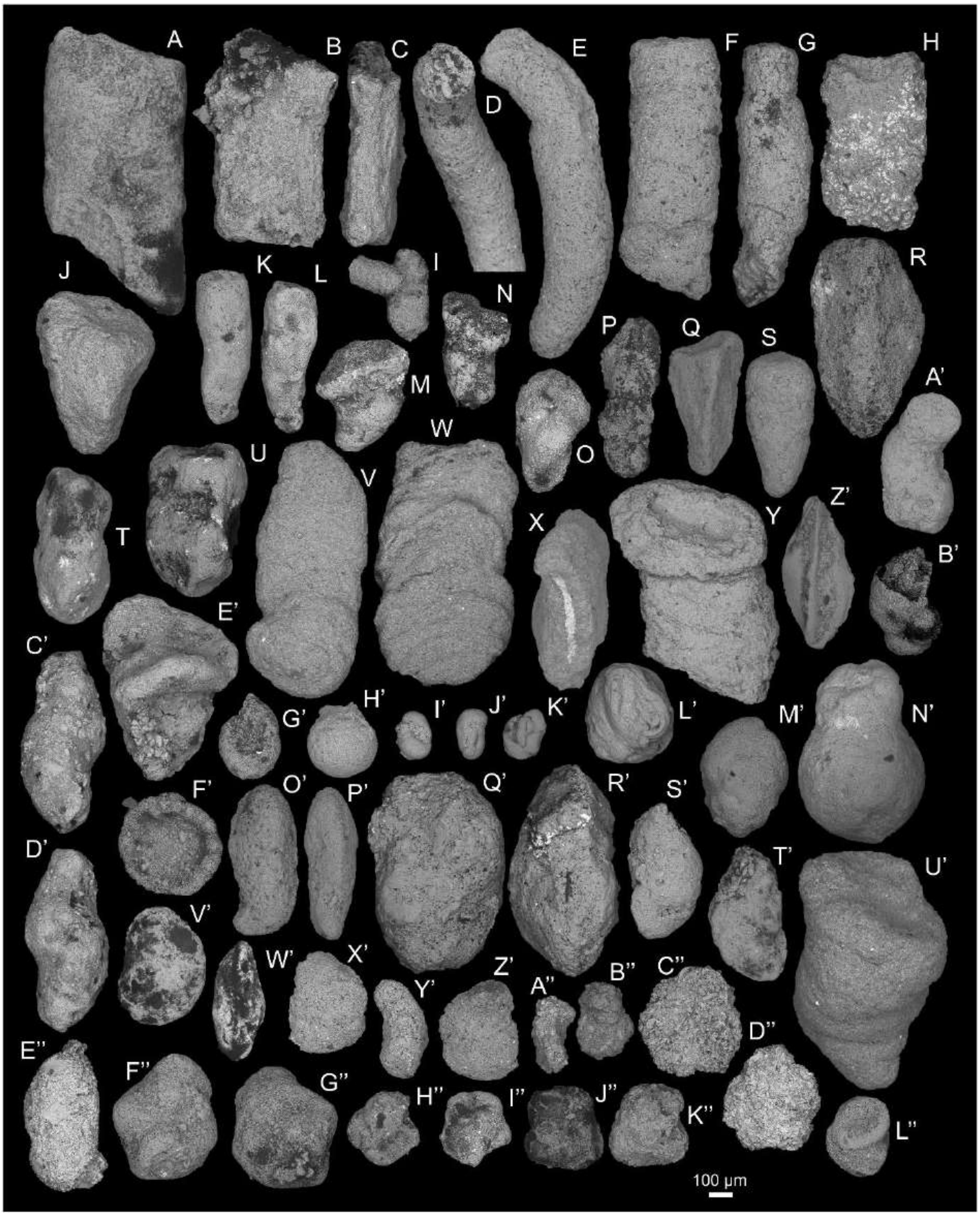


Fig. 9. Benthic foraminifer species. **A,** *Bathysiphon vitta*. **B–C,** *Bathysiphon brosgei*. **D–E,** *Rhizammina indivisa*. **F–G,** *Hyperammina gaultina*. **H,** *Rhabdammina* sp. **I,** *Ramulina* sp. **J,** *Marssonella oxycona*. **K–L,** *Marssonella hauteriviana*. **M–N,** *Marssonella subtrochus*. **O,** *Verneulinoides* sp. 1. **P,** *Reophax* sp. **Q,** *Tritaxia dividens*. **R,** *Tritaxia pyramidata*. **S,** *Orthokarstenia*? Sp. **T–U,** *Tritaxia* sp. **V–Y,** *Ammobaculites irregulariformis*. **Z,** *Tribrachia*? sp. **A'–B',** *Bulbobaculites* sp. **C'–D',** *Falsogaudryinella tealbyensis*. **E',** *Ammovertella cellensis*. **F',** *Ammosdiscus pleurotomarioides*. **G',** *Rzehakina* sp. **H',** *Psammosphaera* sp. **I'–K',** *Agathammina* sp. **L',** *Glomospira* sp. **M',** *Aerobulimina* sp. **N',** *Pseudonodosaria* sp. **O'–**

P', *Saracenaria* sp. **Q'–R',** *Recurvoides* sp. **S'–T',** *Ammtoium* spp. **U',** *Verneulinoides* sp. 2. **V'–W',** *Gavelinella* sp. **X'–Z',** *Trochammina* sp. **A''–B'',** *Trochammina umiatensis*. **C''–D'',** *Trochammina* sp. 2. **E'',** *Haplophragmium* sp. **F''–G'',** *Recurvoides*? sp. **H''–I'',** *Ammosphaerodina* aff. *A. minuta*. **J''–K'',** *Ammosphaerodina* aff. *A. minuta*. **L'',** *Tolypammina* sp. (A–L'') scale bar: 100 µm.

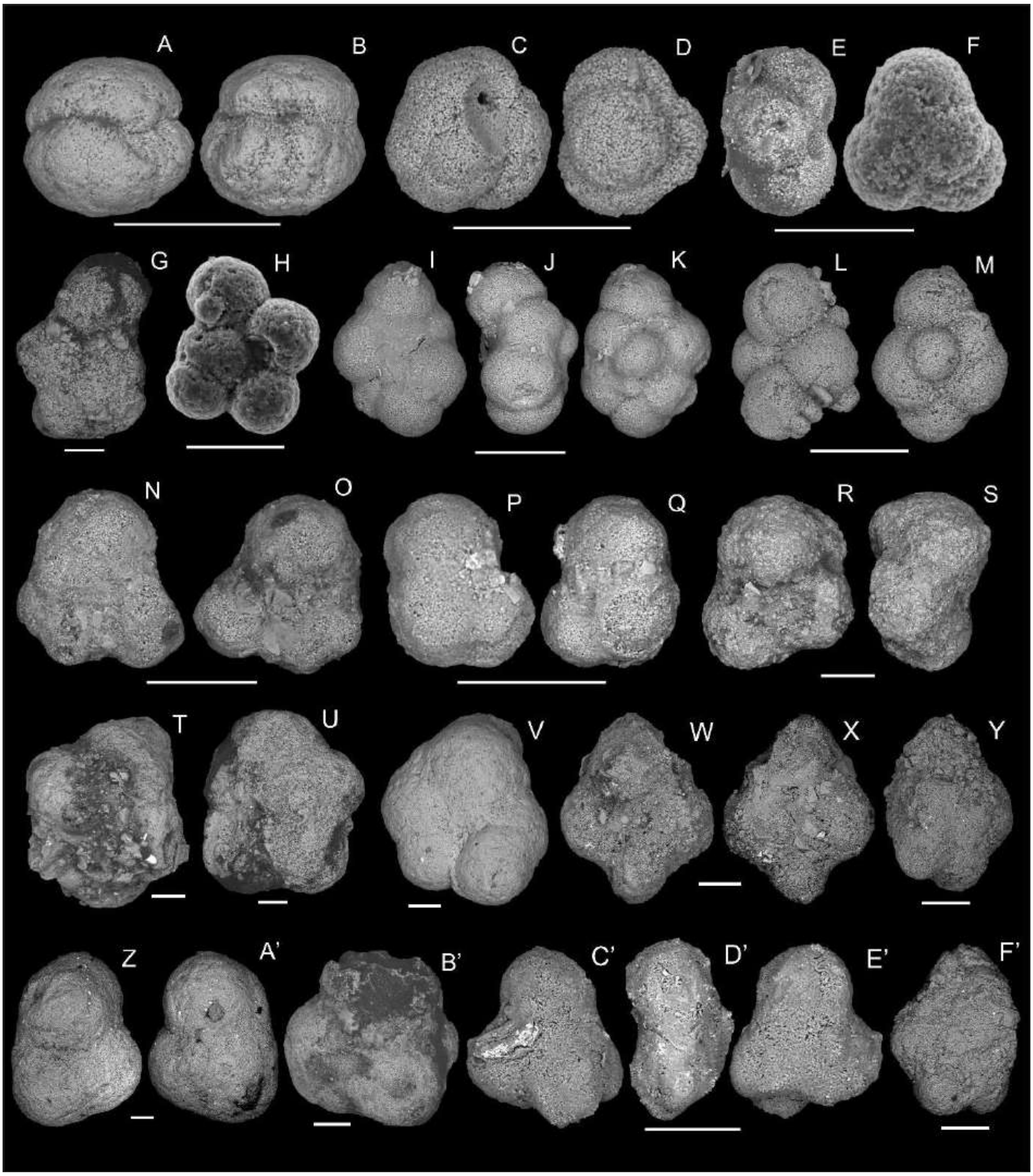


Fig. 10. Planktic foraminifer species. **A–B,** *Gubkinella* sp. **C–D,** *Pseudoguembelitria blakenosensis*. **E–F,** *Microhedbergella miniglobularis*. **G–H,** *Hedbergella* ex gr. *H. aptiana*. **I–K,** *Hedbergella* cf. *H. infracretacea*. **L–M,** *Hedbergella sigali*. **N–O,** *Hedbergella* aff. *H. tatianae*. **P–Q,** *Hedbergella* sp. 1. **R–S,** *Hedbergella* sp. 2. **T–U,** *Hedbergella* cf. *H. excelsa*. **V,** *Hedbergella gorbachikae*. **W–X,** *Hedbergella*? sp. **Y, F',** *Clavihedbergella* sp. **Z–A',**

Gorbachikella kugleri. **B’,** *Gorbachikella depressa*. **C’–E’,** *Favulsella* cf. *F. hoterivica*. (A–E') scale bars: 100 µm.

The occurrence of *Favusella* cf. *F. hoterivica* to the top of the Barbalha Formation led to the chronostratigraphic positioning of the upper sequence of the Barbalha Formation in the lower Aptian. The certainty of *Favusella* cf. *F. hoterivica* identification was limited by the poorly preserved wall texture, nevertheless the reticulate ornamentation typical of the genus as appointed by Gradstein et al. (2019), suggest is this species. *Favusella hoterivica* presents a wide chronostratigraphic range, occurring from Berriasian up to lower Aptian strata (last occurrence within the *Leupoldina cabri* Zone) and is reported widely in Tethyan to sub-Tethyan marine facies along continental margins (Coccioni and Silva, 1994; Huber et al., 2016; Gradstein et al., 2019). The occurrence of the palynomorph *Sergipea variverrucata* in the Batateira Beds (Vallejo et al., 2023) and the dinocyst *Subtilisphaera* in the topmost shales of the Barbalha Formation (Varejão et al., 2021a), appoint the Aptian age (Regali and Viana, 1989; Arai, 2009, 2014; Arai and Assine, 2020) for the complete upper sequence of the Barbalha Formation. This interval corresponds to the foraminiferal *Leupoldina cabri* Zone of early Aptian age (Coccioni and Silva, 1994; Ogg et al., 2016; Gale et al., 2020). The lower *Pattersoncypris cucurves* (OST-011.1) and *Pattersoncypris cucurves-Neuquenocypris berthoui* (OST-011.2) ostracod subzones are stratigraphically positioned within the foraminiferal *Leupoldina cabri* Zone (Fig. 11). Nevertheless, the lack of the index species or another biomarker did not allow the accurate establishing of the upper boundary of the *Leupoldina cabri* Zone.

In the median part of the Santana Group section, that corresponds to the Crato Formation characterised by the ostracod *Damonella grandiensis* Subzone (OST-011.3), it was not possible its chonostratigraphic positioning due to the scarce planktic foraminiferal taxa with no markers. That way, the second international biostratigraphical interval comprises the upper units of the Santana Group, the Ibupi and Romualdo formations. The planktic foraminiferal content of the assemblages 3 and 4 is abundant and diverse, stand out in these assemblages small hedbergellids. The planktic foraminifers recovered from this interval led the chronostratigraphic positioning between the *Hedbergella infracretacea* and *Microhedbergella miniglobularis* zones (Fig. 11), correlated with the ostracod *Pattersoncypris crepata* Subzone (OST-011.4). This interval is assigned to the uppermost Aptian *Hedbergella infracretacea*–*Microhedbergella miniglobularis* composite zone based on the occurrences of *Pseudoguembelitria blakenosensis*, *Hedbergella gorbachikae* and *Microhedbergella* *miniglobularis*, which characterise these zones. *Pseudoguembelitria blakenosensis* ranges from near the base of the *Hedbergella infracretacea* Zone up to the top of the *Paraticinella rohri* Zone, where *Microhedbergella miniglobularis* first occurs ranging up within the Albian *Microhedbergella renilaevis* Zone (Huber and Leckie, 2011; Petrizzo et al., 2012; Ando et al., 2013; Huber et al., 2016). To the south of the Araripe Basin, Araripe et al. (2022) recovered from the top of the Romualdo Formation (Santo Antonio section) the calcareous nannofossil *Hayesites albiensis*, which occurs in association with planktic foraminifers and ostracods typical of the foraminiferal *Paraticinella rohri* and ostracod *Pattersoncypris micropapillosa* zones, leading them to assume a early Albian age for the topmost Romualdo Formation in the Araripe Basin. Nevertheless, the stratigraphic range of *Hayesites albiensis* is not constrained to the Albian, its lowest occurrence coincides with the base of the NC8b Subzone and is recorded up to the mid part of the NC10a Subzone (Young et al., 2022). According to Kennedy et al. (2017) with the proposal of the base of the Albian Stage marked by the first occurrence of the planktic foraminifer *Microhedbergella renilaevis*, the Aptian/Albian boundary lies within the widely recognised crisis interval that affected planktic foraminifera worldwide within the lowermost NC8/CC8 nannofossil Zone, which base corresponds to the uppermostAptian within the foraminiferal *Paraticinella rohri* Zone. The GSSP for the base of the Albian Stage considering the lowest occurrence of the planktic foraminifer *Microhedbergella renilaevis* was ratified by Gale et al. (2020) (see Figure 27.4). As indicated by Melo et al. (2020), the lack of the typical Albian assemblage (e.g., *Microhedbergella renilaevis* and *Microhedbergella rischi*) that marks the top of the *Microhedbergella miniglobularis* Zone and the base of the Albian, corroborates the Aptian age for the topmost Santana Group. Thus, the ostracod *Pattersoncypris crepata* Subzone age can be confirmed as upper Aptian, so other microfossil groups like palynomorphs and dinoflagellates indicate for the Romualdo Formation (e.g., Arai and Assine, 2020; Melo et al., 2020; Vallejo et al., 2023).

7. Palaeoenvironmental evolution of the Aptian Santana Group.

Environmental parameters most influence the composition of the benthic foraminifera community are temperature, salinity, water depth, food availability, substrate, oxygen levels and light conditions (Boltovskoy and Wright, 1976). Agglutinated foraminifera are among the most widely distributed and abundant groups in marine environments (e.g., marshes, deep-sea), they are tolerant to extremes conditions, tending to live where the evolutionarily more advanced calcareous foraminifera cannot survive (Hemleben et al., 1990). The Foraminifera diversity and abundance can be controlled by regional scale palaeoceanographic changes, these shifts in marine communities are here used to reconstitute the environmental evolution of the Aptian Santana Group (Fig. 11, Fig. 12). Furthermore, the foraminiferal assemblages allowed to better understand the habitat of the associated ostracod taxa recovered throughout the Santana Group, which several has been for decades assumed as firmly continental, in view of the no recovery of clearly marine microfossils by previous studies. Temporal variations in benthic foraminiferal assemblages in terms of environmental parameters are extensively used interpreting palaeoenvironments (e.g., Corliss, 1985; Koutsoukos and Hart, 1990; Thomas and Gooday, 1996). The distribution patterns of Santana Group Foraminifera (Fig. 8) and Ostracoda (Fig. 4) are here discussed from a palaeoenvironmental standpoint in order of stratigraphic succession.

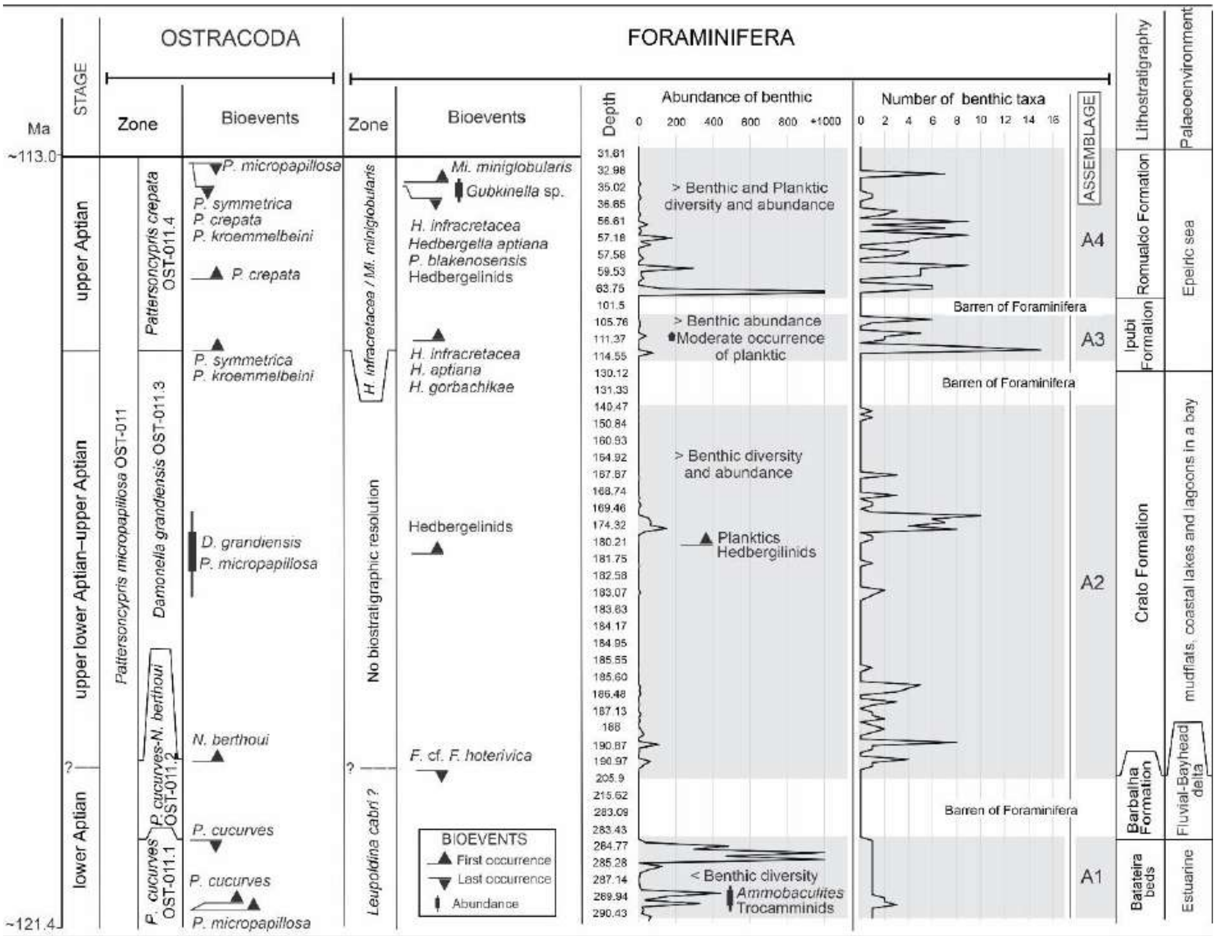


Fig. 11. Correlation of ostracods and planktic foraminifera zonal schemes proposed for the Aptian Alagoas local stage through the Santana Group, Araripe Basin at global scale. Bioevents considered for chronostratigraphic positioning and benthic foraminifera abundance and diversity for palaeoenvironmental interpretations of the Santana Group.

The lower Aptian foraminiferal *Leupoldina cabri* Zone and ostracod *Pattersoncypris cucurves* Subzone, record a low energy environment characterised by organic-rich black shales and limestones of the Batateira Beds, Barbalha Formation bearing both foraminifera and ostracods in low diversity and high abundance. Associations of low diversity but high abundance are typical of unstable environments, in particular low oxygen, or low temperature conditions (Kaminski et al., 1995). The foraminiferal assemblage recovered from the Batateira Beds by this study is exclusively dominated by ammomarginulinids (*Ammobaculites*) and trochamminids (*Trocahmmina*), characteristic of the *Ammobaculites* Association of Haig (1979) that suggests eutrophic conditions and restricted marine circulation. The persistence of agglutinated foraminifers in the Batateira Beds indicate deposition in a confined transitional environment under anoxic conditions. The low diversity and abundant siliceous agglutinated foraminifers with very small and unornamented hyaline calcareous specimens of the *Ammobaculites* Association characterised shallow land-locked, hyposaline epeiric seas (Haig, 1979). Koutsoukos and Hart (1990) recognised this association in the Sergipe Basin, for which an infaunal habit life was inferred and interpreted as locally developed in very shallow brackish lagoons within the tropical paralic biotopes belt. According to Copestake and Johnson (1989) and (Ballent, 2004), the genus *Ammobaculites* is a typical estuarine taxon, when occurring in sandy lithology related to a deltaic influence. Infaunal species of *Ammobaculites* recovered from Jurassic estuarine sediments (10–15 cm depth), might perhaps presented less stringent oxygen requirements than other forms (Buzas, 1974; Jones and Charnock, 1985). Similarly, in the Upper Jurassic–Lower Cretaceous of Dorset, the species *Ammobaculites* cf. *A. obliquus* is interpreted as being an environmentally tolerant opportunist, which inhabited muddy, brackish lagoonal substrates or marginal mudflats under ephemeral dysaerobic conditions (Radley, 1993). With the new evidence, the traditionally interpreted as lacustrine facies of the Batateira Beds, Barbalha Formation corresponds to a confined estuarine deposit within a flooded valley (Fig. 12A). The palynofacies of the Batateira Beds exhibits characteristics of a proximal environment close to fluvial-deltaic source of the parent flora (Vallejo et al., 2023). According to Varejão et al. (2021a), the upper sequence of the Barbalha Formation (overlying the Batateira Beds) represents the evolution of a fluvial to a bayhead delta environment (Fig. 12B) of the lowstand system tract to the transgressive surface, where the authors reported the occurrence of *Subtilisphaera* dinocyst and ichnotaxa as evidence of the first marine ingression in the basin. Commonly, bayhead deltas develop in the innermost part of bays and estuaries in transgressive coastlines (Aschoff et al., 2018), and represent the lowermost estuarine unit that forms above fluvial strata and are the initial evidence of an increase in accommodation (Simms et al., 2018).

The benthic foraminiferal assemblage characterises the Batateira estuarine (Fig. 12A) and indicates that the marine influence was even earlier in the Araripe Basin. Posteriorly, a fluvial system registered a continental progradation and again a marine transgression deposited bayhead delta sediments of the upper sequence of the Barbalha Formation (Fig. 12B). The ostracod species of the genera *Damonella* and *Pattersoncypris* whose lowest occurrences in the basin are reported from the Batateira Beds, like *D. grandiensis*, *D. pumilla*, *P. cucurves* and *P. micropapillosa*, as well the species *Candonopsis*? *alagoensis*, could be assigned as typical of transitional palaeoenvironments in view of their association with abundant benthic foraminifera. When described *Pattersoncypris micropapillosa*, Bate (1972) inferred freshwater environments as habitat of this species due to the limited diversity of the ostracod fauna recovered, nevertheless the material of the description were found entombed with the fish species *Cladocyclus gardneri*, which hints marine links (Brito, 2007; Brito and Yabumoto, 2011). Also, the type species of the genus *Damonella*, *D. pygmaea*, is one of the most ubiquitous marine or quasi-marine species in the Purbeck and Wealden strata (Upper Jurassic–Lower Cretaceous) of England (Anderson, 1966). In those strata, *Damonella* species occurring in association with ostracod species other than of the genus *Cypridea*, were related to phases of higher salinity assumed to indicate brackish-water or marine conditions (Anderson, 1985).

During the early late Aptian took place the deposition of the Crato Formation in the Araripe Basin, recording the first calcareous foraminiferal forms like *Quinqueloculina*? sp., *Agathammina* sp., *Pleurostomella* sp., *Conorboides* sp., *Globorotalites* sp., *Saracenaria* sp., as well as the first hedbergelinids foraminifers suggesting a greater marine influence in the depositional environment. This unit has been interpreted as resulted from a transgressive system tract (TST) represented by sediments deposited in a broad non-marine environment under freshwater and marine influence oscillations that generated different water bodies (Varejão et al., 2021a). The presence of the genera *Reophax*, *Rhizammina* and *Haplophragmoides* in this unit indicates a restricted basin (King et al., 1989). In addition, the occurrence of the species *Marssonella oxycona*, *M. subtrochus* and *M. hauteriviana* suggest the *Marssonella* Association of Haig (1979). The *Marssonella* Association is characterised by agglutinated specimens associated with a diverse assemblage of calcareous Foraminifera which appear to be confined to carbonate-rich sediments (e.g., calcareous mudstones, limestones) deposited in coastlines from a broad latitudinal range (Haig, 1979). Although an increase in the diversity of foraminifera is observed in the Crato Formation, in general terms the agglutinated forms are predominant, like other assemblages of Jurassic–Cretaceous deposits that have been typically related to hyposaline or oxygen depleted conditions (e.g., Nagy et al., 1990; Yakovleva-O'Neill et al., 2011; Reolid et al., 2014). Moreover, the abundant specimens of the genus *Agathammina* recovered from the carbonate layers indicates shallow marine, including reef environments (Okay and Altiner, 2007; Roozbahani, 2011; Araripe et al., 2021). To the topmost Crato Formation, the rare foraminiferal linings are consistent of marine conditions, reinforcing this interval was deposited in a lagoonal coastal plain to marine environment (Goldberg et al., 2019; Vallejo et al., 2023). The distribution of the ostracod fauna also demonstrates the freshwater or marine predominant influence from the upper Barbalha Formation throughout the Crato Formation, levels where specimens of the genera *Pattersoncypris* and *Damonella* are extremely abundant, present diverse benthic Foraminifera, leading to confirm their transitional environment characteristic. Fluvial-lacustrine typical ostracods, as the genera *Alicenula*, *Cypridea* and *Theriosynoecum*, as well as *Rhinocypris*, *Ilyocypris* and *Neuquenocypris* of rare occurrence in some levels, supports as interpreted by (Varejão et al. 2021a), freshwater inputs into the mudflats, coastal lakes, and lagoons of the Crato bay coastal watershed (Fig. 12C). Darwinulids and the genus *Theriosynoecum* are belived to inhabited fresh to slightly saline, permanent water bodies, whilst *Cypridea* is considered a freshwater genus of both permanent and temporary environments (Horne, 2002). According to Anderson (1985), as a steady progression towards a less saline environment through the Purbeck and Wealden strata, darwinulids become increasingly abundant, whilst nearer to freshwater conditions are indicated by species of the genus *Cypridea*. Nevertheless, rather than to salinity, the alternations between *Cypridea*-dominated and *Cypridea* non-dominated assemblages, may be related to the relative abundance of permanent and temporary water bodies, whether linked to climate or marine influence (Horne, 2002).

To the uppermost Aptian, the marine conditions became to be better-established. The more abundant and diverse presence of Foraminifera, mainly the planktic hedbergilinids recovered from shales of the Ipubi Formation, suggest the Araripe Basin reached a more open circulation with the ocean. According to Goldberg et al. (2019) the marine fossils in the topmost organic shales of the Crato Formation, immediately beneath the Ipubi Formation evaporites, corroborates the already established marine connection and ion supply that coupled with increasing aridity prompted to thick salt layers precipitation. The predominance of agglutinated foraminiferal forms and rarity of the calcareous benthic ones, suggest a shallow near-shore environment. According to Melo et al. (2020), the final deposition of the Santana Group occurred on a marine ramp, from the Ipubi Formation the present study recovered planktic foraminifera, which supports the deposition of the Ipubi evaporites occurred in a lagoon of a marine ramp restricted by shoals, under extreme aridity (Fig. 12D). The coastal sandstones of the Romualdo Formation disconformably covered the evaporitic facies association of the Ipubi Formation (Assine et al., 2014). The persistent occurrence of ostracods like *Pattersoncypris crepata*, *P. kroemmelbeini*, *P. symmetrica* and the foraminifers *Hedbergella* ex. gp. *aptiana*, *Gorbachikella kugleri* among other in both Ipubi and Romualdo Formations suggest a briefly period of no deposition before the re-establishing of the sea in the Araripe Basin. The Romualdo Formation comprises transgressive and highstand systems tracts, including coastal alluvial, tide-dominated facies, and marine black shales that encompass the maximum flooding zone and to the top the continentalization progradational package (Custódio et al., 2017). Melo et al. (2020) interpreted as a ramp-type marine shelf without steep slope at edge the depositional environment of the Romualdo Formation, supporting as indicated by Arai (2009, 2014, 2016), a seaway through the Araripe Basin. The present study records from this sequence a high diversity and abundance of foraminifer species both benthic and planktic, several *Hedbergella* species as well the specimens of the genus *Gubkinella* predominate. The genus *Gubkinella* is one of the main representatives of the "Epicontinental Sea Fauna" (Leckie, 1987). According to Leckie (1989), Coccioni et al., (2014) and Ferraro et al. (2020) the accumulation of these planktic foraminiferal genera may be related to the Oceanic Anoxic Event OAE 1b that occurred between the latest Aptian to the early Albian. Benthic foraminiferal genera as the infaunal *Bathysiphon* and *Rhizammina*, and others as *Falsogaudryinella* and *Glomospira* suggest poorly oxygenated conditions in a middle neritic-upper bathyal environment (Jones and Charnock, 1985; Kaminski and Kuhnt, 1995; Kaminski et al., 1995; Gradstein et al., 1999). Those organisms are found in maximum flooding zone facies of the Romualdo Formation that characterise deposition from the mid-ramp shoal to the basin (50–200 m depth) on a mixed siliciclastic-carbonate marine ramp (Fig. 12E) (Melo et al., 2020). Araripe et al. (2021, 2022) reported a similar foraminiferal assemblage from several outcrops of the topmost Romualdo Formation, also the ostracod assemblage contents species of the *Pattersoncypris crepata* Subzone among typical marine species, demonstrating the extension of the Aptian seaway through the south-central to the west areas of the basin. The seawater of the Araripe Basin during the deposition of the Santana Group was supplied by the Tethys Ocean, as indicated by Foraminifera such as favusellids, hedbergellids, globigerinelloidids, gavelinellids, ammosphaeroidinids, haplophragmiids, trochamminids among others also recovered from the Sergipe Basin (Koutsoukos, 1992) and the *Subtilisphaera* Ecozone with a wide geographic distribution including Morocco, Senegal, Venezuela, and several Brazilian basins (Arai, 2014).

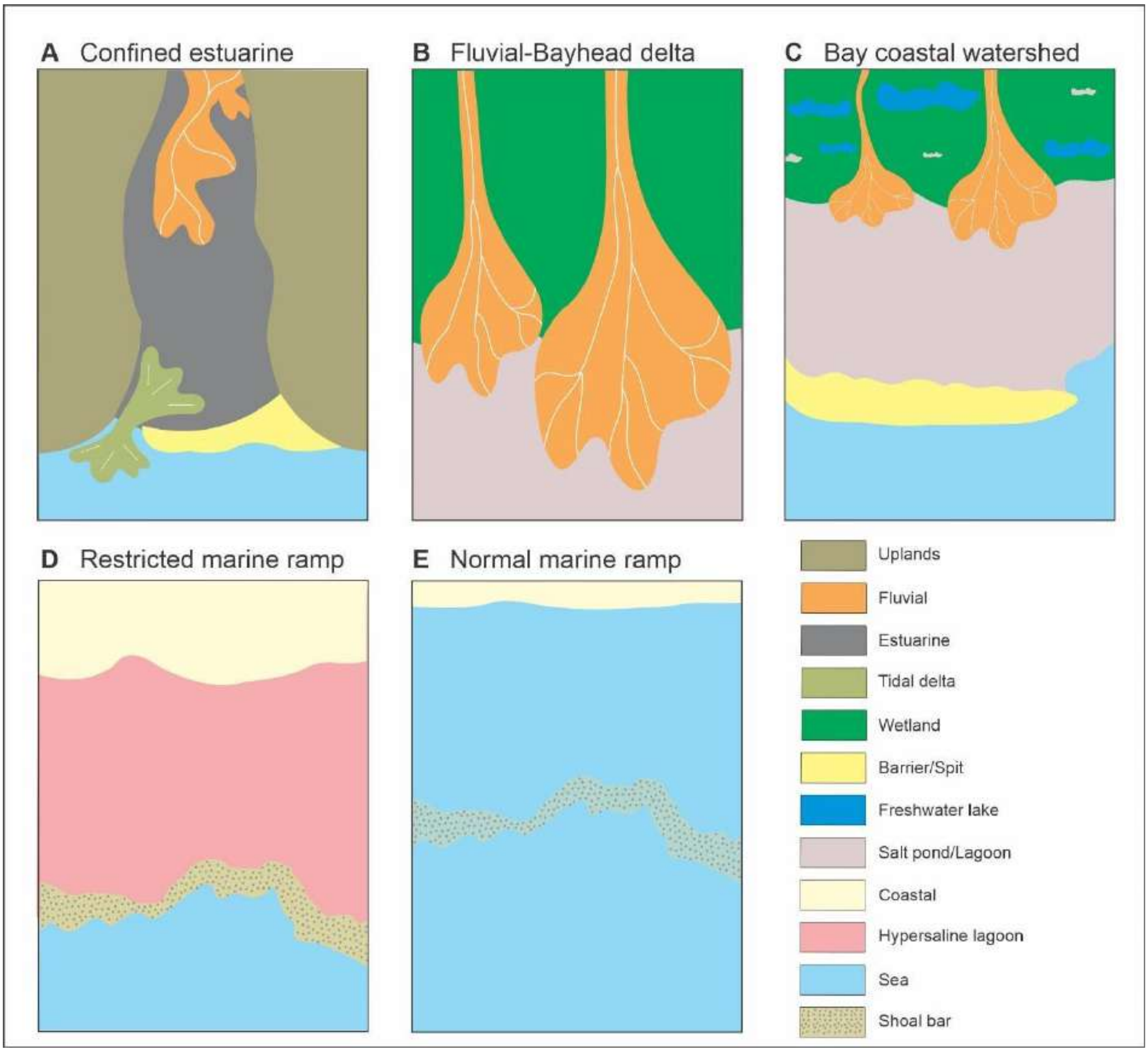


Fig. 12. Depositional evolution of the Santana Group in the Araripe Basin during the Aptian. **A,** Confined estuarine environment of the Batateira Beds, topmost lower sequence of the Barbalha Formation. **B,** Fluvial system of the upper sequence of the Barbalha Formation that evolved to a bayhead delta with a new marine transgression. **C,** Crato Bay Coastal Watershed (Crato Formation). **D,** Hypersaline lagoon in a restricted marine ramp represented by the Ipubi Formation. **E,** Normal marine ramp of a full installed seaway during the deposition of the Romualdo Formation.

8. Conclusions

The Santana Group in the Araripe Basin records the sedimentation during the establishment of a transitional to marine environment through the Aptian. Four ostracod subzones were described within the *Pattersoncypris micropapillosa* Taxon-range Biozone (OST-011): *Pattersoncypris cucurves* Taxon-range Subzone (OST-011.1), *Pattersoncypris cucurves-*

Neuquenocypris berthoui Interval Subzone (OST-011.2), *Damonella grandiensis* Assemblage Subzone (OST-011.3) and *Pattersoncypris crepata* Interval Subzone (OST-011.4). Besides, two planktic foraminiferal zones were recognised, the *Leupoldina cabri* Zone of the lower Aptian, within which are stratigraphically positioned the OST-011.1 and OST-011.2 ostracod subzones, and the *Hedbergella infracretacea–Microhedbergella miniglobularis* composite zone of the upper Aptian age which is correlated with the OST-011.4 ostracod subzone. This work presents an improvement on the knowledge of the palaeoenvironmental evolution based on ostracods and foraminifers, determining different depositional phases from the integrated biostratigraphy. The Batateira Estuarine marks the first marine influence in the basin during the early Aptian, followed by a continental progradation of the Barbalha fluvial system that evolved to a bayhead delta with a new marine transgression. During the early late Aptian, were developed mudflats, coastal lakes, and lagoons along the Crato Bay Coastal Watershed. Subsequent, more open marine circulation reached the basin under extremely aridity, causing high-rate evaporation of the restricted marine ramp and the Ipubi salt precipitation. The last depositional phase took place during the latest Aptian with the full installation of the seaway on the Romualdo normal ramp.

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Author contribution

J.G. wrote the main part of the manuscript, organised, and prepared most figures. J.G. and V.H.M.L.N. conducted the sedimentological description of well cores and outcrops. J.G., D.S.A-L. and E.K.P. performed the descriptive research of ostracods. R.M.M. performed the descriptive research of foraminifera and figures related. J.G. and R.M.M. prepared the depositional evolution figure and graphical abstract. E.K.P., V.H.M.L.N. and A.J.S. designed the project. All authors contributed and reviewed the manuscript.

Appendix A. Appendix

Alphabetical list of Ostracoda and Foraminifera taxa (with authors and dates) identified in this study.

Ostracoda

Alicenula martinsi (Silva, 1978)

Brasacypris subovatum Do Carmo, Coimbra, Whatley, Antonietto and Citon, 2013

Candonopsis? *alagoensis* Tomé, Lima Filho and Neumann, 2014

Cypridea araripensis Silva, 1978

Damonella grandiensis Tomé, Lima Filho and Neumann, 2014

Damonella pumila Guzmán, Almeida-Lima and Piovesan, 2022

Ilyocypris coimbrai Guzmán, Almeida-Lima and Piovesan, 2022

Neuquenocypris Mussachio, 1973

Neuquenocypris berthoui Colin and Dépêche, 1997

Pattersoncypris Bate, 1972

Pattersoncypris alta (Antonietto, Gobbo, Do Carmo, Assine, Fernandes and Silva, 2012)

Pattersoncypris crepata (Do Carmo, Coimbra, Whatley, Antonietto and Citon, 2013)

Pattersoncypris cucurves Guzmán, Almeida-Lima and Piovesan, 2022

Pattersoncypris kroemmelbeini Guzmán, Almeida-Lima and Piovesan, 2022

Pattersoncypris micropapillosa Bate, 1972

Pattersoncypris symmetrica (Krömmelbein and Weber, 1971)

Rhinocypris spinata Guzmán, Almeida-Lima and Piovesan, 2022

Timiriasevia Mandelstam, 1947

Theriosynoecum Branson, 1936 emend. Sames, 2011

Theriosynoecum colini Do Carmo, Coimbra, Whatley, Antonietto and Citon, 2013

Theriosynoecum silvai (Silva, 1978)

Zonocypris berthoui Piovesan, Melo, Cabral and Guzmán, 2022

Zonocypris dorsoconvexa Piovesan, Melo, Cabral and Guzmán, 2022

Benthic Foraminifera

Agathammina Neumayr, 1887

Ammobaculites Cushman, 1910

Ammobaculites irregulariformis Bartenstein and Brand, 1951

Ammodiscus pleurotomarioides Chapman, 1894

Ammodiscus Reuss, 1862

Ammomarginulina Wiesner, 193

Ammosphaerodina aff. *A. minuta* = *Ammosphaeroidina minuta* Khan, 1950

Ammotium Loeblich and Tappan, 1953

Ammovertella cellensis Bartenstein and Brand, 1951

Arenobulimina Cushman, 1927

Bathysiphon brosgei Tappan, 1957

Bathysiphon vitta Nauss, 1947

Bulbobaculites Maync, 1952

Clavulinoides Cushman, 1936

Conorboides Hofker, 1952

Dorothia Plummer, 1931

Fausogaudryinella tealbyensis (Bartenstein, 1956)

Gaudryina cf. *G. dividens* = *Gaudryina dividens* Grabert, 1959

Gaudryinella alexandria Mcmillan, 2003

Gavelinella Brotzen, 1942

Globorotalites Brotzen, 1942

Glomospira Rzehak, 1885

Haplophragmium aff. *H. asperum* = *Haplophragmium? asperum* Perner, 1897

Haplophragmium Reuss, 1860

Haplophragmoides Cushman, 1910

Hyperammina Brady, 1878

Hyperammina gaultina Dam, 1950

Marsonella oxycona (Reuss, 1860)

Marsonella subtrochus Bartenstein, 1962

Marssonella hauteriviana Moullade, 1961

Orthokarstenia Dietrich, 1935

Palaeotextularia Schubert, 1920

Paleogaudryina maghararensis Said and Barakat, 1958

Pleurostomella Reuss, 1860

Psammosphaera Schulze, 1875

Pseudomarssonella Redmond, 1965

Pseudonodosaria Boomgaart, 1949

Pseudotriloculina Rasheed, 1971

Quinqueloculina Orbigny, 1826

Ramulina Jones, 1875

Recurvoides Earland, 1934

Reophax Montfort, 1808

Rhabdammina Sars, 1869

Rhizammina Brady, 1879

Rhizammina indivisa Brady, 1884

Rzehakina Cushman, 1927

Saracenaria Defrance, 1824

Simmobaculites raghavapuramensi (Bhalla, 1965)

Subtilina Alekseychik-Mitskevich, 1973

Tolypammina cretacea Dayn, 1958

Tolypammina Rhumbler, 1895

Tribrachia Schubert, 1912

Tritaxia dividens (Grabert, 1959)

Tritaxia pyramidata Reuss, 1863

Tritaxia Reuss, 1860

Trochammina Parker and Jones, 1859

Trochammina umiatensis Tappan, 1957

Verneuilinoides Loeblich and Tappan, 1949

Planktic Foraminifera

Hedbergella Bronnimann and Brown, 1958

Gorbachikella depressa Boudagher-Fadel, Banner, Brown, Simmons, Gorbachil, 1995

Hedbergella cf. *H. excelsa* = *Hedbergella excelsa* Longoria, 1974

Hedbergella aff. *H. tatianae* = *Hedbergella tatianae* (Banner and Desai, 1988)

Hedbergella gorbachikae Longoria, 1974

Hedbergella cf. *H. infracretacea* = *Hedbergella infracretacea* (Glaessner, 1937)

Hedbergella ex gr. *aptiana* = *Hedbergella aptiana* Bartenstein, 1965

Gorbachikella kugleri (Bolli, 1959)

Gubkinella Suleymanov, 1955

Clavihedbergella Banner and Blow, 1959

Hedbergella sigali Moullade, 1966

Blefuscuiana cf. *B. cumulus* = *Blefuscuiana cumulus* (Banner, Copestake, and White, 1993)

Hedbergella praelippa Huber and Leckie, 2011

Loeblichella Pessagno, 1967

Globigerinelloides clavatus Verga and Premoli Silva, 2005

Pseudoguembelitria blakenosensis Huber and Leckie, 2011

Microhedbergella miniglobularis Huber and Leckie, 2011

Gorbachikella Banner and Desai 1988

References

Anderson, F.W., 1985. Ostracod faunas in the Purbeck and Wealden of England. J. Micropalaeontology 4, 1–68. https://doi.org/10.1144/jm.4.2.1

Anderson, F.W., 1966. New genera of Purbeck and Wealden Ostracoda. Bull. Br. Museum (Natural Hist.) Geol. II, 436–487.

Ando, A., Huber, B.T., Premoli Silva, I., 2013. *Paraticinella rohri* (Bolli, 1959) as the valid name for the latest Aptian zonal marker species of planktonic foraminifera traditionally called *bejaouaensis* or *eubejaouaensis*. Cretac. Res. 45, 275–287. https://doi.org/10.1016/j.cretres.2013.05.002

Antonietto, L.S., Do Carmo, D.A., Viviers, M.C., Adôrno, R.R., 2015. Biostratigraphic and paleozoogeographic review of the upper Aptian-Albian ostracods of Riachuelo Formation, Sergipe-Alagoas Basin, Northeastern Brazil. Rev. Bras. Paleontol. 18, 355–368. https://doi.org/10.4072/rbp.2015.3.02

Antonietto, L.S., Do Carmo, D.A., Viviers, M.C., Neto, J.V.Q., Hunt, G., 2016. Ostracoda (Arthropoda, Crustacea) from the Riachuelo formation, Sergipe-Alagoas Basin, Brazil, Upper Aptian-Albian. Eur. J. Taxon. 244, 1–57. https://doi.org/10.5852/ejt.2016.244

Antonioli, L., Arai, M., 2002. O registro da Ecozona *Subtilisphaera* na Formação Codó (Cretáceo Inferior da Bacia do Parnaíba, Nordeste Do Brasil): seu significado paleogeográfico, in: Boletim Do 6º Simpósio Sobre o Cretáceo Do Brasil/2º Simpósio Sobre El Cretácico de América Del Sur. São Pedro, pp. 25–30.

Arai, M., 2009. Paleogeografia do Atlântico Sul no Aptiano: um novo modelo a partir de dados micropaleontológicos recentes. Bol. Geociências da Petrobras 17, 331–351.

Arai, M., 2014. Aptian/Albian (early Cretaceous) paleogeography of the South Atlantic: a paleontological perspective. Brazilian J. Geol. 44, 339–350. https://doi.org/10.5327/Z2317-4889201400020012

Arai, M., 2016. Reply to the comments of Assine et al. (Comments on paper by M. Arai "Aptian/Albian (early Cretaceous) paleogeography of the South Atlantic: a paleontological perspective"). Brazilian J. Geol. 46, 9–13. https://doi.org/10.1590/2317-4889201620150046B

Arai, M., Assine, M.L., 2020. Chronostratigraphic constraints and paleoenvironmental interpretation of the Romualdo Formation (Santana Group, Araripe Basin, Northeastern Brazil) based on palynology. Cretac. Res. 116, 104610. https://doi.org/10.1016/j.cretres.2020.104610

Arai, M., Coimbra, J.C., 1990. Análise paleoecológica do registro das primeiras ingressões marinhas na Formação Santana (Cretáceo Inferior da Chapada do Araripe), in: I Simpósio Sobre a Bacia Do Araripe e Bacias Interiores Do Nordeste. Crato, pp. 225–239.

Araripe, R.C., Oliveira, D.H., Tomé, M.E., Moura de Mello, R., Barreto, A.M.F., 2021. Foraminifera and Ostracoda from the Lower Cretaceous (Aptian–lower Albian) Romualdo Formation, Araripe Basin, northeast Brazil: Paleoenvironmental inferences. Cretac. Res. 122, 104766. https://doi.org/10.1016/j.cretres.2021.104766

Araripe, R.C., Pedrosa Lemos, F.A., do Prado, L.A.C., Tomé, M.E., Oliveira, D.H., Pereira, P.A., Nascimento, L.R.S.L., Asakura, Y., Ng, C., Viviers, M.C., Barreto, A.M.F., 2022. Upper Aptian–lower Albian of the southern-central Araripe Basin, Brazil: Microbiostratigraphic and paleoecological inferences. J. South Am. Earth Sci. 116. https://doi.org/10.1016/j.jsames.2022.103814

Aschoff, J.L., Olariu, C., Steel, R.J., 2018. Recognition and significance of bayhead delta deposits in the rock record: A comparison of modern and ancient systems. Sedimentology 65, 62–95. https://doi.org/10.1111/sed.12351

Assine, M.L., 2007. Bacia do Araripe. Bol. Geociências da Petrobras 15, 371–389.

Assine, M.L., Perinotto, J.A. de J., Custódio, M.A., Neumann, V.H., Varejão, F.G., Mescolotti, P.C., 2014. Sequências deposicionais do Andar Alagoas da Bacia do Araripe, Nordeste do Brasil. Bol. Geociências da Petrobras 22, 3–28.

Ballent, S.C., 2004. A micropalaeontological study of two Jurassic sequences in the Neuquén Basin, central-west Argentina. Ameghiniana 41, 331–345.

Bate, R.H., 1972. Phosphatized ostracods with appendages from the Lower Cretaceous of Brazil. Palaeontology 15, 379–393. https://doi.org/10.1038/230397a0

Berthou, P.Y., Dépêche, F., Colin, J.P., Filgueira, J.B. de M., Teles, M. do S.L., 1994. New data on the ostracodes from the Crato lithologic units (lower member of the Santana Formation, latest Aptian–lower Albian) of the Araripe Basin (Northeastern Brazil). Acta Geol. Leopoldensia XVII, 539–554.

Bobco, F.E.R., Goldberg, K., Bardola, T.P., 2017. Modelo deposicional do Membro Ipubi (Bacia do Araripe, nordeste do Brasil) a partir da caracterização faciológica, petrográfica e isotópica dos evaporitos. Pesqui. em Geociências 44, 431–451. https://doi.org/10.22456/1807-9806.83267

Boltovskoy, E., Wright, R., 1976. Recent Foraminifera. Springer-Science+Business Media, B.V. https://doi.org/10.1007/978-94-017-2860-7

Branner, J.C., 1963. The Estancia beds of Bahia, Sergipe and Alagoas, Brazil. Am. J. Sci. 35, 619–632.

Brito Neves, B.B., 2002. Main stages of the development of the sedimentary basins of South America and their relationship with the tectonics of supercontinents. Gondwana Res. 5, 175–196.

Brito Neves, B.B., Santos, E.J., Van Schmus, W.R., 2000. Tectonic history of the Borborema Province, in: Cordani, U., Milani, E., Thomaz Filho, A., Campos, D.A. (Eds.), Tectonic Evolution of South America. Rio de Janeiro, pp. 151–182.

Brito, P.M., 2007. The Crato Formation fish fauna, in: Martill, D.M., Bechly, G., Loveridge, R.F. (Eds.), The Crato Fossil Beds of Brazil: Window into an Ancient World. Cambridge University Press, pp. 429–443.

Brito, P.M., Yabumoto, Y., 2011. An updated review of the fish faunas from the Crato and Santana formations in Brazil, a close relationship to the Tethys fauna. Bull. Kitakyushu Museum Nat. Hist. Hum. Hist. Ser. A 9, 107–136.

Buzas, M.A., 1974. Vertical distribution of *Ammobaculites* in the Rhode River, Maryland. J. Foraminifer. Res. 4, 144–147. https://doi.org/10.2113/gsjfr.4.3.144

Cesero, P. de, Ponte, F.C., 1972. Análise comparativa da paleogeologia dos litorais atlânticos brasileiro e africano. Bol. Geociências da Petrobras 11, 1-18.

Coccioni, R., Sabatino, N., Frontalini, F., Gardin, S., Sideri, M., Sprovieri, M., 2014. The neglected history of oceanic anoxic event 1b: Insights, new data from the Poggio le Guaine section (Umbria-Marche Basin). Stratigraphy 11, 245–282.

Coccioni, R., Silva, I.P., 1994. Planktonic foraminifera from the lower cretaceous of Rio Argos sections (southern Spain) and biostratigraphic implications. Cretac. Res. 15, 645–687. https://doi.org/10.1006/cres.1994.1037

Coimbra, J.C., Arai, M., Carreño, A.L., 2002. Biostratigraphy of Lower Cretaceous microfossils from the Araripe Basin, northeastern Brazil. Geobios 35, 687–698. https://doi.org/10.1016/s0016-6995(02)00082-7

Colin, J.-P., Dépêche, F., 1997. Faunes d’ostracodes lacustres des bassins intra-cratoniques d’âge albo-aptien en Afrique de l’Ouest (Cameroun, Tchad) et au Brésil: considérations d’ordre paléoécologique et paléobiogéographique. Africa Geosci. Rev. 4, 431–450.

Copestake, P., Johnson, B., 1989. The Hettangian to Toarcian (Lower Jurassic), in: Jenkins, D.G., Murray, J.W. (Eds.), Stratigraphical Atlas of Fossil Foraminifera. Ellis Horwood, pp. 129–188.

Corliss, B.H., 1985. Microhabitats of benthic foraminifera within deep-sea sediments. Nature 314, 435–438. https://doi.org/10.1038/314435a0

Custódio, M.A., Quaglio, F., Warren, L.V., Simões, M.G., Fürsich, F.T., Perinotto, J.A.J., Assine, M.L., 2017. The transgressive-regressive cycle of the Romualdo Formation (Araripe Basin): Sedimentary archive of the Early Cretaceous marine ingression in the interior of Northeast Brazil. Sediment. Geol. 359, 1–15. https://doi.org/10.1016/j.sedgeo.2017.07.010

de Lima Barros, C., Silva, S.C., Machado, L.L., de Moraes Rios Netto, A., Sames, B., Alves, T.D., da Silva Júnior, R.P., 2022. Non-marine ostracods of the Codó Formation (upper Aptian, Lower Cretaceous), Parnaíba Basin, NE Brazil: new biostratigraphic and paleoecological insights. Cretac. Res. 133, 105125. https://doi.org/10.1016/j.cretres.2021.105125

de Moura, W.A.L., Araújo, J.C.M., Lúcio, T., Neto, J.A. de S., 2020. Paleoambiente deposicional e origem da matéria orgânica dos folhelhos betuminosos da Formação Ipubi, porções leste e sudeste da Bacia do Araripe, NE do Brasil: evidência de N-alcanos e isoprenoides. Estud. Geológicos 30, 31–44.

Do Carmo, D.A., Coimbra, J.C., Whatley, R.C., Antonietto, L.S., Citon, R.T. de P., 2013. Taxonomy of limnic Ostracoda (Crustacea) from the Alagamar Formation, middle–upper Aptian, Potiguar Basin, northeastern Brazil. J. Paleontol. 87, 91–104. https://doi.org/10.1666/11-108r.1

Do Carmo, D.A., Spigolon, A.L.D., Guimarães, E.M., Richter, M., Mendonça-Filho, J.G., Dangpeng, X., Caixeta, G.M., Leite, A.M., 2018. Palaeoenvironmental assessment of Early Cretaceous limnic ostracods from the Alagamar Formation, Potiguar Basin, NE Brazil. Cretac. Res. 85, 266–279. https://doi.org/10.1016/j.cretres.2018.01.009

Do Carmo, D.A., Whatley, R., Queiroz Neto, J.V., Coimbra, J.C., 2008. On the validity of two Lower Cretaceous non-marine ostracode genera: biostratigraphic and paleogeographic implications. J. Paleontol. 82, 790–799. https://doi.org/10.1666/07-008.1

Fambrini, G.L., de Lemos, D.R., Tesser Jr., S., De Araújo, J.T., Da Silva-Filho, W.F., de Souza, B.Y.C., Neumann, V.H., 2011. Estratigrafia, arquitetura deposicional e faciologia da Formação Missão Velha (Neojurássico-Eocretáceo) na área-tipo, Bacia do Araripe, Nordeste do Brasil: Exemplo de sedimentação de estágio de início de rifte a clímax de rifte. Geol. USP - Ser. Cient. 11, 55–87. https://doi.org/10.5327/z1519-874x2011000200004

Ferraro, S., Coccioni, R., Sabatino, N., Del Core, M., Sprovieri, M., 2020. Morphometric response of late Aptian planktonic foraminiferal communities to environmental changes: A case study of *Paraticinella rohri* at Poggio le Guaine (central Italy). Palaeogeogr. Palaeoclimatol. Palaeoecol. 538, 109384. https://doi.org/10.1016/j.palaeo.2019.109384

Gale, A.S., Mutterlose, J., Batenburg, S.J., Gradstein, Felix M., Agterberg, F.P., Ogg, J.G., Petrizzo, M.R., 2020. The Cretaceous Period, in: Gradstein, F. M., Ogg, J.G., Schmitz, M.D., Ogg, G.M. (Eds.), Geologic Time Scale 2020. Elsevier BV, pp. 1023–1086. https://doi.org/10.1016/B978-0-12-824360-2.00027-9

Goldberg, K., Premaor, E., Bardola, T., Souza, P.A., 2019. Aptian marine ingression in the Araripe Basin: Implications for paleogeographic reconstruction and evaporite accumulation. Mar. Pet. Geol. 107, 214–221. https://doi.org/10.1016/j.marpetgeo.2019.05.011

Gradstein, F.M., Kaminski, M.A., Agterberg, F.P., 1999. Biostratigraphy and paleoceanography of the Cretaceous seaway between Norway and Greenland. Earth Sci. Rev. 46, 27–98. https://doi.org/10.1016/S0012-8252(99)00018-5

Gradstein, F.M., Waskowska, A., Kopaevich, L., Watkins, D.K., Friis, H., Pérez Panera, J., 2019. Berriasian planktonic foraminifera and calcareous nannofossils from Crimea Mountains, with reference to microfossil evolution. Swiss J. Palaeontol. 138, 213–236. https://doi.org/10.1007/s13358-018-0175-8

Grosdidier, E., Braccini, E., Dupont, G., Moron, J.-M., 1996. Biozonation du Crétacé Inférieur non marin des bassins du Gabon et du Congo, in: Géologie de l'Afrique et de l'Atlantique Sud: Actes Colloques Angers 1994. pp. 67–82.

Guzmán, J., Piovesan, E.K., Almeida-lima, Débora Soares, Sousa, A. de J., Neumann, V.H., 2022. Aptian ostracods from the Santana Group, Araripe Basin, Brazil. Rev. micropaléontologie 77, 100694. https://doi.org/10.1016/j.revmic.2022.100694

Haig, D.W., 1979. Global distribution patterns for Mid-Cretaceous foraminiferids. J. Foraminifer. Res. 9, 29–40. https://doi.org/10.2113/gsjfr.9.1.29

Heimhofer, U., Martill, D.M., 2007. The sedimentology and depositional environment of the

Crato Formation, in: Martill, D.M., Bechly, G., Loveridge, R.F. (Eds.), The Crato Fossil Beds of Brazil: Window into an Ancient World. Cambridge University Press, pp. 44–62.

Hemleben, C., Kaminski, M.A., Kuhnt, W., Scott, D.B. (Eds.), 1990. Paleoecology, biostratigraphy, paleoceanography and taxonomy of agglutinated foraminifera, Series C: ed, Proceedings of the NATO Advanced Study Institutes Series. Kluwer Academic Publishers.

Horne, D.J., 2002. Ostracod biostratigraphy and palaeoecology of the Purbeck Limestone Group in Southern England. Spec. Pap. Palaeontol. 68, 53–70. https://doi.org/10.1017/CBO9781107415324.004

Huber, B.T., Leckie, R.M., 2011. Planktic foraminiferal species turnover across deep-sea Aptian/Albian boundary sections. J. Foraminifer. Res. 41, 53–95. https://doi.org/10.2113/gsjfr.41.1.53

Huber, B.T., Petrizzo, M.R., Young, J.R., Falzoni, F., Gilardoni, S.E., Bown, P.R., Wade, B.S., 2016. Pforams@microtax: A new online taxonomic database for planktonic foraminifera. Micropaleontology 62, 429–438.

Jones, R., Charnock, M., 1985. Morphogroups of agglutinating foraminifera. Their life positions and feeding habits and potential applicability in (paleo)ecological studies. Rev. paléobiologie.

Kaminski, Michael A., Boersma, A., Tyszka, J., Holbourn, A.E.L., 1995. Response of deep-water agglutinated foraminifera to dysoxic conditions in the California Borderland basins, in: Kaminski, M.A., Geroch, S., Gasiƒski, M.A. (Eds.), Proceedings 4th International Workshop on Agglutinated Foraminifera, Krakow, 1993. pp. 131–140.

Kaminski, Michael A, Kuhnt, W., 1995. Tubular agglutinated foraminifera as indicators of organic carbon flux, in: Kaminski, M.A, Geroch, S., Gasiƒski, M. (Eds.), Proceedings of the Fourth International Workshop on Agglutinated Foraminifera 1993. Grzybowski Foundation Special Publication no. 3, Kraków Poland, pp. 141–144.

Kellner, A.W.A., Campos, D. de A., 2002. The function of the cranial crest and jaws of a unique pterosaur from the Early Cretaceous of Brazil. Science 297, 389–392. https://doi.org/10.1126/science.1073186

Kennedy, J.W., Gale, A.S., Huber, B.T., Petrizzo, M.R., Bown, P., Jenkyns, H.C., 2017. The

Global Boundary Stratotype Section and Point (GSSP) for the base of the Albian Stage, of the Cretaceous, the Col de Pré-Guittard section, Arnayon, Drôme, France. Episodes 40, 177–188. https://doi.org/10.18814/epiiugs/2017/v40i3/017021

King, C., Bailey, H.W., Burton, C.A., King, A.D., 1989. Cretaceous of the North Sea, in: Jenkins, D.G., Murray, J.W. (Eds.), Stratigraphical Atlas of Fossil Foraminifera. Ellis Horwood, pp. 372–417.

Koutsoukos, E.A.M., 1992. Late Aptian to Maastrichtian foraminiferal biogeography and palaeoceanography of the Sergipe Basin, Brazil. Palaeogeogr. Palaeoclimatol. Palaeoecol. 92, 295–324. https://doi.org/10.1016/0031-0182(92)90089-N

Koutsoukos, E.A.M., Hart, M.B., 1990. Cretaceous foraminiferal morphogroup distribution patterns, palaeocommunities and trophic structures: a case study from the Sergipe Basin, Brazil. Trans. R. Soc. Edinburgh Earth Sci. 81, 221–246.

Kuchle, J., Scherer, C.M.D.S., 2010. Sismoestratigrafia de bacias rifte: Técnicas, métodos e sua aplicação na Bacia do Recôncavo. Bol. Geociências da Petrobras 18, 179–206.

Kuchle, J., Scherer, C.M. dos S., Born, C.C., Alvarenga, R. dos S., Adegas, F., 2011. A contribution to regional stratigraphic correlations of the Afro-Brazilian depression – The Dom João Stage (Brotas Group and equivalent units - Late Jurassic) in Northeastern Brazilian sedimentary basins. J. South Am. Earth Sci. 31, 358–371. https://doi.org/10.1016/j.jsames.2011.02.007

Leckie, R.M., 1987. Paleoecology of mid-Cretaceous planktonic foraminifera: A comparison of open ocean and epicontinental sea assemblages. Micropaleontology 33, 164–176. https://doi.org/10.2307/1485491

Leckie, R.M., 1989. A paleoceanographic model for the early evolutionary history of planktonic foraminifera. Palaeogeogr. Palaeoclimatol. Palaeoecol. 73, 107–138. https://doi.org/10.1016/0031-0182(89)90048-5

Maisey, J.G., 1991. Santana Fossils: An ilustrated atlas. T.F.H. publications, Inc.

Martill, D.M., Bechly, G., Loveridge, R.F. (Eds.), 2007. The Crato fossil beds of Brazil, Window into an Ancient World. Cambridge University Press, Cambridge.

Melo, R.M., Guzmán, J., Almeida-Lima, D., Piovesan, E.K., Neumann, V.H., Sousa, A. de J. e., 2020. New marine data and age accuracy of the Romualdo Formation, Araripe Basin, Brazil. Sci. Rep. 10, 15779. https://doi.org/10.1038/s41598-020-72789-8

Moura, J.A., 1988. Ostracods from non-marine Early Cretaceous Sediments of the Campos Basin, Brazil, in: Hanai, T., Ikeya, N., Ishizaki, K. (Eds.), Developments in Palaeontology and Stratigraphy. Evolutionary Biology of Ostracoda: Its Fundamentals and Applications - 9th International Symposium on Ostracoda. Elsevier, Japan, pp. 1207–1216. https://doi.org/10.1016/S0920-5446(08)70250-4

Moura, J.A., Praça, U.M., 1985. Ostracodes das sequências não marinhas e transicionais mesozóicas (Andares Jiquiá e Alagoas), Bacia de Campos, in: Campos, D.A., Ferreira, C.S., Brito, I.M., Viana, C.F. (Eds.), Coletânea de Trabalhos Paleontologicos: Série Geologia. Departamento Nacional da Produção Mineral / Ministério das Minas e Energia, Brasília, pp. 401–408.

Moura, W.A.L.de., Araújo, J.C.M.de., Lúcio, T., Souza Neto, J.A.de., 2020. Paleoambiente deposicional e origem da matéria orgânica dos folhelhos betuminosos da Formação Ipubi, porções leste e sudeste da Bacia do Araripe, NE do Brasil: evidência de n-alcanos e isoprenoides. Estudos Geológicos 30 (1), 31–44. https://doi.org/10.18190/1980-8208/estudosgeologicos.v30n1p31-44

Nagy, J., Pilskog, B., Wilhelmsen, R., 1990. Facies controlled distribution of foraminífera in the Jurassic North Sea Basin, in: Hemleben, C., Kaminski, M.A., Kuhnt, W., Scott, D.B. (Eds.), Paleoecology, Biostratigraphy, Paleoceanography and Taxonomy of Agglutinated Foraminifera. Kluwer Academic Press, pp. 621–657.

Nascimento, L.R.S.L., Tomé, M.E., Barreto, A.M.F., Oliveira, D.H., Neumann, V.H., 2017. Biostratigraphic analysis based on palynomorphs and ostracods from core 2-JNS-01PE, Lower Cretaceous, Jatobá Basin, northeastern Brazil. J. South Am. Earth Sci. 76, 115–136. https://doi.org/10.1016/j.jsames.2017.02.012

Neumann, V.H., Borrego, A.G., Cabrera, L., Dino, R., 2003. Organic matter composition and distribution through the Aptian-Albian lacustrine sequences of the Araripe Basin, northeastern Brazil. Int. J. Coal Geol. 54, 21–40. https://doi.org/10.1016/S0166-5162(03)00018-1

Neumann, V.H., Cabrera, L., 1999. Una nueva propuesta estratigráfica para la tectono-sequência Pós-rifte de la Cuenca de Araripe, Noreste de Brasil, in: 5° Simpósio Sobre o Cretáceo Do Brasil. UNESP, Rio Claro, pp. 279–285.

Ogg, J.G., Ogg, G.M., Gradstein, F.M., 2016. A Concise Geologic Time Scale, A Concise Geologic Time Scale. Elsevier, Amsterdam. https://doi.org/10.1016/c2009-0-64442-1

Okay, A.I., Altiner, D., 2007. A condensed Mesozoic succession North of İzmir: A fragment of the Anatolide-Tauride platform in the Bornova Flysch Zone. Turkish J. Earth Sci. 16, 257–279.

Pereira, P.A., Prado, L.A.C. do, Araripe, R.V., Oliveira, D.H., Lemos, F.A.P., Lobo, L.R. da S., Tomé, M.E., Barreto, A.M.F., 2022. Gastropods Colour Patterns in Cassiopids and Naticids from Romualdo Formation, Araripe Basin, Northeast Brazil. Anu. do Inst. Geociencias 45, 1–16. https://doi.org/10.11137/1982-3908_2022_45_51358

Petrizzo, M.R., Huber, B.T., Gale, A.S., Barchetta, A., Jenkyns, H.C., 2012. Abrupt planktic foraminiferal turnover across the Niveau Kilian at Col de Pré-Guittard (Vocontian Basin, southeast France): New criteria for defining the Aptian/Albian boundary. Newsletters Stratigr. 45, 55–74. https://doi.org/10.1127/0078-0421/2012/0013

Piovesan, E.K., Nicolaidis, D.D., Fauth, G., Viviers, M.C., 2013. Ostracodes from the Aptian and Santonian of the Santos, Campos and Espírito Santo basins, Brazil. J. South Am. Earth Sci. 48, 240–254. https://doi.org/10.1016/j.jsames.2013.09.012

Ponte, F.C., Dauzacker, M. V, Porto, R., 1978. Origem e acumulação de petróleo nas bacias sedimentares brasileras, in: Anais Do Congresso Brasileiro de Petróleo. Rio de Janeiro, pp. 121–147.

Poropat, S.F., Colin, J.P., 2012. Early Cretaceous ostracod biostratigraphy of eastern Brazil and western Africa: An overview. Gondwana Res. 22, 772–798. https://doi.org/10.1016/j.gr.2012.06.002

Prado, L.A.C. do, Calado, T.C. dos S., Barreto, A.M.F., 2019. New records of shrimps from the Lower Cretaceous Romualdo Formation, Araripe Basin, northeastern Brazil, with new taxa of Penaeoidea (Crustacea: Decapoda: Dendrobranchiata). Cretac. Res. 99, 96–103. https://doi.org/10.1016/j.cretres.2019.02.023

Prado, L.A.C. do., Fambrini, G.L., Barreto, A.M.F., 2018a. Tafonomy of macroinvertebrates and Albian marine ingression as recorded by the Romualdo Formation (Cretaceous, Araripe Basin, Brazil). Brazilian J. Geol. 48, 519–531. https://doi.org/10.1590/2317-4889201820180048

Prado, L.A.C. do, Luque, J., Barreto, A.M.., Palmer, A.R., 2018b. New brachyuran crabs from the Aptian–Albian Romualdo Formation, Santana Group of Brazil: Evidence for a Tethyan connection to the Araripe Basin. Acta Palaeontol. Pol. 63, 737–750. https://doi.org/10.4202/app.00480.2018

Prosser, S., 1993. Rift-related linked depositional systems and their seismic expression, in: Williams, G.D., Dobb, A. (Eds.), Geological Society of London Special Publication. Lyell Collection, pp. 35–66. https://doi.org/10.1144/GSL.SP.1993.071.01.03

Radley, J.D., 1993. An occurrence of *Ammobaculites* (Foraminiferida, Lituolacea) in the Purbeck Formation (late Jurassic-early Cretaceous) of Dorset, south-west England. J. Micropalaeontology 12, 119–120. https://doi.org/10.2475/ajs.s4-31.185.432

Ramos, M.I.F., Rossetti, D.F., Paz, J.D.S., 2006. Caracterização e significado paleoambiental da fauna de ostracodes da Formação Codó (Neoaptiano), leste da Bacia de Grajaú, MA, Brasil. Rev. Bras. Paleontol. 9, 339–348.

Regali, M.S.P., Viana, C.F., 1989. Sedimentos do Neojurássico-Eocretáceo do Brasil: idade e correlação com a escala internacional. Petrobras, Rio de Janeiro.

Reolid, M., Nikitenko, B.L., Glinskikh, L., 2014. *Trochammina* as opportunist foraminifera in the Lower Jurassic from north Siberia. Polar Res. 33, 1–14. https://doi.org/10.3402/polar.v33.21653

Roozbahani, P.R., 2011. Lithostratigraphy and biostratigraphy of the Lower Cretaceous of the Jalmajird area (northeast of Khomeyn, Central Iran Basin), Iran. Geo. Alp. 9, 48–58.

Sanjinés, A.E.S., Viviers, M.C., Costa, D.S., dos Anjos Zerfass, G. de S., Beurlen, G., Strohschoen Jr., O., 2022. Planktonic foraminifera from the Aptian section of the Southeastern Brazilian Atlantic margin. Cretac. Res. 134, 105141 Contents. https://doi.org/10.1016/j.cretres.2022.105141

Sayão, J.M., Saraiva, A.Á.F., Brum, A.S., Bantim, R.A.M., de Andrade, R.C.L.P., Cheng, X., de Lima, F.J., de Paula Silva, H., Kellner, A.W.A., 2020. The first theropod dinosaur (Coelurosauria, Theropoda) from the base of the Romualdo Formation (Albian), Araripe Basin, Northeast Brazil. Sci. Rep. 10, 1–15. https://doi.org/10.1038/s41598-020-67822-9

Schaller, H., 1969. Revisão estratigráfica da Bacia de Sergipe/Alagoas. Bol. Técnico da Petrobras 12, 21–86.

Scherer, C.M. dos S., Goldberg, K., Bardola, T., 2015. Facies architecture and sequence stratigraphy of an early post-rift fluvial succession, Aptian Barbalha Formation, Araripe Basin, northeastern Brazil. Sediment. Geol. 322, 43–62. https://doi.org/10.1016/j.sedgeo.2015.03.010

Scherer, C.M. dos S., Sá, E.F.J. de, Córdoba, V.C., Sousa, D. do C., Aquino, M.M., Cardoso, F.M.C., 2014. Tectono-stratigraphic evolution of the Upper Jurassic-Neocomian rift succession, Araripe Basin, Northeast Brazil. J. South Am. Earth Sci. 49, 106–122. https://doi.org/10.1016/0191-8141(88)90108-3

Simms, A.R., Rodriguez, A.B., Anderson, J.B., 2018. Bayhead deltas and shorelines: Insights from modern and ancient examples. Sediment. Geol. 374, 17–35. https://doi.org/10.1016/j.sedgeo.2018.07.004

Smith, R.J., 2000. Morphology and ontogeny of Cretaceous ostracods with preserved appendages from Brazil. Palaeontology 43, 63–98.

Thomas, E., Gooday, A.J., 1996. Cenozoic deep-sea benthic foraminifers: Tracers for changes in oceanic productivity? Geology 24, 355–358. https://doi.org/10.1130/0091-7613(1996)024<0355:CDSBFT>2.3.CO;2

Tomé, M.E., Araripe, R.V., Oliveira, D.H., Barreto, A.M.F, Prado, L., Pedrosa, F., Pereira, P., Nascimento, L.R., Ng, C., 2022. Early Cretaceous Ostracoda (Crustacea) from south-central Araripe Basin, Brazil, with descriptions of seven new species. Zootaxa 5159, 535–557. https://doi.org/10.11646/zootaxa.5159.4.4

Tomé, M.E., Lima Filho, M.F., Neumann, V.H., 2014. Taxonomic studies of non-marine ostracods in the Lower Cretaceous (Aptian-lower Albian) of post-rift sequence from Jatobá and Araripe basins (Northeast Brazil): Stratigraphic implications. Cretac. Res. 48, 153–176. https://doi.org/10.1016/j.cretres.2013.12.007

Vallejo, J.D., Piovesan, E.K., Carvalho, M. de A., Guzmán, J., 2023. Palynofacies analyses of Santana Group, Upper Aptian of the Araripe Basin, northeast Brazil: paleoenvironmental Reconstruction. J. South Am. Earth Sci. 121, 104154. https://doi.org/10.2139/ssrn.4261938

Varejão, F.G., Fürsich, F.T., Warren, L. V., Matos, S.A., Rodrigues, M.G., Assine, M.L., Sales, A.M.F., Simões, M.G., 2019. Microbialite fields developed in a protected rocky coastline: The shallow carbonate ramp of the Aptian Romualdo Formation (Araripe Basin, NE

Brazil). Sediment. Geol. 389, 103–120. https://doi.org/10.1016/j.sedgeo.2019.06.003

Varejão, F.G., Warren, L. V., Simões, M.G., Buatois, L.A., Mángano, M.G., Bahniuk Rumbelsperger, A.M., Assine, M.L., 2021a. Mixed siliciclastic–carbonate sedimentation in an evolving epicontinental sea: Aptian record of marginal marine settings in the interior basins of north-eastern Brazil. Sedimentology 68, 2125–2164. https://doi.org/10.1111/sed.12846

Varejão, F.G., Silva, V.R., Assine, M.L., Warren, L.V., Matos, S.A., Rodrigues, M.G., Fürsich, F.T., Simões, M.G., 2021b. Marine or freshwater? Accessing the paleoenvironmental parameters of the Caldas Bed, a key marker bed in the Crato Formation (Araripe Basin, NE Brazil). Brazilian J. Geol. 51, e2020009. https://doi.org/10.1590/2317-4889202120200009

Viana, C.F., 1965. Stratigraphic distribution of Ostracoda in the Bahia supergroup, in: Hinte, J.E.V. (Ed.), West African Micropaleontological Colloquium. Ibadan, pp. 240–257.

Viana, C.F., da Gama Junior, E.G., Simões, I. de A., Moura, J.A., Fonseca, J. dos R., Alves, R.J., 1971. Revisão estratigráfica da Bacia Recôncavo/Tucano. Bol. Técnico da Petrobras 14, 157–192.

Vicalvi, M.A., Carvalho, I.D.S., 2002. Carófitas cretácicas da Bacia do Parnaíba (Formação Itapecuru), Estado do Maranhão, Brasil, in: de Castro, J.C., Dias-Brito, D., Mussachio, E., Rohn, R. (Eds.), Boletim Do 6º Simpósio Sobre o Cretáceo Do Brasil/2º Simpósio Sobre El Cretáceo de América Del Sur. UNESP, são Pedro, pp. 83–88.

Viviers, M.C., Koutsoukos, E.A.M., Silva-Telles Jr., A.C., Bengston, P., 2000. Stratigraphy and biogeographic affinities of the late Aptian-Campanian ostracods of the Potiguar and Sergipe basins in northeastern Brazil. Cretac. Res. 21, 407--455. https://doi.org/10.1006/cres.2000.0205

Viviers, M.C., Regali, M.S.P., 1987. Estudo Paleoambiental Preliminar Do Cretáceo Da Bacia Potiguar. Rev. Bras. Geociências 17, 123–130. https://doi.org/10.25249/0375-7536.1987123130

Yakovleva-O’Neill, S.P., Kaminski, Michael A., Gradstein, F.M., 2011. Jurassic Benthic Foraminiferal Biostratigraphy & Palaeoecology at the Shtokman Structure, Barents Sea, in: Kaminski, M.A., Filipescu, S. (Eds.), Proceedings of the eighth international workshop on agglutinated foraminifera. Grzybowski Foundation Special Publication, pp. 343–356.

https://doi.org/10.2307/1485967

Young, J.R., Bown, P.R., Lees, J.A., 2022. Nannotax3 website. International Nannoplankton Association [WWW Document]. www.mikrotax.org/Nannotax3.

4.4 MICROFÁCIES E DISTRIBUIÇÃO ESTRATIGRÁFICA DE MICROFÓSSEIS CARBONÁTICOS DA SEQUÊNCIA PÓS-RIFTE DAS BACIAS DE TUCANO NORTE E JATOBÁ E A SUA CORRELAÇÃO COM A BACIA DO ARARIPE

A correlação faciológica e bioestratigráfica das unidades cronocorrelatas correspondentes às formações Barbalha/Marizal, Crato, Ipubi e Romualdo, sequência pós-rifte das bacias do Araripe, Tucano Norte e Jatobá será apresentada neste item. As informações taxonômicas, bioestratigráficas e paleoambientais da sequência pós-rifte da Bacia do Araripe foram apresentadas nos dois artigos anteriores e compõem a base da correlação com as outras bacias.

4.4.1 Bacia de Tucano Norte

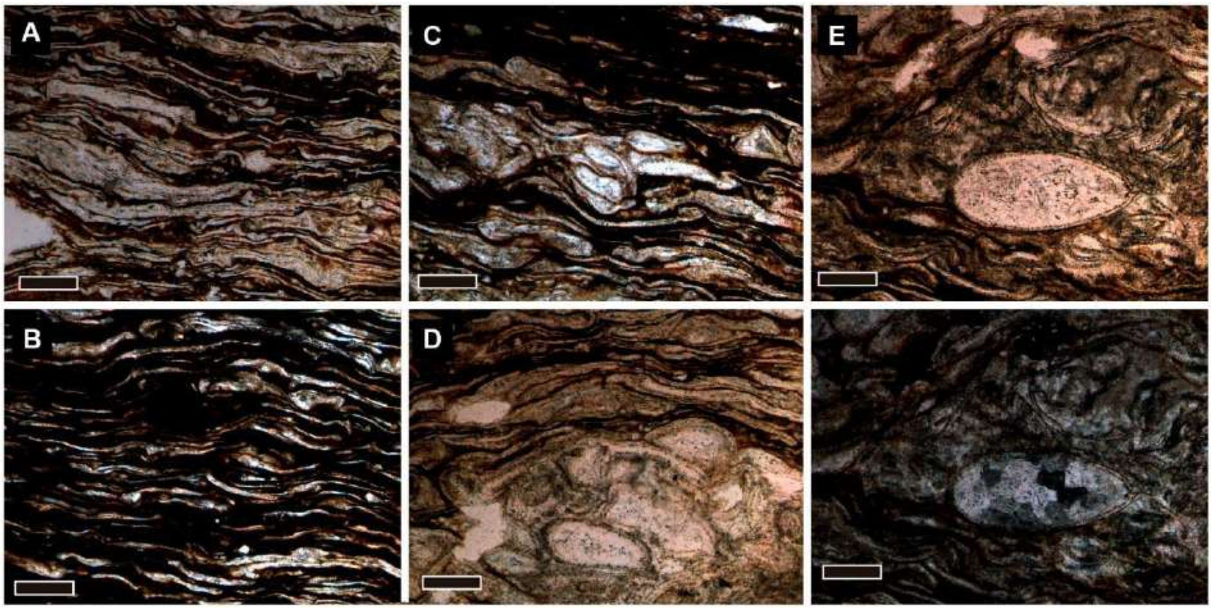
4.4.1.1 Testemunho 2-TN-SM-BA

A seção sedimentar do testemunho é predominantemente psamítica apresentando arcósios e quarzoarenitos atribuídos à Formação Marizal. Na porção superior (18,8 – 40,2 m) a litologia é dominantemente pelítica com intercalações de carbonato e sílica, estes níveis corresponde as Camadas Amargosa. Da porção pelítica-carbonática foram coletadas três amostras para a confecção de lâminas delgadas e análise petrográfica.

A lâmina JG-PTNSM- 05, intervalo de profundidade 30,44–30,46 m, foi classificada como calcário bioclástico laminado intercalado com folhelho escuro. Lâminas onduladas e rítmicas de valvas e carapaças de ostracodes, matéria orgânica e minerais opacos muito finos formando uma estrutura microbianamente induzida (MISS) (Figura 11A–F). Os ostracodes encontram-se em alguns níveis como valvas amassadas, compactadas e compostas por micrita e em outros níveis conservando o formato de carapaça completa. Observa-se somente um ostracode bem preservado morfologicamente de fina carapaça micrítica preenchido por esparita (Figura 11E–F).

A lâmina JG-PTNSM-04, intervalo de profundidade 30,51–30,56 m, é um calcário peloidal, composto por uma matriz de micrita e esparita (Figura 12), com peloides e sílica abundante. A sílica é observada de duas maneiras, como recristalização em quartzo criptocristalino de extinção em tons de cinza ou como calcedônia marrom apresentando extinção radial em tons marrom (Figura 12C–D). Os peloides tendem a estar orientados e ao seu redor se observa matéria orgânica e minerais opacos finos (Figura 12E–F). Poucos ostracodes presentes como carapaças micríticas, preenchidas por quartzo criptocristalino (Figura 12B). Estruturas sedimentares de indução microbiana foram observadas em finas camadas.

Figura 11 – Fotomicrografias da lâmina petrográfica JG-PTNSM-05: A–B, D e F. Nicóis cruzados; C e E. Luz paralela. Escala: 200 µm

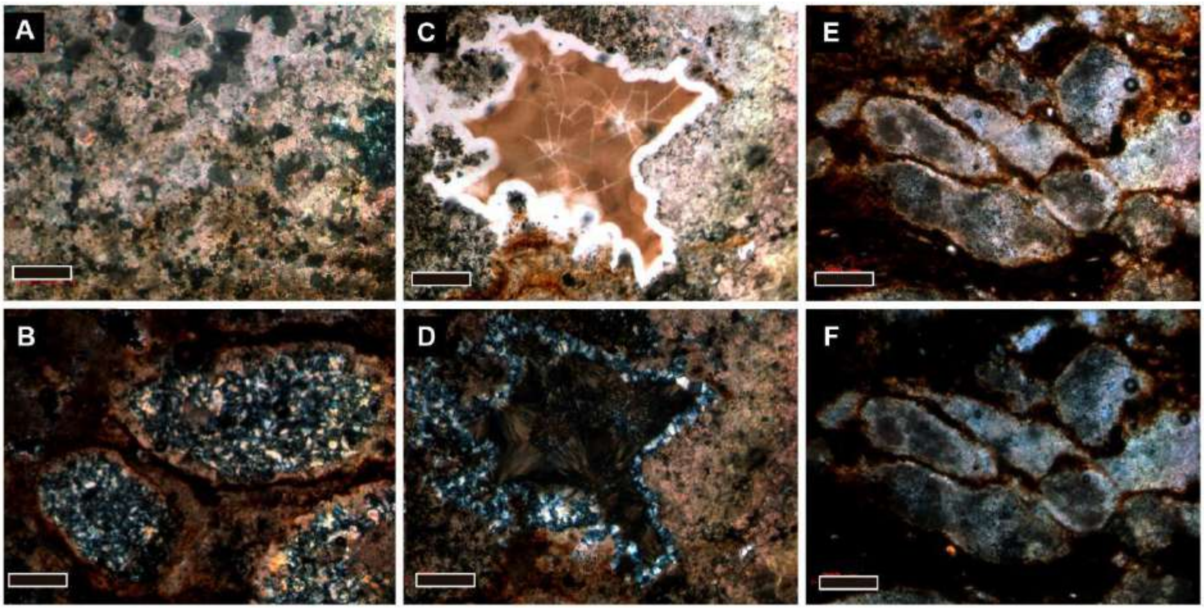


Fonte: A autora (2023).

A lâmina JG-PTNSM-03, intervalo de profundidade 30,62–30,64 m, corresponde a um calcário bioclástico laminado intercalado com folhelho escuro. Lâminas onduladas e rítmicas de valvas e carapaças de ostracodes, matéria orgânica e minerais opacos muito finos (Figura 13A–B). Os ostracodes encontram-se em níveis preservando o formato de carapaça completa, preenchidos seja por micrita, esparita e calcedônia (Figura 13C–D) e em outros níveis como valvas desarticuladas.

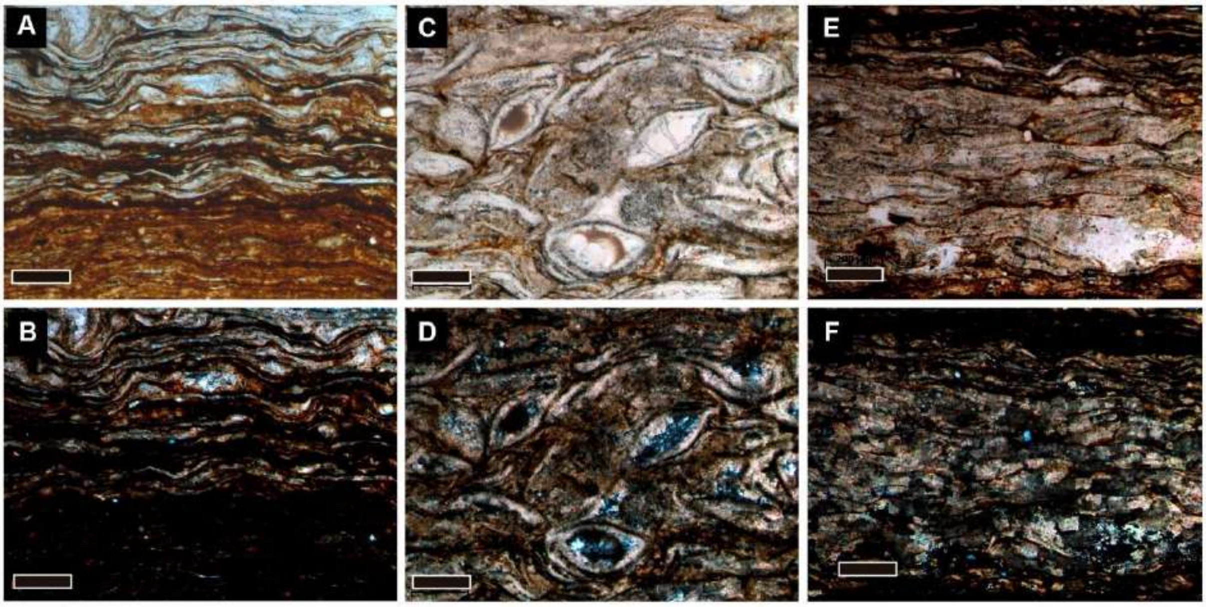
As maiores abundâncias de ostracodes no testemunho 2-TN-SM-BA foram encontradas em um intervalo de 1 metro, possuindo mais de 1.000 espécimes recuperados entre carapaças, valvas, moldes e fragmentos. Do testemunho foram identificados os táxons *Candonopsis*? *alagoensis, Damonella grandiensis, Damonella* sp. 1 *Pattersoncypris* spp., *Pattersoncypris cucurves* e *Pattersoncypris micropapillosa* (Figura 14, 16). Devido à preservação, a nomenclatura de morfotipos do gênero *Pattersoncypris*, adultos e juvenis, permanece aberta como *Pattersoncypris* spp.

Figura 12 – Fotomicrografias da lâmina petrográfica JG-PTNSM-04: A–B, D e F. Nicóis cruzados; C e E. Luz paralela. Escala: 200 µm



Fonte: A autora (2023).

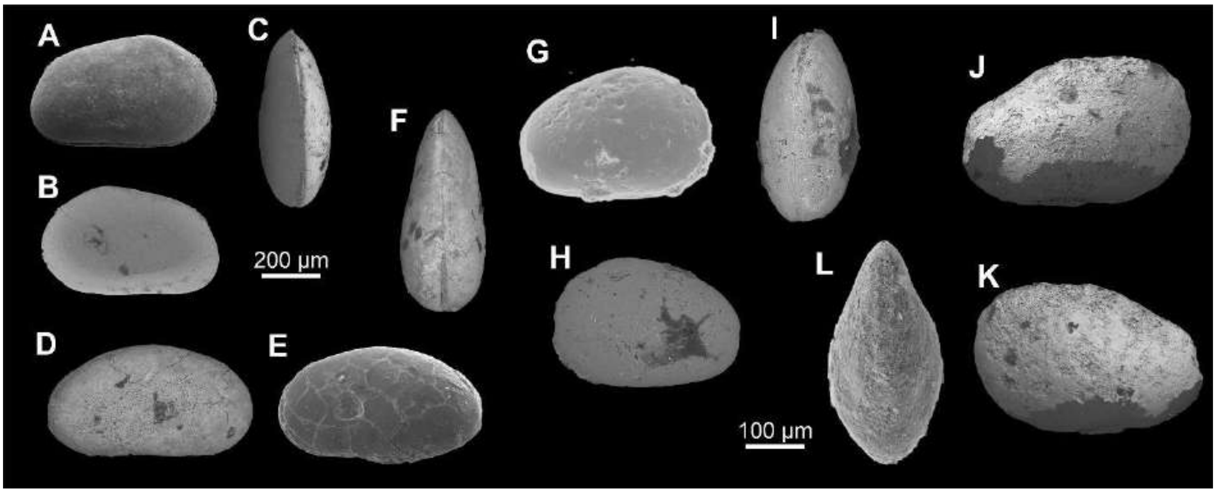
Figura 13 – Fotomicrografias da lâmina petrográfica JG-PTNSM-03: A, C, E. Imagens superiores em luz paralela; B, D, F. Imagens em nicóis cruzados Escala: 200 µm



Fonte: A autora (2023).

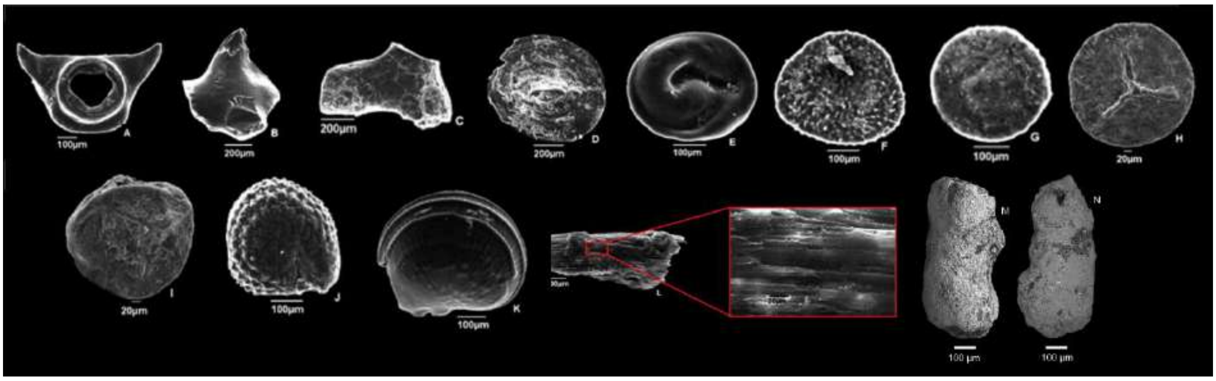
Poucos indivíduos de ostracodes foram pontualmente recuperados em outras profundidades, bem como representantes de outros grupos de microfósseis, com destaque para a primeira ocorrência de foraminíferos bentônicos nas Camadas Amargosa da Formação Marizal da Bacia de Tucano Norte (Figuras 15, 16).

Figura 14 – Fauna de ostracodes do Testemunho 2-TN-SM-BA: A–C. Vistas LD, LE e dorsal de *Candonopsis*? *alagoensis*; D–F. Vistas LD, LE e dorsal de *Damonella grandiensis*; G–I. Vistas LD, LE e dorsal de *Pattersoncypris micropapillosa*; J–L. Vistas LD, LE e dorsal de *Pattersoncypris* spp.



Fonte: A autora (2023).

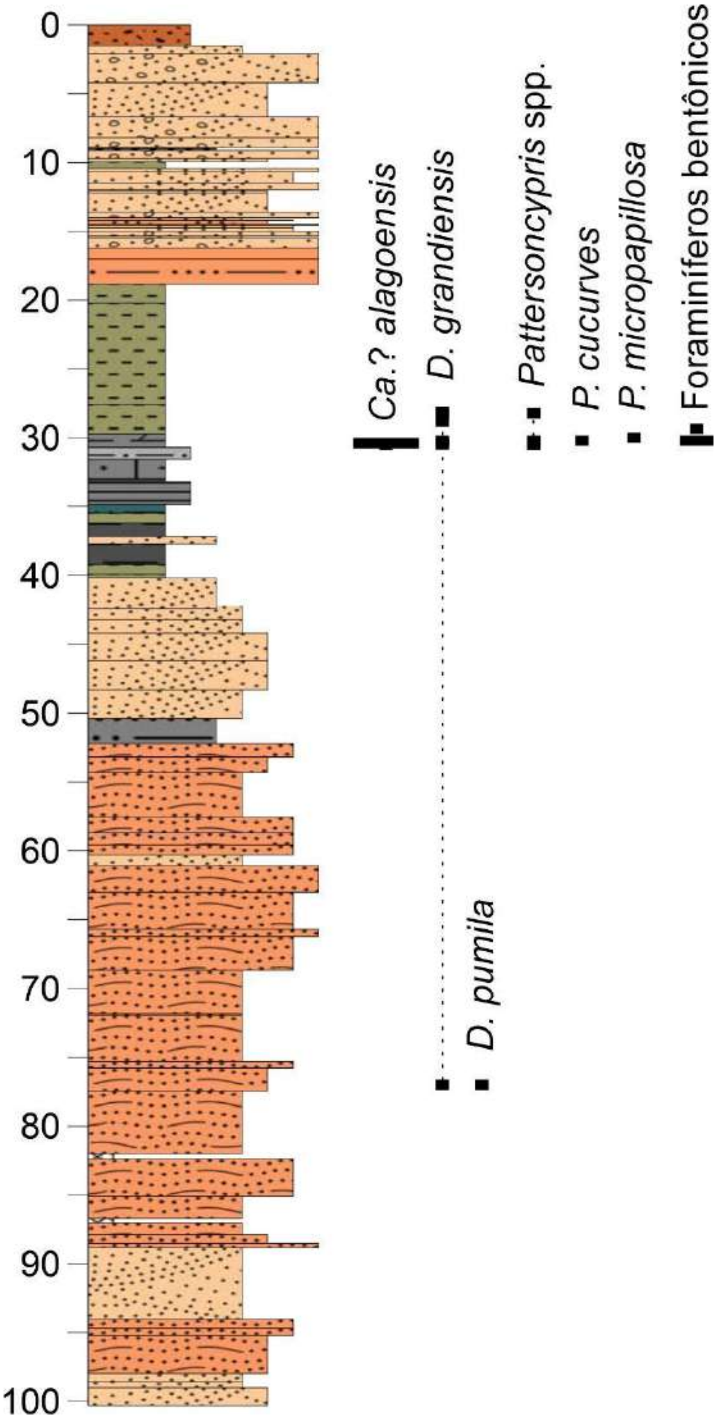
Figura 15 – Outros grupos de microfósseis presentes nas amostras do Testemunho 2-TN-SM-BA: A. Vértebra; B. Dente; C. Fragmento ósseo; D. Bivalve (?); E–I. Palinomorfos; J–K. Microsementes; L. Fragmento vegetal e ampliação de detalhes de suas estruturas anatômicas; M–N. Foraminíferos bentônicos



Fonte: A autora (2023).

As espécies *Pattersoncypris cucurves* e *Candonopsis*? *alagoensis* são táxons marcadores da Subzona *Pattersoncypris cucurves* (OST-011.1), permitindo correlacionar bioestratigráficamente os estratos das Camada Amargosa da Formação Marizal da Bacia de Tucano Norte com as Camadas Batateira da Formação Barbalha da Bacia do Araripe, onde também ocorrem foraminíferos bentônicos.

Figura 16 – Coluna estratigráfica do Testemunho 2-TN-SM-BA (em metros), apresentando a distribuição de espécies de ostracodes e a ocorrência de foraminíferos bentônicos



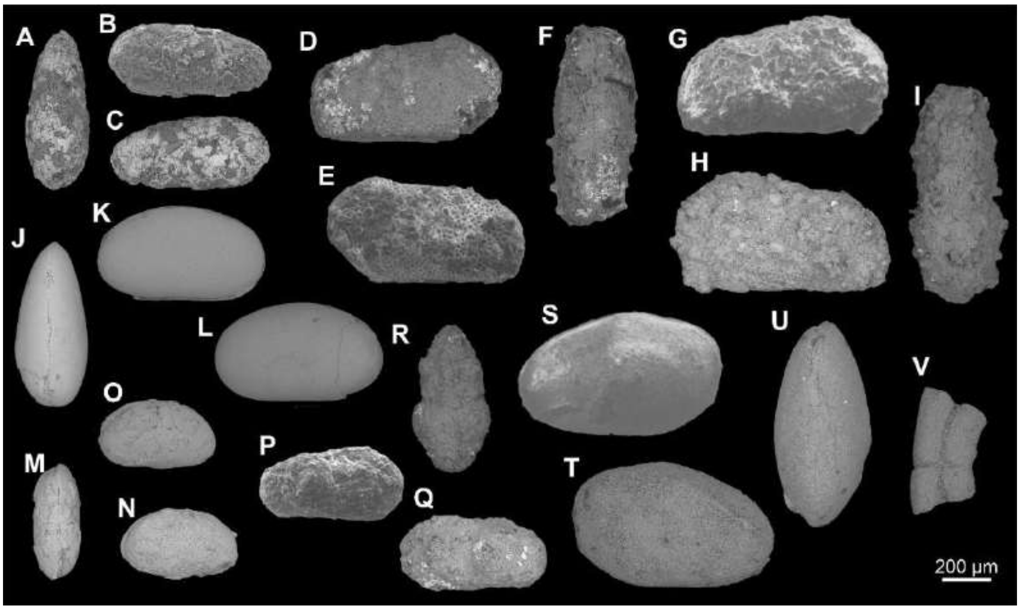
Fonte: A autora (2023).

4.4.1.2 Testemunho 2-TN-ST-3A-BA

A seção é predominantemente pelítica. Na parte mediana da seção, um nível fino de calcário laminado foi observado. Na porção superior do testemunho (7 – 31 m) a litologia corresponde a calcário de lama carbonática, que passa a se intercalar com folhelhos de coloração castanho a cinza. Abaixo da porção carbonática o pacote sedimentar corresponde a um lamito arenoso com intercalações de quartzoarenito de granulação fina a grossa. Os sedimentos que compõem a seção podem corresponder em sua totalidade à Formação Crato, embora intervalos inconsolidados de lamito arenoso da profundidade 55 m para a base, poderiam representar coluviões alóctones.

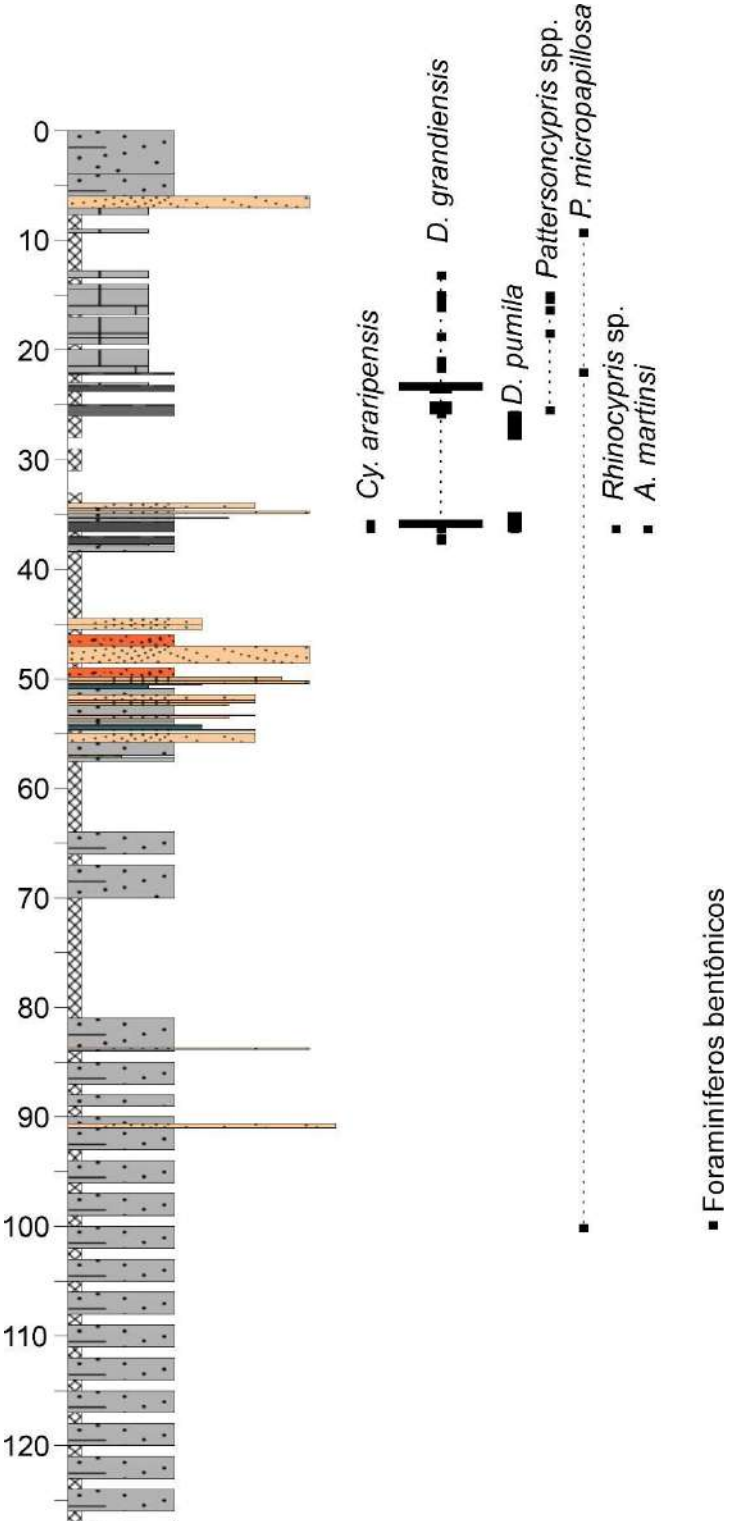
Foram triados 1.827 ostracodes das amostras coletadas do testemunho. A assembleia é constituída em sua maioria pelas espécies *Damonella grandiensis* que ocorre em abundância e *Pattersoncypris micropapillosa*, possuindo também a ocorrência de *Pattersoncypris* spp., *Damonella pumila*, *Cypridea araripensis*, *Rhinocypris* sp. e *Alicenula martinsi*. Além disso, foi recuperado um espécime que provavelmente corresponde a um foraminífero bentônico (Figuras 17, 18). A ausência de *Pattersoncypris cucurves* e de *Pattersoncypris crepata* e a marcante abundância de *D. grandiensis* permitem atribuir a associação recuperada à Subzona *Damonella grandiensis* (OST-011.3) e assim correlacionar bio e litologicamente a porção superior do testemunho 2TN-ST-3A-BA com a porção inferior da Formação Crato da Bacia do Araripe.

Figura 17 – Carapaças de ostracodes do Testemunho TN-ST-3A-BA: A–C. vistas LD e dorsal de *Alicenula martinsi*; D–I. Vista LD, LE e dorsal de *Cypridea araripensis*; J–L. Vista LD, Le e dorsal de *Damonella grandiensis*; M–O. Vista dorsal, LD e LE de *Damonella pumila*; P–R. Vista LD, Le e dorsal de *Rhinocypris* sp.; S – U. Vista LD, Le e dorsal de *Pattersoncypris micropapillosa*; V. Foraminífero bentônico



Fonte: A autora (2023).

Figura 18 – Coluna estratigráfica do Testemunho 2-TN-ST-3A-BA (em metros), apresentando a distribuição de espécies de ostracodes e a ocorrência de foraminíferos bentônicos



Fonte: A autora (2023).

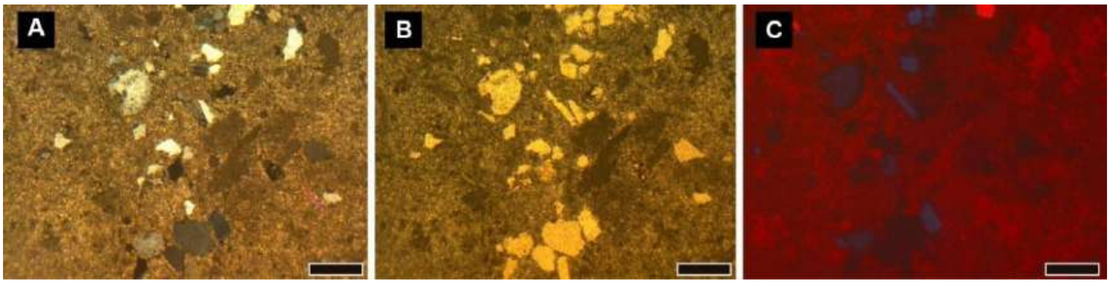
4.4.2 Bacia de Jatobá

4.4.2.1 Testemunho 2-JB-SN-2A-PE

A seção é predominantemente pelítica com abundante muscovita de tamanho silte. Na parte mediana da seção, um nível fino de calcário laminado foi observado. Na porção inferior do testemunho (84,4–87,4 m) a litologia corresponde a um calcário brechoide. Em direção ao topo, o tamanho de grão é maior representado por quartzoarenitos conglomeráticos. As litologias registradas neste testemunho podem ser atribuídas às das formações Romualdo (dois tércios superiores) e Crato.

Foi realizado o estudo petrográfico e de catodoluminescência (CL) dos carbonatos do Testemunho 2-JB-SN-2A-PE através da análise de cinco lâminas delgadas. A lâmina JB-1, profundidade 84,30 m é um calcário com siliciclásticos, composto por micrita e grãos de quartzo subarredondados muitos com extinção ondulante. A maioria dos grãos não se tocam, implicando num empacotamento frouxo. Grande parte dos grãos de quartzo são monocristalinos e poucos (0-5%) são policristalinos. Analisando com CL os feldpatos apresentam coloração azul mais clara e brilhante. Observou-se a presença de muscovita (Figura 19).

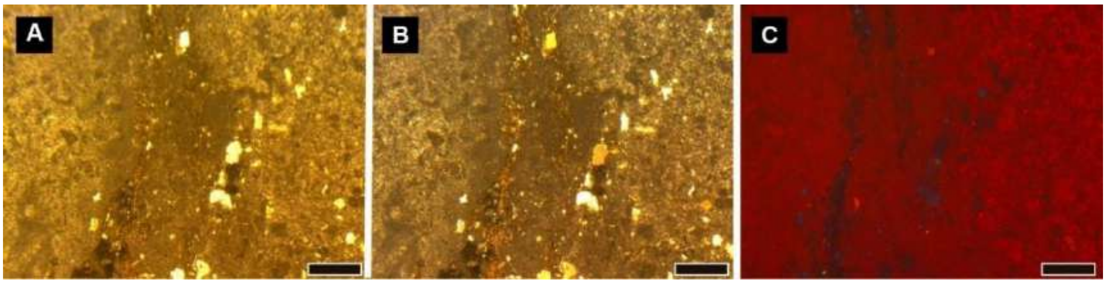
Figura 19 – Fotomicrografias da lâmina delgada JB-1: A. Luz paralela; B. Nicóis cruzados; C. Catodoluminescência. Escala: 100 µm



Fonte: A autora (2023).

A lâmina JB-2, profundidade 84,50 m, corresponde a um calcário com siliciclásticos, composto por uma matriz micrítica com clastos de quartzo subarredondados, muitos com extinção ondulante. A maioria dos grãos estão orientados e não se tocam implicando num empacotamento frouxo. Utilizando CL, os grãos de quartzo apresentam uma coloração azul escuro a marrom e as vezes verde, os feldspatos apresentam coloração azul mais clara e brilhante (Figura 20).

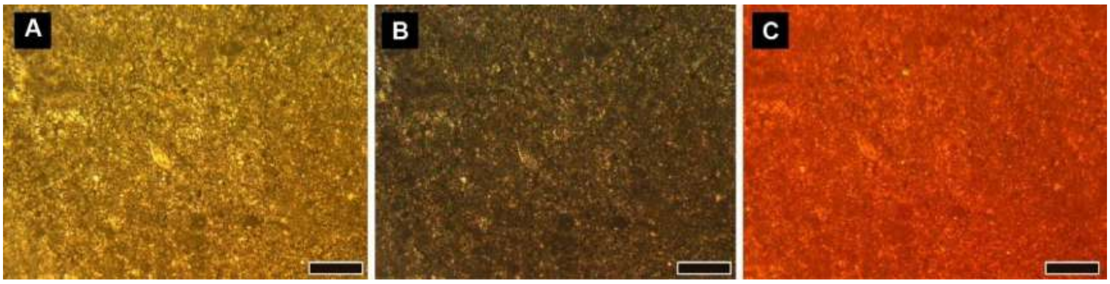
Figura 20 – Fotomicrografias da lâmina delgada JB-2: A. Luz paralela; B. Nicóis cruzados; C. Catodoluminescência. Escala: 100 µm



Fonte: A autora (2023).

A lâmina JB-3, profundidade 85,10 m, é um calcário biomicrito. Rocha composta por uma matriz micrítica com bioclastos de ostracodes (Figura 21).

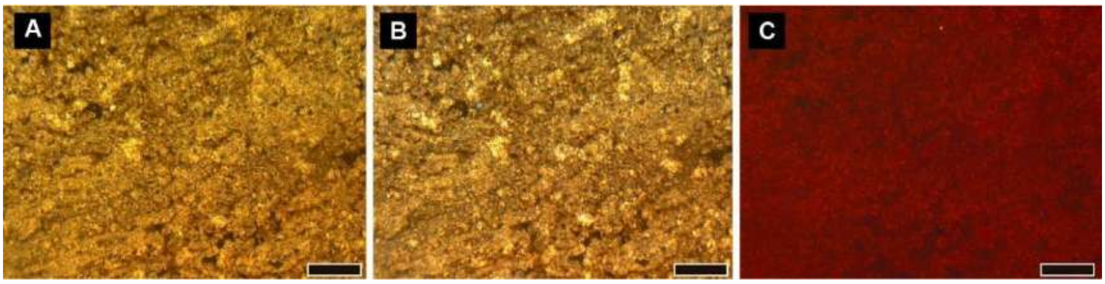
Figura 21 – Fotomicrografias da lâmina delgada JB-3: A. Luz paralela; B. Nicóis cruzados; C. Catodoluminescência. Escala: 100 µm



Fonte: A autora (2023).

A lâmina JB-4, profundidade 87,10 m, foi classificada como calcário com siliciclásticos, composto por uma matriz micrítica e grãos de dolomita. A maioria dos grãos não se tocam implicando num empacotamento frouxo. Baixo CL observam-se grãos de quartzo apresentam uma coloração azul escuro a marrom (Figura 22).

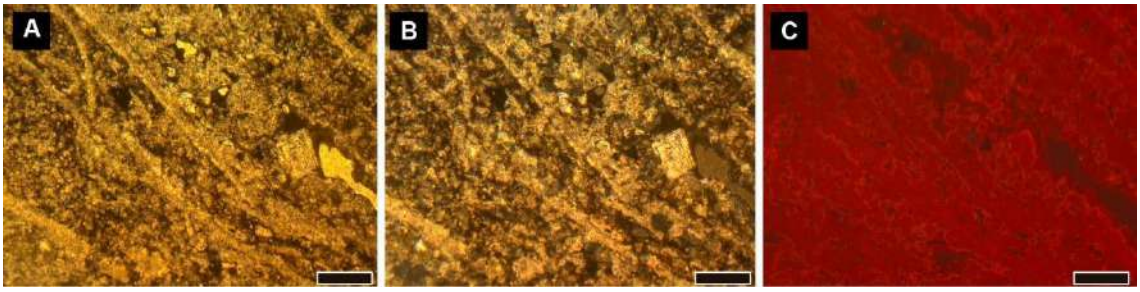
Figura 22 – Fotomicrografias da lâmina delgada JB-4: A. Luz paralela; B. Nicóis cruzados; C. Catodoluminescência. Escala: 100 µm



Fonte: A autora (2023).

A lâmina JB-5, profundidade 75,50 m, corresponde a um calcário com dolomitas, composto por uma matriz micrítica com grãos de dolomita. Observa-se a presença de um grande cristal de dolomita romboédrica. Os cristais de dolomita são mais luminescentes na CL (Figura 23)

Figura 23 – Fotomicrografias da lâmina delgada JB-5: A. Luz paralela; B. Nicóis cruzados; C. Catodoluminescência. Escala: 100 µm



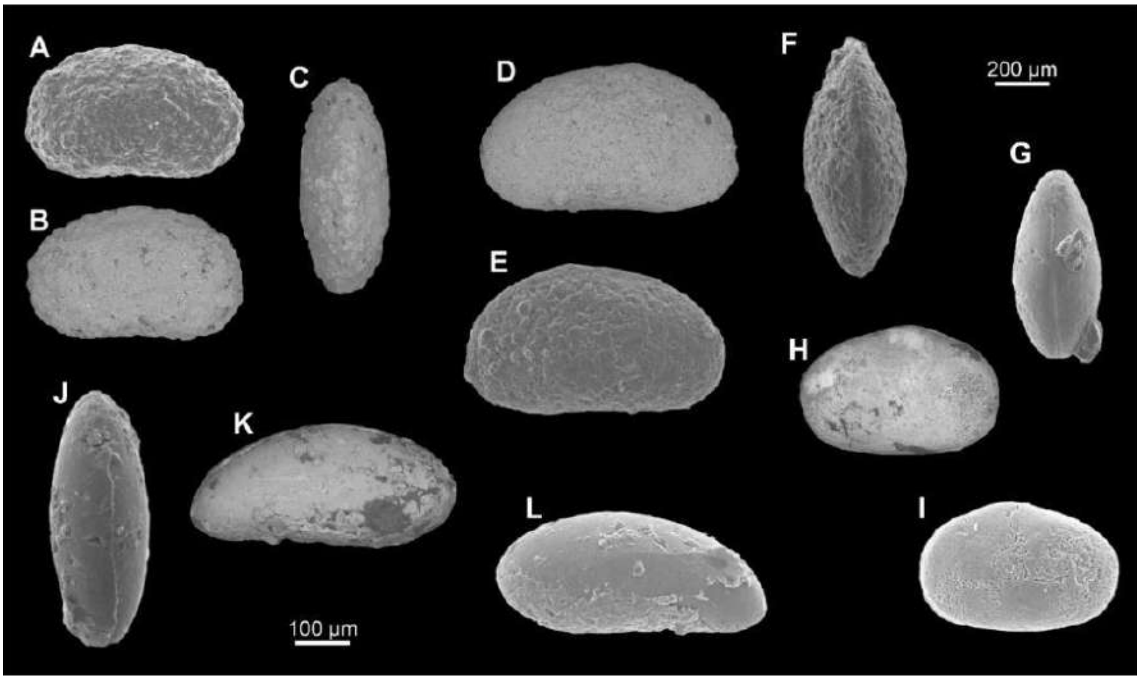
Fonte: A autora (2023).

A recuperação de ostracodes do testemunho 2-JB-SN-2A-PE se mostrou menos abundante quando comparada aos testemunhos de Araripe e Tucano Norte, isto pode ter sido influenciado pela preparação que correspondeu às três metodologias mencionadas na seção 3.1, principalmente sob ataque com H_2O_2, além do controle de preservação nos sedimentos arenosos da porção superior. Foraminíferos não foram recuperados deste testemunho. Foram identificadas as espécies de ostracodes *Damonella grandiensis*, *Pattersoncypris crepata* e *P. micropapillosa* (Figura 24, 25). Alguns táxons foram mantidos em nomeclatura aberta como *Paracypria*? sp. e *Pattersoncypris* spp. (Figura 24). A espécie *P. crepata* representa a guia da subzona de mesmo nome (OST-011.4) registrada nos estratos da Formação Romualdo da Bacia do Araripe. Assim, a porção mediana do testemunho 2-JB-SN-2A-PE corresponde à Formação Romualdo. Na porção inferior a ausência de microfósseis carbonáticos, não permite sua correlação.

4.4.2.2 Testemunho 2-JB-SN-2B-PE

O testemunho 2-JB-SN-2B-PE apresenta uma amplia variedade litológica. A porção superior (0–9 m) corresponde a um solo conglomerático inconsolidado de matriz de lama carbonática com fragmentos de calcário laminado, interpretado como um depósito de colúvio alóctone. O resto da seção registra intercalação de calcários laminados, lamitos, ritmitos e níveis de quartzoarenito de granulometria muito fina a média. Na base do testemunho ocorre um conglomerado de matriz de lama carbonática e clastos de quartzo e gnaisse. As litologias registradas podem corresponder à Formação Crato.

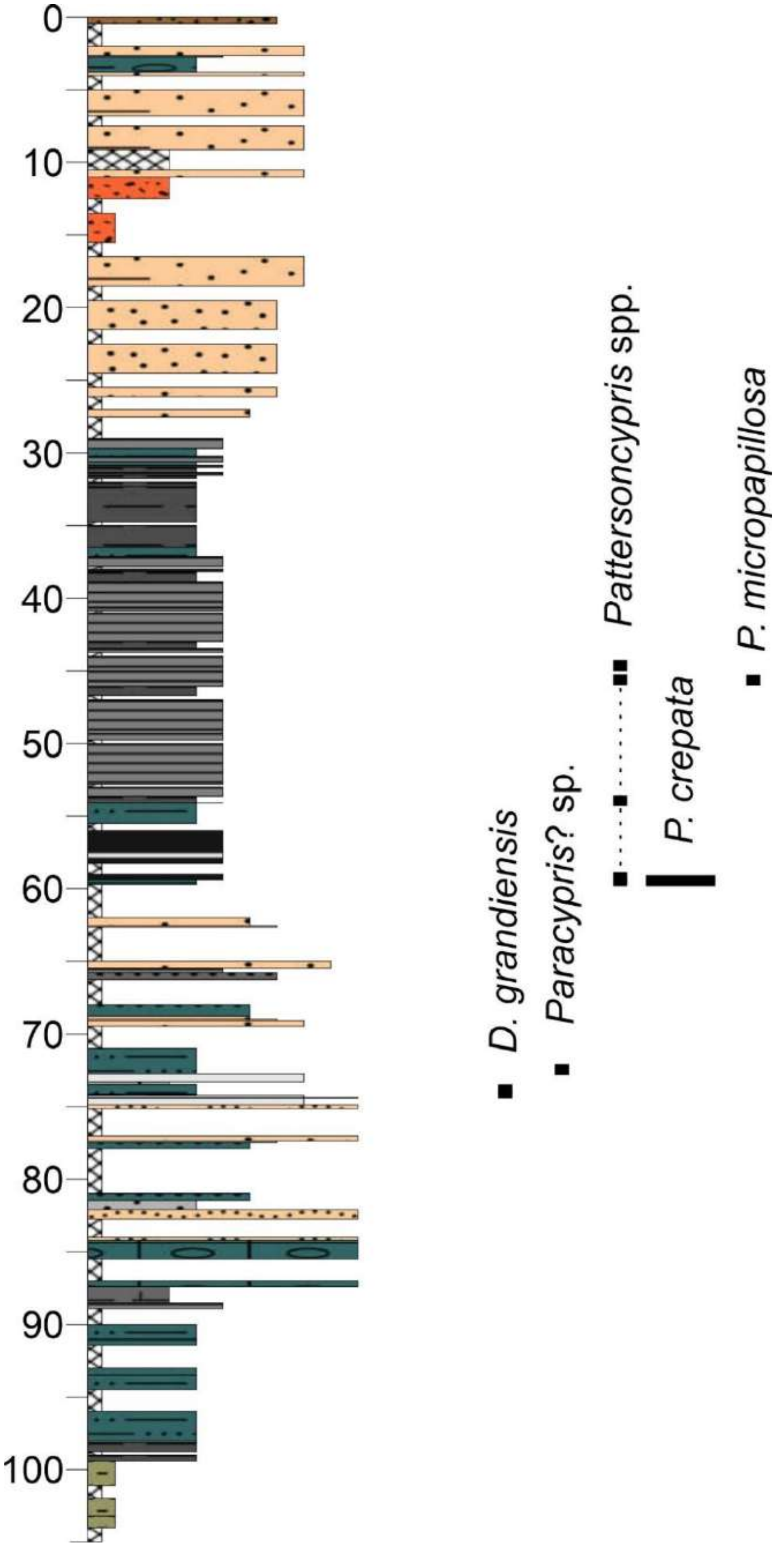
Figura 24 – Ostracodes do Testemunho 2-JB-SN-2A-PE: A–C. Vistas LD, LE e dorsais de *Damonella grandiensis*; D–F. Vistas LD, LE e dorsal de *Pattersoncypris crepata*; G–I. Vistas LD, LE e dorsal de *Pattersoncypris micropapillosa*; J–L. D–F. Vistas LD, LE e dorsal de *Pattersoncypris crepata*; G–I. Vistas LD, LE e dorsal de *Pattersoncypris micropapillosa*; J–L. D–F. Vistas LD, LE e dorsal de *Paracypria*? sp.



Fonte: A autora (2023).

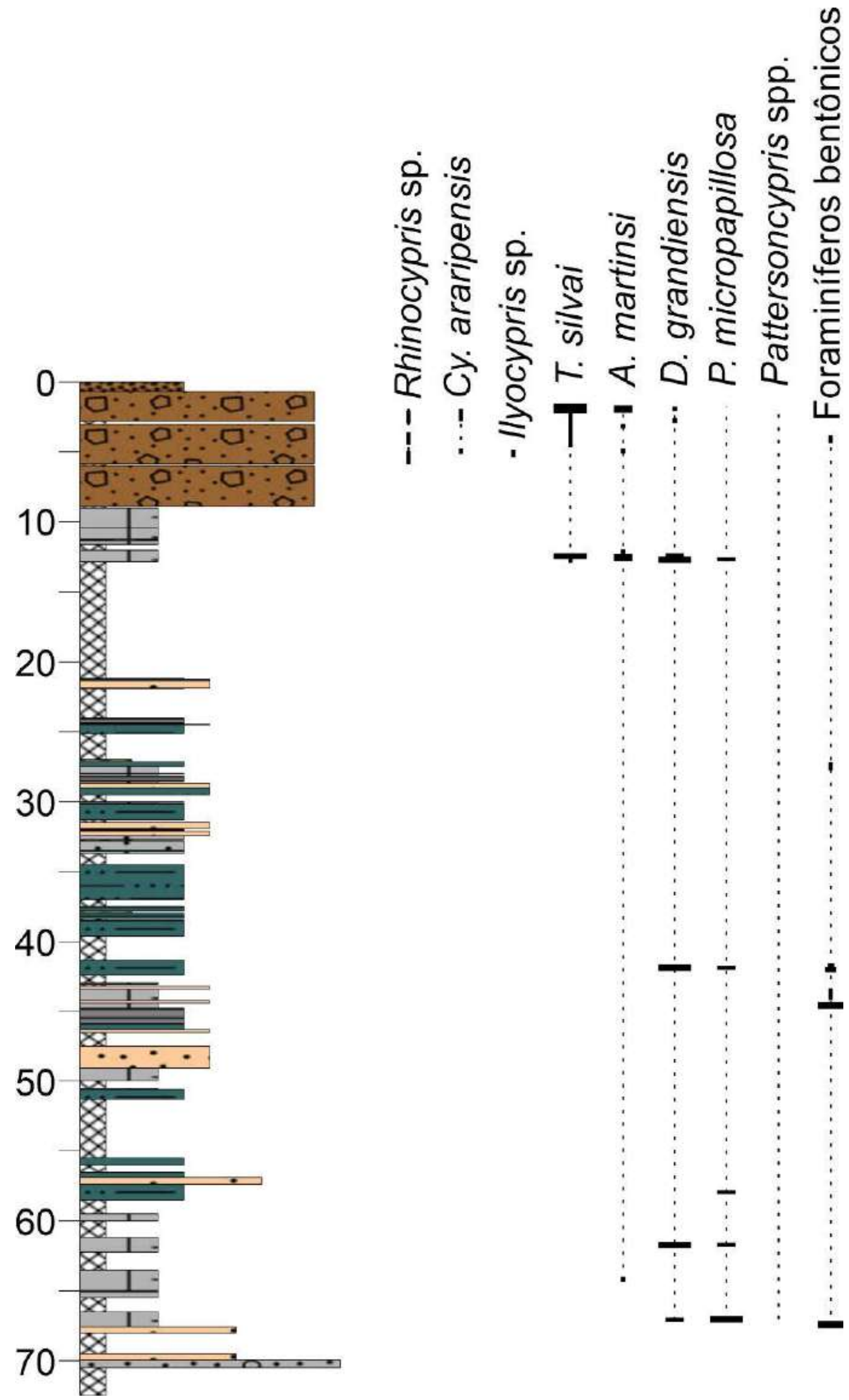
Espécimes de *Alicenula martinsi*, *Cypridea araripensis*, *Damonella grandiensis*, *Ilyocypris* sp., *Pattersoncypris micropapillosa*, *Pattersoncypris* spp., *Rhinocypris* sp., *Theriosynoecum silvai*, além de foraminíferos bentônicos, foram recuperados ao longo da seção (Figura 26). Até o momento espécimes não foram ilustrados. O registro de microfósseis na porção superior que corresponde a um colúvio alóctone, foi identificado como retrabalhado. A falta das espécies marcadoras das subzonas *Pattersoncypris cucurves* (OST-011.1) e *Pattersoncypris crepata* (OST-011.4), além da abundância de *Damonella grandiensis* e *Pattersoncypris micropapillosa*, assim como de foraminíferos bentônicos em níveis ao longo da seção, permite tentativamente atribuir a seção in situ à Subzona *Damonella grandiensis* (OST-011.3), e correlacioná-la com a Formação Crato da Bacia do Araripe.

Figura 25 – Coluna estratigráfica do Testemunho 2-JB-SN-2A-PE (em metros), apresentando a distribuição de espécies de ostracodes e a ocorrência de foraminíferos bentônicos



Fonte: A autora (2023).

Figura 26 – Coluna estratigráfica do Testemunho 2-JB-SN-2B-PE (em metros), apresentando a distribuição de espécies de ostracodes e a ocorrência de foraminíferos bentônicos



Fonte: A autora (2023).

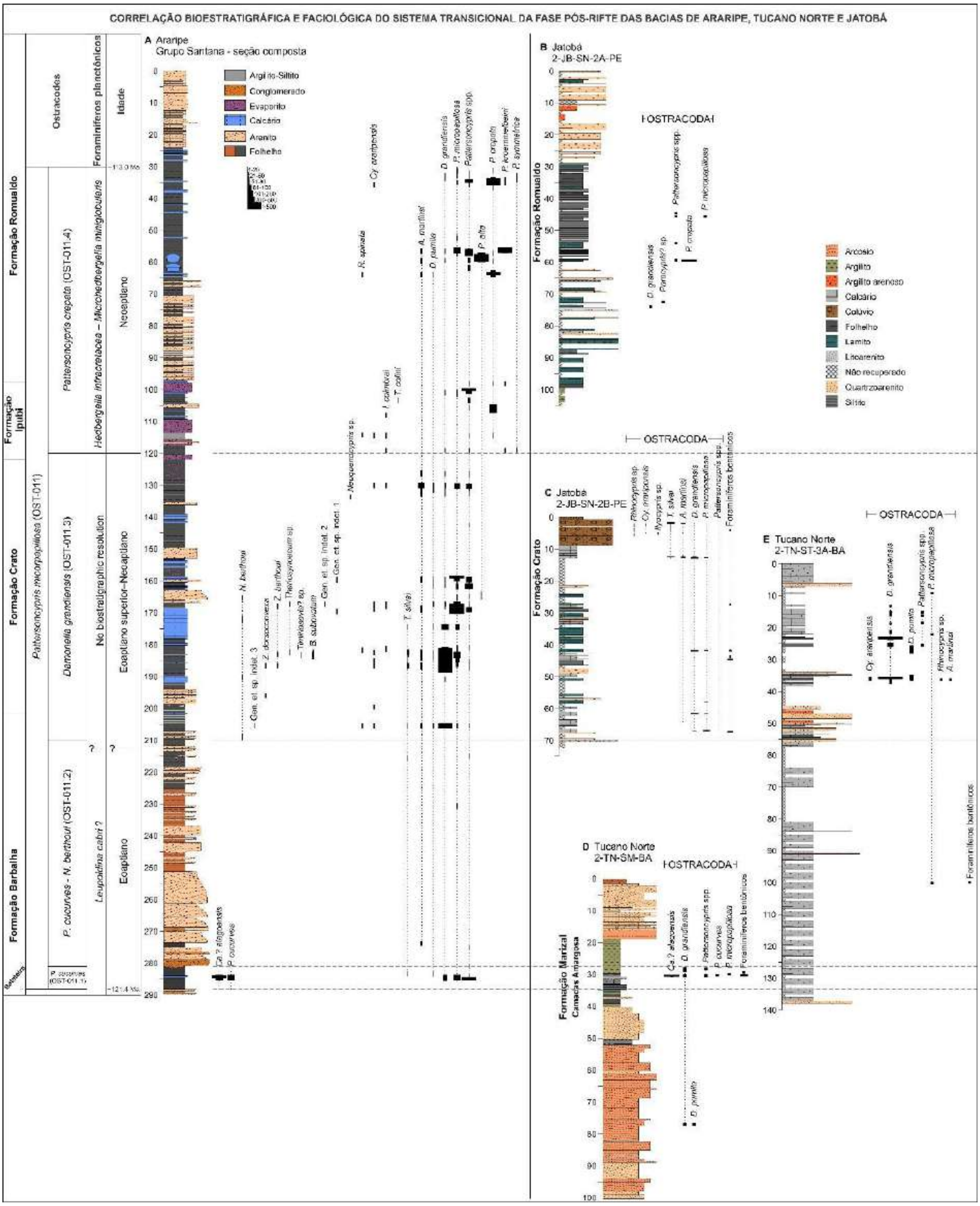
4.4.3 Correlação faciológica e bioestratigráfica do Aptiano das bacias de Araripe, Tucano Norte e Jatobá

A partir das associações de ostracodes e da ocorrência de foraminíferos e da análise macroscópica de litofácies e de microfácies carbonáticas nos estratos da sequência pós-rifte I das bacias de Araripe, Tucano Norte e Jatobá, foi possível estabelecer a correlação entre as unidades das três bacias estudadas (Figura 27).

A base da seção pós-rifte I, denominada na Bacia do Araripe como Formação Barbalha, unidade inferior do Grupo Santana, é nomeada como Formação Marizal nas bacias de Tucano Norte e Jatobá. Esta formação é caracterizada por arenitos fluviais contendo para a porção média o intervalo de calcários laminados e folhelhos fossilíferos com abundante matéria orgânica das Camadas Batateira (na Bacia do Araripe) / Amargosa (na Bacia de Tucano Norte e Jatobá). Ostracodes da Subzona *Pattersoncypris cucurves* (OST-011.1) são registrados nas bacias de Araripe e Tucano Norte, ocorrendo em associação com foraminíferos bentônicos. A ocorrência do palinomorfo *Sergipea variverrucata* nas Camadas Batateira indica idade aptiana (VALLEJO et al. 2023). Na Bacia do Araripe a identificação da espécie de foraminífero bentônico *Ammobaculites irregulariformis* permite interpretar como estuarino restrito o ambiente deposicional das Camadas Batateira. A ocorrência dos ostracodes *P. cucurves* e *Candonopsis*? *alagoensis* em argilitos, folhelhos e carbonatos laminados interestratificados nos arenitos da Formação Marizal na Bacia de Tucano Norte, permite a correlação das Camadas Amargosa com as Camadas Batateira, podendo ser interpretadas como o registro de estuários que se estendem numa ampla região.

Interpretada como depositada por sistemas fluviais e de delta de cabeceira, a sequência superior da Formação Barbalha da Bacia do Araripe (VAREJÃO et al. 2021) registra a Subzona *Pattersoncypris cucurves-Neuquenocypris berthoui* (OST-011.2). Nesta subzona, foi registrada a ocorrência do foraminífero planctônico *Favusella hoterivica*, o qual apresenta a sua última ocorrência dentro da Zona *Leupoldina cabri* datada como Eoaptiano. A idade aptiana é corroborada pelo registro de dinoflagelados da Ecozona *Subtilisphaera* nos folhelhos do topo da Formação Barbalha (VAREJÃO et al. 2021). Esta subzona, caracterizada por uma baixa diversidade, não foi identificada nas bacias de Tucano Norte e Jatobá.

Figura 27 – Correlação bioestratigráfica e faciológica do sistema transicional da fase pós-rifte das bacias de Araripe, Tucano Norte e Jatobá



Fonte: A autora (2023).

A porção média-superior da sequência pós-rifte I nas bacias de Araripe, Tucano Norte e Jatobá é representada pela Formação Crato. Bancos de ritmitos calcário-argilito intercalados com folhelhos compõem predominantemente a unidade. Na Bacia do Araripe, a sedimentação da Formação Crato oscilou entre condições continentais e marinhas como resultado de um processo alocíclico associado à combinação de variações climáticas, tectônicas e eustáticas (VAREJÃO et al. 2021). A Subzona *Damonella grandiensis* (OST-011.3) caracteriza bioestratigraficamente a unidade, apresentando alta diversidade tanto de ostracodes como de foraminíferos. Níveis de ocorrência abundante das espécies de ostracodes *Damonella grandiensis* e *Pattersoncypris micropapillosa*, associadas com foraminíferos bentônicos e hedbergelinídeos planctônicos, sustentam a influência marinha. As raras ocorrências de ostracodes tipicamente fluvio-lacustres como *Alicenula*, *Cypridea* e *Theriosynoecum*, além de *Rhinocypris*, *Ilyocypris* e *Neuquenocypris* sugerem a entrada de água doce no sistema. De acordo com Horne (2002), *Cypridea* é considerado um gênero de água doce, tanto de ambientes permanentes como temporários, enquanto os darwinulideos e os representantes do gênero *Theriosynoecum* habitavam corpos permanentes de água doce a levemente salina. A partir desta pesquisa, é possível interpretar a Formação Crato da Bacia do Araripe como uma bacia hidrográfica costeira de baía onde se desenvolveram planícies de maré, lagos e lagoas. Baseado na identificação de intervalos de abundância de *Damonella grandiensis*, *Pattersoncypris micropapillosa* e foraminíferos bentônicos, foi possível identificar a biozona OST-011.3 nos testemunhos 2-JB-SN-2B-PE da Bacia de Jatobá e 2-TN-ST-3A-BA da Bacia de Tucano Norte. A falta de registro das espécies marcadoras das subzonas *Pattersoncypris cucurves* (OST-011.1) e *Pattersoncypris crepata* (OST-011.4) também sugere a correlação das seções 2-JB-SN-2B-PE e 2-TN-ST-3A-BA (porção superior) com a Formação Crato.

As unidades superiores da sequência pós-rifte I, das bacias de Araripe, Tucano Norte e Jatobá correspondem às formações Ipubi (unicamente registrada na Bacia do Araripe) e Romualdo (sem registro na Bacia de Tucano Norte). Folhelhos e lentes de evaporitos intercalados são sobrepostos por conglomerados estratificados, arenitos, calcários, margas e folhelhos. Nestes estratos, *Pattersoncypris crepata* representa a espécie guia da biozona OST-011.4. A ocorrência desta espécie em associação com foraminíferos planctônicos de afinidade tetiana, como *Pseudoguembelitria blakenosensis*, *Hedbergella gorbachikae*, *Hedbergella infracretacea*, *Hedbergella aptiana* e *Microhedbergella miniglobularis* (zona composta *Hedbergella infracretacea-Microhedbergella miniglobularis*) permite posicionar estratigraficamente estes estratos no Aptiano superior. Esta associação sugere que o mar ingressou no interior do nordeste do Brasil vindo do Oceâno Atlântico Central, como já sugerido por Melo et al. (2020) e que as áreas das bacias de Araripe e Jatobá correspondiam a rampas de um *seaway* de caráter regional. A extensão lateral da Formação Ipubi, restrita a área da Bacia do Araripe, e com ocorrência de foraminíferos planctônicos, sugere uma alta evaporação de uma rampa marinha restrita. A Formação Romualdo representa a completa instalação do mar epírico sobre uma rampa externa mista siliciclástica-carbonática (MELO et al. 2020). A ocorrência de *Pattersoncypris crepata* na seção 2-JB-SN-2A-PE da Bacia de Jatobá apresenta o marco de correlação bioestratigráfico e permite associar a sua porção média com a Formação Romualdo da Bacia do Araripe.

5 CONSIDERAÇÕES FINAIS

A presente tese contém os resultados e interpretações da pesquisa em faciologia, taxonomia, bioestratigrafia e paleoambientes dos depósitos pós-rifte I das bacias de Araripe, Tucano Norte e Jatobá, Nordeste do Brasil.

Vinte e cinco táxons de ostracodes, incluindo cinco espécies novas e três em nomenclatura aberta, foram identificados ao longo do Grupo Santana da Bacia do Araripe: *Alicenula martinsi*, *Brasacypris subovatum*, *Cypridea araripensis*, *Candonopsis*? *alagoensis*, *Damonella grandiensis*, *Damonella pumila* nov. sp., *Ilyocypris coimbrai* nov. sp., *Neuquenocypris berthoui*, *Neuquenocypris* sp., *Pattersoncypris alta*, *Pattersoncypris crepata*, *Pattersoncypris cucurves* nov. sp., *Pattersoncypris kroemmelbeini* nov. sp., *Pattersoncypris micropapillosa*, *Pattersoncypris symmetrica*, *Rhinocypris spinata* nov. sp., *Timiriasevia*? sp., *Theriosynoecum colini*, *Theriosynoecum silvai*, *Theriosynoecum* sp., *Zonocypris berthoui* e *Zonocypris dorsoconvexa*.

A Biozona *Pattersoncypris micropapillosa* (OST-011) foi descrita na Bacia do Araripe ocorrendo ao longo do Grupo Santana. Esta zona corresponde à comumente denominada Biozona 011 relacionada ao grupo de ostracodes *Cytheridea*? spp. 201–218, presente em várias bacias mesozoicas do Brasil. Com a formalização da biozona e suas subzonas na publicação internacional, o nome e código destas poderão ser padronizados para as demais bacias tipo rifte que as registrarem, assim como a uniformização dos códigos OST-001 a OST-010 para as biozonas inferiores.

As subzonas *Pattersoncypris cucurves* (OST-011.1), *Pattersoncypris cucurves-Neuquenocypris berthoui* (OST-011.2), *Damonella grandiensis* (OST-011.3) e *Pattersoncypris crepata* (OST-011.4) calibradas à estratigrafia internacional (zonas de foraminíferos planctônicos *Leupoldina cabri* e *Hedbergella infracretacea–Microhedbergella miniglobularis*) datam do Eoaptiano ao Neoaptiano.

A presente tese contém a reinterpretação paleoambiental do Grupo Santana da Bacia do Araripe, anteriormente entendido como fluvio-lacustre com ingressões marinhas intermitentes, a partir da deposição do topo da sequência superior da Formação Barbalha. A ocorrência de foraminíferos tanto bentônicos como planctônicos ao longo do Grupo Santana, sustenta que a influência marinha foi ainda mais antiga e que o ambiente deposicional teve uma progressão constante de caráter transicional a completamente marinho.

As análises bioestratigráficas nas bacias de Tucano Norte e Jatobá permitiram corroborar a a relação ambiental e cronocorrelação das unidades pós-rifte I com o Grupo Santana da Bacia do Araripe. As Camadas Amargosa da Formação Marizal, Bacia de Tucano Norte, correspondem a Subzona *Pattersoncypris cucurves* de idade eoaptiana, a qual registra uma deposição estuarina restrita. Tanto na Bacia do Araripe como nas bacias de Tucano Norte e Jatobá, a Formação Crato apresenta a Subzona *Damonella grandiensis* atribuída à parte inferior do Aptiano superior e depositada em amplas baías. Para o topo da Serra Negra, Bacia de Jatobá, o registro da Subzona *Pattersoncypris crepata* permitiu inferir que a Formação Romualdo foi também depositada durante o estabelecimento do mar epírico no interior do nordeste do Brasil.

REFERÊNCIAS

ALMEIDA-LIMA, D. S. DE et al. Non-marine ostracods from the Late Jurassic–Early Cretaceous of Araripe, Jatobá and Tucano Norte basins, northeast Brazil. **Revue de Micropaleontologie**, v. 74, p. 100605, 2022a.

______. et al. Freshwater ostracod *Theriosynoecum pricei* (Pinto and Sanguinetti, 1958): ecophysiological variations, taxonomic review and palaeoenvironmental implications. **Palaeobiodiversity and Palaeoenvironments**, 2022b.

ARAI, M. et al. Cretaceous dinoflagellate provincialism in Brazilian marginal basins. **Cretaceous Research**, v. 21, p. 351–366, 2000.

ARAI, M. Paleogeografia do Atlântico Sul no Aptiano: um novo modelo a partir de dados micropaleontológicos recentes. **Boletim de Geociencias da Petrobras**, v. 17, n. 2, p. 331–351, 2009.

______. Aptian/Albian (early Cretaceous) paleogeography of the South Atlantic: a paleontological perspective. **Brazilian Journal of Geology**, v. 44, n. 2, p. 339–350, 2014.

______. Reply to the comments of Assine et al. (Comments on paper by M. Arai “Aptian/Albian (early Cretaceous) paleogeography of the South Atlantic: a paleontological perspective”). **Brazilian Journal of Geology**, v. 46, n. 1, p. 9–13, 2016.

ARAI, M.; ASSINE, M. L. Chronostratigraphic constraints and paleoenvironmental interpretation of the Romualdo Formation (Santana Group, Araripe Basin, Northeastern Brazil) based on palynology. **Cretaceous Research**, v. 116, p. 104610, 2020.

ARARIPE, R. C. et al. Foraminifera and Ostracoda from the Lower Cretaceous (Aptian–lower Albian) Romualdo Formation, Araripe Basin, northeast Brazil: Paleoenvironmental inferences. **Cretaceous Research**, v. 122, p. 104766, 2021.

ASSINE, M. L. Análise estratigráfica da Bacia do Araripe, Nordeste do Brasil. **Revista Brasileira de Geociências**, v. 22, n. 3, p. 289–300, 1992.

______. Bacia do Araripe. **Boletim de Geociências da Petrobras**, v. 15, n. 2, p. 371–389, 2007.

ASSINE, M. L. et al. Sequências deposicionais do Andar Alagoas da Bacia do Araripe, Nordeste do Brasil. **Boletim de Geociencias da Petrobras**, v. 22, n. 1, p. 3–28, 2014.

BERTHOU, P. Y. et al. New data on the ostracodes from the Crato lithologic units (lower member of the Santana Formation, latest Aptian–lower Albian) of the Araripe Basin (Northeastern Brazil). **Acta Geologica Leopoldensia**, v. XVII, n. 39/2, p. 539–554, 1994.

BRITO NEVES, B. B.; SANTOS, E. J.; VAN SCHMUS, W. R. Tectonic history of the Borborema Province. In: CORDANI, U. et al. (Eds.). **Tectonic Evolution of South America**. Rio de Janeiro: [s.n.]. p. 151–182, 2000.

BRITO, P. M.; NASCIMENTO, B. M.; MEUNIER, F. J. Amiid remains (Actinopterygii, Amiiformes) from the Early Cretaceous Marizal Formation (Tucano Basin) of Northeastern Brazil. **Cybium**, v. 45, n. 4, p. 311–316, 2021.

BRITO, P. M.; YABUMOTO, Y. An updated review of the fish faunas from the Crato and Santana formations in Brazil, a close relationship to the Tethys fauna. **Bulletin of Kitakyushu Museum of Natural History and Human History, Series A**, v. 9, n. January, p. 107–136, 2011.

BUENO, G. V. **Serra do Tonã: um elo entre as bacias de Tucano Norte (BA) e Araripe CE, Nordeste do Brasil**. 4° Simpósio sobre o Cretáceo do Brasil. **Anais**... Rio Claro: UNESP, p. 143–146, 1996

CAIXETA, J. M.; BUENO, G. V.; MAGNAVITA, L. P.; FEIJÓ, F. J. Bacias do Recôncavo, Tucano e Jatobá. **Boletim de Boletim de Geociências da Petrobras**, v. 8, n. 1/2, p. 163–172, 1994.

CESERO, P. DE; PONTE, F. C. Análise comparativa da paleogeologia dos litorais atlânticos brasileiro e africano. **Boletim de Geociências da Petrobras**, v. 11, n. 1/2, p. 1–18. 1997, 1972.

CHANG, H. K. et al. Tectonics and stratigraphy of the East Brazil Rift system: an overview. **Tectonophysics**, v. 213, p. 97–138, 1992.

CHANG, H. K.; KOWSMANN, R. O.; FIGUEREIDO, A. M. F. New concepts on the development of East Brazilian Marginal Basins. **Episodes**, p. 194–202, 1988.

COIMBRA, J. C.; ARAI, M.; CARREÑO, A. L. Biostratigraphy of Lower Cretaceous microfossils from the Araripe Basin, northeastern Brazil. **Geobios**, v. 35, n. 6, p. 687–698, 2002.

COLIN, J.-P.; DÉPÊCHE, F. Faunes d’ostracodes lacustres des bassins intra-cratoniques d’âge albo-aptien en Afrique de l’Ouest (Cameroun, Tchad) et au Brésil : considérations d’ordre paléoécologique et paléobiogéographique. **Africa Geoscience Review**, v. 4, n. 3 & 4, p. 431–450, 1997.

COSTA, I. P. et al. Sub-bacia de Tucano Norte e Bacia de Jatobá. **Boletim de Geociências da Petrobras**, v. 15, n. 2, p. 445–453, 2007.

CUNHA, M. DA C. C.; MOURA, J. A. Espécies novas de Ostracodes não-marinhos da série do Reconcavo: Paleontologia e Bioestratifrafia. **Boletim Técnico da Petrobrás**, v. 22, n. 2, p. 87–100, 1979.

CUSTÓDIO, M. A. et al. The transgressive-regressive cycle of the Romualdo Formation (Araripe Basin): Sedimentary archive of the Early Cretaceous marine ingression in the interior of Northeast Brazil. **Sedimentary Geology**, v. 359, p. 1–15, 2017.

GARCIA, A. J. V. Evolução sedimentar da sequência pré-rift das bacias costeiras e interiores do nordeste brasileiro. **Pesquisas, Instituto de Geociências, UFRGS**, v. 18, p. 3–12, 1991.

GOLDBERG, K. et al. Aptian marine ingression in the Araripe Basin: Implications for paleogeographic reconstruction and evaporite accumulation. **Marine and Petroleum Geology**, v. 107, n. May, p. 214–221, 2019.

GUZMÁN-GONZÁLEZ, J. et al. Non-marine ostracoda from the Aliança Formation in the north-central portion of the Jatobá Basin, Northeastern Brazil. **Revista Brasileira de Paleontologia**, v. 19, n. 1, p. 15–24, 2016.

GUZMÁN, J. et al. Estratigrafia da Bacia de Jatobá: Estado da Arte. **Estudos Geológicos**, v. 25, n. 1, p. 53–76, 2015.

HAQ, B. U. Cretaceous eustasy revisited. **Global and Planetary Change**, v. 113, p. 44–58, 2014.

HEINE, C.; ZOETHOUT, J.; MÜLLER, R. D. Kinematics of the South Atlantic rift. **Solid Earth**, v. 4, n. 2, p. 215–253, 2013.

HORNE, D.J., 2002. Ostracod biostratigraphy and palaeoecology of the Purbeck Limestone Group in Southern England. **Special Papers in Palaeontology**, v. 68, p. 53–70.

KUCHLE, J. et al. A contribution to regional stratigraphic correlations of the Afro-Brazilian depression - The Dom João Stage (Brotas Group and equivalent units - Late Jurassic) in

Northeastern Brazilian sedimentary basins. **Journal of South American Earth Sciences**, v. 31, n. 4, p. 358–371, 2011.

KUCHLE, J.; SCHERER, C. M. D. S. Sismoestratigrafia de bacias rifte: Técnicas, métodos e sua aplicação na Bacia do Recôncavo. **Boletim de Geociências da Petrobras**, v. 18, n. 2, p. 179–206, 2010.

MAGNAVITA, L. P. **Sobre a implantação da fase sinrifte em riftes continentais**. Congresso Brasileiro de Geologia, 39. **Anais**...Salvador: Sociedade Brasileira de Geologia, p. 335–338, 1996

MATOS, R. M. D. The Northeast Brazilian Rift System. **Tectonics**, v. 11, n. 4, p. 766–791, 1992.

MELO, R. M. et al. New marine data and age accuracy of the Romualdo Formation, Araripe Basin, Brazil. **Scientific Reports**, v. 10, n. 1, p. 15779, 2020.

MENDES, D. DE M. et al. Geological and stratigraphic characterization of the Region North of Inajá (PE), Jatobá Basin , Northeast Brazil. **Revista de Geociências do Nordeste**, v. 6, n. 2, p. 32–44, 2020.

NEUMANN, V. H. et al. **Microfácies e microestruturas dos calcários laminados das serras do Periquito e Negra, Bacia do Jatobá**. 5º Congresso Brasileiro De Pesquisa E Desenvolvimento Em Petróleo E Gás. **Anais**...Fortaleza: UFC, CD-ROM, 2009

NEUMANN, V. H.; CABRERA, L. **Una nueva propuesta estratigráfica para la tectono-sequência Pós-rifte de la Cuenca de Araripe, Noreste de Brasil**. 5° Simpósio sobre o Cretáceo do Brasil. **Anais**...Rio Claro: UNESP, p. 279–285, 1999

NEUMANN, V. H. D. M. L.; ASSINE, M. L. **Stratigraphic Proposal to the Post-Rift I Tectonic-Sedimentary Sequence of Araripe Basin, Northeastern Brazil**. Strati 2015. **Anais**...Graz: Berichte des Institutes für Erdwissenschaften der Karl-Franzens-Universität Graz, v. 21, p. 274, 2015

NEUMANN, V. H.; ROCHA, D. E. G. A. **Stratigraphy of the Post-Rift Sequences of the Jatobá Basin, Northeastern Brazil**. (R. Rocha et al., Eds.) Strati 2013 First International Congress on Stratigraphy At the Cutting Edge of Stratigraphy. **Anais**...Lisboa: Universidade Nova de Lisboa, Springer International Publishing Switzerland, p. 553–557, 2014

NEVES, S. P. Proterozoic history of the Borborema Province (NE Brazil): correlations with neighboring cratons and Pan-African belts and implications for the evolution of Western Gondwana. **Tectonics**, v. 22, n. 4, p. 1–14, 2003.

PIOVESAN, E. K.; GUZMÁN, J.; ALMEIDA-LIMA, D.; MELO, R. M. **Projeto ARTUNJA: correlações bioestratigráficas dos sistemas flúvio-lacustres das fases rifte e pós-rifte das bacias do Araripe, Jatobá e Tucano Norte, NE do Brasil**. Relatório interno processo ANP/PETROBRAS 2017/00263-2, p 87, 2021.

PONTE, F. C.; DAUZACKER, M. V; PORTO, R. **Origem e acumulação de petróleo nas bacias sedimentares brasileras**. Anais do Congresso Brasileiro de Petróleo. **Anais**...Rio de Janeiro: v. 2, p. 121–146, 1978

PONTE, F. C.; PONTE FILHO, F. C. **Estrutura geológica e evolução tectônica da Bacia do Araripe.** Recife DNPM, 1996.

POROPAT, S. F.; COLIN, J. P. Early Cretaceous ostracod biostratigraphy of eastern Brazil and western Africa: An overview. **Gondwana Research**, v. 22, n. 3–4, p. 772–798, 2012.

PRADO, L. A. C. DO; CALADO, T. C. DOS S.; BARRETO, A. M. F. New records of shrimps from the Lower Cretaceous Romualdo Formation, Araripe Basin, northeastern Brazil, with new taxa of Penaeoidea (Crustacea: Decapoda: Dendrobranchiata). **Cretaceous Research**, v. 99, p. 96–103, 2019.

PRADO, L. A. C. DO; FAMBRINI, G. L.; BARRETO, A. M. F. Tafonomy of macroinvertebrates and Albian marine ingression as recorded by the Romualdo Formation (Cretaceous, Araripe Basin, Brazil). **Brazilian Journal of Geology**, v. 48, n. 3, p. 519–531, 2018.

PRADO, L. A. et al. New brachyuran crabs from the Aptian–Albian Romualdo Formation, Santana Group of Brazil: Evidence for a Tethyan connection to the Araripe Basin. **Acta Palaeontologica Polonica**, v. 63, n. 4, p. 737–750, 2018.

PROSSER, S. Rift-related linked depositional systems and their seismic expression. In: WILLIAMS, G. D.; DOBB, A. (Eds.). **Geological Society of London Special Publication**. 71. ed. [s.l.] Lyell Collection, 1993. v. 71, p. 35–66.

REGALI, M. DA S. P.; VIANA, C. F. **Sedimentos do Neojurássico-Eocretáceo do Brasil: idade e correlação com a escala internacional**. Rio de Janeiro: Petrobras, p 95, 1989.

SANTOS, C. F.; CUPERTINO, J. A.; BRAGA, J. A. Síntese sobre a geologia das bacias do

Recôncavo, Tucano e Jatobá. In: RAJA GABAGLIA, G. P.; MILANI, E. J. (Eds.). **Origem e evolução de bacias sedimentares**. Rio de Janeiro: Petrobras, 1990. p. 235–266.

SCHALLER, H. Revisão estratigráfica da Bacia de Sergipe/Alagoas. **Boletim Técnico da Petrobras**, v. 12, n. 1, p. 21–86, 1969.

SCHERER, C. M. DOS S. et al. Tectono-stratigraphic evolution of the Upper Jurassic-Neocomian rift succession, Araripe Basin, Northeast Brazil. **Journal of South American Earth Sciences**, v. 49, p. 106–122, 2014.

SILVA-TELLES JR., A. C.; VIANA, M. S. S. **Paleoecologia dos ostracodes de Formação Santana (Bacia do Araripe): um estudo ontogenético de populações**. 1 Simpósio sobre a Bacia do Araripe e Bacias interiores do Nordeste, Crato. **Anais**...Crato: DNPM/SBP/SBG, p. 309–322, 1990

TOMÉ, M. E. T. R.; LIMA FILHO, M. F.; NEUMANN, V. H. M. L. Taxonomic studies of non-marine ostracods in the Lower Cretaceous (Aptian-lower Albian) of post-rift sequence from Jatobá and Araripe basins (Northeast Brazil): Stratigraphic implications. **Cretaceous Research**, v. 48, p. 153–176, 2014.

VALLEJO, J.D. et al. Palynofacies analyses of Santana Group, Upper Aptian of the Araripe Basin, northeast Brazil: paleoenvironmental Reconstruction. **Journal of South American Earth Science**, v. 121, 104154, 2023.

VAN SCHMUS, W. R. et al. Proterozoic links between the Borborema Province. NE Brazil, and the Central African Fold Belt. In: PANKHURST, R. J. et al. (Eds.). . **West Gondwana: Pre-Cenozoic Correlations Across the South Atlantic Region**. 294. ed. [s.l.] Geological Society. Special Publications, p. 69–99, 2008.

VAREJÃO, F. G. et al. Upper Aptian mixed carbonate-siliciclastic sequences from Tucano Basin, Northeastern Brazil: Implications for paleogeographic reconstructions following Gondwana break-up. **Cretaceous Research**, v. 67, p. 44–58, 2016.

______. et al. Microbialite fields developed in a protected rocky coastline: The shallow carbonate ramp of the Aptian Romualdo Formation (Araripe Basin, NE Brazil). **Sedimentary Geology**, v. 389, p. 103–120, 2019.

______. et al. Mixed siliciclastic–carbonate sedimentation in an evolving epicontinental sea: Aptian record of marginal marine settings in the interior basins of north-eastern Brazil.

Sedimentology, v. 68, n. 5, p. 2125–2164, 2021.

VAZ, P. T. et al. Bacia do Parnaíba. **Boletim de Geociências da Petrobras**, v. 15, n. 2, p. 253–263, 2007.

VIANA, C. F. et al. Revisão estratigráfica da Bacia Recôncavo/Tucano. **Boletim Técnico da Petrobrás**, v. 14, n. 3/4, p. 157–192, 1971.

APÊNDICE A - ARTIGO PUBLICADO NA *REVUE DE MICROPALÉONTOLOGIE*

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Research paper

Aptian ostracods from the Santana Group, Araripe Basin, Brazil[☆,☆☆]

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A R T I C L E I N F O

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A B S T R A C T

The Class Ostracoda provides a well preserved and diverse microfossil succession throughout the Aptian Santana Group, Araripe Basin, Brazil. The Santana Group, consisting of the Barbalha, Crato, Ipubi and Romualdo formations, records the post-rift sequence (Alagoas local stage) of the Gondwana break-up. The Alagoas Stage is characterised by ostracods grouped as *Cytheridea*? spp. 201–218 of which several have been identified as belonging to *Pattersoncypris* Bate and *Damonella* Anderson. From 2 well cores and 10 outcrops of the Santana Group, 25 taxa were identified, 5 of which are here newly described. Throughout the Santana Group, *Pattersoncypris micropapillosa* Bate and *Damonella grandiensis* Tomé, Lima Filho and Neumann were recovered. Restricted to the Barbalha Formation, *Candonopsis*? *alagoensis* Tomé, Lima Filho and Neumann and *Pattersoncypris cucurves* nov. sp are abundant. The Crato Formation shows higher ostracod diversity with *Damonella grandiensis* being the most abundant and associated with *Cypridea araripensis* Silva, *Brasacypris subovatum* Do Carmo, Coimbra, Whatley, Antonietto and Citon, *Damonella pumila* nov. sp., *Pattersoncypris alta* (Antonietto, Gobbo, Do Carmo, Assine, Fernandes and Silva), *Zonocypris berthoui* Piovesan, Melo, Cabral and Guzmán, *Zonocypris dorsoconvexa* Piovesan, Melo, Cabral and Guzmán, *Ilyocypris coimbrai* nov. sp., *Neuquenocypris berthoui* Colin and Dépêche, *Neuquenocypris* sp., *Rhinocypris spinata* nov. sp., *Theriosynoecum silvai* (Silva), *Theriosynoecum* sp., *Timiriasevia*? sp. and *Alicenula martinsi* (Silva). The Ipubi and Romualdo formations record abundant *Pattersoncypris crepata* (Do Carmo, Coimbra, Whatley, Antonietto and Citon) in association with *P. alta, Pattersoncypris kroemmelbeini* nov. sp., *P. symmetrica* (Krömmelbein and Weber) and *Alicenula martinsi* (Silva). *Theriosynoecum colini* Do Carmo, Coimbra, Whatley, Antonietto and Citon, *Ilyocypris coimbrai* nov. sp. and *Rhinocypris spinata* nov. sp. also occur in the Ipubi Formation.

RÉSUMÉ: La Classe Ostracoda présente une représentation fossile bien conservée et diversifiée au long du Groupe Santana, Aptien, Bassin d'Araripe, Brésil. Le Groupe Santana, constitué des formations Barbalha, Crato, Ipubi et Romualdo, enregistre la séquence post-rift (étage local Alagoas) de la rupture du Gondwana. L'Étage Alagoas est caractérisé par des ostracodes regroupés à l'instar de *Cytheridea*? spp. 201–218, dont certains ont été identifiés comme appartenant aux genres *Pattersoncypris* Bate et *Damonella* Anderson. Des deux carottes de sondage et dix affleurements du Groupe Santana, vingt-cinq taxons ont été identifiés et cinq d'entre eux ont été décrits. Au long du Groupe Santana, *Pattersoncypris micropapillosa* Bate et *Damonella grandiensis* Tomé, Lima Filho and Neumann ont été récupérés. Bien que limité à la Formation Barbalha, *Candonopsis*? *alagoensis* Tomé, Lima Filho and Neumann et *Pattersoncypris cucurves* nov. sp. ont été abondants. La Formation Crato montre une grande diversité, et, *Damonella grandiensis*, qui est la plus abondante, est associée à *Cypridea araripensis* Silva, *Brasacypris subovatum* Do Carmo, Coimbra, Whatley, Antonietto and Citon, *Damonella pumila* nov. sp., *Pattersoncypris alta* (Antonietto, Gobbo, Do Carmo, Assine, Fernandes and Silva), *Zonocypris berthoui* Piovesan, Melo, Cabral and Guzmán, *Zonocypris dorsoconvexa* Piovesan, Melo, Cabral and Guzmán, *Ilyocypris coimbrai* nov. sp., *Neuquenocypris berthoui* Colin and Dépêche, *Neuquenocypris* sp., *Rhinocypris spinata* nov. sp., *Theriosynoecum silvai* (Silva), *Theriosynoecum* sp.,

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[☆] Mots clés

[☆☆] Ostracoda; *Pattersoncypris*; *Damonella*; *Ilyocypris*; *Rhinocypris*; Étage Alagoas

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Timiriasevia? sp. et *Alicenula martinsi* (Silva). Les formations Ipubi et Romualdo enregistrent une abondance de *Pattersoncypris crepata* (Do Carmo, Coimbra, Whatley, Antonietto and Citon) en association avec *P. alta, Pattersoncypris kroemmelbeini* nov. sp., *P. symmetrica* (Krömmelbein and Weber) et *Alicenula martinsi. Theriosynoecum colini* Do Carmo, Coimbra, Whatley, Antonietto and Citon, *Ilyocypris coimbrai* nov. sp. et *Rhinocypris spinata* nov. sp se produisent également dans le Formation Ipubi.

1. Introduction

Ostracods have been extensively studied since the late fifties from basins along the coasts of the South Atlantic Ocean. The first works of Ostracoda in Brazil and Africa identified several genera and species (Grosdidier, 1967; Krömmelbein, 1965, 1962; Krömmelbein and Weber, 1971; Pinto and Sanguinetti, 1958; Viana, 1966; Wicher, 1959), leading to the establishment of the Mesozoic biostratigraphic frameworks of West African and East Brazilian basins (Moura, 1988; Moura and Praça, 1985; Schaller, 1969; Tambareau, 1982; Viana et al., 1971).

In Brazil, rift-type interior basins record the evolution of the West Gondwana break-up, divided mainly into three tectono-stratigraphic stages: the early rift, rift climax and post-rift (see Ponte and Asmus, 1976; Chang et al., 1992; Kuchle and Scherer, 2010; Scherer et al., 2014). From the early rift stage, ostracods mainly belonging to *Theriosynoecum* Branson, 1936 and from the rift climax stage, *Cypridea* Bosquet, 1852 and *Paracypridea* Swain, 1946 are the most dominant. The post-rift stage is characterised by abundant non-ornamented ostracods that initially were grouped by Schaller (1969) as *Cytheridea*? spp. 201–218 and up to current date, several of these have been assigned to the genera *Damonella* Anderson, 1966 and *Pattersoncypris* Bate, 1972.

The Araripe Basin in northeast Brazil (Fig. 1) is known by the well preserved and abundant Cretaceous fossils of the Santana Group, recording such macro- and microfossils, as dinosaurs and pterosaurs (Kellner and Campos, 2002; Sayão et al., 2020a,b; Bantim et al., 2021), foraminifers and ostracods (Melo et al., 2020; Araripe et al., 2021), plants (Lima et al., 2012; Mohr et al., 2007; Sucerquia et al., 2015), terrestrial and marine palynomorphs (Arai and Assine, 2020; Goldberg et al., 2019; Teixeira et al., 2017), insects (Silva and Arruda, 1976; Dos Santos et al., 2021) and fishes (Brito and Yabumoto, 2011) among other groups. The Santana Group consists of, the Barbalha, Crato, Ipubi and Romualdo formations from base to top (Assine et al., 2014), with the Crato and Romualdo formations corresponding to two Cretaceous *Konservat-Laggerstätten*.

The Class Ostracoda provides an excellently preserved and diverse fossil biota throughout the Santana Group. Species initially attributed to the *Cytheridea*? spp. 201–218 group were formally described from this unit during the seventies, as *Pattersoncypris angulata* (Krömmelbein and Weber, 1971), *P. salitrensis* (Krömmelbein and Weber, 1971), *P. sinuata* (Krömmelbein and Weber, 1971), *P. symmetrica* (Krömmelbein and Weber, 1971) and *P. micropapillosa* Bate, 1972 with preserved appendages and eggs (Bate, 1972; Smith, 2000). Other associated ostracod species represented by *Theriosynoecum silvai* (Silva, 1978), *Alicenula martinsi* (Silva, 1978) and *Cypridea araripensis* Silva, 1978 were also described during the same decade. From 1990 onwards, studies on taxonomy of ostracods from the Santana Group, Araripe Basin resulted in the proposal of many other taxa (Berthou et al., 1994; Colin and Dépêche, 1997; Silva-Telles Jr. and Viana, 1990; Tomé et al., 2014), allowing a more complete record of ostracod assemblage for the post-rift sequence of the basin and its correlation with other Brazilian and African basins (Coimbra et al., 2002; Poropat and Colin, 2012a; Tomé et al., 2014). Nevertheless, the abundance of ostracods possessing a smooth or subtle ornamented carapaces and similar outlines from the post-rift strata of the Santana Group, Araripe Basin have left many taxa under open nomenclature leading to an underestimate of the diversity and poorly refined biostratigraphic framework of the Aptian RT-011 Biozone (Alagoas Local Stage). The present manuscript presents a taxonomic update of the ostracod record of the Santana Group of the Araripe Basin, including 25 taxa of which 5 are newly described, which in future studies will expectedly improve the biostratigraphy of the Alagoas Local Stage.

2. Stratigraphical background of the Santana group

The Araripe Basin in the Borborema Province (BP) of northeast Brazil, is elongated in the E–W direction (Fig. 1) and is the most extensive of the basins located south of the E–W Patos Shear Zone. The Santana Group corresponds to the local Alagoas Stage (Aptian) record of the Araripe Basin. Its deposition is related to the first post-rift tectono-stratigraphic stage of the Gondwana break-up in northeast Brazil. Continental and coastal to marine deposits constitute the Santana Group, which from base to top include the Barbalha, Ipubi, Crato and Romualdo formations (Assine et al., 2014; Custódio et al., 2017; Varejão et al., 2021).

The Barbalha Formation, with an average thickness of about 200 m, can be subdivided into two large fining-upward cycles. It is essentially composed of fluvial sandstones, and also encompasses an important interbedded lacustrine pelitic interval known as Batateira Beds (Assine, 2007; Assine et al., 2014). The two depositional sequences in the Barbalha Formation reflect a variation in the accommodation-to-sediment supply ratio, characterised within each sequence by amalgamated channel-fill beds (low-accommodation system tract) at the base that pass upwards into floodplain-dominated and lacustrine successions (high-accommodation system tract) (Scherer et al., 2015). The fluvial deposition in the lower sequence, which is associated with ephemeral river systems, is separated from the upper sequence of perennial systems by an erosive unconformity formed during a period of stratigraphic base-level lowering (Fambrini et al., 2019). The sandstone layers of the Barbalha Formation upper sequence progressively become thinner to the top, representing delta systems that prograde to unstable shallow lakes with shale deposition (Assine et al., 2014). According to Varejão et al. (2021), the presence of dinoflagellates and marine ichnotaxa evidence marine deposition in bayhead delta settings for the Barbalha Formation.

The Crato Formation represents a fully established paleolake with a carbonate depocenter in a constant expansion; it is constituted by six rhythmite limestone-claystone shoals (C1–C6) interspersed with shales forming a 50-70 m-thick lacustrine complex (Neumann and Cabrera, 1999; Neumann, 1999). The Crato Formation limestones represent a transgressive surface followed by tide-dominated bay deposits with distinct subtidal, intertidal and supratidal portions recorded (Varejão et al., 2021). Overlying the sediments of the Crato Formation, evaporite lenses in association with green and black shales of up to 30 m-thick composed the Ipubi Formation and record extreme aridity conditions in the Araripe Basin (Assine et al., 2014). Dark shale of below foreshore to shoreface facies marks the commencement of the maximum flooding surface of the highstand systems tract that culminates with the final deposition of the Ipubi Formation evaporites in a supralittoral zone of coastal sabkha type (Varejão et al., 2021). An allocyclic process associated with combined climatic, tectonic and eustatic variations resulted in fluctuating continental and marine sedimentation conditions. This depositional sequence encompasses the previous units in which marine ingressions are linked to siliciclastic-dominated deposits, while carbonate-dominated successions record deposition in freshwater to hypersaline water bodies (Varejão et al., 2021).

The upper unit of the Santana Group, the Romualdo Formation, either disconformably overlies the Ipubi and Crato formations, or rests nonconformably on Precambrian basement to the west of the Araripe

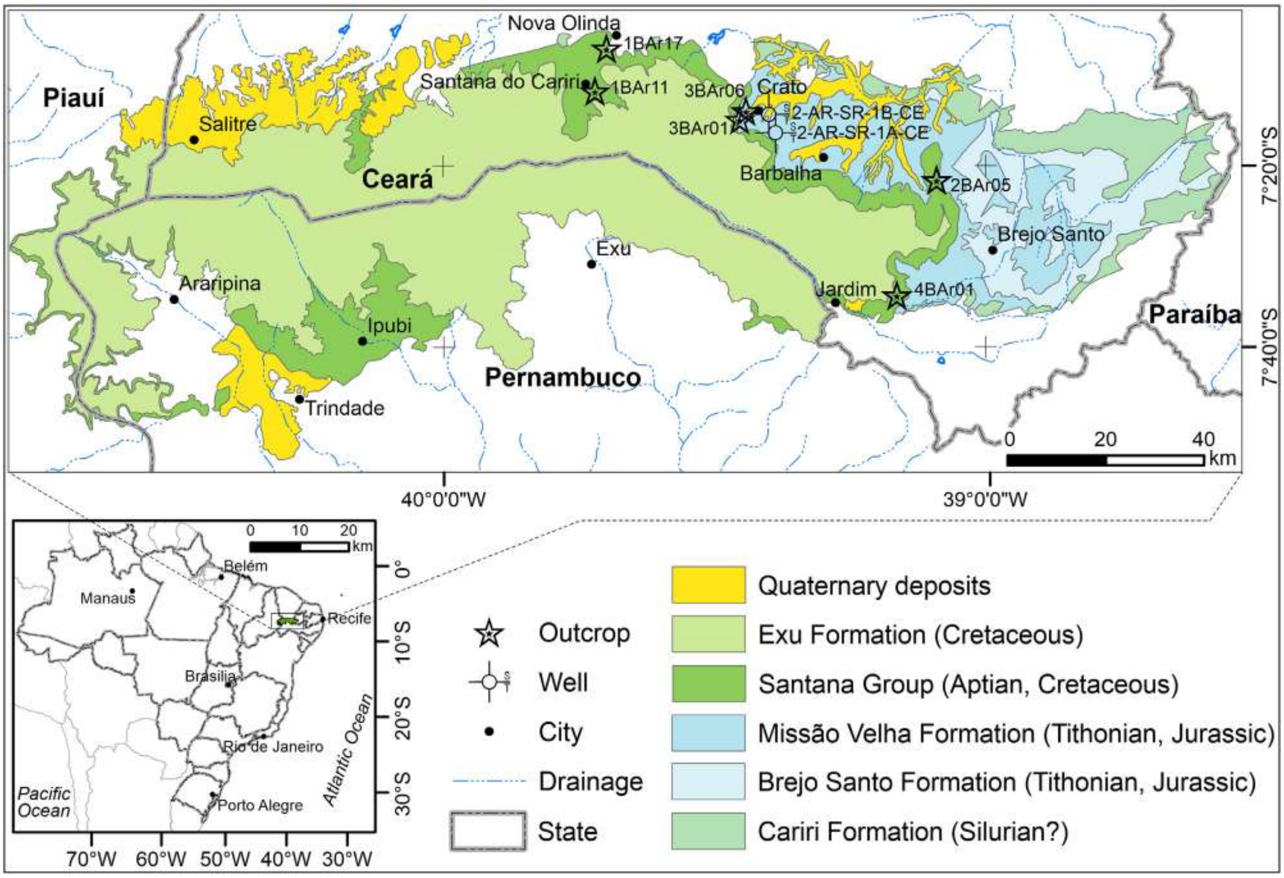

Fig. 1. Geological map of the Araripe Basin created using ESRI ArcMap v.10.3 software (https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview) with metadata acquired from the online Geosciences Service of the Geological Service of Brazil-CPRM.

Basin (Custódio et al., 2017). Well established marine conditions in the basin are represented by sediments of the Romualdo Formation that is characterised by stratified conglomerates, sandstones, limestones, marls and shales (Assine et al., 2014). According to Custódio et al. (2017), the Romualdo depositional sequence comprises a transgressive-regressive cycle with depositional dip towards the southeast, decreasing in thickness towards northwest, and with source areas located at the northern side of the basin. To the east of the basin, the facies associations recorded are related to a deepening-upward sequence on a mixed siliciclastic-carbonate marine ramp (Melo et al., 2020), whereas to the west, the facies associations indicate a rocky-protected lagoon (Varejão et al., 2019), thus corroborating a low-gradient ramp marine environment, that deepens to the east of the Araripe Basin.

3. Material and methods

A total of 88,862 ostracods were recovered from 218 samples collected from two well cores and ten outcrops from Araripe Basin (AR), northeast Brazil (Fig. 1). Samples were collected based on the lithology, with intervals of 1 m between samples along sandstones, and intervals of approximately 10 cm in mudstones, shales and carbonates. The well cores were drilled at the Romualdo Farm (SR), Crato Municipality, Ceará (CE) State, Brazil (Table 1). The 2-AR-SR-1A-CE well core with an altitude of 541 m reached a depth of 141 m and cuts across the Romualdo, Ipubi, Crato and the Barbalha formations of the Santana Group (Fig. 2A); it yielded 65,541 ostracods recovered from 170 samples. The 2-AR-SR-1B-CE well core with an altitude of 525 m reached a depth of 109 m and cuts across the base of the Crato Formation and Barbalha Formation (Fig. 2B), with 8644 ostracods recovered from 18 samples.

The outcrop samples were obtained from five localities in the Ceará State (Table 1). The outcrop 1BAr11 corresponds to the Conceição Preta Quarry, Ipubi Formation gypsum (Fig. 2C); the outcrop 1BAr17 corresponds to the Três Irmãos Quarry, Crato Formation limestone (Fig. 2D). The outcrops 2BAr04 and 2BAr05 (Fig. 2E) are located near the top of the Serra do Mãozinha hill and correspond to the Romualdo Formation and Crato Formation, respectively. The outcrops 3BAr01–3BAr06 (Fig. 2F), which correspond to the Barbalha Formation from the Batateira Beds up to the contact with the Crato Formation, are located along the Batateira River. The outcrop 4BAr01 (Fig. 2G) is at a farm widely known as the Sítio Sobradinho section of the Romualdo Formation. A total of 14,677 ostracods were recovered from 30 samples of outcrops.

The rock samples were completely processed at the Applied Micropalaeontology Laboratory (LMA) of the Federal University of Pernambuco (UFPE), where the ostracod specimens are deposited. An average of 60 g of each sample was broken into small (millimetre sized) pieces and submerged in water for 24 h. Each sample was then washed through a set of sieves with meshes of 500, 250, 180 and 63 μm. Each fraction of sample was dried in an oven at 50 °C for 24 h. Aiming to identify the adult ostracod specimens, the 250 and 180 μm fractions were analysed using a stereomicroscope Zeiss Stemi-305 and the ostracod specimens were picked out and transferred to micropaleontological slides. After previous recognition of the morphotypes, the specimens with the best preservation were selected for image acquisition in the SEM (Scanning Electron Microscope) Phenom XL. The 500 and 63 μm fractions of samples bearing unidentified morphotypes were analysed to pick out specimens for an ontogeny reconstitution and description of the new species. The illustrated specimens are deposited in the calcareous microfossils collection of the LMA under the numbers LMA-00042,

Table 1
Sampling locations, geographic coordinates, geologic units and municipalities.

Well core/Outcrop	Coordinates S	W	Formation	Municipality
2-AR-SR-1A-CE	7°17’29.88”	39°23’34.84”	Romualdo/Ipubi/Crato	Crato
2-AR-SR-1B-CE	7°15’28.44”	39°24’20.78”	Crato/Barbalha	Crato
1BAr11	7°6’58.6”	39°40’44.33”	Crato	Santana do Cariri
1BAr17	7°7’2.28”	39°41’51.39”	Crato	Nova Olinda
2BAr04	7°21’27.73”	39°5’28.56”	Romualdo	Abaiara
2BAr05	7°21’35.61”	39°5’23.93”	Crato	Abaiara
3BAr01	7°14’1.28”	39°26’30.41”	Barbalha	Crato
3BAr02	7°14’4.72”	39°26’38.05”	Barbalha	Crato
3BAr03	7°14’5.53”	39°26’40.01”	Barbalha	Crato
3BAr05	7°14’51.91”	39°27’8.22”	Barbalha	Crato
3BAr06	7°14’53.70”	39°27’10.90”	Crato	Crato
4BAr01	7°34’18.42”	39°48.42”	Romualdo	Jardim

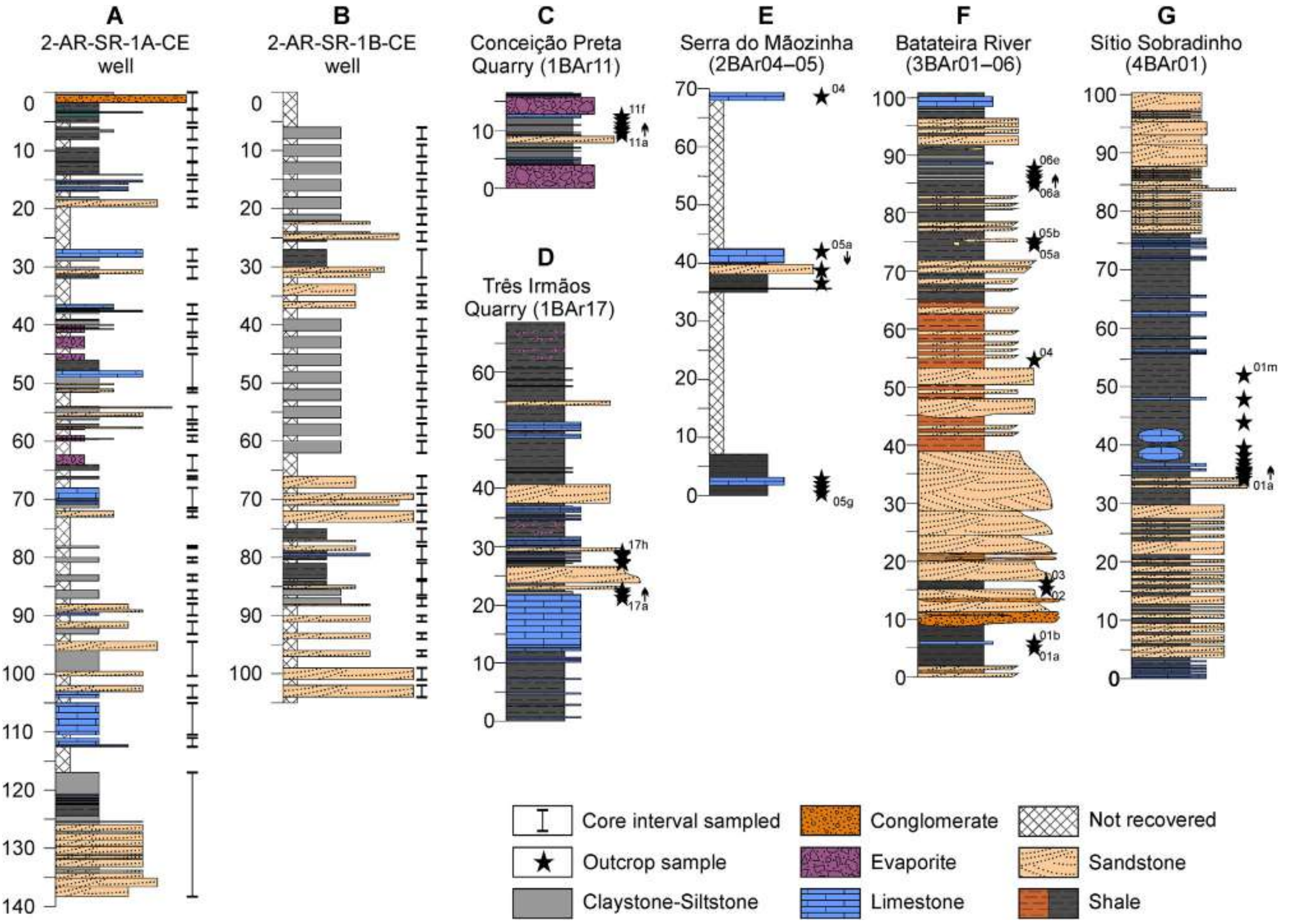

Fig. 2. Lithological profiles of well cores and outcrops (in meters) of the Santana Group, Araripe Basin, Brazil showing the intervals sampled from cores and the samples collected from outcrops. **A,** 2-AR-SR-1A-CE well core. **B,** 2-AR-SR-1A-CE well core. **C,** Conceição Preta Quarry, 1BAr11 outcrop, Ipubi Formation. **D,** Três Irmãos Quarry, 1BAr17 outcrop, Crato Formation. **E,** Composite profile containing the 3BAr01–3BAr06 outcrops along the Batateira River, Barbalha Formation up to the contact with the Crato Formation. **F,** Composite profile containing the 2BAr04 and 2BAr05 outcrops at Serra do Mãozinha hill, Crato Formation and to the top the Romualdo Formation. **G,** Sítio Sobradinho section, 4BAr01 outcrop, Romualdo Formation. (C–G) Outcrop profiles adapted from Assine et al. (2014), Custodio et al. (2017) and Varejão et al. (2020; 2021). The black arrow indicates the vertical direction of sampling in each outcrop.

LMA-00279 to LMA-00320, LMA-322 to LMA-00330, and LMA-00335 to LMA-00340.

4. Systematic palaeontology

The suprageneric taxonomy adopted in this work follows Liebau (2005). According to Horne (2005), adult ostracods are typically of 0.5–2.0 mm length; however, smaller as well as larger specimens do exist. Here we consider small sized adult ostracods are those of < 0.7 mm length, median size are those between 0.7 and 1.5 mm length and large those with a length > 1.5 mm. Twenty-five ostracod taxa recorded from the Santana Group, Araripe Basin, Ceará State, Brazil and placed into seven families and twelve genera; of these, five new species are formally described and three are retained in open nomenclature.

Abbreviations: RV, right valve; LV, left valve; L, length; H, height; W, width.

Subclass OSTRACODA Latreille, 1802

Superorder PODOCOPOMORPHA Kozur, 1972

Order PODOCOPIDA Sars, 1866

Suborder CYPRIDOCOPINA Jones, 1901

Superfamily CYPRIDOIDEA Baird, 1845

Family CANDONIDAE Kaufmann, 1900

Subfamily CANDONINAE Kaufmann, 1900

Genus *Candonopsis* (Vavra, 1891) emend. Karanovic and Marmonier, 2002

Candonopsis? *alagoensis* Tomé, Lima Filho and Neumann, 2014 (Fig. 3A-C)

2010 *Mantelliana* sp. - Tomé and Lima Filho, p.56, pl.2, fig.g-i.

2014 *Candonopsis alagoensis* nov. sp. - Tomé Lima Filho and Neumann, p.168, fig.14D-F, 15A-C, 16A-C.

Material: More than 1400 carapaces, comprising both adults and juveniles.

Dimensions: LMA-00279, juvenile A-1, L: 0.85 mm, H: 0.49 mm, W: 0.36 mm (Fig. 3A-C).

Occurrence: Batateira beds, Barbalha Formation, Santana Group, Araripe Basin. 2-AR-SR-1B-CE well core samples, depth interval 79.37–79.78 m. Outcrop sample 3BAr01b (Batateira River).

Stratigraphic and geographic distribution: Aptian, Batateira beds, Barbalha Formation (Tomé et al., 2014; this study), Araripe Basin, Crato and Missão Velha municipalities, Ceará State, Brazil. Aptian, Crato Formation, Cedro Basin, Cedro Municipality, Pernambuco State, Brazil (Tomé and Lima Filho, 2010; Tomé et al., 2014). Aptian, Crato Formation, Jatobá Basin, Serra Negra hill, Ibimirim Municipality, Pernambuco State, Brazil (Tomé et al., 2014).

Remarks: The assignation of this species in the genus *Candonopsis* is just possible with reservations. Vavra (1891) described the genus *Candonopsis* including some species previously assigned to the genus *Candona* Baird, 1846; both Recent genera were described from soft tissues, not preserved within the carapaces of the Cretaceous *C.*? *alagoensis* specimens. Moreover, the general outline of Recent *Candonopsis* is ellipsoidal, whilst our specimens display a subtrapezoidal outline. Thus, the morphotypes attributed to *Candonopsis*? *alagoensis* should be reallocated into a new genus in further studies. Although, Tomé et al. (2014) indicates that *Candonopsis*? *alagoensis* occurs in strata of the Crato Formation, from Cedro (Cedro Municipality, Pernambuco State) and Jatobá (Serra Negra hill, Ibimirim Municipality, Pernambuco State) basins, it is probable that these strata correspond to the Barbalha and Marizal formations, respectively. Also as reported by Tomé et al. (2014), individuals recovered from the Sergipe-Alagoas Basin (lithological unit not specified) and now stored in the Krömmelbein and Weber collections of the Senckenberg Museum, Germany, but were not officially described, could be assigned to *Candonopsis*? *alagoensis*.

Family CYPRIDEIDAE Martin, 1940 emend. Sames, 2011

Genus *Cypridea* Bosquet, 1852 emend. Sames, 2011

Cypridea araripensis Silva, 1978 (Fig. 3D–F)

1978a *Cypridea araripensis* nov. sp. - Silva, p.1023, pl.1, –.

1990 *Cypridea araripensis* Silva - Silva-Telles Jr. and Viana, pl.2, fig.5.

1994 *Cypridea araripensis* Silva - Berthou et al., pl.1, fig.1–4.

1997 *Cypridea araripensis* Silva - Colin and Dépêche, fig.2.16.

2002 *Cypridea araripensis* Silva - Coimbra et al., fig.4.33.

2013 *Cypridea araripensis* Silva - Do Carmo et al., p.92, fig.3.1-3.2.

2014 *Cypridea araripensis* Silva - Tomé et al., p.156, fig.7A-E, fig.8B-C.

Material: A total of 20 specimens of complete adult and juvenile carapaces and fragments were recovered.

Dimensions: LMA-00280, adult, L: 0.88 mm, H: 0.5 mm, W: 0.34 mm (Fig. 3D–F).

Occurrence: Crato, Ipubi and Romualdo formations, Santana Group, Araripe Basin. 2-AR-SR-1A-CE well core samples, depth intervals 15.76–15.79 m, 54.40–54.43 m, 57.13–57.15 m, 106.84–106.87 m, 120.47–120.50 m, 122.93–122.97 m, 124.30–124.58 m and 137.52– 137.55 m. Outcrop samples 1BAr17b (Três Irmãos Quarry), and 3BAr06b–c (Batateira River).

Stratigraphic and geographic distribution: Aptian, Romualdo Formation (Coimbra et al., 2002; this study), Ipubi Formation (Coimbra et al., 2002; this study) and Crato Formation (Silva, 1978a; Silva-Telles and Viana, 1990; Colin and Dépêche, 1997, Coimbra et al., 2002; this study), Araripe Basin, Ceará, Brazil. Crato Formation, Jatobá Basin, Serra Negra hill, Ibimirim, Pernambuco, Brazil (Tomé et al., 2014). Mid-upper Aptian, Alagamar Formation, Potiguar Basin, Rio Grande do Norte and Ceará states, Brazil (Do Carmo et al., 2013).

Family CYPRIDIDAE Baird, 1845

Genus *Brasacypris* Krömmelbein, 1965

Brasacypris subovatum Do Carmo, Coimbra, Whatley, Antonietto and Citon, 2013 emend. Guzmán, Almeida-Lima and Piovesan (Fig. 4A–H)

1990 Gen. indet. sp. D - Silva-Telles Jr. and Viana, pl.III, fig.1-2.

2013 *Brasacypris subovatum* nov. sp. - Do Carmo, Coimbra, Whatley, Antonietto and Citon, p.97, fig.5.10-5.11.

Original diagnosis: Large, subrectangular to ovate in lateral view. The left valve overlaps the right along the free margin. The maximum width occurs at posterior one third of length.

Emended diagnosis: A very large, well-calcified cypridoid with subrectangular to subovoid lateral outline and biconvex dorsal outline. Maximum width and maximum height just behind the mid-length.

Emended description: Carapace very large, of >2 mm length. Subrectangular to subovoid in lateral view, biconvex in dorsal and ventral views. Carapace surface smooth or finely punctate ornamentation. Maximum height just behind mid-length. Maximum length at mid-height, greatest width at posterior one third of length. Anterior end lower than the posterior. Left valve larger than right valve, overlapping it all around the margin, more pronounced at anterior and ventral margins. Ventral margin slightly convex. Dorsal margin convex, more inclined towards anterior end, which is almost symmetrically rounded. Posterior cardinal angle obtuse, posterior margin nearly straight joining the ventral outline at an almost right angle.

Material: A total of 116 carapaces of adults and juveniles were recovered.

Dimensions: LMA-00281, adult, L: 2.1 mm, H: 1.4 mm, W: 1.07 mm (Fig. 4A-D); LMA-00282, juvenile A-1, L: 1.9 mm, H: 1.3 mm, W: 0.69 mm (Fig. 4E); LMA-00283, juvenile A-3, L: 1.3 mm, H: 0.86 mm, W: 0.49 mm (Fig. 4F), LMA-00284, juvenile A-5, L: 1.05 mm, H: 0.63 mm, W: 0.36 mm (Fig. 4G); LMA-00285, juvenile A-6, L: 0.66 mm, H: 0.41 mm, W: 0.23 mm (Fig. 4H).

Occurrence: Crato Formation, Santana Group, Araripe Basin. 2-AR-SR-1A-CE well core samples, depth interval 120.39–123.18 m.

Stratigraphic and geographic distribution: Aptian, lower strata of Crato Formation, Araripe Basin, Ceará State, Brazil (this study). Mid-upper Aptian, Alagamar Formation, Potiguar Basin, Rio Grande do Norte and Ceará states, Brazil (Do Carmo et al., 2013).

Remarks: *Brasacypris subovatum* Do Carmo, Coimbra, Whatley, Antonietto and Citon, 2013, was described based on a juvenile specimen, comparable in size to our A-3 illustrated specimen (Fig. 4F). In our study, larger morphotypes including some subtly ornamented carapaces were recovered from the 500 μm mesh. For this reason, re-description of *Brasacypris subovatum* has been made. Do Carmo et al. (2013) pointed out that *Brasacypris subovatum* differs from *Brasacypris ovum* Krömmelbein (1965) by its more subrectangular outline in lateral view, nonetheless their description was not of an adult specimen. Our adults show a more subovoid to subrectangular outline, with a marked convexity approximately at mid-length of dorsal margin, at the carapace maximum height. Instars of *Brasacypris subovatum*, as the A-3 juvenile described by Do Carmo et al. (2013), display a more subrectangular outline in lateral view with a dorsal margin slightly convex. The adults of *Brasacypris subovatum* have the anterior end lower than the posterior, a feature that differentiates *B. subovatum* from *B. ovum*, which has a comparatively higher anterior region. *Brasacypris fulfaroi* Musacchio (2001) also differs from *B. subovatum* by the more subrectangular outline and presence of a relatively more pronounced cardinal angles.

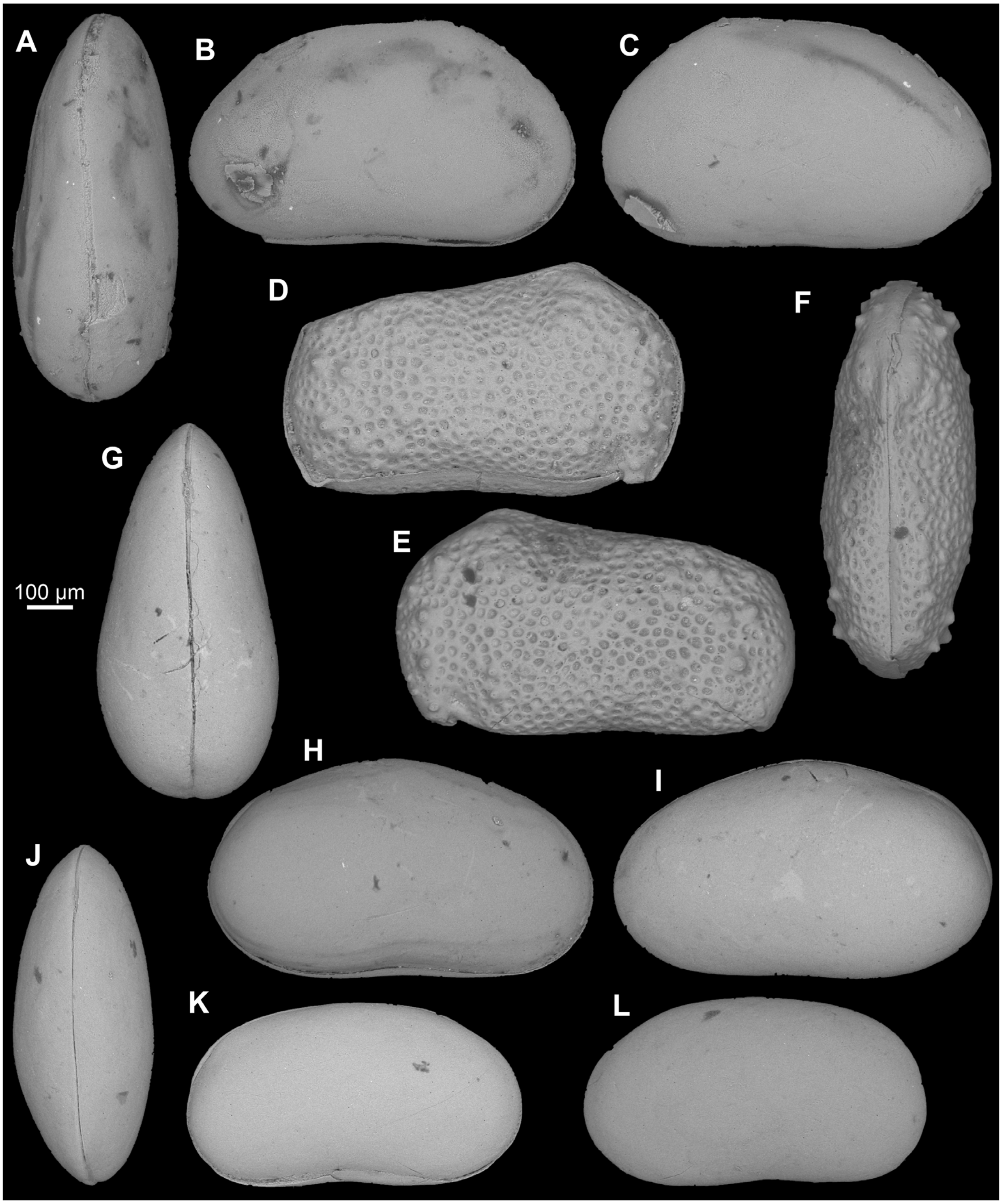

Fig. 3. Ostracod specimens of the Candonidae, Cyprideidae and Cyprididae. **A–C,** *Candonopsis*? *alagoensis*, LMA-00279 (well 2-AR-SR-1B-CE, sample 79.37 m), juvenile A-1, dorsal (A), right (B) and left (C) views. **D–F,** *Cypridea araripensis*, LMA-00280 (outcrop 3BArc6, sample c), adult, right (D), left (E) and dorsal (F) views. **G–I,** *Damonella grandiensis*, LMA-00286 (well 2-AR-SR-1A-CE, sample 121.17 m), adult, dorsal (G), right (H) and left (I) views. **J–L,** *Damonella grandiensis*, LMA-00287 (well 2-AR-SR-1A-CE, sample 124.22 m), juvenile A-1, dorsal (J), right (K) and left (L) views. (A–L) scale bar: 100 µm.

Genus *Damonella* Anderson, 1966

Damonella grandiensis Tomé, Lima Filho and Neumann, 2014 (Fig. 3G–L)

? 1990 Gen. indet. sp. C - Silva-Telles and Viana, pl.II, fig.10.

2002 Ostracod 207 - Coimbra et al., fig.4.31.

2006 *Candona* sp. - Ramos et al., p.344, fig.4Z-Z".

2010 *Damonella* sp. - Tomé and Lima Filho, pl.2, fig.a-c.

2013 *Candona* (?) sp. - Do Carmo et al., p.99, fig.5.12-5.14.

2014 *Damonella grandiensis* nov. sp. - Tomé, Lima Filho and Neumann, p.161, fig.10A-F, 11A-M.

Non 2021 *Damonella grandiensis* Tomé, Lima Filho and Neumann - Araripe et al., fig.5M-P.

Non 2022 *Damonella grandiensis* Tomé, Lima Filho and Neumann - Araripe et al., fig.5.10a-b.

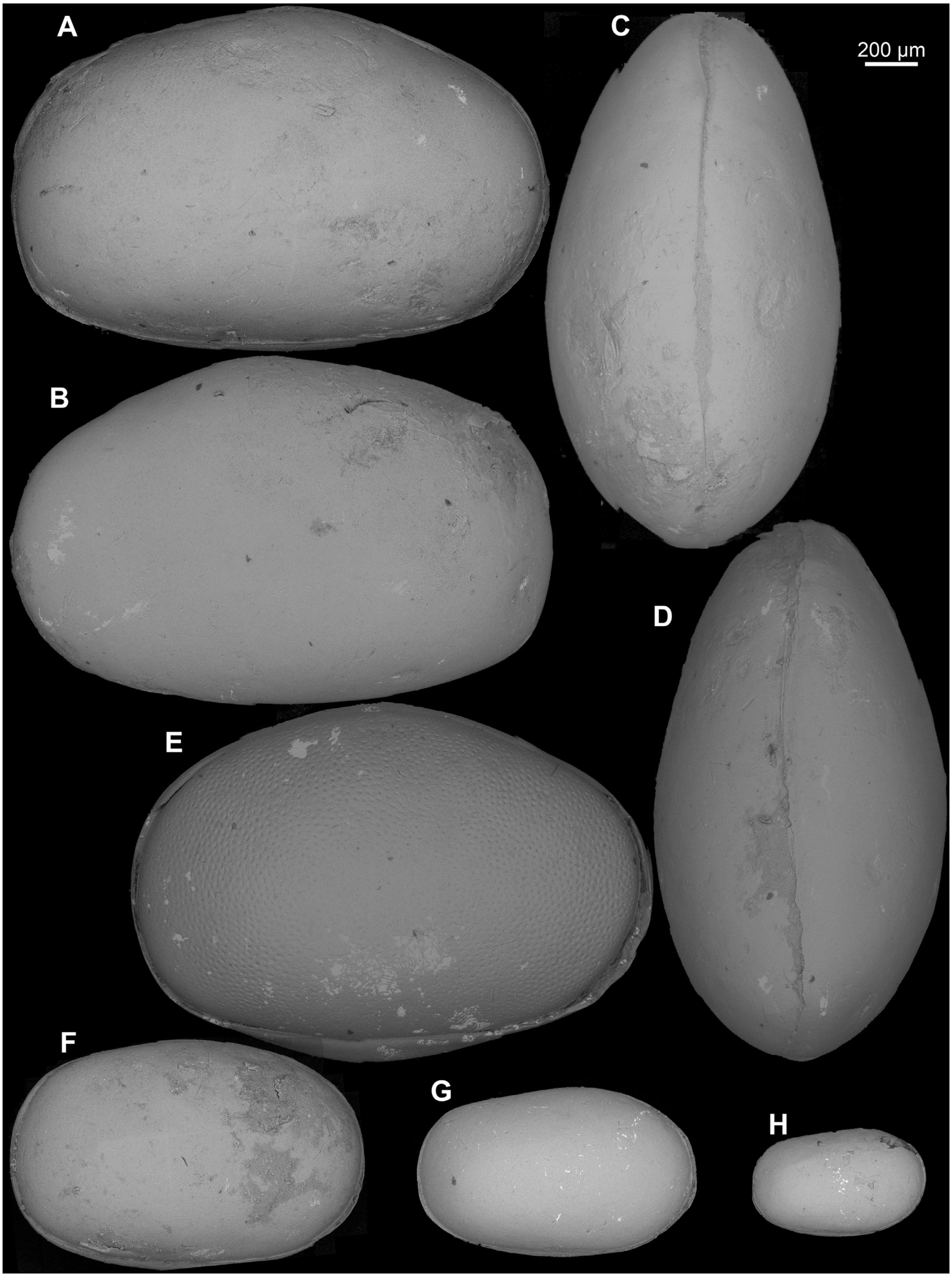

Fig. 4. *Brasacypris subovatum*. **A–D,** LMA-00281 (well 2-AR-SR-1A-CE, sample 121.05 m), adult, right (A), left (B), dorsal (C) and ventral (D) views. **E,** LMA-00282 (well 2-AR-SR-1A-CE, sample 120.39 m), juvenile A-1, right view. **F,** LMA-00283 (well 2-AR-SR-1A-CE, sample 121.05 m), juvenile A-3, right view. **G,** LMA-00284 (well 2-AR-SR-1A-CE, sample 121.05 m), juvenile A-5, right view. **H,** LMA-00285 (well 2-AR-SR-1A-CE, sample 121.05 m), juvenile A-6, right view. (A–H) scale bar: 200 µm.

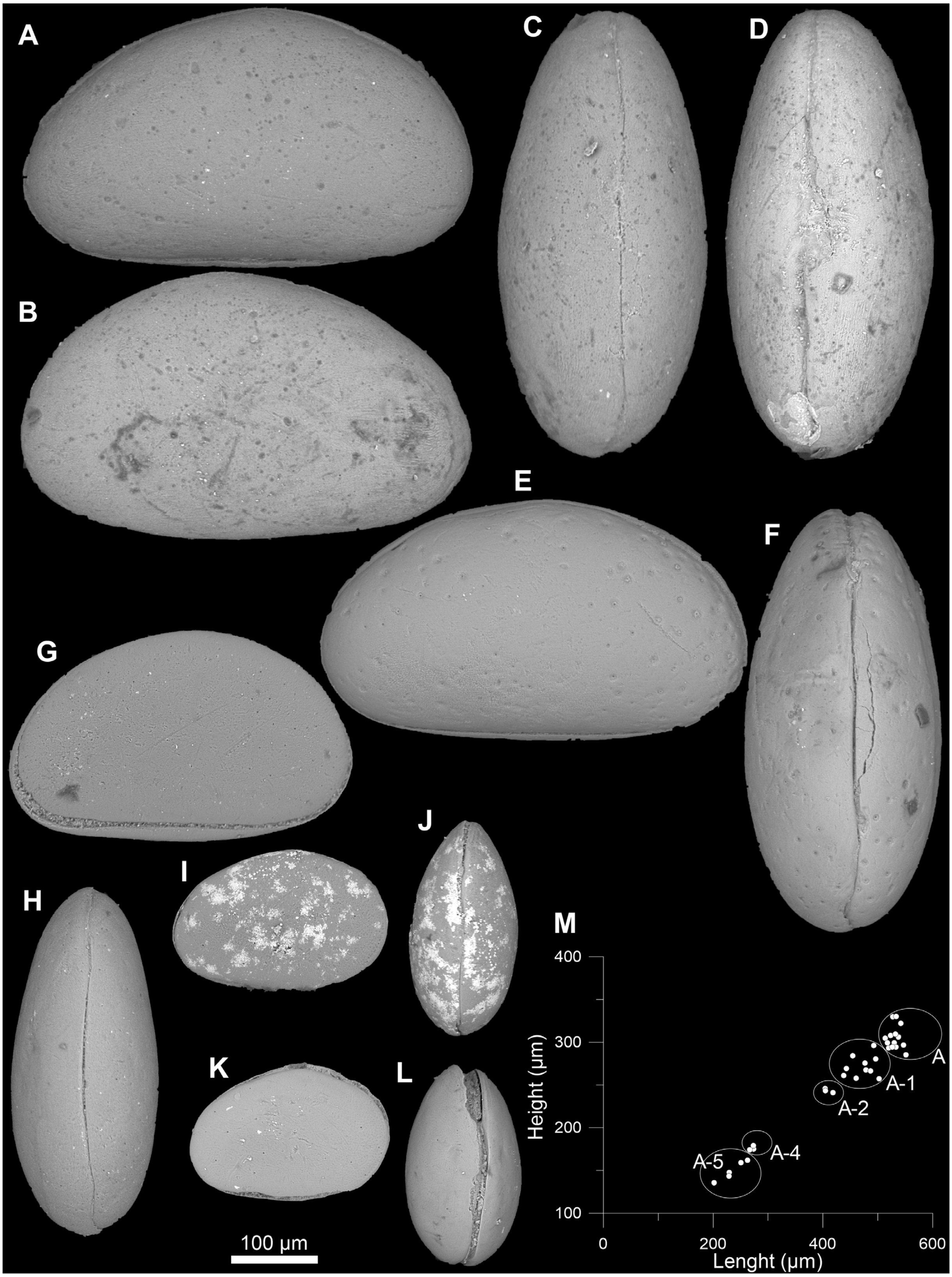

Fig. 5. *Damonella pumila* nov. sp. **A–D,** holotype, LMA-00288 (outcrop 3BAr06, sample d), adult, right (A), left (B), dorsal (C) and ventral (D) views. **E–F,** paratype 1, LMA-00322 (outcrop 2BAr05, sample f), juvenile A-1, right (E) and dorsal (F) views. **G–H,** paratype 2, LMA-00323 (well 2-AR-SR-1A-CE, sample 68.11 m), juvenile A-2, right (G) and dorsal (H) views. **I–J,** paratype 3, LMA-00324 (outcrop 3BAr06, sample d), juvenile A-4, right (I) and dorsal (J) views. **K–L,** paratype 4, LMA-00325 (outcrop 3BAr06, sample d), juvenile A-5, right (K) and dorsal (L) views. (A–L) scale bar: 100 µm. **M,** scatter plot of the length and height measurements of 35 carapaces of *Damonella pumila* nov. sp. showing clusters of A, A-1, A-2, A-4 and A-5 ontogenetic stages.

Non 2022 *Damonella grandiensis* Tomé, Lima Filho and Neumann - Tomé et al., p.542, fig.3P-R.

Material: More than 10,000 carapaces of adults and juveniles were recovered.

Dimensions: LMA-00286, adult, L: 0.83 mm, H: 0.47 mm, W: 0.41 mm (Fig. 3G-I); LMA-00287, juvenile A-1, L: 0.75 mm, H: 0.41 mm, W: 0.31 mm (Fig. 3J–L).

Occurrence: Barbalha, Crato, Ipubi and Romualdo formations, Santana Group, Araripe Basin. 2-AR-SR-1A-CE well core samples, depth intervals 12.97–13.76 m, 36.60–36.63 m, 39.52–39.55 m, 57.13–57.15 m, 64.37–64.40 m, 68.11–68.13 m, 69.67–70.85 m, 99.39–99.41 m, 112.50–112.52 m and 119.53–128.89 m. 2-AR-SR-1B-CE well core samples, interval depth 79.32–79.68 m. Outcrop samples 1BAr11f (Conceição Preta Quarry), 1BAr17a–b, e (Três Irmãos Quarry), 2BAr05a, d, f (Mãozinha hill), and 3BAr01b, 3BAr03a and 3BAr06b–e (Batateira River).

Stratigraphic and geographic distribution: Aptian, strata of Barbalha (Coimbra et al., 2002; this study), Crato (Coimbra et al., 2002; Tomé et al., 2014; this study), Ipubi (Coimbra et al., 2002; this study) and Romualdo (Coimbra et al., 2002; this study) formations, Santana Group, Araripe Basin, Ceará State, Brazil. Upper Aptian, Crato Formation, Cedro Basin, Cedro Municipality, Pernambuco State, Brazil (Tomé and Lima Filho, 2010). Upper Aptian, Codó Formation, Grajaú Basin, Codó Municipality, Maranhão State, Brazil (Ramos et al., 2006). Mid-upper Aptian, Alagamar Formation, Potiguar Basin, Rio Grande do Norte and Ceará states, Brazil (Do Carmo et al., 2013).

Remarks: *Damonella grandiensis* was described by Tomé et al. (2014), giving identity to the Ostracod 207 of the Krömmelbein and Weber collection in the Research Institute of the Senckenberg Museum, Germany. The description of Tomé et al. (2014) includes features attributed to sexual dimorphism. However, the female and male symbols figured in the paragraph of abbreviations in the introduction of their systematic palaeontology section are not correct and throughout the entire text are very controversial. For example, the sexual symbol indication of the illustrated specimens of Tomé et al. (2014) (p. 165: Fig. 10A–F and p. 167: Fig. 11A–M) do not correspond to the textual descriptions: '… the carapace of the female is wider than that of the male, with the maximum width in the posteromedial region. In both views, the male specimen is always smaller than the female.' (p. 163). Having access to the illustrated specimens of Tomé et al. (2014), hosted in the Microfossil Collection of the Geology Department of the UFPE under the prefix DG-CTG-UFPE, numbers 1.157–1.158 and 1.175–1.184, we observed that the largest paratypes with > 0.99 mm length (♂ in Table 5, p. 166), display a more subtriangular outline with maximum height in the medial region, symbolised by the authors in the diagnosis with ♀ (p. 163); while the smaller paratypes (♀ in Table 5, p.166) show a more subrectangular outline and maximum height in the anteromedian region, symbolised in the diagnosis with ♂ (p. 163). Among the *D. grandiensis* we recovered, the largest morphotype always corresponds to specimens with ellipsoid subtriangular outline in lateral view and are wider at the posterodorsal region. Our smaller specimens are more subrectangular in lateral view and in dorsal view are thinner. Thus, the different *D. grandiensis* morphologies can be attributed to ontogeny and not to sexual dimorphism.

Damonella pumila Guzmán, Almeida-Lima and Piovesan nov. sp. (Fig. 5A–L)

Non 1971 *Reconcavona*? *ultima* nov. sp. - Krömmelbein and Weber, p.27, pl.9, fig.39a-c.

? 1997 *Mantelliana* (?) sp. - Colin and Dépêche, fig.3.7.

2014 *Damonella ultima* nov. comb. (Krömmelbein and Weber) - Tomé et al., p.161, fig.7T-X.

2017 *Damonella ultima* (Krömmelbein and Weber) - Carignano et al., p.215, fig.5Q-T, 7A-E.

2020 *Damonella* sp. - Melo et al., fig.5.13.

Diagnosis: *Damonella* species with subtriangular carapace. Dorsal outline broadly convex and laterally extended, anterior end higher than posterior end.

Derivation of name: From Latin *pumilus*, smallness.

Description: Carapace of small size, about 0.55 mm length, subtriangular to elongate in lateral view. In dorsal view, carapace biconvex with broadly rounded outline; greatest width at mid-length. Dorsal margin with an incipient angle just in front to mid-length, at the position of maximum height. In right view, very obtuse incipient cardinal angles are displayed. Left valve larger than right valve, overlapping it along the entire free margin. Anterior outline rounded, nearly equicurved. Posterior outline narrower, equicurved to slightly infracurved. Ventral outline straight in right valve; in left one slightly convex. Juveniles display a more ovoid rather than elongate outline. No internal features were observed.

Holotype: LMA-00288, adult, L: 0.52 mm, H: 0.31 mm, W: 0.25 mm (Fig. 5A–D).

Paratypes: LMA-00322, juvenile A-1, L: 0.49 mm, H: 0.28 mm, W: 0.23 mm (Fig. 5E–F); LMA-00323, juvenile A-2, L: 0.40 mm, H: 0.24 mm, W: 0.17 mm (Fig. 5G–H); LMA-00324, juvenile A-4, L: 0.25 mm, H: 0.16 mm, W: 0.13 mm (Fig. 5I–J); LMA-00325, juvenile A-5, L: 0.23 mm, H: 0.15 mm, W: 0.13 mm (Fig. 5K–L).

Material: A total of 120 carapaces (adults and instars) were recovered.

Type locality: Sítio Romualdo, Crato Municipality, Ceará State, Brazil.

Type horizon: Crato Formation, Santana Group, Araripe Basin, Brazil. 2-AR-SR-1A-CE well core samples, depth intervals 68.11–68.13 m, 69.60–69.70 m, 97.67–97.70 m, 99.39–99.41 m, 120.91–121.09 m, 122.16–122.18 m and 122.48–122.53 m. Outcrop samples 1Bar17d–e, g (Três Irmãos Quarry), 2Bar05f (Mãozinha hill), and 3Bar06c–e (Batateira River). Also, two specimens were recovered from the Romualdo Formation at Sítio Sobradinho section, outcrop sample 4Bar01e and 2-AR-SR-1A-CE well core samples, depth interval 36.82–37.28 m.

Stratigraphic and geographic distribution: Aptian, Crato and Romualdo formations, Crato and Jardim Municipalities, Araripe Basin, Ceará State, Brazil (this study). Aptian, Crato Formation, Santana Group, Jatobá Basin, Serra Negra hill, Ibimirim Municipality, Pernambuco State, Brazil (Tomé et al. 2014). Barremian?–Aptian, Pozo D-129 Formation, Golfo San Jorge Basin, Patagonia, Argentina (Carignano et al. 2017).

Remarks: The specimens assigned by Tome et al. (2014) as *Damonella ultima* (Krömmelbein and Weber, 1971) differs from the original material of *Reconcavona*? *ultima* Krömmelbein and Weber, 1971 from the deposits of Buracica–lower Jiquiá local stages (Barremian). *R.*? *ultima* was originally described to display a slightly convex dorsal margin, greatest height roughly at mid-length, posterior margin tightly curved and truncated and ventral margin slightly concave at posterior third in lateral view; in dorsal view, it is biconvex with slightly flattened flanks. The Aptian specimens identified as *Damonella ultima* by Tomé et al. (2014) and those recovered in the present study from Alagoas deposits in Brazil are certainly *Damonella*. They show the greatest height just in front of mid-length where they seem to have an incipient angle on the dorsal margin, which is broadly convex and laterally extended, culminating in an almost equicurve posterior outline. The ventral margin of the *Damonella* specimens is straight in the right valve and slightly convex in the left. Considering these differences, the Alagoas *Damonella* specimens do not correspond to *Reconcavona*? *ultima*. Thus, a new diagnosis and description is proposed herein to accommodate the specimens recovered in the Alagoas local Stage. Compared with *Damonella*? *tinkoussouensis* Grosdidier, 1967 from the Wealden Facies of the Congo, the Brazilian *Damonella pumila* nov. sp. displays a more subtriangular outline with narrower anterior and posterior ends.

Genus *Pattersoncypris* Bate, 1972

Type species: *Pattersoncypris micropapillosa* Bate, 1972

Remarks: Morphological similarities between *Pattersoncypris* Bate, 1972, *Hourcqia* Krömmelbein, 1965, and *Harbinia* Tsao, 1958 led to the controversial assignment of some species and reallocation of other species to the Chinese genus *Harbinia* and to the proposing of the genus *Kroemmelbeincypris* Poropat and Colin, 2012. The Barremian type species *Hourcqia africana* Kröemmelbein, 1965 was originally described to display a stocky or elongate ovate carapace and an inverse valve overlapping (right valve larger than left). Krömmelbein and Weber (1971) identified two subspecies of *Hourcqia* gr. *africana* (*Ho. africana africana* Kröemmelbein, 1965 and *Ho. africana confluens* Krömmelbein and Weber, 1971) and described four subspecies of *Hourcqia* gr. *angulata* (*Ho. angulata angulata* Krömmelbein and Weber, 1971, *Ho. angulata salitrensis* Krömmelbein and Weber, 1971, *Ho. angulata sinuata* Krömmelbein and Weber, 1971 and *Ho. angulata symmetrica* Krömmelbein and Weber, 1971), all are characterised by roof-shaped angled dorsal margin, mostly truncated posterior margin and normal valve overlap (left valve larger than right), and are recovered from Brazilian Aptian strata. Bate (1972) introduced the genus *Pattersoncypris* with the Aptian–Albian type species *P. micropapillosa* having ovoid carapace with acute dorsal hump and normal valve overlap and recognised the subspecies *Pattersoncypris angulata salitrensis* (Krömmelbein and Weber, 1971) and *Pattersoncypris angulata sinuata* (Krömmelbein and Weber, 1971). Do Carmo et al. (2008) elevated to species level the four subspecies of *Hourcqia* gr. *angulata* and along with *Pattersoncypris micropapillosa* transferred them to the genus *Harbinia*. The synonymising of *Pattersoncypris*, a genus restricted to the Aptian–Albian of Brazil and western Africa, with *Harbinia*, an exclusively Chinese genus, was extremely problematic from a palaeobiogeographical perspective (Poropat and Colin 2012b), as well as the reallocation of *Hourcqia* gr. *angulata*. Based on the degree of valve asymmetry far greater in *Harbinia hapla* Tsao, 1958 than in all species of *Pattersoncypris*, the fact that *Pattersoncypris* and *Harbinia* demonstrate no geographic or temporal overlap and the discrepancy between the palaeoenvironmental settings with which they are associated, such synonymising is not correct and the three species initially assigned by Bate (1972) to *Pattersoncypris* were revalidated by Poropat and Colin (2012b). Considering few morphological differences between the three species assigned to *Pattersoncypris* genus, mainly the absence of anterodorsal concavity on the right valve and the presence of tessellate ornamentation of *Hourcqia angulata angulata* and *Hourcqia angulata symmetrica* (not officially assigned but eventually referred to *Pattersoncypris* even by Bate), Poropat and Colin (2012b) transferred them to the new genus *Kroemmelbeincypris*. As the morphological differences on the right valve mentioned by Poropat and Colin (2012b), not clearly shown in their manuscript, are very subtle in the original Krömmelbein and Weber (1971) and the latest illustrations by Bate et al. (2022), this reallocation is here considered invalid. Moreover, the fine ornamentation on carapace surface, described by Bate (1972) as small papillae and by Poropat and Colin (2012b) as tessellation, have been observed on all morphotypes of the species here discussed and referred to *Pattersoncypris*, indicating that the occurrence or absence of this feature could be related to preservation.

Pattersoncypris alta (Antonietto, Gobbo, Do Carmo, Assine, Fernandes and Silva, 2012) (Fig. 6A–C)

Non 1971 *Hourcquia angulata angulata* nov. sp. - Krömmelbein and Weber, p.20, pl.6, Fig.23a-c.

1990 *Hourcquia angulata angulata* Krömmelbein and Weber - Silva-Telles and Viana, pl.III, fig.3.

2006 *Harbinia angulata* (Krömmelbein and Weber) - Ramos et al., p.343, fig.4E-H.

2012 *Harbinia alta* nov. sp. - Antonietto, Gobbo, Do Carmo, Assine, Fernandes and Silva, p.664, fig.4.11-4.20.

2013 *Harbinia alta* Antonietto, Gobbo, Do Carmo, Assine, Fernandes and Silva - Do Carmo et al., p.95, fig.3.5-3.8.

Material: More than 3000 of adults and juveniles were recovered.

Dimensions: LMA-00289, adult, L: 0.80 mm, H: 0.58 mm, W: 0.43 mm (Fig. 6A–C).

Occurrence: Lower Romualdo Formation in contact with the Ipubi Formation gypsum, and Crato Formation, Santana Group, Araripe Basin, Brazil. 2-AR-SR-1A-CE well core samples, depth intervals 37.51–39.70 m and 99.39–99.77m.

Stratigraphic and geographic distribution: Aptian, upper part of the Crato Formation and lower deposits of the Romualdo Formation near to their contacts with the Ipubi Formation, Araripe Basin, Crato, Santana do Cariri and Nova Olinda municipalities, Ceará State, and Araripina Municipality, Pernambuco State, Brazil (Silva-Telles and Viana, 1990; Antonietto et al., 2012; this study). Mid-upper Aptian, Alagamar Formation, Potiguar Basin, Rio Grande do Norte and Ceará states, Brazil (Do Carmo et al., 2013). Upper Aptian, Codó Formation, Grajaú Basin, Codó Municipality, Maranhão State, Brazil (Ramos et al., 2006).

Pattersoncypris crepata (Do Carmo, Coimbra, Whatley, Antonietto and Citon, 2013) (Fig. 6D–F)

?1990 Gen. indet. aff. sp. 207 - Silva-Telles and Viana, pl.II, fig.1, 3.

2013 *Harbinia crepata* nov. sp. - Do Carmo, Coimbra, Whatley, Antonietto and Citon, p.95, fig.3.9-3.18.

2016 *Harbinia crepata* - Do Carmo, Coimbra, Whatley, Antonietto and Citon - Antonietto, Gobbo, Do Carmo, Assine, Fernandes and Silva, p.20, fig.6E.

2020 *Pattersoncypris crepata* (Do Carmo, Coimbra, Whatley, Antonietto and Citon) - Melo et al., fig.5.1-5.4, 5.7.

Material: More than 4000 of adults and juveniles were recovered.

Dimensions: LMA-00290, adult, L: 0.93 mm, H: 0.56 mm, W: 0.44 mm (Fig. 6D–F).

Occurrence: Romualdo and Ipubi formations, Santana Group, Araripe Basin. 2-AR-SR-1A-CE well core samples, depth intervals 11.38–11.41 m, 14.17–15.16 m, 16.68–16.71 m, 37.25–37.28 m, 39.68–41.17 m, 48.65–49.50 m and 54.36–54.43 m. Outcrop samples 2BAr04a (Mãozinha hill) and 4BAr01g–h (Sítio Sobradinho section).

Stratigraphic and geographic distribution: Aptian. Ipubi and Romualdo formations, Araripe Basin, Crato, Abaiara and Jardim municipalities, Ceará State, Brazil (Melo et al., 2020; this study). Mid-upper Aptian, Alagamar Formation, Potiguar Basin, Rio Grande do Norte and Ceará states, Brazil (Do Carmo et al., 2013). Upper Aptian–lower Albian, Riachuelo Formation, Sergipe-Alagoas Basin, Rosário do Catete Municipality, Sergipe State, Brazil (Antonietto et al., 2016).

Pattersoncypris cucurves Guzmán, Almeida-Lima and Piovesan nov. sp. (Fig. 7A–M)

Diagnosis: A *Pattersoncypris* species characterised by its highly convex anterodorsal hump and conspicuous flange along the free margin of both valves.

Derivation of name: Adopted from the Latin *cucurvus*, referring to the pronounced hump on the anterodorsal region of the carapace.

Description: Carapace of medium size, ovoid in lateral view. A prominent convex hump is observed just in front of mid-length on dorsal margin of both valves, marked even in instars. In dorsal view, carapace biconvex presenting a remarkable subcircular structure which corresponds to the hump. Anterior margin broadly rounded. Dorsal margin straight along the hinge. Hinge inclined to the equicurve and subrounded posterior margin. Ventral margin sinuous with a concavity at the median part. Great length at mid-height, maximum height slightly anterior to mid-length, maximum width at the median region. LV larger than RV overlapping it along the free margin. Both valves display pronounced and weakly calcified flanges along the free margin. Carapace smooth or with subtle small papillae on the whole valves surface. Sexual dimorphism not observed. Internal characters not available.

Holotype: LMA-00291, adult, L: 0.93 mm, H: 0.63 mm, W: 0.41 mm (Fig. 7A–D).

Paratypes: LMA-00293, juvenile A-1, L: 0.87 mm, H: 0.60 mm, W: 0.42 mm (Fig. 7E); LMA-00294, juvenile A-2, L: 0.78 mm, H: 0.53 mm, W: 0.35 mm (Fig. 7F); LMA-00295, juvenile A-2, L: 0.80 mm, H: 0.54 mm, W: 0.35 mm (Fig. 7G), LMA-00296, juvenile A-3, L: 0.69 mm, H: 0.49 mm, W: 0.32 mm (Fig. 7H); LMA-00297, juvenile A-4, L: 0.52 mm, H: 0.38 mm, W: 0.26 mm (Fig. 7I); LMA-00298, juvenile A-5, L: 0.39 mm, H: 0.30 mm, W: 0.22 mm (Fig. 7J); LMA-00299, juvenile A-6, L: 0.32 mm, H: 0.25 mm, W: 0.18 mm (Fig. 7K); LMA-00300, juvenile A-7,

Fig. 6. Ostracod specimens of the genus *Pattersoncypris*. **A–C,** *Pattersoncypris alta*, LMA-00289 (well 2-AR-SR-1A-CE. sample 37.70 m), adult, right (A), left (B) and dorsal (C) views. **D–F,** *Pattersoncypris crepata* (well 2-AR-SR-1A-CE, sample 15.00 m), LMA-00290, adult, dorsal (D), right (E) and left (F) views. **G–I,** *Pattersoncypris micropapillosa* (well 2-AR-SR-1A-CE, sample 121.05 m), LMA-00302, adult, right (G), left (H) and dorsal (I) views. **J–L,** *Pattersoncypris symmetrica*, LMA-00341 (well 2-AR-SR-1A-CE, sample 46.38 m), adult, right (J), left (K) and dorsal (L) views. (A–L) scale bar: 100 μm.

L: 0.26 mm, H: 0.20 mm, W: 0.15 mm (Fig. 7L); LMA-00301, juvenile A-8, L: 0.17 mm, H: 0.14 mm, W: 0.10 mm (Fig. 7M).

Material: 374 carapaces of adults and juveniles.

Type locality: Sítio Romualdo, Crato Municipality, Ceará State, Brazil.

Type horizon: Batateira beds, Barbalha Formation, Santana Group, Araripe Basin, Brazil. 2-AR-SR-1B-CE well core samples, from a depth between 79.37 and 79.44 m. Outcrop 3BAr01 (Batateira River), sample b.

Stratigraphic and geographic distribution: Aptian, Batateira beds, Barbalha Formation, Araripe Basin, Crato Municipality, Ceará State, Brazil (this study).

Remarks: In size, *Pattersoncypris cucurves* nov. sp. is similar to other species of the genus except *Pattersoncypris minima* Almeida-Lima and Piovesan, 2020, which was also proposed based on its complete ontogenetic series. *Pattersoncypris cucurves* nov. sp. is similar to *P. micropapillosa* Bate, 1972, differing by its more pronounced hump in all the ontogenetic stages and its higher and more rounded posterior margin.

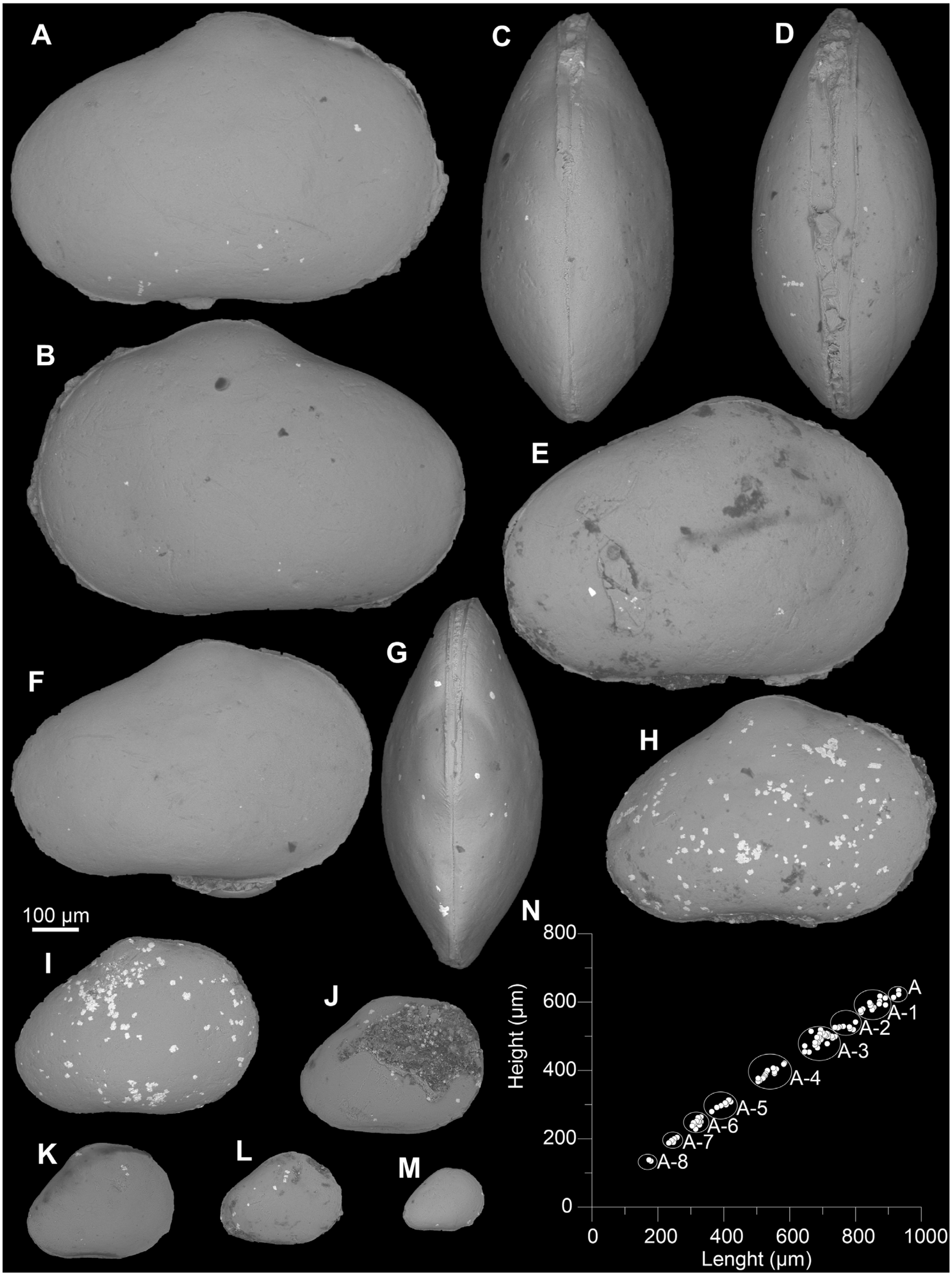

Fig. 7. *Pattersoncypris cucurves* nov. sp. **A–D,** holotype, LMA-00291 (well 2-AR-SR-1B-CE, sample 79.37 m), adult, right (A), left (B), dorsal (C) and ventral (D) views. **E,** paratype 1, LMA-00293 (well 2-AR-SR-1B-CE, sample 79.37 m), juvenile A-1, right view. **F,** paratype 2, LMA-00294 (well 2-AR-SR-1B-CE, sample 79.37 m), juvenile A-2, right view. **G,** paratype 3, LMA-00295 (well 2-AR-SR-1B-CE, sample 79.37 m), juvenile A-2, dorsal view. **H,** paratype 4, LMA-00296 (well 2-AR-SR-1B-CE, sample 79.37 m), juvenile A-3, right view. **I,** paratype 5, LMA-00297 (well 2-AR-SR-1B-CE, sample 79.37 m), juvenile A-4, right view. **J,** paratype 6, LMA-00298 (well 2-AR-SR-1B-CE, sample 79.37 m), juvenile A-5, right view. **K,** paratype 7, LMA-00299 (well 2-AR-SR-1B-CE, sample 79.37 m), juvenile A-6, right view. **L,** paratype 8, LMA-00300 (well 2-AR-SR-1B-CE, sample 79.32 m), juvenile A-7, right view. **M,** paratype 9, LMA-00301, juvenile A-8, right view. (A–M) scale bar: 100 µm. **N,** scatter plot of the length and height measurements of 97 carapaces of *Pattersoncypris cucurves* nov. sp. showing the complete ontogeny.

Compared with *P. crepata* (Do Carmo et al., 2013), the hump of *P. cucurves* nov. sp. is more pronounced and the hinge is more inclined to the posterior. *P. cucurves* nov. sp. differs from *P. alta* (Antonietto, Gobbo, Do Carmo, Assine, Fernandes and Silva), *P. angulata* (Krömmelbein and Weber, 1971), *P. salitrensis* (Krömmelbein and Weber, 1971) and *P. sinuata* (Krömmelbein and Weber, 1971) by its more pronounced curved hump and less inclined hinge, and from *P. symmetrica* (Krömmelbein and Weber, 19 71) by having its greatest width positioned at the posteromedian region thereby presenting a more subtriangular outline in lateral view and pyriform in dorsal view. *Pattersoncypris cucurves* nov. sp. occurs associated with *Candonopsis alagoensis, P. micropapillosa* and *Damonella grandiensis* in the Batateira beds, Barbalha Formation, Araripe Basin, Brazil.

Pattersoncypris kroemmelbeini Guzmán, Almeida-Lima and Piovesan sp. nov. (Fig. 8A–P)

Diagnosis: A *Pattersoncypris* species with greatest width at the posteromedian region and maximum height at mid-length.

Derivation of name: In memory of Karl Krömmelbein for his contributions in Systematic Palaeontology of Mesozoic Ostracoda of Brazil.

Description: Carapace of medium size, subtriangular to subrectangular in lateral view. In dorsal view, carapace outline like an inverted kite, wider at the posteromedian region, dorsal suture slightly sinuous. Carapace compressed at posterodorsal region. Anterior and posterior outlines rounded, the posterior is narrower than the anterior one. Dorsal margin convex with a subtle hump at the median region. Ventral margin straight. Maximum height at mid-length and greatest length just below the mid-height. LV larger than RV overlapping it along the dorsal margin. Both valves display weak flanges along the anterior and posterior margins; more developed in the right valve. Carapace smooth. Sexual dimorphism not observed. Internal characters not available.

Holotype: LMA-00335, adult, L: 0.91 mm, H: 0.57 mm, W: 0.43 mm (Fig. 8A–C).

Paratypes: LMA-00303, juvenile A-1, L: 0.84 mm, H: 0.55 mm, W: 0.42 mm (Fig. 8D–F); LMA-00336, juvenile A-2, L: 0.76 mm, H: 0.50 mm, W: 0.37 mm (Fig. 8G–H); LMA-00337, juvenile A-3, L: 0.63 mm, H: 0.41 mm, W: 0.32 mm (Fig. 8I–J); LMA-00338, juvenile A-4, L: 0.53 mm, H: 0.35 mm, W: 0.25 mm (Fig. 8K–L); LMA-00339, juvenile A-5, L: 0.42 mm, H: 0.28 mm, W: 0.20 mm (Fig. 8M–N); LMA-00340, juvenile A-6, L: 0.34 mm, H: 0.23 mm, W: 0.16 mm (Fig. 8O–P).

Material: More than 3000 carapaces of both adults and juveniles were recovered.

Type locality: Sítio Romualdo, Crato Municipality, Ceará State, Brazil.

Type horizon: Romualdo and Ipubi formations, Santana Group, Araripe Basin. 2-AR-SR-1A-CE well core samples, depth intervals 14.17–15.04 m, 36.82–36.85 m, 37.17–37.28 m, 41.14–41.17 m and 57.13–57.15 m.

Stratigraphic and geographic distribution: Aptian, Romualdo and Ipubi formations (this study), Araripe Basin, Ceará State, Brazil.

Remarks: *Pattersoncypris kroemmelbeini* nov. sp. displays some similarity in lateral view with *P. salitrensis* (Krömmelbein and Weber, 1971). The main differences between these species are observed in the position of the maximum height at mid-length and greatest width at the posteromedian region in the new species, whilst *P. salitrensis* is wider at the median region and higher just in front mid-length. Another important characteristic is the more broadly rounded anterior margin of *P. salitrensis* compared with *P. kroemmelbeini* nov. sp.

Pattersoncypris micropapillosa Bate, 1972 (Fig. 6G–I)

1972 *Pattersoncypris micropapillosa* nov. sp. - Bate, p.381, pl.66-71.

1990 *Pattersoncypris* sp. - Silva-Telles and Viana, pl.II, fig.6-7.

1997 *Hourcqia* gr. *angulata* (Krömmelbein and Weber) - Colin and Dépêche, fig.6.17.

?1997 *Hourcqia* gr. *angulata* (Krömmelbein and Weber) - Colin and Dépêche, fig.2.19.

2000 *Pattersoncypris micropapillosa* Bate - Smith, p. 70, pl.1-9, text-fig.2-9.

2006 *Harbinia micropapillosa* (Bate) - Ramos et al., p.341, fig.4A-D.

2008 *Harbinia micropapillosa* (Bate) - Do Carmo et al., p.796, fig.6.6.

2010 *Pattersoncypris micropapillosa* Bate - Tomé and Lima Filho, p.52, pl.1, fig.a-c.

2012b *Pattersoncypris micropapillosa* Bate - Poropat and Colin, p.710, fig.4.1.

2014 *Pattersoncypris micropapillosa* Bate - Tomé et al., p.166, fig.10J-P.

2020 *Pattersoncypris micropapillosa* Bate - Melo et al., fig.5.5-5.6.

Non 2021 *Pattersoncypris* cf. *P. micropapillosa* Bate - Araripe et al., fig.5J-L.

2022 *Pattersoncypris angulata* (Kröemmelbein and Weber) - Araripe et al., fig.5.14a-b.

2022 *Pattersoncypris micropapillosa* Bate - Araripe et al., fig.5.15a-b.

2022 *Pattersoncypris angulata* (Kröemmelbein and Weber) - Tomé et al., p.539, fig.3D-F.

2022 *Pattersoncypris micropapillosa* Bate - Tomé et al., p.540, fig.3G-I.

2022 *Pattersoncypris micropapillosa* Bate - Bate et al., p.55, fig.14.1a-d.

Material: More than 7000 of adults and juveniles.

Dimensions: LMA-00302, adult, L: 0.99 mm, H: 0.66 mm, W: 0.46 mm (Fig. 6G–I).

Occurrence: Barbalha, Crato, Ipubi and Romualdo formations, Santana Group, Araripe Basin. 2-AR-SR-1A-CE well core samples, depth intervals 10.98–11.63 m, 12.27–13.00 m, 15.00–15.04 m, 37.25–37.47 m, 68.30–68.46 m, 95.65–97.70 m, 99.39–99.89 m, 103.18–103.20 m, 107.36–107.62 m, 112.39–11247 m, 118.95–118.99 m, 120.39–121.72 m, 122.16–122.75 m and 123.15–123.18 m. 2-AR-SR-1B-CE well core samples, depth interval 79.37–79.61 m. Outcrop samples 1BAr11e–f (Conceição Preta Quarry), 1BAr17a–b, d–e (Três Irmãos Quarry), 2BAr05d, f (Mãozinha hill), 3BAr04 and 3BAr06c–e (Batateira River), and 4BAr01k–l (Sítio Sobradinho section).

Stratigraphic and geographic distribution: Aptian, along the complete Santana Group, Araripe Basin, Ceará State, Brazil (Bate, 1972; Smith, 2000; Coimbra et al., 2002; Poropat and Colin, 2012; this study), Araripe Basin, Ceará and Pernambuco states, Brazil. Aptian, Crato Formation, Cedro Basin, Cedro Municipality, Pernambuco State, Brazil (Tome and Lima Filho, 2010). Aptian, Crato Formation, Jatobá Basin, Serra Negra hill, Ibimirim Municipality, Pernambuco State, Brazil (Tomé et al., 2014). Upper Aptian, Codó Formation, Grajaú Basin, Codó Municipality, Maranhão State, Brazil (Ramos et al., 2006). According to Bate (1972), *Pattersoncypris micropapillosa* also occurs from Aptian–Albian strata in Liberia, northwest Africa. From Aptian–Albian strata of the Bongor, Doba and Doseo basins in Chad, north-central Africa, Colin and Dépêche (1997) identified the taxon *Hourcqia* gr. *angulata* Krömmelbein and Weber, 1971; but we believe that it corresponds to *P. micropapillosa* and thus its distribution extends to north-central Africa.

Pattersoncypris symmetrica (Krömmelbein and Weber, 1971) (Fig. 6J–L)

1971 *Hourqcia angulata symmetrica* nov. ssp. - Krömmelbein and Weber, p.36, pl.6, fig.26a-c.

1990 *Hourqcia*? sp. 2 - Silva-Telles and Viana, pl. III, fig.5-6.

2002 *Pattersoncypris angulata symmetrica* (Krömmelbein and Weber) - Coimbra et al., fig.4.30.

Non 2006 *Harbinia* aff. *H. symmetrica* (Krömmelbein and Weber) - Ramos et al., p.345, fig.4M-P.

2008 *Harbinia symmetrica* (Krömmelbein and Weber) - Do Carmo et al., fig.6.9.

2012b *Kroemmelbeincypris symmetrica* (Krömmelbein and Weber) - Poropat and Colin, p.713, fig.4.4.

2021 *Pattersoncypris symmetrica* (Krömmelbein and Weber) - Araripe et al., fig.5D-F.

? 2021 *Pattersoncypris sinuata* (Krömmelbein and Weber) - Araripe et al., fig.5G-I.

2022 *Hourcqia angulata symmetrica* Krömmelbein and Weber - Bate et al., p.46, fig.11.5a-c.

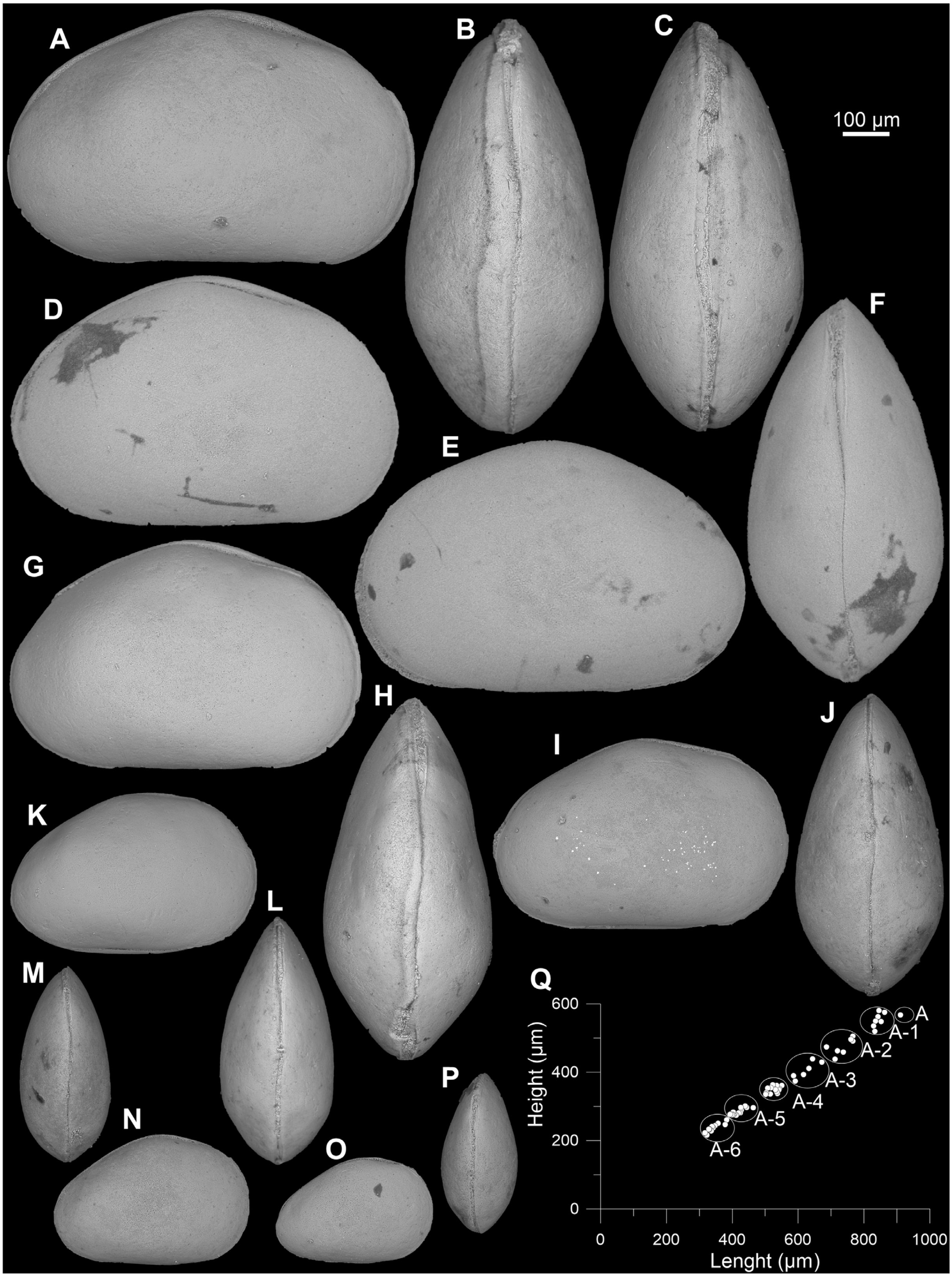

Fig. 8. *Pattersoncypris kroemmelbeini* nov. sp. **A–C,** holotype, LMA-00335 (well 2-AR-SR-1A-CE, sample 37.17 m), adult, right (A), dorsal (B) and ventral (C) views. **D–F,** paratype 1, LMA-00303 (well 2-AR-SR-1A-CE, sample 37.25 m), juvenile A-1, right (D), left (E) and dorsal (F) views. **G–H,** paratype 2, LMA-00336 (well 2-AR-SR-1A-CE, sample 37.17 m), juvenile A-2, right (G) and dorsal (H) views. **I–J,** paratype 3, LMA-00337 (well 2-AR-SR-1A-CE, sample 37.17 m), juvenile A-3, right (I) and dorsal (J) views. **K–L,** paratype 4, LMA-00338 (well 2-AR-SR-1A-CE, sample 37.17 m), juvenile A-4, right (K) and dorsal (L) views. **M–N,** paratype 5, LMA-00339 (well 2-AR-SR-1A-CE, sample 37.17 m), juvenile A-5, dorsal (M) and right (N) views. **O–P,** paratype 6, LMA-00340 (well 2-AR-SR-1A-CE, sample 37.17 m), juvenile A-6, right (O) and dorsal (P) views. (A–P) scale bar: 100 μm. **Q,** scatter plot of the length and height measurements of 58 carapaces of *Pattersoncypris kroemmelbeini* nov. sp. showing clusters from A to A-6 ontogenetic stages.

Material: A total of 42 adult and juvenile carapaces were recovered.

Dimensions: LMA-00341, adult, L: 0.96 mm, H: 0.57 mm, W: 0.42 mm (Fig. 6J–L).

Occurrence: Romualdo and Ipubi formations, Santana Group, Araripe Basin, Brazil. 2-AR-SR-1A-CE well core samples, depth intervals 12.97–13.00 m, 14.17–14.20 m, 46.38–46.40 m, 54.40–54.43 and 57.13–57.15 m.

Stratigraphic and geographic distribution: Aptian, Romualdo Formation (Silva-Telles and Viana, 1990; Coimbra et al., 2002; Araripe et al., 2021; this study) and Ipubi Formation (Coimbra et al., 2002; this study), Araripe Basin, Ceará and Pernambuco states, Brazil. Aptian, Codó Formation, Parnaíba Basin, Maranhão State, Brazil (Krömmelbein and Weber, 1971; Do Carmo et al., 2008). Aptian, along the Congo, Gabon and Kwanza marginal pre-salt basins of west Africa (Bate, 1999).

Genus *Zonocypris* G. W. Müller, 1898

Zonocypris berthoui Piovesan, Melo, Cabral and Guzmán, 2022 (Fig. 9A–C)

1994 *Zonocypris* sp. - Berthou et al., pl.1, fig.5-7.

1997 *Zonocypris* sp. - Colin and Dépêche, fig.2.14, 2.17.

2022 *Zonocypris berthoui* nov. sp. - Piovesan, Melo, Cabral and Guzmán, p. 584, fig.2A-K.

Material: A total of three carapaces were recovered.

Dimensions: LMA-00305, L: 0.40 mm, H: 0.28 mm, W: 0.26 mm (Fig. 9A–C).

Occurrence: Crato Formation, Santana Group, Araripe Basin, Brazil. 2-AR-SR-1A-CE well core samples, depth intervals 121.05–121.09 m and 124.55–124.58 m. Outcrop sample 1BAr17a (Três Irmãos Quarry).

Stratigraphic and geographic distribution: Aptian, Crato Formation, Araripe Basin, Barbalha, Crato and Nova Olinda municipalities, Ceará State, Brazil (Berthou et al., 1994; Colin and Dépêche, 1997; this study).

Zonocypris dorsoconvexa Piovesan, Melo, Cabral and Guzmán, 2022 (Fig. 9D–F)

2022 *Zonocypris dorsoconvexa* nov. sp. - Piovesan, Melo, Cabral and Guzmán, p.586, fig.3A-H.

Material: A total of three carapaces were recovered.

Dimensions: LMA-00306, L: 0.40 mm, H: 0.27 mm, W: 0.27 mm (Fig. 9D–F).

Occurrence: Crato Formation, Santana Group, Araripe Basin, Brazil. 2-AR-SR-1A-CE well core samples, depth intervals 124.55–124.58 m and 134.00–134.05 m.

Stratigraphic and geographic distribution: Aptian, Crato Formation, Araripe Basin, Crato Municipality, Ceará State, Brazil (this study).

Genus indeterminate

Gen. et sp. indet. 1 (Fig. 9G–L)

1990 *Hourqcia*? sp. 1 - Silva-Telles and Viana, pl.II, fig.9-10.

2013 *Ilyocypris* sp. - Do Carmo et al., p.101, fig.6.1-6.5.

Material: Just two illustrated specimens were recovered.

Dimensions: LMA-00307, L: 0.83 mm, H: 0.53 mm, W: 0.27 mm (Fig. 9G–I); LMA-00308, L: 0.86 mm, H: 0.53 mm, W: 0.36 mm (Fig. 9J–L).

Occurrence: Crato Formation, Santana Group, Araripe Basin, Brazil. 2-AR-SR-1A-CE well core samples, depth intervals 97.67–97.70 m and 107.59–107.62 m.

Stratigraphic and geographic distribution: Aptian, Crato Formation, Santana Group, Araripe Basin, Ceará State, Brazil (Silva-Telles and Viana, 1990; Do Carmo et al., 2013; this study). Mid-upper Aptian, Alagamar Formation, Potiguar Basin, Rio Grande do Norte State, Brazil (Do Carmo et al., 2013).

Remarks: Do Carmo et al. (2013), assigned this morphotype to the genus *Ilyocypris* due to the weakly-developed anterodorsal double sulci present in the specimens recorded in the Potiguar Basin. However, in the illustrated specimens of Do Carmo et al. (2013), as well as those of Silva-Telles and Viana (1990), this is not a visible feature and the preservation of the specimens illustrated in dorsal view do not show these features. The specimens here do not display sulci, and the general outline, both in lateral and in dorsal view, is similar to the Family Cyprididae. Thus, it was opted to maintain this taxon as indeterminate but included in the family Cyprididae. The description of a new taxon to accommodate these morphotypes should be considered, but in the present study this was not possible due to scarcity of the recorded specimens.

Family Ilyocyprididae Kaufmann, 1900

Genus *Ilyocypris* Brady and Norman, 1889

Ilyocypris coimbrai Guzmán, Almeida-Lima and Piovesan nov. sp. (Fig. 10A–H)

1994 *Ilyocypris* sp. - Berthou et al., pl.1, fig.11-14.

1997 *Ilyocypris* sp. - Colin and Dépêche, fig.2.13.

Diagnosis: Subrectangular carapace with three pronounced tubercles and two sulci between them. In dorsal view, carapace characterised by a transverse depression along the dorsal region above the sulci.

Derivation of name: As a tribute to Professor João Carlos Coimbra for his contribution to the knowledge of Ostracoda and stratigraphic palaeontology of Brazil.

Description: In lateral view, carapace subrectangular with marked cardinal angles; the posterior is almost straight and the anterior is obtuse. Dorsal margin straight, slightly sloping down to the posterior cardinal angle. Ventral margin concave. Anterior margin truncated with the dorsal margin and smoothly joins the ventral margin. Posterior margin straight, narrow rounded at posteroventral position. Posterior third of the carapace more quadrate, with the valve outlines higher than the dorsal margin displaying ridge-like overreaches. Greatest height anteriorly, at the anterior cardinal angle position. Three strong tubercles with two sulci between them occur near mid-height with the posterior tubercle more elongated. Left valve larger than right valve, more markedly at the anterodorsal and posterior margins. In dorsal view, carapace subpyriform with the tubercles protruding, the posterior one stronger- developed and the median and anterior ones with similar morphology; anterior and posterior regions are compressed. Carapace surface reticulate, with spines along the anterior, ventral and posterior regions.

Holotype: LMA-00309, adult, L: 0.65 mm, H: 0.34 mm, W: 0.33 mm (Fig. 10A–D).

Paratypes: LMA-00326, juvenile A-1, L: 0.58 mm, H: 0.30 mm, W: 0.28 mm (Fig. 10E–G); LMA-00327, right valve of a juvenile A-2, L: 0.49 mm, H: 0.26 mm (Fig. 10H).

Material: 84 carapaces of adults and juveniles were recovered.

Type locality: Sítio Romualdo, Crato Municipality, Ceará State, Brazil.

Type horizon: Ipubi and Crato formations, Santana Group, Araripe Basin, Brazil. 2-AR-SR-1A-CE well core samples, depth intervals 51.07–51.10 m, 54.40–54.56 m, 54.53–54.56, 57.13–57.15 m. Outcrop samples 1BAr17a–b (Três Irmãos Quarry).

Stratigraphic and geographic distribution: Aptian, Ipubi Formation (this study) and Crato Formation (Berthou et al., 1994; Colin and Dépêche, 1997; this study), Araripe Basin, Ceará State, Brazil.

Remarks: The genus *Ilyocypris* was previously reported in several studies from Araripe Basin, but not all are illustrated (e.g. Do Carmo et al., 2004). From our material, specimens of three ontogenetic stages were recovered, adults, A-1 and A-2 juveniles (Fig. 9I). Our specimens are very similar to those illustrated by Berthou et al. (1994) and Colin and Dépêche (1997); differences could be due to preservation or illustration. From Jatobá Basin, Brazil, Tomé et al. (2014) reported one *Ilyocypris* specimen from the Crato Formation, but this specimen does not correspond to the illustrated Araripe Basin specimens, differing mainly in the number of sulci, tubercles, and dorsal outline. *I. coimbrai* nov. sp., differs from *Ilyocypris riograndensis* Mussachio and Simeoni, 1991 by having more rounded posterior margin, obtuse posterior cardinal angle and more concave ventral margin and lacking spines.

Genus *Neuquenocypris* Mussachio, 1973

Neuquenocypris berthoui Colin and Dépêche, 1997 (Fig. 11A–C)

1994 *Ilyocyprimorpha* sp. - Berthou et al., pl.1, fig.5-7.

1997 *Neuquenocypris berthoui* nov. sp. - Colin and Dépêche, p.447, fig.2.1-2.3, 2.5.

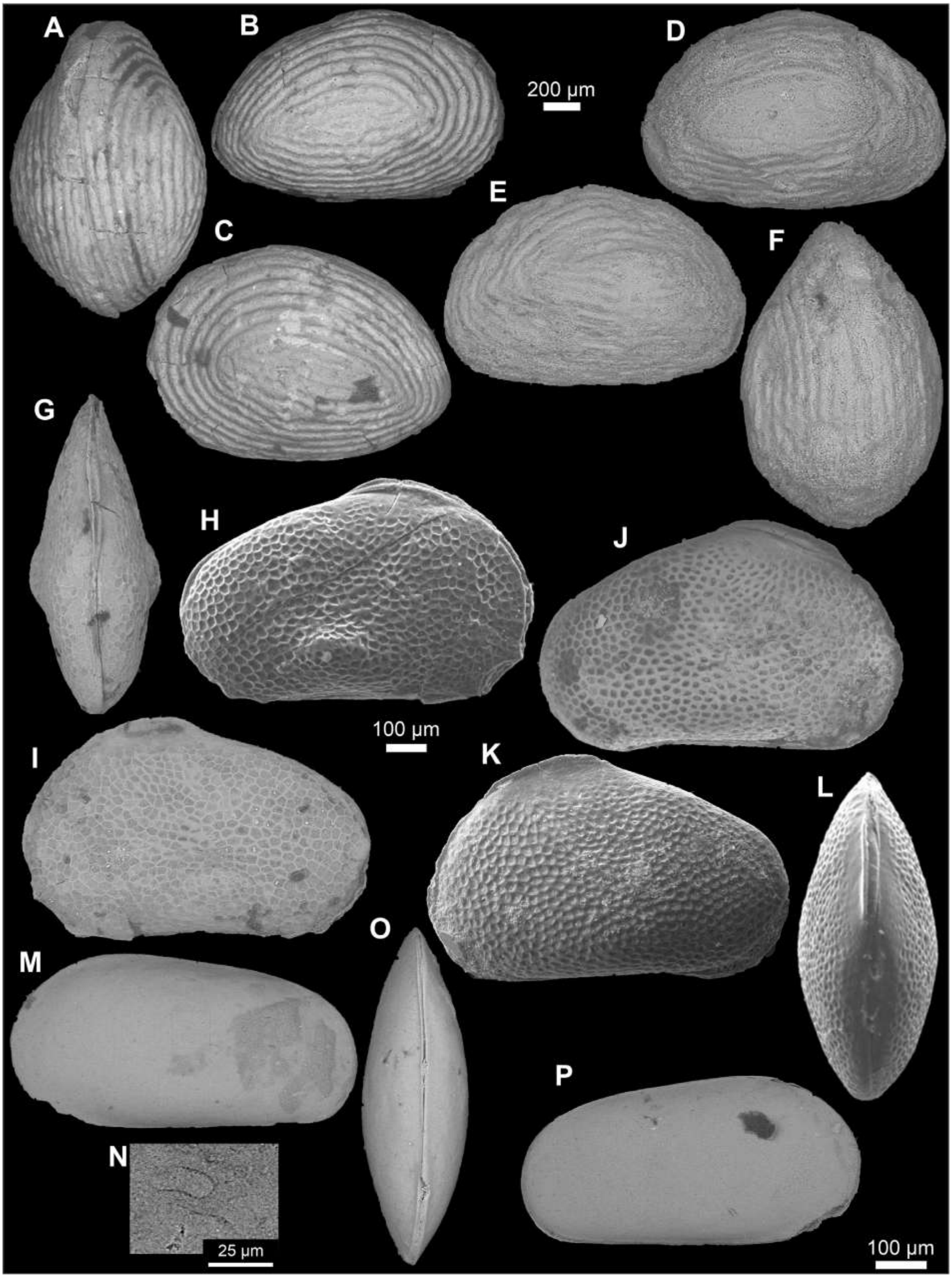

Fig. 9. Ostracod specimens of the Cyprididae and the indeterminated family. **A–C,** *Zonocypris berthoui*, LMA-00305 (outcrop 1BAr17, sample a), adult female, right (A), left (B) and dorsal (C) views. **D–F,** *Zonocypris dorsoconvexa*, LMA-00306 (well 2-AR-SR-1A-CE, sample 134.00 m), adult female, right (D), left (E) and dorsal (F) views. **G–I,** Gen et. sp. indet. 1, LMA-00307 (well 2-AR-SR-1A-CE, sample 97.67 m), dorsal (G), right (H) and left (E) views. **J–L,** Gen et. sp. indet. 1, LMA-00308 (well 2-AR-SR-1A-CE, sample 107.59 m), right (J), left (K) and dorsal (L) views. **M–P,** Gen et. sp. indet. 3, LMA-00042 (outcrop 3BAr06, sample e), right (M), left (O) and dorsal (P) views, (N) close-up of the central muscle scars on right (M) valve. (A–F) scale bar: 200 µm, (G–L) scale bar: 100 µm, (M, O–P) scale bar: 100 µm, (N) scale bar: 25 µm.

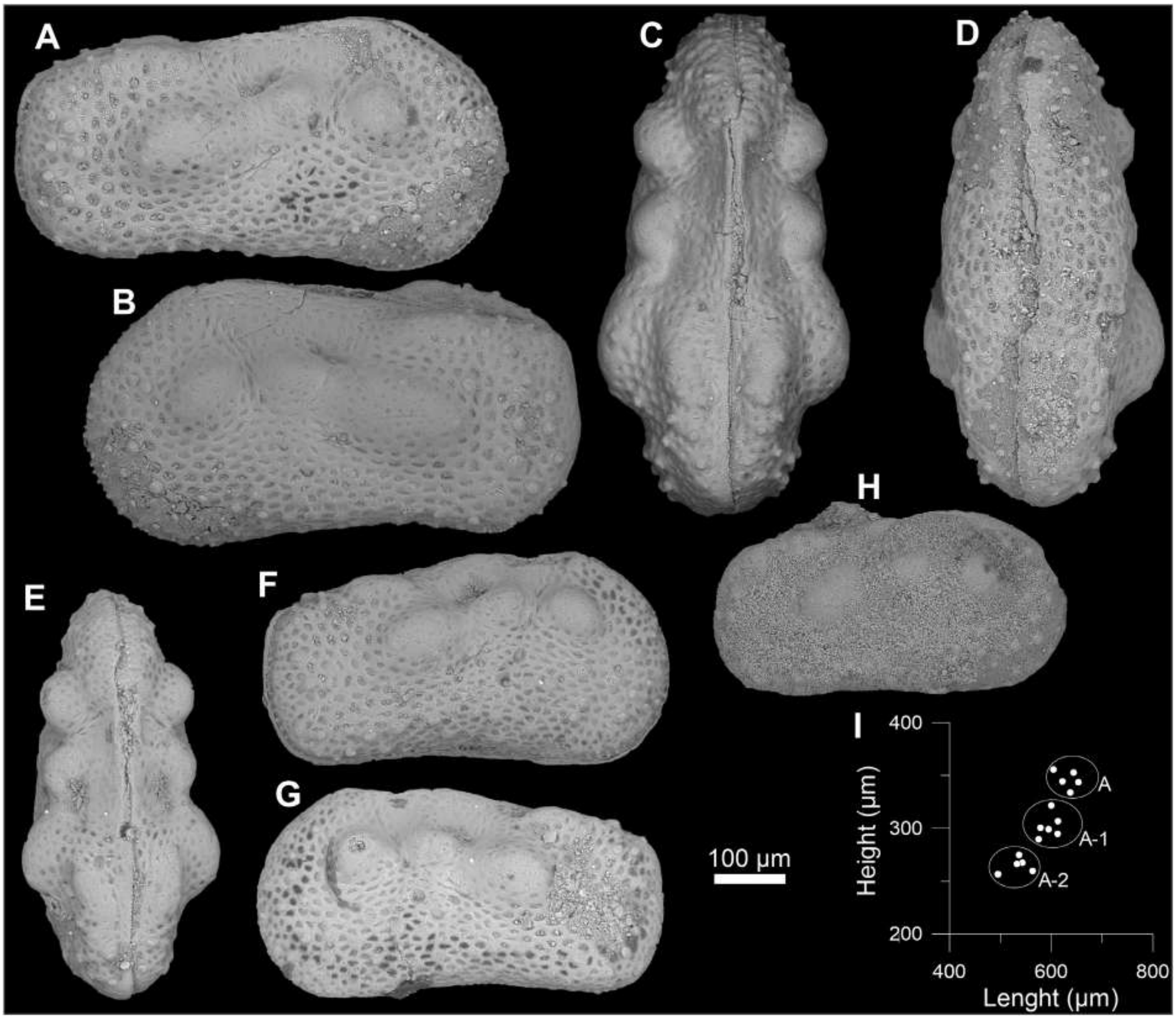

Fig. 10. *Ilyocypris coimbrai* nov. sp. **A–D,** holotype, LMA-00309 (well 2-AR-SR-1A-CE, sample 54.53 m), adult, right (A), left (B), dorsal (C) and ventral (D) views. **E–G,** paratype 1, LMA-00326 (well 2-AR-SR-1A-CE, sample 54.40 m), juvenile A-1, right (E), left (F) and dorsal (G) views. **H,** paratype 2, LMA-00327 (well 2-AR-SR-1A-CE, sample 54.40 m), juvenile A-2, right view. (A–H) scale bar: 100 µm. **I,** scatter plot of the length and height measurements of 16 carapaces of *Ilyocypris coimbrai* nov. sp. showing clusters of A, A-1 and A-2 ontogenetic stages.

2013 *Ilyocyprimorpha berthoui* (Colin and Dépêche) - Do Carmo et al., fig.5.15-5.17.

2014 *Neuquenocypris berthoui* Colin and Dépêche - Tomé et al., p.158, fig.7G-L.

Material: 13 carapaces of two adults and 11 juveniles were recovered.

Dimensions: LMA-00328, adult, L: 0.82 mm, H: 0.47 mm, W: 0.37 mm (Fig. 11A–C).

Occurrence: Crato Formation, Santana Group, Araripe Basin, Brazil. 2-AR-SR-1A-CE well core samples, depth intervals 99.74–99.77 m, 106.95–106.98 m and 124.55–124.58 m. Outcrop samples 1BAr17a (Três Irmãos Quarry) and 3BAr06b (Batateira River).

Stratigraphic and geographic distribution: Aptian, Crato Formation, Araripe Basin, Ceará State, Brazil (Berthou et al., 1994; Colin and Dépêche, 1997; this study). Aptian, Crato Formation, Jatobá Basin, Serra Negra hill, Ibimirim Municipality, Pernambuco (Tomé et al., 2014). Mid-upper Aptian, Alagamar Formation, Potiguar Basin, Rio Grande do Norte State, Brazil (Do Carmo et al., 2013). Upper Aptian–lower Albian, Bongor Basin, Chad, north-central Africa (Colin and Dépêche, 1997).

Neuquenocypris sp. (Fig. 11D–F)

Material: One carapace of a juvenile was recovered.

Dimensions: LMA-00310, juvenile, L: 0.49 mm, H: 0.25 mm, W: 0.21 mm (Fig. 11D–F).

Occurrence: Crato Formation, Santana Group, Araripe Basin, Brazil. 2-AR-SR-1A-CE well core sample from depth interval 68 .11–68.13 m.

Stratigraphic and geographic distribution: Aptian, Crato Formation, Araripe Basin, Ceará State, Brazil (this study).

Remarks: This species differs from *N. berthoui* by the ornamentation pattern and the more concave dorsal margin. We have decided to maintain this species under open nomenclature due the scarcity of material.

Gen. et. sp. indet. 2 (Fig. 11G–I)

Material: Two carapaces.

Dimensions: LMA-00312, L: 0.32 mm, H: 0.16 mm, W: 0.15 mm (Fig. 11G–I).

Occurrence: Crato Formation, Santana Group, Araripe Basin, Brazil. Outcrop sample 1BAr17b (Três Irmãos Quarry).

Stratigraphic and geographic distribution: Aptian, Crato Formation, Araripe Basin, Nova Olinda Municipality, Ceará State, Brazil (this study).

Remarks: The recovered specimens were assigned to the family Ilyocyprididae by its subrectangular to subtrapezoidal carapace, three pronounced sulci from the dorsal region to mid-height, and straight dorsal

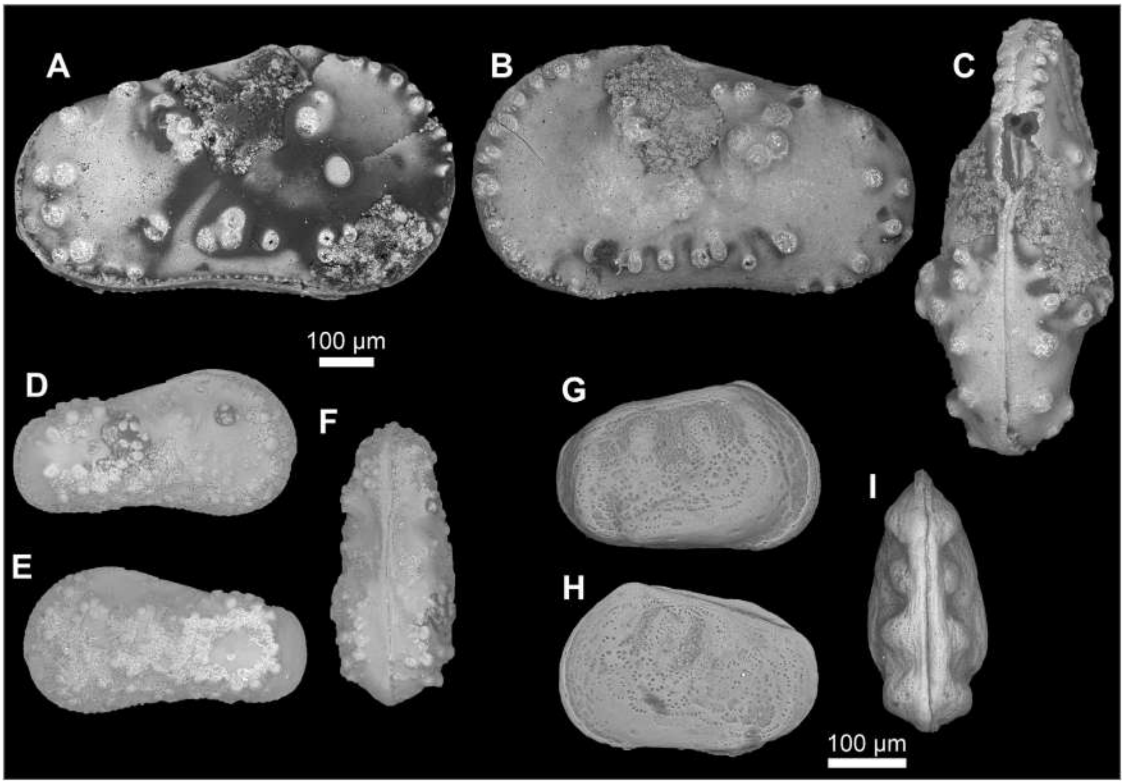

Fig. 11. Ostracod specimens of the Ilyocyprididae. **A–C,** *Neuquenocypris berthoui*, LMA-00328 (outcrop 1BAr17, sample a), adult, right (A), left (B) and dorsal (C) views. **D–F,** *Neuquenocypris* sp., LMA-00310 (well 2-AR-SR-1A-CE, sample 68.11 m), right (D), left (E) and dorsal (F) views. **G–I,** Gen. et. sp. indet. 2, LMA-00312 (outcrop 1BAr17, sample b), right (G), left (H) and dorsal (I) views. (A–F) scale bar: 100 µm, (G–I) scale bar: 100 µm.

margin. Differences can be observed between this taxon and the genus *Ilyocypris*, it displays rib-like features, one very pronouncedly along the anterodorsal to the posteroventral region bordering the outline and another less pronouncedly from the posterodorsal to the posteroventral region. Gen. et. sp. indet. 2 has a lateral outline similar to that of *Looneyellopsis* Kröemmelbein and Weber, 1971, but with a broader posterior end and less marked posterior cardinal angle. In dorsal view, it differs by possessing three pronounced sulci extending from the dorsal region to mid-height. *Looneyellopsis*, on the other side, displays three nodules in an upper row of which the anterior two are stronger developed, other two nodules at ventral position with the anterior well marked and the posterior subtler when seen in lateral view, and a more sharply-developed ventrolateral rib.

Genus *Rhinocypris* Anderson, 1940

Rhinocypris spinata Guzmán, Almeida-Lima and Piovesan nov. sp. (Fig. 12A–H)

2020 *Ilyocypris* sp. - Melo et al., p.9, fig.5.8-5.10.

Diagnosis: A *Rhinocypris* species with marked ventral concavity, two shallow sulci in the centrodorsal region and valve surface densely covered by small spines.

Derivation of name: In reference to the spines on the surface ornamentation.

Description: Carapace small, subrectangular in lateral view. Dorsal margin straight, gently sloping down to the posterior end. Ventral margin concave at mid-length. Anterior margin broadly rounded; posterior margin straight to weakly rounded at posteroventral position. Maximum height at the anterior cardinal angle. In dorsal view, carapace ellipsoidal with the median part rectilinear. Two shallow sulci are present from the dorsal region to just above mid-height; the first at one-third anteriorly and the second one at mid-length position. Carapace surface ornamented with spines, a straight line of dense spines is observed along the ventral, anteroventral and posteroventral margins in each valve; nodules also present at the anterior and posterior regions and papillae on the centroventral region. Internal features display the central muscle scars as typical of the family; duplicature wider anteriorly than posteriorly. Simple pore canals densely grouped between the sulci.

Holotype: LMA-00329, juvenile A-2, L: 0.46 mm, H: 0.25 mm (Fig. 12A–F).

Paratype: LMA-00330, juvenile A-2, L: 0.43 mm, H: 0.22 mm, W: 0.17 mm (Fig. 12G–H).

Material: In total 30 carapaces were recovered, 4 poorly preserved correspond to adults.

Type locality: Sítio Romualdo, Crato Municipality, Ceará State, Brazil.

Type horizon: Crato, Ipubi and Romualdo formations, Santana Group, Araripe Basin, Brazil. 2-AR-SR-1A-CE well core samples, depth intervals 54.26–54.29 m, 68.11–68.13 m, 119.32–119.35 m, 119.53–119.56 m and 119.74–119.77 m. Outcrop samples 3BAr05b (Batateira river) and 4BAr01e (Sítio Sobradinho section).

Stratigraphic and geographic distribution: Aptian, Romualdo Formation (Melo et al. 2020), Araripe Basin, Jardim Municipality, Ceará State, Brazil. Ipubi and Crato (this study) formations, Araripe Basin, Crato Municipality, Ceará State, Brazil.

Remarks: The specimens representing the present new species display two weak sulci and lack tubercles, establishing its difference from *Ilyocypris*. In dorsal view, the posterodorsal and anterodorsal regions of each valve are narrower compared with the representatives of the genus *Ilyocypris*. From the Crato Formation, Jatobá Basin, Pernambuco State, Brazil, Tomé et al. (2014) identified specimens belonging to *Rhinocypris* cf. *R. jurassica* Martin, 1940 and *Rhinocypris* aff. *R. jurassica* Martin, 1940. Their specimens exhibit a more angled subrectangular outline with posterior cardinal angle almost straight compared to our specimens, here proposed as a new species.

Family indeterminate

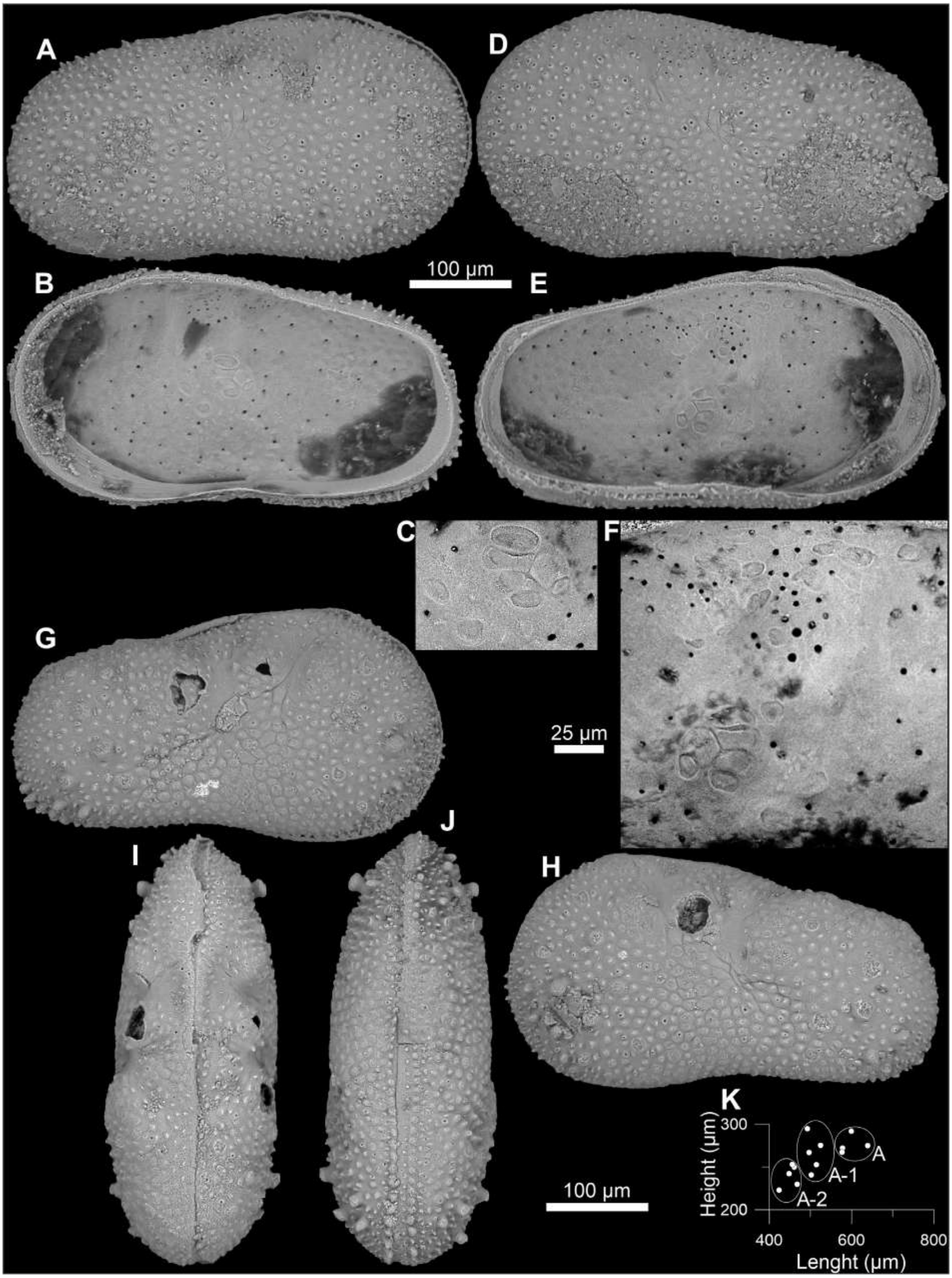

Fig. 12. *Rhinocypris spinata* nov. sp. **A–F,** holotype, LMA-00329 (well 2-AR-SR-1A-CE, sample 119.32 m), juvenile A-2, external (A) and (B) internal right views, (C) close-up of the central muscle scars in right (B) valve, external (D) and internal (E) left view, (F) close-up of the central muscle scars in left (E) valve. **G–J,** paratype 1, LMA-00330 (well 2-AR-SR-1A-CE, sample 119.32 m), juvenile A-2, right (G), left (H), dorsal (I) and ventral (J) views. (A–E, G–J) scale bar: 100 µm, (C, F) scale bar: 25 µm. **K,** scatter plot of the length and height measurements of 14 carapaces of *Rhinocypris spinata* nov. sp. showing clusters of A, A-1 and A-2 ontogenetic stages.

Genus indeterminate

Gen. et. sp. indet. 3 (Fig. 9M–P)

Material: A total of 7 carapaces were recovered.

Dimensions: LMA-00042, juvenile? L: 0.63 mm, H: 0.32 mm, W: 0.19 mm (Fig. 9M–P).

Occurrence: Crato Formation, Santana Group, Araripe Basin, Brazil. Outcrop samples 3BAr06c, (Batateira River).

Stratigraphic and geographic distribution: Aptian, Crato Formation, Santana Group, Araripe Basin, Crato Municipality, Ceará State, Brazil (this study).

Remarks: The present recorded specimens are characterised by having greatest width and height at the posterior region, a feature typical of the Superfamily Darwinuloidea. Nonetheless, the individuals recovered have a fusiform outline in dorsal view and are narrower than any genus in this superfamily. Furthermore, the central muscle scar (Fig. 9N) is characteristic of a cypridoid.

Suborder CYTHEROCOPINA Gründel, 1967

Infraorder ARCHAEOCYTHERININA Liebau, 1991

Superfamily LIMNOCYTHEROIDEA Klie, 1938

Family TIMIRIASEVIIDAE Mandelstam, 1960

Genus *Theriosynoecum* Branson, 1936 emend. Sames, 2011

Theriosynoecum colini Do Carmo, Coimbra, Whatley, Antonietto and Citon, 2013 (Fig. 13A–F)

1999 NC 36 - Colin and Dépêche, fig.4.10, 4.12.

2013 *Theriosynoecum colini* nov. sp. - Do Carmo, Coimbra, Whatley, Antonietto and Citon, p.101, fig.6.13-6.18.

Material: In total, two carapaces were recovered.

Dimensions: LMA-00316, adult female, L: 0.97 mm, H: 0.58 mm, W: 0.50 mm (Fig. 13A–C); LMA-00317, male juvenile A-1, L: 0.74 mm, H: 0.44 mm, W: 0.34 mm (Fig. 13D–F).

Occurrence: Ipubi Formation, Santana Group, Araripe Basin, Brazil. 2-AR-SR-1A-CE well core sample, depth interval 46.38–46.40 m

Stratigraphic and geographic distribution: Aptian, Ipubi Formation, Araripe Basin, Nova Olinda Municipality, Ceará State, Brazil (this study). Mid-upper Aptian, Alagamar Formation, Potiguar Basin, Rio Grande do Norte State, Brazil (Do Carmo et al., 2013). Upper Aptian–lower Albian, Bongor, Doba and Doseo basins, Chad, north-central Africa (Colin and Dépêche, 1997).

Theriosynoecum silvai (Silva, 1978) emend. Do Carmo et al., 2004 (Fig. 13G–L)

1978b *Bisulcocypris silvai* nov. sp. - Silva, p.1014, pl.1, fig.1-4.

1978 *Bisulcocypris munizi* nov. sp. Silva, p.1016, pl.1, fig.5-8.

1978 *Bisulcocypris quadrinodosa* nov. sp. - Silva, p.1018, pl.1, fig.9-12.

1994 *Theriosynoecum silvai* (Silva) - Berthou et al., pl.2, fig.5-8, 12-13.

1994 *Theriosynoecum munizi* (Silva) - Berthou et al., pl.2, fig.1-2.

1994 *Theriosynoecum quadrinodosa* (Silva) - Berthou et al., pl.2, fig.3-4.

1997 *Theriosynoecum silvai* (Silva) - Colin and Dépêche, fig.2.4, 2.6, 2.9, 2.15.

1997 *Theriosynoecum silvai* (Silva) - Colin and Dépêche, fig.4.6-4.7, 4.11.

1997 *Theriosynoecum munizi* (Silva) - Colin and Dépêche, fig.2.7-2.8, 2.10-2.12.

2002 *Theriosynoecum silvai* (Silva) - Coimbra et al., fig.4.34-4.35.

2002 *Theriosynoecum munizi* (Silva) - Coimbra et al., fig.4.36-4.37.

2004 *Theriosynoecum silvai* (Silva) - Do Carmo et al., p.154, fig.3.1-3.20.

2013 *Theriosynoecum silvai* (Silva) - Do Carmo et al., p.101, fig.6.9-6.12.

2014 *Theriosynoecum silvai* (Silva) - Tomé et al., p.169, fig.14G-S.

2022 *Theriosynoecum quadrinodosum* Krömmelbein and Weber - Araripe et al., fig.5.11a-b.

2022 *Theriosynoecum* cf. *quadrinodosum* Krömmelbein and Weber - Tomé et al., p.552 fig.5P-R.

Material: In total 245, carapaces between adults and juveniles were recovered.

Dimensions: LMA-00314, adult female, L: 0.86 mm, H: 0.41 mm, W: 0.51 mm (Fig. 13G–I); LMA-00315, adult male, L: 0.80 mm, H: 0.42 mm, W: 0.37 mm (Fig. 13J–L).

Occurrence: Barbalha, Ipubi and Crato formations, Santana Group, Araripe Basin, Brazil. 2-AR-SR-1A-CE well core samples from, depth intervals 54.26–54.29 m, 120.23–121.98 m, 122.33–122.35 m, 122.93–122.97 m, 124.47–124.58 m and 125.00–125.24 m. 2-AR-SR-1B-CE well core sample, depth interval 78.29–78.30 m. Outcrop samples 3BAr05a and 3BAr06b (Batateira River).

Stratigraphic and geographic distribution: Aptian, Crato Formation (Silva, 1978b; Berthou et al., 1994; Colin and Dépêche, 1997; Coimbra et al., 2002; Tomé et al., 2014; this study), Barbalha (this study) and Romualdo Formation (Araripe et al., 2022; Tomé et al., 2022). Araripe Basin, Ceará State, Brazil. Aptian, Crato Formation, Jatobá Basin, Serra Negra hill, Ibimirim Municipality, Pernambuco (Tomé et al., 2014). Mid-upper Aptian, Alagamar Formation, Potiguar Basin, Rio Grande do Norte State, Brazil (Do Carmo et al., 2013). Upper Aptian–lower Albian, Bongor, Doba and Doseo basins, Chad, north-central Africa (Colin and Dépêche, 1997).

Theriosynoecum sp. (Fig. 13M–O)

Material: In total two carapaces were recovered.

Dimensions: LMA-00318, L: 0.32 mm, H: 0.20 mm, W: 0.17 mm (Fig. 13M–O).

Occurrence: Crato Formation, Santana Group, Araripe Basin, Brazil. 2-AR-SR-1A-CE well core sample, depth interval 120.39–120.42 m. Outcrop sample 1BAr17b (Três Irmãos Quarry).

Stratigraphic and geographic distribution: Aptian, Crato Formation, Araripe Basin, Nova Olinda Municipality, Ceará State, Brazil (this study).

Remarks: A *Theriosynoecum* species with subrhomboidal to subrectangular outline in lateral view, dorsal margin straight. Cardinal angles well defined, especially the posterior one. Surface reticulate. Our specimens are probably juveniles and could not be assigned to a described *Theriosynoecum* species.

Genus *Timiriasevia* Mandelstam, 1947

Timiriasevia? sp. (Fig. 13P–R)

Material: One carapace.

Dimensions: LMA-00319, L: 0.40 mm, H: 0.24 mm, W: 0.22 mm (Fig. 13P–R).

Occurrence: Crato Formation, Santana Group, Araripe Basin, Brazil. 2-AR-SR-1A-CE well core sample, depth interval 121.28–121.31 m.

Stratigraphic and geographic distribution: Aptian, Crato Formation, Araripe Basin, Nova Olinda Municipality, Ceará State, Brazil (this study).

Remarks: This taxon is questionably included in the genus *Timiriasevia* because of some shared features. The ventral margin is similarly concave at the anterior third, the dorsal margin is almost straight, and the carapace surface is completely reticulate, with reticules narrower in a ridge-like pattern towards ventral margin, displaying an incipient rib in each valve. However, the anterior outline differs from that described for the genus *Timiriasevia*. Our morphotype shows an asymmetrical outline from the anterior cardinal angle to mid-height where it curves ventrally making a trunk-like projection.

Suborder DARWINULOCOPINA Sohn, 1988

Superfamily DARWINULOIDEA Brady and Norman, 1889

Family DARWINULIDAE Brady and Norman, 1889

Genus *Alicenula* Rossetti and Martens, 1998

Alicenula martinsi (Silva, 1978) emend. Do Carmo et al., 2004 (Fig. 13S–U)

1978c *Darwinula martinsi* nov. sp. - Silva, p.1028, pl.1, fig.1-2.

1990 *Darwinula* cf. *martinsi* Silva - Silva-Telles and Viana, pl.2 fig.4.

1997 *Darwinula martinsi* Silva - Colin and Dépêche, fig.2.18.

1997 *Darwinula* cf. *martinsi* Silva - Colin and Dépêche, fig.6.11.

2002 *Darwinula martinsi* Silva - Coimbra et al., fig.4.32.

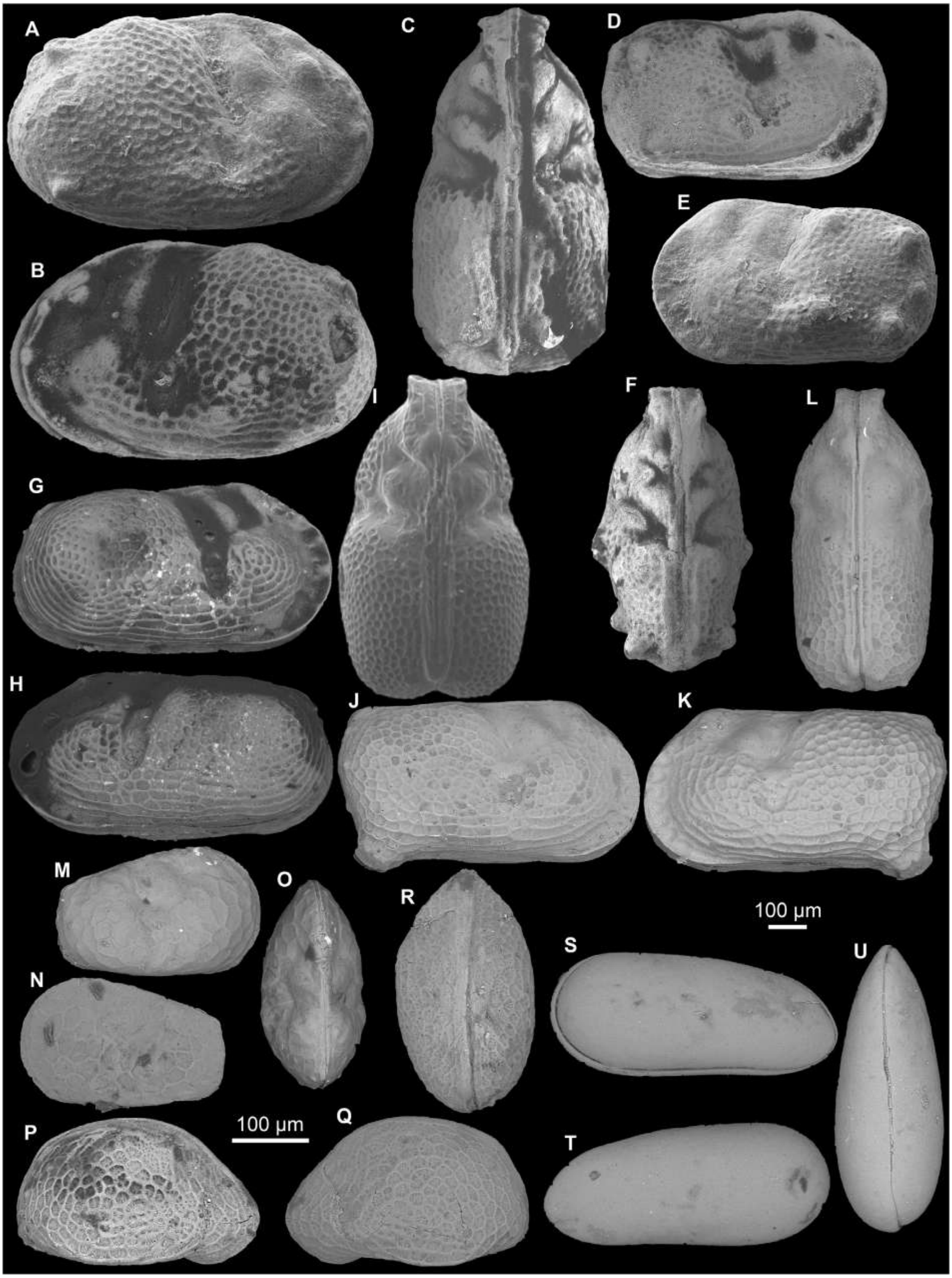

Fig. 13. Ostracod specimens of the Timiriaseviidae and Darwinulidea. **A–C,** *Theriosynoecum colini*, LMA-00316 (well 2-AR-SR-1A-CE, sample 46.38 m), adult female, right (A), left (B) and dorsal (C) views. **D–F,** *Theriosynoecum colini*, LMA-00317 (well 2-AR-SR-1A-CE, sample 46.38 m), male juvenile A-1, right (D), left (E) and dorsal (F) views. **G–I,** *Theriosynoecum silvai*, LMA-00314 (well 2-AR-SR-1A-CE, sample 120.39 m), adult female, right (G), left (H) and dorsal (I) views. **J–L,** *Theriosynoecum silvai*, LMA-00315 (well 2-AR-SR-1A-CE, sample 121.05 m), adult male, right (J), left (K) and dorsal (L) views. **M–O,** *Theriosynoecum* sp., LMA-00318 (outcrop 1BAr17, sample b), right (M), left (N) and dorsal (O) views. **P–R,** *Timiriasevia*? sp., LMA-00319 (well 2-AR-SR-1A-CE, sample 121.28 m), right (P), left (Q) and dorsal (R) views. **S–U,** *Alicenula martinsi*, LMA-00320 (well 2-AR-SR-1A-CE, sample 121.05 m), right (S), left (T) and dorsal (U) views. (A–L, S–U) scale bar: 100 µm, (M–R) scale bar: 100 µm.

2004 *Darwinula martinsi* Silva - Do Carmo et al., p.156, fig.3.21-3.27.
2013 *Darwinula martinsi* Silva - Do Carmo et al., p.103, fig.5.9.
2014 *Alicenula leguminella* (Forbes) - Tomé et al., p.171, fig.14T-V.
2020 *Alicenula* sp. Melo et al., fig.5.11-5.12.
2022 *Alicenula leguminella* (Forbes) - Araripe et al., fig.5.12a-b.
2022 *Alicenula* cf. *leguminella* (Forbes) - Tomé et al., p.550 fig.5M-O.

Material: In total, 181 carapaces of adults and juveniles were recovered.

Dimensions: LMA-00320, A L: 0.76 mm, H: 0.32 mm, W: 0.29 mm (Fig. 13S–U).

Occurrence: Crato, Ipubi and Romualdo formations, Santana Group, Araripe Basin, Brazil. 2-AR-SR-1A-CE well core samples, depth intervals 36.51–36.54 m, 39.52–39.70 and 64.37–64.40 m, 68.11–68.33 m, 69.67–69.70 m, 70.78–70.85 m, 97.67–97.70 m, 106.60–106.62 m, 107.09–107.11 m, 120.39–120.50 m, 120.82–120.84 m, 121.05–121.31 m, 121.68–121.86 m, 121.16–122.18 m, 124.30–124.58 m and 125.00–125.14 m. Outcrop samples 3BAr06c (Batateira River) and 4BAr01e (Sítio Sobradinho section).

Stratigraphic and geographic distribution: Aptian, Romualdo Formation (Coimbra et al., 2002; Melo et al., 2020; Araripe et al., 2022; Tomé et al., 2022; this study), Ipubi Formation (Silva, 1978c; Silva-Telles and Viana 1990; this study) and Crato Formation (Silva, 1978c; Silva-Telles and Viana, 1990; Colin and Dépêche, 1997; Do Carmo et al., 2004; Tomé et al., 2014; this study), Araripe Basin, Ceará State, Brazil. Aptian, Crato Formation, Jatobá Basin, Serra Negra hill, Ibimirim Municipality, Pernambuco (Tomé et al., 2014). Mid-upper Aptian, Alagamar Formation, Potiguar Basin, Rio Grande do Norte State, Brazil (Do Carmo et al., 2013). Upper Aptian–lower Albian, Bongor, Doba and Doseo basins, Chad, north-central Africa (Colin and Dépêche, 1997).

Remarks: The species *Alicenula martinsi* was originally described belonging to the genus *Darwinula* Brady and Robertson, 1885, in sight of its elongated outline. Nevertheless, the genus *Darwinula* was described as having the right valve much larger than left. The Aptian specimens assigned to this genus display the left valve overlapping the right one along the free margin. A taxonomic revision of the Recent and Holocene representatives of the Darwinulidae was made by Rossetti and Martens (1998) comprising internal carapace characters and resulted in the description of three genera including *Alicenula*, a small darwinulid showing both normal (LV>RV) and reverse (RV>LV) overlapping. Thus, the Aptian morphotype occurring in Brazil and Africa better fits into the genus *Alicenula*.

Author contributions

J.G. wrote the main part of the manuscript, organized and prepared all figures. J.G. and V.H.M.L.N. conducted the sedimentogical description of well cores and outcrops. J.G., D.S.A-L. and E.K.P. performed the descriptive research of ostracods. E.K.P., V.H.M.L.N. and A.J.S. designed the project. All authors contributed and reviewed the manuscript.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Enelise Katia Piovesan reports financial support was provided by Petrobras.

Data Availability

No data was used for the research described in the article.

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References

Almeida-Lima, D.S., Piovesan, E.K, Almeida-Lima, D.S.de, Piovesan, E.K., Sayão, J.M., Lima, F.J.de, 2020. Description and ontogeny of *Pattersoncypris minima* sp. nov. (Crustacea: Ostracoda), Araripe Basin, Northeast Brazil. Zootaxa 4851, 171–179. doi:10.11646/zootaxa.4851.1.8.

Anderson, F.W., 1966. New genera of Purbeck and Wealden Ostracoda. Bull. Br. Museum Natural Hist. Geol. II, 436–487.

Anderson, F.W., 1940. Ostracoda from the Portland and Purbeck Beds at Swindon. Proc. Geol. Assoc. London 51, 373–384. doi:10.1016/S0016-7878(40)80031-X.

Antonietto, L.S., Do Carmo, D.A., Viviers, M.C., Neto, J.V.Q., Hunt, G., 2016. Ostracoda (Arthropoda, Crustacea) from the Riachuelo formation, Sergipe-Alagoas Basin, Brazil, Upper Aptian-Albian. Eur. J. Taxon. 244, 1–57. doi:10.5852/ejt.2016.244.

Antonietto, L.S., Gobbo, S.R., Do Carmo, D.A., Assine, L.M., Castanheira, M.A.M., Silva, J.E.L., 2012. Taxonomy, ontogeny and paleoecology of two species of *Harbinia* Tsao, 1959 (Crustacea, Ostracoda) from the Santana formation, Lower Cretaceous, Northeastern Brazil. J. Paleontol. 86, 659–668.

Arai, M., Assine, M.L., 2020. Chronostratigraphic constraints and paleoenvironmental interpretation of the Romualdo Formation (Santana Group, Araripe Basin, Northeastern Brazil) based on palynology. Cretac. Res. 116, 104610. doi:10.1016/j.cretres.2020.104610.

Araripe, R.C., Oliveira, D.H., Tomé, M.E., Mello, R.M., Barreto, A.M.F., 2021. Foraminifera and Ostracoda from the Lower Cretaceous (Aptian–lower Albian) Romualdo Formation, Araripe Basin, northeast Brazil: Paleoenvironmental inferences. Cretac. Res. 122, 104766. doi:10.1016/j.cretres.2021.104766.

Araripe, R.C., Lemos, F.A.P., Prado, L.A.C., Tomé, M.E.T.R., Oliveira, D.H., Pereira, P.A., Nascimento, L.R., Asakura, Y., Ng, C., Viviers, M.C., Barreto, A.F., 2022. Upper Aptian–lower Albian of the southern-central Araripe Basin, Brazil: Microbiostratigraphic and paleoecological inferences. J. South Am. Earth Sci. 116, 103814. doi:10.1016/j.jsames.2022.103814.

Assine, M.L., 2007. Bacia do Araripe. Bol. Geociências da Petrobras 15, 371–389.

Assine, M.L., Perinotto, J.A., de, J., Custódio, M.A., Neumann, V.H., Varejão, F.G., Mescolotti, P.C., 2014. Sequências deposicionais do Andar Alagoas da Bacia do Araripe, Nordeste do Brasil. Bol. Geociências da Petrobras 22, 3–28.

Baird, W., 1845. Arrangement of the British Entomostraca, with a List of species, particularly noticing those which have as yet been discovered within the bounds of the Club. Trans. Berwicksh. Nat. Club 2, 145–158.

Bantim, R.A.M., de Andrade, R.C.L.P., Ferreira, J.S., Saraiva, A.Á.F., Kellner, A.W.A., Sayão, J.M., 2021. Osteohistology and growth pattern of a large pterosaur from the Lower Cretaceous Romualdo Formation of the Araripe Basin, Northeastern Brazil. Cretac. Res. 118. doi:10.1016/j.cretres.2020.104667.

Bate, R.H., 1999. Non-marine ostracod assemblages of the Pre-Salt rift basins of West Africa and their role in sequence stratigraphy. Geol. Soc. Spec. Publ. 153, 283–292. doi:10.1144/GSL.SP.1999.153.01.17.

Bate, R.H., 1972. Phosphatized ostracods with appendages from the Lower Cretaceous of Brazil. Palaeontology 15, 379–393. doi:10.1038/230397a0.

Bate, R.H., Horne, D.J., Horne, S.E., Douglas, L., Miller, C.G., Lord, A.R., 2022. Non-marine Ostracoda (Crustacea) of the Early Cretaceous ‘Pre-Salt’ sediments of Brazil: an illustrated catalogue of the type specimens of Wicher, Krömmelbein, Krömmelbein & Weber, and Bate. Zootaxa 5098 (1), 001–084. doi:10.11646/zootaxa.5098.1.1.

Berthou, P.Y., Dépêche, F., Colin, J.P., Filgueira, J.B., de, M., Teles, M.do S.L., 1994. New data on the ostracods from the Crato lithologic units (lower member of the Santana Formation, latest Aptian–lower Albian) of the Araripe Basin (Northeastern Brazil). Acta Geol. Leopoldensia XVII, 539–554.

Bosquet, J., 1852. Description des Entomostracés fossiles des terrains Tertiares de la France et de la Belgique. Mémoires Couronnés Mémoires des Savants Étrangers 24, 1–142.

Brady, G.S., Norman, A.M., 1889. A monograph of the marine and freshwater Ostracoda of the North Atlantic and of Northwestern Europe. Section 1: Podocopa. Sci. Trans. R. Dublin Soc. 63–270 Series 2.

Branson, C.C., 1936. New name for a Morrison ostracod genus. J. Paleontol. 10, 323.

Brito, P.M., Yabumoto, Y., 2011. An updated review of the fish faunas from the Crato and Santana formations in Brazil, a close relationship to the Tethys fauna. Bull. Kitakyushu Museum Nat. Hist. Hum. Hist. Ser. A 9, 107–136.

Carignano, A.P., Paredes, J.M., Olazábal, S.X., Valle, M.N., 2017. Ostracoda (Crustacea) from the Pozo D-129 Formation (upper Barremian?–Aptian), Golfo San Jorge Basin, Patagonia, Argentina: Taxonomic descriptions, palaeoenvironments and palaeogeographical implications. Cretac. Res. 78, 206–220. doi:10.1016/j.cretres.2017.06.015.

Chang, H.K., Kowsmann, R.O., Figueiredo, A.M.F., Bender, A.A., 1992. Tectonics and stratigraphy of the East Brazil Rift system: an overview. Tectonophysics 213, 97–138. doi:10.1016/0040-1951(92)90253-3.

Coimbra, J.C., Arai, M., Carreño, A.L., 2002. Biostratigraphy of Lower Cretaceous microfossils from the Araripe Basin, northeastern Brazil. Geobios 35, 687–698. doi:10.1016/s0016-6995(02)00082-7.

Colin, J.-P., Dépêche, F., 1997. Faunes d'ostracods lacustres des bassins intra-cratoniques d'âge albo-aptien en Afrique de l'Ouest (Cameroun, Tchad) et au Brésil : considérations d'ordre paléoécologique et paléobiogéographique. Afr. Geosci. Rev. 4, 431–450.

Custódio, M.A., Quaglio, F., Warren, L.V., Simões, M.G., Fürsich, F.T., Perinotto, J.A.J., Assine, M.L., 2017. The transgressive-regressive cycle of the Romualdo Formation (Araripe Basin): Sedimentary archive of the Early Cretaceous marine ingression in the interior of Northeast Brazil. Sediment. Geol. 359, 1–15. doi:10.1016/j.sedgeo.2017.07.010.

Do Carmo, D.A., Coimbra, J.C., Whatley, R.C., Antonietto, L.S., Citon, R.T., de, P., 2013. Taxonomy of limnic Ostracoda (Crustacea) from the Alagamar Formation, middle–upper Aptian, Potiguar Basin, northeastern Brazil. J. Paleontol. 87, 91–104. doi:10.1666/11-108r.1.

Do Carmo, D.A., Rafael, R.M.L., Vilhena, R.M., Tomassi, H.Z., 2004. Redescrição de *Theriosynoecum silvai* e *Darwinula martinsi*, Membro Crato (Formação Santana), Cretáceo Inferior, Bacia do Araripe, NE, Brasil. Rev. Bras. Paleontol. 7, 151–158. doi:10.4072/rbp.2004.2.07.

Do Carmo, D.A., Whatley, R., Queiroz Neto, J.V., Coimbra, J.C., 2008. On the validity of two Lower Cretaceous non-marine ostracode genera: biostratigraphic and paleogeographic implications. J. Paleontol. 82, 790–799. doi:10.1666/07-008.1.

Dos Santos, M.F.A., Mattos, I., Mermudes, J.R.M., Scheffler, S.M., Reyes-Castillo, P., 2021. A new passalid fossil (Insecta: Coleoptera) from the Santana Formation (Crato Member, Lower Cretaceous), Araripe Basin, NE Brazil: Paleoecological and paleobiogeographic implications. Cretac. Res. 118. doi:10.1016/j.cretres.2020.104664.

Fambrini, G.L., Silvestre, D.D.C., Menezes-Filho, J.A.B.de, Costa, I.C.da, Neumann, V.H.D.M.L., 2019. Architectural and facies characterization of the Aptian fluvial Barbalha Formation, Araripe Basin, NE Brazil. In: Corbett, P.W.M., Owen, A., Hartley, A.J., Pla-Pueyo, S., Barreto, D., Hackney, C., Kape, S.J. (Eds.), River to Reservoir: Geoscience to Engineering. Geological Society, London, pp. 119–150. doi:10.1144/SP488-2017-275.

Goldberg, K., Premaor, E., Bardola, T., Souza, P.A., 2019. Aptian marine ingression in the Araripe Basin: implications for paleogeographic reconstruction and evaporite accumulation. Mar. Pet. Geol. 107, 214–221. doi:10.1016/j.marpetgeo.2019.05.011.

Grosdidier, E., 1967. Quelques ostracodes nouveaux de la Série Anté-Salifère ("Wealdienne") des bassins côtiers du Gabon et du Congo. Rev. Micropaleontol. 10, 107–118.

Gründel, J., 1967. Zur Großgliederung der Ordnung Podocopida G. W. Müller, 1894 (Ostracoda). Neues Jahrb. für Geol. und Paläontologie 321–332.

Horne, D.J., 2005. Ostracoda. In: Selley, R.C., Cocks, R.M., Limer, I.R. (Eds.), Encyclopedia of Geology. Elsevier, Oxford, pp. 453–463.

Jones, T.R., Chapman, F., 1901. On some Fossils of Wenlock Age from Mulde, near Klinteberg, Gotland. Ann. Mag. Nat. Hist. 7, 141–160.

Karanovic, I., Marmonier, P., 2002. On the genus *Candonopsis* (Crustacea: Ostracoda: Candoninae) in Australia, with a key to the world recent species. Ann. Limnol. 38, 199–240. doi:10.1051/limn/2002018.

Kaufmann, A., 1900. Zur systematik der Cypriden. Mitth. der Naturforschenden Gesellschaft Bern 103–109.

Kellner, A.W.A., Campos, D., de, A., 2002. The function of the cranial crest and jaws of a unique pterosaur from the Early Cretaceous of Brazil. Science 297, 389–392. doi:10.1126/science.1073186, 80-.

Klie, W., 1938. Krebstiere oder Crustacea – III: Ostracoda, Muschelkrebse. Verlag von Gustav Fischer, Jena.

Kozur, H., 1972. Einige Bemerkungen zur Systematik der Ostracoden und Beschreibung neuer Platycopida aus der Trias Ungarns und der Slowakei. Geol. Mitteilungen 2, 1–29.

Krömmelbein, K., 1965. Neue, für Vergleiche mit West-Afrika wichtige ostracoden-Arten der Brasilianischen Bahia Serie (Ober-Jura? Unter-Kreide in Wealden-Fazies). Sonderdruck aus Sennckenbergiana Lethaea 46, 177–213.

Krömmelbein, K., 1962. Zur taxionomie und biochronologie stratigraphisch wichtiger Ostracoden-Arten aus der oberjurassisch?-unterkretazischen Bahia-Serie (Wealden–Fazies) NE-Brasiliens. Senckenbergiana lethaea 43, 437–527.

Krömmelbein, K., Weber, R., 1971. Ostracoden des "Nordost-Brasilianischen Wealden". Beihefte zum Geol. Jahrb. 115, 3–93.

Kuchle, J., Scherer, C.M.D.S., 2010. Sismoestratigrafia de bacias rifte: Técnicas, métodos e sua aplicação na Bacia do Recôncavo. Bol. Geociencias da Petrobras 18, 179–206.

Latreille, P.A., 1802. Histoires des Cypris et des Cytherées. In: Histoire Naturelle, Générale et Particulière Des Crustacés et Des Insectes, pp. 232–254.

Liebau, A., 2005. A revised classification of the higher taxa of the Ostracoda (Crustacea). In: Ikeya, N., Tsukagoshi, A., Horne, D.J. (Eds.), Evolution and Diversity of Ostracoda. Springer, pp. 115–137. doi:10.1007/s10750-004-4943-7.

Liebau, A., 1991. Skulptur-Evolution bei Ostrakoden am Beispiel europäischer 'Quadracytheren. Geol. und Palaeontol. Westfalen 13, 1–395.

Lima, F.J.De, Saraiva, A.Á.F., Sayão, J.M., 2012. Revisão da paleoflora das formações Missão Velha, Crato e Romualdo, Bacia do Araripe, Nordeste do Brasil. Estud. Geol. 22, 99–115.

Mandelstam, M.I., Kashevarova, N.P., Mandelstam, M.I., Schneider, G.F., 1960. Ostracoda: nadsemeystvo cytheracea. In: Orlov, Y.A. (Ed.), Osnovy Paleontologii Vol. 8. Gosudarstvennoe Nauchno–Technicheskoe Isdatelstvo Literaturiy po Geologii i Ochrane Nedra, Moskva, pp. 365–411 [in Russian].

Mandelstam, M.I., 1947. Ostracoda iz otlozheniy Sredney Yuri Poluostrova Mangyshlaka [Ostracoda from Middle Jurassic deposits of the Mangishlak peninsula]. Mikrofauna Neftyanykh Mestorozhdeniy Kavkasa, Emby i Sredney Azii [Microfauna of the Oil Fields of the Caucasus, Emba and Central Asia]. VNIGRI, pp. 239–259 [in Russian].

Martin, G.P.R., 1940. Ostracoden des norddeutschen Purbeck und Wealden. Senckenbergiana 22, 275–361.

Melo, R.M., Guzmán, J., Almeida-Lima, D., Piovesan, E.K., Neumann, V.H.de M.L., Sousa, A.de J.e., 2020. New marine data and age accuracy of the Romualdo Formation, Araripe Basin, Brazil. Sci. Rep. 10, 15779. doi:10.1038/s41598-020-72789-8.

Mohr, B.A.R., Bernardes-de-Oliveira, M.E.C., Loveridge, R.F., 2007. The macrophyte flora of the Crato Formation. In: Martill, D.M., Bechly, G., Loveridge, R.F. (Eds.), Crato Fossil Beds of Brazil: Window into an Ancient World. Cambridge University Press, pp. 537–565. doi:10.1017/CBO9780511535512.020.

Moura, J.A., 1988. Ostracods from Non-marine Early Cretaceous Sediments of the Campos Basin, Brazil. Dev. Palaeontol. Stratigr. 11, 1207–1216. doi:10.1016/S0920-5446(08)70250-4.

Moura, J.A., Praça, U.M., 1985. Ostracodes das Sequencias não marinhas e transicionais Mesozóicas (Andares Jiquiá e Alagoas), Bacia de Campos. Coletânea Trab. Paleontol. 27, 401–408.

Müller, G.W., 1898. Ergebnisse einer zoologischen Forschungsreise in Madagaskar und Ost-Afrika 1889–1895 von Dr A Voeltzkow: die Ostracoden. Abhandlungen der Senckenbergischen Naturforschenden Gesellschaft 21, 255–296.

Musacchio, E., 1973. Carophytas y ostracodos no marinos del grupo Neuquen (Cretácico Superior) en algunos afloramientos de las provincias de Rio Negro y Neuquen, Republica Argentina. Rev. del Mus. La Plata 48, 1–32.

Musacchio, E., Simeoni, M., 1991. Taxonomy of some Cretaceous non-marine ostracods of palaeobiographical interest. Neues Jahrb. Geol. Palaontol. Abh..

Musacchio, E.A, Dias-Brito, D., Musacchio, E.A., de Castro, J.C., Maranhão, M.S.A.S., Suárez, J.M., Rodrigues, R., 2001. Grupo Bauru: uma unidade continental do Cretáceo no Brasil - concepções baseadas em dados micropaleontológicos, isotópicos e estratigráficos. Rev. Paleobiol. 20, 245–304.

Neumann, V.H., Cabrera, L., 1999. Una nueva propuesta estratigráfica para la tectono-sequência Pós-rifte de la Cuenca de Araripe, Noreste de Brasil. In: 5° Simpósio Sobre o Cretáceo Do Brasil. UNESP, Rio Claro, pp. 279–285.

Neumann, V.H.M.L., 1999. Estratigrafia, sedimentologia, geoquímica y diagénesis de los sistemas lacustres aptienses-albienses de lá Cuenca de Araripe (Noreste do Brasil). Universitat de Barcelona.

Pinto, I.D., Sanguinetti, Y.T., 1958. *Bisulcocypris* a new mesozoic genus and preliminary note about its relation with metacypris and allied forms. Bol. da Soc. Bras. Geol. 7, 75–90.

Piovesan, E.K., Melo, G.D., Cabral, M.C., Guzmán, J., 2022. New early Cretaceous species of *Zonocypris* G. W. Müller, 1898 (Crustacea: Ostracoda) from the Crato Formation, Brazil. Zootaxa 5141 (6), 581–591. doi:10.11646/zootaxa.5141.6.4.

Ponte, F.C., Asmus, 1976. The Brazilian marginal basins: current state of knowledge. An. Acad. Bras. Cienc. 48, 215–239.

Poropat, S.F., Colin, J.P., 2012a. Early Cretaceous ostracod biostratigraphy of eastern Brazil and western Africa: An overview. Gondwana Res. 22, 772–798. doi:10.1016/j.gr.2012.06.002.

Poropat, S.F., Colin, J.P., 2012b. Reassessment of the early Cretaceous non-marine ostracod genera *Hourqcia* Krömmelbein, 1965 and *Pattersoncypris* Bate, 1972 with the description of a new genus, Kroemmelbeincypris. J. Paleontol. 86, 699–719.

Ramos, M.I.F., Rossetti, D.F., Paz, J.D.S., 2006. Caracterização e significado paleoambiental da fauna de ostracodes da Formação Codó (Neoaptiano), leste da Bacia de Grajaú, MA, Brasil. Rev. Bras. Paleontol. 9, 339–348.

Rossetti, G., Martens, K., 1998. Taxonomic revision of the Recent and Holocene representatives of the family Darwinulidae (Crustacea, Ostracoda), with a description of three new genera. Bull. l'Institut R. des Sci. Nat. Belqique, Biol. 68, 55–110.

Sames, B., 2011. Taxonomic studies in early Cretaceous nonmarine Ostracoda of North America. Micropaleontology 57, 289–290.

Sars, G.O., 1866. Oversigt af Norges marine ostracoder. Forh. i Vidensk. i Christ. 7, 1–30.

Sayão, J.M., Saraiva, A.Á.F., Brum, A.S., Bantim, R.A.M., de Andrade, R.C.L.P., Cheng, X., de Lima, F.J., de, Paula, Silva, H., Kellner, A.W.A., 2020a. The first theropod dinosaur (Coelurosauria, Theropoda) from the base of the Romualdo Formation (Albian), Araripe Basin, Northeast Brazil. Sci. Rep. 10, 1–15. doi:10.1038/s41598-020-67822-9.

Sayão, J.M., Saraiva, A.Á.F., Brum, A.S., Bantim, R.A.M., de Andrade, R.C.L.P., Cheng, X., de Lima, F.J., de, Paula, Silva, H., Kellner, A.W.A., 2020b. Author Correction: The first theropod dinosaur (Coelurosauria, Theropoda) from the base of the Romualdo Formation (Albian), Araripe Basin, Northeast Brazil (Scientific Reports, (2020), 10, 1, (10892), 10.1038/s41598-020-67822-9). Sci. Rep. 10, 7–8. doi:10.1038/s41598-020-70349-8.

Schaller, H., 1969. Revisão estratigráfica da Bacia de Sergipe/Alagoas. Bol. Técnico da Petrobras 12, 21–86.

Scherer, C.M.dos S., Goldberg, K., Bardola, T., 2015. Facies architecture and sequence stratigraphy of an early post-rift fluvial succession, Aptian Barbalha Formation, Araripe Basin, northeastern Brazil. Sediment. Geol. 322, 43–62. doi:10.1016/j.sedgeo.2015.03.010.

Scherer, C.M.dos S., Sá, E.F.J.de, Córdoba, V.C., Sousa, D.do C., Aquino, M.M., Cardoso, F.M.C., 2014. Tectono-stratigraphic evolution of the Upper Jurassic-Neocomian rift succession, Araripe Basin, Northeast Brazil. J. South Am. Earth Sci. 49, 106–122. doi:10.1016/0191-8141(88)90108-3.

Silva-Telles Jr, A.C., Viana, M.S.S., 1990. Paleoecologia dos ostracodes de Formacao Santana (Bacia do Araripe) : um estudo ontogenetico de populações. In: 1 Simpósio Sobre a Bacia Do Araripe e Bacias Interiores Do Nordeste, Crato, pp. 309–327.

Silva, M.D., 1978a. Ostracodes da Formação Santana (Cretáceo Inferior) - Grupo Araripe - nordeste do Brasil II - Nova espécie do gênero *Cypridea*. XXX Congresso Brasileiro de Geologia, Recife, pp. 1023–1027.

Silva, M.D., 1978b. Ostracodes da Formação Santana (Cretáceo Inferior) - Grupo Araripe -

nordeste do Brasil I - Novas espécies do gênero *Bisulcocypris*. XXX Congresso Brasileiro de Geologia, Recife, pp. 1014–1022.

Silva, M.D., 1978c. Ostracodes da Formação Santana (Cretáceo Inferior) - Grupo Araripe - nordeste do Brasil III - Nova espécie do gênero *Darwinula* Brady and Robertson, 1885. XXX Congresso Brasileiro de Geologia, Recife, pp. 1028–1031.

Silva, M.D., Arruda, G., 1976. Insetos (Hymenoptera) cretáceos do Grupo Araripe - Nordeste do Brasil. An. do Inst. Ciências Biol. 3, 45–54.

Smith, R.J., 2000. Morphology and ontogeny of Cretaceous ostracods with preserved appendages from Brazil. Palaeontology 43, 63–98.

Sohn, I.G., 1988. Darwinulocopina (Crustacea: Podocopa), a new suborder proposed for nonmarine Paleozoic to Holocene Ostracoda. Proc. Biol. Soc. Washingt. 101, 817–824.

Sucerquia, P.A., Bernardes-de-Oliveira, M.E.C., Mohr, B.A.R., 2015. Phytogeographic, stratigraphic, and paleoclimatic significance of *Pseudofrenelopsis capillata* sp. nov. from the Lower Cretaceous Crato Formation, Brazil. Rev. Palaeobot. Palynol. 222, 116–128. doi:10.1016/j.revpalbo.2015.07.012.

Swain, F.M., 1946. Middle Mesozoic nonmarine Ostracoda from Brazil and New Mexico. J. Paleontol. 20, 543–555.

Tambareau, Y., 1982. Les ostracodes et l'histoire géologique de l'Atlantique Sud au Crétacé. Bull. Centres Rech. Explor.-Prod. Elf. Aquitaine 6, 1–37.

Teixeira, M.C., Mendonça Filho, J.G., Oliveira, A.D.de, Assine, M.L., 2017. Faciologia orgânica da Formação Romualdo (Grupo Santana, Cretáceo Inferior da Bacia do Araripe): caracterização da matéria orgânica sedimentar e interpretação paleoambiental. Geol. USP. Série Científica 17, 19. doi:10.11606/issn.2316-9095.v17-347.

Tomé, M.E., Lima Filho, M.F., 2010. Ostracodes da Bacia de Cedro, Andar Alagoas, Estado de Pernambuco, NE, Brasil: implicações paleoambientais e bioestratigráficas. Estud. Geol. 20, 49–63.

Tomé, M.E.T.R., Lima Filho, M.F., Neumann, V.H.M.L., 2014. Taxonomic studies of non-marine ostracods in the Lower Cretaceous (Aptian-lower Albian) of post-rift sequence from Jatobá and Araripe basins (Northeast Brazil): stratigraphic implications. Cretac. Res. 48, 153–176. doi:10.1016/j.cretres.2013.12.007.

Tomé, M.E., Araripe, R., Oliveira, D., Barreto, A.M.F., Prado, L., Pedrosa, F., Pereira, P., Nascimento, L.R., Ng, C., 2022. Early Cretaceous Ostracoda (Crustacea) from south-central Araripe Basin, Brazil, with descriptions of seven new species. Zootaxa 5159 (4), 535–557. doi:10.11646/zootaxa.5159.4.4.

Varejão, F.G., Fürsich, F.T., Warren, L.V., Matos, S.A., Rodrigues, M.G., Assine, M.L., Sales, A.M.F., Simões, M.G., 2019. Microbialite fields developed in a protected rocky coastline: the shallow carbonate ramp of the Aptian Romualdo Formation (Araripe Basin, NE Brazil). Sediment. Geol. 389, 103–120. doi:10.1016/j.sedgeo.2019.06.003.

Varejão, F.G., Silva, V.R., Assine, M.L., Warren, L.V., Matos, S.A., Rodrigues, M.G., Fürsich, F.T., Simões, M.G., 2020. Marine or freshwater? Accessing the paleoenvironmental parameters of the Caldas Bed, a key marker bed in the Crato Formation (Araripe Basin, NE Brazil). Braz. J. Geol. 51 (1), e2020009. doi:10.1590/2317-4889202120200009.

Varejão, F.G., Warren, L.V., Simões, M.G., Buatois, L.A., Mángano, M.G., Bahniuk Rumbelsperger, A.M., Assine, M.L., 2021. Mixed siliciclastic–carbonate sedimentation in an evolving epicontinental sea: Aptian record of marginal marine settings in the interior basins of north-eastern Brazil. Sedimentology 68, 2125–2164. doi:10.1111/sed.12846.

Vavra, W., 1891. Monographie der Ostracoden Bohmens. Arch. Naturwiss. Landesdurch. 8, 1–116.

Viana, C.F., 1966. Correspondência entre os ostracodes das séries Cocobeach (Gabão) e Bahia (Brasil). Bol. Técnico da Petrobras 9, 367–382.

Viana, C.F., da Gama Junior, E.G., Simões, I.de A., Moura, J.A., Fonseca, J.dos R., Alves, R.J., 1971. Revisão estratigráfica da Bacia Recôncavo/Tucano. Boltim Técnico da Petrobrás 14, 157–192.

Wicher, C.A., 1959. Ein Beitrag zur Altersdeutung des Reconcavo Bahia (Brasilien) mit einem Anhang von Beata Moos. Geol. Jahrb. 77, 35–57.