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TESE DE DOUTORADO

**OSTRACODES NÃO-MARINHOS DA FORMAÇÃO ORÓS, CRETÁCEO INFERIOR DA
BACIA DO IGUATU: TAXONOMIA E INFERÊNCIAS BIOESTRATIGRÁFICAS E
PALEOAMBIENTAIS**

MARCOS ANTONIO BATISTA DOS SANTOS FILHO

SÃO LEOPOLDO

2020

Marcos Antonio Batista dos Santos Filho

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PALEOAMBIENTAIS**

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Este documento aborda a introdução e os artigos científicos que contém os resultados e as discussões desta tese de doutorado.

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RESUMO

As Bacias Interiores do Nordeste do Brasil são um grupo de bacias situadas ao sul da Bacia Potiguar criadas durante o rifteamento que deu origem ao Oceano Atlântico, podendo ser usadas como análogas para os ambientes deposicionais das bacias da margem continental. Porém, muitas dessas bacias possuem uma escassez de estudos, apesar de possuírem um importante registro do Cretáceo Inferior, contendo inclusive um extenso registro fossilífero. Ostracodes não-marinhos, grupo importante para a bioestratigrafia e correlação de bacias brasileiras no Cretáceo Inferior, são abundantes na região. Essa tese tem como por objetivo o estudo da ostracofauna de duas seções contínuas localizadas na Bacia do Iguatu, denominadas Transnordestina A e Transnordestina B, com o intuito de contribuir para o conhecimento bioestratigráfico e paleoambiental deste grupo para o Cretáceo Inferior da região. Foram coletadas 156 amostras, de onde foram encontrados 19 espécies em 11 gêneros: *Cypridea hystricoides*, *C. paraibensis*, *C. cf. C. clavata*, *C. punctacentralis* sp. nov., *Brasacypris ovum*, *Pattersoncypris sinuata*, *P. cf. P. sinuata*, *Pattersoncypris?* sp., *Ilyocypris?* *arca.*, *Ilyocypris?* *latanodi.*, *Rhinocypris?* *ericius*, *Pythagoracypris latavectis*, *Hastacypris adamantem*, *Looneyellopsis mvili*, *Musacchiocythere plastica*, *Musacchiocythere?* sp., *Alicenula leguminella*, *A. cf. D. oblonga*, e uma espécie *incerta sedis*. Baseando-se nas espécies encontradas, uma idade Hauteriviana-Aptiana foi inferida para o intervalo. Em termos paleoambientais, observou-se a presença de dois grupos principais de ostracodes: um dominado por *Alicenula*, que indica momentos de maior umidade, e um dominado por *Cypridea*, que indicaria maior aridez na região. Altos valores das razões elementares Ca/Ti e Ca/ Σ Ti, Fe, Al indicam a dominância de condições áridas próximo da base das seções. A análise cicloestratigráfica identificou seis ciclos de 120 ka para a base da seção e 10 ciclos de 120 ka e três de 405 ka para o meio e topo. Se espera que este trabalho demonstre potencial que os depósitos das pequenas bacias internas do Nordeste possuem para avançar o conhecimento sobre a bioestratigrafia e o paleoambiente para o Cretáceo Inferior, que ainda necessita de maiores dados para seu melhor entendimento.

ABSTRACT

The Interior Northeast Basins of Brazil are a group of basins situated to the south of the Potiguar Basin that originated during the rifting that led to the establishment of the Atlantic Ocean, and can be used as analogues to the depositional environments of the continental margin. However, many of these basins were not comprehensively studied, even though they have an important record of the Lower Cretaceous, with an extensive fossiliferous content. Non-marine ostracods, an important group for the biostratigraphy and correlation between Lower Cretaceous Brazilian basins, are abundant in the region. The objective of this thesis is to study the ostracod fauna of two continuous sections in the Iguatu Basin, named Transnordestina A and Transnordestina B, in order to contribute to the biostratigraphic and paleoenvironmental knowledge of this group for the region. 156 samples were collected, in which 19 species from 11 genera were found: *Cypridea hystricoides*, *C. paraibensis*, *C. cf. C. clavata*, *C. punctacentralis* sp. nov., *Brasacypris ovum*, *Pattersoncypris sinuata*, *P. cf. P. sinuata*, *Pattersoncypris?* sp., *Ilyocypris?* *arca.*, *Ilyocypris?* *latanodi.*, *Rhinocypris?* *ericus*, *Pythagoracypris latavectis*, *Hastacypris adamantem*, *Looneyellopsis mvili*, *Musacchiocythere plastica*, *Musacchiocythere?* sp., *Alicenula leguminella*, *A. cf. D. oblonga*, and an *incerta sedis* species. Based on the species found, a Hauterivian – Aptian age interval was inferred. For the paleoenvironmental interpretation, two main ostracod groups were found: one dominated by *Alicenula*, indicative of higher humidity periods, and one dominated by *Cypridea*, indicating dryer periods. High values of the elemental ratios Ca/Ti and Ca/ Σ Ti, Fe, Al indicated that arid conditions dominated at the base of the sections. Ciclostratigraphic analysis indicated the presence of six 120 ka cycles for the base of the section and 10 120 ka and three 405 ka for the middle and top. The author hopes that this work demonstrates the potential that the deposits of the small Northeastern basins have to help advancing the biostratigraphic and paleoenvironmental knowledge for the Lower Cretaceous, which still requires greater amount of date for its better understanding.

1. INTRODUÇÃO

O termo “Bacias Interiores do Nordeste” se refere a um grupo de bacias situadas ao sul da Bacia Potiguar. Elas surgiram durante o processo de rifteamento que eventualmente deu origem ao Oceano Atlântico, que formou vastos sistemas de lagos e rios tanto na América do Sul quanto na África. Com exceção da Bacia do Araripe, com grande extensão (9,000 km²), essas bacias são de pequeno tamanho, tendo áreas em torno de 1.000 km². Considerando sua origem, os sedimentos acumulados nessas bacias podem ser usados como análogos para melhor entender e estudar os ambientes deposicionais das bacias da margem continental (Arima, 2007; Carvalho e Melo, 2012).

Possivelmente pela excepcionalidade de seu conteúdo fossilífero, a Bacia do Araripe foi o foco de um grande número de estudos paleontológicos, tendo sido achados nesta fósseis de pólenes e esporos, fragmentos vegetais, icnofósseis, conchostráceos, ostracods (inclusive com partes moles preservadas), moluscos, peixes, crocodilomorfos e pterossauros (ex. Bate, 1972; Tinoco e Mabesoone, 1975; Cavalcanti e Viana, 1992; Hessel et al., 1994; Leonardi e Spezzamonte, 1994; Hessel et al., 2006; Fortier e Schultz, 2006; Fortier, 2008; Leonardi, 2011; Pinheiro et al., 2011). Porém, essa mesma excepcionalidade fez com que as bacias vizinhas de menor tamanho tenham sido relativamente ignoradas, apesar das mesmas possuírem um importante e pouco estudado registro do Cretáceo Inferior.

Entre essas bacias menores se encontra a Bacia do Iguatu. Composta por quatro sub-bacias (Iguatu, Icó, Malhada Vermelha e Lima Campos), os poucos trabalhos realizados nela relatam a presença de um rico conteúdo fossilífero, dentre os quais estão os ostracodes, que podem ocorrer em quantidades grandes o suficiente para que a rocha em que eles se encontram sejam referidas como “ostracoditos” (ex., Beurlen and Mabesoone, 1969; Srivastava, 1990).

Ostracodes não-marinhos são importantes em estudos do Cretáceo Inferior brasileiro devido a sua aplicabilidade bioestratigráfica. Vários estudos demonstram que os ostracodes podem ser utilizados para correlações e biozoneamentos estratigráficos em diferentes bacias sedimentares brasileiras, como em Krömmelbein (1962) e Krömmelbein e Van Hinte (1966) para a série Bahia;

Schaller (1969) para a Bacia de Sergipe; Moura (1972) e Cunha e Moura (1979) para a Bacia do Recôncavo; Moura e Praça (1985), Moura (1987) e Moura (1988) para a Bacia de Campos; e Coimbra et al. (2002) para a Bacia do Araripe.

Tendo em vista a grande utilidade de ostracodes não-marinhos em análises de depósitos continentais no Brasil e os raros trabalhos realizados na bacia estudada, essa tese de doutorado tem como por objetivo estudar a abundante ostracofauna presente na Bacia de Iguatu, com o objetivo de contribuir para o conhecimento bioestratigráfico e paleoambiental deste grupo de microfósseis para o Cretáceo Inferior do Brasil.

2. OBJETIVOS

2.1. Objetivo Geral

- Contribuir para o entendimento taxonômico, bioestratigráfico e paleoambiental da fauna de ostracodes do Cretáceo Inferior do Brasil a partir do estudo de amostras recuperadas na Bacia do Iguatu.

2.2. Objetivos Específicos

- Estudar e classificar taxonomicamente a fauna de ostracodes recuperadas de amostras da Bacia de Iguatu;
- Realizar inferências bioestratigráficas a partir das espécies e gêneros de ostracodes encontrados;
- Realizar inferências paleoambientais baseando-se nas preferências ecológicas registradas na literatura dos táxons de ostracodes identificados, utilizando-se de técnicas como fluorescência de raio X (XRF), carbono orgânico total (COT), enxofre total (S total), e cicloestratigrafia para complementar essas interpretações.

3. ÁREA DE ESTUDO

3.1. *Bacia do Iguatu*

O termo Bacia do Iguatu refere-se a um pequeno grupo quatro de sub-bacias localizadas ao norte da Bacia do Araripe, no sudeste do estado do Ceará: são elas as sub-bacias de Iguatu, Malhada Vermelha, Lima Campos e Icó (Fortier, 2008) (Figura 1). A origem e evolução dessas áreas foram controladas pela estrutura tectônica do embasamento cristalino pré-Cambriano da região (Françolin e Szatimari, 1987). A idade atribuída a essas sub-bacias é de Cretáceo Inferior, baseando-se em palinomorfos (Lima, 1990), conchostráceos, e ostracodes (Ghignone, 1972; Mabesoone and Campanha, 1974; Tinoco e Mabesoone, 1975; Ponte Filho et al., 1990). A sub-bacia Iguatu, em que as seções estudadas nessa tese estão localizadas, é a maior das quatro, com uma área de aproximadamente 820 km², formando um elipsoide de orientação NE-SW.

A classificação litoestratigráfica da Bacia do Iguatu é controversa, com diversas propostas de nomenclatura para os seus depósitos, todas sendo informais e com muitas tendo sido publicadas em anais de eventos e congressos. A Tabela 1 mostra um resumo das propostas feitas até hoje.

Oliveira (1940) providenciou a primeira individualização das rochas sedimentares da bacia, criando a Formação Iguatu, que enquadrava todos os sedimentos da bacia. Castro (1963) e Melo (1964) mantiveram essa classificação, sem modificações.

Cruz (1962) subdividiu a Formação Iguatu em três membros: Inferior (arenitos conglomeráticos), Médio (arenitos siltíticos) e Superior (arenitos). Pesquisas hidrogelógicas na região do Jaguaribe pela SUDENE/ASMIC (1967) levou à subdivisão da Formação Iguatu em seis unidades informais.

Lemos (1973) propôs quatro facies para a bacia: Facies A (conglomerados com concreções de arenitos e argila), Facies B (arenitos médios a muito grossos e arenitos conglomeráticos), Facies C (pelitos, siltitos e arenitos calcáreos médios) e Facies D (arenitos finos a grossos e arenitos conglomeráticos).

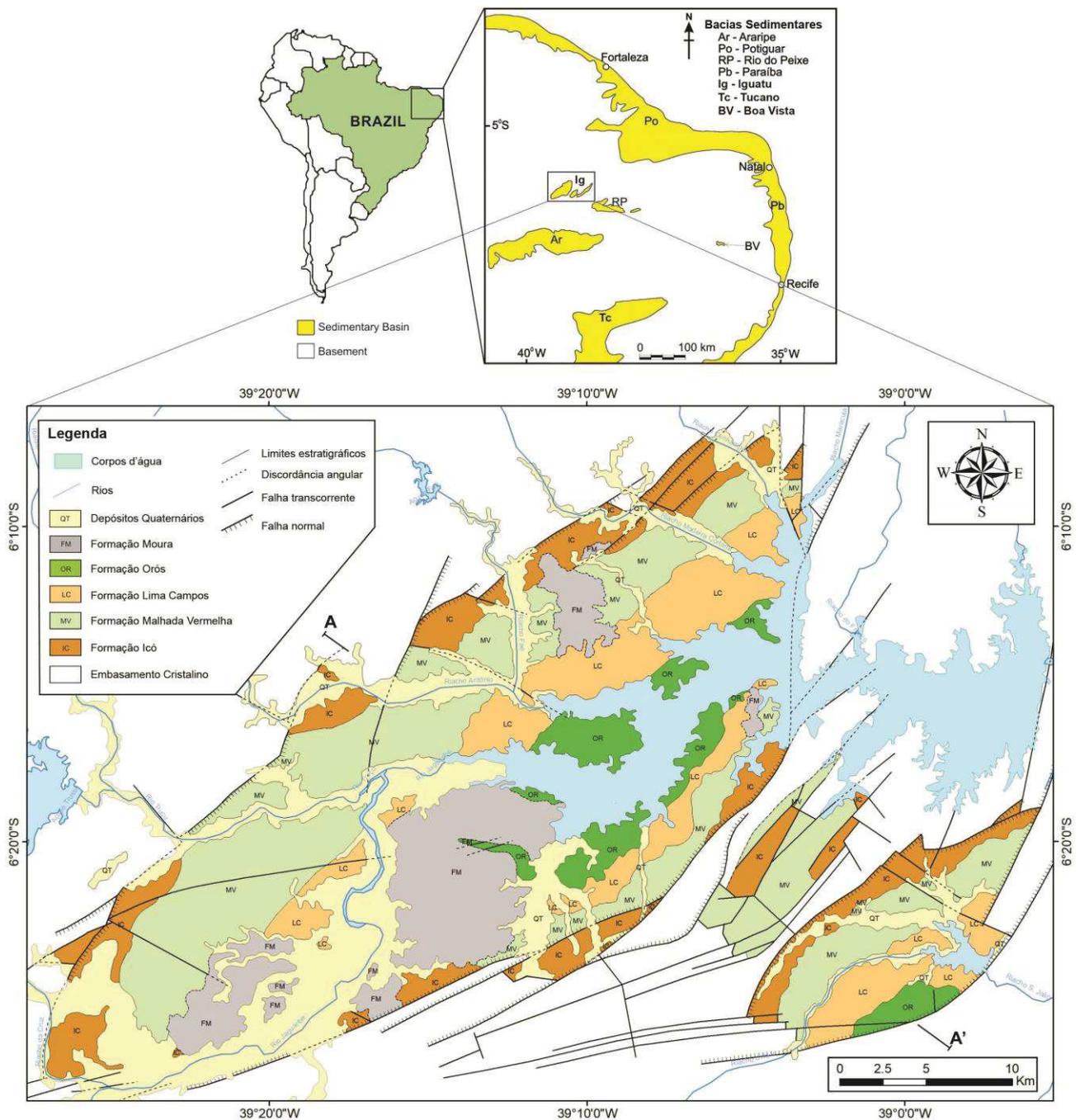


Figura 1: Localização da Bacia do Iguatu, com destaque para a sub-bacia Iguatu (Silva, 2018).

Mabessone e Campanha (1974) formalizaram o termo Grupo Iguatu, que se torna a base para a maior parte dos estudos litoestratigráficos posteriores da área. Eles definiram também três formações para o grupo: Quixoá, Malhada Vermelha, e Lima Campos, que correspondem, respectivamente, aos membros Inferior, Médio e Superior de Cruz (1962).

Campos et al. (1979) e Gomes et al. (1981) tentaram unificar a nomenclatura da Bacia do Iguatu e Bacia do Rio do Peixe, sinonimizando o Grupo Iguatu com o Grupo Rio do Peixe.

Ghignone et al. (1986) rejeitaram essa classificação, afirmando que a litologia das duas bacias não seria equivalente, e propuseram então quatro subdivisões para o Grupo Iguatu, nomeadas K1 a K4. Unidades K1 e K3 eram dominadas por arenitos, enquanto pelitos predominavam nas unidades K2 e K4.

Srivastava (1990) definiu outra subdivisão informal para a bacia: Unidade 1, que corresponderia a um sistema fluvial entrelaçado; Unidade 2, interpretada como depósitos fluvio-lacustres; e a Unidade 3, que representa um segundo sistema fluvial entrelaçado. Ponte Filho et al. (1990) utilizou uma designação similar à de Mabesoone e Campanha (1974), substituindo somente o nome da formação Quixoá for formação Icó, e subdividindo a formação Lima Campos em um membro Inferior, dominado por conglomerados, e Superior, composto principalmente por pelitos.

Cavalcante e Viana (1992) não identificaram as unidades descritos por Mabesoone e Campanha (1974), dividindo a litologia em 3 unidades informais: Unidade Inferior, composta por conglomerados e arenitos que representariam um sistema fluvial entrelaçado e leques aluviais; Unidade Intermediária, de camadas alternantes de arenitos e pelitos com algumas lentes carbonáticas, que representaria sistemas deposicionais deltaicos, lacustres, e fluviais meandrantés; e uma Unidade Superior, composta principalmente por arenitos, que seriam indicativos de um outro sistema fluvial entrelaçado.

Ponte Filho (1994) dividiu os sedimentos da Bacia do Iguatu em duas sequências tectônicas: Litd 1 e Litd 2. Esses intervalos foram associados a eventos tectônicos, com a deposição de sedimentos clásticos grossos na base, representando o ápice do evento, e pelitos ao topo, que representariam momentos de “calma” tectônica.

Em 1998, a Serviço Geológico Brasileiro (CPRM) publicou o mapa geológico da Bacia do Iguatu (Vasconcelos e Mendonça, 1998), que subdividiu o Grupo Iguatu entre as unidades Inferior, Média e Superior.

A nomenclatura estabelecida por Ponte Filho et al. (1990) foi utilizada por Fortier (2008), em sua dissertação de mestrado, que descrevia o conteúdo microfossilífero da bacia.

Por último, Silva (2018), em sua dissertação de mestrado, utilizou uma nomenclatura informal para a bacia, utilizando-se como base as unidades definidas por Ponte Filho (1994); a unidade ISD1 foi referida como formação Icó, ISD2 como formação Malhada Vermelha, ISD3 como Formação Lima Campos, e ISD 4 como formação Orós.

Nesta tese, foi seguida a mesma nomenclatura utilizada por Silva (2018), vindo que as seções aqui estudadas foram primeiro descritas pelo referido autor.

Tabela 1: Histórico das propostas de nomenclatura para os depósitos do Cretáceo Inferior da Bacia do Iguatu através dos anos. Modificado de Silva (2018).

Oliveira (1943), Castro (1963), Melo (1964)	Formação Iguatu					
Cruz (1962)	Formação Iguatu					
	Membro Superior		Membro Médio		Membro Inferior	
SUDENE/ASMIC (1967)	Formação Iguatu					
	K6	K5	K4	K3	K2	K1
Lemos (1973)	Facies D		Facies C		Facies B	Facies A
Mabesoone and Campanha (1973/1974)	Grupo Iguatu					
	Formação Lima Campos		Formação Malhada Vermelha		Formação Quixóá	
Campos et al. (1979), Gomes et al. (1981)	Rio do Peixe Group					
	Formação Rio Piranha		Formação Souza		Formação Antenor Navarro	
Ghignone et al. (1986)	Grupo Iguatu					
	K4	K3	K2	K1		
Ponte Filho et al. (1990)	Grupo Iguatu					
	Formação Lima Campos		Formação Malhada Vermelha		Formação Icó	
	Membro Superior	Membro Inferior				
Srivastava (1990)	Unidade III		Unidade II		Unidade I	
Cavalcanti and Viana (1992)	Unidade Superior		Unidade Intermediária		Unidade Inferior	
Ponte Filho (1994)	Tectonic-Sequence Iguatu					
	ISD4	ISD3	ISD2		ISD1	
	Litd 2			Litd 1		
Vasconcelos and Mendonça (1998)	Grupo Iguatu					
	Unidade Superior		Unidade Média		Unidade Inferior	
Feitosa and Vidal (2004)	Grupo Iguatu					
	Formação Lima Campos		Formação Malhada Vermelha		Formação Icó	
Fortier (2008)	Grupo Iguatu					
	Formação Lima Campos		Formação Malhada Vermelha		Formação Icó	
Silva (2018)	Grupo Iguatu					
	Formação Orós	Formação Lima	Formação Malhada Vermelha		Formação Icó	

3.2. Formação Orós

De acordo com Ponte Filho (1994), os sedimentos da unidade ISD4, equivalentes à formação Orós pela nomenclatura de Silva (2018), representam um segundo pulso de deposição de sedimentos finos na bacia, sobrepondo os sedimentos grossos da formação Lima Campos. A Formação Orós é composta por grandes pacotes de siltitos vermelhos, argilitos verdes, e arenitos brancos, que são associados a planícies de inundação, depósitos lacustres, e sistemas de leque aluvial e fluvial entrelaçado.

De acordo com Silva (2018), essa formação pode ser vista principalmente no depocentro das sub-bacias de Iguatu e Lima Campos, onde seus ambientes deposicionais predominavam. O limite entre essa formação e a de Lima Campos é difícil de se identificar, já que grande parte de ambas estão cobertas pela formação Moura (de idade Neogena) e por depósitos quaternários. A idade dessa formação é desconhecida, mas baseando-se em dados magnetoestratigráficos, Silva (2018) indica que ela pode ser Berriasiana, Valanginiana, ou Hauteriviana-Barremiana.

3.2. Seções Transnordestina A/B

As seções estudadas nesta tese, denominadas de Transnordestina A e B, estão localizadas na área sudeste da sub-bacia de Iguatu, começando nas coordenadas WGS84 UTM 24M 474350 9360031 (Figura 2). Silva (2018) descreve a seção como sequências deposicionais cíclicas de intercalações de siltitos marrons e argilitos esverdeados laminados, com a ocorrência ocasional de arenitos, que representam depósitos fluviais que podem ocorrer tanto na forma de camadas espessas e estratificadas quanto como pequenas lentes irregulares. Pequenas camadas de peleolos podem, às vezes, ser observadas nos contatos entre as camadas de argilito/siltito e de arenito. Juntas, as seções possuem um comprimento total de 1,2 km, com suas camadas mergulhando 133/36, totalizando um pacote sedimentar em torno de 850 metros. As seções Transnordestina A e Transnordestina B são separadas por uma falha normal, de rejeito desconhecido.

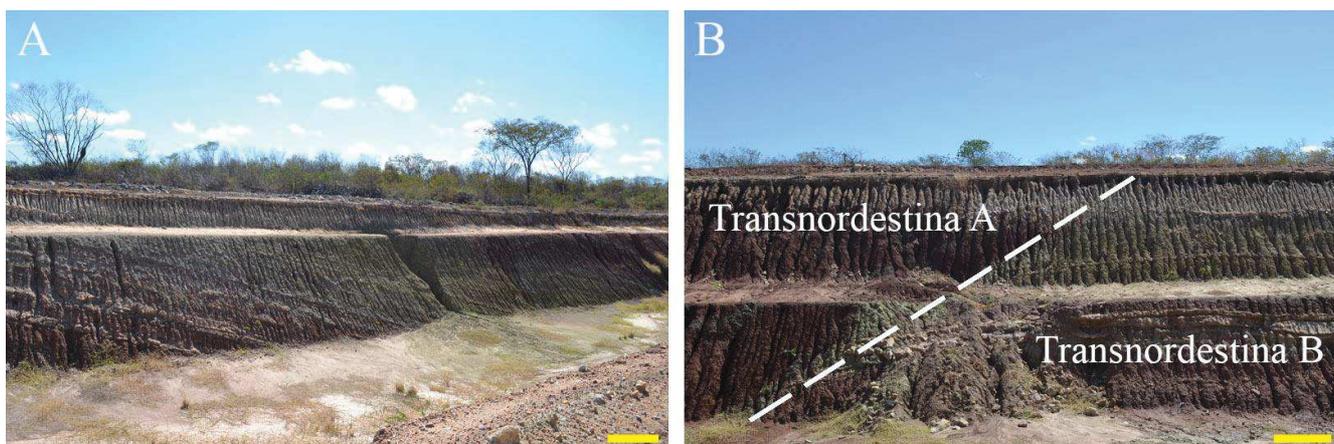


Figura 2: a) Imagem geral das seções Transnordestina A/B. b) Falha que divide as seções Transnordestina A e Transnordestina B.

De acordo com Silva (2018), as rochas dessa seções representam uma intercalação em ambientes de canais fluviais e planícies de inundação. Ele interpreta as camadas de siltitos e argilitos como indicativas de um ambiente estável húmido relacionado a variações climáticas sazonais, que começam na base com depósitos fluviais (representados pelos arenitos), progredindo para os siltitos amarronzados e terminando com os argilitos, indicando a diminuição da descarga sedimentar dos rios e o aumento da profundidade d'água na região. Ele interpreta os siltitos como sendo depósitos de planície de inundação, e os argilitos como lagos rasos tipo *playa*.

A assimetria destes “ciclos” é atribuída à natureza oscilatória de seu sistema deposicional, e que eles foram limitados pela capacidade de acomodação e a variação da superfície de equilíbrio da bacia (Berger, 1988; Silva, 2018).

4. MATERIAIS E MÉTODOS

4.1. Generalidades

Para o desenvolvimento desta tese, foram realizadas duas campanhas de campo para a Bacia do Iguatu: uma primeira, em Agosto de 2017, em que foram coletadas 112 amostras ao redor de toda a sub-bacia Iguatu, que se mostraram em geral estéreis com exceção de 10 amostras coletadas nas seções contínuas Transnordestina A e B, da formação Orós, que se mostraram extremamente abundantes; e uma segunda, entre outubro e novembro de 2017, focada nas seções Transnordestina A e B, em que foram coletadas 156 amostras. Essas seções estão localizadas na região sudeste da sub-bacia de Iguatu, a partir das coordenadas WGS84 24M 474350 9300031. Elas são compostas por intercalações de siltitos vermelhos, argilitos esverdeados, e arenitos finos a médios maciços ou com estratificações cruzadas tangenciais.

4.2. Ostracodes

Foram retiradas 100 gramas de cada amostra para processamento e recuperação de ostracodes, as quais foram processadas seguindo a metodologia padrão para microfósseis calcários, que consistiu em:

- Imersão das amostras em aproximadamente 150 ml de peróxido de hidrogênio glacial (H₂O₂ 10%) em béquer de vidro por 24 horas;
- Lavagem das amostras em água corrente por uma peneira de malha 38µm, seguido de imersão em H₂O₂ 10% por mais duas horas em banho de areia a uma temperatura de 60°C;
- Segunda lavagem das amostras, utilizando peneiras de malha 250 µm, 125 µm e 63 µm;
- Secagem das diferentes frações em estufa a 60°C por 48 horas.

Na sequência, as amostras foram triadas utilizando-se um microscópio estereoscópio Zeiss, retirando-se todos os exemplares encontrados. Os espécimes encontrados foram então separados por morfotipos, e os espécimes melhor preservados foram imageados utilizando-se do microscópio eletrônico de varredura SEM, Zeiss, EVO/MA15. Através das imagens resultantes, os espécimes foram classificados ao nível de espécie ou gênero utilizando-se bibliografia especializada (ex., Krömmelbein, 1962; Cunha e Moura, 1979; Moura, 1988). A partir dos táxons identificados, foram então feitas inferências bioestratigráficas.

Interpretações paleoambientais utilizando a fauna de ostracodes foram feitas com base nas preferências ecológicas registradas na literatura para os gêneros e espécies encontrados, com auxílio de análises estatísticas baseadas nas variações de abundância e diversidade de espécies ao longo das seções, utilizando os programas R (R Core team, 2017), PAST (v. 3.15; Hammer et al. 2001), Microsoft Excel, e o *website* MEDCALC (<https://www.medcalc.org/calc/>).

4.2. Razões elementares derivadas de escaneamento XRF, COT, e S total

Aproximadamente um grama do sedimento das 156 amostras foi pulverizado para uma fração <63 µm, e a concentração elementar do sedimento foi determinada por uma análise semi-quantitativa usando fluorescência de raio-X em um equipamento Panalytical Epsilon 1.

O valor de COT foi obtido pela acidificação de uma pequena fração das amostras por HCl para remover o carbono inorgânico. Depois das amostras terem sido lavadas usando água destilada, elas foram analisadas usando a técnica de combustão em um LECO SC-144DR. O mesmo

equipamento também providenciou os valores de carbono total (CT) e enxofre total (S). O valor total de CaCO_3 foi obtido através da equação $\% \text{CaCO}_3 = (\% \text{CT} - \% \text{COT}) * 8,33$.

4.2. Análise espectral

Os dados obtidos pela análise de XRF foram utilizados para identificar frequências harmônicas. Para tanto, foi calculado a razão molar Ti/Al, que pode ser utilizada como um proxy para proximidade de área fonte e input terrígeno, não só em sistemas pelágicos mas também para ambientes terrestres (Neuhuber et al., 2016).

Os programas PAST e R foram aplicados para analisar a razão molar Ti/Al, com o segundo tendo sido utilizado com o pacote de *software* “astrochron” (Meyers, 2014). Picos espectrais foram calculados usando “Locally Weighted Regression Spectral Background Estimation” (LOWSPEC, Meyers, 2014), com uma análise harmônica evolutiva (EHA; Meyers, 2014; Thomson, 1982) ilustrando a evolução do espectro dominante pela seção. As análises espectrais foram realizadas separadamente para os intervalos de 0 – 233 metros e 233 a 836 metros, vendo que foram observados padrões de sedimentação diferentes que provavelmente refletem paleoambientes diferentes.

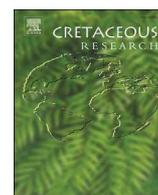
A análise cicloestratigráfica utilizou-se também da análise magnetoestratigráfica de Silva (2018), que propôs três possíveis intervalos de tempo para as seções: Hauterivian-Barremian (132.0 a 128.7 Ma / Chrons M3-M7), Valanginian (138.2 a 136.9 Ma / Chrons M11–M11A), e Berriasian (145.2 to 142.2 Ma / Chrons M17–19).

5. ARTIGOS CIENTÍFICOS

A partir dos dados coletados, foram desenvolvidos dois artigos científicos para esta tese de doutorado. O primeiro, intitulado “*Lower Cretaceous non-marine ostracods of the Orós Formation, Iguatu basin: Taxonomy and biostratigraphic considerations*”, possui a descrição das espécies e gêneros encontrados, assim como as inferências bioestratigráficas feitas a partir deles. Ele foi submetido ao periódico *Cretaceous Research*, de classificação qualis B1, já publicado e disponível online.

O segundo artigo que compõe essa tese, “*Paleoenvironmental analysis of a Lower Cretaceous paleolake from the Iguatu Basin, based on its ostracod fauna and XRF data*”, possui os resultados adquiridos a partir das análises paleoambientais baseadas em análise estatística da fauna de ostracodes, XRF, COT, S total, e a análise cicloestratigráfica, assim como as discussões e conclusões feitas a partir destas. Ele foi submetido ao periódico *Geobiology*, de classificação qualis A2.

5.1. ARTIGO 1: *Lower Cretaceous non-marine ostracods of the Orós Formation, Iguatu basin: Taxonomy and biostratigraphic considerations*



Lower Cretaceous non-marine ostracods of the Orós Formation, Iguatu basin: Taxonomy and biostratigraphic considerations

Marcos Antonio Batista dos Santos Filho ^{a,*}, Gerson Fauth ^a, Benjamin Sames ^b

^a *Itt Fossil – Instituto Tecnológico de Micropaleontologia, UNISINOS – Universidade do Vale do Rio dos Sinos, Av. Unisinos, 950, Cristo Rei, São Leopoldo, RS, Brazil*

^b *Department für Geodynamik und Sedimentologie, Universität Wien, Althanstrasse 14, Vienna, Austria*

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ABSTRACT

Non-marine ostracods have been used for a long time to aid in the understanding of the Lower Cretaceous sedimentary deposits of Brazil, with various studies showing their value for biostratigraphic zonation in different basins. The northeastern region of Brazil contains several basins south of the Potiguar Basin which originated from the rifting that resulted from the opening of the Atlantic Ocean, and thus contain an important record of the Cretaceous Period. This paper has the objective of studying the ostracods recovered from two adjacent sections (Transnordestina A and Transnordestina B) belonging to the Orós Formation, Iguatu Basin, Ceará, Brazil, detailing their taxonomy and developing biostratigraphic inferences based on the observed fauna. A total of 19 species were found in the analyzed samples, distributed among 11 genera and five families: *Cypridea hystricoides*, *Cypridea paraibensis*, *Cypridea* cf. *C. clavata*, *Cypridea punctacentralis* sp. nov., *Brasacypris ovum*, *Pattersoncypris sinuata*, *Pattersoncypris* cf. *P. sinuata*, *Pattersoncypris*? sp., *Ilyocypris? arca* sp. nov., *Ilyocypris? latanodi* sp. nov., *Rhynocypris? ericius* sp. nov., *Pythagoracypris latavectis* gen. et sp. nov., *Hastacypris adamantem* gen. et sp. nov., *Looneyellopsis mvili*, *Musacchiocythere plastica*, *Musacchiocythere?* sp., *Alicenula leguminella*, *Alicenula* cf. *D. oblonga*, and an *incertae sedis* species. From the recovered species, a Hauterivian–Aptian interval can be inferred for the studied sections.

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1. Introduction

Non-marine ostracods have long been utilized in the analysis of the Lower Cretaceous sedimentary deposits of Brazil, with various studies showing their value for biostratigraphic zonation in numerous Brazilian basins. Some that can be mentioned are the works of Krömmelbein (1962, 1966), whose biozonation scheme for the Bahia series was later applied by Schaller (1969), with some modifications, for the Sergipe Basin; the zonations described by Moura (1972) and Cunha and Moura (1979) for the Recôncavo Basin and their application of a modified version of the scheme developed by Schaller (1969) to the Campos Basin (Moura and Praça, 1985; Moura, 1987; Moura, 1988); Silva-Telles (1992), who used ostracod faunas to biostratigraphically characterize the coquina sequences of the Campo Basin; and Coimbra et al. (2002), who applied a modified version of the biozones described in the

previously mentioned study for the Araripe Basin, one of the northeastern inner basins of Brazil.

This term, northeastern inner basins, refers to a group of basins situated south of the Potiguar Basin that developed over the Precambrian basement of the Borborema Province. With the exception of the Araripe Basin, they tend to be small in size, usually with areas totaling around 1,000 km². These were created during the rifting process that gave origin to the Atlantic Ocean, which formed numerous lakes and drainage systems as the South American and African continents split apart (Carvalho and Melo, 2012). The Cretaceous sedimentary record of these basins can be used as an analog for the better understanding of the evolution and the depositional environments of the continental margin basins (Arima, 2007).

Among these basins, the Araripe Basin is particularly noteworthy. At around 9,000 km² in area, it is the largest of the northeastern inner basins (Assine, 1992). Numerous paleontological studies of its deposits have been conducted, not only due its abundant fossil content, but also due to the very good preservation

* Corresponding author.

E-mail address: abatistas@unisinos.br (M.A. Batista dos Santos Filho).

of its fossils. In comparison, however, the smaller basins adjacent to it have been relatively ignored.

This is the case for the Iguatu Basin. Located to the north of the Araripe Basin, it exhibits a rich fossil record, which includes ostracods, sometimes found in quantities large enough for the rocks to be classified as “ostracodites” (e.g., [Beurlen and Mabeoone, 1969](#); [Srivastava, 1990](#)). So far, however, they have been poorly studied, with only occasional mentions of the presence of certain genera.

Therefore, this paper has the objective of studying the ostracod fauna of an extensive, relatively continuous section belonging to the Orós Formation, Iguatu Basin, with the aim of contributing to the taxonomic and biostratigraphic knowledge of this microfossil group for the Cretaceous of Brazil.

2. Geological setting

2.1. Iguatu Basin

The Iguatu Basin refers to the grouping of the sub-basins Iguatu, Malhada Vermelha, Lima Campos and Icó, located in the south-eastern area of the Ceará state ([Fortier, 2008](#)). The genesis and evolution of these depositional areas were controlled by the tectonic structures of their pre-Cambrian basement ([Françolin and Szatimari, 1987](#)) (Fig. 1). The age attributed to these deposits encompasses the entire Early Cretaceous, based on palynomorphs ([Lima, 1990](#)), spinicaudatans (‘conchostracans’), and ostracods ([Ghignone, 1972](#); [Mabeoone and Campanha, 1974](#); [Tinoco and Mabeoone, 1975](#); [Ponte et al., 1990](#)). The Iguatu sub-basin, in which the studied section is located, is by far the largest of the four, with an area of approximately 820 km² and forming an ellipsoid with a NE-SW orientation.

The lithostratigraphy of the Iguatu Basin was, and still is, subject to controversy, with many different formations having been proposed since [Cruz \(1962\)](#) first subdivided the Iguatu Formation into three members. Newer studies were published by [Cavalcanti and Viana \(1992\)](#), who subdivided the depositional sequences of the basin into three units (Upper, Middle and Lower), by [Ponte Filho \(1994\)](#), who designated two Tectono-depositional Intervals for the deposits of this basin, and by [Silva \(2018\)](#), who developed the stratigraphic classification adopted for this paper, which consists of six distinct facies groups, with four Cretaceous groups covered by two Neogene ones, denominated GF-I through GF-VI.

The paleontological record for this basin is extensive, with numerous fossils having been found in the area. In addition to the previously mentioned palynomorphs, ostracods, and spinicaudatans, there are mollusks, fishes, reptile bone fragments, crocodylomorphs, dinosaur footprints, and plants (e.g. [Mussa et al., 1991](#); [Leonardi and Spezzamonte, 1994](#); [Carvalho, 2000](#); [Fortier and Schultz, 2006](#); [Fortier, 2008](#)).

2.2. Sections Transnordestina A/B

The sections analyzed in this study, denominated Transnordestina A and B, are located in the southeastern area of the Iguatu sub-basin (Fig. 1), starting at the WGS84 UTM coordinates 24M 474350. 9300031. According to [Silva \(2018\)](#), they belong to the facies group GF-V of the Orós Formation, which is described as cyclic depositional sequences of intercalated brown siltstones and laminated green mudstones, with the occasional occurrence of sandstones, which represent channel deposits that can occur both as large stratified layers or as smaller, irregular lenses (Fig. 2, 3A). Thin paleosol layers can be seen in the contact between the mudstone/siltstone and sandstone layers. Both sections combined have approximately 1.2 km in length, with its layers dipping at 133/

36, totaling a thickness of around 850 m of piled deposits. The sections Transnordestina A and B are adjacent to each other, separated only by a normal fault, recognizable by the brittle arching of the sandstone layers. Its offset is unknown (Fig. 3B).

According to [Silva \(2018\)](#), the rocks of this section are representative of an intercalation between channel environments and inundation plains. The author interprets the large scale of the siltstone and mudstone layers as indicative of a stable humid environment, and their cyclic nature as being related to large seasonal climatic variations, beginning with a fluvial base, represented by sandstones, progressing to the massive brown siltstones, and ending with the laminated mudstones, with this succession happening due to a progressively lower sedimentary discharge from local rivers and the increase of water depth in the region. [Silva \(2018\)](#) interprets the brown siltstones as having been deposited in an inundation plain, and the green mudstones as being playa lakes.

The asymmetry of these cycles is attributed to the oscillatory nature of their depositional systems, and to the fact that they were limited by the capacity for sediment accommodation and the variation of the equilibrium surface of the basin ([Berger, 1988](#); [Silva, 2018](#)).

3. Material and methods

3.1. Sample collection and preparation

A total of 156 samples were recovered from the studied section, collected in intervals of approximately five meters (Fig. 7). Samples were preferentially taken from the mudstones and siltstones, as previous analyses showed that the sandstones do not contain microfossils, although samples from thin siltstone and mudstone layers located within the sandstone layers were also collected. Sample preparation followed the conventional methodology for the recovery of ostracod fossils, consisting in (a) sample weighing (approximately 100 g); (b) immersion of the sample in 200 ml of hydrogen peroxide (H₂O₂ at 10%) for 24 h; (c) washing the sample with running water through 250, 125 and 63 µm meshes; (d) drying the sample in a kiln at 60 °C; (e) hand picking and grouping of ostracod morphotypes from all fractions with the use of a stereoscopic microscope; (f) taxonomic identification of the genera and species through the use of images generated through scanning electron microscopy (SEM, Zeiss, EVO/MA15) and selected literature.

Both the preparation and the SEM imaging were conducted at the Instituto Tecnológico de Micropaleontologia (itt Fossil), Universidade do Vale do Rio dos Sinos (UNISINOS).

3.2. Ostracod description and taxonomic classification

Suprageneric taxonomy follows [Horne \(2002\)](#), [Horne et al. \(2002\)](#), [Brandão et al. \(2020\)](#) and specific literature given below, if applicable. The ostracod morphologic terms used here followed [Sames \(2011a–d\)](#), [Sames 2011c](#) being the primary reference for explanation of terms with supporting figures and references in [Sames, 2011a, b, and d](#)). For the genera in which new species or species left as cf. were described, the genus diagnosis is provided. The following abbreviations are used: LV (left valve), RV (right valve), L (length), H (height), L/H (length/height-ratio), W (width), ACA (anterior cardinal angle), PCA (posterior cardinal angle), RLV (right lateral view), LLV (left lateral view), IV (internal view), VV (ventral view), DV (dorsal view), and AMS (adductor muscle scar). Size classification followed [Ayres and Whatley \(2014\)](#): Small: 0.40–0.50 mm; Medium: 0.51–0.70 mm; Large: 0.71–1.00 mm, Very Large: 1.10–2.00 mm, Gigantic: >2.00 mm. Measurements were obtained using the software Bivalve©, developed by V3D

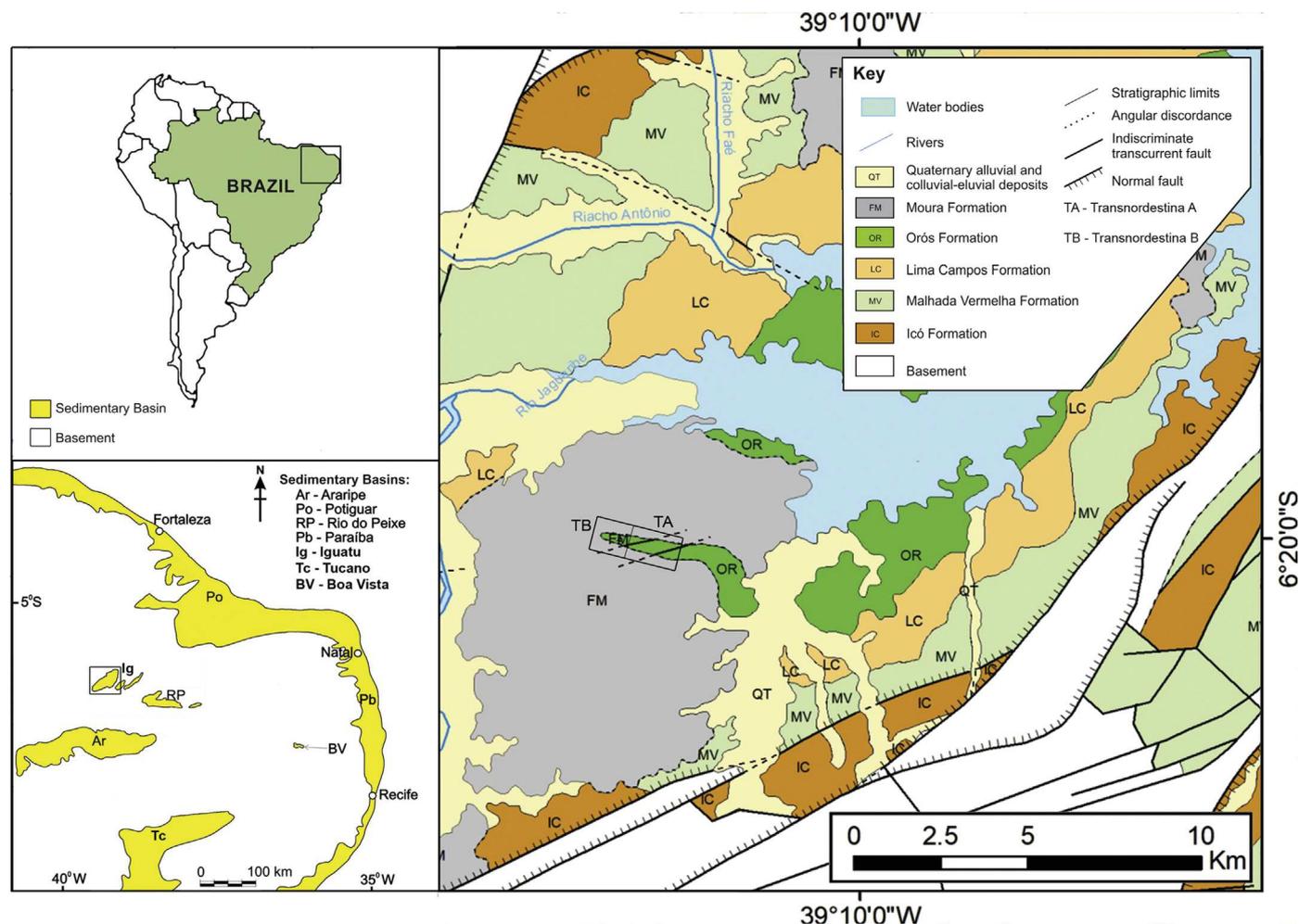


Fig. 1. Location of the Iguatu Basin. Black rectangle in lower right inset map indicates the study area, encompassing both Transnordestina A and B. Modified after Silva (2018).

(www.v3d.com.br). When counting specimens, valves and carapaces of adults and juveniles were considered as being a single individual, as due to post-mortem transportation and time-averaging, it is unlikely that two separated valves of the same ostracod would be present in the same sample, and although different juvenile specimens may be molts of a single organism, it is not possible to differentiate between molts and juvenile carapaces (Villegas-Martín et al., 2019).

The studied material is deposited in the Laboratório de História da Vida e da Terra (LAVIGEIA), at UNISINOS, under the curatorial numbers ULVG-12598 to ULVG-12653.

4. Results and discussion

As a whole, ostracods were very abundant within the Transnordestina A/B sections, especially in the upper parts of section A and throughout the entirety of section B (Figs. 4–6). Of the 156 samples analyzed, 121 contained fossils. In total, 17,150 specimens were recovered, distributed between 19 species, 11 genera and five families, with six species and two genera being new.

Preservation varied from moderate to poor, with virtually all recovered specimens having suffered recrystallization or having

been heavily oxidized. The vast majority of the recovered material consists of disarticulated valves (15,113), with only comparatively few carapaces having been recovered (1,777), which indicates the presence of energy flowing into the depositional environment.

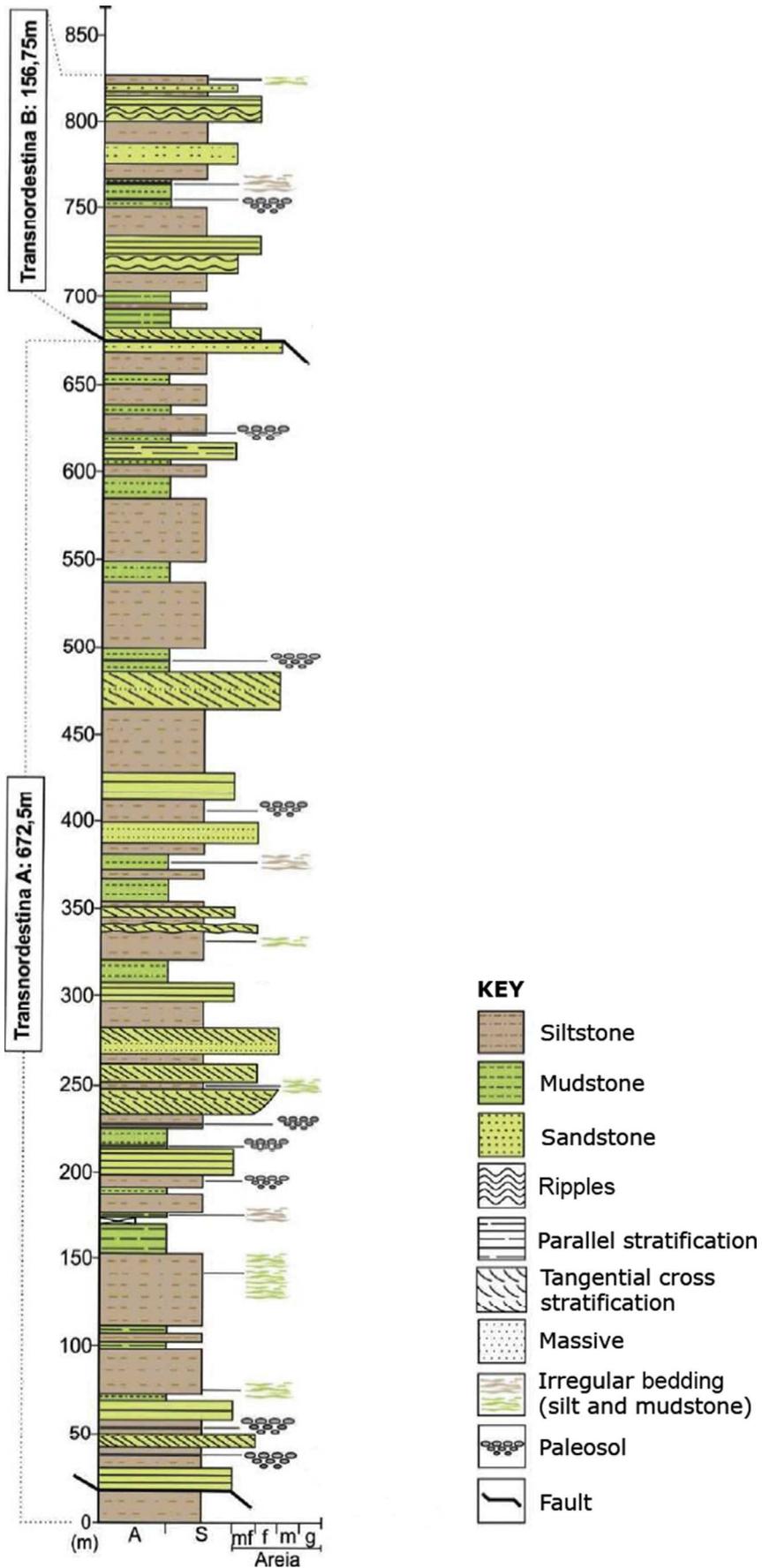
A large quantity of molds was found, with many detailed carapace molds composed of iron oxide. Juveniles of many genera, particularly of *Alicenula* and *Pattersoncypris*, were recovered, indicating some degree of autochthony for this fauna.

4.1. Taxonomy

The species here described are illustrated on Figs. 4–6. The distribution of the species throughout the two sections can be seen in Fig. 7.

4.1.1. Systematic paleontology

Class OSTRACODA Latreille, 1802
 Order PODOCOPIIDA Sars, 1866
 Suborder CYPRIDOCOPINA Jones, 1901
 Superfamily Cypridoidea Baird, 1845
 Family Cypridoidea (Martin, 1940) emended Sames, 2011b



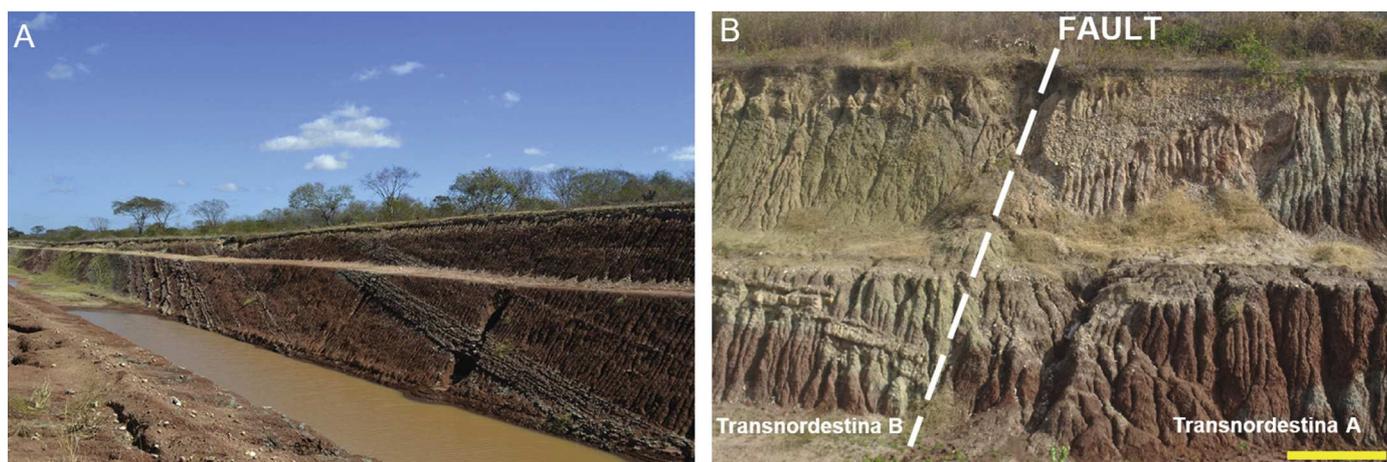


Fig. 3. Stratigraphic column for Transnordestina A/B, Orós Formation, Iguatu Basin.

Genus *Cypridea* (Bosquet, 1852) emended [Sames, 2011b](#)
Type species: *Cypris granulosa* Sowerby, 1836

Stratigraphic range. Upper Jurassic (Kimmeridgian) to Paleogene (lower Eocene) ([Sames, 2011b](#)).

Diagnosis. “Small to medium-sized, rarely large, with ovate, rectangular, triangular or oblique-trapezoidal lateral outline. Antero-ventral rostrum of highly variable shape, size, and reflexion always present, with adjoining alveolus posterior to it. Alveolar notch always present, although sometimes barely cognizable. Development of alveolar furrow highly variable, sometimes almost absent and often delimited by an alveolar ridge. Weakly to extremely inequivalve, LV > RV mostly, rarely with inverse (RV > LV) overlap but hinge always normal. Strong convex ventral overlap. Postero-ventrally with a curved or triangular cyathus usually in larger valve only, sometimes hardly apparent; some forms with cyathus like protrusion (postero-ventral extension in smaller valve also). Hinge margin distinctly incised (hinge incisure), causing the dorsal furrow. With or without local ornamentation elements (nodes and/or spines and tubercles). Surface finely to moderately punctate, rarely totally smooth, in the latter case also lacking any other ornamentation elements” ([Sames, 2011b](#), p. 365).

***Cypridea hystricoides* Krömmelbein, 1962.**
(Fig. 4.1A–D)

1962 *Cypridea hystricoides* Krömmelbein, p. 507, pl. 55, fig. 19a–c.
2018 non *Cypridea hystrix* Leite et al., p. 8, fig. 4.10–14.

Figured specimens. ULVG-12598 (juvenile), valve, sample TA-065, 365 m; ULVG-12599, valve, sample TA-065, 365 m; ULVG-12600, valve, sample TA-065, 365 m.

Material. Nine valves.

Dimensions (mm). L: 0.80–0.90; H: 0.50–0.60; W: 0.30–0.40 (valve).

Discussion. Although most of the material is fragmentary and only valves were recovered, the three very large node-like tubercles aligned in the ventral area and the two large node-like tubercles in the anterior and posterior dorsal regions are highly characteristic of *C. hystricoides*, in addition to the slightly concave dorsal and ventral margins of the right valve. It differs from all other *Cypridea* species

in this paper due to its very large node-like tubercles, giving it a distinct lateral and dorsal outline. [Leite et al. \(2016, 2018\)](#) considered *C. hystricoides* as a junior synonym to *C. hystrix* [Krömmelbein, 1962](#). However, it is the opinion of the authors of this paper that both species present relevant differences and should not be considered synonymous: *C. hystricoides* has a narrower carapace in dorsal view, and its dorsal outline is very distinct from *C. hystrix*; the ventral margin of *C. hystricoides* is straight in the RV to slightly concave in the LV, and shows a well-developed ventral ridge in its LV, whereas the ventral margin of *C. hystrix* is slightly convex on both valves; the distribution and development of the node-like tubercles differ greatly, with *C. hystricoides* possessing larger and much less numerous tubercles than *C. hystrix*; the puncta that adorn the surface of the carapace of *C. hystricoides* are noticeably smaller than the ones of *C. hystrix*; and finally, the dorsal furrow of *C. hystricoides* is noticeably narrower and shorter than that of *C. hystrix*. In addition, while a number of specimens that can be attributed with certainty to the *C. hystricoides* morphotype were found in the present study, none that could be associated to *C. hystrix* were identified, indicating that no such intraspecific variation occurred in this population as attributed by [Leite et al. \(2018\)](#). In the latter study, the authors argue that the differences can be attributed to sexual dimorphism, and mention that they found specimens of *C. hystrix* in their material less wide than the one described by [Krömmelbein \(1962\)](#); however, the figured specimen in their paper shows significant differences from both species, with a very different tubercle distribution pattern, a smooth dorsal margin, a straight to slightly concave ventral margin, and with an ornamentation pattern that extends to nearly the anterior margin. It is likely that their specimens are representative of a new species, and neither of *C. hystrix* nor of *C. hystricoides*. We therefore consider *C. hystricoides* to be a valid species.

Stratigraphic and geographic distribution. Sergipe-Alagoas Basin, RT-006 zone, Aratu Stage, Barremian, Brazil ([Krömmelbein, 1962](#); [Cassab et al., 1994](#)); Iguatu Basin, Orós Formation, Hauterivian–Aptian, Brazil (this study).

***Cypridea paraibensis* Sousa et al., 2018**
(Fig. 4.2A–B)

2018 *Cypridea paraibensis* Sousa et al., p. 26, fig. 3.10–21.

Fig. 2. A) Photo of an interval of the section Transnordestina A, showing the brown siltstones, green mudstones, and sandstones; B) Normal fault dividing Transnordestina A and B. The yellow bar equals 5 m. Both sections belong to the Orós Formation, Iguatu Basin. Modified after [Silva \(2018\)](#). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

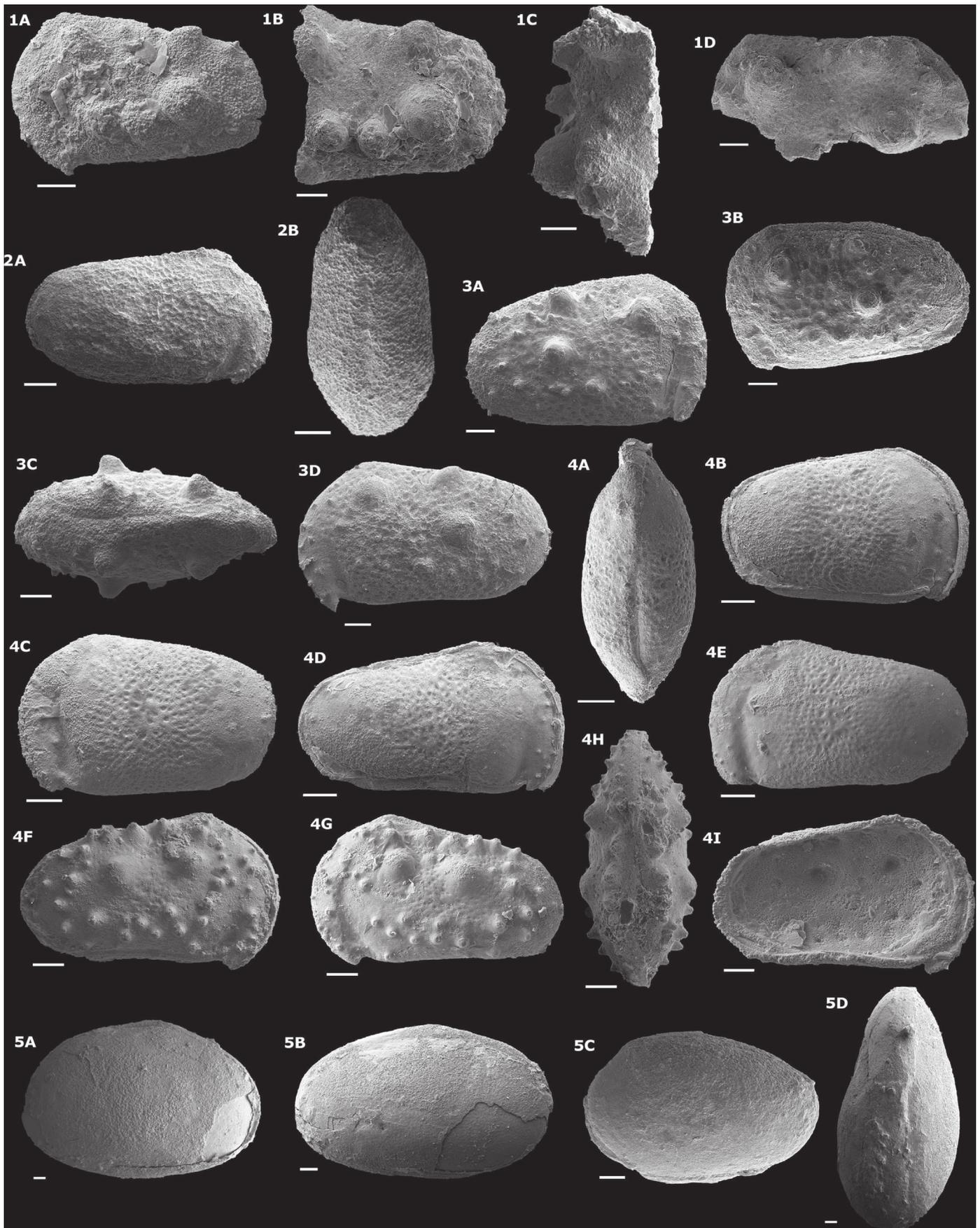


Fig. 4. All scale bars represent 100 μm . 1 *Cypridea hystricoides*. 1A, ULVG-12598 (juvenile) – LLV; 1B, ULVG-12599 – LLV; 1C, ULVG-12599 – DV; 1D, ULVG-12600 – LLV. 2 *Cypridea paraibensis*. 2A, ULVG-12601 – RLV; 2B, ULVG-12601 – DV. 3 *Cypridea* cf. *C. clavata*. 3A, ULVG-12602 – RLV; 3B, ULVG-12602 – LLV; 3C, ULVG-12602 – DV; 3D, ULVG-12603 – LLV; 4

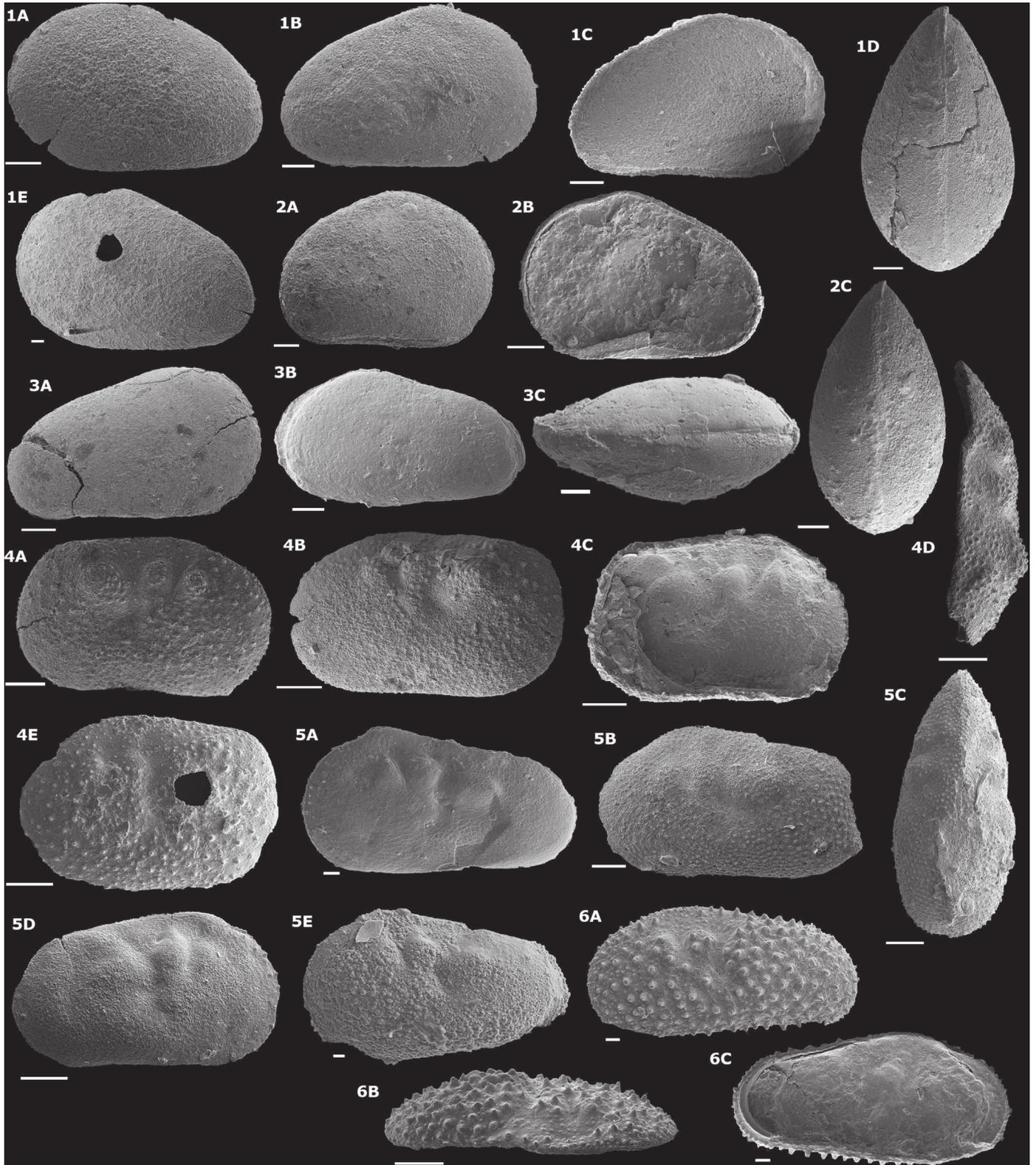


Fig. 5. All scale bars represent 100 μm , except for 5A, 6A and 6C, which represent 30 μm , and 1E and 5E, which represent 20 μm . 1 *Pattersoncypris sinuata*. 1A, ULVG-12611 – LLV; 1B, ULVG-12612 – RLV; 1C, ULVG-12613 – IV; 1D, ULVG-12614 – DV; 1E – LLV, ULVG-12654. 2 *Pattersoncypris* cf. *P. sinuata*. 2A, ULVG-12615 – RLV; 2B, ULVG-12616 – IV; 2C, ULVG-12617 – DV. 3 *Pattersoncypris*? sp. 3A, ULVG-12618 – RLV; 3B, ULVG-12619 – LLV; 3C, ULVG-12619 – DV. 4 *Ilyocypris*? *arca* sp. nov. 4A, ULVG-12620 (Holotype) – RLV; 4B, ULVG-12621 (Paratype) – LLV; 4C, ULVG-12622 (Paratype) – IV; 4D, ULVG-12623 (Paratype) – DV; 4E, ULVG-12624 (Paratype, juvenile) – LLV. 5 *Ilyocypris*? *latanodi* sp. nov. 5A, ULVG-12626 (Paratype) – LLV; 5B, ULVG-12627 (Paratype) – LLV; 5C, ULVG-12625 (Holotype) – DV; 5D, ULVG-12628 (Paratype) – RLV; 5E, ULVG-12629 (Paratype, juvenile) – LLV. 6 *Rhinocypris*? *ericus* sp. nov. 6A, ULVG-12630 (Holotype) – LLV; 6B, ULVG-12630 – DV; 6C, ULVG-12630 – IV.

Cypridea punctacentralis. 4A, ULVG-12605 (Paratype) – DV; 4B, ULVG-12605 – RLV; 4C, ULVG-12605 – LLV; 4D, ULVG-12604 (Holotype) – RLV; 4E, ULVG-12604 (Paratype) – LLV; 4F, ULVG-12606 (Paratype)0020 – RLV; 4G, ULVG-12606 – LLV; 4H, ULVG-12606 – DV; 4I, ULVG-12607 – IV. 5 *Brasacypris ovum*. 5A, ULVG-12608 – RLV; 5B, ULVG-12609 – RLV; 5C, ULVG-12610 – LLV; 5D, ULVG-12608 – DV.

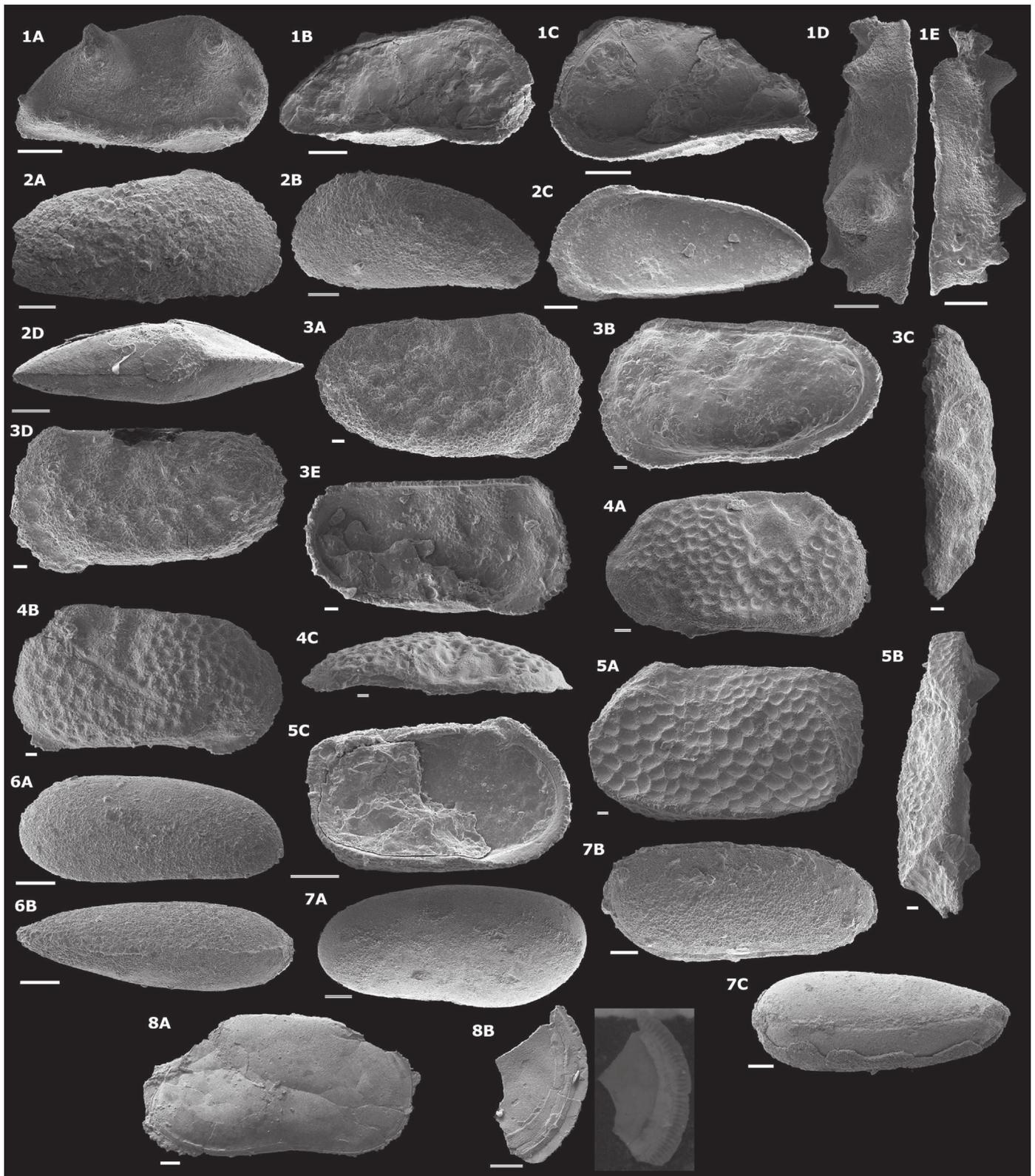


Fig. 6. All scale bars are equal to 100 μm , except for 3A-E, 4A-C, 5A-B, which are equal to 20 μm , and 8A-B, which are equal to 200 μm . 1 *Pythagoracypris latavectis* gen. et sp. nov. 1A, ULVG-12634 (juvenile) – RLV; 1B, ULVG-12635 (Holotype) – IV; 1C, ULVG-12636 – IV; 1D, ULVG-12635 – DV; 1E, ULVG-12635 – VV. 2 *Hastacypris adamantem* gen. et sp. nov. 2A, ULVG-12638 – LLV; 2B, ULVG-12639 – RLV; 2C, ULVG-12637 (Holotype) – IV; 2D, ULVG-12640 – DV. 3 *Looneyellopsis mvili*. 3A, ULVG-12641 – RLV; 3B, ULVG-12641 – IV; 3C, ULVG-12641 – DV; 3D, ULVG-12642 – LLV; 3E, ULVG-12642 – IV. 4 *Musacchiocythere plastica*. 4A, ULVG-12643 – RLV; 4B, ULVG-12644 – LLV; 4C, ULVG-12645 – DV. 5 *Musacchiocythere?* sp. 5A, ULVG-12646 – LLV; 5B, ULVG-12646 – DV; 5C, ULVG-12646 – IV. 6 *Alicenula leguminella*. 6A, ULVG-12647 – RLV; 6B, ULVG-12648 – DV. 7 *Alicenula* cf. *A. oblonga*. 7A, ULVG-12649 – LLV; 7B, ULVG-12650 – RLV; 7C, ULVG-12651 – DV. 8 Gen. et sp. indet. 8A, ULVG-12652 – RLV; 8B, ULVG-12653 – Fragment.

Figured specimen. ULVG-12601, carapace, sample TB-030, 820 m.

Material. 631 specimens, both carapaces and valves.

Dimensions (mm). L: 0.70–0.90; H: 0.40–0.50; W: 0.30–0.40.

Discussion. The morphology observed followed the one described for this species in Sousa et al. (2018): normal overlap, oblong lateral outline, supracurvate posterior region, slight sulcus in the center of the dorso-lateral region, absence of cyathus, L/H ratio between 1.95 and 1.79, and well-developed rostrum and alveolar notch. The supracurvate posterior region, oblong lateral outline, and the slight sulcus in the dorso-lateral region are distinctive characters that differentiate this species from the other *Cypridea* found in this study. The specimens identified in the Iguatu Basin have their dorsal margins not as strongly inclined as those described by Sousa et al. (2018) for the Rio do Peixe Basin, but as the found specimens otherwise fit the species description, they are assigned to this species.

Stratigraphic and geographic distribution. Sousa Basin, Sousa Formation, Berriasian-Hauterivian, Brazil (Sousa et al., 2018); Iguatu Basin, Orós Formation, Hauterivian–Aptian, Brazil (this study).

***Cypridea* cf. *C. clavata* Anderson, 1939**
(Fig. 4.3A–D)

?1985 *Cypridea clavata talaria* Anderson, p. 63, pl. 10, fig. 3.

?2008 *Cypridea clavata* Nye et al., p.436, fig. 10.A–P.

Figured specimens. ULVG-12602, carapace, sample TA-092, 500 m; ULVG-12603, valve, sample TA-108, 580 m.

Material. Seven specimens, one carapace and six valves.

Dimensions (mm). L: 0.80–1.00; H: 0.50–0.60; W: 0.50.

Description. Large carapace of sub-rectangular outline in lateral view, oval in dorsal view. RV larger than LV, overlap visible throughout the entire carapace outline. Equicurvate and rounded posterior and anterior margins, with the posterior margin being narrower than the anterior. Dorsal margin straight, declining towards the posterior; ventral margin straight in RV, slightly concave in LV. Greatest height at the ACA, greatest length at mid-height, greatest width at the posterior third. Well-developed rostrum that appears to point backwards towards the ventral margin, although the tip was broken in all recovered specimens. Alveolar notch well-marked, extending up to mid-height or slightly above it. Small cyathus located in the larger RV. Dorsal furrow is long, extending from the posterior up to the middle of the carapace.

Area-wide ornamentation elements include round, large puncta, densely arranged throughout the whole carapace except the anterior and posterior margins. Local ornamentation elements include small nodules that can be seen in the antero-ventral, centro-ventral, and posterior areas, and around eight equally distant small nodules adorn the anterior margin, beginning at the base of the rostrum and ending at the antero-dorsal area. Three larger tubercles adorn the carapace; one in the central/postero-central area, one located directly above it in the dorso-lateral region, and one in the antero-dorsal area. These tubercles are cylindrical, noticeably protruding from the carapace.

The ontogenetic sequence for this species is unknown. Two forms were observed in the material: a more common, longer one (Fig. 3.3D), and a single, more laterally compressed one (Fig. 4.3A–C), which is also the only carapace recovered. This might be indicative of sexual dimorphism, with the longer carapace in lateral view potentially being the male, the more compressed one the female, although not enough specimens of the second form were recovered to properly describe it.

Internal features could not be observed, as all valves recovered were filled with sediment, poorly preserved, or broken.

Discussion. A rare *Cypridea* species, easily differentiated from others in the studied sections due to its inverse overlap. *Cypridea clavata* is an inverse species first described from the Wealden and Purbeck of England by Anderson (1939) and later further subdivided into numerous subspecies based on the degree of development and pattern of its tubercles (Anderson, 1967, 1985). However, the definition of these subspecies is somewhat arbitrary, as their differences are sometimes very subtle and there are many intermediate forms, as Anderson (1967) himself admits (Nye et al., 2008). The forms here recovered have an outline that resembles *C. clavata* illustrated by Nye et al. (2008), falling within their size range. They do differ heavily regarding ornamentation pattern, sharing only the punctation on the surface of the carapace, but as previously discussed, the degree of ornamentation development and its positioning seems to vary heavily within the species. The more elongated specimens also bear some resemblance to the *Cypridea clavata talaria* illustrated by Anderson (1985), although the position and pattern of the three main tubercles is different, and the tubercles in *C. clavata talaria* are narrower and more similar to spines. Due to these differences and as there was a considerable geographic distance between the English Wealden depositional area and the contemporaneous Brazilian ones, we slightly questionably assign our taxon to this species. However, it is not impossible, and indeed rather probable, that the English and Brazilian specimens belong to the same species, as non-marine ostracods, including species of the extinct family Cyprideidae Martin, 1940, had the potential to become widely dispersed passively by larger animals, at least since the Upper Jurassic (Sames and Horne, 2012).

Stratigraphic and geographic distribution. Iguatu Basin, Orós Formation, Hauterivian–Aptian, Brazil (this study).

***Cypridea punctacentralis* sp. nov.**
(Fig. 4.4A–I)

1893 non *Cypridea wyomingensis* Jones, p. 391, fig. 1.5 (a, b) and 1.6 (a, b).

1962 non *Cypridea vulgaris* Krömmelbein, p. 509, pl. 56.24a–c.

1962 non *Cypridea ambigua* Krömmelbein, p. 511, pl. 57.28a–c.

1971 non *Cypridea acicularis*, Krömmelbein and Weber, p. 73, pl. 2, fig. 9 (a–c).

Etymology. Named after its ornamentation, which consists of numerous puncta concentrated near the center of its carapace.

Holotype. ULVG-12604, carapace, sample TB-010, 720 m, long morphotype.

Paratypes. ULVG-12605, carapace, sample TA-063, 355 m, short morphotype; ULVG-12606, carapace, sample TB-023, 785 m, tuberculate morphotype; ULVG-12607, valve, sample TA-107, 575 m, tuberculate morphotype.

Material. 1,737 specimens, both carapaces and valves.

Dimensions (mm). L: 0.70–0.95; H: 0.40–0.55; W: 0.30–0.45.

	Length	Height	Width
ULVG-12604 (Holotype)	0.82	0.47	0.33
ULVG-12605 (Paratype)	0.76	0.48	0.32
ULVG-12606 (Paratype)	0.87	0.50	0.44
ULVG-12607 (Paratype)	0.91	0.54	–

Type locality and horizon. Orós Formation, Iguatu Basin, Transnordestina B, sample TB-010, 720 m, latitude: 6°19'58", longitude 39°13'53", Hauterivian–Aptian.

Diagnosis. A large *Cypridea* species with dense punctation in the central, dorso-lateral and ventro-lateral areas, and with smooth posterior and anterior regions. It can potentially display two large, node-like tubercles in the central and antero-central regions, a line of tubercles in the dorsal area, and two diagonal lines of tubercles in the ventral area that dip towards the postero-ventral margin, in addition to numerous small tubercles in the postero- and antero-lateral regions.

Description. Large carapace of sub-rectangular outline in lateral view, sub-elliptical in dorsal view. LV larger than RV, overlap visible throughout the entire carapace outline, particularly in the ventral margin. Equicurved and rounded posterior and anterior margins, with the posterior margin being thinner than the anterior. Dorsal margin sinuous in the RV, straight in the LV, both sloping downwards towards the posterior area; ventral margin slightly convex in RV, straight in LV. Greatest height at the ACA, greatest width at the postero-central area. Rostrum is thick in the LV and thin in the RV, ending in a point, pointing slightly backwards, ending at the same height as the ventral margin. Alveolar groove well marked and noticeably triangular in shape, broad at the base and tapering to a point around the mid-height of the valve. Dorsal furrow very well delimited; laterally thin and extending from the postero-dorsal to the middle of the dorsal margin. LV with a large cyathus.

Area-wide ornamentation elements consist of dense punctation in the central, dorso-lateral and ventro-lateral areas, with a smooth posterior and anterior. Punctation is coarser in the central area, with larger puncta located near the middle of the carapace and smaller ones near the dorsal and ventral margins. Local ornamentation elements include a variable number of small nodules in the anterior margin, which start near the rostrum and end at around mid-height. In addition, some specimens show a surface heavily ornamented with numerous tubercles. There are two large ones located in the central and antero-central regions. One line of five smaller tubercles adorn the dorsal region. Two diagonal lines, the upper with three tubercles and the lower with four, can be observed near the ventral region, starting in the antero-lateral region and dipping downwards towards the ventro-lateral region. Three to five tubercles can be observed in the postero-lateral region, and three tubercles appear in the antero-lateral region, close to the anterior margin. These tubercles are round and short, not extending far.

The complete ontogenetic sequence was not recovered, but some juveniles were. They resemble the adults, although smaller in size. There seems to be the presence of sexual dimorphism in this species, as two forms were observed: a more common, longer one (Fig. 4.4D-E), and a more laterally compressed one (4.4A-C). Despite the large amount of recovered material, preservation of the valves is poor, and internal characteristics could not be properly observed. The hinge appears to be merodont and of lophodont type, with a smooth bar and two sockets in the RV and the opposite elements on the LV. What appears to be the AMS was observed in one valve, consisting on three slightly upwards curved, oblong scars of approximately same size organized in a vertical row towards the anterior region, with two smaller ones arranged diagonally towards the posterior.

Discussion. The most common *Cypridea* species in both sections, it can be distinguished from the other ones by the sinuous margin of its RV and by the distinct overlap of the LV over the RV, which is present along the entire carapace outline, particularly in the ventral margin. *C. punctacentralis* sp. nov. shows some degree of plasticity, and can display a large number of tubercles; even in the less adorned specimens, it is possible to observe a degree of distortion in the puncta located in the areas where tubercles can develop, as well as the presence of small tubercles in the anterior region, close to the rostrum. This degree of variation in the ornamentation of

Cypridea species is not uncommon, as discussed by Sames (2011b) and Nye et al. (2008), and are likely related to environmental factors. *Cypridea punctacentralis* sp. nov. resembles *C. vulgaris* Krömmelbein, 1962, but *C. punctacentralis* sp. nov. is larger, has its punctation limited to the central, dorso-lateral and ventro-lateral areas, has a narrower rostrum, and the dorsal and ventral margins of the LV are straight instead of convex like in *C. vulgaris*. *C. punctacentralis* sp. nov. also similar to *C. ambigua* Krömmelbein, 1962, but it differs in the distribution of its punctate ornamentation, which is not as widespread as it is in *C. ambigua*. Moreover, the carapace of *C. punctacentralis* sp. nov. is wider than in *C. ambigua*, its dorsal furrow is much more well-developed, its rostrum is narrower, and whereas *C. ambigua* has relatively symmetrical anterior and posterior margins, *C. punctacentralis* has a posterior margin that is noticeably narrower than the anterior one. The more heavily ornamented forms of *C. punctacentralis* sp. nov. somewhat resemble the species *C. wyomingensis* Jones, 1893 and *C. acicularis* Krömmelbein and Weber, 1971, but both of those species lack the two large tubercles that *C. punctacentralis* sp. nov. can develop, and it overall possess a larger number of tubercles.

Stratigraphic and geographic distribution. Iguatu Basin, Orós Formation, Hauterivian–Aptian, Brazil (this study).

Family Cyprididae Baird, 1845

Genus *Brasacypris* Krömmelbein, 1965

Type species: *Brasacypris ovum* Krömmelbein, 1965

Stratigraphic range. Lower Cretaceous (Krömmelbein, 1965; Sousa et al., 2018).

***Brasacypris ovum* Krömmelbein, 1965 emended Sousa et al., 2018.** (Fig. 4.5A–D)

?2004 *Brasacypris ovum*? Do Carmo et al., p. 144, fig. 4.4.

2018 non *Brasacypris ovum* Leite et al., p. 8, fig. 4.1–6.

2018 *Brasacypris ovum*, Sousa et al., p. 30, fig. 5.1–22.

Figured specimens. ULVG-12608, carapace, sample TA-122, 650 m; ULVG-12609, carapace, sample TA-092, 500 m; ULVG-12610 (juvenile), carapace, sample TA-092, 500 m.

Material. 1,017 specimens, both carapaces and valves.

Dimensions (mm). L: 2.00–2.20; H: 1.20–1.48; W: 0.90–1.10.

Discussion. This very large to gigantic species is very common throughout the sections, although perhaps due to its large size, it is most frequently found fragmented or crushed. Adult specimens are rare, with the majority of the material consisting of juveniles around the length of 1.5 mm or lower (Fig. 4.5B–D). No recovered specimens of the Iguatu Basin displayed the nodules that were observed by Sousa et al. (2018), which might indicate that salinity levels in these samples were never high enough to trigger the development of such ornamentation. The ontogenetic sequence recovered in our samples corroborate with the descriptions of Sousa et al. (2018) that the juveniles tend to have a more triangular outline. Despite the recovery of numerous valves, the material was too poorly preserved to observe internal characteristics.

Stratigraphic and geographic distribution. Tucano Basin, Itaparica and Candeias formations, Berriasian (Krömmelbein, 1965, 1966); Sergipe–Alagoas Basin, Berriasian sections (Cassab et al., 1994); Sousa Basin, Sousa Formation, Berriasian–Hauterivian (Sousa et al., 2018); Iguatu Basin, Orós Formation, Hauterivian–Aptian, Brazil (this study).

Subfamily Cyprinotinae Bronstein, 1947

Genus *Pattersoncypris* Bate, 1972

Type species: *Pattersoncypris micropapillosa* Bate, 1972 emended Poropat and Colin, 2012a

Stratigraphic range. Lower Cretaceous (Aptian–Albian) (Bate, 1972).

Diagnosis (as emended by Poropat and Colin, 2012a, p. 707). “Carapace ovate in lateral view. Greatest carapace height approximately at mid-length, forming a pronounced hump. Both valves strongly convex in dorsal view, carapace thickest at or slightly posterior of mid-length. Carapace surface lacks coarse ornamentation. Left valve slightly larger than right, with at least a slight overlap on all margins. Anterior and posterior margins obliquely rounded, anterior margin more so than the posterior, with higher apex. Antero-dorsal margin of right valve slightly concave; convex to concave on left valve (though always less concave than right), accentuating dorsal hump of carapace and antero-dorsal angle. Hinge margin slightly convex, angled postero-ventrally. Ventral margin ranges from slightly concave to slightly convex. Carapace surface smooth to papillate. No coarse ornamentation. No recognized sexual dimorphism of the carapace. Hinge adont; right valve was described by Bate (1972) as having a groove for accommodation of the dorsal margin of the left valve, though this does not appear to accurately describe the nature of the hinge of the holotype specimen (Fig. 4.1) unless the valves of the carapace have been detached. Muscle scars typical of Cyprididae”.

Remarks. A genus with a controversial taxonomic history, first established by Bate (1972) based on remarkable specimens from the Santana Formation, Araripe Basin, which contained phosphatized soft parts. Three species were initially attributed to it: *Pattersonocypris micropapillosa*, *Hourcquia angulata sinuata* (Krömmelbein and Weber, 1971), and *H. angulata salitrensis* (Krömmelbein and Weber, 1971). Later works by Bate also considered the *H. angulata* subspecies *H. angulata symmetrica* (Krömmelbein and Weber, 1971) and *H. angulata angulata* (Krömmelbein and Weber, 1971) as belonging to *Pattersonocypris*, although they were never officially reassigned to it. Smith (2000) redescribed *P. micropapillosa*, describing not only its ontogenetic sequence, but also placing it into the subfamily Cyprinotinae based on the features of its upper lip.

Do Carmo et al. (2008) considered the genus *Pattersonocypris* to be a junior synonym of *Harbinia* Tsao 1959, also transferring the previously mentioned species to this genus. Poropat and Colin (2012a), in their review of the genera *Hourcquia* and *Pattersonocypris*, considered that there are enough morphological differences between *Pattersonocypris* and *Harbinia*, as well as sufficient disparity between their stratigraphic ranges (Lower Cretaceous for *Pattersonocypris* and Upper Cretaceous for *Harbinia*) and paleoenvironmental settings (*Pattersonocypris* is found in formations associated to or underlying evaporite layers, indicating a preference for saline water bodies, while *Harbinia* has never been found associated with evaporitic successions), to revalidate the former. Poropat and Colin (2012a) also attributed the species *Pattersonocypris symmetrica* and *P. angulata* to a new genus, *Kroemmelbeincypris*, based on the absence of the concavity in the antero-dorsal margin of the right valve, the antero-ventral slope of the posterior margin, the weak convexity of the ventral margin, and the presence of a tessellated pattern over the entire carapace. This classification has not been adhered to in later works, as no later mentions of this genus can be found. Synonymy discussions regarding *Harbinia* and *Pattersonocypris* are likely to remain open until a proper revision of the type material from both is done. In this paper, the authors have opted to use *Pattersonocypris*, as they agree with the evaluation developed by Poropat and Colin (2012a) regarding the differences between *Harbinia* and *Pattersonocypris*.

Pattersonocypris sinuata (Krömmelbein and Weber, 1971) emended Poropat and Colin, 2012a (Fig. 5.1A–E)

1971 *Hourcquia angulata sinuata* Krömmelbein and Weber, p. 81, pl. 6, fig. 24a–c.

2012a *Pattersonocypris sinuata* Poropat and Colin, p. 708, fig. 4.2.

Figured specimens. ULVG-12611, valve, sample TA-104, 560 m; ULVG-12612, valve, sample 104, 560 m; ULVG-12613, valve, sample TA-092, 500 m; ULVG-12614, carapace, sample TA-092, 500 m; ULVG-12654 (juvenile, lost), valve, sample TA-064, 360 m.

Material. 3,051 specimens, both carapaces and valves.

Dimensions (mm). L: 0.70–0.80; H: 0.45–0.50; W: 0.40–0.50.

Discussion. By far the most common *Pattersonocypris* species in the section, it can be distinguished from other species of this genus identified in this paper by being proportionally longer and of shorter height than *P. cf. P. sinuata*, and with a longer anterior region and more prominent dorsal hump than *Pattersonocypris?* sp. It is similar to *P. sinuata*, particularly to the specimen illustrated in Krömmelbein and Weber (1971), being of similar size and with an overall similar lateral and dorsal outline, including the characteristic concavity in the antero-dorsal margin and the slightly concave ventral margin, and it possesses the shorter anterior region of the *Harbinia sinuata* specimens illustrated by Ramos et al. (2006) and Do Carmo et al. (2013). Although the recovered specimens tend to have a dorsal outline that is not as steep and a more pronounced antero-dorsal angle than what is usually observed in the available literature, the authors consider that these variations might be the result of populations of the same species developing in distinct environments leading to phenotypic variations, and that this species can thus be classified as *Pattersonocypris sinuata*.

Stratigraphic and geographic distribution. Riachuelo Formation, Sergipe-Alagoas Basin, Upper Aptian, Brazil (Krömmelbein and Weber, 1971); Romualdo Member, Santa Formation, Araripe Basin, Aptian–Albian (Silva-Telles Jr. and Viana, 1990); Alagamar Formation, Potiguar Basin, mid-upper Aptian (Do Carmo et al., 2013); Iguatu Basin, Orós Formation, Hauterivian–Aptian, Brazil (this study).

Pattersonocypris* cf. *P. sinuata (Krömmelbein and Weber, 1971). (Fig. 5.2A–C)

?1971 *Hourcquia angulata sinuata* Krömmelbein and Weber, p. 81, pl. 6, fig. 24a–c.

?2006 *Harbinia sinuata* Ramos et al., p. 344, fig. 4.I–L.

?2008 *Harbinia sinuata* Do Carmo et al., fig. 6.10.

?2012a *Pattersonocypris sinuata* Poropat and Colin, p. 708, fig. 4.2.

?2013 *Harbinia sinuata* Do Carmo et al., p. 96, fig. 4.1–27.

Figured specimens. ULVG-12615, carapace, sample TA-104, 560 m; ULVG-12616, valve, sample 104, 560 m (lost); ULVG-12617, carapace, sample 104, 560 m.

Material. 850 specimens, both carapaces and valves.

Dimensions (mm). L: 0.80–0.90; H: 0.50–0.60; W: 0.40–0.50.

Description. Large carapace with sub-triangular outline in lateral view, ovoid in dorsal view. LV larger than RV, overlap visible throughout the anterior, posterior, and ventral margins. Anterior margin equicurved and broadly rounded, posterior margin infra-curved and rounded. Dorsal margin with a well-marked dorsal hump in the antero-dorsal margin, close to the middle point of the carapace, which slopes gently downwards towards the anterior and posterior margins at the same angle. Ventral margin slightly concave on both valves. Greatest height at the dorsal hump, greatest length at mid-height, greatest width at the posterior third of the carapace.

Surface smooth. No sexual dimorphism was observed. A number of younger instars were recovered, with juveniles having a similar outline to adults, although usually exhibiting a relatively stronger elongated posterior region.

Despite its abundance, specimens were overall poorly preserved, and their internal characteristics could not be properly observed.

The hinge appears to be adont, with a thin smooth bar located in the RV and the opposite elements located in the LV.

Discussion. A common *Pattersonocypris* species in the section, being only subordinate to *Pattersonocypris sinuata* in abundance. It differs from both other *Pattersonocypris* species found by being larger and more laterally compressed. Due to the way the antero-dorsal margin slopes gently downwards, the infracarvate posterior region, and the proportionally shorter length, the outline of the recovered specimens differs from that of many *P. sinuata* specimens illustrated in the published literature (e.g., Ramos et al., 2006; Poropat and Colin, 2012a; Do Carmo et al., 2013; Araripe, 2017). Therefore, the authors have decided to slightly questionably assign the recovered specimens to this species.

Stratigraphic and geographic distribution. Iguatu Basin, Orós Formation, Hauterivian–Aptian, Brazil (this study).

***Pattersonocypris?* sp.**

(Fig. 5.3A–C)

Figured specimens. ULVG-12618, valve, sample TA-064, 360 m; ULVG-12619, carapace, sample TA-112, 600 m.

Material. 626 specimens, both carapaces and valves.

Dimensions (mm). L: 0.70–0.90; H: 0.40–0.50; W: 0.40–0.50.

Description. Large carapace of sub-rectangular outline in lateral view, sub-elliptical in dorsal view. Anterior margin equicurved and rounded, posterior margin infracarvate. LV larger than RV, overlap visible throughout the anterior, posterior, and the ventral margins. Anterior region significantly shorter than the posterior one, which accounts for up to two-thirds of the overall length of the carapace. Dorsal margin marked by a slight dorsal hump in the anterior third of the carapace, sloping gently downwards towards the posterior margin. Ventral margin straight to slightly concave. Greatest height at the dorsal hump, greatest length at mid-height, greatest width at the posterior third.

Surface smooth. No sexual dimorphism was observed. A number of younger instars were recovered, with juveniles having a similar outline to adults, being however slightly more laterally compressed. No specimen with well-preserved internal features was recovered.

Discussion. This species appears to be related to the genus *Pattersonocypris*, although its elongated carapace gives it a distinct outline. The dorsal hump of this species can also appear somewhat diminished because of the less inclined antero-dorsal margin, which also appears to lack the slight concavity in the RV. It has been tentatively included in the genus *Pattersonocypris* due to the fact that its characteristics seem to overall match those of the genus.

Stratigraphic and geographic distribution. Iguatu Basin, Orós Formation, Hauterivian–Aptian, Brazil (this study).

Family Ilyocyprididae Kaufmann, 1900

Subfamily Ilyocypridinae Kaufmann, 1900

Genus *Ilyocypris* Brady and Norman, 1889

Type species: *Cypris gibba* Ramdohr, 1808

Stratigraphic range. Early Cretaceous to Recent (Van Morkhoven, 1961; Krömmelbein, 1962; Sousa et al., 2019).

Diagnosis. “Elongate, subquadrate, compressed, bisulcate; with marginal compressed rim; surface pitted, pustulose or tuberculate; dimorphic posterior thickening in females” (Benson et al., 1961, p. 239–240).

Remarks. The genus *Origoilyocypris* Mandelstam, 1956 was originally established to include species similar to species of *Ilyocypris* found in the Upper Jurassic–Lower Cretaceous of Europe, but the genus has seen little use in literature, and has in fact been considered as a synonym to *Rhinocypris* Anderson, 1941 instead (e.g., Benson et al., 1961; Van Morkhoven, 1963; Barker, 1966; Wang

et al., 2016). A number of *Ilyocypris* species have, however, been described for the Cretaceous, such as *I. wichmanni* Musacchio, 1973 and *I. riograndensis* Musacchio and Simeoni, 1991, both from the Upper Cretaceous of Argentina. The oldest records of species of this genus in Brazilian basins are those of *Ilyocypris* sp. by Krömmelbein (1962, Candeais Formation, Ilhas Group, Recôncavo Basin, Brazil, dated as Berriasian to Barremian), and *Ilyocypris* sp. 1 of Sousa et al. (2018, Sousa Basin, Sousa Formation of the Rio do Peixe Group, which was considered as being of Hauterivian age (Sousa et al., 2018, 2019). The two new species described below, thus, would represent the earliest record (Hauterivian–Barremian) of species of the genus *Ilyocypris*. However, the generic assignment of the respective Cretaceous taxa is debated since the diagnosis provided by Benson et al. (1961) is not (fully) applicable to many Cretaceous species. This applies to the compressed marginal rim, which is absent in numerous Cretaceous species attributed to the genus (e.g., *I. riograndensis*, *Ilyocypris* sp. described by Krömmelbein, 1962, and Sousa et al., 2018, and the ones described in this paper). A comprehensive revision of the taxonomy and phylogeny of Cretaceous species of this genus and its close relatives (such as the genus *Rhinocypris*) is needed, but it falls beyond the scope of this paper. Therefore, the generic assignment of our two new species are applied with reservation.

***Ilyocypris?* arca sp. nov.**

(Fig. 5.4A–E)

Etymology. Named after the Latin word “arca”, which means “box”, due to the sub-quadrangular lateral outline of the species.

Holotype. ULVG-12620, valve, sample TA-104, 560 m.

Paratypes. ULVG-12621, valve, sample TA-108, 580 m; ULVG-12622, valve, sample TB-018, 760 m; ULVG-12623, valve, sample TA-103, 555 m; ULVG-12624 (juvenile), valve, sample TA-121, 645 m.

Material. 1,092 specimens, only valves were recovered.

Dimensions (mm). L: 0.60–0.75; H: 0.30–0.40; W: 0.30–0.40.

	Length	Height	Width (Valve)
ULVG-12604 (Holotype)	0.67	0.41	0.20
ULVG-12621 (Paratype)	0.62	0.37	0.17
ULVG-12622 (Paratype)	0.63	0.40	0.16
ULVG-12623 (Paratype)	0.60	0.38	0.17
ULVG-12624 (Paratype)	0.53	0.33	0.11

Type locality and horizon. Orós Formation, Iguatu Basin, Transnordestina A, sample TA-104, 560 m, latitude: 6°19'58", longitude 39°13'53", Hauterivian–Aptian.

Diagnosis. A medium to large *Ilyocypris?* species with a laterally compressed carapace, pustulose surface, three round and short nodes in the dorso-lateral area with the one close to the posterior being the largest, distributed in a slightly curved array.

Description. Medium to large, thin valve of sub-quadrangular outline in lateral view, likely ovoid in dorsal view. LV slightly larger than the RV, overlap unknown. Anterior and posterior margins equicurved, anterior margin broadly rounded, posterior margin round and with the same height as or higher than the anterior. Dorsal margin straight, with the antero-dorsal margin gently sloping downwards at the ACA and the postero-dorsal margin abruptly pointing downwards at the PCA. Ventral margin concave. Greatest height at the ACA, greatest length at mid-height,

greatest length at the posterior third, close to the middle point of the carapace.

Area-wide ornamentation elements include small round pustules spread throughout the entire surface of the carapace, with variable density. Local ornamentation elements include two wide, continuous sulci located in the central area of the dorso-lateral region, with the one closer to the posterior being longer, reaching the central area of the valve, and the anterior one being shorter, stopping at the edge of the dorso-lateral region. There are also three round and short nodes located between the sulci, with the one close to the posterior being the largest. They are distributed in a slightly curved array, and can also be covered with pustules.

A number of younger instars were recovered; juveniles have a more compressed anterior region and more sparse ornamentation, but are otherwise similar to adults. Sexual dimorphism was not observed in the recovered valves.

Hinge apparently merodont, with a bar and two sockets in the LV, although preservation was too poor to verify if these elements were smooth or crenulated. RV houses the corresponding elements. The inner lamella is very wide in the anterior and posterior margins, forming a well-developed vestibule in the latter. AMS not visible in any of the recovered specimens.

Discussion. A very common species throughout the sections. It can be distinguished from *Ilyocypris? latanodi* sp. nov. by its more laterally compressed carapace, the much less pronounced slope of the dorsal margin towards the posterior region, and the fact that its nodes are not aligned in a straight line. It is a distinct species in this genus due to its very quadrangular carapace. Despite its carapace not being elongated, it contains all the other main characteristics of the genus, such as the sub-quadrangular outline, a pustulose surface, and the two sulci in the dorso-lateral area; therefore, we tentatively assign this species to *Ilyocypris*.

Stratigraphic and geographic distribution. Iguatu Basin, Orós Formation, Hauterivian–Aptian, Brazil (this study).

Ilyocypris? latanodi sp. nov.

(Fig. 5.5A–E)

Etymology. From the Latin words “lata”, meaning wide, and “nodi”, meaning “nodes”, in reference to the wide nodes that the species has.

Holotype. ULVG-12625, carapace, sample TA-092, 500 m.

Paratypes. ULVG-12626 (juvenile), valve, sample TA-097, 525 m; ULVG-12627, valve, sample TA-104, 560 m; ULVG-12628 (juvenile), valve, sample TA-121, 645 m; ULVG-12629 (juvenile), valve, sample TB-020, 770 m.

Material. 332 specimens, both carapaces and valves.

Dimensions (mm). L: 0.65–0.80; H: 0.40–0.50; W: 0.25–0.35.

	Length	Height	Width
ULVG-12625 (Holotype)	0.74	0.45	0.34
ULVG-12626 (Paratype)	0.58	0.31	–
ULVG-12627 (Paratype)	0.78	0.46	–
ULVG-12628 (Paratype)	0.58	0.34	–
ULVG-12629 (Paratype)	0.53	0.31	–

Type locality and horizon. Orós Formation, Iguatu Basin, Transnordestina A, sample TA-092, 500 m, latitude: 6°19'58", longitude 39°13'53", Hauterivian–Aptian.

Diagnosis. A medium to large *Ilyocypris?* species with an elongated carapace, straight ventral margin, pustulose or reticulate surface,

and three round and short nodules aligned in a straight line in the central area, with the most posterior one being the largest.

Description. Medium to large, thin carapace of sub-rectangular outline in lateral view, ovoid in dorsal view. Anterior and posterior margins equicurved. LV slightly larger than RV. Anterior margin broadly rounded, posterior margin coming to a slight point at mid-height, turned slightly upwards. Dorsal margin straight, sloping downwards from the ACA towards the posterior margin. Postero-dorsal margin slightly concave. Ventral margin straight, with the postero-ventral margin being slightly convex. Greatest height at the ACA, greatest length at mid-height.

Area-wide ornamentation elements are small pustules or a faint reticulated pattern with small cells over the entire surface of the carapace. Local ornamentation elements include two well-defined, continuous sulci in the dorso-lateral area, with the posterior sulcus reaching the middle of the carapace and the anterior one ending at the edge of the dorso-lateral region. There are also three round and short nodes located in the dorso-lateral area, aligned in a straight line, with the most posterior one being the largest. These nodes contain the local ornamentation elements.

A number of younger instars were recovered; the dorsal margin of the juveniles slopes downwards towards the posterior at a steeper angle than in the adults, but otherwise juveniles resemble adults (Fig. 5.4D). Sexual dimorphism was not observed in the recovered specimens. Internal features could not be observed due to the poor preservation.

Discussion. A common species throughout the sections. It can be distinguished from *Ilyocypris? arca* sp. nov. by its more pronounced downwards slope towards the posterior margin, and the fact its three nodes are located closer to the middle of the carapace and are distributed in a straight line. *I.? latanodi* sp. nov. bears certain resemblance to *I. riograndensis* Musacchio and Simeoni, 1991, but the nodes are not as well-developed, the ornamentation is pustulose, the posterior margin is not infracurved, the downward angle towards the anterior margin anteriorly to the ACA is much sharper, and the ventral margin is straight. *I.? latanodi* sp. nov. is similar to *I. triebeli* Bertels, 1972, but its ventral margin is straight, the posterior margin is pointed slightly upwards, and the surface ornamentation is much more well-developed. It also resembles a number of different species described as *Ilyocypris* sp. in various publications (e.g., Krömmelbein, 1962; Uliana and Musacchio, 1978; Do Carmo et al., 2004; Sousa et al., 2018), but its ventral margin being straight and the rounded posterior margin makes it distinct from them. Of those, the species to which is most similar is *Ilyocypris* sp. 1 from Krömmelbein (1962); however, the tubercles of *I.? latanodi* sp. nov. here are less developed and much closer to the central area of the carapace than the ones of the specimen described by Krömmelbein (1962).

Stratigraphic and geographic distribution. Iguatu Basin, Orós Formation, Hauterivian–Aptian, Brazil (this study).

Genus *Rhinocypris* Anderson, 1940

Type species: *Ilyocypris jurassica* Martin, 1940

Stratigraphic range. Upper Jurassic to Upper Cretaceous (Anderson, 1940; Benson et al., 1961; Van Itterbeek et al., 2004).

Diagnosis. “Carapace very small, ovoid; shell thin; LV slightly larger than RV; internally a narrow shelf of uniform width all around except dorsally; shallow groove extending from middle of dorsal margin almost to center of each valve with smaller groove anterior to this, carapace widest in front. Hinge simple, knurled anteriorly and flexed to right posteriorly; slight overlap of LV over RV on all margins except dorsally, greatest ventrally; ventral margin slightly concave; surface covered with minute closely arranged blunt spines or pustules of uniform size. RV hinge on elevated ?smooth ridge” (Benson et al., 1961, p. 241).

Remarks. The genus *Rhinocypris* has a complicated taxonomic history, from being often synonymized with *Origoilyocypris*, as previously discussed, to being considered a subgenus to *Ilyocypris* (Van Morkhoven, 1963). It is obvious that the taxonomy and phylogeny of this genus require thorough revision, as Van Itterbeek et al. (2004) mention. The majority of the taxa attributed to it do not match a number of characters from its diagnosis after Benson et al., 1961. This namely includes its ovoid form, which is absent from species such as *Rhinocypris jurassica* as described or illustrated by numerous authors (e.g. Barker, 1964; Bielecka, 1975; Anderson, 1985; Arp and Mennerich, 2008; Wang et al., 2016) and *Rhinocypris diadema* Musacchio and Simeoni, 1991, both of which are sub-elliptical and show a noticeable concavity in their ventral margin, which is absent from the type species. Such revision of the taxonomy including diagnosis and phylogeny is, however, beyond the scope of this paper. We accommodate for the current taxonomic uncertainties in that *Rhinocypris* is here tentatively used with the reservations mentioned above in mind.

***Rhinocypris? ericius* sp. nov.**

(Fig. 5.6A-C)

Etymology. Named after the Latin word “ericius”, which means “porcupine”, after its many spinelet-like tubercles.

Holotype. ULVG-12630, valve, sample TA-123, 655 m.

Paratype. ULVG-12631, valve, sample TA-103, 555 m; ULVG-12632, valve, sample TB-017, 755 m; ULVG-12633, valve, sample TB-019, 765 m.

Material. 217 specimens, only valves were recovered.

Dimensions (mm). L: 0.50–0.60; H: 0.30–0.35; W: 0.10–0.20.

	Length	Height	Width (valve)
ULVG-12630 (Holotype)	0.64	0.31	0.16
ULVG-12631 (Paratype)	0.57	0.28	0.13
ULVG-12632 (Paratype)	0.54	0.30	0.12
ULVG-12633 (Paratype)	0.59	0.30	0.13

Type locality and horizon. Orós Formation, Iguatu Basin, Transnordestina A, sample TA-123, 655 m, latitude: 6°19'58", longitude 39°13'53", Hauterivian–Aptian.

Diagnosis. A small to medium *Rhinocypris?* species covered with spinelet-like tubercles, small pustules, and with three nodes which are also covered in spinelet-like tubercles located in the dorso-lateral area of the valve, close to its anterior.

Description. Small to medium, thin valve of sub-rectangular outline, sub-elliptical in dorsal view. Anterior and posterior margin equicurved and rounded. Dorsal margin straight, sloping gently downwards towards the posterior area. Ventral area slightly concave to straight. Greatest height at the ACA, greatest length at mid-height, greatest width at the posterior third.

Area-wide ornamentation elements include spinelet-like tubercles, which are regularly distributed over the entire carapace except at the antero-dorsal region. Between the tubercles, very small, circular pustules can be observed, randomly distributed over the carapace. Local ornamentation elements are two wide, continuous sulci located in the most anterior area of the dorso-lateral region, with the most posterior one being the longest, reaching the central area of the carapace, and the anterior one ending at the edge of the dorso-lateral area. Three nodes covered with small tubercles are

located between the sulci, close to its anterior. The most posterior node is not well defined, merging with the carapace.

Of the ontogenetic sequence, both adults and juveniles were recovered. Juveniles differ from adults mainly in size, having a similar ornamentation pattern. No sexual dimorphism was observed.

Hinge merodont and of lophodont type, consisting of a smooth bar and two elongated sockets on the LV. The free inner lamella is wide in the anterior region, becoming narrow towards the ventral and posterior areas. AMS not visible in any of the recovered specimens.

Discussion. The only *Rhinocypris?* species found in the studied sections, it is relatively rare compared to other Ilyocypridinae. The spinelet-like structures were considered tubercles due to their distribution pattern matching that of the usual location of pores in the surface of an ostracod carapace. The coarse, well-developed tuberculate ornamentation and the way its most posterior nodule merges with the posterior of the carapace sets it apart from other Lower Cretaceous species of this genus, such as *Rhinocypris diadema* Musacchio and Simeoni, 1991 from Argentina and *R. jurassica* Martin, 1940 from Germany, as well as other open nomenclature species such as *Rhinocypris* sp. described by van Van Itterbeek et al. (2004) for Mongolia, and *R. aff. R. jurassica*, R. cf. *R. jurassica* and *R. aff. R. diadema* reported by Tomé et al. (2014) and Nascimento et al. (2017) for Brazil.

Stratigraphic and geographic distribution. Iguatu Basin, Orós Formation, Hauterivian–Aptian, Brazil (this study).

Family incertae sedis.

Genus ***Pythagoracypris*** gen. nov.

Type species: *Pythagoracypris latavectis* gen. et sp. nov.

Etymology. Named after the Greek philosopher Pythagoras and his theorem, due to the sub-triangular outline of the genus in lateral view.

Diagnosis. Medium to large sub-triangular valve in lateral view, sub-rectangular in dorsal view. Broadly round anterior margin, ventrally acuminate posterior margin. Can display large, conical tubercles and a very wide and thick ventral ridge as ornamentation.

Remarks. The lack of specimens with preserved AMS or a well-preserved hinge makes it difficult to properly place this new genus into a particular family. Whereas it could tentatively be placed under Pontocyprididae Müller 1894 due to its carapace outline, no other member of the family is known to display such heavy ornamentation, particularly the wide ventral ridge. Thus, its family classification is left open.

Pythagoracypris latavectis gen. et sp. nov.

(Fig. 6.1A-E)

Etymology. Named after the Latin words “lata”, meaning “broad”, and “vectis”, meaning “bar”, in reference to the broad ridge located in the ventral area of this species.

Holotype. ULVG-12635, valve, sample TA-104, 560 m.

Paratypes. ULVG-12634 (juvenile), valve, sample TA-107, 575 m; ULVG-12636, valve, sample TA-104, 560 m.

Material. 26 specimens, only valves were recovered.

Dimensions (mm). L: 0.60–0.70; H: 0.35–0.40; W: 0.15–0.25.

	Length	Height	Width (valve)
ULVG-12635 (Holotype)	0.68	0.34	0.21
ULVG-12634 (Paratype)	0.58	0.32	0.19
ULVG-12636 (Paratype)	0.62	0.34	0.20

Type locality and horizon. Orós Formation, Iguatu Basin, Transnordestina A, sample TA-104, 560 m, latitude: 6°19'58", longitude 39°13'53", Hauterivian-Aptian.

Diagnosis. Same as the genus.

Description. Medium to large valves of sub-triangular outline in lateral view, sub-rectangular in dorsal view. Anterior margin equicurved and broadly rounded, posterior margin elongated and pointed at ventral height. Dorsal margin straight, sloping gently downwards from the ACA to the PCA, with the postero-dorsal margin slightly convex and sloping downwards. Ventral margin nearly straight, with a slight median concavity, and with the antero-ventral region curving upwards. Greatest height at the ACA, greatest length below mid-height, greatest width in the posterior third.

Local ornamentation elements are large tubercles located in the dorso-lateral, anterior and posterior regions, which include; a small one near the middle of the anterior margin, right above the end of the ventral ridge; a large one in the antero-dorsal margin beneath the ACA; two very large ones at the postero-dorsal margin beneath the PCA, jutting out from the same root; and a small one at the tip of the posterior margin. The ventral margin also displays small, triangular, thin spikes arranged one after the other, forming a frill-like structure that is very fragile. Area-wide ornamentation elements consist of a very thick and wide ventral ridge can be seen in the ventro-lateral region, with a downward curve in its middle.

A few juveniles were found, with even the earlier stage displaying the distinct ornamentation (Fig. 6.1A). No sexual dimorphism was observed. Hinge appears to be merodont, with the RV containing one elongated tooth with a small groove in the middle in the anterior portion, and LV with two elongated sockets, one in the posterior and one in the anterior, with a short bar between them. Inner lamella wide, following the entire margin of the carapace with the exception of the dorsal margin. AMS could not be observed.

Discussion. A very distinct species with a limited distribution in the studied sections, being found only near the end of Transnordestina A. It is the only known species of this genus so far.

Stratigraphic and geographic distribution. Iguatu Basin, Orós Formation, Hauterivian–Aptian, Brazil (this study).

Genus *Hastacypris* gen. nov.

Type species: *Hastacypris adamantem* gen. et sp. nov.

Etymology. Named after the Latin word “hasta”, meaning “spear”, in reference to the lateral and dorsal outline of this genus resembling the tip of a spear.

Diagnosis. Large elongated carapace with a round, infracurved anterior margin and a pointed, ventrally acuminate posterior margin. On dorsal view, the carapace displays a rhomboidal outline, close to a lozenge. Surface smooth. Inner lamella is broad and of continuous thickness, restricted to the anterior margin.

Remarks. The lack of preserved AMS and the simple adont hinge makes it difficult to attribute it to any particular family. Due to similar reasons as the ones mentioned in the description of the genus *Pythagoracypris*, its family assignment is left in open nomenclature.

Stratigraphic and geographic distribution. Iguatu Basin, Orós Formation, Hauterivian–Aptian, Brazil (this study).

Hastacypris adamantem sp. nov.

(Fig. 6.2A–D)

Etymology. Named after the Latin word “adamantem”, meaning “diamond”, in reference to the dorsal outline of the species, which resembles a lozenge, a shape often referred to as a diamond.

Holotype. ULVG-12637, valve, sample TA-109, 585 m.

Paratype. ULVG-12638, valve, sample TA-104, 560 m; ULVG-12639, valve, sample TA-104, 560 m; ULVG-12640, carapace, sample TA-095, 515 m.

Material. 2,292 specimens, both carapaces and valves.

Dimensions (mm). L: 0.75–0.90; H: 0.35–0.45; W: 0.20–0.30.

	Length	Height	Width
ULVG-12637 (Holotype)	0.84	0.36	–
ULVG-12638 (Paratype)	0.76	0.37	–
ULVG-12639 (Paratype)	0.83	0.41	–
ULVG-12640 (Paratype)	0.79	0.36	0.23

Type locality and horizon. Orós Formation, Iguatu Basin, Transnordestina A, sample TA-109, 585 m, latitude: 6°19'58", longitude 39°13'53", Hauterivian-Aptian.

Diagnosis. Same as the genus.

Description. Large elongated carapace of sub-ovoid outline in lateral view, subrhomboidal on dorsal view, close to a lozenge. Valves nearly equal in size, might display an overlap of the RV over the LV in the anterior margin, although it might be an artifact of preservation in the few recovered carapaces. Anterior margin infracurved and round, posterior margin pointed, ventrally acuminate. Dorsal margin straight, sloping gently downwards towards the posterior; antero-dorsal margin curving downwards abruptly past the ACA; postero-dorsal margin straight, sloping downwards ventrally past the PCA. Ventral margin straight to slightly convex. Greatest height at the point of the ACA, greatest length around mid-height, closer to the ventral margin, greatest width antero-medially.

Surface smooth. Many younger instars were found; juveniles display more laterally compressed carapaces and a sharper antero-dorsal angle. Despite the abundance of recovered material, none had the AMS preserved. Hinge adont, with a smooth bar located in the RV. Inner lamella wide, located throughout the entire anterior margin, although it does not extend past it.

Remarks. A common species present throughout both sections, although more common in their upper part. It is the only known species of this genus.

Stratigraphic and geographic distribution. Iguatu Basin, Orós Formation, Hauterivian–Aptian, Brazil (this study).

Suborder CYTHEROCOPINA Baird, 1850

Superfamily Cytheroidea Baird, 1850

Family Limnocytheridae Klie, 1938

Genus *Looneyellopsis* Krömmelbein and Weber, 1971

Type species: *Looneyellopsis brasiliensis* Krömmelbein and Weber, 1971

Stratigraphic range. Lower Cretaceous (Musacchio, 1970; Krömmelbein and Weber, 1971; Ayress and Whatley, 2014).

Diagnosis (translated from Krömmelbein and Weber, 1971, p. 29). “Carapace obliquely trapezoidal; upper margin broadly rounded, posterior margin narrower, not “caudate”. Rough ornamentation: large median sulcus, moderately deep. Three noduliform swellings in each valve, in an upper row. Ventral margin with a large protuberance, relatively long (around 2/3 of the length of the C), in the shape of a wing, which can be anteriorly reinforced with a nodule. Fine ornamentation: moderately rough pore cavities. LV bigger than RV; LV with more salient dorsal angles”.

Looneyellopsis mvili (Grosdidier, 1967) Poropat and Colin, 2012b. (Fig. 6.3A–E)

1967 *Orthonotacythere mvili* Grosdidier, pl. 3.8a–g.

Figured specimens. ULVG-12641, valve, sample TA-104, 560 m; ULVG-12642, valve, sample TA-104, 560 m.

Material. 209 specimens, both carapaces and valves.

Dimensions (mm). L: 0.40–0.50; H: 0.20–0.30; W: 0.15.

Discussion. A *Looneyellopsis* species without the large nodules common to the genus, although the carapace outline, weak ventral inflation, and two sulci near the anterior region are otherwise characteristic. *L. mvili* (Grosdidier, 1967) was originally attributed to *Orthonotacythere*, but was transferred to *Looneyellopsis* by Poropat and Colin (2012b) and, later, to *Paranotacythere* by Ayress and Whatley (2014). As *Orthonotacythere* and *Paranotacythere* are both marine genera, the authors have opted to follow the classification of Poropat and Colin (2012b). Although there are some few apparent differences, such as being slightly larger and its posterior margin being rounder and not ending in a point, they might be attributed to environmental factors or even due to the low quality of the holotype and carapace pictures provided by Grosdidier (1967).

Stratigraphic and geographic distribution. Wealden of the Congo Basin, Congo (Grosdidier, 1967); Iguatu Basin, Orós Formation, Hauterivian–Aptian, Brazil (this study).

Genus *Musacchiocythere* Ayress and Whatley, 2014.

Type species: *Wolburgia sarunata* Musacchio, 1978

Stratigraphic range. Lower to Upper Cretaceous (Uliana and Musacchio, 1978).

Diagnosis (after Ayress and Whatley, 2014, p. 1160). “Thin shelled. Elongate trapezoidal in lateral view. Truncated in the extreme postero-dorsal area and very strongly acuminate mid-posteriorly. Crest subperipheral and enclosing large excavated area on either side of the well-developed, vertical median sulcus, lanceolate in dorsal view. Hinge delicate lophodont”.

Musacchiocythere plastica (Musacchio, 1970) Ayress and Whatley, 2014.

(Fig. 6.4A–C)

1970 *Wolburgiopsis plastica*, Musacchio, p. 303, pl. 1.1–5.

2011 *Wolburgiopsis plastica*, Ballent et al., fig. 15.6.

Figured specimens. ULVG-12643, valve, sample TA-107, 575 (lost) m; ULVG-12644, valve, sample TA-104, 560 m; ULVG-12645, valve, sample TA-102, 550 m.

Material. 14 specimens, only valves were recovered.

Dimensions (mm). L: 0.45–0.55; H: 0.25–0.35; W: 0.10–0.15 (valve).

Discussion. Ayress and Whatley (2014) transferred the species *Wolburgiopsis plastica* to their newly erected genus *Musacchiocythere*, arguing that the alar-like crest located in its ventro-lateral region and the more central position of its sulcus make the species more closely associated to the latter genus than the former. The specimens recovered in this study resemble a transitional form between the 1A and 2A illustrations of *Musacchiocythere plastica* from Musacchio (1970), identified there as *Wolburgia plastica*, with the general outline being very similar, in addition to the presence of a weak ventral inflation. It does, however, differ in being slightly taller and with a reticulate ornamentation, as well as deeper sulci. Considering the high plasticity attributed to this species, these differences might be a reflection of different environmental factors, as other references of this species in literature show the same variation in ornamentation, such as the specimen illustrated by Ballent et al. (2011), which is virtually identical to the ones illustrated here except for a less dense reticulate pattern. The outline of the specimens of *M. plastica* recovered in this study resemble that of the specimens classified as cf. *Wolburgiopsis plastica* identified by Olivo et al. (2019) and as *W. plastica* by Do Carmo et al. (2004),

although in both cases, the preservation of the material recovered by those authors was very poor and did not allow proper comparisons.

Stratigraphic and geographic distribution. Neuquén Basin, La Amarga Formation, Lower Cretaceous, Argentina (Musacchio, 1970; Ballent et al., 2011); Iguatu Basin, Orós Formation, Hauterivian–Aptian, Brazil (this study).

Musacchiocythere? sp.

(Fig. 6.5A–C)

Figured specimens. ULVG-12646, valve, sample TA-122, 650 m.

Material. Four valves.

Dimensions (mm). L: 0.50–0.60; H: 0.30–0.40; W: 0.10–0.20 (valve).

Description. Medium carapace of sub-trapezoidal outline in lateral view, lanceolate in dorsal view. No carapaces were found, but LV assumed to be slightly larger than RV, as usual for the genus. Anterior margin equicurved and rounded, posterior margin straight, truncated in the postero-dorsal area. Dorsal margin straight, ventral margin slightly convex. Greatest height at the point of the ACA, greatest length at mid-height, greatest width at the posterior third.

Area-wide ornamentation consists of widespread reticulation, with large fossae separated by thin muri. The fossae are smaller closer to the dorsal margin of the carapace. A shallow sulcus can be seen in the central area, close to the anterior region, extending from the dorsal margin to the middle of the carapace. There is also a thin marginal ridge that extends into a ventral ridge, turning upwards into the carapace at the postero-ventral margin and ending close to the posterior end of the dorso-lateral area. The ridge extends laterally from the carapace with a width large enough to balance the valve on top of it.

No juveniles were recovered. No sexual dimorphism was observed. The hinge is entomodont, with the LV containing a crenulated, straight bar that runs through almost the entire length of the dorsal margin, limited at both sides with a round socket. RV contains the opposite elements. AMS could not be observed.

Discussion. A rare species; all specimens were recovered from a single sample. Although certain characteristics match the definition for *Musacchiocythere*, the valves display only a single sulcus instead of two, and the hinge is entomodont instead of lophodont. Therefore, the authors have decided to tentatively place this species into the genus *Musacchiocythere*, and leave the species in open nomenclature.

Stratigraphic and geographic distribution. Iguatu Basin, Orós Formation, Hauterivian–Aptian, Brazil (this study).

Suborder DARWINULOCOPINA Sohn, 1988

Superfamily Darwinuloidea Brady and Norman, 1889

Family Darwinulidae Brady and Norman, 1889

Genus *Alicenula* Rossetti and Martens, 1998

Type species: *Darwinula serricaudata* Klie, 1935

Stratigraphic range. Upper Jurassic to Recent (Rossetti and Martens, 1998; Martens et al., 2003).

Diagnosis (after Rossetti and Martens, 1998, p. 61). “Elongate darwinulids, without internal teeth in the LV and without ventral keel on the RV. Hinge adont. Le[ngth] mostly c 0.6 mm. Valves with R/L or with L/R overlap. Dorsal margin evenly sloping, not rounded or straight over part of its length. Cms [central muscle scars] always situated towards the front in adult specimens. Large caudal brooding cavity externally visible. First segment of A1 with two dorsal setae, second segment with one dorso-apical seta and three ventral setae. A2 with two long setae and a spine on exopodite; first endopodal segment with two ventroapical setae. Seta y on

penultimate segment of Md[Mandibula]-palp absent. Adults with Fu[rca]. P-abd [Postabdomen] mostly large and ‘spinuous’”.

Remarks. The diagnosis of this genus is in need of updating, as later authors (e.g., [Martens et al., 2003](#)) mention the presence of internal teeth in the LV of species belonging to this genus. The classification of the Darwinulidae in Brazilian basins has been the subject of some controversy. Some species from these basins originally attributed to the genus *Darwinula*, such as *A. leguminella* ([Lyell, 1855](#)), have been transferred to the genus *Alicenula*, based both on internal (presence of internal teeth in the LV) and external (LV overlapping RV, elongated valves) characteristics ([Martens et al., 2003](#)). Many Upper Jurassic–Lower Cretaceous Darwinulidae species described from Brazilian deposits – e.g. *D. cf. D. oblonga* ([Krömmelbein, 1962](#)), *A. sousaensis* ([Sousa et al., 2018](#)), *A. longiformis* ([Leite et al., 2018](#)), *D. martinsi* (Silva, 1978 emend. [Do Carmo et al., 2004](#)) and *Penthesilenula pintoii* ([Leite et al., 2018](#)) – show the LV overlapping the RV, which indeed precludes their placement in *Darwinula*. However, many of the internal characteristics of these species remain undescribed, which makes a proper taxonomic classification for them difficult, as external characters are highly variable. For instance, [Guzmán-González et al. \(2016\)](#) attempted to verify the presence of intraspecific differences between the 26 carapaces of *Alicenula* they recovered from the Aliança Formation, Tithonian of the Jatobá Basin by analyzing variations in their L/H ratio. They concluded that the relatively wide range shown, which did not display clusters, in addition to the small variations in carapace outline, seemed to be more indicative of an ontogenetic series. In this paper, the authors have also chosen to follow the suggestions of [Rossetti and Martens \(1998\)](#) and [Martens et al. \(2003\)](#) that many representatives of the genus *Alicenula* had been erroneously attributed to the genus *Darwinula*, as the RV overlapping the LV is the norm for the latter and, thus, species with the LV overlapping the RV do not belong to it.

Alicenula leguminella (Forbes, 1855 in [Lyell, 1855](#)) [Martens, Rossetti and Horne, 2003](#).
(Fig. 6.6A–B)

1855 *Cypris leguminella* Forbes (in [Lyell, 1855](#)), p. 294, fig. 334.c.
2003 *Alicenula leguminella* comb. nov., [Martens et al.](#), p. 726, fig. 3.

Figured specimens. ULVG-12647, valve, sample TA-104, 560 m; ULVG-12648, carapace, sample TA-104, 560 m.

Material. 4,638 specimens, both carapaces and valves.

Dimensions (mm). L: 0.60–0.80; H: 0.25–0.30; W: 0.20–0.25.

Discussion. A very common *Alicenula* species throughout the sections, and overall one of the main components of the ostracod fauna in the studied area. The authors chose to follow [Martens et al. \(2003\)](#) in their classification of the species *Alicenula leguminella* due to the normal overlap that the specimens present. This species has a problematic taxonomic identification, with their worldwide distribution in Upper Jurassic–Lower Cretaceous deposits necessitating revision due to the way its classification has been carried out, that is, using mainly external carapace features ([Trabelsi et al., 2015](#)). It can be differentiated from *A. cf. D. oblonga* by being generally smaller, by its infracurvate anterior margin, and its equicurve posterior margin.

Stratigraphic and geographic distribution. This species has a global distribution that ranges from the Upper Jurassic to the Lower Cretaceous. Examples for Brazil include: Araripe Basin, Brejo Santos Formation, Upper Jurassic ([Coimbra et al., 2002](#)); Potiguar Basin, Alagamar Formation, Aptian ([Do Carmo et al., 2013](#)); Cedro Basin, strata correlated to the Crato Formation, Aptian ([Tomé et al., 2014](#)); Jatobá Basin, strata correlated to the Crato Formation, upper Aptian

([Tomé et al., 2014](#)); Sousa Basin, Sousa Formation, Lower Cretaceous ([Sousa et al., 2018](#)); Iguatu Basin, Orós Formation, Hauterivian–Aptian (this study).

Alicenula cf. D. oblonga Roemer, 1839
(Fig. 6.7A–C)

?1962 *Darwinula cf. oblonga* Krömmelbein, p. 513, pl. 58, fig. 37
?1970 *Darwinula cf. oblonga* Musacchio, p. 311, lamina 3, fig. 9.a–c.
?1985 *Darwinula oblonga* Anderson, p. 65, fig. 9.

Figured specimens. ULVG-12649, valve, sample TA-063, 355 m; ULVG-12650, carapace, sample TA-092, 500 m; ULVG-12651, carapace, sample TA-092, 500 m.

Material. 216 specimens, both carapaces and valves.

Dimensions (mm). L: 0.90–1.10; H: 0.40–0.50; W: 0.35–0.45.

Description. Large, elongate carapace of oblong outline in lateral view, sub-ovoid in dorsal view. LV larger than RV, overlap visible throughout the entire carapace outline, although less so in the dorsal margin. Anterior margin slightly acute and equicurve, posterior margin rounded and supracurve. Dorsal and ventral margins slightly convex in the posterior third, with the postero-ventral margin of the LV curving abruptly upwards. Greatest height and width in the anterior third, close to the middle, greatest length at mid-height.

Surface smooth. A number of juveniles were recovered; they tend to be more laterally compressed, but are otherwise similar to adults in shape. A few well-preserved valves were found, showing a simple addont hinge. Duplicature small, restricted to the anterior margin. The internal teeth of the LV and ventral keel of the RV typical to *Alicenula* could not be observed, which might be related to poor preservation. AMS could not be observed.

Discussion. The other *Alicenula* species in the sections is relatively rare when compared to *A. leguminella*, although still quite common. *A. oblonga* is often differentiated from *A. leguminella* or *Penthesilenula martinsi* (Silva, 1978) [Do Carmo et al., 2004](#) mainly by its size (e.g., [Do Carmo et al., 2004](#); [Tomé and Lima Filho, 2010](#); [Tomé et al., 2014](#); [Trabelsi et al., 2015](#)); the specimens recovered here, however, also show a distinctly supracurve posterior margin. It resembles *Darwinula cf. D. oblonga* described by [Krömmelbein \(1962\)](#) and later authors (e.g., [Regali and Viana, 1989](#); [Coimbra et al., 2002](#)), although the latter does not have the supracurve posterior margin. It also resembles *Darwinula* aff. *oblonga* identified by [Musacchio \(1970\)](#), although the outline in lateral and dorsal view of *D. aff. oblonga* is more rectangular than the one described in this study. It also resembles greatly the *D. oblonga* specimen illustrated by [Anderson \(1985\)](#), differing mainly in the anterior margin of the species described here, which is slightly rounder. [Anderson \(1985\)](#) is not a taxonomic paper and, thus, does not provide a description of the illustrated specimen; in addition, there is only a picture of its LV, making it difficult to properly compare it with the specimens described here. As such, the authors have chosen to questionably assign this taxon to this species.

Stratigraphic and geographic distribution. Iguatu Basin, Orós Formation, Hauterivian–Aptian, Brazil (this study).

INDETERMINATE TAXA.

Gen. et sp. indet.

(Fig. 6.8A–B)

Figured specimens. ULVG-12652, valve, sample TB-025, 795 m; ULVG-12653, fragment, sample TB-025, 795 m.

Material. Six valves.

Dimensions (mm). L: 3.0; H: 1.5.

Description. Gigantic carapace with a reniform outline in lateral view. Overlap unknown. Anterior and posterior margins broadly rounded and of similar heights. Dorsal margin slightly convex, ventral margin strongly concave. Greatest length at mid-height, greatest height median.

Surface smooth. Poor preservation did not allow for observation of the hinge or the AMS. Evenly distributed marginal structures can be seen passing through the calcified portion of the duplicature, extending throughout the entire free margin. It is unknown if these structures are pore channels or septa.

Discussion. A very rare species found only in Transnordestina B, although there are many indistinct fragments throughout both sections whose gigantic size might indicate that they belong to this species. Based on its relatively thin shell and overall shape, it might belong to the Cypridoidea superfamily; however, the size and outline do not match that of any currently described genus, and as there were few specimens found and none in good conditions, the authors have chosen to not erect a new genus and to leave this species in open nomenclature.

Stratigraphic and geographic distribution. Iguatu Basin, Orós Formation, Hauterivian–Aptian, Brazil (this study).

4.2. Biostratigraphic considerations

The fauna recovered from sections Transnordestina A and B is rather exceptional for a Lower Cretaceous non-marine Brazilian ostracod assemblage, showing a number of new genera and species. Although the studied sections do not contain many of the biostratigraphically valuable species usually utilized for dating the Lower Cretaceous of Brazil, a few inferences regarding age can be made.

Cypridea hystricoides is a rare species, first reported by Krömmelbein (1962) in the upper portion of the “Bahia Super-group” of the Recôncavo Basin, Brazil, which corresponds to the upper portion of the Ilhas Group. As previously discussed, Leite et al. (2018) had merged *C. hystricoides* with *C. hystrix*, although their taxonomic justifications for such were somewhat dubious and were, thus, not considered in this paper. It is absent from the biostratigraphic chart drawn by Moura (1972) and its updated form in Poropat and Colin (2012b). Cassab et al. (1994), in their review of the stratigraphic range of Cretaceous mega and microfossils of Brazil, gave it a stratigraphic range encompassing the top of the Aratu Stage, which would correspond to the RT-006 zone. This was likely related to the fact that Krömmelbein (1962) mentions the type locality of the species as being the upper Ilhas Group, whose top is dated as being mid-Barremian (Costa et al., 2007a, 2007b); the original author, however, had not inferred such a specific age range for the species.

Cypridea clavata had its seven subspecies given distinct stratigraphic ranges by Anderson (1985), implying that these forms had precise biostratigraphical values. As previously discussed, however, the taxonomic validity of these subspecies is dubious under a more conservative taxonomic approach, as they could be merely eco-phenotypic variants (Nye et al., 2008). Regardless, the total range of *C. clavata* is still constrained between the Hauterivian–Barremian. Although the species found in this paper was classified as *C. cf. C. clavata*, if later studies confirm the classification, it will aid in the age determination of the sections.

Originally attributed to the genus *Orthonotacythere*, Grosdidier (1967) first described *Looneyellopsis mvili* from the “pre-salt” of the Congo Basin. De Klasz and Micholet (1972), in their review of the biostratigraphy of the Gabon Basin, identified this species as occurring alongside *Hourcqia africana* in the N’Gwanzé Member of the Bingone Formation, placing it into the AS-9 or AS-10 West African biozones, upper Barremian–lower Aptian. Davison et al.

(2004) cite this species as being upper Barremian, although they refer to the original Grosdidier (1967) paper, which does not give the detailed stratigraphic location or range of that species.

Musacchiocythere plastica was originally described by Musacchio (1970) for the Barremian of the La Amarga Formation, Neuquén Basin, Argentina. Subsequently, Do Carmo et al. (2004) found it in the Quiricó Formation of the Sanfrancisco Basin, Brazil, of Barremian–Aptian age. Olivo et al. (2019) found this species, which they referred to as *cf. Wolburgiopsis plastica*, in the Mulichinco Formation of the Neuquén Basin, Argentina, alongside the palynofossil *Cyclusphaera psilata*, which is a key marker for the *Cyclusphaera psilata*–*Classopollis* Association, of upper Valanginian–Barremian age, established by Volkheimer (1980), or the upper Valanginian–Hauterivian Zone 2 delimited by Quattrocchio et al. (2003). If Olivo et al. (2019) indeed found *M. plastica*, the range of the species is longer than previously registered. The specimen illustrated by these authors, however, is very badly preserved, with basically no external features of the carapace having been preserved, making their classification dubious.

Brasacypris ovum was found in the Itaparica and Candeias formations of the Bahia series in the Tucano Basin, Brazil, which are of Berriasian age (Krömmelbein, 1965, 1966). It was also recovered from Berriasian deposits of the Sergipe–Alagoas Basin (Cassab et al., 1994) and in the Sousa Formation of the Sousa Basin (Sousa et al., 2018).

Species of *Pattersoncypris* have been predominately described for the upper portion of the Lower Cretaceous. They have proven highly important for studies in the upper pre-salt of costal basins of the South Atlantic Ocean due to its prevalence in these layers (Poropat and Colin, 2012a). Many species belonging to *Pattersoncypris*, first ascribed to the genus *Hourcqia* (such as *P. angulata*, *P. sinuata*, *P. symmetrica*, and *P. salitrensis*) were identified by Krömmelbein and Weber (1971) for deposits younger than the Bahia Series. Numerous other authors identified this taxa of this genus from the Aptian–Albian deposits of many Brazilian basins (although most of the time, the genus is referred to as *Harbinia*), such as: Araripe Basin (Bate, 1972; Dépêche et al., 1990; Coimbra et al., 2002; Syrio and Rios-Netto, 2002; Antonietto et al., 2012), Potiguar Basin (Do Carmo et al., 1999; Viviers et al., 2000), Parnaíba Basin (Vicalvi and Carvalho, 2002), Sanfranciscana Basin (Do Carmo et al., 2004; Leite et al., 2018), and Sergipe Basin (Viviers et al., 2000; Antonietto et al., 2015). There is, thus, a long record of this genus being distinctly Aptian–Albian.

Therefore, considering the frequent occurrence of *Pattersoncypris* species, as well as *Cypridea hystricoides*, *Looneyellopsis mvili* and *Musacchiocythere plastica*, and likely *C. clavata*, we suggest that the age of the studied sections is Lower Cretaceous, likely constrained between a Hauterivian–Aptian age. This would increase the stratigraphic range of *Brasacypris ovum* up to the Aptian, and possibly extend the range of the genus *Pattersoncypris* down to the Hauterivian.

5. Summary and conclusions

In total, 17,150 ostracod specimens were found, distributed between 19 species, 11 genera, and five families: *Cypridea hystricoides*, *Cypridea paraibensis*, *Cypridea cf. C. clavata*, *Cypridea punctacentralis* sp. nov., *Brasacypris ovum*, *Pattersoncypris sinuata*, *Pattersoncypris cf. P. sinuata*, *Pattersoncypris? sp.*, *Ilyocypris? arca* sp. nov., *Ilyocypris? latanodi* sp. nov., *Rhinocypris? ericius* sp. nov., *Pythagoracypris latavectis* gen. et sp. nov., *Hastacypris adamantem* gen. et sp. nov., *Looneyellopsis mvili*, *Musacchiocythere plastica*, *Musacchiocythere? sp.*, *Alicenula leguminella*, *Alicenula cf. D. oblonga*, and an indeterminate species of indeterminate genus. The recovered fauna is relatively unique and diverse, with two new genera and six new

species having been described. The ostracod fauna is exclusively non-marine, and is composed primarily of species of *Alicenula*, *Cypridea*, *Pattersonocypris*, and the new genus *Hastacypris*, with the proportion between these components varying throughout the section.

It was possible to infer a broad age range for the studied sections based on the ostracod species recovered. *Cypridea hystricoides* can be used to infer the presence of the RT-006 biozone, and species of *Pattersonocypris*, alongside the species *C. clavata*, *Looneyellopsis mvili*, and *Musacchiocythere plastica*, all point towards a Hauterivian–Aptian age interval. Although *Brasacypris ovum* had been thus far only found in Berriasian deposits, their presence in the studied sections alongside the previously mentioned species could indicate that its stratigraphic range is more extensive than what was previously recorded.

The highly abundant ostracod fauna of the Transnordestina sections from the Iguatu Basin shows that the smaller basins that surround the Araripe Basin contain a large amount of important Lower Cretaceous material that is yet to be studied. Further work in these basins will doubtlessly reveal greater insights not only regarding the paleoenvironments that developed in the area, but also potentially help in developing an even more detailed biostratigraphic framework for the Lower Cretaceous of the Brazilian basins.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.cretres.2020.104634>.

5.2. ARTIGO 2: *Paleoenvironmental analysis of a Lower Cretaceous paleolake from the Iguatu Basin, based on its ostracod fauna and XRF data*

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PALEOENVIRONMENTAL ANALYSIS OF A LOWER CRETACEOUS PALEOLAKE FROM THE IGUATU BASIN BASED ON ITS OSTRACOD FAUNA AND XRF DATA

Santos Filho, M.A.B.^{1*}; Fauth, G.¹; Sames, B.²; Wolfgring, E.³; Villegas-Martín, J.¹

¹Itt Fossil – Instituto Tecnológico de Micropaleontologia, UNISINOS – Universidade do Vale do Rio dos Sinos, Av. Unisinos 950, Cristo Rei, São Leopoldo, RS, 93022-750 São Leopoldo, Brazil; *Corresponding author (e-mail: abatistas@unisinos.br)

²Institut für Geologie, Universität Wien, UZA 2, Althanstrasse 14, 1090 Vienna, Austria;

³Department of Earth Sciences, Università degli Studi di Milano, Via Mangiagalli 34, Milano 20133, Italy

Abstract

We paleoenvironmentally interpret two Hauterivian–Aptian adjacent sections (Transnordestina A and Transnordestina B) of the Iguatu Basin based on ostracods and aided by X-ray fluorescence (XRF), total organic carbon (TOC), total sulfur (S), and spectral analyses. The ostracod assemblages primarily occur in the form of valves, but with enough young instars to indicate that it was a moderate energy autochthonous thanatocoenosis. The 11 genera found were divided into two groups based on cluster analysis: one composed of species of *Alicenula*, *Pattersonocypris*, *Brasacypris*, *Hastacypris*, and *Ilyocypris?*, and one of species of *Cypridea*, *Looneyellopsis*, *Rhinocypris?*, and *Pythagoracypris*. The first group is interpreted as representing paleoenvironments with permanent waterbodies, such as a lake, and the second was inferred as being indicative of ephemeral settings, such as temporary pools in an inundation plain. XRF analysis using the positive peaks from Ca/Ti and Ca/ Σ Ti, Fe and Al ratios show a number of dry periods, particularly in the lower and middle part of Transnordestina A, between 0 to 175 m (samples TA-001 to TA-036) and 385 to 475 m (TA-069 to TA-087), which also display a very small number of ostracods. Total S shows low values, except for several high peaks which might be indicative of gypsum deposition during droughts. Spectral analysis of molar Ti/Al ratio shows two intervals with different sedimentation rates, between 0 and 233 m, and 233 to 836 m. For the first interval, six 120 ka eccentricity cycles were identified; the overall low number of ostracods for the interval and highly variable Ca/Ti and Ca/ Σ Ti, Fe and Al values indicate that the different sedimentation rate was likely due to a drier environment. For the second interval, ten 120 ka and three possible 405 ka cycles were identified; its higher ostracod count and more stable Ca/Ti and Ca/ Σ Ti, Fe and Al values could be indicative of increasing humidity.

Keywords: South America, Brazil, Northeastern inner basins, Paleolimnology, Cyclostratigraphy.

1. INTRODUCTION

During the Cretaceous, the successive breakup of Pangaea culminated in the split-up of Gondwana, leading to the formation of the South Atlantic Ocean.

The beginning of the rifting process of Gondwana created a number of smaller rifts throughout what is now Northeastern Brazil during the Early Cretaceous, forming numerous lakes that occupied low latitude regions (Petri, 1987; Ponte, 1992; Silva et al., 1997; Scotese et al., 1999; Carvalho and Melo, 2012; Heine et al., 2013). The paleoclimate of these smaller areas to the south of the tropical domain (Recôncavo-Tucano-Jatobá basins) between the Berriasian and the early Barremian is considered to have had been locally warm and humid, based on palynomorphs, the presence of thick fluvio-lacustrine deposits, and ichnofossils, such as extensive dinosaur tracks (Lima, 1983, 1987; Petri, 1983; Carvalho, 2000; Leonardi, 2011; Leonardi and Carvalho, 2000).

The Iguatu Basin was tectonically established in one of these small NE Brazilian rifts, and its sedimentary filling is composed of Lower Cretaceous sedimentary rocks covered by Neogene and Quaternary ones that were deposited in four sub-basins (Iguatu, Malhada Vermelha, Lima Campos, and Icó basins) between two moments of intense tectonic activity associated to the orogenic band Orós-Jaguaribe (Petri, 1977; Bedregal et al., 1992; Arima, 2007). Recent studies in the Lower Cretaceous Orós Formation in the Iguatu sub-basin have shown the presence of a large continuous outcrop in the area that was denominated Transnordestina A/B. The great sedimentary thickness of these sections, in addition to the abundance of ostracod fossils, makes them well-suited for detailed studies regarding the evolution of the fluvio-lacustrine setting under which its sediments were deposited (Silva, 2018; Santos Filho et al., 2021).

This paper presents a paleoenvironmental analysis of the aforementioned sections of the Orós Formation, Iguatu Basin, using its ostracod fauna and X-ray fluorescence (XRF) data, and discusses possible time constraints derived from a cyclostratigraphic analysis, with the aim of contributing to the better understanding of the environment of the region during the Lower Cretaceous.

2. GEOLOGICAL SETTING

2.1. Iguatu Basin

The term Iguatu Basin refers to the grouping of the sub-basins Iguatu, Malhada Vermelha, Lima Campos and Icó, located in the southeastern area of Ceará State (Fortier, 2008) (Fig. 1). The genesis and evolution of these depositional areas and their sedimentary successions were controlled by the tectonic structures of their pre-Cambrian basement (Françolin & Szatimari, 1987). The age attributed to these successions encompasses the entire Lower Cretaceous, based on biostratigraphy with palynomorphs (Lima, 1990), spinicaudatans ('conchostracans'), and ostracods (Ghignone, 1972; Mabesoone and Campanha, 1974; Tinoco and Mabesoone, 1975; Ponte Filho et al., 1990). The Iguatu sub-basin, in which the studied section is located, is by far the largest of the four sub-basins, with an area covering approximately 820 km² and forming an ellipsoid with a NE-SW orientation.

The Lower Cretaceous lithostratigraphy of the Iguatu Basin is the subject of controversy, with numerous different proposals for the nomenclature of its deposits, with many of them being informal or having been published in the annals of events and congresses. Table 1 shows a summary of the nomenclatures used throughout the years. Much of the lithostratigraphic

terminology used is informal, i.e., not applying unit-terms that are defined and named according to guidelines conventionally established, e.g. the Stratigraphic Guide of the International Commission on Stratigraphy (<https://stratigraphy.org/guide/>). Following the latter, informal terms are indicated by the use of lower case for the lithostratigraphic unit (e.g. Orós f_ormation'), formal terms by upper case of the unit (Iguatu G_roup).

The first subdivision of the Lower Cretaceous sedimentary rocks of the Iguatu Basin was published by Oliveira (1943), who grouped them into the Iguatu Formation, a classification that was kept by Castro (1963) and Melo (1964). This formation was subdivided by Cruz (1962) into three members: Lower (conglomeratic sandstones), Middle (silty sandstones) and Upper (sandstones) member. Still during that decade, hydrological research in the Jaguaribe region by SUDENE/ASMIC (1967) led to the subdivision of the Iguatu Formation into six informal units.

Lemos (1973), in their description regarding possible Uranium prospection in the basin, proposed four facies for the Iguatu Formation: Facies A (conglomerates with clay-sandstone concretions), Facies B (medium to very coarse and conglomeratic sandstones), Facies C (shales, siltstones and fine to medium calcareous sandstones) and Facies D (fine to coarse and conglomeratic sandstones). These designations saw no later use, and a year later, Mabesoone and Campanha (1974) formalized the proposal for the Iguatu Group, which formed the basis of the majority of the later lithostratigraphic studies in the area. They defined three formal formations for this group: Quixoá, Malhada Vermelha, and Lima Campos, which corresponded, respectively, to the Lower, Middle and Upper members defined by Cruz (1962).

Campos et al. (1979) and Gomes et al. (1981) designated the Iguatu Group as the Rio do Peixe Group, in an attempt to unify the nomenclature of the Iguatu and Rio do Peixe basins. Ghignone et al. (1986) rejected this classification, claiming that their lithology were not equivalent, and instead informally subdivided the Iguatu Group into four lithostratigraphic units, designated K1 to K4 from base to top, all composed of varying amounts of sandstones, red shales, green shales, and calcareous rocks; K1 and K3 were dominated by sandstones, while shales predominated in K2 and K4.

Srivastava (1990) used another informal subdivision for the basin, defining three units: Unit 1, corresponding to a braided fluvial system; Unit 2, interpreted as fluvio-lacustrine deposits; and Unit 3, which would be another braided fluvial system. In that same year, Ponte Filho et al. (1990) used a designation similar to Mabesoone and Campanha (1974), though they replaced the name Quixoá Formation with Icó Formation, and subdivided the Lima Campos Formation into two members: a Lower one, in which conglomerates dominated, and an Upper one, which was mostly composed of shales.

Cavalcante and Viana (1992) were not able to properly identify the lithological units described by Mabesoone and Campanha (1974), and thus divided the Lower Cretaceous succession in three informal units: a Lower Unit, composed of conglomerates and sandstones that represented a braided fluvial system and alluvial fan; an Intermediate Unit, made of alternating sandstone and shale layers with a few carbonate lenses, which represented deltaic, lacustrine,

and meandering fluvial depositional systems; and an Upper Unit, primarily composed of sandstones, which indicated another braided system.

Ponte Filho (1994) designated the sediments of the Iguatu Basin as 'Iguatu Tectono-Sequence', which encompassed two Tectono-Depositional Intervals: Litd 1 and Litd 2. These intervals were each associated to two successive tectonic pulses of the Rift Phase that affected the Borborema Province, which that led to the deposition of distinct alluvial-fluvial-lacustrine depositional system tracts. Litd 1, deposited during the first tectonic pulse, encompasses one of these systems, which is divided into an Alluvial and Braided Fluvial Depositional System (ISD 1), composed of coarse to conglomeratic sandstones; and a Meandering Fluvial and Lacustrine Depositional System (ISD 2), composed of rhythmic intercalations of fine to medium sandstones with green to reddish mudstone and siltstones. Litd 2, which was deposited during the second tectonic pulse of the Rift Phase, and is comprised of a depositional system tract similar to Litd 1, though of smaller expression, divided into: an Alluvial and Braided Fluvial Depositional System (ISD 3), which is lithologically similar to ISD 1 in composition; and a Meandering Fluvial and Lacustrine Depositional System (ISD 4), which is similar to ISD 2, but has a predominance of grey and greenish shales over the red ones.

In 1998, the Brazilian Geological Service (CPRM) published a geological map for the Iguatu Basin (Vasconcelos and Mendonça, 1998), which subdivided the Iguatu Group into a Lower, Middle and Upper unit, which corresponds to earlier threefold concepts and subdivisions of the succession, such as those of Cruz (1962), Mabesoone and Campanha (1973, 1974), Srivastava (1990), and Cavalcanti and Viana (1992).

The Ponte Filho et al. (1990) designation was utilized by Fortier (2008), in his Master's dissertation, which dealt with the microfossil content of the Iguatu Basin.

Finally, Silva (2018), in his Masters' dissertation, used an informal fourfold subdivision and nomenclature for the Lower Cretaceous rocks of the basin, based primarily on the work developed by Ponte Filho (1994), with the main difference being that he applied the term 'Lima Campos formation' to the third unit and informally named the fourth, uppermost unit 'Orós formation' (informally as unpublished thus far).

For this paper, the authors have chosen to follow the informal nomenclature and definitions of Silva (2018), as it was the study in which the sections here analyzed were first described.

2.2. Orós formation

According to Ponte Filho (1994), the sediments of his unit ISD4, which corresponds to the Orós formation as informally used by Silva (2018), represent a second pulse of deposition of fine sediments in the basin, following the coarser sediments of the underlying Lima Campos Formation. It is composed of extensive red siltstones, green mudstones, and white sandstones, which are associated to inundation plains, lacustrine deposits, and braided fluvial and alluvial fan systems.

Table 1: Lithostratigraphic subdivisions proposed for the Early Cretaceous strata of the Iguatu Basin throughout the years, as well as their correlations. Modified from Silva (2018).

Inferred Age	Oliveira (1943), Castro (1963), Melo (1964)	Cruz (1962)	SUDENE/A SMIIC (1967)	Lemos (1973)	Mabesoone and Campanha (1973/1974)	Campos et al. (1979), Gomes et al. (1981)	Ghignone et al. (1986)	Ponte Filho et al. (1990)	Srivastava (1990)	Cavalcanti and Viana (1992)	Ponte Filho (1994)	Vasconcelos and Mendonça (1998)	Feltosa and Vidal (2004)	Fortier (2008)	Silva (2018)	
Lower Cretaceous	Iguatu Formation	Upper member	Iguatu Formation	K6	Facies D	Lima Campos formation	Rio Piranha Formation	Lima Campos formation	Unit III	Upper unit	ISD4	Litd 2	Upper Unit	Lima Campos formation	Lima Campos formation	Orós formation
		K4		Facies B	Quixóá formation	Antenor Navarro Formation	Icó formation	Unit I	Lower unit	ISD2	Litd 1	Lower Unit	Icó formation	Icó formation	Malhada Vermelha formation	
																K3
K2	Facies A	Iguatu Group	Rio do Peixe Group	Iguatu Group	Iguatu Group	Tectonic-Sequence Iguatu	Iguatu Group	Iguatu Group	Iguatu Group	Iguatu Group	Iguatu Group	Iguatu Group	Iguatu Group	Iguatu Group		
															K1	Facies A

According to Silva (2018), rocks of the Orós formation can be primarily observed in the depocenter of the Iguatu and Lima Campos sub-basins, in which these environments predominated. The identification and separation of the Orós formation from the underlying Lima Campos Formation is difficult, as in most areas the former is covered by the Neogene Moura Formation (and Quaternary deposits). The exact age for the formation is unknown, but based on magnetostratigraphic data, Silva (2018) indicates that it could be Berriasian, Valanginian, or Hauterivian–Barremian. Santos Filho et al. (2021), based on ostracods, infer an Hauterivian–Aptian interval for the formation. The paper at hand presents the detailed analysis of the underlying taxonomic and biostratigraphic data of Santos Filho et al. (2021).

2.3. Sections Transnordestina A/B

The sections analyzed in this study, denominated Transnordestina A and B, are located in the southeastern area of the Iguatu sub-basin (Fig. 1), starting at the WGS84 UTM coordinates 24M 474350 9360031. Silva (2018) described the section as cyclic depositional sequences of intercalated brown siltstones and laminated green mudstones, with the occasional occurrence of sandstones, which represent channel deposits that can occur both as large stratified layers or as smaller, irregular lenses (Fig. 2A). Thin paleosol layers can be seen in the contact between the mudstone/siltstone and sandstone layers. It has approximately 1.2 kilometers in length, with its layers dipping at 133/36, totaling around 850 meters of piled deposits. The sections Transnordestina A and B are separated by a normal fault, recognizable by the brittle arching of the sandstone layers. Its offset is unknown (Fig. 2B).

According to Silva (2018), the rocks of this section are representative of an intercalation between channel environments and inundation plains. He interprets the large scale of the siltstone and mudstone layers as indicative of a stable humid environment related to large seasonal climatic variations. They begin with a fluvial base, represented by sandstones, progress towards the massive brown siltstones, and end with the laminated mudstones being deposited due to the progressively lower sedimentary discharge from local rivers and the increase of the water depth in the region. Silva (2018) interprets the

brown siltstones as having been deposited in an inundation plain, and the green mudstones as representing shallow lakes.

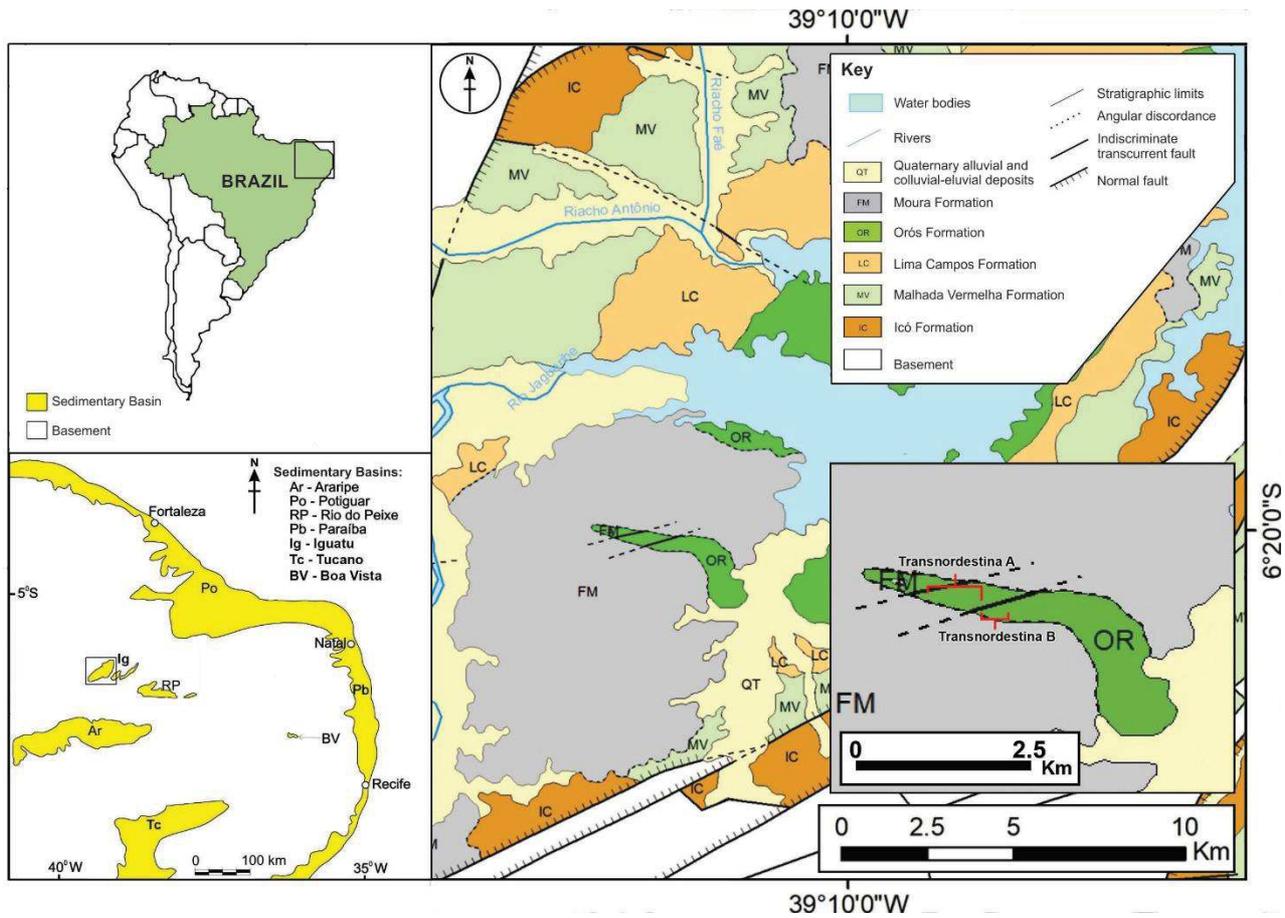


Figure 1: Location and geologic overview of the Iguatu Sub-Basin. Black rectangle indicates the studied area, with the location of the two sections. Modified after Silva (2018).

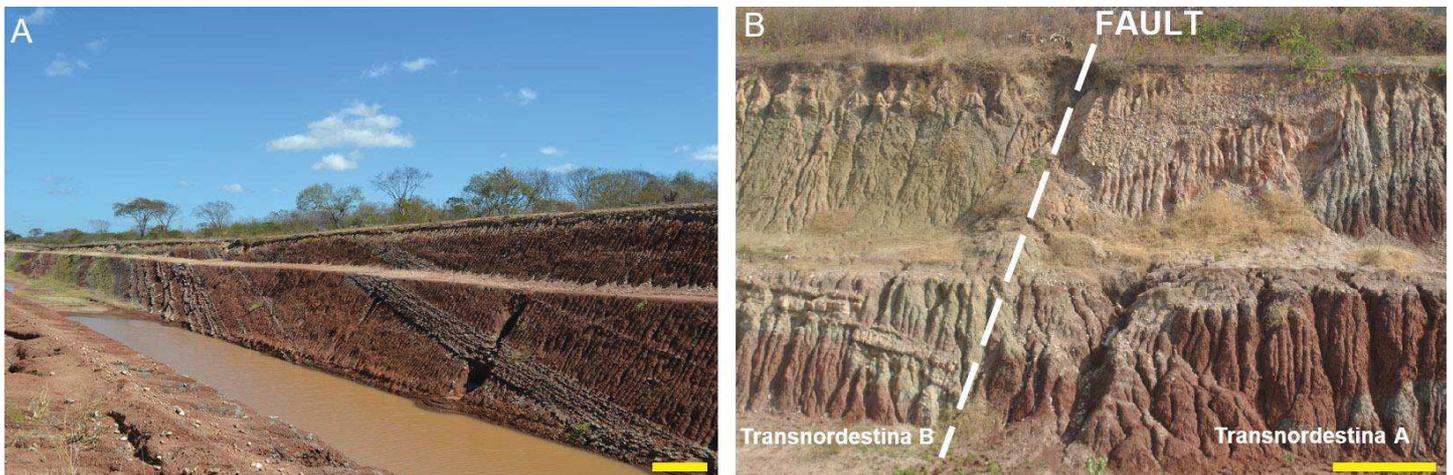


Figure 2: A) Photo of an interval of the section Transnordestina A, showing the brown siltstones, green mudstones, and sandstones; B) Normal fault dividing Transnordestina A and B. Yellow bars equal 5 meters.

The asymmetry of these 'cycles' is attributed to the oscillatory nature of their depositional systems, and to the fact that they were limited by the capacity for sediment accommodation and the variation of the equilibrium surface of the basin (Berger, 1988; Silva, 2018).

3. MATERIAL AND METHODS

3.1. Ostracods

The ostracods used in this study were recovered from 156 bulk rock samples from the studied sections, collected in intervals of approximately five meters each. Samples were preferentially taken from the mudstones and siltstones, as previous analyses showed that the sandstones do not contain microfossils, although samples from thin siltstone and mudstone layers located within the sandstone layers were also collected. 100 grams from each of these samples were prepared following the conventional methodology for the recovery of ostracod fossils. Santos Filho et al. (2021) details the preparation of the samples, as well as the systematic classification used and the taxonomic description of the recovered fauna.

Santos Filho et al. (2021) identified and described 19 species of 11 genera, and six families for the studied sections: *Cypridea hystricoides*, *Cypridea paraibensis*, *Cypridea* cf. *C. clavata*, *Cypridea punctacentralis*, *Brasacypris ovum*, *Pattersoncypris sinuata*, *Pattersoncypris* cf. *P. sinuata*, *Pattersoncypris?* sp., *Ilyocypris?* *arca*, *Ilyocypris?* *latanodi*, *Rhinocypris?* *ericius*, *Pythagoracypris latavectis*, *Hastacypris adamantem*, *Looneyellopsis mvili*, *Musacchiocythere plastica*, *Musacchiocythere?* sp., *Alicenula leguminella*, *Alicenula* cf. *D. oblonga*, and an *incertae sedis* species (Fig. 3, 4). From the species found, a Hauterivian–Aptian interval was inferred for the studied sections.

Taphonomic analysis of the material using the valve/carapace and the juvenile/adult ratios were used to aid in paleoenvironmental interpretations (Whatley, 1983, 1988; Boomer et al., 2003). For these, valves and carapaces of adults and juveniles were counted as single individuals and specimens, as due to post-mortem transportation and time-averaging, it is unlikely that two separated valves of the same ostracod would be present in the same sample, and although different juvenile specimens may be molts of a single organism, it is not possible to differentiate between molts and juvenile carapaces (Villegas-Martín et al., 2019).

Using the Bivalve software, length and height measurements of 6.482 specimens were taken in order to better identify the number of instars found (documented in Annex 1), which were chosen based on how complete and well-preserved they were. Following Kosnik et al. (2006), the geometric mean of length and height was used to acquire an approximate area of the measured valves; this value was then used to approximate instar sizes based on Przibram (1931) and Kesling (1953), who considered that each linear dimension from one instar to the next would become, on average, 1.26 times larger.

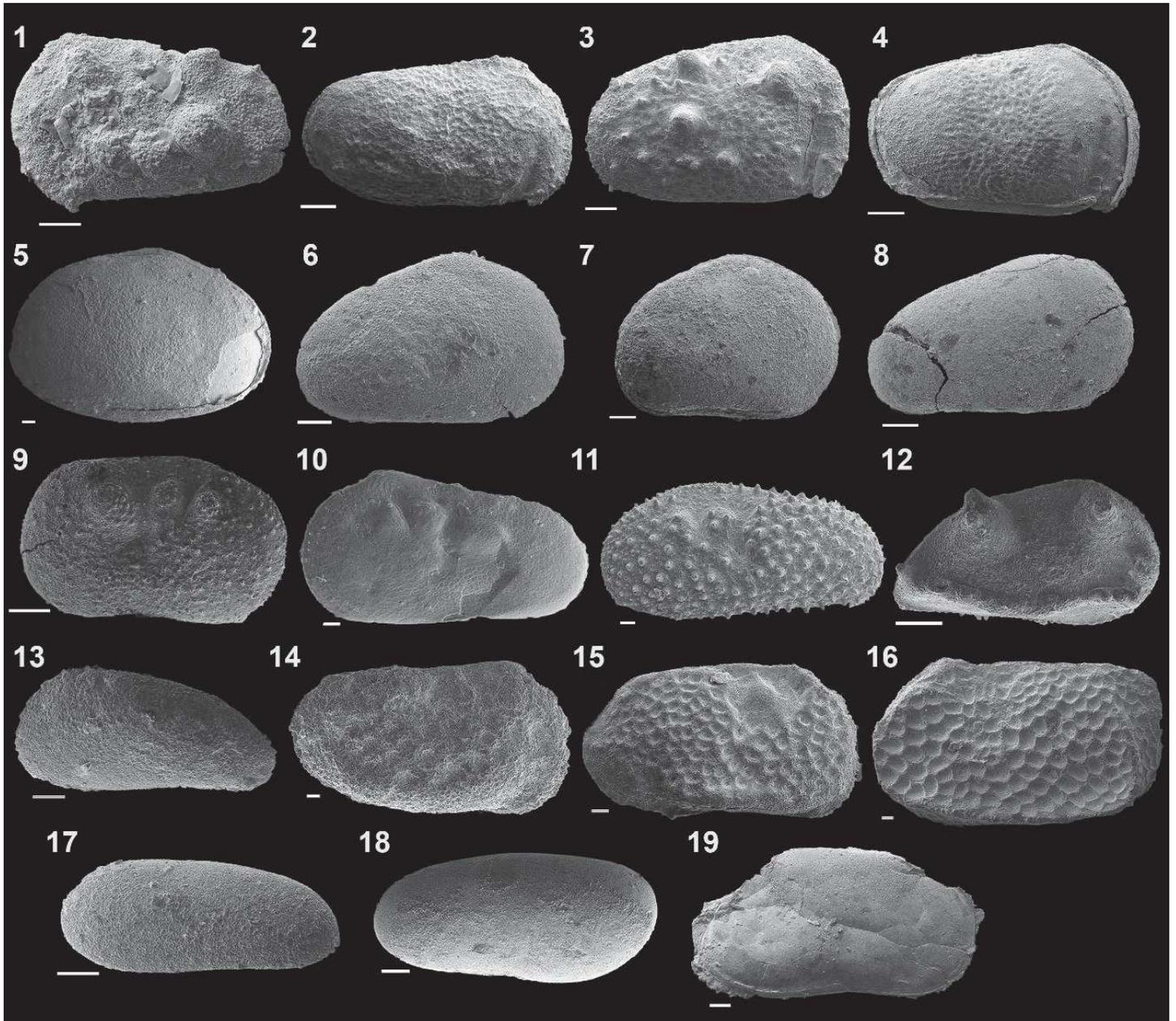


Figure 3: Ostracods of the Transnordestina sections. All scale bars represent 100 μm except for ten and 11, which represent 30 μm , 14, 15 and 16, which represent 20 μm , and 19, which represents 200 μm . 1 *Cypridea hystericoides*; 2 *Cypridea paraibensis*; 3: *Cypridea* cf. *clavata*; 4 *Cypridea punctacentralis*; 5 *Brasacypris ovum*; 6 *Pattersoncypris angulata*; 7 *Pattersoncypris* cf. *P. angulata*; 8 *Pattersoncypris?* sp.; 9 *Ilyocypris? arca*; ten *Ilyocypris? latanodi*; 11 *Rhinocypris? ericius*; 12 *Pythagoracypris latavectis*; 13 *Hastacypris adamantem*; 14 *Looneyelopsis mvili*; 15 *Musacchiocythere plastica*; 16 *Musacchiocythere?* sp.; 17 *Alicenula leguminella*; 18 *Alicenula* cf. *D. oblonga*; 19 Gen. et sp. indet.

Paleoenvironmental analysis using ostracods was based on the variations of abundance and diversity of the aforementioned species. The programs PAST (v. 3.15; Hammer et al. 2001) and Microsoft Excel, as well as the website MEDCALC (<https://www.medcalc.org/calc/>), were used for statistical analyses and the creation of graphs. A χ^2 -test was used to determine whether there was a difference between the proportion of both *Alicenula* and *Cypridea* in siltstones

and mudstones, due to their high abundance and apparent 'preference' for one lithology, i.e., the substrate corresponding to these lithologies (mudstones for *Alicenula* and siltstones for *Cypridea*) (Annex 2). In addition, a rarefaction curve (number of species vs the number of specimens) was constructed to determine whether most species were collected by combining data from all samples. Finally, a cluster analysis was performed to identify similarities between the different genera based on relative abundance per genera and per samples in the R program, using the Bray-Curtis dissimilarity index (relative abundance values are documented in Annex 2).

3.2. XRF-scanning derived elemental ratios, TOC, and total S

Approximately one gram of sediment from all 156 recovered samples was grounded to a fraction of <63 μm , and element concentration was determined in the sediment through a semi-quantitative analysis using x-ray fluorescence in a Panalytical Epsilon 1 equipment.

The total organic carbon content (TOC) was obtained through the acidification of the samples with HCl to remove the inorganic carbon. After being washed using distilled water and dried, samples were analyzed using the combustion technique in a LECO SC-144DR. The same equipment also provided values for total carbon (CT) and sulfur (S). CaCO_3 content was obtained through the equation $\% \text{CaCO}_3 = (\% \text{CT} - \% \text{COT}) * 8,33$.

3.3. Spectral analyses

An analysis of the geochemical data obtained through XRF was done in order to identify harmonic frequencies in the dataset. For that, the molar Ti/Al ratio was calculated, as it is understood as a proxy for terrigenous input, not only in pelagic, but also in terrestrial depositional systems (Neuhuber et al., 2016) (Annex 3).

The program packages PAST, R (R Core team, 2017) with the software package "astrochron" (Meyers, 2014) were applied. Spectral peaks were calculated using Locally-Weighted Regression Spectral Background Estimation (LOWSPEC, Meyers, 2014), an Evolutive Harmonic Analysis (EHA; Meyers, 2014; Thomson, 1982) illustrates the evolution of dominant spectra through the section. Spectral analysis was performed separately on the older (0-233 m) and younger (233- 836 m) parts of the section as we record different sedimentation rates that likely reflect different paleoenvironments.

Before calculating spectral density, mean values and linear trend were removed. Data were interpolated by piecewise linear interpolation (Meyers, 2014).

Spectral density was estimated using a LOWSPEC spectrogram, padded to $5*n$ datapoints, where "n" is the total of datapoints, applying a time-bandwidth product of 2 and an 80% CI for the harmonic F-test estimates (Meyers, 2012).

An EHA window with a size of 40 m was applied for the older segment (0-233 m) of the section, and a 100 m was used for the younger interval (233-836 m), with a window step of 4 and 3 m, respectively. Significant orbital frequencies were isolated using a bandpass filter with a rectangular window. Signals were band-passed to wavelengths corresponding to possible 405 ka and ~100 ka eccentricity variations determined in spectral analysis.

The cyclostratigraphic analysis relied on magnetostratigraphic time constraints. Positions and durations of magnetochrons M3–M7 were based on the magnetostratigraphic analysis by Silva (2018), who proposed three possible time intervals for the section: Hauterivian-Barremian (132.0 to 128.7 Ma / Chrons M3-M7), Valanginian (138.2 to 136.9 Ma / Chrons M11–M11A), and Berriasian (145.2 to 142.2 Ma / Chrons M17–19). The first proposal was chosen for the cyclostratigraphic analysis based on the ostracod fauna identified by Santos Filho et al. (2021), which, as previously discussed, indicated a Hauterivian–Aptian age for the interval.

4. RESULTS

4.1. Ostracods

The rarefaction curve (Fig. 5) indicates that most species were collected. Preservation of the recovered fauna varied from moderate to poor, with virtually all recovered specimens having suffered recrystallization or having been heavily oxidized, covered in a reddish to black iron oxide layer. The vast majority of the recovered material consists of disarticulated valves, with few carapaces having been recovered.

Juveniles of many genera, particularly of *Alicenula* and *Pattersonocypris*?, were recovered, indicating some degree of autochthony for this fauna. Faunal composition consisted of a majority of adults, though instars down to the A-6 level were also identified. Table 2 shows the total count of identified instars for each species. Annex 1 shows the full distribution of ostracod instars per sample.

The ostracod fauna is dominated by species of the genera *Alicenula* (28.36% of the total specimen count) and *Pattersonocypris* (26.40%). These were followed by species of the genera *Cypridea* (14.96%) and *Hastacypris* (13.37%). The other genera together make up for 16.97% of the total specimen count, with species of the genera *Musacchiocythere* (0.10%) and *Pythagoracypris* (0.15%) being the rarest. Figure 6 shows the proportions between all genera.

In terms of species, the predominant one is *Alicenula leguminella*, with 4.638 specimens, followed by *Pattersonocypris sinuata* (3.651 specimens), *Hastacypris adamantem* (2.292 specimens) and *Cypridea punctacentralis* (1.918 specimens).

The amount of ostracod specimens increases substantially at around 495 meters (sample TA-091), with a total of 4.411 ostracods from samples TA-001 to TA-091 (90 samples) and 12.598 specimens from samples TA-092 to TB-031 (65 samples). This can be observed in Figure 4.

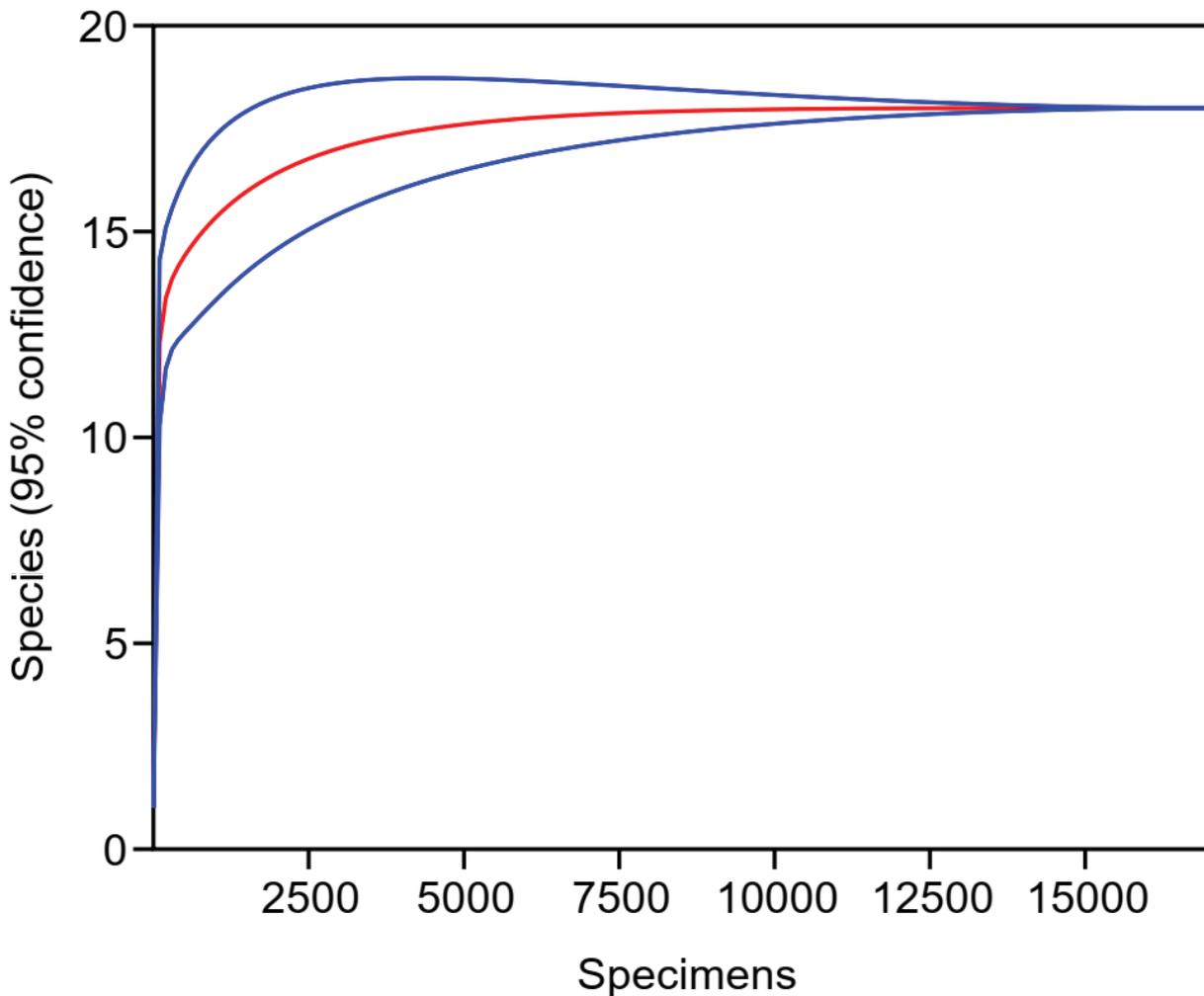


Figure 5: Rarefaction curve with 95 % confidence intervals of the ostracod species recovered from the Transnordestina A/B sections. Specimens for which the genus could not be determined were excluded. The number of specimens used was 17,149, which was the total amount of specimens recovered.

Although the section is overall highly fossiliferous, of the two lithologies from which samples were collected, the green mudstones contain, proportionally, a significantly higher amount of ostracod specimens, with 8.711 specimens having been collected from 36 samples, compared to 8.438 specimens from the 120 red siltstone samples. The abundance of ostracod genera between the two lithologies can be seen in Table 3. The Shannon Diversity Index for the mudstones had a minimum value of 0.47 (sample TA-017) and a maximum of 1.961 (sample TB-006), with an average of 1.44, while the siltstones has a minimum of 0.32 (sample TA-042) and a maximum of 2.03 (sample TA-098), with an average of 1.24.

The comparison of proportions between the genera *Alicenula* and *Cypridea* was calculated for both the mudstone and siltstone samples, as they have well understood environmental preferences (as previously discussed) and display the most significant variation in abundance between the two lithologies, with 3,554 specimens of *Alicenula* in mudstones and 1,238 specimens in

siltstones, and 561 specimens of *Cypridea* in mudstones and 2,059 specimens in siltstones (Table 3). Comparing the proportions between these two genera, a significant difference is observed in the mudstones ($\chi^2 = 2967.699$; $p < 0.001$) and siltstones ($\chi^2 = 217.690$; $p < 0.001$).

A cluster heat map grouping the nine studied genera and all 110 non-barren samples was generated (Fig. 7). It shows two distinct ostracod groups: one containing species of *Alicenula*, *Hastacypris*, *Brasacypris*, *Pattersoncypris?*, and *Ilyocypris?*, and another containing species of *Cypridea*, *Looneyellopsis*, *Rhinocypris?*, *Musacchiocythere*, and *Pythagoracypris*. Samples were separated into two main groups, with one being characterized by a majority of *Cypridea*, and the other subdivided into five smaller groups characterized by the predominance of *Alicenula*, *Hastacypris*, *Brasacypris*, *Pattersoncypris?*, or *Ilyocypris?* Through the sections.

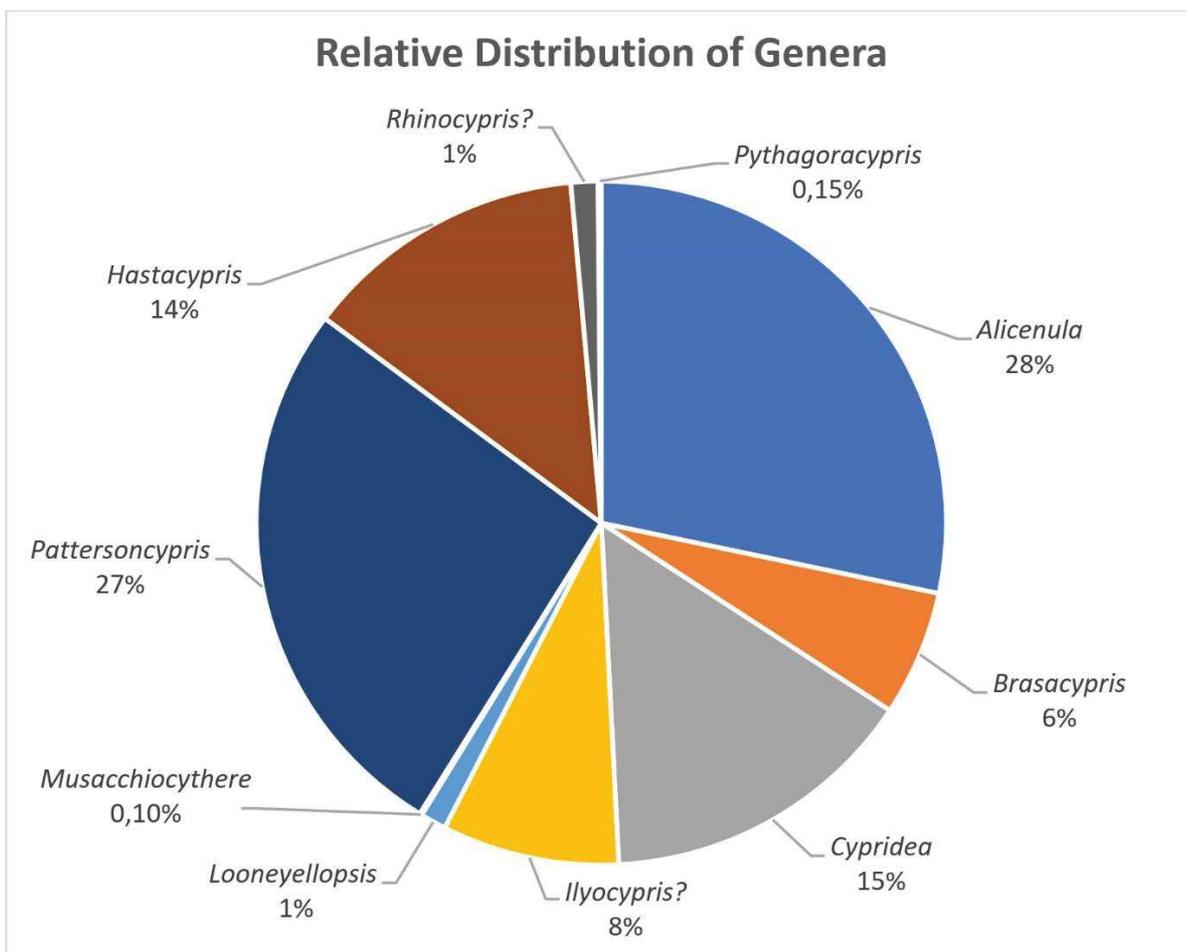


Figure 6: Relative percentage of the ostracod genera in the Transnordestina A/B sections.

Table 2: Number of instar specimens identified per species.

	Total Instar Count							
	Adult	A-1	A-2	A-3	A-4	A-5	A-6	A-7
<i>Cypridea hystricoides</i>	2	1	0	0	0	0	0	0
<i>Cypridea paraibensis</i>	17	136	82	20	4	1	0	0
<i>Cypridea cf. clavata</i>	1	0	0	0	0	0	0	0
<i>Cypridea punctacentralis</i>	475	200	27	7	0	0	0	0
<i>Brasacypris ovum</i>	24	85	123	70	59	4	1	0
<i>Pattersoncypris sinuata</i>	434	324	211	93	7	0	0	0
<i>Pattersoncypris cf. sinuata</i>	134	160	122	55	12	1	0	0
<i>Pattersoncypris? sp.</i>	141	93	46	7	1	0	0	0
<i>Ilyocypris? arca</i>	129	49	14	2	1	0	0	0
<i>Ilyocypris? latanodi</i>	19	55	81	30	9	1	0	0
<i>Rhinocypris? ericius</i>	50	35	3	0	0	0	0	0
<i>Pythagoracypris latavectis</i>	3	6	0	0	0	0	0	0
<i>Hastacypris adamantem</i>	272	222	113	55	17	5	1	0
<i>Looneyellopsis mvili</i>	80	20	2	1	0	0	0	0
<i>Musacchiocythere plastica</i>	3	0	0	0	0	0	0	0
<i>Musacchiocythere? sp.</i>	4	0	0	0	0	0	0	0
<i>Alicenula leguminella</i>	864	737	211	37	11	2	0	0
<i>Alicenula cf. oblonga</i>	60	27	15	7	0	0	0	0
TOTAL	2712	2150	1050	384	121	14	2	0

Table 3: Number of ostracod specimens per genus identified per lithology.

Genus	Abundance	
	Siltstone	Mudstone
<i>Alicenula</i>	1238	3554
<i>Cypridea</i>	2059	561
<i>Brasacypris</i>	405	644
<i>Ilyocypris?</i>	840	584
<i>Looneyellopsis</i>	154	53
<i>Musacchiocythere</i>	14	4
<i>Pattersoncypris</i>	2180	2347
<i>Hastacypris</i>	1433	857
<i>Rhinocypris?</i>	121	96
<i>Pythagoracypris</i>	15	11

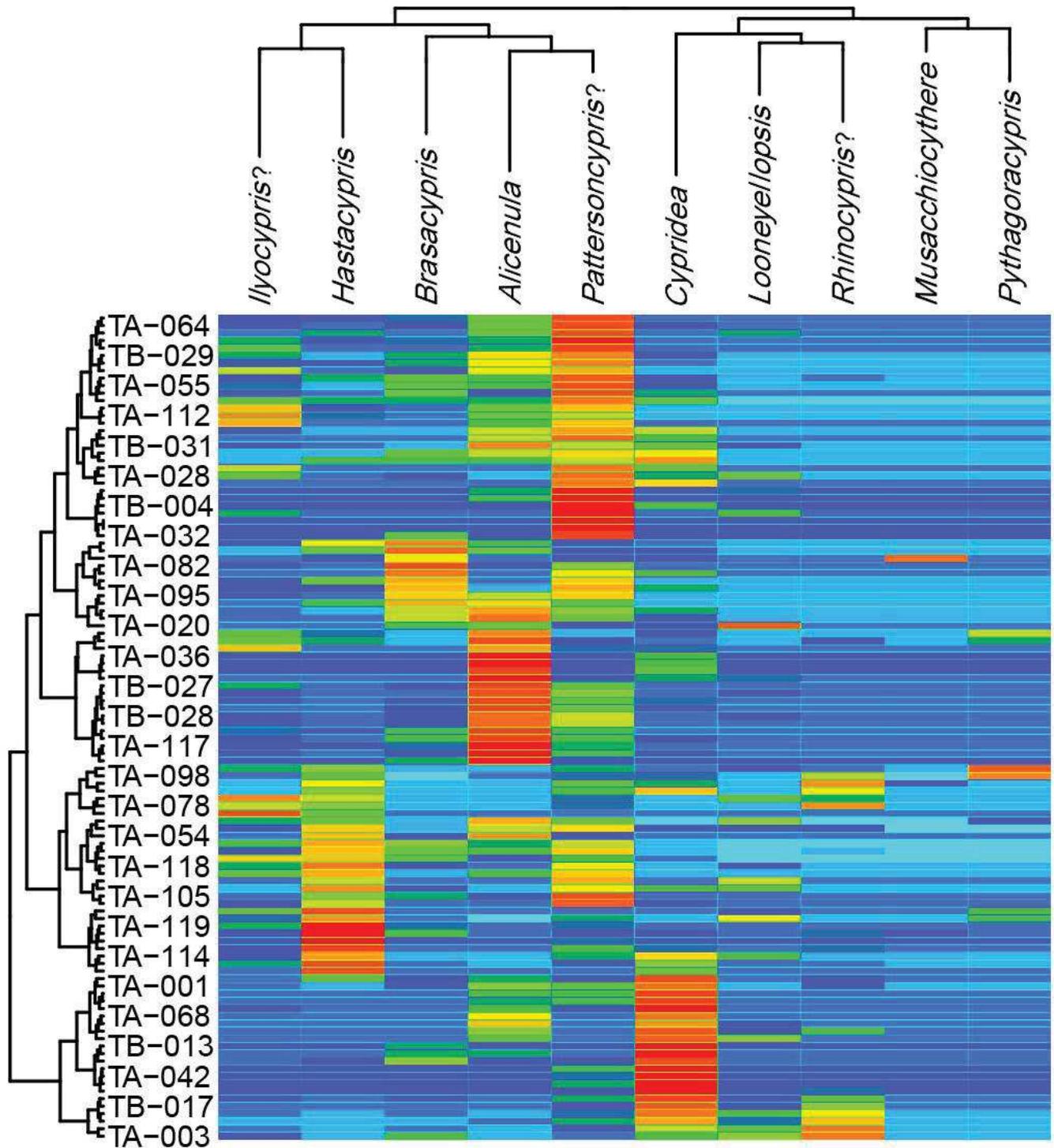


Figure 7: Cluster analysis heatmap grouping the ostracod genera identified for the sections and the samples collected, based on relative abundance. Warmer colors indicate a higher amount of specimens of species of that genus in each respective sample.

4.2. XRF-scanning derived elemental ratios, TOC, and total S

4.2.1. Ca/Ti and Ca/ Σ Ti, Fe and Al

The Ca/Ti and Ca/ Σ Ti, Fe and Al proportions have been used to determinate hydrological variability in lakes by inferring changes in their evaporation/precipitation ratio, based on the idea that lower rainfall reduces the introduction of detrital Ti, Fe and Al in the water body while also allowing for the concentration of dissolved substances in the water column, leading to an increase in the precipitation of authigenic carbonate (CaCO₃). Thus, high values for both ratios reflect dry phases, while low values indicate more humid conditions (Haberzettl et al., 2007; 2008; 2009; Mueller et al., 2009; Jouve et al., 2013).

Ca/Ti values varied between 0.38 (Sample TA-023) and 18.5 (Sample TA-074). The highest values are concentrated in the lower (TA-001 to TA-036) and middle (TA-069 to TA-087) parts of the studied sections (Fig. 8).

Ca/ Σ Ti, Fe and Al values varied between 0.015 (TA-055) and 0.73 (Sample TA-074). Similar to the Ca/Ti proportion, the highest values found were concentrated in the lower (TA-001 to TA-036) and middle (TA-069 to TA-087) parts of the studied sections (Fig. 8).

All Ca/Ti and Ca/ Σ Ti, Fe and Al values are documented in Annex 4.

4.2.2. TOC and Total S

TOC and total S values for the studied sections were low. TOC values ranged between 0.05% (Sample TA-048) and 0.21% (Sample TA-034), while total S values varied between 0,001% (Sample TA-035) and 0.41% (Sample TA-086). Though TOC values remain relatively even throughout the section, there are a number of spikes in the total S values at the lower, middle and upper parts of the studied sections, at samples TA-009 (0.23%), TA-014 (0.14%), TA-028 (0.13%), TA-072 (0.38%), TA-086 (0.42%), TB-005 (0.1%), and TB-025 (0.38%) (Fig. 8).

4.3. Spectral analyses

4.3.1. Ti/Al

The molar Ti/Al signature presents a cyclic pattern (Fig 9). Between 0 and 220m, a rapidly fluctuating signal was observed, oscillating between 1.7 and 3.7 with two significant excursions at 100m, followed by a slight increase of the Ti/Al curve, peaking at 4.1 at 310 m. Between 310 and 630 m, the signal fluctuates between 1.5 and 3. Afterwards, the Ti/Al signature increases to a peak at 710 m with an excursion of 3.8, that is followed by an overall decline of the signal during the last ~100m of the section.

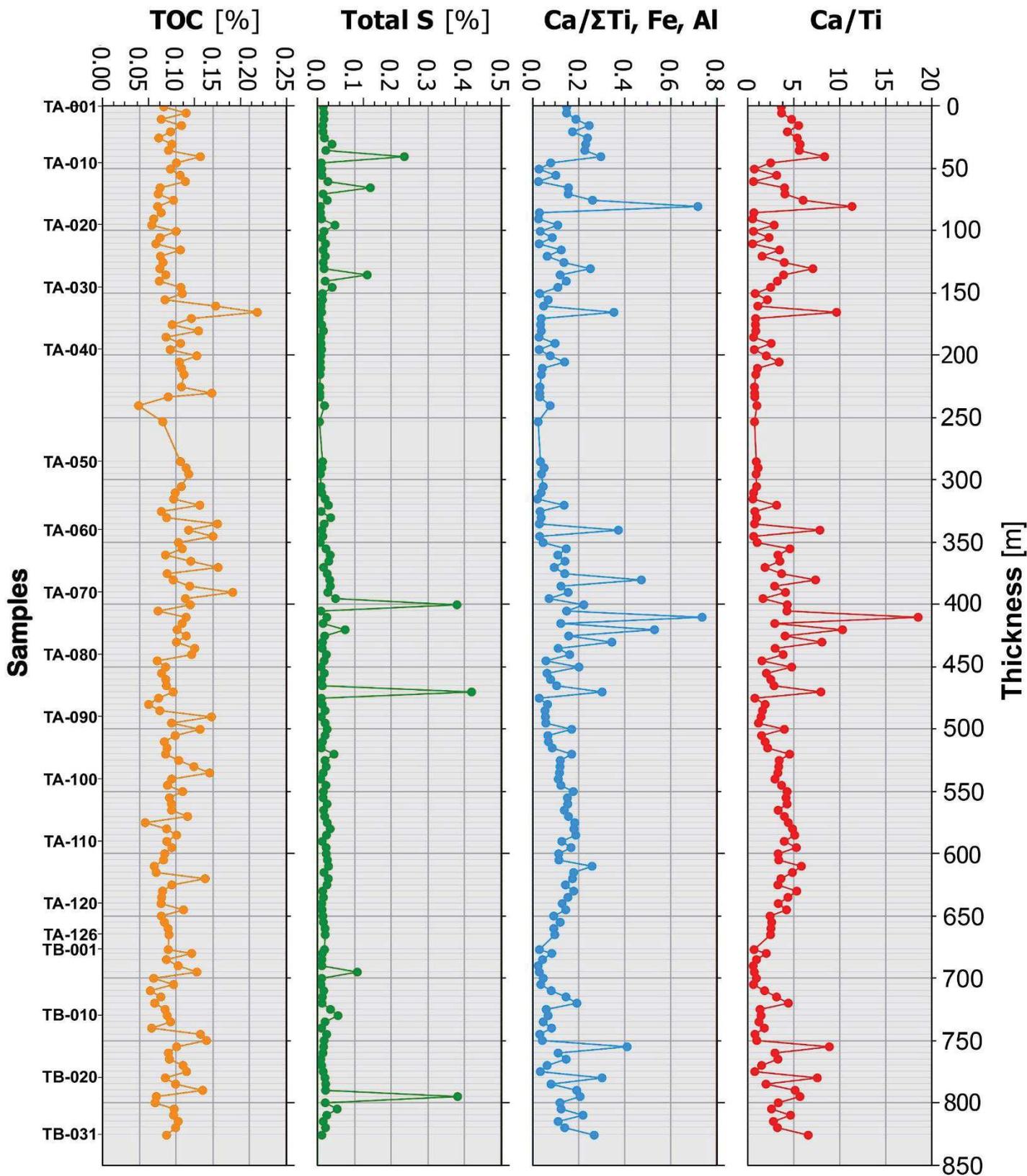


Figure 8: Ca/Ti, Ca/ΣTi, Fe and Al, TOC (%) and Total S (%) graphs for the Transnordestina A/B sections

4.3.1. LOWSPEC analysis

The LOWSPEC analysis reveals well expressed harmonic frequencies that exceed the 95% LOWSPEC confidence level (CI) in both segments (Fig. 9, Table 4). The older interval (0–233m) shows two well expressed frequency bands: Between wavelengths of 0.015 and 0.35 (corresponding to 66 and 28 m), and 0.07 and 0.13 (4 and 22 m). LOWSPEC analysis identified a total of three spectral peaks in this segment. Two peaks were identified within the frequency band from 0.07 and 0.13: at 0.071 (14 m) and at 0.08 (12 m). Another spectral peak was identified at a frequency of 0.02 (41 m).

More datapoints are available for analysis in the younger interval (233–826 m). Five out of seven peaks identified show a LOWSPE CI higher than 90% (Table 4). We identified three significant frequency bands: between wavelengths of 0.005 and 0.01 (200 and 100 m), 0.01 and 0.02 (100 and 50 m) and a prominent frequency band between 0.045 and 0.065 (22 and 15 m). Prominent peaks exceeding the 90% LOWSPEC CI were identified at frequencies of 0.005 (184 m), 0.016 (61 m), 0.05 (18 m), 0.06 (16 m) (Fig. 9, Table 4).

Table 4: Theoretical durations of significant cycles recorded in the Transnordestina A/B sections.

0–230m

Cycle	Frequency	Period in m	LOWCSPEC CI	Harmonic Ftest	ka
1	0.0243	41.14	95	95	120
2	0.0711	14	91	84	40.8361692
3	0.08	12	90	100	35.0024307

233–826m

Cycle	Frequency	Period in m	LOWCSPEC CI	Harmonic Ftest	ka
1	0.005	184	98	91	405
2	0.0162	61	99	84	134.266304
3	0.0447	22	93	78	48.423913
4	0.0477	20	88	99	44.0217391
5	0.0552	18	95	99	39.6195652
6	0.0616	16	99	96	35.2173913
7	0.0844	11	87	94	24.2119565

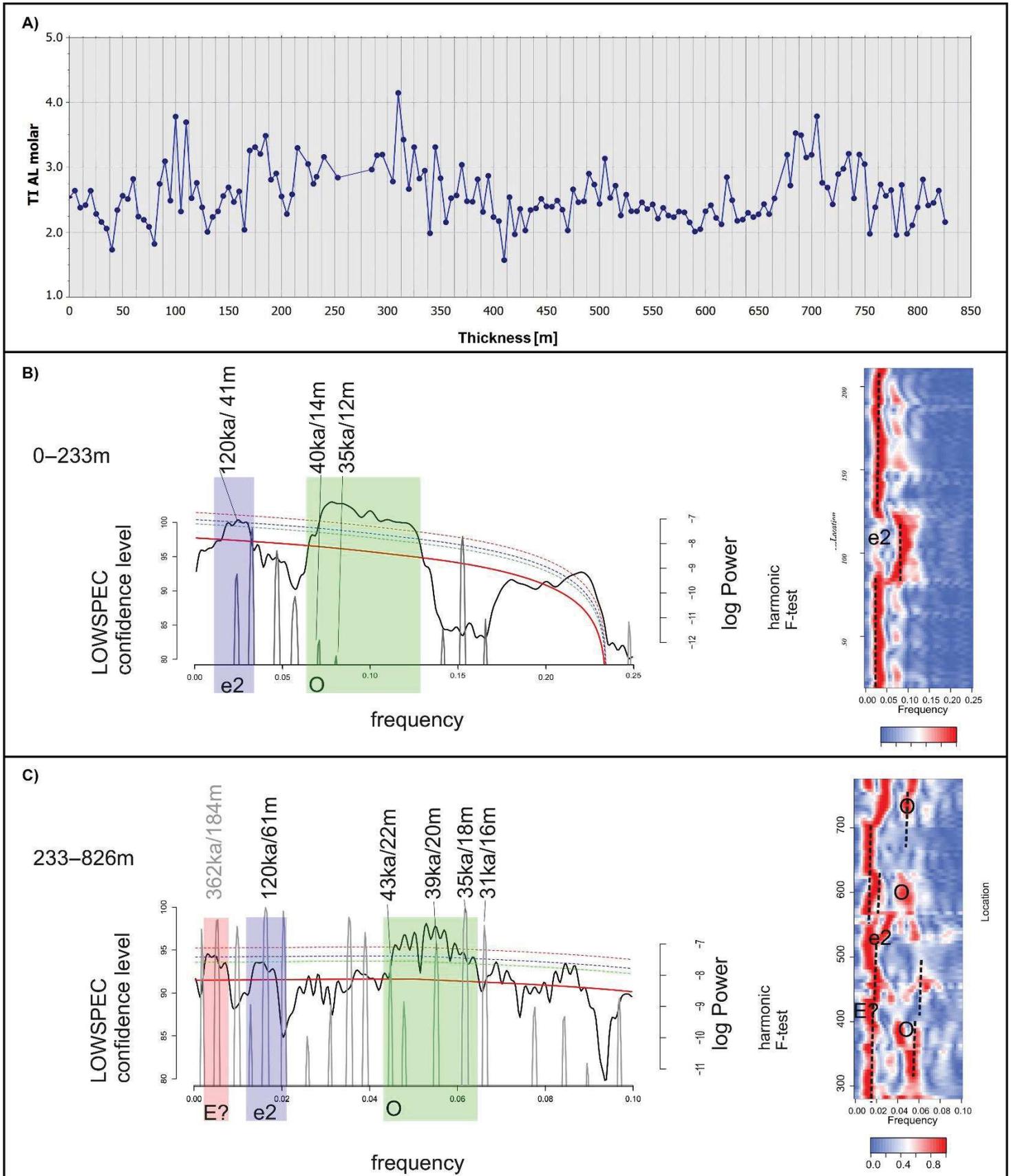


Fig. 9: LOWSPEC and EHA analysis of Ti/Al ratios for the older and younger intervals of the studied section. Significant frequency bands are highlighted (red: 405 ky eccentricity cycle, blue: ~100 ky eccentricity cycle, green: obliquity ~30–40 ky).

The EHA of the profile section between 0–233 m clearly shows a frequency band at ~0.025 and one at ~0.075. The harmonic signal at 0.025 is dominant through this section, yet we record a shift in dominant/significant frequencies between 90 and 120 m; the dominant frequency band shifts from a frequency of 0.025 to 0.750 in this interval.

The EHA of the younger profile section (233–836 m) shows several spectral bands: a dominant, continuous signal was identified at a frequency of 0.017 (Fig. 9), another, not as stable, high power signal is evident at a frequency of ~0.05. We record fluctuations in the position of the dominant signals throughout this spectrogram.

4.3.2. *Orbital cycles and magnetostratigraphic time constraints*

Applying the magnetostratigraphic time constraints delimited by Silva (2018) and the biostratigraphic inferences from Santos Filho et al. (2021) for the studied sections, the dominant frequencies were transferred into possible orbital cycles (Table 2) according to possible durations of the delineated chrons outlined in Gradstein et al. (2012). Transfer into orbital cycles had to be focused on the 100 ka eccentricity variations (calculated with a 120 ka period), as time constraints and the length of the timeseries (i.e., the amount of datapoints) did not permit for the identification of the 405 ka cycle, especially in the lower part of the section (see Table 2 for orbital terms assigned to frequencies). Upon transferring the results of spectral analysis into orbital terms, we identified 6 possible 120 ka short eccentricity cycles in the lower part of the section, ten in the upper part, as well as 3 possible 405 ka cycles in the upper part.

5. DISCUSSION

Before meaningful inferences can be made about the paleoenvironmental preferences of an ostracod fauna, it is important to determinate the autochthony of the recovered material. For ostracods, the proportion of valves/carapaces and adults/juveniles are good indicators of transportation (Whatley, 1983, 1988; Boomer et al., 2003). The ostracods recovered from Transnordestina A/B are represented in their vast majority by valves, which could be indicative of transportation; however, the assemblage also consists predominately of adults and juveniles of the last instars, with a very wide range of sizes between species (e.g., *Brasacypris ovum*, whose adult length ranges from 2.0 to 2.2 mm, and *Looneyellopsis mvili*, which are usually 0.40 to 0.50 mm in length). The preservation of younger instars varies greatly by sample. Overall, samples from the mudstones show a greater range of preserved instars while the siltstone ones tend to favor the last three instars (adult, A-1 and A-2). There are, however, exceptions, with some siltstone samples preserving a number of younger instars (such as A-3 or A-4) as well (e.g., TA-22, TA-67, TA-104, TB-018). When added together, the total instar count for both lithologies show a very similar pattern (Fig. 10). Thus, we consider that the recovered fauna generally represents a moderate energy autochthonous thanatocoenosis; that is, the youngest instars were likely removed due to water movements, and that the assemblage is a good paleoenvironmental indicator. The significantly higher number of valves in relation to carapaces found throughout the section might be indicative of an environment with mid to high bottom energy, perhaps derived from the fact that

the sediments of the studied sections were likely deposited close to the depocenter of the sub-basin (Silva, 2018).

The assemblages recovered from the two studied sections are overwhelmingly dominated by species of the genera *Alicenula*, *Pattersoncypris*, *Cypridea*, and *Hastacypris*. The respective genera the species of which dominate each assemblage, however, vary from sample to sample (Figs. 4, 6; Tab. 2), indicating a constantly changing paleoenvironment.

Horne (2002), through comparison with extant taxa, argued that already in the Mesozoic representatives of the Limnocytheridae and Darwinulidae families (to which genera such as *Looneyellopsis* and *Alicenula* belong to, respectively) had developed certain reproductive strategies that involve brooding and, therefore, did not have desiccation resistant eggs and were adapted and restricted to permanent water bodies. *Alicenula*, and particularly the most abundant taxon group found in this study, *Alicenula leguminella*, is thought to have had a large ecological tolerance, being wide-spread in at least the Northern Hemisphere during the Early Cretaceous, as well as being quite common in terms of total abundance in samples where it appears (Martens et al., 2003). Similarly, studies with extant darwinulids have shown that the taxa within that family with the widest distributions, such as *Darwinula stevensoni*, *Penthesilenula brasiliensis*, and *Microdarwinula zimmeri*, have the broadest ecological tolerance (Van Doninck et al., 2003). *D. stevensoni*, in particular, has an extremely wide tolerance for environmental factors, being found, for instance, in lakes and rivers with salinity ranging between 111 and 3440 $\mu\text{S}/\text{cm}^{-1}$ and in water bodies with temperatures varying between 23.9 and 1.7 °C (Gandolfi, 2001; Van Doninck et al., 2003). Sousa et al. (2018) listed *Alicenula leguminella* alongside *Brasacypris ovum*, *Cypridea ambigua* and *Reconcavona swaini* as being able to tolerate arid conditions, high evaporation rates, and even saline non-marine or brackish waters. $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ analyses on carapaces of *Theriosynoecum pricei* and *Alicenula?* sp. by Guzmán-González et al. (2019) seems to support the interpretation for a wider range of ecological tolerance for these genera, showing that their representatives could live both under more humid as well as more arid conditions; their Mg/[Mg+Ca] rates, all below 0.07, also show that these taxa thrived on low salinity, positive precipitation/evaporation balance environments.

Sames (2011), in his extensive review of the genus *Cypridea*, list them as benthic organisms with an ecological preference for freshwater ephemeral water bodies and, to a lesser extent, permanent water bodies (Horne and Martens, 1998; Horne, 2002) with a salinity between 0 to 3.0‰ TDS (Neale, 1988; Schudack, 1993).

Pattersoncypris belongs to the superfamily Cypridoidea, like *Cypridea*, and as such, would likely have been able to lay desiccation-resistant eggs (Poropat and Colin, 2012). Some species of *Pattersoncypris* are considered to have been coprophagous (*P. angulata*, according to Souto, 2002) or detritivore scavengers (*P. micropapillosa*, according to Bate, 1972, and Smith, 2000). Species of this genus are considered to inhabit mixohaline environments, and have primarily been found in deposits of Aptian–Albian age in transitional non-marine to marine settings sometimes even alongside marine species (e.g., Viviers et al., 2000; Syrio and Rios-Netto, 2002; Coimbra et al., 2002; Antonietto et al., 2015; Melo et al., 2020), though different species can display different tolerances; for instance,

Do Carmo et al. (1999) considered *Pattersonocypris* sp. 1 (*Harbinia* in their usage) as being possibly holoeuryhaline due to its occurrence alongside foraminifera, while other open nomenclature *Pattersonocypris* species and *Pattersonocypris sinuata* (*Harbinia sinuata* in their usage) were considered to be better adapted to hypohaline conditions.

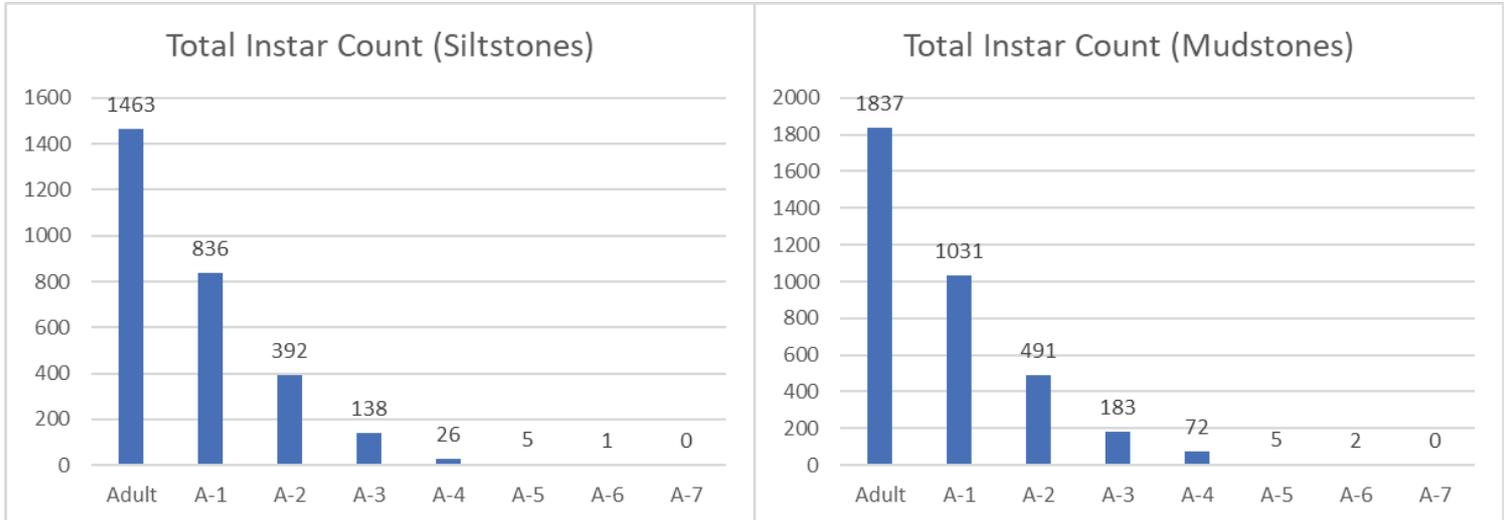


Figure 10: Total instar count for mudstones and siltstones

Ilyocypris and *Rhinocypris* also belong to the superfamily Cypridoidea. Cohen (1983) stated that *Ilyocypris gibba*, the type species of *Ilyocypris*, is a euryhaline-estuarine species capable of tolerating a wide range of alkalinities. Belis et al. (1999), in their analysis of the Pleistocene ostracod record of Lago di Albano in Italy, inferred episodes of low lake level and low lake productivity when the dominant assemblage consisted of *Ilyocypris bradyi*-*Potamocypris* sp. Horne (2002) considered *Rhinocypris* to be closely related to *Ilyocypris*, and mentioned that modern specimens of the latter can be found in environments such as semi-permanent pools in Australia which are filled for more than a few months per year. Although the taxonomic status of *Rhinocypris* and Cretaceous *Ilyocypris* species is debatable, as discussed by Santos Filho et al. (2021), based on carapace morphology they are still likely to belong to the family Ilyocypridae, and might thus share some ecological preferences with modern *Ilyocypris* species.

Species of *Looneyellopsis* and *Musacchiocythere* are relatively rare in the sections and have rarely been reported in literature, with few studies mentioning them (e.g. Grosdidier 1967; Musacchio 1970; Krömmelbein and Weber, 1971; Do Carmo et al., 2004; Ballent et al., 2011; Ayress and Whatley, 2014; Olivo et al., 2019) and none analyzing their paleoenvironmental preferences. As members of the Limnocytheridae, it can be assumed that they relied on brooding strategies and thus were likely restricted to permanent water bodies (Horne, 2002). Grosdidier (1967), who first described *Looneyellopsis mvili* (as *Orthonotocythere mvili*), found its species associated with a diverse fauna of species of *Cypridea*, in addition to *Reconcavona*, *Rhinocypris*, and *Damonella*?

Musacchiocythere plastica was erected by Musacchio (1970) (as *Wolburgia plastica*), who described it alongside species of *Cypridea*, *Looneyellopsis* (as *Wolburgia chinamuertensis*), *Theriosynoecum*, and *Darwinula* (likely *Alicenula*). Similarly, Olivo et al. (2019) found this species alongside *Alicenula*, *Metacypris*, and *Cypridea*.

The genus groups, the 'permanent waterbody (ostracod) group' and the 'ephemeral waterbody (ostracod) group', shown by our cluster analysis reinforce many of the previously mentioned environmental interpretations for these taxa, while challenging others. *Alicenula* and *Cypridea*, for instance, are in separate groups and show very little overlap in occurrence, which is also visible in the abundance graph for ostracod genera, which can be seen in Annex 2. Overall, when *Alicenula* numbers rise, *Cypridea* numbers fall, and vice-versa (Fig. 7; Annex 2). This is in agreement with the environments attributed to these genera: While *Alicenula* has a preference for permanent water bodies, *Cypridea* thrives in more ephemeral settings. Curiously, the limnocytherid *Looneyellopsis* is grouped with *Cypridea*, which could indicate that it had a preference for more ephemeral settings as well, contrary to the trend of its superfamily. Notably, the single species of this genus found, *Looneyellopsis mvili*, does not show sexual dimorphism in the form of brooding pouches, which could indicate that this taxon might have been able to lay desiccation resistant eggs and, thus, did not require a more stable environment to reproduce.

Overall, the sections are dominated by the *Alicenula*, *Pattersonocypris*, *Hastacypris*, *Ilyocypris?* and *Brasacypris* group by a significant quantity in terms of number of specimens (Fig. 7, 11; Annex 2). Based on the overwhelming dominance of *Alicenula*, this group is considered to be indicative of the presence of a paleoenvironmental setting with a permanent water body (such as a big lake), while the other group, which is primarily represented by *Cypridea* specimens (Fig. 7), is considered to be representative of a paleoenvironment dominated by ephemeral environments, such as small ponds and pools formed in inundation plains (Fig. 12).

As previously discussed, Silva (2018) interpreted the intercalating rocks of Transnordestina A/B as reflecting climatic variations. The group of siltstones and mudstones would indicate a stable humid environment, with the siltstones representing inundation plains and the mudstones shallow lakes.

The greater relative quantity of ostracod specimens recovered from the green mudstone samples support the interpretation of these sediments as representative of a, or several successive, permanent water body or bodies, while conversely, the smaller relative quantity of specimens in siltstones indicates the dominance of temporary waterbodies for the respective depositional intervals in the area. In addition, species of genera associated with permanent waterbodies, such as *Alicenula*, occur with much higher frequency in mudstone samples, while species of *Cypridea*, most of which indicate temporary/ephemeral water bodies, are more commonly found in siltstones (Table 3). This is supported by the chi-squared values for the comparisons of these two taxa in the mudstones and siltstones, and by the significant difference between the abundance of *Cypridea* and *Alicenula* in siltstones and mudstones, respectively.

Notably, although *Alicenula* specimen numbers do decrease in the siltstone samples, they still constitute a significant proportion of the ostracods found in that lithology, constituting around 15% of its total ostracod count. This could potentially be explained by the fact that, as previously mentioned, cosmopolitan *Alicenula* species such as *Alicenula leguminella* have a broad ecological tolerance and could thus still thrive in less than ideal circumstances. Another possibility is that these have been transported in by occasional flooding events.

The fact that *Alicenula* and *Pattersoncypris* are grouped together in the cluster analysis and display a heavy overlap in their occurrence is worth of discussion. The latter is highly abundant in both the siltstones (2,180 specimens) and mudstones (2,347 specimens). This means that, while proportionally more abundant in the environmental setting in which the mudstones were deposited, *Pattersoncypris* species were also well-established in the environment in which siltstones were generated. Therefore, while *Pattersoncypris* species seem to have been able to thrive in paleoenvironments dominated by both permanent or temporary waterbodies, they seem to have been outcompeted by species of *Cypridea* in temporary waterbodies, as *Pattersoncypris* specimen numbers drop whenever *Cypridea* specimen numbers rise (Fig. 7; Annex 2).

As previously stated, *Pattersoncypris* is usually associated with more marginal marine and higher-salinity settings, whereas *Alicenula*, while having a wide tolerance range, is usually associated with low salinity permanent waterbody environments. The great abundance of *Pattersoncypris* species in an entirely non-marine setting, with no indication of marine influence, and its occurrence alongside *Alicenula*, shows that it was also a genus comprising species with a wide ecological tolerance. In particular, the most abundant species of the genus recovered, *Pattersoncypris sinuata*, has been suggested to have a preference for hyposaline settings (Do Carmo et al., 1999); thus, its presence alongside *Alicenula* and other genera that have a preference for permanent freshwater to oligohaline waterbodies is not entirely unexpected.

The lack of an overlap between the occurrences of *Ilyocypris?* and *Rhinocypris?* might be indicative that these genera do not share the same environmental preferences, despite likely being related. From its presence in the 'permanent waterbody environment' group, it seems that *Ilyocypris?* showed a preference for such environments, though it bears mentioning that most of the *Ilyocypris?* specimens are found in the siltstone layers instead of the mudstones (Table 2). While the relative abundance of the genus is higher in the mudstones, its strong presence in the siltstones indicates that the genus has a tolerance for settings dominated by temporary waterbodies as well. Conversely, *Rhinocypris?*, when present, is more closely associated with *Looneyellopsis* and, most importantly, with *Cypridea* than any other genus, which suggests that it shared the preference for ephemeral settings of the latter.

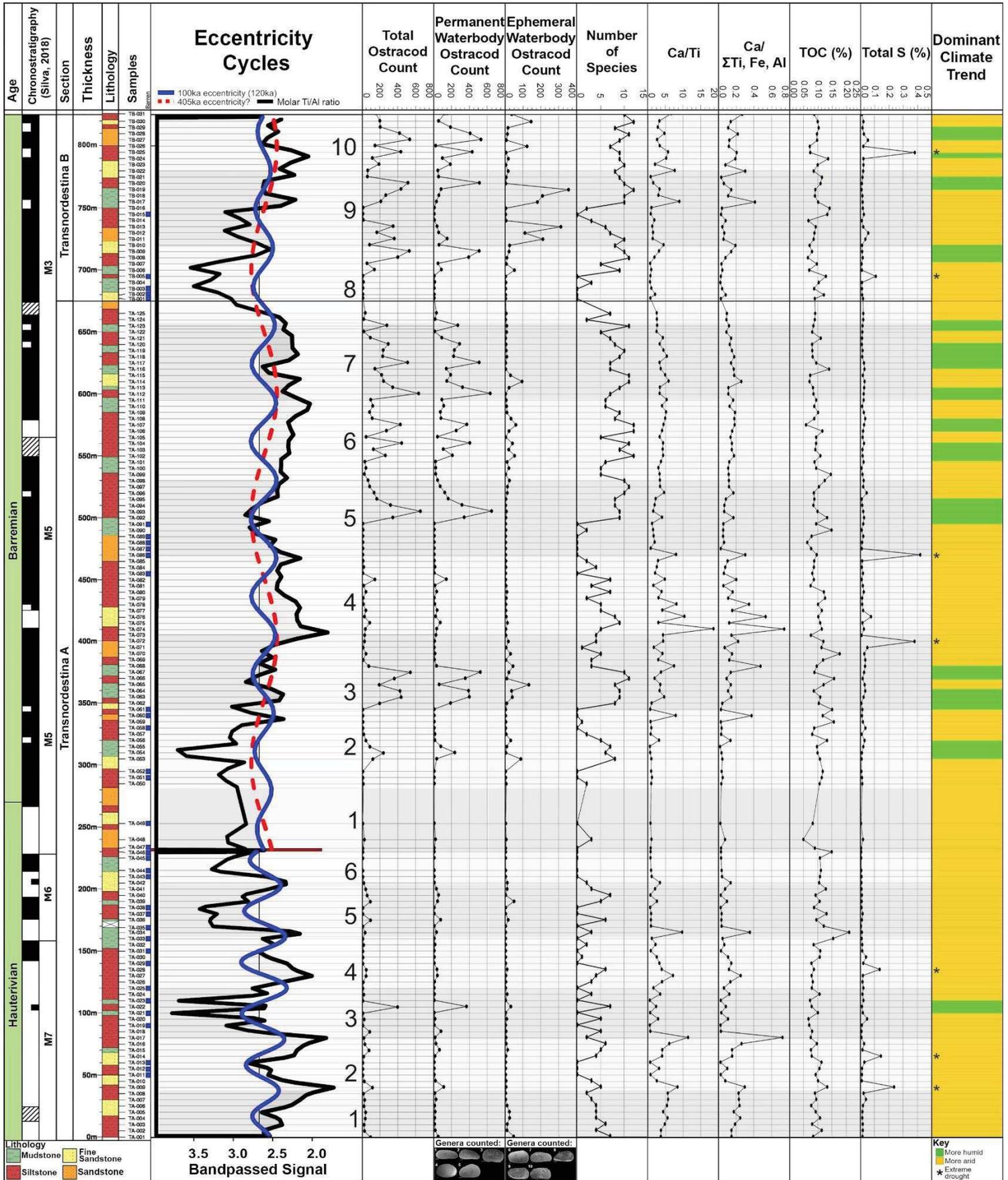
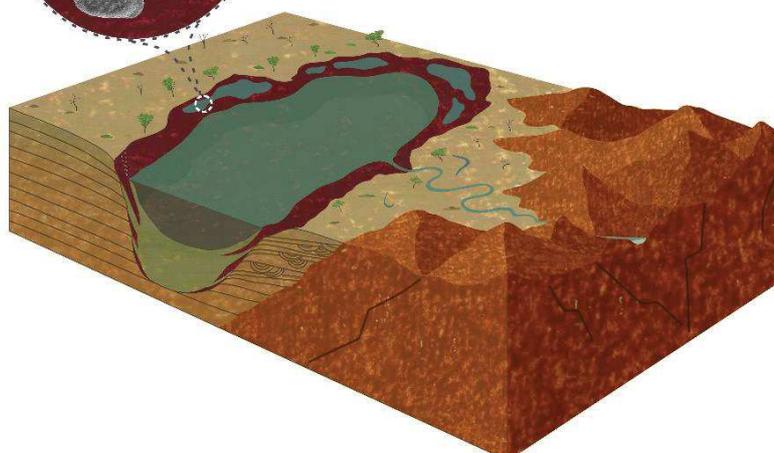
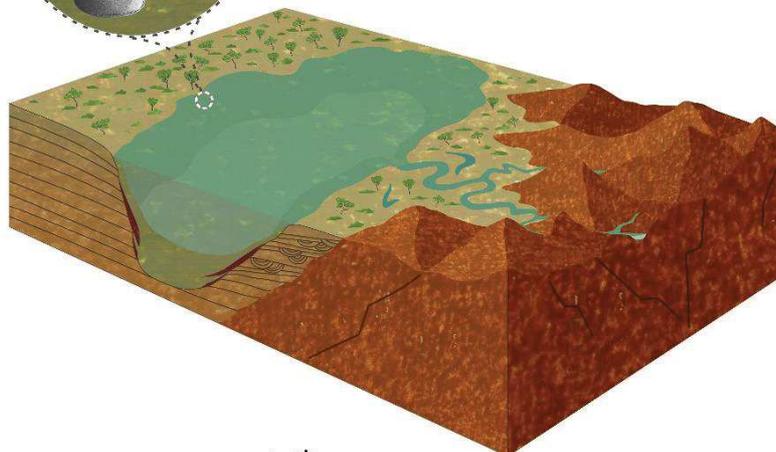
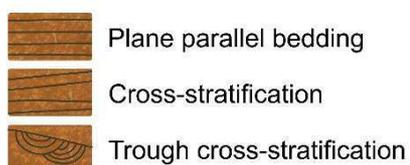


Fig. 11. Figure showing the lithology of the Transnordestina A/B sections, location of the studied samples, eccentricity signal, total ostracod count, specimen count of the permanent and ephemeral waterbody ostracod groups, the total diversity in each sample, the XRF ratios used in this study, TOC and total S, and inferences on the humidity of the area based on the gathered data. Age, chrons and lithology are based on Silva (2018). Ostracod genera shown: 1 – *Alicenula leguminella*, 2 – *Hastacypris adamantem*, 3 – *Ilyocypris? arca*, 4 – *Brasacypris ovum*, 5 – *Pattersoncypris sinuata*, 6 – *Cypridea punctacentralis*, 7 – *Rhinocypris? ericius*, 8 – *Pythagoracypris latavectis*, 9 – *Looneyellopsis mvili*, 10 – *Musacchiocythere plastica*



Sedimentary structures



Lithology



Illustration: Mariah Xavier Rocha

Fig. 12: Idealized reconstructions of the environments in which the studied ostracod groups lived. The Permanent Waterbody Group is exemplified by: 1 – *Alicenula leguminella*, 2 – *Hastacypris adamantem*, 3 – *Ilyocypris? arca*, 4 – *Brasacypris ovum*, 5 – *Pattersoncypris sinuata*. The Ephemeral Waterbody Group is exemplified by: 6 – *Cypridea punctacentralis*, 7 – *Pythagoracypris latavectis*, 8 – *Rhinocypris? ericius*, 9 – *Musacchiocythere plastica*, 10 – *Looneyellopsis mvili*

Being newly described genera, species of *Pythagoracypris* and *Hastacypris* have no known ecological preferences. *Hastacypris*, species of which are highly abundant, was grouped alongside *Alicenula*, *Pattersoncypris*, *Brasacypris* and *Ilyocypris?*, suggesting a preference for settings dominated by permanent waterbodies, though similarly to *Ilyocypris?*, its higher abundance in siltstones instead of mudstones (Table 2) might indicate a strong tolerance for more ephemeral settings as well, or perhaps that they were abundant enough in the nearby paleolake that flooding episodes brought numerous carapaces of the genus into the ephemeral pounds of its inundation plain. The single *Pythagoracypris* species was grouped alongside species of *Cypridea*, *Looneyellopsis*, *Rhinocypris?* and *Musacchiocythere* in the cluster analysis, which could potentially indicate a preference for ephemeral settings; however, as it is extremely rare in the studied sections, it is difficult to properly infer an environmental preference for this species and genus with the data available thus far.

An interesting feature of both groups is the level of ornamentation of the genera present in them. The majority of the taxa found in the permanent water body group have smooth shells, with the sole exception being *Ilyocypris?* with its pustules and sulci, while all species found in the ephemeral water body group display some degree of carapace ornamentation, from the punctuation and nodules in species of *Cypridea* to the spinelet-like nodules of *Rhinocypris?*

Bate (1999) argues that a drying period in a lake is accompanied by the establishment of a predominantly smooth-shelled ostracod fauna due to increased salinity, which propitiates carbonate precipitation. In addition, it is known that heavy rainfall or flash floods leading to the fast decrease in salinity of water bodies can lead to the development of nodding in ostracods, as mainly seen with *Cyprideis torosa* (van Harten, 2000; Keyser and Aladin, 2004; Keyser, 2005; de Deckker and Lord, 2017).

A possible explanation for these differences in ornamentation between the groups might be that the paleolake itself might have had enough salinity to constantly allow for the deposition of carbonates, explaining both the high values of Ca identified through XRF and the predominance of smooth-shelled ostracods during periods in which the paleolake reached the area of the section. Meanwhile, the more ornamented ostracods of the ephemeral pools of the inundation plain of the lake could have been subjected to lower salinity levels due to small scale seasonal events, such as flash floods or heavy rainfalls, which would lead to, for example, the development of nodes in *Cypridea* species.

The cyclostratigraphic interpretation roughly fits the magnetostratigraphic evaluation of Silva (2018) and suggests a total duration of at least 1.92 Ma for the investigated section. The durations of orbital cycles in combination with magnetostratigraphic time constraints given in Gradstein et al. (2012) do not leave too many possibilities for an astrochronological interpretation. The younger (233–836 m) and older (0–233 m) segments of the section had to undergo separate testing for harmonic frequencies as a first evaluation of spectral density, suggesting differences in sedimentation rates. Limits in overall thickness and sample resolution rendered it impossible to identify the 405 ka cycle in the older profile segment. Furthermore, harmonic signals that could relate to a 405 ka cycle in the overlying strata are relatively close to the Rayleigh frequency and can thus

be considered a subtle rather than a robust signal. For a comprehensive cyclostratigraphic interpretation, we chose to pursue the 100ka signal. Six short eccentricity cycles were identified for the interval between 0 and 233 m, and ten cycles for the interval between 233 and 836 m (Fig. 11).

There is a notably lower amount of ostracods at the base of the sections between samples TA-001 (0 m) and TA-047 (225 m) (which encompass the older segment singled out by the spectral analysis), as well as a significant decrease in their number around sample TA-068 (380 m) to TA-091 (495 m). Ca/Ti and Ca/ Σ Ti, Fe and Al show high values in these samples, and as previously stated, peaks of these ratios can be indicative of drier periods in a lake. Short dry periods can also be observed in the Transnordestina B samples; small spikes in these proportions are always accompanied by a decrease in the number of ostracods.

Though generally low, total S values do display peaks in seven samples distributed at the base, middle and top of the section. These samples (TA-009, TA-014, TA-028, TA-072, TA-086, TB-005 and TB-025) are all located in “dry” periods, as indicated by high Ca/Ti and Ca/ Σ Ti, Fe and Al values and low ostracod numbers. High amounts of S have been interpreted as potentially indicative of authigenic precipitation of gypsum (CaSO₄), a mineral that was observed in different levels of the sections, which would be indicative of extreme drought episodes in which enhanced evaporation led to a shallowing and volume reduction of the paleolake (Burn and Palmer, 2014).

Lower sedimentation rates, suggested by differently expressed orbital signals, smaller number of ostracods, and dryer climate indicated by the elemental ratios are indicative of a different depositional environment for the older part of the section. The younger interval (233–836 m, samples TA-48 to TB-031), conversely, is the one in which ostracods begin to be found in abundance, particularly from the height of 495 m (TA-091), in addition to the increasing presence of the green mudstones. The more well-defined cycles, higher amount of ostracods, and the greater presence of the mudstone layers likely reflect that the latter depositional environment of the sections was becoming increasingly more humid, which might have allowed for the main body of the paleolake to more frequently reach the region of the studied sections.

Based on the previously discussed environmental preferences of the ostracods recovered in this study, the first group, composed of *Alicenula*, *Pattersonocypris?* *Brasacypris*, *Hastacypris* and *Ilyocypris?* is considered to be representative of permanent waterbodies. Moments of dominance of taxa of this group in the sections point to periods of existence of a larger paleolake in the basin, covering the section area, which, in turn, would develop in more humid climate intervals with higher precipitation rates and increased water inflow from the catchment area. The second group, composed of species of *Cypridea*, *Rhinocypris?*, *Looneyellopsis*, *Musacchiocythere* and *Pythagoracypris*, would be indicative of the dominance of temporary waterbodies, pointing to less humid/more arid warm to hot and potentially stronger seasonal climate intervals, with higher evaporation rates leading to increased salinities, and only periodical heavy rainfalls leading to rapid salinity decreases in smaller waterbodies and ecophenotypic effects in the ostracods (e.g. nodding). For our section, which does not lie in the proximate depocenter of the paleolake, we interpret that the corresponding decrease of the extension of the paleolake turned the studied area

into its inundation plain, where ephemeral water pools would occasionally be created that allowed only for a less abundant fauna to develop (Fig. 11, 12). Considering the fact that, according to Ponte Filho et al. (1994), the deposits of the Orós formation would have been developed during a period of tectonic quiescence in the region, these variations in humidity for the region are most likely (almost) solely climate-controlled, instead of a combination of climate and tectonic control where the creation of additional depositional space through increased subsidence would lead to higher lake levels.

Finally, it is interesting to note that the composition of the ostracod faunal composition remains relatively constant throughout the two sections, varying mainly in the proportions of the species. The six species that do not occur in both sections are also the rarest (*Cypridea hystricoides*, *Cypridea* cf. *clavata*, *Pythagoracypris latavectis*, *Musacchiocythere plastica*, *Musacchiocythere?* sp., and the unidentified species of an unidentified genus) and thus their disappearance likely does not represent their extinction. This implies that a relatively, geologically small period of time is represented by the studied sections, since no major faunal upheavals could be noticed. This could also indicate that the offset of the fault that divides Transnordestina A from B is likely not to represent a major hiatus. This is corroborated by the Lower Cretaceous magnetostratigraphic age models of Silva (2018), all three of which show few magnetic inversions and postulate an interval with a maximum duration of approximately 3 Ma for the sections.

6. SUMMARY AND CONCLUSIONS

The Transnordestina A/B sections of the Iguatu Basin contain a highly abundant ostracod fossil record that reflects the generally warm and arid environment, with numerous intermittent periods of humid that dominated the region during the Lower Cretaceous.

The ostracod fauna of the sections is dominated by genera with a preference for more permanent waterbodies, such as *Alicenula*, with occasional increases in the number of ostracods which indicate dominance of temporary waterbodies, such as *Cypridea*. Taking these preferences and the variation in their abundance throughout the section into account, it is possible to estimate periods of higher or lesser depth and extent of the interpreted paleolake in the Iguatu Basin using the most abundant genera, with assemblages composed primarily of species of *Alicenula*, *Pattersoncypris?* *Brasacypris*, *Hastacypris* and *Ilyocypris* being indicative of permanent waterbodies, i.e., a lake. An increase in the number of species of *Cypridea*, *Rhinocypris?*, *Looneyellopsis*, *Musacchiocythere* and *Pythagoracypris* suggest periods in which the lake decreased in size and the area of the section was an inundation plain with temporary ponds.

In terms of total abundance, the ostracod fauna of the section is dominated primarily by species of *Alicenula*, *Pattersoncypris*, *Cypridea* and *Hastacypris*. Through cluster analysis, two main ostracod groups were observed: one association composed of *Alicenula*, *Pattersoncypris?* *Brasacypris*, *Hastacypris* and *Ilyocypris?*, and one with *Cypridea*, *Rhinocypris?*, *Looneyellopsis*, *Musacchiocythere* and *Pythagoracypris*. Due to the presence of *Alicenula* in the first group, it is considered to be indicative of an increase in humidity in the

depositional area, with the paleolake becoming larger and more stable, covering the studied area. The presence of *Cypridea* in the second group allowed for the inference of more arid periods, in which the paleolake was reduced in size and the studied area became part of its inundation plain, where short-lived pools would develop.

Ca/Ti and Ca/ Σ Ti, Fe and Al ratios show distinct periods of dryness in the section, particularly at its base, between samples TA-001 and TA-045 and TA-069 and TA-087, which also show a relative lack of ostracods. TOC values remain stable and low throughout the section, with no clear trends; this might be a reflection of poor preservation of organic matter in the sections. Similarly, total S values also remain low and relatively stable, with the exception of TA-009, TA-014, TA-028, TA-072, TA-086, TB-005 and TB-025, which show significant spikes in relation to other samples. These might be also indicative of dryer conditions, as these larger concentrations of S could be indicative of authigenic precipitation of gypsum, which suggest drought episodes.

The cyclostratigraphic analysis identified six 120 ka cycles for the interval between 0 and 233 m (TA-001 to TA-047), and ten 120 ka 'short' cycles and three possible 405 ka "long" cycles between 233 and 836 m (TA-048 to TB-031). The 0 to 233 m interval, with its significantly smaller amount of ostracods and high Ca/Ti and Ca/ Σ Ti, Fe and Al values, could be indicative of a different depositional environment for this part of the section, reflecting a less humid period for this area of the basin, while the increasingly more abundant ostracod fauna of the 233 to 836 m interval, alongside generally more stable Ca/Ti and Ca/ Σ Ti, Fe and Al values, might be indicative of increasing humidity.

The authors believe that this study improves our understanding of the paleoenvironmental settings that predominated in Lower Cretaceous basins of Northeastern Brazil, and that it also brings attention to the fact that the small basins that characterize the region, such as the Iguatu Basin, have great untapped potential in contributing to regional and global paleoclimate trends.

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6. SÍNTESE INTEGRADORA E CONCLUSÕES

Das 156 amostras coletadas para este estudo, em 121 foram recuperados ostracodes, demonstrando uma grande abundância e diversidade para este grupo fóssil. Ao todo, foram encontrados 17.150 espécimes de ostracodes, distribuídas entre 19 espécies, 11 gêneros, e seis famílias: *Cypridea hystricoides*, *Cypridea paraibensis*, *Cypridea* cf. *C. clavata*, *Cypridea punctacentralis* sp. nov., *Brasacypris ovum*, *Pattersoncypris sinuata*, *Pattersoncypris* cf. *P. sinuata*, *Pattersoncypris?* sp., *Ilyocypris? arca.*, *Ilyocypris? latanodi.*, *Rhinocypris? ericius*, *Pythagoracypris latavectis*, *Hastacypris adamantem*, *Looneyellopsis mvili*, *Musacchiocythere plastica*, *Musacchiocythere?* sp., *Alicenula leguminella*, *Alicenula* cf. *D. oblonga*, e uma espécie indeterminada de um gênero indeterminado. Baseando-se na presença de *Cypridea hystricoides*, pode-se inferir a presença da biozona RT-006, de idade Barremiana; além disso, a presença de *Looneyellopsis mvili*, *Musacchiocythere plastica*, *Pattersoncypris*, e a possível presença de *Cypridea clavata*, apontam para uma idade Hauteriviana-Aptiana para o intervalo.

Em termos paleoambientais, observou-se a presença de dois grupos principais de ostracodes, que representam ocasiões em que o ambiente da região se encontrava mais úmido ou mais árido: uma associação composta primariamente por *Alicenula*, *Pattersoncypris?*, *Brasacypris*, *Hastacypris* e *Ilyocypris?*, que indicariam momentos de maior umidade em que o paleolago alcançava a região de estudo; e um grupo composto pelos gêneros *Cypridea*, *Rhinocypris?*, *Looneyellopsis*, *Musacchiocythere* e *Pythagoracypris*, que, devido a presença de *Cypridea*, seria indicativo de momentos de maior aridez, em que houve uma redução do tamanho do paleolago e a área das seções estudadas passava a ser sua planície de inundação, onde poças efêmeras se formavam.

As razões Ca/Ti e Ca/ Σ Ti, Fe, Al indicam a presença dois maiores períodos de aridez na região, entre as amostras TA-001 e TA-045, e TA-069 e TA-087, em que também há uma relativa baixa quantidade de ostracodes. Valores de COT se mostram extremamente baixos e estáveis pela seção, possivelmente indicando a baixa preservação de matéria orgânica na seção. S total também não apresenta grandes variações e se mantém com valores baixos pela seção, com exceção das

amostras TA-009, TA-014, TA-028, TA-072, TA-086, TB-005 e TB-025, que mostram picos significativos; estes podem também significar momentos de aridez, vendo que altas concentrações de S podem estar relacionadas a precipitação de gipsita, um mineral evaporítico associado a episódios de seca.

A análise cicloestratigráfica identificou, no intervalo entre 0 e 233 m (TA-001 a TA-047) 6 ciclos de 120 ka; juntamente com a baixa abundância e diversidade de ostracodes e altos valores de Ca/Ti e Ca/ Σ Ti, Fe, Al, esse intervalo parece representar um período de maior aridez para essa parte da seção. Entre 233 e 836 metros (TA-048 a TB-031), foram identificados 10 ciclos de 120 ka e três ciclos de 405 ka. A maior presença de ostracodes, aliada ao aumento da ocorrência de argilitos esverdeados, possivelmente indica um aumento de umidade para esse intervalo.

Com essa tese de doutorado, se espera ter demonstrado o grande potencial que os depósitos do Cretáceo Inferior das pequenas bacias internas do Nordeste, como os da Bacia do Iguatu, tem para avançar o conhecimento sobre a bioestratigrafia e o paleoambiente deste período, que ainda necessita de maiores dados para seu melhor entendimento.

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