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OSTRACODES BATIAIS DO PLEISTOCENO-HOLOCENO DO CONE DO RIO GRANDE, BACIA DE PELOTAS, BRASIL

Recife
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Dissertação apresentada ao Programa de Pós-Graduação em Geociências do Centro de Tecnologia e Geociências da Universidade Federal de Pernambuco, como requisito parcial para obtenção do título de Mestre em Geociências. Área de concentração: Geologia Sedimentar e Ambiental.

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RESUMO

Ostracodes constituem um grupo de artrópodes bivalves, de tamanho diminuto, dotados de uma carapaça predominantemente carbonática composta por duas valvas articuladas na região dorsal. Possuem hábito essencialmente aquático, podendo ser encontrados em ambientes marinhos, não marinhos e de transição. O estudo das valvas e carapaças preservadas no registro fóssil abrange principalmente pesquisas de cunho sistemático, bioestratigráfico, paleoecológico e paleozoogeográfico. Para a realização desse trabalho, foram estudadas 87 amostras provenientes de cinco *piston cores,* do Cone do Rio Grande, Bacia de Pelotas, Brasil. A Bacia de Pelotas está localizada no extremo sul da margem brasileira, com aproximadamente 210.000 km^2, sendo limitada ao norte pelo Alto Florianópolis, no estado de Santa Catarina, e ao sul pelo Alto Polônio, no Uruguai. A metodologia incluiu a pesagem, lavagem, secagem e triagem das amostras, seguida de imageamento, identificação taxonômica dos espécimes coletados e interpretação dos dados. Um total de 22 gêneros e 32 espécies foram identificadas, revelando uma fauna batial de ostracodes, com dominância dos gêneros *Apatihowella, Cytheropteron* e *Cytherella*, intercalada a uma fauna nerítica alóctone, com dominância do gênero *Cativella. Eucytherura fossapunctata* foi descrita como uma nova espécie. A ocorrência geográfica das espécies *Krithe hunti*, *Poseidonamicus hisayoae* e *Pectocythere magellanensis* foi estendida para a margem sul do Brasil. A análise bioestratigráfica adicional dos foraminíferos planctônicos posicionou as amostras estudadas nas Biozonas Z e Y, correspondentes ao intervalo Pleistoceno–Holoceno. Parte dos táxons recuperados foram relacionados a um ambiente de escape de gás, sendo pertencentes a uma comunidade quimiossintética. Os ostracodes *Paracytherois, Cytheropteron, Cytherella, Macropyxis, Krithe hunti, Krithe reversa, Henryhowella asperrima, Eucytherura fossapunctata, Rimacytheropteron longipunctatum, Apatihowella bernardi* e *Apatihowella convexa* e os foraminíferos *Bolivina, Bulimina, Nonion, Nonionellina, Oridorsalis, Uvigerina*, *Epistominella* e *Cassidulina* estão relacionados a hidratos de gás e ao ambiente eutrófico-mesotrófico em uma condição disóxica-anóxica.

Palavras-chave: Ostracoda; Foraminifera; taxonomia; paleoambiente; Atlântico sul; Quaternário.

ABSTRACT

Ostracods constitute a group of bivalve arthropods, of small size, endowed with a predominantly carbonated carapace composed of two valves articulated in the dorsal region. They have an essentially aquatic habit and can be found in marine, non-marine and transitional environments. The study of valves and carapace preserved in the fossil record mainly includes systematic, biostratigraphic, paleoecological and paleozoogeographic research. To carry out this work, 87 samples from five *piston cores*, from the Rio Grande Cone, Pelotas Basin, Brazil, were studied. The Pelotas Basin is located in the extreme south of the brazilian margin, with approximately 210,000 km^2, being limited to the north by Alto Florianópolis, in the state of Santa Catarina, and to the south by Alto Polônio, in Uruguay. The methodology included weighing, washing, drying and screening the samples, followed by imaging, taxonomic identification of the collected specimens and data interpretation. A total of 22 genera and 32 species were identified, revealing a bathyal fauna of ostracods, with dominance of the genera *Apatihowella, Cytheropteron* and *Cytherella*, interspersed with an allochthonous neritic fauna, with dominance of the genus *Cativella*. *Eucytherura fossapunctata* was described as a new species. The geographic occurrence of the species *Krithe hunti, Poseidonamicus hisayoae* and *Pectocythere magellanensis* was extended to the southern margin of Brazil. Additional biostratigraphic analysis of planktic foraminifera placed the studied samples in Biozones Z and Y, corresponding to the Pleistocene–Holocene interval. Part of the recovered taxa were related to a gas escape environment, belonging to a chemosynthetic community. The ostracods *Paracytherois, Cytheropteron, Cytherella, Macropyxis, Krithe hunti, Krithe reversa, Henryhowella asperrima, Eucytherura fossapunctata, Rimacytheropteron longipunctatum, Apatihowella bernardi* and *Apatihowella convexa* and the foraminifera *Bolivina, Bulimina, Nonion, Nonionellina, Oridorsalis, Uvigerina*, *Epistominella* and *Cassidulina* are related with gas hydrates and the eutrophic-mesotrophic environment in a disoxic-anoxic condition.

Keywords: Ostracoda; Foraminifera; taxonomy; paleoenvironment; south Atlantic; Quaternary.

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LISTA DE ABREVIATURAS

C	Carapaça
LV	Valva esquerda
RV	Valva direita
L	Largura
H	Altura
W	Comprimento

SUMÁRIO

1 INTRODUÇÃO

Esta dissertação foi desenvolvida conforme as normas do Programa de Pós-graduação em Geociências da UFPE e se apresenta na forma de dois artigos científicos, os quais foram submetidos às revistas indexadas: *Revue de Micropaléontologie* e *Micropaleontology*.

O subtópico 1.1 da Introdução apresenta uma breve revisão sobre a Subclasse Ostracoda, incluindo os aspectos referentes aos caracteres morfológicos, à classificação sistemática, à origem e evolução dos ostracodes e às aplicações do grupo nas áreas da tafonomia, bioestratigrafia, paleoclimatologia, paleoceanografia e paleobiogeografia. O subtópico 1.2 apresenta um breve histórico sobre as pesquisas com ostracodes e foraminíferos ocorridas na Bacia de Pelotas. Ao final, no subtópico 1.3, são apresentados o objetivo geral e os específicos do trabalho.

O tópico 2 compreende a caracterização da área de estudo, ressaltando aspectos referentes ao contexto geológico e a estratigrafia da Bacia de Pelotas, com apresentação da carta estratigráfica, além de dados sobre a província de gás do Cone do Rio Grande. O tópico 3 apresenta o material estudado e os métodos empregados durante a execução desse trabalho.

O tópico 4 apresenta os Resultados e Discussões da dissertação na forma de artigos. O primeiro artigo, já publicado e apresentado no APÊNDICE A, aborda a taxonomia dos ostracodes batiais do Pleistoceno da Bacia de Pelotas. O segundo artigo, apresenta a assembleia de ostracodes e foraminíferos Quaternários, além de abordagem bioestratigráfica, baseada em foraminíferos planctônicos, da identificação do paleoambiente batial e da compreensão das relações dos microfósseis estudados com ambientes de hidratos de gás e comunidades quimiossintéticas do Cone do Rio Grande, Bacia de Pelotas.

Por fim, no tópico 5, têm-se as conclusões do trabalho.

1.1 GENERALIDADES DOS OSTRACODES

Os ostracodes constituem um grupo de artrópodes bivalves sem linhas de crescimento, com até 8 pares de apêndices, além de membros copulatórios e uma furca. Os adultos apresentam tamanho que varia, na maioria dos táxons, entre 0,2 e

2 mm. Durante o ciclo de vida, até atingir a fase adulta, ocorrem as fases juvenis, que geralmente totalizam oito estágios ontogenéticos e são caracterizadas por crescimento descontínuo através de mudas (HORNE, 2005; BERGUE, 2006; RODRIGUEZ-LAZARO e RUIZ-MUÑOZ, 2012). Para que ocorram as mudas, a carapaça antiga deverá ser substituída por uma nova, produzida através de células epidérmicas da lamela externa e pela parte periférica da lamela interna, que precipitam quitina e carbonato de cálcio (MORKHORVEN, 1962; ARMSTRONG e BRASIER, 2005). Os ostracodes possuem um habitat essencialmente aquático, podendo ser encontrados em ambientes marinhos, não marinhos e de transição (HORNE, 2005; BERGUE, 2006). Há também registros de espécies que habitam águas de bromélias e utilizam o corpo de anfíbios, lagartos e mamíferos para a dispersão e colonização de outras plantas (LOPEZ et al., 2002; 2005).

Liebau (2005) classificou os ostracodes como pertencentes a Subclasse Ostracoda, e os incluiu na Classe Maxillopoda e no Filo Crustacea. Nessa classificação, duas superordens constituem o grupo: Myodocopomorpha e Podocopomorpha. Diferentemente, Horne (2005) incluiu os ostracodes na Classe Ostracoda e subdividiu o grupo em duas Subclasses: Myodocopa e Podocopa. As estruturas morfológicas de representantes dessas subclasses sugerem que os podocopídeos apresentam maior afinidade com grupos basais do Cambriano e que os miodocopídeos teriam surgido mais tarde, a partir de representantes do Paleozoico, período Siluriano. Atualmente, representantes da Subclasse Podocopa incluem a maioria das formas viventes e amplo registro fóssil (ARMSTRONG e BRASIER, 2005). De acordo com Horne (2002; 2005) os ostracodes quaternários estão agrupados em 10 subordens e 16 superfamílias. Os critérios para a classificação nessas categorias estão baseados na identificação e análises morfológicas das partes moles, que incluem apêndices e as estruturas internas, e das partes duras, que incluem as valvas calcificadas.

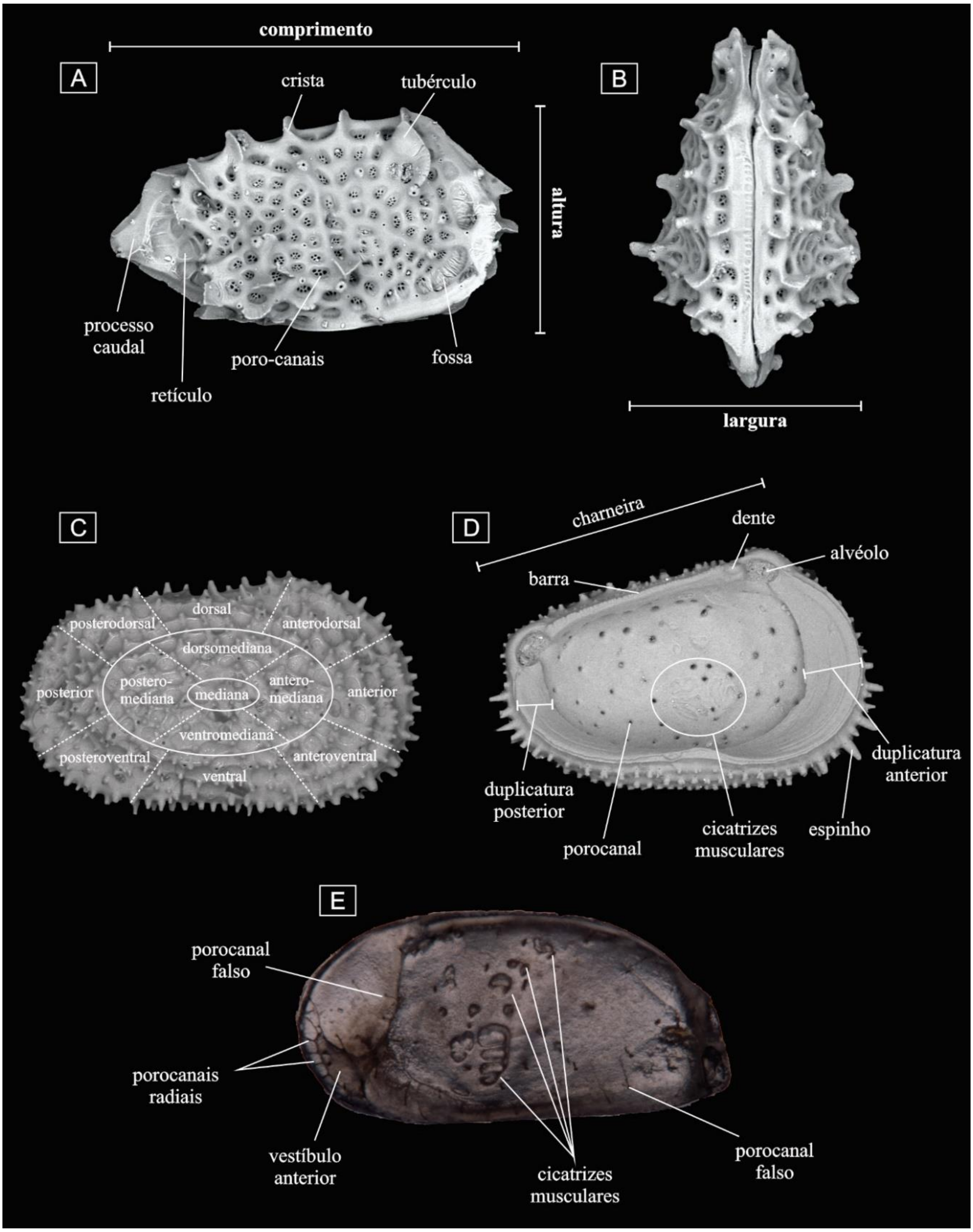
Aproximadamente, 30.000 espécies vivas e 65.000 espécies fósseis de ostracodes já foram descritas. O conteúdo fossilífero inclui táxons do Ordoviano ao presente, sendo considerado o mais completo registro paleontológico para os artrópodes, com cerca de 450 milhões de anos (RODRIGUEZ-LAZARO e RUIZ-MUÑOZ, 2012; BRUSCA et al., 2018). Os registros mais antigos remetem a primeira grande radiação dos ostracodes durante o início do Ordoviciano, com o evento de transgressão global, caracterizado por grande diversidade de gêneros de

Palaeocopida. A redução da diversidade e extinção da ordem ocorreu apenas no Permiano. Ao longo do tempo, a diversidade de ostracodes foi se modificando, com o surgimento e a diversificação de representantes das ordens Myodocopa e Podocopa. Os últimos dominaram as assembleias bentônicas durante o Triássico. O final do Jurássico e o início do Cretáceo, marcados pela expansão de ambientes não marinhos, registraram faunas ricas de ostracodes não-marinhos. O final do Cretáceo foi caracterizado pelo declínio dos ostracodes marinhos. No Cenozoico, durante o Pleistoceno, as assembleias apresentaram um aumento na diversidade, com o surgimento de táxons recentes (ARMSTRONG e BRASIER, 2005).

A morfologia dos ostracodes pode ser dividida em partes moles e partes duras. A primeira inclui os apêndices e a genitália, e a segunda, a carapaça (BERGUE, 2010). Internamente, o corpo divide-se em cabeça e tronco, não havendo distinção entre tórax e abdome (BRUSCA et al., 2018). Localizados na cabeça encontram-se as antênulas, antenas, mandíbulas e maxilas, enquanto no tronco encontram-se as patas, os membros copulatórios e a furca, na extremidade posterior (BENSON et al., 1961; MORKHORVEN, 1962; ARMSTRONG e BRASIER, 2005). As antenas são adaptadas para a natação, caminhada ou escalada e apresentam exopodito desenvolvido e dotado de cerdas natatórias (BENSON et al., 1961; RODRIGUEZ-LAZARO e RUIZ-MUÑOZ, 2012). A região interna da valva é caracterizada pela presença das lamelas (externa e interna), que correspondem a uma fina camada quitinosa da parede do corpo, e das duplicaturas, duas dobras laterais da epiderme, que se formam a partir de uma parte calcificada da lamela que se dobra sobre si mesma. O espaço entre as lamelas constitui o vestíbulo (MORKHORVEN, 1962; ARMSTRONG e BRASIER, 2005).

O estudo da carapaça dos ostracodes baseia-se em caracteres morfológicos (Figura 1), como o contorno, as dimensões e ornamentação, a estrutura da charneira e a identificação das cicatrizes musculares, os quais auxiliam na descrição, classificação e identificação do grupo (MORKHORVEN, 1962; RODRIGUEZ-LAZARO e RUIZ-MUÑOZ, 2012).

Figura 1 - Morfologia geral dos ostracodes. **A.** *Eucytherura fossapunctata* Maia et al., 2021, valva direita, vista externa; **B.** *Eucytherura fossapunctata*, carapaça, vista dorsal; **C.** *Henryhowella asperrima* Reuss, 1850, valva direita, vista lateral, **D.** *Apatihowella convexa* Bergue et al., 2016; valva esquerda, vista interna; **E.** *Krithe hunti* Yasuhara et al., 2014, valva direita, vista interna.



Fonte: A autora (2021)

A carapaça é uma estrutura formada por duas valvas parcialmente unidades pela região dorsal, através de uma estrutura chamada de charneira. Como regra, a valva esquerda é maior e sobrepõe a valva direita. Porém, em alguns gêneros, como *Cypridea* Bosquet, 1852*, Darwinula* Brady and Robertson, 1885 e *Cypridopsis* Brady, 1867*,* a sobreposição é inversa, sendo a valva direita maior e sobreposta a esquerda. Músculos adutores ligam-se à região central das valvas, fechando-as. A localização desses músculos é marcada externamente pelo tubérculo subcentral e internamente por um sulco, constituindo as cicatrizes adutoras, as quais são utilizadas como critério morfológico para identificação das famílias dos ostracodes (BENSON et al., 1961; MORKHORVEN, 1962; ARMSTRONG e BRASIER, 2005; RODRIGUEZ-LAZARO e RUIZ-MUÑOZ, 2012). Também pode ser observada a cicatriz frontal, decorrente da inserção dos músculos mandibulares na carapaça, e duas cicatrizes mandibulares, relacionadas com a fixação de hastes que apoiam as mandíbulas. (ARMSTRONG e BRASIER, 2005). As charneiras são constituídas de dentes, sulcos, barra e alvéolos. Esses componentes estruturais são complementares entre as duas valvas. (MORKHORVEN, 1962; ARMSTRONG e BRASIER, 2005). Charneiras mais fracas, com componentes estruturais reduzidos são típicas de espécies natantes. Já as charneiras com componentes estruturais robustos são adaptações para as espécies que rastejam ao longo dos sedimentos de fundo e estão suscetíveis a sobrecargas no ambiente (MORKHORVEN, 1962).

Externamente, as valvas podem apresentar a superfície com morfologia variável, podendo ser lisas ou ornamentadas. As valvas ornamentadas podem apresentar reticulações, espinhos, pontuações, estrias, tubérculos, cristas, dentículos, entre outros. Esses caracteres morfológicos são amplamente utilizados para a diagnose e identificação das espécies (MORKHORVEN, 1962; RODRIGUEZ-LAZARO e RUIZ-MUÑOZ, 2012). Um tipo peculiar de ornamentação pode ocorrer por influência de fatores ecofenotípicos, na qual modificações no ambiente, tais como mudanças na salinidade, podem levar a formação de estruturas morfológicas na superfície das valvas e, frequentemente, induzindo a um maior polimorfismo interespecífico (HARTMANN, 1982; REYMENT et al., 1988; ARMSTRONG e BRASIER, 2005). Uma identificação taxonômica que desconsidere a influência desses fatores, sem a distinção das características mediadas por mudanças ambientais daquelas que apresentam valor adaptativo para as espécies, pode gerar erros relativos ao enquadramento sistemático e filogenético do grupo. As ornamentações também podem revelar adaptações a ambientes específicos, como demonstrado por Yasuhara et al., 2018 ao sugerirem que as valvas de *Rosaliella svalbardensis* Yasuhara et al., 2018, dotadas de aglomerados de poros, reticulação secundária e aglomerados de fossas, estão associadas à ectossimbiose com bactérias quimioautotróficas em ambiente com infiltração de metano.

Os ostracodes podem ser dióicos e apresentar dimorfismo sexual. Machos e fêmeas normalmente secretam valvas de diferentes formas e tamanhos. A diferenciação dos sexos pode ser constatada também através de uma análise nas carapaças dos espécimes, nas quais as fêmeas podem apresentar uma região posterior mais inflada e serem mais curtas e os machos podem ser mais alongados e estreitos. Durante a cópula no processo de reprodução sexuada, os espermatozoides são depositados nas fêmeas, o que resulta na fertilização dos ovos. A reprodução também pode ocorrer através da partenogênese, evento relativamente comum em espécies de água doce. Após a fertilização, os ovos podem permanecer armazenados em uma cavidade interna do corpo da fêmea até a eclosão das formas juvenis, podendo também ser depositados diretamente no ambiente (HORNE, 2005; ARMSTRONG e BRASIER, 2005).

A mudança da profundidade em ambientes marinhos altera diversos fatores ecológicos, tais como a temperatura da água, a salinidade e a concentração de oxigênio, que atuam na distribuição e diversidade dos ostracodes. Por serem sensíveis às mudanças ambientais, os ostracodes são considerados indicadores das condições do fundo do mar. Os estudos sobre a distribuição geográfica das assembleias batiais fossilíferas são capazes de identificar os diferentes ambientes bentônicos, além das massas de água profundas que atuaram no passado (ARMSTRONG e BRASIER, 2005).

A aplicação dos ostracodes na Micropaleontologia inclui pesquisas relacionadas à interpretação de sequências deposicionais marinhas e não marinhas, de processos tafonômicos, bioestratigráficos, paleoclimáticos, paleoceanográficos e paleobiogeográficos. A identificação genérica e supragenérica dos espécimes fornece dados iniciais sobre o ambiente de deposição. Porém, para que sejam obtidos parâmetros mais confiáveis sobre os paleoambientes, incluindo informações sobre mudanças no nível do mar, com a identificação de transgressões e regressões marinhas, mudanças na temperatura da água e na salinidade, por exemplo, faz-se necessário determinar os componentes autóctones e alóctones da assembleia

(BOOMER et al., 2003). Devido ao transporte, a fauna alóctone reflete mais frequentemente os aspectos sedimentológicos de um ambiente em detrimento dos aspectos biológicos das espécies (VAN HARTEN, 1986). A determinação dos componentes autóctones e alóctones baseia-se na análise da estrutura da população, o que inclui a identificação das preferências ecológicas dos táxons, somados aos estudos sobres as proporções entre os indivíduos juvenis e adultos, bem como a proporção de fêmeas e machos e o estado de preservação das valvas e carapaças recuperadas na assembleia (VAN HARTEN, 1986; BOOMER et al., 2003). Ao final, todos os dados obtidos devem ser correlacionados e um modelo paleoambiental da área estudada poderá ser construído.

1.2 HISTÓRICO DAS PRINCIPAIS PESQUISAS SOBRE OSTRACODES E FORAMINÍFEROS NA BACIA DE PELOTAS

As primeiras pesquisas sobre os ostracodes da Bacia de Pelotas foram desenvolvidas por Sanguinetti (1979; 1980) e Sanguinetti et al. (1991; 1992; 1993) que analisaram os aspectos taxonômicos e bioestratigráficos de assembleias do Mioceno e do Pós-Mioceno da bacia. Análises de cunho paleoceanográfico baseadas em espécies de ostracodes Neógenos também foram realizadas e apresentadas posteriormente em pesquisas de Carreño et al. (1997; 1999). Somado a estes trabalhos, Manica et al. (2015) e Manica e Coimbra (2016) desenvolveram estudos com ênfase nos aspectos taxonômicos e zoogeográficos dos ostracodes do Mioceno Inferior e Maia et al. (2021) apresentou a fauna batial do Pleistoceno Superior. Esse trabalho constitui um dos resultados da presente dissertação.

Relativo aos foraminíferos planctônicos da seção Quaternária da Bacia de Pelotas, destacamos os trabalhos de Carvalho (1980); Rodrigues e Carvalho (1980); Vicalvi (1997; 2011a, b, c, d); Coimbra et al. (2009); Petró et al. al. (2018) os quais realizaram uma abordaram sobre a bioestratigrafia dos foraminíferos planctônicos e o estabelecimento do zoneamento paleoclimático para a bacia.

Estudos sobre os foraminíferos bentônicos também foram realizados, porém em menores proporções quando comparados ao grupo anterior. Podemos destacar os trabalhos de Boltovskoy (1959); Closs e Barberena (1962); Madeira-Falceta (1974); Sprechmann (1978); Carvalho (1980) e Wilson et al. (2020) relacionados a táxons principalmente de ambientes lagunares e de plataforma no sul do Brasil.

1.3 OBJETIVOS

Os objetivos dessa dissertação encontram-se dispostos em dois subtópicos apresentados a seguir:

1.3.1 Objetivo Geral

Realizar um estudo taxonômico da fauna de ostracodes batiais do Pleistoceno–Holoceno da Bacia de Pelotas, bem como realizar inferências paleoambientais com base nas assembleias de ostracodes neríticos e batiais e foraminíferos recuperadas, a fim de ampliar o conhecimento sobre estes grupos de microfósseis na região do Atlântico Sul.

1.3.2 Objetivos Específicos

- Identificar e classificar taxonomicamente os espécimes de ostracodes e foraminíferos com base na bibliografia especializada.
- Realizar uma análise bioestratigráfica dos foraminíferos planctônicos a fim de posicionar as amostras estudadas em biozonas correspondentes a um intervalo cronoestratigráfico.
- Analisar aspectos paleoautoecológicos dos ostracodes e dos foraminíferos recuperados nas amostras, com a finalidade de estabelecer uma interpretação paleoambiental e de compreender a relação da assembleia estudada com os ambientes de hidratos gasosos da Bacia de Pelotas.

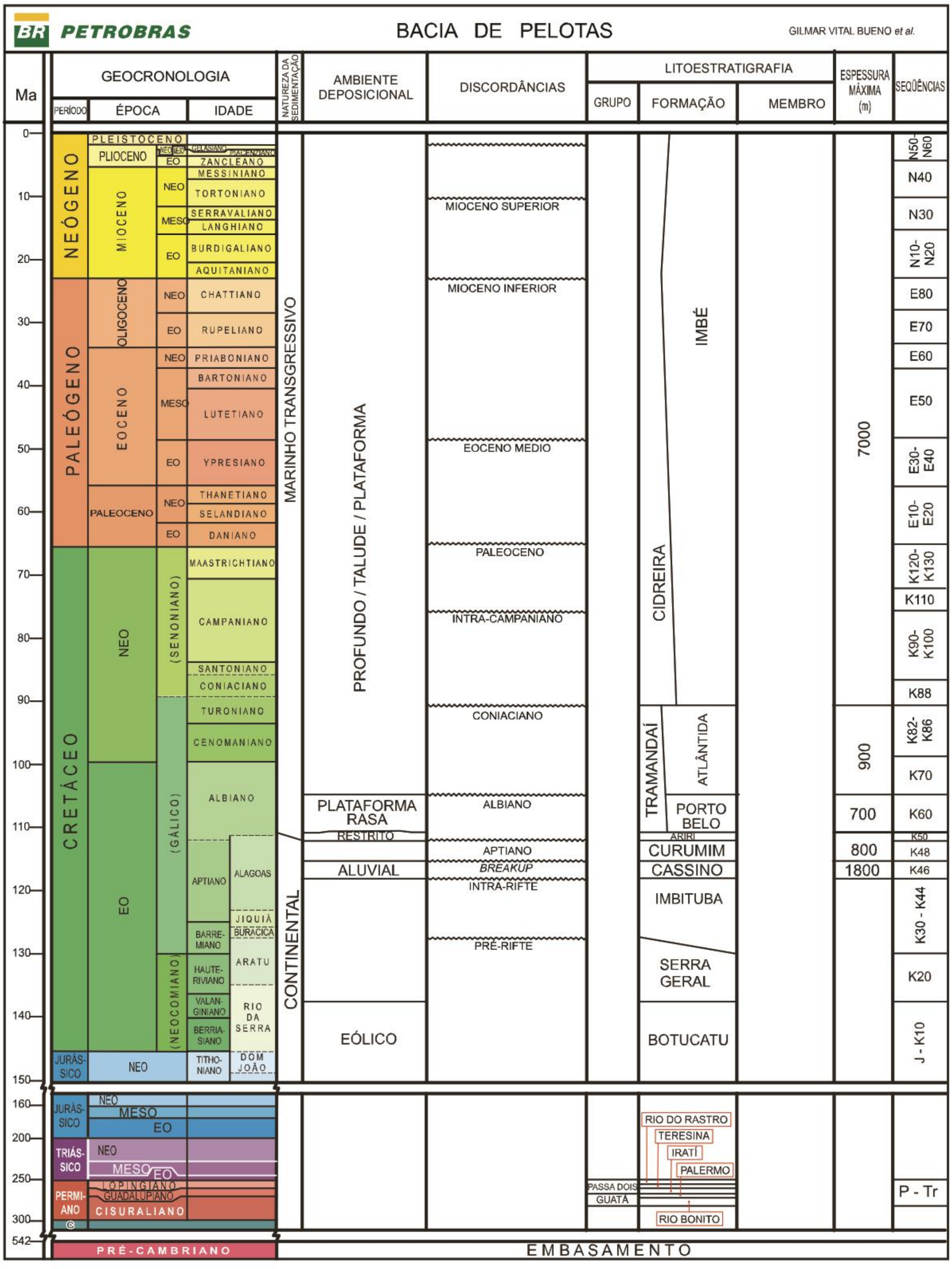
2 ÁREA DE ESTUDO

Á área de estudo está localizada no Cone do Rio Grande, Bacia de Pelotas, e corresponde a uma cunha sedimentar formada através do aporte contínuo e crescente de material terrestre proveniente das drenagens do Rio da Prata e Planalto Rio Grande do Sul, associado a deposições de sedimentos do delta ao sul e depósitos do Sistema Lagunar de Patos (MARTINS, 1983, BUENO et al., 2007). A Bacia de Pelotas, localizada no extremo sul do Brasil, é uma bacia de margem passiva, com depósitos de rochas sedimentares transgressivos do Aptiano e um intervalo regressivo superior, no Holoceno. Originada através do processo de rifteamento que separou o supercontinente Gondwana e originou o oceano Atlântico Sul, esta bacia apresenta um tamanho de aproximadamente 210.000 km^2. Seus limites são ao norte o Alto de Florianópolis, Santa Catarina, e ao sul, a Alta Floresta do Uruguai (BUENO et al., 2007).

A Bacia de Pelotas repousa a sudoeste sobre o cinturão Dom Feliciano constituído por rochas metamórficas de baixo grau, tais como filitos, xistos, quartzitos e mármores, além de granitos e migmatitos cobertos por uma sequência molássica afetada por vulcanismo. No centro do cinturão ocorre o Batólito de Pelotas, cuja origem se deu entre 850 e 450 Ma (VILLWOCK e TOMAZELLI, 1995). Após o ciclo orogênico Brasiliano-Pan Africano, ocorreu o resfriamento e a subsidência térmica da crosta continental. Esses eventos originaram as sequências vulcano-sedimentares da Bacia do Paraná, a qual atua como um embasamento para a Bacia de Pelotas e como área fonte de sedimentação clástica (ZALÁN et al., 1990; BUENO et al., 2007). As demais formações geológicas da Bacia de Pelotas ocorreram em cinco estágios ou supersequências, sendo elas: a supersequência Paleozoica-Mesozoica, a supersequência Pré-rift, a supersequência Rift a supersequência Pós-rift e a supersequência Drifte (BUENO et al., 2007). A carta estratigráfica da bacia encontra-se apresentada na Figura 2.

A Supersequência Paleozoica-Mesozoica (estágio pré-rift) é constituída pelas Formações Rio Bonito, Palermo e Irati, depositadas em ambiente marinho e pertencentes ao Grupo Guatá; na parte superior, pelas Formações Teresina e Rio Rastro, depositadas em ambiente fluvio-lacustre e de maré e pertencentes ao Grupo Passa Dois; e pela Formação Botucatu, formada por arenitos de antigos campos de dunas em toda a extensão da sinéclise do Paraná. As Formações Rio Bonito, Palermo, Irati, Teresina e Rio Rastro foram formadas entre o Permiano e o Triássico, e a Formação Botucatu entre o Jurássico e o Cretáceo (MILANI et al., 1994; BUENO et al., 2007).

Figura 2 – Carta estratigráfica das Bacia de Pelotas.



Fonte: Bueno et al., (2007, p. 557).

A Supersequência Pré-rift (estágio pré-rift - Eocretáceo) é constituída por derrames basálticos da Formação Serra Geral. O basalto corresponde às manifestações magmáticas no estágio de pré-ruptura da Gondwana ou estágio inicial de rifteamento. Estes estão rotacionados e em contado discordante às rochas da supersequência anterior (MILANI et al., 1994; BUENO et al., 2007).

A Supersequência Rift (estágio rift - Barremiano ao Aptiano) é representada por basaltos da Formação Imbituba (rift I) e pela Formação Cassino (rift II) constituída por sedimentos clásticos grossos e finos, além de conglomerados, diamictitos e siltitos que preenchem uma associação de meio-grábens, assimétricos e antitéticos. Esses depósitos são indicativos de ambientes de leques aluviais progradantes da borda flexural em direção a depósitos centrais de ambientes lacustres (BUENO et al., 2007).

A Supersequência Pós-rift (estágio pós-rift - Neoaptiano) corresponde ao estágio de subsidência térmica flexural pós-rifte da bacia, produzido pelo resfriamento e contração termal da crosta oceânica, sendo representado por basaltos, andesitos e traquiandesitos cinza-esverdeado da Formação Curumim (DIAS et al., 1994; BUENO et al., 2007) Caracterizando uma discordância, tem-se de forma sobrejacente a Formação Curumim, os evaporitos da Formação Ariri e as rochas carbonáticas da Formação Portobelo. Ao norte da bacia existem sedimentos de arenitos marinhos e carbonatos no topo, sugerindo uma deposição inicial lacustre com transição para um ambiente marinho (BUENO et al., 2007).

A Supersequência Drifte (estágio drifte - Neoaptiano ao Neógeno) encontra-se dividida em três fases, sendo elas: a fase inicial, a fase intermediária e a fase final. A fase inicial, que ocorreu no Albiano, é representada por uma sequência plataformal de depósitos carbonáticos e siliciclásticos, da Formação Portobelo, que em direção ao continente interdigita-se com arenitos da Formação Tramandaí e, em direção à bacia, gradam para calcilutitos. O contato da parte inferior dessa sequência ora ocorre em concordância com os finos depósitos evaporíticos de anidrita e carbonatos da Formação Ariri, e ora em discordância com as rochas vulcânicas da Formação Curumim. Na parte superior, o contato é discordante em relação aos pelitos da Formação Atlântida (BUENO et al., 2007).

A fase intermediária, que ocorreu do Albiano ao Oligoceno, representa um período transgressivo marcado pela espessa camada de pelitos da Formação Atlântida, que recobre de forma discordante os carbonatos da Formação Portobelo; margas e siltitos interdigitam-se com os arenitos da Formação Tramandaí. Essas camadas representam um ambiente marinho raso, que sofreu a transgressão. A partir dessa sequência, como ocorrido no Paleoceno, verifica-se a alternância maior de transgressões e regressões, com erosões intercaladas a eventos transgressivos. Até o Holoceno, o ambiente modifica-se de costeiro para leques de clásticos grossos e finos da Formação Cidreira. Em direção à bacia, os depósitos dessa formação interdigitam-se com folhelhos e siltitos cinza-esverdeados da Formação Imbé. Há também camadas de arenitos turbidíticos, indicando se tratar de deposição em ambientes marinhos profundos, com plataforma externa, talude e bacia (BUENO et al., 2007).

Constituída por uma cunha sedimentar regressiva no Neógeno, a fase final é representada por siltitos e arenitos finos da Formação Cidreira que progradam sobre os pelitos da Formação Imbé. O aporte contínuo e crescente de sedimentos originou uma feição conhecida como o Cone do Rio Grande (MARTINS et al., 1972; BUENO et al., 2007). Considerado o principal depocentro da Bacia de Pelotas, o Cone do Rio Grande corresponde a um tipo de feição localizada nos taludes e sopés das margens continentais do tipo passiva, na parte *offshore* da Bacia de Pelotas, associados a deposições deltaicas a sul e depósitos de sistema lagunar a norte, sendo a sua formação iniciada no período Mioceno Superior (MARTINS, 1983; MILLER et al., 2015). A abundância de restos vegetais, associada a presença de concreções e fósseis piritizados são indicativos da existência de matéria orgânica associada e depositada junta aos sedimentos, ocasionando uma deficiência de oxigênio devido a grande quantidade de material pelítico acumulado (MARTINS, 1983).

O Cone do Rio Grande apresenta uma província de hidratos de gás, caracterizada por extensos campos de *pockmarks*, depressões submarinas associadas à liberação de gás. Os hidratos de gás contidos nessa região são essencialmente formados por metano (> 99,78%) com pequenas quantidades de etano. Estudos sobre a composição isotópica estável do carbono presente no metano indicam uma possível origem biogênica para o gás (MILLER et al., 2015). Giongo et al. (2016) evidenciaram que na região das *pockmarks* do Cone do Rio Grande existe uma comunidade quimiossintética composta por bactérias e arqueas associadas a metazoários, e diretamente ligada aos hidratos de gás.

3 MATERIAL E MÉTODOS

Para realização deste trabalho foram coletadas e analisadas 87 amostras de cinco poços provenientes do Cone do Rio Grande, Bacia de Pelotas, Rio Grande do Sul. A perfuração dos poços ocorreu na porção *offshore* da bacia durante quatro cruzeiros oceanográficos, entre maio de 2011 e julho de 2013, e foi realizada através de uma parceria entre a PETROBRAS e a Pontifícia Universidade Católica do Rio Grande do Sul (Projeto PUCRS e CONEGAS). As coletas incluíram amostras para estudos geofísicos, geológicos, geoquímicos, biológicos e oceanográficos.

Os métodos laboratoriais (Figura 3) empregados nesse trabalho incluíram:

1) Coleta, pesagem e identificação das amostras, que consistiu na retirada de 17 a 66 g de sedimentos nos poços em locais onde foram observadas mudanças de coloração, granulometria e/ou elementos diagenéticos. Todas as amostras foram identificadas e acondicionadas em recipientes adequados.

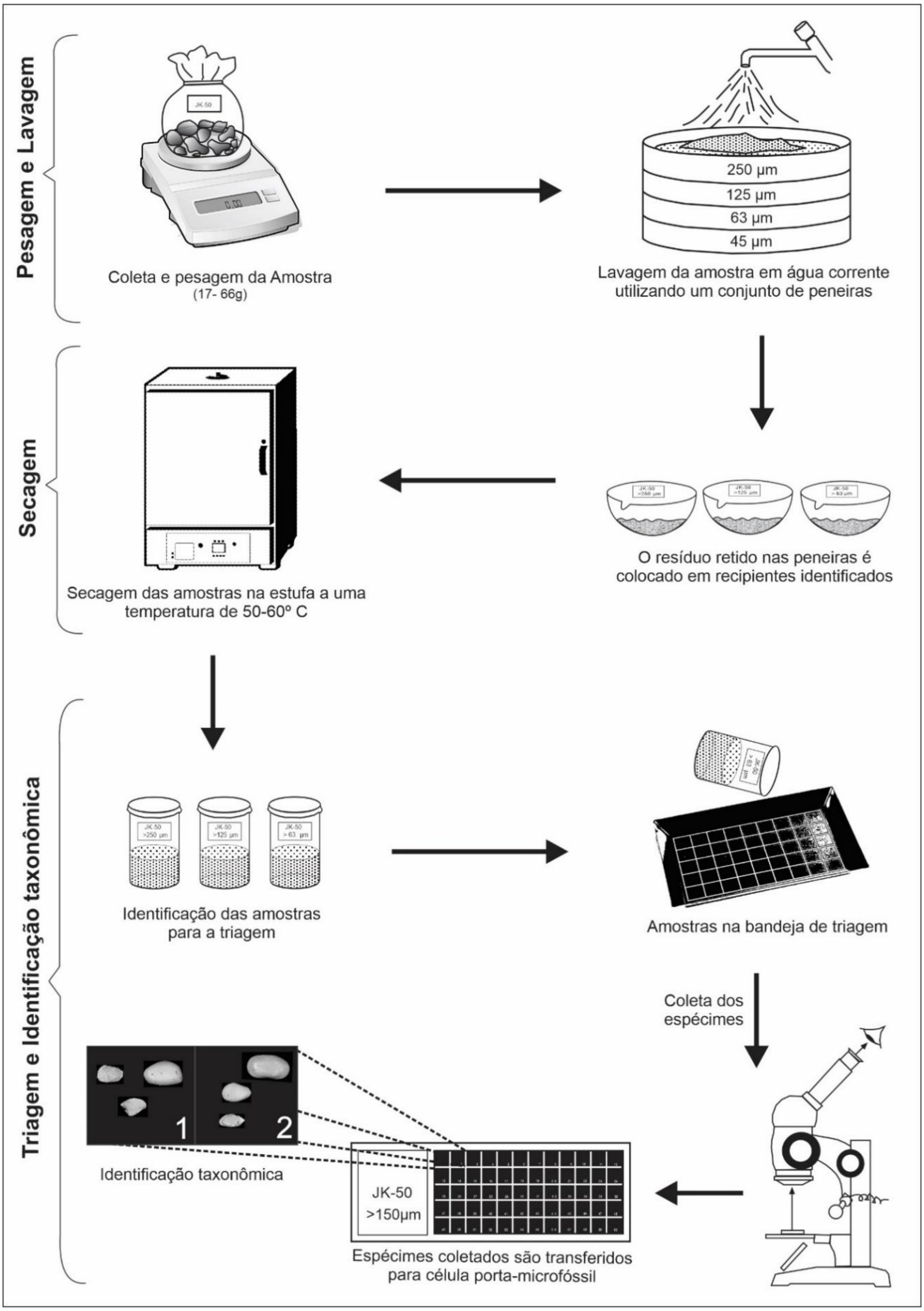
2) Lavagem em água corrente sobre um conjunto de peneiras granulométricas de 0,250 mm, 0,125 mm, 0,063 mm e 0,045 mm, seguida de secagem em estufa a 60 °C.

4) Separação de todos os espécimes de frações acima de 0,063 mm e transferência para células micropaleontológicas com o auxílio do estereomicroscópio Zeiss Stemi-305. Os espécimes mais bem preservados de cada morfotipo foram selecionados para Microscopia Eletrônica de Varredura (PHENOM XL) e estereomicroscopia (Zeiss, AXIO ZOOM V16).

4) Integração dos espécimes coletados à coleção científica do Laboratório de Micropaleontologia Aplicada (LMA) da Universidade Federal de Pernambuco (UFPE). O registro do novo táxon foi realizado no Zoobank (o Registro Oficial de Nomenclatura Zoológica da Comissão Internacional de Nomenclatura Zoológica).

Após as etapas laboratoriais, foram analisados os aspectos morfológicos e taxonômicos dos ostracodes recuperados. A fauna de ostracodes foi correlacionada com os demais microfósseis para o posicionamento bioestratigráfico dos poços estudados. Esses dados forneceram subsídios para a identificação do paleoambiente registrado durante a sedimentação no Cone do Rio Grande nos intervalos de tempo estudados.

Figura 3 - Métodos laboratoriais utilizados para a preparação das amostras.



Fonte: A autora (2021).

A determinação dos ostracodes autóctones e alóctones baseou-se na análise da estrutura da população, o que incluiu a identificação das preferências ecológicas dos táxons identificados, somados aos estudos referentes à riqueza e a abundância dos espécimes, além da análise do estado de preservação das valvas e carapaças recuperadas na assembleia.

A cronoestratigrafia das seções estudadas foi calibrada com as biozonas de foraminíferos planctônicos seguindo o esquema biozonal de Ericson e Wollin (1968) para o Quaternário, o qual se baseia no desaparecimento e reaparecimento do plexus *Globorotalia menardii*.

4 RESULTADOS E DISCUSSÕES

Os resultados e as discussões dessa dissertação são apresentados em dois artigos científicos intitulados:

BATHYAL OSTRACODS FROM THE UPPER PLEISTOCENE OF THE RIO GRANDE CONE, PELOTAS BASIN, BRAZIL (apresentado no APÊNDICE A)

QUATERNARY DEEP-SEA OSTRACODA AND FORAMINIFERA: RELATIONS WITH GAS HYDRATES ENVIRONMENTS AND CHEMOSYNTHETIC COMMUNITIES FROM THE PELOTAS BASIN, BRAZIL

QUATERNARY DEEP-SEA OSTRACODA AND FORAMINIFERA: RELATIONS WITH GAS HYDRATES ENVIRONMENTS AND CHEMOSYNTHETIC COMMUNITIES FROM THE PELOTAS BASIN, BRAZIL

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Este artigo apresenta a identificação da assembleia batial de ostracodes e foraminíferos do Quaternário da Bacia de Pelotas. A análise faunística revelou um total de 20 gêneros e 32 espécies de ostracodes. Os ostracodes batiais estavam associados a espécies neríticas alóctones. Os gêneros autóctones predominantes foram *Apatihowella, Cytheropteron* e *Cytherella*. O gênero nerítico predominante foi *Cativella.* A ocorrência geográfica da espécie nerítica *Pectocythere magellanensis* foi estendida para a margem sul do Brasil. Os foraminíferos bentônicos foram identificados em 72 gêneros. A análise bioestratigráfica dos foraminíferos planctônicos posicionou as amostras no intervalo Pleistoceno–Holoceno. Nesse estudo, parte dos táxons recuperados foram relacionados a um ambiente de escape de gás, sendo pertencentes a uma comunidade quimiossintética do Cone do Rio Grande.

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ABSTRACT

Late Quaternary ostracod and foraminifera assemblages from five piston cores in Pelotas Basin, southern Brazilian margin, were analyzed in this paper. The study revealed a diverse bathyal fauna of ostracods, with an abundance of the genera *Apatihowella, Cytheropteron* and *Cytherella*, interspersed with peaks of an allochthonous neritic fauna. Benthic foraminifera were identified in 72 genera, with highlights of *Bolivina, Bulimina, Cassidulina, Epistominella, Globobulimina*, *Globocassidulina, Nonion, Oridorsalis* and *Uvigerina*. Biostratigraphic analysis of planktonic foraminifera posicionated the samples in Pleistocene–Holocene interval. The ostracods *Paracytherois, Cytheropteron, Cytherella, Macropyxis, Krithe hunti, Krithe reversa, Henryhowella asperrima, Eucytherura fossapunctata, Rimacytheropteron longipunctatum, Apatihowella bernardi,* and *Apatihowella convexa* are related to environments of gas hydrates and associated with a chemosynthetic community in eutrophic-mesotrophic environment in a dysoxic-anoxic condition.

Key words: bathyal ostracod, benthic foraminiferal, methane seepage, methanotrophs, Brazilian margin, Rio Grande Cone

INTRODUCTION

In the last decades, research dealing on fossil ostracod and foraminifera has provided data for understanding the paleobiology of species, the taphonomy, depositional environment, paleoclimates, paleoceanography, paleobiogeography and biostratigraphy in the Pelotas Basin and surrounding Brazilian marginal basins.

Regarding ostracods, Sanguinetti (1979, 1980) and Sanguinetti et al. (1991, 1992, 1993) were pioneers analyzing the Miocene and post Miocene Ostracoda assemblages in taxonomic and biostratigraphic terms. Subsequently, Carreño et al. (1997, 1999) presented a paleoceanographic analysis based on Neogene ostracod species from the Pelotas Basin. Studies focusing taxonomic and zoogeographic aspects of Lower Miocene assemblages were presented by Manica et al. (2015) and Manica and Coimbra (2016). More recently, a taxonomic approach on bathyal ostracods from the upper Pleistocene section of the basin was presented by Maia et al. (2021).

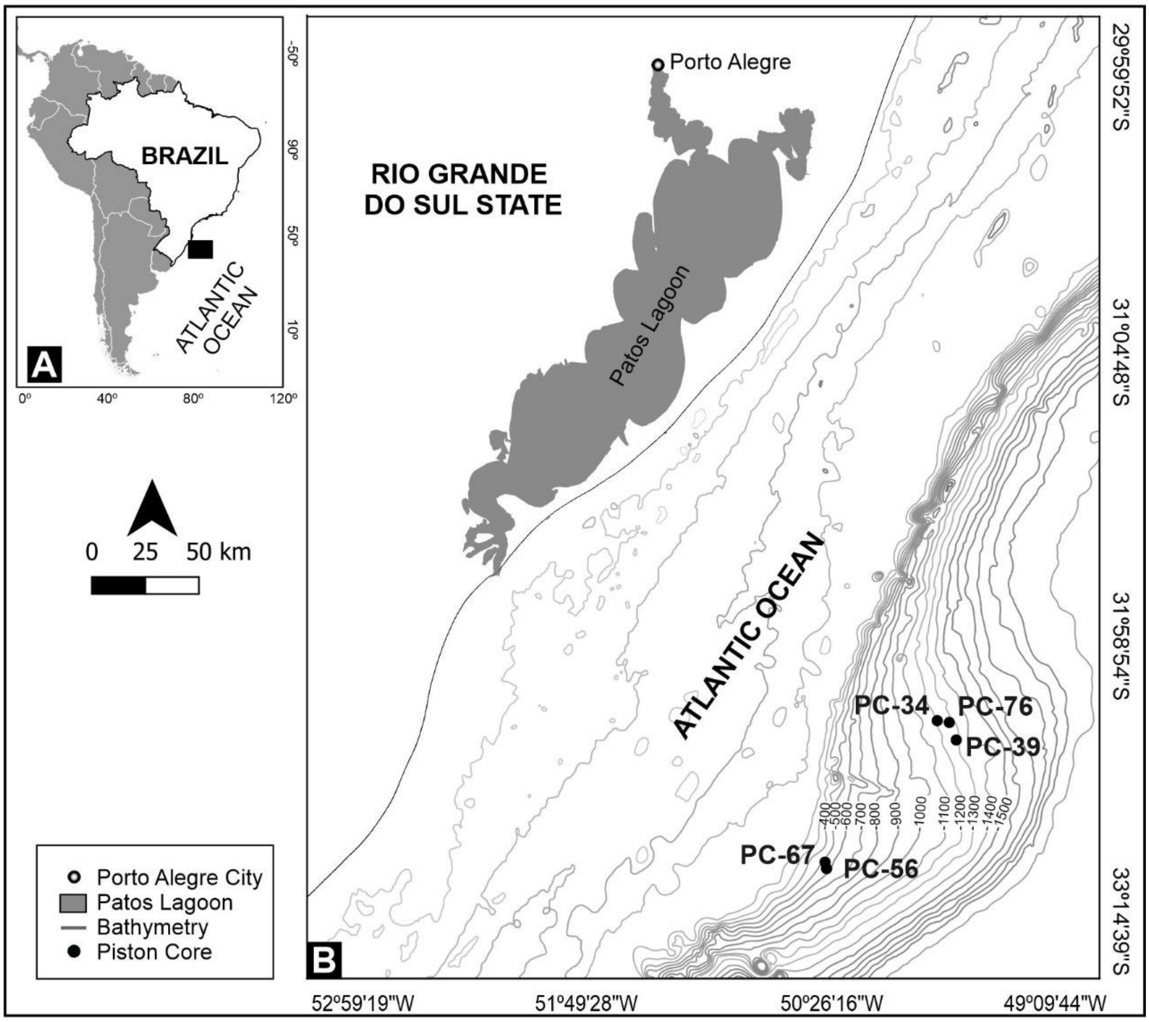
Studies on foraminifera developed in Quaternary section of the Pelotas Basin are mainly focused on biostratigraphy of planktic foraminifera establishing paleoclimatic zoning (Carvalho 1980; Rodrigues and Carvalho 1980; Vicalvi 1997; 2011a, b, c, d; Coimbra et al. 2009; Petró et al. 2018). Benthic foraminifera are major components of deep ocean ecosystems, and their distribution is largely controlled by two main parameters besides the temperature: 1) the flux of organic matter to the ocean floor and its temporal fluctuations, which determine food availability, and 2) bottom and pore water oxygen concentration (e.g. Corliss 1985; Murray 1973; Gooday 1994; Jorissen et al. 1995). In the Pelotas Basin few studies based on benthic foraminifera were carried out, being mainly for lagoon and platform environments in Southern Brazil (Boltovskoy 1959; Closs and Barberena 1962; Madeira-Falceta 1974; Sprechmann 1978; Carvalho 1980; Wilson et al. 2020).

Research of ostracod assemblages related to environments with gas hydrates occurrences are still incipient, but demonstrates a good potencial (e.g. Van Harten 1993; Coles et al. 1996; Tanaka and Yasuhara 2016; Yasuhara et al. 2018). The Rio Grande Cone, in the Pelotas Basin, is characterized by extensive pockmark fields and sediments containing gas hydrates, predominantly methane (> 99.78%), with small amounts of ethane (Miller et al. 2015). The identification of chemosynthetic community represented by bacteria, archaea and a macrofauna of polychaeta and bivalve in the region of pockmarks (Giongo et al. 2016) are evidence of a direct relationship between that community and the environment with gas hydrates in areas adjacent to the one studied in the present study. To contribute to the knowledge of this area, this research carried out an integrative study based on ostracods and foraminifera from the Pleistocene–Holocene interval of the Pelotas Basin, to establish a paleoenvironmental interpretation and the relation of the assemblages with gas hydrate environments and chemosynthetic communities.

STUDY AREA

The Pelotas Basin, located at the southern portion of the Brazilian margin (text-fig. 1), is a passive margin basin originated as a result of the Gondwana breakup and the formation of the South Atlantic Ocean. This basin was infilled with sedimentary deposits ranging in age from Barremian to Recent and covers an area of approximately 210,000 km^2, being limited to the north by Florianópolis High, and to the south, in Uruguay, by the Polônio High (Bueno et al. 2007).

The studied area whose sediments were deposited since the Upper Miocene over the continental slope, comprises a wide sedimentary wedge known as Rio Grande Cone (Martins et al. 1972; Bueno et al. 2007). This fanlike geoform occupies an area of 28,900 km^2 and reaches depths of around 4,000 m margins (Martins 1983; Castillo et al. 2009). The origin of the Rio Grande Cone is related to the accumulation of terrestrial material supplied by the drainages of the Plata River and the Rio Grande do Sul Plateau, associated with depositions of the delta sediments to the south and deposits of the Patos Lagoon System to the north (Martins 1983).



Text-figure 1 - Study area with location of the piston cores. **(A).** Location of Brazil; **(B).** Location drilling area.

The continuous and increasing supply of fine sediments and organic matter in the cone region, were essential for the formation of the biogenic natural gas hydrate originated in the gas province of the Rio Grande Cone (Martins 1983; Miller et al. 2015). Extensive fields of pockmark, submarine depressions associated to gas seepage, are found in the region, with several layers containing gas hydrates interspersed with thick mud sediments, some bioturbated. Indirect evidences of gas hydrates were also found, such as degassing features and authigenic carbonate nodules formed during the consumption of methane due to the microbial activity that increases the alkalinity of the carbonate, promoting the precipitation of crystals, nodules and cemented sediments (Boetius et al. 2000; Miller et al. 2015).

Several water masses compose the oceanographic setting of the Pelotas Basin. In environments where the bathymetry reaches about 600 m, the influence of Tropical Waters (TW) and Central Waters of the South Atlantic (SACW) is recorded. In greater depths circulate the Antarctic Intermediate Water - AAIW (600 – 1,000 m), the Circumpolar Water - CPW (1,000 – 2,000 m), the North Atlantic Deep Water - NADW (2,000 – 4,000 m) and Antarctic Bottom Water - AABW (> 4,000 m) (Stramma and England 1999).

MATERIAL AND METHODS

Sediment samples from five piston cores were prepared for ostracods and foraminiferal analyses (see Maia et al. 2021 - Table 1). The cores were collected during four oceanographic expeditions, realized between May 2011 and July 2013, by the CONEGAS Project, a partnership between the PUCRS (*Pontifícia Universidade Católica do Rio Grande do Sul*) and Petrobras. In general, the cores recovered in this study were composed of massive muddy sediments with some bioturbation. Cores PC-56, PC-67 and PC-76 sampled muddy sediments interspersed with gas hydrates. Indirect evidence of gas hydrates, such as degassing features, autogenic carbonate nodules, chemosynthetic organisms and soup-like sediments were also observed in these wells (Miller et al. 2015).

A total of 87 samples were prepared according to the following steps: 1) sample collection and weighing (17 to 66 g); 2) washing in running water in a set of 0.250 mm, 0.125 mm, 0.063 mm and 0.045 mm sieves; 3) oven drying at 60 °C; 4) removal and transfer of all specimens from fractions above 0.063 mm using the Zeiss Stemi-305 stereomicroscope for micropaleontological cells; 5) photograph in scanning electron microscope (PHENOM XL) of the best preserved specimens; 6) deposit of typographic and figurative material at the LMA (*Laboratório de Micropaleontologia Aplicada*) of UFPE (*Universidade Federal de Pernambuco*).

The suprageneric classification of ostracods and foraminifera follows the proposal by Liebau (2005) and Loeblich and Tappan (1988), respectively. The paleoecological interpretation of benthic foraminifers was based on Murray (1973, 1991), Boltovskoy and Wright (1976) and Van Morkhoven et al. (1986). The biostratigraphical analysis was based on the distribution of planktic foraminifera by biozonal scheme of Ericson and Wollin (1968), whose attributed the Upper Pleistocene and Holocene age to the deposits.

For this study, abbreviations were used to identify the specimens: **C,** carapace; **LV**, left valve; **RV,** right valve; **L**, length; **H**, height; **W**, width. For the classification of the ostracods abundance, the following parameters were adopted: **Rare** 1–4 specimens, **Abundant** 5–20 and **Very abundant** 20–60 specimens. For foraminifers, the criteria were: **Rare** 1–5%, **Abundant** > 5–10 %, **Dominant** > 10%.

RESULTS AND DISCUSSION

Ostracod and Foraminifera Assemblages

A total of 21 genera and 31 species of ostracods (plates 1 and 2) were recovered from the studied samples. The core PC-67 presented the most abundant and diverse ostracod assemblage (385 specimens of 22 species). The second most abundant (117 specimens) and diversified (13 species) ostracod assemblage was recovered from the core PC-56. From the core PC-76, 29 specimens and nine species were identified, and from core PC-39 only three specimens from three different species were identified. Only a juvenile specimen of the genus *Krithe* was recorded in core PC-34. The integrated distribution of species in each core is shown in text-figures 2, 3, 4 and 5.

The four most abundant genera were *Cativella* (169 specimens), *Apatihowella* (152 specimens), *Cytheropteron* (35 specimens) and *Cytherella* (27 specimens). In contrast, the genera with the lowest abundance were *Poseidonamicus, Henryhowella* and *Loxoconchidea* (1 specimen each). A total of 14,225 benthic foraminifera specimens were recovered from the samples. These were identified in 72 taxa (primarily genera), with dominance of *Bolivina, Bulimina, Uvigerina, Nonion Oridorsalis, Globobulimina Cassidulina* and *Globocassidulina* (plate 3). In all analyzed cores, the benthic foraminifera assemblage is diversified. In the core PC-67, bolivinids, nonionids, buliminids and uvigerinids are dominant (relative abundance > 10%), while cassidulinids (*Gobocassidulina* sp. and *Cassidulina* spp.), globobuliminids (*Globobulimina* sp.), alambaminids (*Osangularia* sp.) and the genera *Pullenia* sp. and *Sphaeroidina* sp. are abundant (relative abundance 5–10%). In the core PC-56, benthic assemblage is dominated by bolivininids, buliminids, uvigerinids and pullenids (*Pullenia* sp.) (relative abundance > 10%),

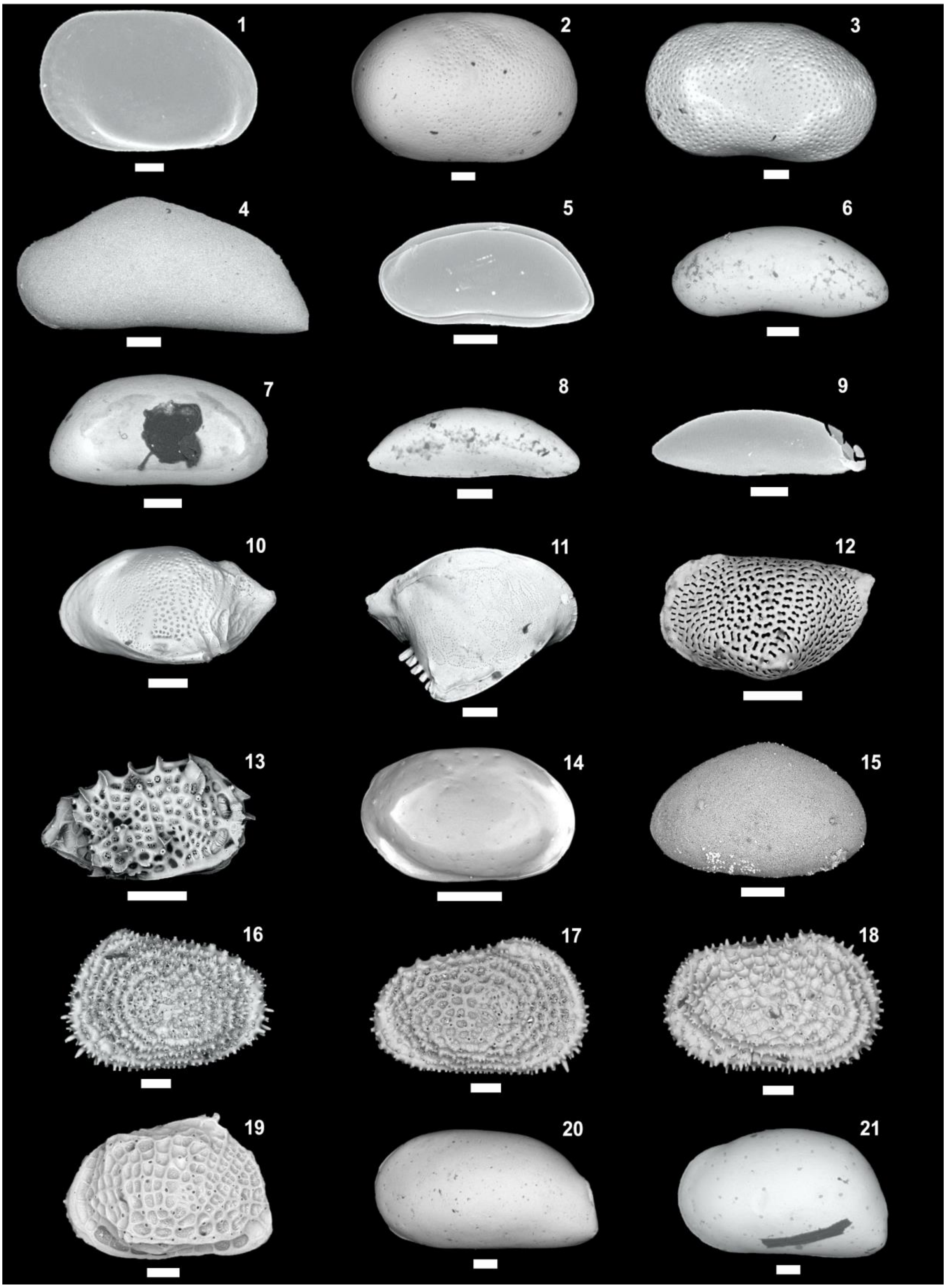


Plate 1. Bathyal ostracods. **1.** *Cytherella santosensis* Bergue, Coimbra and Cronin 2007; LV, lateral view; LMA-00080; **2.** *Cytherella* sp. 1; RV, lateral view, LMA-00081; **3.** *Cytherella* sp. 2; LV, lateral view, LMA-00082; **4.** *Macropyxis* sp. aff. *M. alanlordi* Brandão 2010; LV, lateral view, LMA-00083; **5.** *Argilloecia* sp. 1; C, left lateral view; LMA-00085; **6.** *Argilloecia* sp. 2; LV, lateral view; LMA-00086; **7.** *Argilloecia* sp. 3; RV, lateral view; LMA-00087; **8.** *Paracytherois* sp. 1; RV, lateral view; LMA-00088; **9.** *Paracytherois* sp. 2; RV, lateral view;

LMA-00089; **10.** *Cytheropteron* sp. 1; LV, lateral view; LMA-00090; **11.** *Cytheropteron* sp. 2; RV, lateral view; LMA-00091; **12.** *Rimacytheropteron longipunctatum* (Breman 1976); LV, lateral view; LMA-00092; **13.** *Eucytherura fossapunctata* Maia, Bergue and Piovesan 2021; RV, lateral view; LMA-00093; **14.** *Loxoconchidea minima* Bonaduce, Ciampo and Masoli 1976; C, right lateral view; LMA-00096; **15.** *Xestoleberis* sp. 1; LV, lateral view; LMA-00097; **16.** *Apatihowella convexa* Bergue, Coimbra and Ramos 2016; LV, lateral view; LMA-00098; **17.** *Apatihowella besnardi* Bergue Coimbra and Ramos 2016; RV, lateral view; LMA-00099; **18.** *Henryhowella asperrima* Reuss 1850; RV, lateral view; LMA-00100; **19.** *Poseidonamicus hisayoae* Yasuhara, Cronin, Hunt and Hodell 2009; RV, lateral view; LMA-00101; **20.** *Krithe hunti* Yasuhara, Stepanova, Okahashi, Cronin and Brouwers 2014; LV, lateral view; LMA-00103; **21.** *Krithe reversa* Bold 1958; LV, lateral view; LMA-00104. **Scale bar:** 100 µm.

while cassidulinids (*Gobocassidulina* sp.), globobuliminids (*Globobulimina* sp.), eggerelinids (*Martinottiella* sp.), alambaminids (*Oridorsalis* sp.) are abundant (relative abundance 5–10%). The cores PC-34 and PC-76 are characterized by the dominant presence of uvigerinids and buliminids (with peaks of abundance reaching up 40%), alambaminids (*Oridorsalis* sp.) and bolivininids, while nonionids, buliminids and cassidulinids.

Planktic foraminiferal assemblages (plate 3) are diverse, represented by 28 species distributed in 12 genera, with *Globorotalia menardii* (Parker, Jones and Brady 1865)*, Globorotalia tumida* (Brady 1877)*, Globorotalia inflata* (d'Orbigny 1839)*, Neogloboquadrina dutertrei* (d'Orbigny 1839), *Neogloboquadrina incompta* (Cifelli 1961), *Globigerinoides ruber inflata* (d'Orbigny 1839)*, Globigerinoides conglobatus* (Brady 1879), *Pulleniatina obliquiloculata* (Parker and Jones 1865), *Truncorotalia truncatulinoides* (d'Orbigny 1839) and *Globigerina bulloides* (d'Orbigny 1839) occurring abundantly over the studied intervals.

Biostratigraphical approach

Planktic foraminiferal analyses were undertaken to provide a calibration of the ostracods age distribution. Through biostratigraphic analysis it was possible the recognition of the Biozones Y and Z, following the zonal scheme of Ericson and

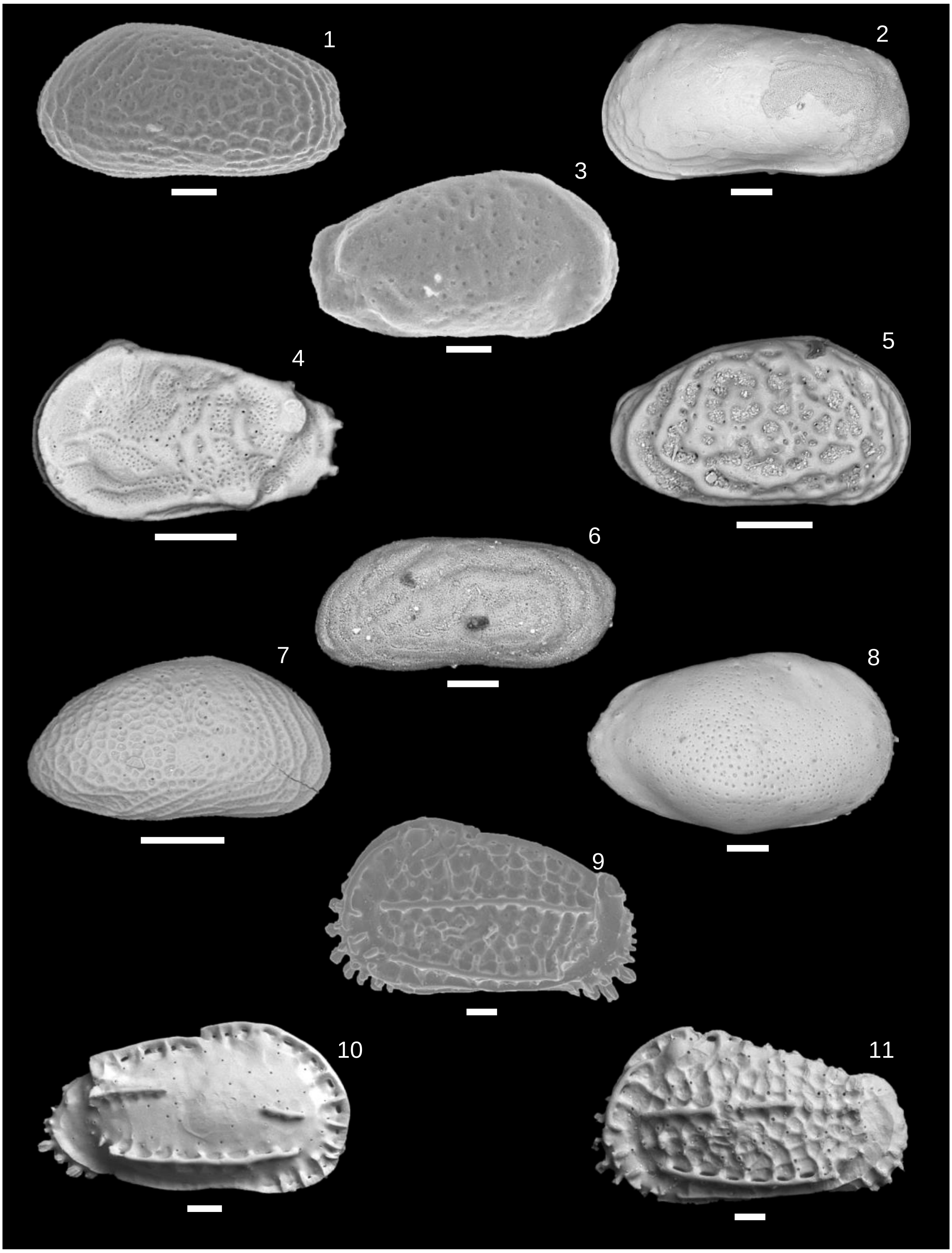


Plate 2 - Neritic ostracods. **1.** *Ameghinocythere reticulata* Whatley, Moguilevsky, Toy, Chadwick and Ramos 1997; LV, lateral view; LMA-00112; **2.** *Pectocythere magellanensis* Whatley, Staunton, Kaesler and Moguilevsky 1996; C, left lateral view; LMA-00105; **3.** *Munseyella* sp. 1; C, right lateral view; LMA-00113; **4.** *Munseyella* sp. 2; LV, lateral view; LMA-00114; **5.** *Callistocythere litoralensis* (Rossi De Garcia 1966); C, right lateral view; LMA-00115; **6.** *Papilosacythere* sp.; C, left lateral view; LMA-00116; **7.** *Loxocythere variasculpta* Whatley, Moguilevsky, Toy, Chadwick and Ramos 1997; RV, lateral view; LMA-00117; **8.** *Argenticytheretta laevipunctata* Sanguinetti, Ornellas and Coimbra 1991; RV, lateral view;

LMA-00118; **9.** *Cativella bensoni* Neale 1967; LV, lateral view; LMA-00119; **10.** *Cativella* sp.; RV, lateral view; LMA-00120; **11.** *Costa* sp.; LV, lateral view; LMA-00121. **Scale bar:** 100 µm.

Wollin (1968). The criteria used to identify the Biozones Y and Z were the disappearance and reappearance of the *Globorotalia menardii* plexus and variations in abundance of *Globorotalia inflata* and *Truncorotalia truncatulinoides*. In the portion of the cores where ostracods were recovered, the absence or rare presence of the *G. menardii* plexus and the abundance *Globorotalia inflata* and *T. truncatulinoides*, permitted to characterize the Biozone Y (upper Pleistocene).

The reappearance of the *G. menardii* plexus, including *Globorotalia fimbriata* (Brady 1884), indicated the limit between Biozones Y and Z in the cores PC-34, PC-56 and PC-67, marking the base of the Holocene. In the studied cores (PC-34, PC-56, PC-67, PC-76), only in the PC-76 the Holocene interval was not identified. For the core PC-39, foraminifera were not recovered, only typical bathyal ostracods *Poseidonamicus hisayoae* Yasuhara, Cronin, Hunt and Hodell 2009, *Apatihowella besnardi* Bergue, Coimbra and Ramos 2016 and *Apatihowella convexa* Bergue, Coimbra and Ramos 2016. The *Apatihowella* species were correlated with those identified in PC-67, calibrated with foraminifera zoning allows inferring an upper Pleistocene age for our material. Considering all identified species of ostracods, only *Eucytherura fossapunctata* Maia et al. 2021 is restricted to the Pleistocene, being here considered a marker species of this age.

Paleoenvironments and relation with natural gas hydrates

The occurrence of a rich and abundant microfossil association in the analyzed samples, with predominance of bathyal species of ostracods and foraminifera characterized a slope environment.

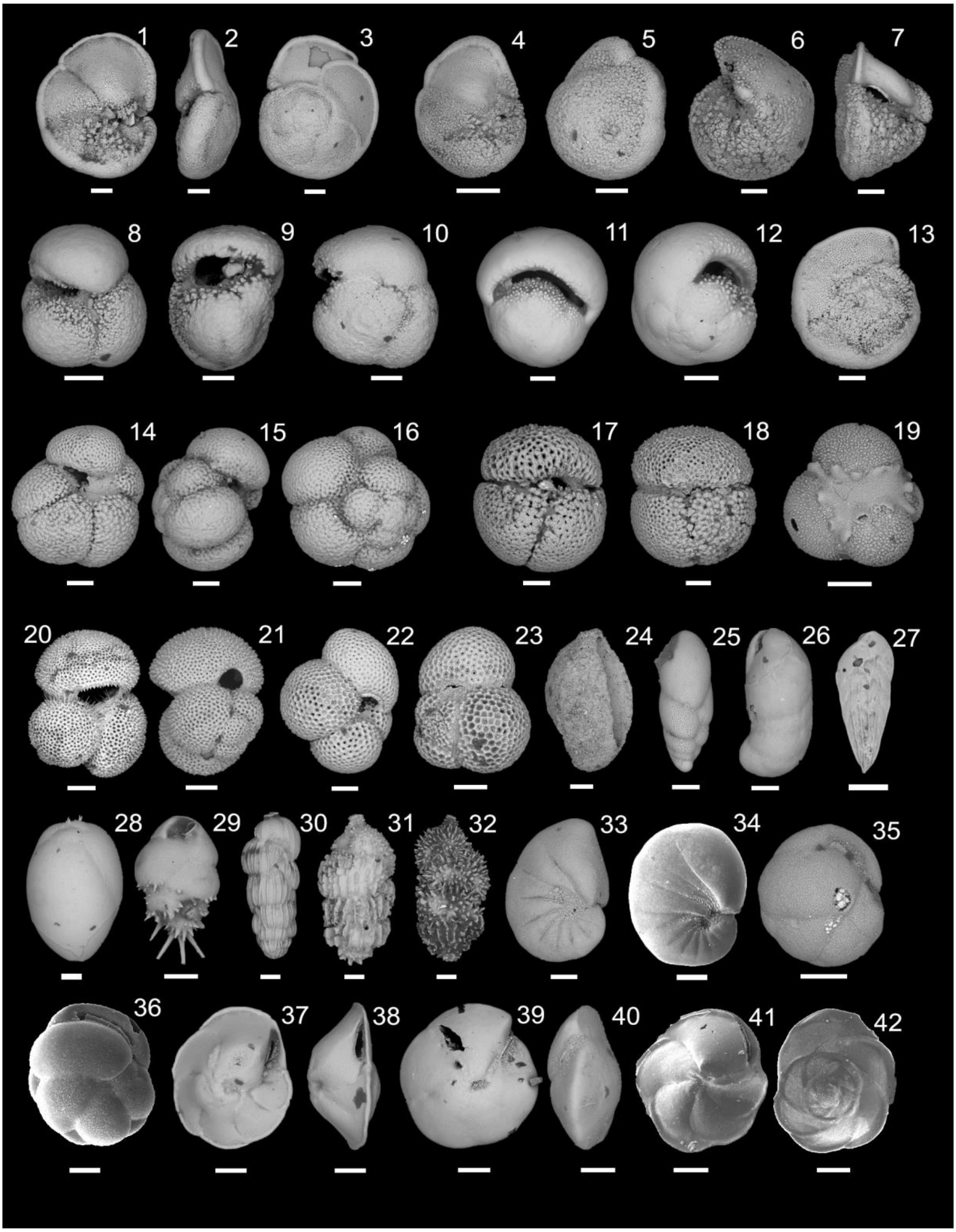


Plate 3. Foraminifera. **Planktic foraminifera: 1–3.** *Globorotalia menardii* (Parker, Jones and Brady 1865); LMA-00122 (PC-34, 04–06 cm); **4–5.** *Globorotalia tumida* (Brady 1877); LMA-00123 (PC-67, 14–16 cm); **6–7, 13**. *Truncorotalia truncatulinoides* (d'Orbigny 1839); LMA-00124 (PC-56, 04–06 cm); **8–10.** *Globorotalia inflata* (d'Orbigny 1839) LMA-00125 (PC-56, 04–06 cm); **11–12.** *Pulleniatina obliquiloculata* (Parker and Jones 1865); LMA-00126 (PC-56, 84–86 cm); **14–16.** *Neogloboquadrina dutertrei* (d'Orbigny 1839); LMA-00127 (PC-56, 44–46 cm); **17–18.** *Globigerinoides conglobatus* (Brady, 1879); LMA-00128 (PC-56, 04–06 cm); **19.** *Globigerinita glutinata* (Egger 1893); LMA-00129 (PC-56, 94–96 cm); **20–21.** *Globigerinoides ruber* (d'Orbigny 1839); LMA-00130 (PC-56, 04–06 cm); **22–23.** *Trilobatus saculifer* (Brady 1877); LMA-00131 (PC-56, 44–46 cm); **Benthic foraminifera: 24.** *Sigmoilopsis*

schlumbergeri (Silvestri 1904); LMA-00132 (PC-76, 160–162 cm); **25.** *Buliminella* sp.; LMA-00133 (PC-67, 94–96 cm); **26.** *Rutherfordoides* sp.; LMA-00134 (PC-67, 94–96 cm); **27.** *Bolivina* sp.; LMA-00135 (PC-67, 134–136 cm); **28**. *Globobulimina* sp.; LMA-00136 (PC-56, 94–96 cm); **29.** *Bulimina aculeata* d'Orbigny 1826; LMA-00137 (PC-56, 04–06 cm); **30–31.** *Uvigerina peregrina* Cushman 1923; LMA-00138 (PC-67, 134–136 cm); **32.** *Uvigerina hispida* Schwager 1866; LMA-00139 (PC-76, 160–162 cm); **33.** *Nonion* sp.; LMA-00140 (PC-67, 134–136 cm) **34.** *Nonionella atlantica* Cushman, 1947; **35.** *Globocassidulina* sp.; LMA-00141 (PC-67, 144–146 cm); **36.** *Cassidulina delicata* Cushman 1927; **37–38.** *Osangularia* sp.; LMA-00142 (PC-67, 134–136 cm); **39–40.** *Oridorsalis umbonatus* (Reuss 1851) LMA-00143 (PC-76, 24–26 cm); **41–42.** *Epistominella smithi* (Stewart and Stewart 1930). **Scale bar:** 100 µm.

Based on the ecological preferences and morphological characteristics of the ostracods, components of the bathyal fauna (plate 1) and the neritic fauna (plate 2) were recognized. The first one is represented by the genera *Krithe, Henryhowella, Macropyxis*, *Poseidonamicus*, *Cytherella, Paracytherois, Loxoconchidea, Eucytherura, Argilloecia, Apatihowella, Xestoleberis*, *Cytheropteron* and *Rimacytheropteron*. The high-energy neritic ostracods include the genera *Ameginocythere, Pectocythere, Munseyella, Callistocythere, Papilosacythere, Loxocythere*, *Argenticytheretta, Cativella* and *Costa*. The identification of neritic assemblages is necessary to identify and discriminate allochthonous elements in bathyal assemblages (Bergue et al. 2016).

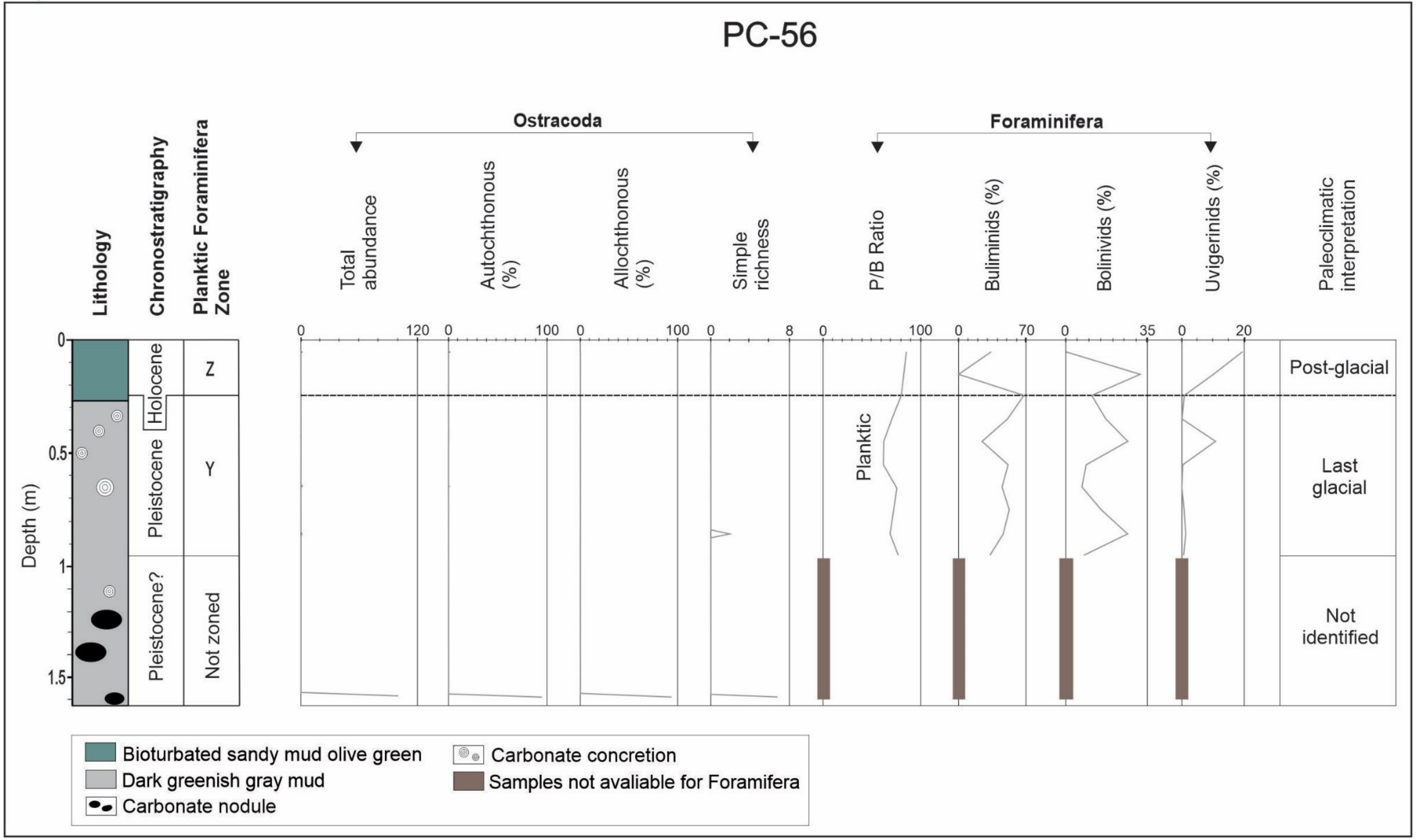
In general terms, the bathyal foraminiferal assemblages include the genera *Uvigerina* (*Uvigerina peregrina* and *U. hispida), Sigmoilopsis, Bolivina, Bulimina* (*Bulimina aculeata* d'Orbigny 1826), *Pullenia, Oridorsalis umbonatu* (Reuss 1851), and *Osangularia* (Murray 1991, 2006; Van Morkhoven et al. 1986; Smith 1964; Boltovskoy and Wrigth 1976; Mackensen et al. 1985). In addition, in the cores PC-34, PC-56, PC-67 and PC-76, the high the P/B ratio demonstrate bathyal environments for the studied interval (Gibson 1989; Van der Zwaan et al. 1990). The low abundance of planktic foraminifera in core PC-34 (text-fig. 3) was attributed to dissolution, due to local water acidification associated to gas hydrate dissociation, leading to methane release.

The environment of the Rio Grande Cone presents a gas hydrate province from biogenic origin (Miller et al. 2015). The presence of a very diversified chemosynthetic community, supported by methane gas and by-products of its decomposition, such as H_2S, in an area adjacent to the location of the studied wells (Giongo et al. 2016), indicate that the assemblage of ostracods and benthic foraminifera studied here could be part of a chemosynthetic community in the past. Highly negative values of $\delta^{13}C$ obtained from foraminifera recovered in ancient pockmarks situated 200 km north of the Rio Grande Cone indicate methane release to the water column during the last glacial period (Portilho-Ramos et al. 2018). Additionally, Ketzer et al. (2019) points the presence of centimetric carbonate concretions as an evidence that methane release has been active during thousand years.

From the analyzes performed on samples of cores PC-56, PC-67 and PC-76, we identified an assemblage associated with gas hydrates (text-figures 2, 4 and 5) represented by ostracods of the genera *Paracytherois, Macropyxis, Cytheropteron, Cytherella, Krithe, Henryhowella, Eucytherura, Rimacytheropteron* and *Apatihowella*, and by foraminifera of the genera *Bolivina, Bulimina, Uvigerina, Nonionellina, Oridorsalis, Cassidulina* and *Epistominella.* The cosmopolitan foraminifera genera *Uvigerina, Bolivina, Chilostomella, Globobulimina*, *Rutherfordoides* and *Nonionella* are abundant in organic-rich sediments, reducing environments, make way that seem to be preadapted to methane seeps (Akimoto et al. 1994; Rathburn et al. 2000). Representative locations of cold seeps, globally distributed present a differentiate assemblage composition with bolivinids, buliminids, nonionellids and uvigerinids as dominant (Sen Gupta et al. 1997; Rathburn et al. 2000; Heinz et al. 2005). The similarity of these assemblages with those found in the studied cores corroborates the assumption of a microfauna highly conditioned by gas seeps.

In general, the analysis of the assemblage of the wells showed that *Apatihowella* occurred with greater frequency associated with the genera *Cytherella* and *Cytheropteron*. In these occurrences, there was a similarity regarding the association with benthic foraminifera *Bolivina, Uvigerina, Bulimina* and *Nonionellina.* The genera *Paracytherois, Eucytherura, Rimacytheropteron* and *Krithe* were commonly associated with the foraminifera *Epistominella* and *Bulimina*. *Cytherella* and *Krithe* showed similarity in the association with foraminifera *Oridorsalis. Apatihowella* was the only genus associated with the foraminifera *Nonionella. Henryhowella asperrima* Reuss 1850 was associated only with the foraminifera *Bolivina. Cytheropteron, Cytherella* and *Apatihowella*, in the core PC-67, were mostly associated with the foraminifera bolinivids. In the core PC-76, it was verified that the genera *Cytherella, Cytheropteron, Krithe* and *Apatihowella* were associated with the foraminifera *Bulimina* and *Bolivina.* At the core PC-56, *Krithe* and *Apatihowella* had in common the association with the genera *Bulimina, Uvigerina, Oridorsalis* and *Buliminella.*

Peak abundances of neritic ostracods occurred in three wells (PC-56, PC-67 and PC-76). The analysis of wells PC-56 and PC-67 revealed similarities regarding the occurrence of the genus *Cativella* and the species *Ameghinocythere reticulata* Whatley et al. 1997. The most abundant neritic genera were *Cativella,* in wells PC-56 and PC-67, and *Callistocythere*, in well PC-76, which in turn occurs associated with foraminifera of the genus *Uvigerina, Bolivina* and *Bulimina*. *Cativella* was

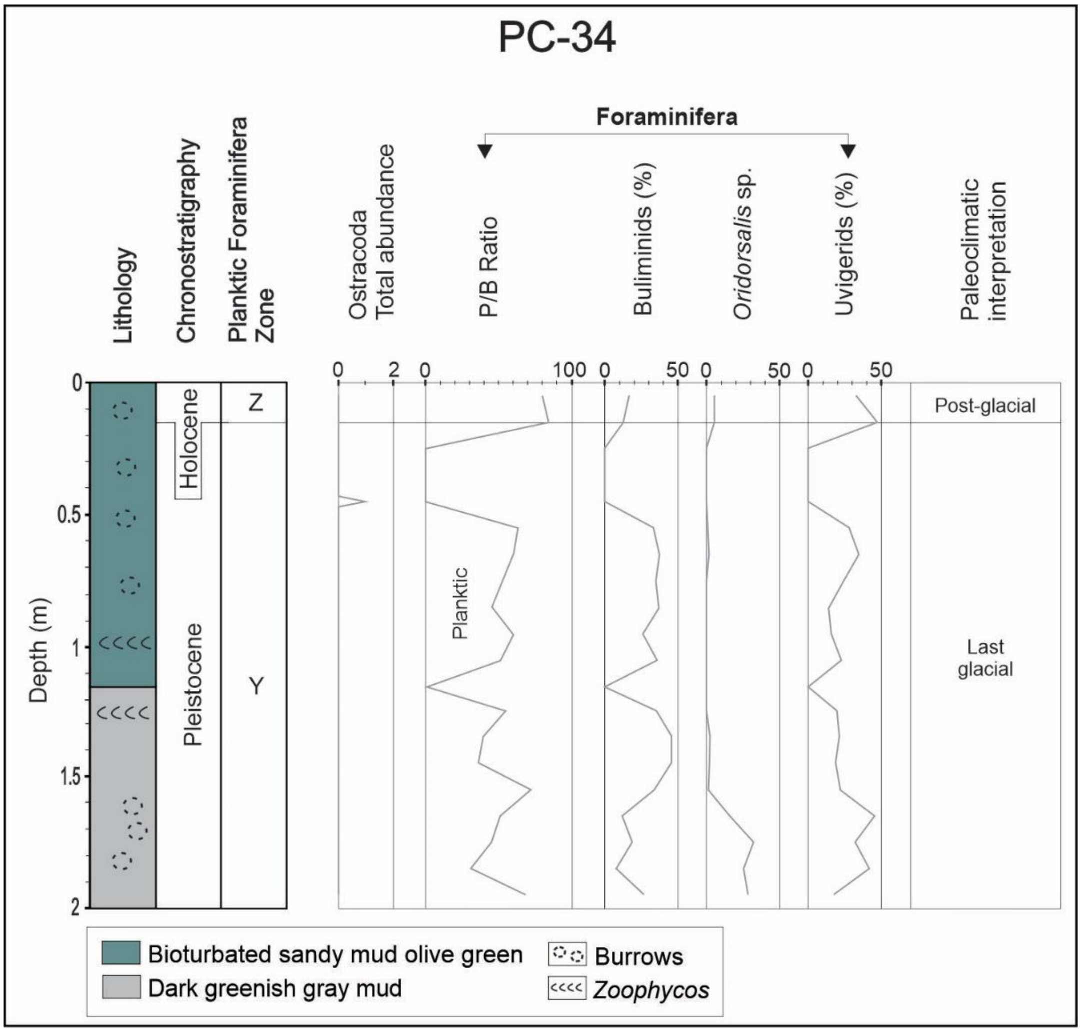


Text-figure 2. Distribution of ostracods and foraminifera in the core PC-56 and their lithological, biostratigraphic and paleoclimatological aspects.

associated with bathyal ostracods of the genera *Cytherella, Cytheropteron, Argilloecia, Apatihowella* and *Krithe*. In the well PC-67 (sample 144–146 cm), the occurrence of the allochthonous neritic ostracod *Pectocythere magellanensis* Whatley et al. 1996, described in shallow waters (34.34 to 270 m) at Cape Valentin, Bahia Borja and Punta Arenas (Whatley et al. 1996), corresponds to the first record of the genus and species for the sedimentary basins of Brazil.

The sedimentation in the slope and continental elevation in the Pelotas Basin occurs through gravitational flows and the diffusion of fine suspended material. In addition to these events, parallel to the bathymetric curves, the contouring geostrophic currents act, responsible for deposition of bottom sediments (Martins 1984). These events could be responsible by the co-occurrence of the allochthonous neritic ostracods transported by gravitational flow to bathyal environments.

The analysis of the assemblage of ostracods (*Cytherella, Cytheropteron, Apatihowella Paracytherois* and *Henryhowella)* associated with foraminifera (*Bolivina* spp.) allowed us to infer that they tolerate low amount of oxygen in the water, the presence of H_2S in sediments and a high bacterial productivity in the environment. These data are also observed by Pujos-Lamy (1973) who demonstrated that *Bolivina* could be adapted to conditions of low oxygen dissolved in water and to the presence of H_2S in the sediment of an underwater canyon, in the Bay of Biscay. In the Gulf of Mexico, the high bacterial productivity in hydrocarbon seeps could be a major factor in sustaining the foraminiferal populations, which mainly includes bolivinids, especially *Bolivina,* considered as possibly facultative anaerobes (Lobegeier and Sen Gupta 2008).

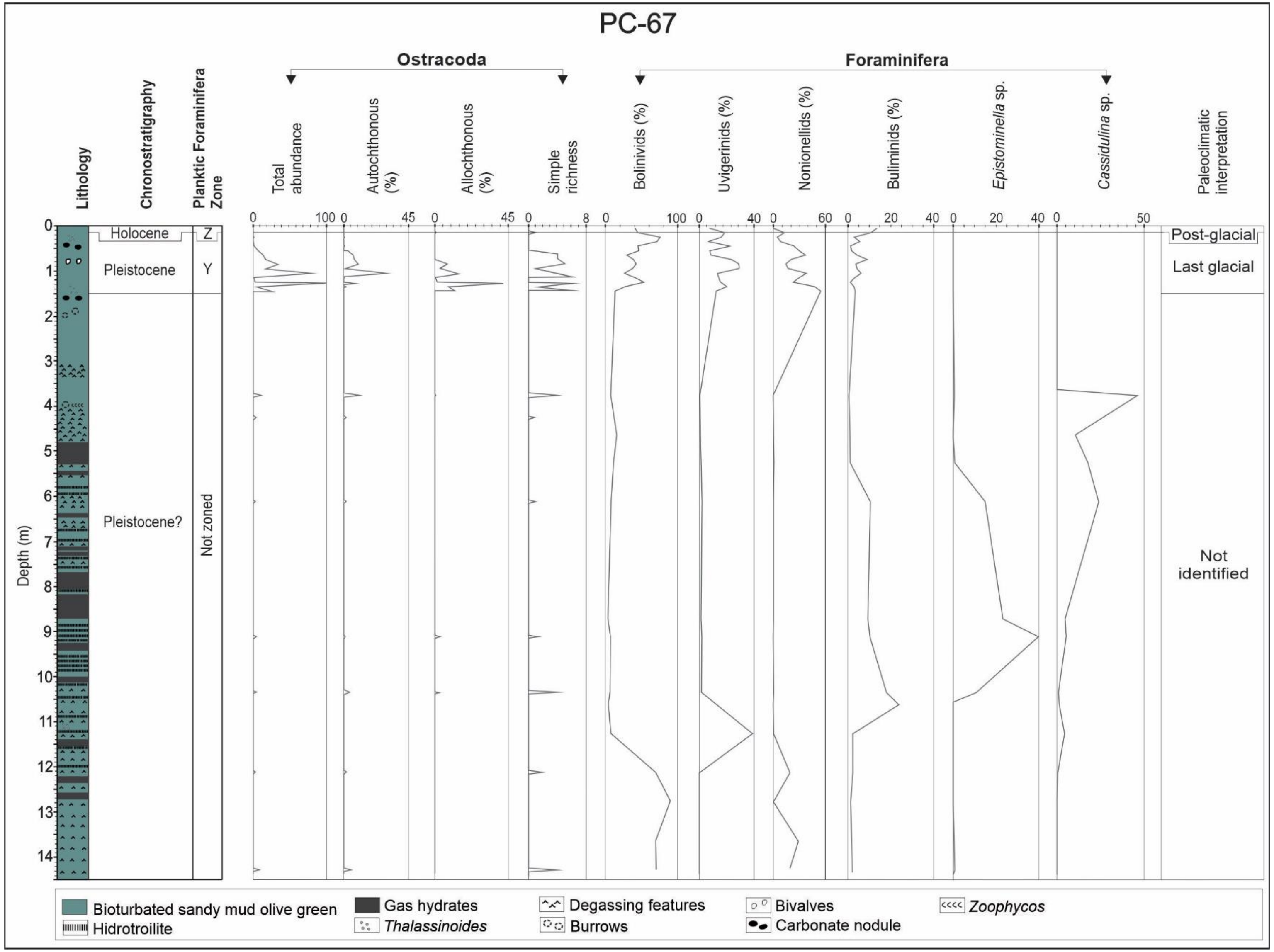


Text-figure 3. Distribution of ostracods and foraminifera in the core PC-34 and their lithological, biostratrigraphic and paleoclimatological aspects.

The relationship between ostracods (*Macropyxis, Cytheropteron, Krithe* and *Apatihowella)* and foraminifera (*Bulimina* spp. and *Uvigerina* spp.) suggests that both are adapted to deep waters and tolerated environments with rich in organic matter and the presence of bacteria. These data can be corroborated by studies that demonstrated that *Bulimina* colonizes deep environments in anoxic sediments, feeding on bacteria and *Uvigerina* presents greater abundance where there is a rich supply of labile organic matter and a high concentration of bacteria (Altenbach and Sarnthein 1989; Altenbach et al. 1999; Fontanier et al. 2002; Torres et al. 2003; Panieri 2005). In addition, Bernhard et al. (2001) demonstrated when analyzing samples collected from cold infiltrations in Monterey Bay, California that *Uvigerina peregrina* harbored prokaryotes in its pores. The authors also suggested that the relationship with these bacteria would be related to the survival of foraminifera in infiltration environments.

In the cores PC-67 and PC-76, data analysis of benthic foraminifera showed a reduction in the abundance of the genus *Bulimina*. This event may be associated with the proximity of degassing features, suggests that this species cannot tolerate low-oxygen stressful environment. Research developed by Jones (1993) and Coles et al. (1996) in the North Sea and Porcupine Basin (Offshore Western Ireland) corroborate this data, by showing a positive correlation with seepage and an association formed by *Uvigerina peregrina*, buliminids (*Cassidulina*) and rotaliids (*Hyalinea* and *Elphidium*) leading to a greater abundance of these taxa. In contrast, a negative correlation was observed between gas escape and the abundance of *Bulimina marginata* d'Orbigny 1826 and *Trifarina angulosa* (Williamson 1858), which suffered a great reduction. In this study, the occurrence of the ostracods (*Apatihowella*, *Cytherella* and *Macropyxis*) associate with infaunal foraminifera (*Cassidulina* spp.), in a deep and cold environment, indicates that its presence may also be related to pulses of organic matter in the area (Thomas Gooday 1996; Murray 2006).

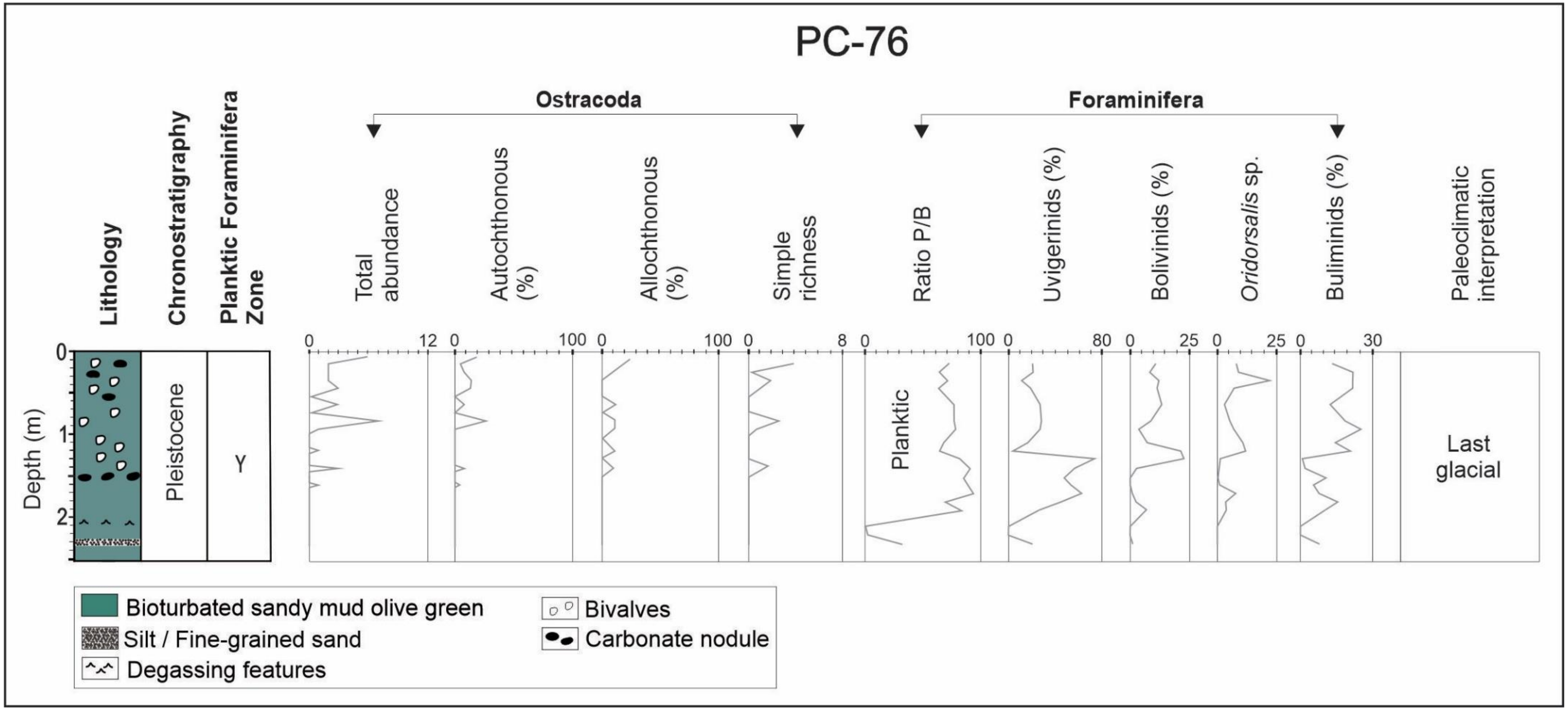
In the core PC-67, although it is dominated by infaunal species (especially uvigerinids and buliminds), which may indicate a constant organic matter entry, the restricted association between *Eucytherura fossapunctata* and *Rimacytheropteron longipunctatum* (Breman 1976) with opportunistic species of the genus *Epistominella* suggests that ostracods can also occur in environments with



Text-figure 4. Distribution of ostracods and foraminifera in the core PC-67 and their lithological, biostratrigraphic and paleoclimatological aspects.

seasonal phytodetritus inputs. The abundance of *Epistominella* spp. in the core PC-67 (samples 872.5 cm, 912.5 cm and 1032.5 cm) may be associated with intervals with seasonal phytoplankton productivity and phytodetritus deposition (Thomas et al. 1995; de Almeida et al. 2015; Rodrigues et al. 2018). Furthermore, a negative correlation between the relative abundances of *Epistominella* spp. (epifauna) and *Uvigerina* spp. (infaunal), evidence of a period characterized by variations in the intensity of entry of organic matter into the environment (Gooday 1993; Thomas and Gooday 1996; Rodrigues et al. 2018).

The occurrence of *E. fossapunctata* in samples containing gas hydrates, added to the morphological characteristics of the valves surface, corroborates the idea that this species belonged to a chemosynthetic community in the Rio Grande Cone. Maia et al. (2021) identified the species *E. fossapunctata* ornamented with groups of wells, secondary cross-linking and pore clusters. Similar results can be observed in the research by Van Harten (1993) who verified in an environment of hydrothermal vents that the genus *Xylocythere* had clusters of pores covered by colonies of exosymbiont bacteria and suggested that the clusters of pores functioned as facilitators for the absorption of nutrients. In addition, Yasuhara et al. (2018) studied ostracods cold methane seep site from an active pockmark, at the western Svalbard margin, Fram Strait, and suggested that the primary crosslinking and pore clusters observed in *Rosaliella svalbardensis* Yasuhara et al. 2018 and the secondary crosslinking and pores present in *Cytheropteron carolinae* Whatley and Coles 1987 may be



Text-figure 5. Distribution of ostracods and foraminifera in the core PC-76 and their lithological, biostratrigraphic and paleoclimatological aspects.

strongly associated with ectosymbiosis with chemoautotrophic bacteria. Based on this relationship between the morphological characteristic and symbiosis with chemoautotrophic bacteria, the species *R. svalbardensis* was considered an indicator of paleo-methane. The results of these works suggest that *E. fossapunctata, Xylocythere, R. svalbardensis* and *C. carolinae* present morphological similarities that can represent a convergence and evolutionary adaptation to chemosynthetic environments.

It was possible to observe a similarity between the ostracod and foraminifera assemblage in the present work with the assemblage associated with gas hydrates recovered by Coles et al. (1996) in Porcupine Basin, Ireland. The similarities between the Porcupine and Pelotas basins assemblages are also clear regarding to the ostracod fauna, with the presence of the following genera: *Paracytherois, Cytheropteron, Cytherella, Krithe* and *Henryhowella*. This result demonstrates that these ostracod genera are adapted to several marine environments, including deep environments and associated with gas hydrates.

CONCLUSIONS

The present work identified a bathyal assemblage of ostracods associated with allochthonous neritic species. Among the autochthonous taxa identified, *Paracytherois, Cytheropteron, Cytherella, Macropyxis, Krithe hunti, Krithe reversa, Henryhowella asperrima, Eucytherura fossapunctata, Rimacytheropteron longipunctatum, Apatihowella bernardi* and *Apatihowella convexa* are related to environments of gas hydrates and associated with a chemosynthetic community in bathyal eutrophic-mesotrophic environment in a dysoxic-anoxic condition. The foraminifera of the genus *Bolivina, Bulimina, Nonion, Nonionellina, Oridorsalis,* *Uvigerina*, *Epistominella* and *Cassidulina* were also related to environments with gas hydrates.

Although a positive relationship was verified between *Eucytherura fossapunctata* and *Rimacytheropteron longipunctatum* with the ranges of high phytoplankton productivity and seasonal deposition of phytodetritus, new studies could be developed to better understand this relationship.

This study also revealed that the fauna of bathyal ostracods showed greater abundance and richness in samples recovered from wells with direct and indirect evidence of gas hydrates.

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SYSTEMATIC PALAEONTOLOGY – Bathyal ostracods

Subclass OSTRACODA Latreille 1802
Superorder PODOCOPOMORPHA Kozur 1972
Order PLATYCOPIDA Sars 1866
Superfamily CYTHERELLOIDEA Sars 1866
Family CYTHERELLIDAE Sars 1866
Genus *Cytherella* Jones 1894
Cytherella santosensis Bergue, Coimbra and Cronin 2007
Cytherella sp. 1
Cytherella sp. 2

Order PODOCOPIDA Sars 1866

Suborder CYPRIDOCOPINA Jones 1901

Superfamily MACROCYPRIDOIDEA Müller 1912

Family MACROCYPRIDIDAE Müller 1912

Genus *Macropyxis* Maddocks 1990

Macropyxis sp. aff. *M. alanlordi* Brandão 2010

Superfamily PONTOCYPRIDOIDEA Müller 1894

Family PONTOCYPRIDIDAE Müller 1894

Genus *Argilloecia* Sars 1866

Argilloecia sp. 1

Argilloecia sp. 2

Argilloecia sp. 3

Suborder CYTHEROCOPINA Gründel 1967

Superfamily PARADOXOSTOMATOIDEA Brady and Norman 1889

Family PARADOXOSTOMATIDAE Brady and Norman 1889

Genus *Paracytherois* Müller 1894

Paracytherois sp. 1

Paracytherois sp. 2

Suborder CYTHEROCOPINA Gründel 1967

Infraorder NOMOCYTHERININA Liebau 1991

Superfamily CYTHEROIDEA Baird 1850

Family CYTHERURIDAE Müller 1894

Genus *Cytheropteron* Sars 1866

Cytheropteron sp. 1

Cytheropteron sp. 2

Genus *Rimacytheropteron* Whatley and Coles 1987

Rimacytheropteron longipunctatum (Breman 1976)

Genus *Eucytherura* Müller 1894

Eucytherura fossapunctata Maia, Bergue and Piovesan 2021

Family LOXOCONCHIDAE Sars 1925

Genus *Loxoconchidea* Bonaduce, Ciampo and Masoli 1976

Loxoconchidea minima Bonaduce, Ciampo and Masoli 1976

Family XESTOLEBERIDIDAE Sars 1928

Genus *Xestoleberis* Sars 1866

Xestoleberis sp.

Superfamily TRACHYLEBERIDOIDEA Sylvester-Bradley 1948

Family TRACHYLEBERIDIDAE Sylvester-Bradley 1948

Genus *Apatihowella* Jellinek and Swanson 2003

Apatihowella convexa Bergue, Coimbra and Ramos 2016

Apatihowella besnardi Bergue, Coimbra and Ramos 2016

Genus *Henryhowella* Puri 1957

Henryhowella asperrima Reuss 1850

Family HEMICYTHERIDAE Puri 1953

Subfamily THAEROCYTHERINAE Hazel 1967

Genus *Poseidonamicus* Benson 1972

Poseidonamicus hisayoae Yasuhara, Cronin, Hunt and Hodell 2009

Superfamily CYTHERIDEOIDEA Liebau 2005

Family KRITHIDAE Mandelstam 1958

Genus *Krithe* Brady, Crosskey and Robertson 1874

Krithe hunti Yasuhara, Stepanova, Okahashi, Cronin and Brouwers 2014

Krithe reversa Bold 1958

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Subclass OSTRACODA Latreille 1972

Order PODOCOPIDA Sars 1866

Suborder CYTHEROCOPINA Gründel 1967

Infraorder NOMOCYTHERININA Liebau 1991

Superfamily CITHEROIDEA Baird 1850

Family PECTOCYTHERIDAE Hanai 1957

Genus *Ameginocythere* Whatley, Moguilevsky, Toy, Chadwick and Ramos 1997

Ameghinocythere reticulata Whatley, Moguilevsky, Toy, Chadwick and Ramos 1997

Genus *Pectocythere* Hanai 1957

Pectocythere magellanensis Whatley, Staunton, Kaesler and Moguilevsky 1996

Genus *Munseyella* Bold 1957

Munseyella sp. 1

Munseyella sp. 2

Family LEPTOCYTHERIDAE Hanai 1957

Genus *Callistocythere* Ruggieri 1953

Callistocythere litoralensis (Rossi De Garcia 1966)

Family NEOCYTHERIDEIDIDAE Puri 1957

Genus *Papilosacythere* Whatley, Chadwick, Coxill and Toy 1987

Papilosacythere sp.

Family CYTHERIDAE Baird 1850

Genus *Loxocythere* Hornibrook 1952

Loxocythere variasculpta Whatley, Moguilevsky, Toy, Chadwick and Ramos 1997

Superfamily TRACHYLEBERIDOIDEA Sylvester-Bradley 1948

Family TRACHYLEBERIDIDAE Sylvester-Bradley 1948

Genus *Argenticytheretta* Rossi De Garcia 1969

Argenticytheretta laevipunctata Sanguinetti, Ornellas and Coimbra 1991

Genus *Cativella* Coryell and Fields 1937

Cativella bensoni Neale 1967

Cativella sp.

Genus *Costa* Xu and Ling 2012

Costa sp.

5 CONCLUSÕES

1) Os ostracodes batiais apresentaram maior abundância e diversidade de gêneros e espécies, quando comparados aos ostracodes neríticos alóctones.

2) A identificação da nova espécie *Eucytherura fossapunctata*, apontada como marcadora do Pleistoceno, demonstra a importância de estudos taxonômicos e bioestratigráficos nas regiões batiais do Atlântico Sul, as quais ainda são pouco exploradas no que diz respeito à pesquisa de ostracodes em ambientes marinhos profundos.

3) A distribuição paleozoogeográfica das espécies batiais *Krithe hunti* e *Poseidonamicus hisayoae,* bem como da espécie nerítica alóctone *Pectocythere magellanensi,* foi ampliada para a margem sul do Brasil.

4) A assembleia de ostracodes e foraminíferos relacionada a escape de gás teve seu primeiro registro de ocorrência para as Bacias do Brasil, em amostras provenientes da região do Cone do Rio Grande e demonstrou ser similar às assembleias associadas a escape de gás registradas em outras localidades do mundo.

5) As características morfológicas externas (aglomerados de poros, reticulação secundária e aglomerados de fossas) não são exclusivas de espécies de ambientes com infiltração de metano que realizam ectossimbiose com bactérias quimioautotróficas.

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APÊNDICE A - BATHYAL OSTRACODS FROM THE UPPER PLEISTOCENE OF THE RIO GRANDE CONE, PELOTAS BASIN, BRAZIL

Autores: Renata Juliana Arruda Maia, Enelise Katia Piovesan, Cristianini Trescastro Bergue, Geise de Santana dos Anjos Zerfass e Robbyson Mendes Melo.

Este artigo apresenta a taxonomia de 21 espécies pertencentes a 13 gêneros de ostracodes batiais do Pleistoceno Superior do Cone do Rio Grande, Bacia de Pelotas, Brasil. *Eucytherura fossapunctata* nov. sp. foi descrita como uma nova espécie. *Apatihowella, Cytheropteron* e *Cytherella* foram os gêneros dominantes. *Krithe hunti* e *Poseidonamicus hisayoae* tiveram suas ocorrências geográficas estendidas para a margem sul do Brasil. A assembleia recuperada apresentou similaridade faunística às registradas nas regiões batiais do sudoeste brasileiro, que incluem as Bacias de Santos e de Campos. A idade das amostras foi estabelecida a partir da análise bioestratigráfica dos foraminíferos planctônicos.

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OSTRACODES BATHYAUX DU PLÉISTOCÈNE SUPÉRIEUR DU CÔNE DE RIO GRANDE, BASSIN DE PELOTAS, BRÉSIL

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Cenozoic
marginal basin.

ABSTRACT

Quaternary deep-sea ostracods supply invaluable data for the understanding of both hydrological and sedimentary processes in the continental slope. A huge portion of western South Atlantic bathyal regions is still poorly explored with respect to deep-sea ostracod research. This article contributes to the study of the assemblage ostracod of the Upper Pleistocene of five piston cores recovered in the Cone of Rio Grande, Pelotas Basin, Brazil. Taxonomic analysis revealed 21 species belonging to 13 genera: *Cytherella, Macropyxis, Argilloecia, Paracytherois, Cytheropteron, Rimacytheropteron, Eucytherura, Loxoconchidea, Xestoleberis, Apatihowella, Henryhowella, Poseidonamicus* and *Krithe*. The assemblages are quite similar to those registered in southwestern Brazilian bathyal regions. A taxon left in open nomenclature is probably a new genus and species. *Eucytherura fossapunctata* nov. sp. is here described.

RESUME

Mots clés:
taxinomie
ostracodes bathyaux
Cénozoïque
bassin de marge.

Les ostracodes des fonds marins quaternaires fournissent des données précieuses pour comprendre les processus hydrologiques et sédimentaires le long des marges continentales. Une grande partie des régions côtières de l'Atlantique Sud-Ouest est encore mal explorée en ce qui concerne les ostracodes d'eau profonde. Cet article contribue à ces racherches par l'étude des assemblages du Pléistocène supérieur de cinq carottes récupérées dans le Rio Grande Cone, Bassin de Pelotas, Brésil. L'analyse taxonomique a révélé 21 espèces, appartenant à 13 genres: *Cytherella, Macropyxis, Argilloecia, Paracytherois, Cytheropteron, Rimacytheropteron, Eucytherura, Loxoconchidea, Xestoleberis, Apatihowella, Henryhowella, Poseidonamicus* et *Krithe*. Les assemblages sont assez similaires à ceux des régions bathyales du sud-ouest du Brésil. Un taxon conservé en nomenclature ouverte est probablement un nouveau genre et une nouvelle espèce. *Eucytherura fossapunctata* nov. sp. est décrit ici.

1. Introduction

Research on ostracods in the Pelotas Basin, both in taxonomic and biostratigraphical aspects, began with the study of Miocene assemblages (Sanguinetti, 1979, 1980) followed by post-Miocene ones (Sanguinetti et al., 1991, 1992). Later, Carreño et al. (1997, 1999), presented an ostracod-based paleoceanographic analysis of the Neogene of this basin assessing the influence of sea level changes on assemblages composition and their biostratigraphic significance. Do Carmo and Sanguinetti (1999) analyzed the pattern of distribution of *Krithe* Brady, Crosskey and Robertson, 1874 and its implication to the paleocirculation in the Southwestern Atlantic. Regarding the Cretaceous–Early Paleogene

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assemblages Ceolin et al. (2011) carried out analyses in five cores characterizing neritic environments. More recently, Manica et al. (2015) and Manica and Coimbra (2016) studied taxonomic and zoogeographic aspects of Lower Miocene assemblages of the well 2-RSS-1.

Although fossil and recent shallow-marine ostracods in the Pelotas Basin area are fairly well known (see, for instance, Sanguinetti et al., 1991, 1993; Ramos et al., 2009; Ramos et al., 2012; Ramos et al., 2014) researches on deep-sea assemblages are still scarce. Therefore, the main objective of this article is the taxonomic study of autochthonous bathyal ostracod assemblages from five piston cores obtained between 570 and 1,320 m water depth in the Rio Grande Cone, in the southernmost basin of the Brazilian Margin.

2. Study Area

The Pelotas Basin is located in the southernmost part of Brazilian margin (Figure 1). This basin records, along its sedimentary evolution initiated in the Aptian, successive transgressive deposits which are overlaid by Holocene regressive strata (Bueno et al., 2007). The basin covers approximately 210,000 km^2, and is limited in the north by the Florianópolis High (in Santa Catarina State), and in the south by the Polônio High, in Uruguay (Bueno et al., 2007).

The piston cores herein studied were recovered from a progradational mud stack in the Neogene section of the Pelotas Basin, represented mainly by pelitic terrigenous sediments deposited at high sedimentation rates (Martins, 1984; Fontana, 1990). Discharge from La Plata River and Rio Grande do Sul Highlands drainages gave rise to a progradational fan-like feature named Rio Grande Cone (Martins et al., 1972; Martins, 1984; Bueno et al., 2007), which is associated with delta deposits in the south and deposits of the Patos Lagoon system in the north, whose deposition began during the Miocene (Martins, 1983).

High sedimentation rates and slope physiography favored preservation of organic matter in the Rio Grande Cone as well as formation of a complex slip structure shaped by downslope movements of the sediments in gravitational flows (Castillo et al., 2009; Fontana, 1990; Martins, 1984).

In the Rio Grande Cone a huge province of gas hydrate occurs trapped in the fine sediments as layers, nodules, disseminated grains and pipes (Miller et al., 2015). The hydrate-forming gas has organic origin, composed mainly by methane (Miller et al., 2015). The Rio Grande Cone Gas Hydrate Province is characterized by variable methane flux from local diffusion to areas of high flux, associated to gas chimneys and pockmarks in the proximal area (extensional domain) of the Cone (Rodrigues et al., 2017; Miller et al., 2015). The presence of a deep-sea chemosynthetic community associated to a pockmark in the Rio Grande Cone (Giongo et al., 2016) reinforce the role of gas seeps in the marine ecosystems of the region.

Biostratigraphic studies based on microfossils from the offshore deposits of Neogene age of the Pelotas Basin were developed by Koutsoukos (1982), Gomide (1989) and Anjos and Carreño (2004). For the Quaternary, biostratigraphic zoning based on foraminifers shows climatic oscillations of glacial and interglacial intervals (Carvalho, 1980; Rodrigues and Carvalho, 1980; Vicalvi, 1997, 2011a,b,c,d; Petró et al., 2018).

3. Material and Methods

The piston cores (see Table 1) herein studied were collected by the Conegas Project, a partnership between the *Pontifícia Universidade Católica do Rio Grande do Sul* (PUCRS) and Petrobras, in four oceanographic expeditions carried out between May 2011 and July 2013. Five piston-cores from different isobaths were used for ostracod analysis.

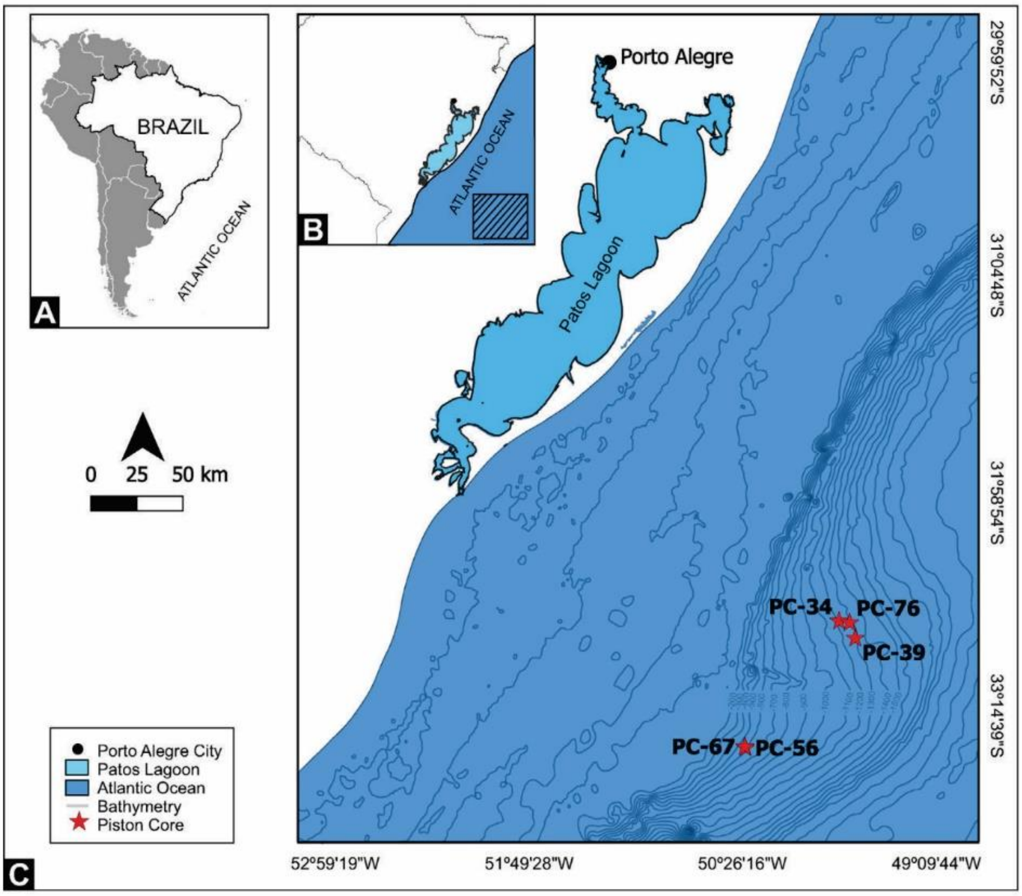

Figure 1. Study area with location of the piston cores studied. **(A).** Location of Brazil; **(B).** Study area; **(C).** Core location. The wells 67 and 56 are very close and, for this reason, they appear superimposed on the map.

Table 1
Location data, bathymetry, final depth and number of samples by piston core. Geographic coordinates data was obtained by Datum SIRGAS 2000 2QS; Zone 22 (Central meridian: 51).

Piston Core	Coordinates		Bathymetry	Final depth (m)	Samples
	S	W			
PC-34	32 46'33.47"	49 53'57.08"	1,232 m	3.4	20
PC-39	32 51'30.08"	49 48'14.59"	1,329 m	0.55	1
PC-56	33 24'4.41"	50 26'19.20"	583 m	4.73	16
PC-67	33 23'38.39"	50 26'31.22"	570 m	14	23
PC-76	32 46'58.82"	49 50'16.81"	1,312 m	11	20
				Total	**80 samples**

In general, the sedimentary facies from which the ostracods were recovered correspond to layers of muddy sediments ranging from olive gray to dark greenish gray with some bioturbation, in addition to evidence of gas hydrates, authigenic carbonate nodules and carbonate concretions. Core 39 was the only one to present gravel in its base associated with carbonate nodules, without the presence of mud.

A total of 80 samples of 17 to 66 g were prepared through washing in running water over a set of granulometric sieves of 0.250 mm, 0.125 mm, 0.063 mm and 0.045 mm, followed by oven drying at 60 C. All specimens from the fractions over 0.125 mm were picked out under Zeiss Stemi-305 stereomicroscope and transferred to micropaleontological cells.

Well-preserved specimens of each morphotype were selected for Scanning Electron Microscopy (PHENOM XL) and stereomicroscopy (Zeiss, AXIO ZOOM V16). Type and figured material are deposited at *Laboratório de Micropaleontologia Aplicada* (LMA), *Universidade Federal de Pernambuco,* under the prefix LMA and curatorial numbers 00080 to 00105. The new taxon is registered in Zoobank (the Official Registry of Zoological Nomenclature of the International Commission on Zoological Nomenclature).

The chronostratigraphic positioning of the studied sections was calibrated with the distribution of planktic foraminifera, following the biozonal scheme of Ericson and Wollin (1968) for the Quaternary, which takes into account the disappearance and reappearance of the *Globorotalia menardii* plexus.

4. Results

A total of 135 specimens were recovered from the studied samples. The core PC-67 showed greater abundance, with 95 specimens, followed by the PC-56, with 25 specimens. The cores PC-76 and PC-39 presented lower abundance and the PC-39 was barren for ostracods. From the total of thirteen genus recorded in the present work, *Cytherella, Loxoconchidea, Cytheropteron, Eucytherura, Xestoleberis, Apatihowella, Henryhowella,* and *Poseidonamicus* also occur in the Santos and Campos basins. However, the *Argilloecia* and *Paracytherois* are common in the assemblages of the Pelotas and Campos basins and *Rymacytheropteron* occurs only in the Pelotas and Santos basins.

The most abundant genus was *Apatihowella*, occurring predominantly in PC-67 (seven samples), with records also in PC-39 (two samples) and PC-56 (one sample). Cytheruridae (three genera) was the most diverse family. *Krithe* had low diversity and frequency of specimens, being recorded only on PC-67 (one sample) and PC-76 (three samples). The geographical occurrence of some taxa has been extended to the southern margin of Brazil from this work. The species *Poseidonamicus hisayoae,* previously described in the Southern Ocean, expanded its occurrence to the Pelotas Basin. In addition, we document *Krithe hunti*, whose previous occurrences were restricted to the Arctic region (Yasuhara et al., 2014a; Jöst et al., 2017; Gemery et al., 2017).

The biostratigraphic analysis based on planktic foraminifera allowed the recognition of the biozones Y and Z, following the zonal scheme of Ericson and Wollin (1968), which represent glacial intervals of the Pleistocene and interglacial of the Holocene. The datum used to identify the Y and Z biozones was based on the disappearance and reappearance of the *Globorotalia menardii* plexus. In the portion of the cores where ostracods were recovered, the absence or rare presence of the G. *menardii* plexus and the abundance *Globorotalia inflata* and *Truncorotalia truncatulinoides,* permitted to characterize the Biozone Y (upper Pleistocene).

The reappearance of the G. *menardii* plexus, including *Globorotalia fimbriata,* indicated the limit between Biozones Y and Z in the cores PC-34 (depth 16 cm), PC-56 (depth 16 cm) and PC-67 (depth 26 cm), marking the base of the Holocene. In the studied cores (PC-34, PC-56, PC-67, PC-76), only in the PC-76 the Holocene interval was not identified. In the core PC-39 there was no recovery of planktic foraminifera, but the ostracod taxa were correlated with the species identified in the PC-67, corresponding to the upper Pleistocene.

4.1. Systematic Palaeontology

The suprageneric taxonomy follows Liebau (2005). Abbreviations: **C,** carapace; **LV**, left valve; **RV,** right valve; **L**, length; **H**, height; **W**, width.

Subclass OSTRACODA Latreille, 1802
Superorder PODOCOPOMORPHA Kozur, 1972
Order PLATYCOPIDA Sars, 1866
Superfamily CYTHERELLOIDEA Sars, 1866
Family CYTHERELLIDAE Sars, 1866
Genus *Cytherella* Jones, 1894
Cytherella santosensis Bergue et al., 2007
(Plate 1, Figure 1)
2007 *Cytherella santosensis* - Bergue et al., p. 10, pl. 3, figs. I–L.

Figured specimen. LMA-00080, juvenile LV, PC-76 (84–86 cm), L. 0.78 mm; H. 0.48 mm.

Material. three C (juvenile), one LV (juvenile), two RV (juvenile).

Occurrence. PC-56 (159.6 cm), PC-67 (104–106 cm), PC-76 (34–36 cm), PC-76 (44–46 cm), PC-76 (84–86 cm).

Geographic and stratigraphic distribution. Pleistocene: Santos Basin, Brazil (Bergue et al., 2007), Pelotas Basin, Brazil (this study).

Remarks. The figured specimen is a juvenile and therefore the ventrolateral rib and the peripheral reticulation along both the anterior and posterior margins, is not visible. The morphological characteristics of this species are very conspicuous, even when dealing with juvenile specimens (Bergue et al., 2007).

Cytherella sp. 1
(Plate 1, fig. 2)

Figured specimen. LMA-00081, RV, PC-67 (127.5 cm), L. 0.97 mm; H. 0.61 mm.

Material. five LV (three adults + one juvenile), nine RV (two adults + seven juveniles), one C (adult).

Occurrence. PC-56 (159.6 cm), PC-67 (74–76 cm), PC-67 (104–106 cm), PC-67 (127.5 cm), PC-67 (372.5 cm), PC-76 (84–86 cm).

Geographic and stratigraphic distribution. Pleistocene: Pelotas Basin, Brazil (this study).

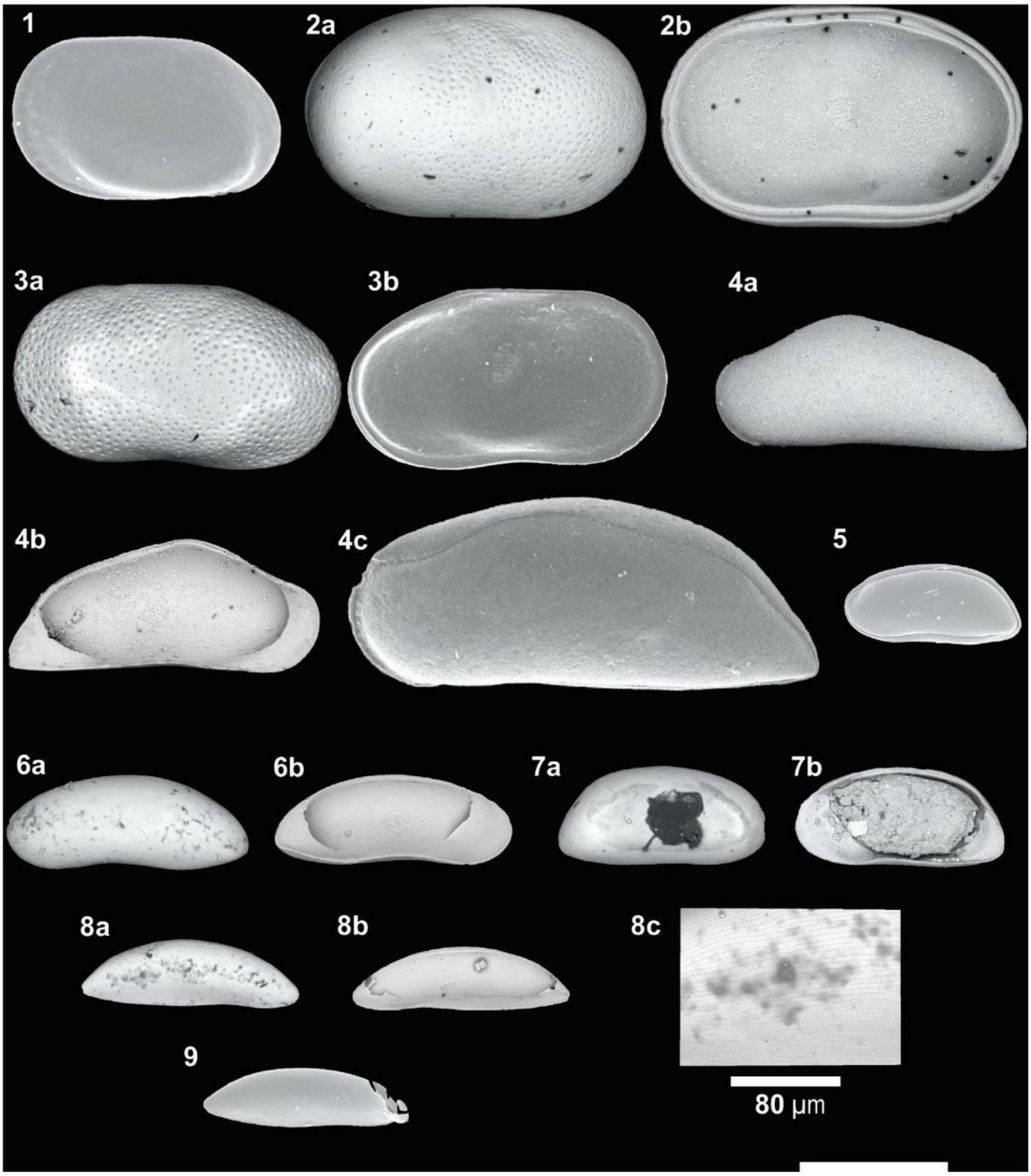

Plate 1. 1. *Cytherella santosensis* Bergue et al., 2007; LV, lateral view; LMA-00080; **2.** *Cytherella* sp. 1; LMA-00081; **2a.** RV, lateral view; **2b**. RV, internal view. **3.** *Cytherella* sp. 2; LMA-00082; **3a**. LV, lateral view; **3b.** LV, internal view. **4.** *Macropyxis* sp. aff. *M. alanlordi* Brandão, 2010; **4a.** LV, lateral view; LMA-00083; **4b.** LV, internal view; LMA-00083; **4c.** C, left lateral view; LMA-00084; **5.** *Argilloecia* sp. 1; C, left lateral view; LMA-00085; **6.** *Argilloecia* sp. 2; LMA-00086; **6a.** LV, lateral view; **6b.** LV, internal view; **7.** *Argilloecia* sp. 3; LMA-00087; **7a.** RV, lateral view; **7b.** RV, internal view; **8.** *Paracytherois* sp. 1; LMA-00088; **8a.** RV, lateral view; **8b.** RV, internal view; **8c.** detail of the horizontal striations; **9.** *Paracytherois* sp. 2. RV, lateral view; LMA-00089. **Scale bar:** 400 µm.

Remarks. *Cytherella* sp. 1 differs from *Cytherella* sp.1 registered by Manica et al. (2015) in the Lower Miocene of the Pelotas Basin by the outline of the posterior margin and in having the middle part of carapace more densely punctuate.

Cytherella sp. 2

(Plate 1, figs. 3a–b)

Figured specimen. LMA-00082, LV, PC-56 (159.6 cm), L. 0.91 mm; H. 0.51 mm.

Material. two LV (adults), two RV.

Occurrence. PC-56 (159.6 cm), PC-67 (74–76 cm), PC-67 (427.5 cm).

Geographic and stratigraphic distribution. Pleistocene: Pelotas Basin, Brazil (this study).

Remarks. *Cytherella* sp. 2 strongly differs from *Cytherella* sp. 1 in outline and in having puncta more widely distributed on the lateral surface.

Order PODOCOPIDA Sars, 1866

Suborder CYPRIDOCOPINA Jones, 1901

Superfamily MACROCYPRIDOIDEA Müller, 1912

Family MACROCYPRIDIDAE Müller, 1912

Genus *Macropyxis* Maddocks, 1990

Macropyxis sp. aff. *M. alanlordi* Brandão, 2010

(Plate 1, figs. 4a–c)

aff. 2010 *Macropyxis alanlordi* Brandão - Brandão, p. 595, figs. 15–17.

Figured specimens. LMA-00083, juvenile LV, PC-67 (612.5 cm), L. 0.28 mm; H. 0.12 mm; LMA-00084, adult C, PC-76 (14–16 cm), L. 1.25 mm; H. 0.52 mm.

Material. one C (adult), two LV (one juvenile + one adult).

Occurrence. PC-67 (612.5 cm), PC-76 (14–16 cm).

Geographic and stratigraphic distribution. Pleistocene: Pelotas Basin, Brazil (this study).

Remarks. The adult specimen herein figured (fig. 4c) is similar to *Macropyxis alanlordi* Brandão (2010) but differs in the pronounced anterodorsal overlap. It probably represents a new species, whose scarcity of specimens in the samples herein analyzed precludes description.

Superfamily PONTOCYPRIDOIDEA Müller, 1894

Family PONTOCYPRIDIDAE Müller, 1894

Genus *Argilloecia* Sars, 1866

Argilloecia sp. 1

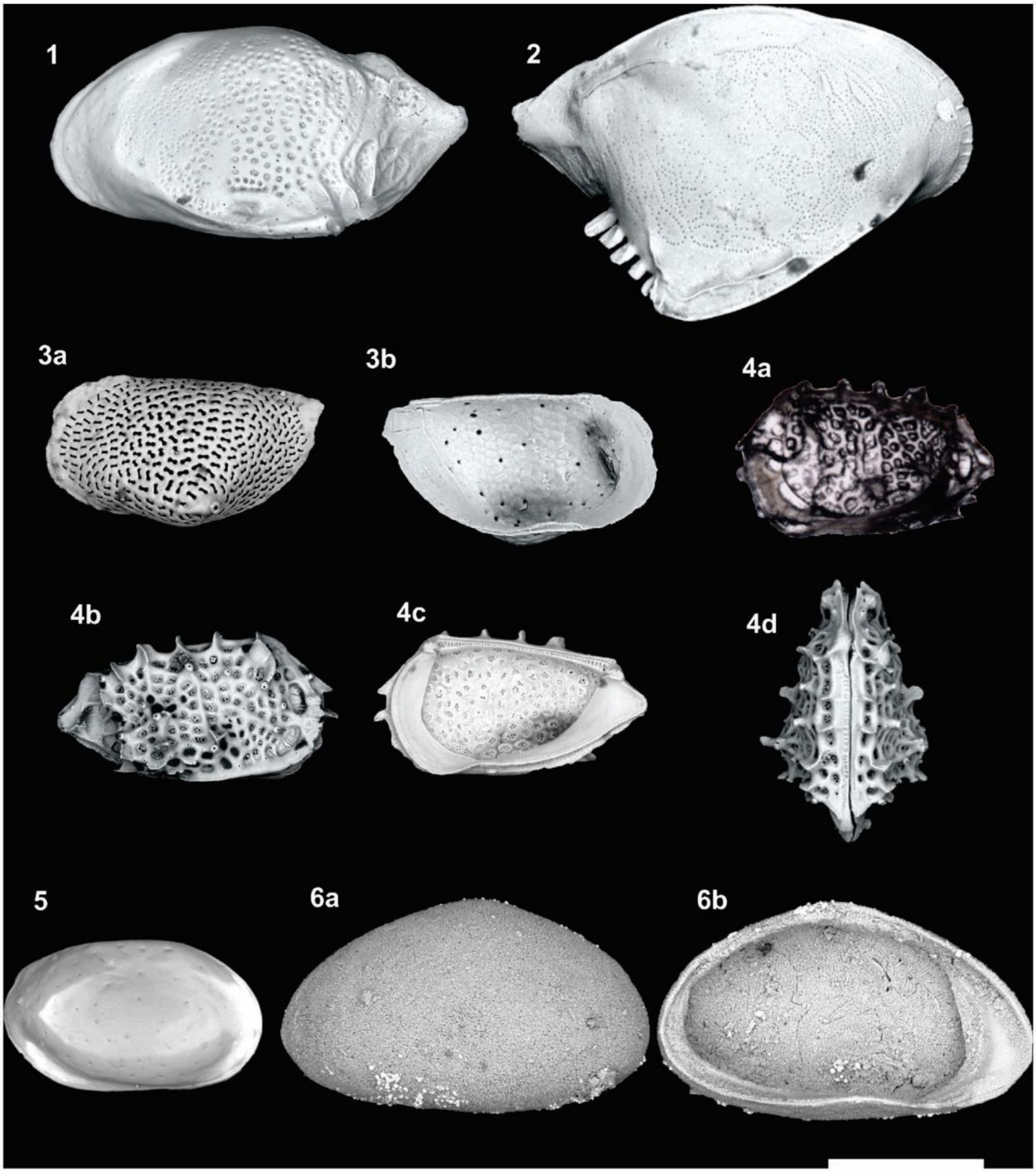

Plate 2. 1. *Cytheropteron* sp. 1; LV, lateral view; LMA-00090; **2.** *Cytheropteron* sp. 2; RV, lateral view; LMA-00091; **3.** *Rimacytheropteron longipunctatum* (Breman, 1976); LMA-00092; **3a**. LV, lateral view; **3b.** LV, internal view. **4.** *Eucytherura fossapunctata* sp. nov. **4a**. Optical microscopy RV, internal view; LMA-00093; **4b.** RV, internal view; LMA-00093; **4c.** RV, lateral view; LMA-00093; **4d.** C, dorsal view; LMA-00094. **5.** *Loxoconchidea minima* Bonaduce et al., 1976; C, rigth lateral view; LMA-00096; **6.** *Xestoleberis* sp.; LMA-00097; **6a.** LV, lateral view; **6b.** LV, internal view. **Scale bar:** 200 µm.

(Plate 1, fig. 5)

Figured specimen. LMA-00085, C, PC-67 (144–146 cm), L. 0.49 mm; H. 0.22 mm.

Material. one C.

Occurrence. PC-67 (144–146 cm).

Geographic and stratigraphic distribution. Pleistocene: Pelotas Basin, Brazil (this study).

Argilloecia sp. 2

(Plate 1, figs. 6a–b)

Figured specimen. LMA-00086, LV, PC-56 (159.6 cm), L. 0.65 mm; H. 0.24 mm.

Material. one LV.

Occurrence. PC-56 (159.6 cm).

Geographic and stratigraphic distribution. Pleistocene: Pelotas Basin, Brazil (this study).

Remarks. *Argilloecia* sp. 2 differs from *Argilloecia* sp. 1 in having the valve more elongated laterally and the posterior margin less acuminate.

Argilloecia sp. 3

(Plate 1, figs. 7a–b)

Figured specimen. LMA-00087, RV, PC-56 (84–86 cm), L. 0.56 mm; H. 0.27 mm.

Material. one RV.

Occurrence. PC-56 (84–86 cm).

Geographic and stratigraphic distribution. Pleistocene: Pelotas Basin, Brazil (this study).

Remarks. *Argilloecia* sp. 3 resembles *Argilloecia conoidea* Sars, 1923, but differs in the less acuminate posterior margin.

Suborder CYTHEROCOPINA Gründel, 1967

Superfamily PARADOXOSTOMATOIDEA Brady and Norman, 1889

Family PARADOXOSTOMATIDAE Brady and Norman, 1889

Genus *Paracytherois* Müller, 1894

Paracytherois sp. 1

(Plate 1, figs. 8a–c)

Figured specimen. LMA-00088, RV, PC-67 (1427.5 cm), L. 0.59 mm; H. 0.18 mm.

Material. two RV (adults).

Occurrence. PC-67 (1032.5 cm), PC-67 (1427.5 cm).

Geographic and stratigraphic distribution. Pleistocene: Pelotas Basin, Brazil (this study).

Paracytherois sp. 2

(Plate 1, fig. 9)

Figured specimen. LMA-00089, juvenile RV, PC-67 (1427.5 cm), L. 0.53 mm; H. 0.16 mm

Material. one RV.

Occurrence. PC-67 (1427.5 cm).

Geographic and stratigraphic distribution. Pleistocene: Pelotas Basin, Brazil (this study).

Remarks. *Paracytherois* sp. 2 differs from *Paracytherois* sp. 1 in having the dorsal margin more arched and greater height.

Suborder CYTHEROCOPINA Gründel, 1967

Infraorder NOMOCYTHERININA Liebau, 1991

Superfamily CYTHEROIDEA Baird, 1850

Family CYTHERURIDAE Müller, 1894

Genus *Cytheropteron* Sars, 1866

Cytheropteron sp. 1

(Plate 2, fig. 1)

Figured specimen. LMA-00090, adult LV, PC-56 (159.6 cm), L. 0.58 mm; H. 0.28 mm.

Material. nine RV (three adults + four juveniles), 13 LV (two adult + eleven juveniles).

Occurrence. PC-56 (159.6 cm), PC-67 (64–66 cm), PC-67 (127.5 cm), PC-67 (1212 cm), PC-67 (1427.5 cm), PC-76 (14–16 cm), PC-76 (140–142 cm).

Geographic and stratigraphic distribution. Pleistocene: Pelotas Basin, Brazil (this study).

Remarks. This species differs slightly from *Cytheropteron* sp. registered by Ramos et al. (2014) in the posterodorsal outline and the size. The morphological characteristics of this specimen are not observed in any other described species of this genus. Possibly constitutes a new species.

Cytheropteron sp. 2

(Plate 2, fig. 2)

Figured specimen. LMA-00091, RV, PC-67 (1212 cm), L. 0.59 mm; H. 0.40 mm.

Material. six RV (two adults + four juveniles), seven LV (four juveniles + three adults).

Occurrence. PC-56 (159.6 cm), PC-67 (64–66 cm), PC-67 (1212 cm), PC-67 (1427.5 cm), PC-76 (14–16 cm).

Geographic and stratigraphic distribution. Pleistocene: Pelotas Basin, Brazil (this study).

Remarks. *Cytheropteron* sp. 2 differs from *Cytheropteron* sp. 1 for the punctate ornamentation, less pronounced caudal process and prominent alar process with posterior spines.

Genus *Rimacytheropteron* Whatley and Coles, 1987

Rimacytheropteron longipunctatum (Breman, 1976)

(Plate 2, figs. 3a–b)

1976 *Monoceratina longipunctata* Breman, p. 77, pl. 12, fig. 183.

1987 *Rimacytheropteron longipunctata* (Breman) - Whatley and Coles, p. 70, pl. 3, figs. 2–3.

2000 *Rimacytheropteron longipunctatum* (Breman) - Aiello et al., p. 97, pl. 3, fig. 11.

2000 *Rimacytheropteron longipunctata* (Breman) - Didié and Bauch, p. 115, pl. 4, fig. 26.

2004 *Rimacytheropteron longipunctatum* (Breman) - Aiello and Szczechura, p. 56, pl. 14, figs. 7–8.

2006 *Rimacytheropteron longipunctatum* (Breman) - Bergue et al., p. 207, fig. 7 M.

2008 *Rimacytheropteron longipunctatum* (Breman) - Bergue and Coimbra, p. 133, pl. 7, fig. 12.

2009 *Rimacytheropteron longipunctatum* (Breman) - Yasuhara, Okahashi and Cronin, p. 909, pl. 14, figs. 1–5.

Figured specimen. LMA-00092, LV, PC-67 (912.5 cm), L. 0.34 mm; H. 0.19 mm.

Material. two LV.

Occurrence. PC-67 (912.5 cm), PC-67 (1032.5 cm).

Geographic and stratigraphic distribution. Middle Miocene: Central Paratethys, southwestern Poland (Aiello and Szczechura, 2004); Plio-Pleistocene: Sicily, Italy (Aiello et al., 2000); Late Quaternary: Rockall Plateau, North Atlantic (Didié and Bauch, 2000); ; Pleistocene: Santos Basin, Brazil (Bergue et al., 2006; Bergue and Coimbra, 2008); Pleistocene–Holocene: ODP Hole 1055B, western North Atlantic (Yasuhara et al., 2009b); Pleistocene: Pelotas Basin, Brazil (this study).

Genus *Eucytherura* Müller, 1894

Eucytherura fossapunctata Maia, Bergue and Piovesan nov. sp.

(Plate 2, figs. 4a–d)

2008 *Eucytherura* sp. B Bergue and Coimbra, p. 129, pl. 6, fig. 7,8.

Derivation of name. L. *fossa* + *punctata,* in reference to ornamentation with fossae and pores.

Diagnosis. A species of *Eucytherura* subrectangular in lateral view, with surface densely reticulated. Fossae subrounded with thick muri. Sola perforated with one to seven pores. Acute crests protruding from the carapace in the dorsal, anterior and ventral regions. Caudal process short and median.

Material: Holotype. LMA-00093, RV, PC-67 (1032.5 cm), L. 0.34 mm, H. 0.19 mm. Paratype 1. LMA-00094, C, PC-67 (1032.5 cm), L. 0.32 mm; H. 0.17 mm; W. 0.22 mm. Paratype 2. LMA-00095, LV, PC-67 (1032.5 cm), L. 0.34 mm; H. 0.19 mm.

Zoobank code: http://zoobank.org/urn:lsid:zoobank.org:pub:A15729C2-B860-4071-A69C-43A5E9431D4F

Description. A small species of *Eucytherura* with subrectangular outline in lateral view. Dorsal margin slightly convex, but obscured by dorsal ornament; ventral margin strongly sinuous but hidden by a ventrolateral carina except in the anterior portion. Anterior margin symmetrically rounded but hidden by overgrown ornament; posterior margin with median, short and obtuse caudal process. Surface densely reticulated forming fossae subrounded with thick muri. Intramural pore-canals few and scattered through surface, mostly rimmed. Sola with pore-clusters composed by up to seven pores, absent in the posterior region. In the two largest fossae, at the anteromedian and anteroventral regions, pore-clusters are also absent. Dorsal region with five conspicuous spines perpendicular to dorsal margin, some of them overlaid with short carina. Degenerate eye-tubercle (i.e. without ocular sinus) adjoined to a short curved carina present in the RV. Ventrolateral region with two well-developed carina, one of them seen only in internal view. The other one, which originates from a ridge running along the anterior margin vanishes immediately after mid-length. Anterior margin rimmed by narrow carina holding two short and downwardly projected spines. At posterior region, an oblique and sinuous carina separates the posterior margin from the rest of carapace. Internal view: Anterior duplicature moderately wide; posterior duplicature widening towards the dorsal region. Selvage

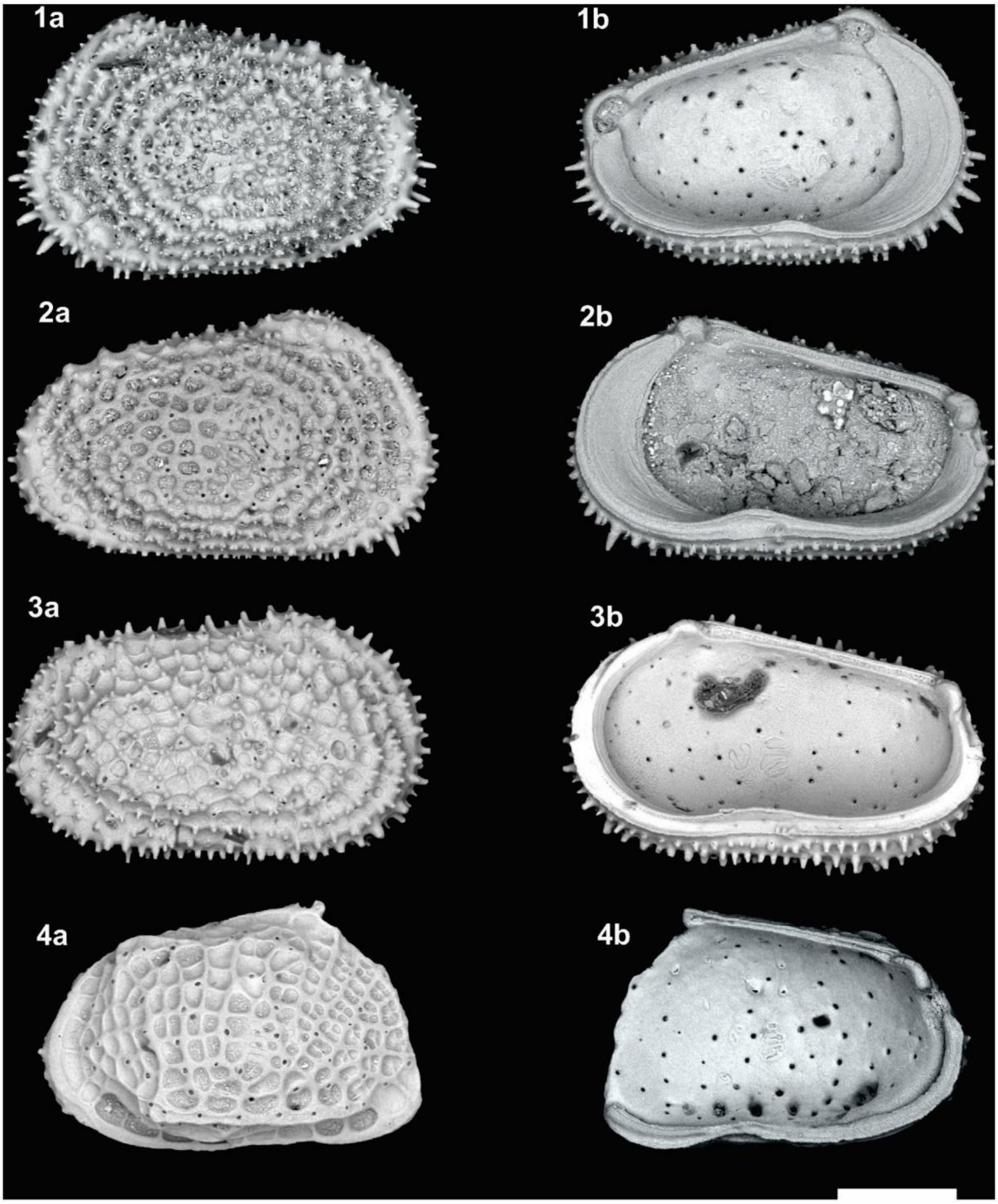

Plate 3. 1. *Apatihowella besnardi* Bergue et al., 2016; LMA-00098; **1a.** LV, lateral view. **1b.** LV, internal view; **2.** *Apatihowella convexa* Bergue et al., 2016; LMA-00099; **2a.** RV, lateral view; **2b**. RV, internal view; **3.** *Henryhowella asperrima* Reuss, 1850; LMA-00100; **3a.** RV, lateral view; **3b.** RV, internal view; **4.** *Poseidonamicus hisayoae* Yasuhara et al., 2009a; LMA-00101; **4a**. RV, lateral view; **4b**. RV, internal view. **Scale bar:** 200 μm.

conspicuous along the anterior and ventral margins. Hinge antimerodont with posterior element larger than the anterior one, and with narrow accommodation groove running along all its length. Internal surface thoroughly marked by pore-clusters. Central muscle-scars not seen in detail.

Geographic and stratigraphic distribution. Pleistocene: Santos Basin, Brazil (Bergue and Coimbra, 2008); Pelotas Basin, Brazil (this study).

Remarks. Coimbra et al. (1999) present the only descriptions of *Eucytherura* in the Brazilian margin, but the species therein described (i.e. *E. dinglei* and *E. pulchra*) are quite different from the one herein proposed. The diversity of this genus in deep waters, however, seems to be higher. *E. mayressi* Yasuhara et al. (2009b) described in North Atlantic, differs in the outline and in having a well-developed median carina. *E. namericana* Yasuhara et al. (2009b), described in the same site, also has degenerate eye-tubercles, the RV one being far more developed. However, that species differs from *E. fossapunctata* nov. sp. in having trefoil ornamentation and conspicuous subcentral tubercle.

Family LOXOCONCHIDAE Sars, 1925

Loxoconchidea Bonaduce et al., 1976

Loxoconchidea minima Bonaduce et al., 1976

(Plate 2, fig. 5)

1976 *Loxoconchidea minima* Bonaduce et al., p. 112, pl. 59, figs 1–7.

2004 *Loxoconchidea minima* Bonaduce et al., - Aiello and Szczechura, p. 35, pl. 7, figs. 1–3.

2006 *Loxoconchidea minima* Bonaduce et al., - Bergue et al., p. 206, fig. 6E.

2008 *Loxoconchidea minima* Bonaduce et al., - Bergue and Coimbra, p. 115, pl. 1, fig. 16.

2009 *Loxoconchidea minima* Bonaduce et al., - Yasuhara, Okahashi and Cronin, p. 37, pl. 17, figs. 8–11

2015 *Loxoconchidea minima* Bonaduce et al.,–Yasuhara and Okahashi, p. 44, pl. 15, fig. A.

Figured specimen. LMA–00096, juvenile C, PC-56 (84–86 cm), L. 0.33 mm; H. 0.15 mm.

Material. one C.

Occurrence. PC-56 (84–86 cm).

Geographic and stratigraphic distribution. Middle Miocene: Central Paratethys, southwestern Poland (Aiello and Szczechura, 2004); Quaternary: Adriatic Sea (Bonaduce et al., 1976); Pleistocene–Holocene: ODP Hole 1055B, western North Atlantic (Yasuhara et al., 2009b); Quaternary: North Atlantic, Hole 982A (Yasuhara and Okahashi, 2015); Pleistocene: Santos and Pelotas Basins, Brazil (Bergue et al., 2006, 2008; this study).

Family XESTOLEBERIDIDAE Sars, 1928

Genus *Xestoleberis* Sars, 1866

Xestoleberis sp.

(Plate 2, figs. 6a–b)

Figured specimen. LMA-00097, juvenile LV, PC-67 (84–86 cm), L. 0.49 mm; H. 0.29 mm.

Material. one RV.

Occurrence. PC-67 (84–86 cm).

Geographic and stratigraphic distribution. Pleistocene: Pelotas Basin, Brazil (this study).

Remarks. *Xestoleberis* sp. differs from all species of the genus described in the Brazilian continental shelf (see Da Luz and Coimbra, 2015). It also differs from other shallow water *Xestoleberis* species registered by Whatley et al. (1997) and Whatley et al. (1998a,b) along Argentinian and Uruguayan shelves. It is similar to *Xestoleberis* sp. registered by Ertekin and Tunoglu (2008) (p. 320, pl. 4. fig. 17) but differs in having the ventral margin more convex.

Superfamily TRACHYLEBERIDOIDEA Sylvester-Bradley, 1948

Family TRACHYLEBERIDIDAE Sylvester-Bradley, 1948

Genus *Apatihowella* Jellinek and Swanson, 2003

Apatihowella convexa Bergue et al., 2016

(Plate 3, figs. 1a–b)

2016 *Apatihowella convexa* Bergue et al., p. 81, pl. 5, figs. 1–8.

Figured specimen. LMA-00098, LV, PC-56 (159.6 cm), L. 0.71 mm; H. 0.46 mm.

Material. two C (adults), 12 RV (adults), 16 LV (adults).

Occurrence. PC-39 (0–6 cm), PC-56 (159.6 cm), PC-67 (64–66 cm), PC-67 (74–76 cm), PC-67 (84–86 cm), PC-67 (104–106 cm), PC-67 (127.5 cm), PC-67 (144–146 cm), PC-67 (372.5 cm).

Geographic and stratigraphic distribution. Quaternary: Southern Brazilian Margin (Bergue et al., 2016); Pleistocene: Pelotas Basin, Brazil (this study).

Apatihowella besnardi Bergue et al., 2016

(Plate 3, figs. 2a–b)

2003 *Henryhowella macrocicatricosa* Whatley et al. - Drozinski et al., p. 68, fig. 8H.

Non 1998 *Henryhowella macrocicatricosa* Whatley et al., p. 110, pl. 5, figs. 18–22.

2003 *Henryhowella* sp. Drozinski et al., p. 68, fig. 8I.

2016 *Apatihowella besnardi* Bergue et al., p. 79, pl. 4, figs. 12–18.

Figured specimens. LMA-00099, adult RV, PC-67 (84–86 cm), L. 0.74 mm; H. 0.438 mm.

Material. nine LV (adults), seven RV (adults), one C.

Occurrence. PC-39 (0–6 cm), PC-67 (64–66 cm), PC-67 (74–76 cm), PC-67 (84–86 cm), PC-67 (104–106 cm), PC-67 (372.5).

Geographic and stratigraphic distribution. Holocene: Continental Margin of Rio Grande do Sul, Brazil (Drozinski et al., 2003, Bergue et al., 2016); Pleistocene: Pelotas Basin, Brazil (this study).

Genus *Henryhowella* Puri, 1957

Henryhowella asperrima Reuss, 1850

(Plate 3, figs. 3a–b)

2015 *Henryhowella asperrima* (Reuss) - Yasuhara et al., p. 82, fig. 42A–O (see this for a comprehensive synonymy before 2015).

2017 *Henryhowella asperrima* (Reuss) - Bergue et al., p. 501, pl. 2, fig. 18; pl. 3, fig. 1.

2019 *Henryhowella asperrima* (Reuss) - Bergue et al., p. 1288, figs. 4J–K.

Figured specimen. LMA-00100, juvenile RV, PC-67 (1427.5 cm), L. 0.72 mm; H. 0.44 mm.

Material. one RV (juvenile), one LV (juvenile).

Occurrence. PC-67 (1427.5 cm).

Geographic and stratigraphic distribution. Tertiary, Austria (Reuss, 1850); Paleogene: southern Upper Rhine Graben, Heidelberg Basin, Germany (Pirkenseer and Berger, 2011); Late Eocene–Oligocene: Kerguelen Plateau, Southern Indian Ocean (Bergue and Govindan, 2010); Late Oligocene–Miocene: Lower Elbe area, German Tertiary Basin (Uffenorde, 1981); Miocene–Pleistocene: Rio Grande Rise, western South Atlantic (Bergue et al., 2019); Miocene: Badenian; Vienna Basin (Kempf and Nink, 1993); Middle Miocene: Central Paratethys, southwestern Poland (Aiello and Szczechura, 2004); Pliocene–Pleistocene: SE Laconia, Peloponnese, Greece (Malz and Jellinek, 1984); Quaternary: Arctic Ocean (Joy and Clark, 1977; Cronin, 1996); Late Quaternary: East Greenland (Whatley et al., 1998a,b); Rockall Plateau, North Atlantic (Didié and Bauch, 2001); Pleistocene–Holocene: ODP Hole 1055B, western North Atlantic (Yasuhara et al., 2009b); Pleistocene: Campos Basin, Brazil (Bergue et al., 2017) and Pelotas Basin, Brazil (this study).

Remarks. *Henryhowella asperrima* is a widely distributed deep-sea species, with occurrences in several oceanic basins in Paleogene, Neogene and Quaternary, although the conspecificity of all those records is questioned by some authors (e.g. Jellinek and Swanson, 2003). The anterior and posterior elements of the hinge and the contour of the posterior region demonstrate that the specimen is juvenile (probably A-1). Morphological characteristics of this species are very conspicuous, even when dealing with juvenile specimens.

Family HEMICYTHERIDAE Puri, 1953

Subfamily THAEROCYTHERINAE Hazel, 1967

Genus *Poseidonamicus* Benson, 1972

Poseidonamicus hisayoae Yasuhara et al., 2009a

(Plate 3, figs. 4a–b)

2009a *Poseidonamicus hisayoae* Yasuhara et al., p. 8, pl. 6, figs. 1–8.

Figured specimens. LMA-00101, juvenile RV, PC-39 (0–6 cm), L. 0.64 mm, H. 0.41 mm.

Material. one RV.

Occurrence. PC-39 (0–6 cm).

Geographic and stratigraphic distribution. Quaternary: Southern Ocean (Yasuhara et al., 2009a); Pleistocene: Pelotas Basin, Brazil (this study).

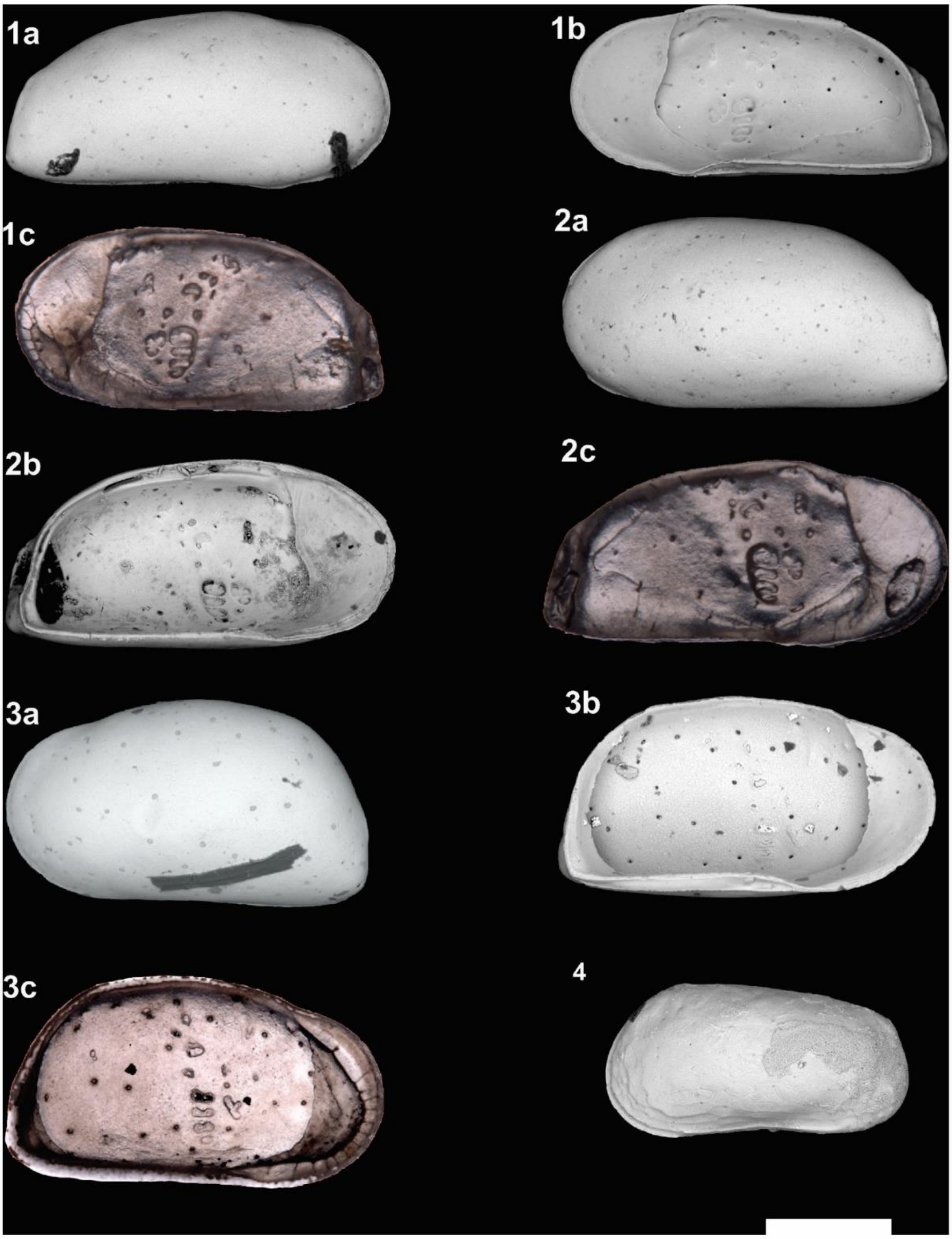

Plate 4. 1. *Krithe hunti* Yasuhara et al., 2014a; LMA-00102; **1a.** RV, lateral view; **1b.** RV, internal view; **1c.** Optical microscopy RV, internal view; **2.** *Krithe hunti* Yasuhara et al., 2014a; LMA-00103; **2a.** LV, lateral view; **2b.** LV, internal view; **2c.** Optical microscopy LV, internal view; **3.** *Krithe reversa* Bold, 1958; LMA-00104; **3a.** LV, lateral view; **3b.** LV, internal view; **3c.** Optical microscopy LV, internal view. **4.** Gen. et sp. indet.; LMA-00105; C, left lateral view; **Scale bar:** 300 μm.

Remarks. Although the studied specimen is broken and juvenile, the number and position of normal pore-canals allowed its identification at species level.

Superfamily CYTHERIDEOIDEA Liebau, 2005

Family KRITHIDAE Mandelstam, 1958

Genus *Krithe* Brady, Crosskey and Robertson, 1874

Krithe hunti Yasuhara et al., 2014a

(Plate 4, figs. 1a–c, 2a–c)

2014 *Krithe hunti* Yasuhara et al., p. 431, pl. 13, figs. 1–11; p. 432, pl. 14, figs. 1–11.

Figured specimens. LMA-00102, RV, PC-76 (34–36 cm), L. 0.91 mm; H. 0.42 mm; LMA-00103, LV, PC-76 (140–142 cm), L. 0.91 mm; H. 0.46 mm.

Material. one RV; one LV.

Occurrence. PC-76 (34–36 cm), PC-76 (140–142 cm).

Geographic and stratigraphic distribution. Arctic Ocean (Yasuhara et al., 2014); Pleistocene: Pelotas Basin, Brazil (this study).

Krithe reversa Bold, 1958

(Plate 4, figs. 3a–c)

1958 *Krithe reversa* Bold, p. 399, pl. 1, figs. 4a–g.

1983 *Krithe* sp. C - Cronin, pl. 10, figs. A, B, C.

1994 *Krithe reversa* Bold, 1958 - Coles et al., p. 77, pl. 1, figs. 1–6.

1995 *Krithe* sp. 4 - Do Carmo and Sanguinetti, p.493, pl. 2, fig. E.

1996 *Krithe reversa* Bold, 1958 - Van Harten, p. 300, pl. 3, fig. j.

1999 *Krithe reversa* Bold, 1958 - Do Carmo and Sanguinetti, p. 6, pl. 1, fig. 2.

1999 *Krithe reversa* Bold, 1958 - Rodriguez-Lázaro and Cronin, p. 345, fig. 3 B8; p. 346, pl. 1, figs. 16–17.

2004 *Krithe reversa* Bold, 1958 - Ayress et al., p. 31.

2016 *Krithe* sp. 2 - Bergue et al., p. 83, figs. 6.5–6.7.

2019 *Krithe reversa* Bold, 1958 - Yasuhara et al., p. 6, pl. 3, figs. A–F.

Figured specimens. LMA-00104, female LV, PC-67 (127.5 cm), L. 0.89 mm; H. 0.48 mm.

Material. two LV.

Occurrence. PC-67 (127.5 cm), PC-76 (84–86 cm).

Geographic and stratigraphic distribution. Eocene: Brasso Formation, Trinidad (Bold, 1958); Florida-Hatteras slope, USA (Cronin, 1983); Tertiary–Quaternary: North Atlantic (Coles et al., 1994), Brazilian continental margin (Do Carmo and Sanguinetti, 1995, 1999); Recent: North Atlantic (Van Harten, 1996); Quaternary: Florida–Hatteras Slope/ Blake Plateau (FHS/BP) and Little Bahama Bank (LBB) (Rodriguez-Lázaro and Cronin, 1999); Quaternary: Kerguelen and Heard Islands, South Indian Ocean (Ayress et al., 2004); Quaternary: Southern Brazilian Margin (Bergue et al., 2016); Quaternary: Shatsky Rise, northwestern Pacific Ocean (Yasuhara et al., 2019); Pleistocene: Pelotas Basin, Brazil (this study).

Family *incertae sedis*

Gen. et sp. indet.

(Plate 4, figs. 4)

Figured specimens. LMA-00105, C, PC-67 (144–146 cm), L. 0.74 mm; H. 0.37 mm.

Material. three C.

Occurrence. PC-67 (144–146 cm).

Geographic and stratigraphic distribution. Pleistocene: Pelotas Basin, Brazil (this study).

Remarks. The scarcity and type of material recovered did not allow a taxonomic classification of the specimen at the level of family. Gen. et sp. indet. it is probably a new genus and species.

5. Conclusions

Compared to previous studies on bathyal ostracods in the Santos, Campos and Pelotas Brazilian marginal basins, the assemblages herein studied are similar at generic and specific level, which reflects the wide pattern of geographic distribution of many deep-sea taxa in the South Atlantic region. The diversity, measured simply as the number of species (S), is considerably lower compared to other bathyal regions in the Brazilian margin. Nonetheless, some of the species left in open nomenclature in this paper, most probably constitute new taxa.

The data provided by the present work corroborate previous researches on bathyal ostracods that have demonstrated Trachyleberididae, Cytheruridae, Pontocyprididae as important constituents of South Atlantic deep-sea ostracod assemblages (Bergue and Coimbra, 2008; Yasuhara et al., 2009a,b; Sousa et al., 2013; Bergue et al., 2016). Additional research, however, is necessary to investigate the factors influencing the low diversity in this sector of the southern Brazilian continental margin.

Declaration of Competing Interest

The authors report no declarations of interest.

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