UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
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PROGRAMA DE PÓS-GRADUAÇÃO EM GEOCIÊNCIAS

EVOLUÇÃO PALEOGEOGRÁFICA DA PLANÍCIE COSTEIRA MÉDIA DO RIO GRANDE DO SUL: ANÁLISE DE FÓSSEIS CALCÁRIOS E SILICOSOS EM TESTEMUNHOS DA LAGOA DOS PATOS

BEATRIZ APPEL DEHNHARDT

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Em memória de

Ely Alberto Dehnhardt

meu pai

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Resumo

O enfoque deste trabalho se refere ao estudo de biogênicos fósseis calcários e silicosos, obtidos de três testemunhos de sondagem localizados no interior da Lagoa dos Patos. Os testemunhos estão inseridos ao longo de perfis sísmicos de alta resolução e são identificados como: Bojuru (Bo), Mostardas (Mo) e Palmares do Sul (Pa). A escolha desses locais amostrados foi feita com base em estudos de sísmica de alta resolução que identificou um sistema de vales incisos. No testemunho Mo, é apresentado um zoneamento qualitativo a partir dos biogênicos (moluscos, foraminíferos, ostracodes e diatomáceas) onde foram identificadas três zonas biogênicas. A zona I resultou no reconhecimento de um ambiente marinho a marinho mixohalino com influência marinha através da presença de diatomáceas. A zona II identificou um ambiente marinho associado a espécies marinhas a marinhas mixohalinas com a presença de todos os biogênicos inventariados somados a diatomáceas dulciaquícolas. E a zona III um ambiente marinho associado a espécies marinhas a marinhas mixohalinas onde ocorre uma redução dos biogênicos. No testemunho Pa, é feito um zoneamento quantitativo onde são identificados cinco grupos distintos de biogênicos constituídos por moluscos (G1), foraminíferos (G2), ostracodes (G3), equinodermas, cirrípedes e poríferos (G4) e diatomáceas (G5). Os táxons foram analisados e classificados de acordo com a abundância relativa, onde quatro zonas biogênicas (Zonas I, II, III e IV) são reconhecidas. Os biogênicos ocorrem de forma diferenciada ao longo de todo o testemunho, sendo a presença de diatomáceas observada em todos os intervalos amostrados enquanto os demais se concentram na porção basal. A Zona I (base do testemunho) apresenta os cinco grupos de biogênicos e é indicativa de ambiente marinho raso. A Zona II é caracterizada pela dominância de diatomáceas marinhas, indicando ambiente marinho. As diatomáceas de água doce são exclusivas da Zona III e indicam um ambiente fluvial com alguma influência marinha. E na Zona IV são observadas somente diatomáceas marinhas, marinhas a marinhas mixohalinas e mixohalinas, caracterizando um ambiente marinho. O conteúdo malacológico, identificado nos três testemunhos, englobam 19 táxons que foram examinados de forma detalhada sobre a ecologia e alguns aspectos tafonômicos. Os moluscos também são analisados quanto a sua identidade, diversidade e utilização para interpretações paleoambientais que identificaram duas assembleias distintas sendo uma mixohalina e outra mixohalina a marinha que preencheram os paleovales apontados pela sísmica. Este trabalho se insere no projeto sobre a Evolução Paleogeográfica da Planície Costeira do Rio Grande do Sul e o estudo dos biogênicos representa mais um dado no entendimento do quadro evolutivo da planície costeira gaúcha.

Abstract

The focus of this work is on the study of calcareous and siliceous biogenic fossils recovered from three stratigraphic cores obtained in the Patos Lagoon interior. The cores were named as Bojuru (Bo), Mostardas (Mo), and Palmares do Sul (Pa) according to the local drilling site, and the localization of three incised valley systems, which were previously collected and addressed in high-resolution seismic studies performed in the lagoon. A biostratigraphic zonation based on biogenic assemblage (mollusks, foraminifera, ostracoda, and diatoms) was presented in the qualitative analysis of core Mo. Three biogenic zones were recognized. Zone I is characterized by the exclusive presence of diatoms, which are indicative of a marine to marine-estuarine environment. Zone II is related to an estuarine environment associated with marine to marine-estuarine species of all biogenic groups, including freshwater diatoms. Zone III is characterized by the reduction of the biogenic taxa, and the presence of marine and marine-estuarine species, which are indicative of a marine environment. In core Pa, a quantitative analysis of biogenic assemblages reveled the presence of five distinct groups of mollusks (G1), foraminifera (G2), ostracoda (G3), echinoderms, cirripeds and poriferous (G4), and diatoms (G5). The biogenic taxa were analyzed and classified according to the percentage of individual species, and the interpretations were based on the relative abundances (%) of the most representative groups. Four biogenic zones (Zones I-IV) were recognized. The spatial distribution of the most representative taxa was variable through core. Diatom species occurred in all sampled intervals, while those other groups are concentrated in the basal part of the core. All biogenic groups occurring in the basal part of the core Pa are indicative of a shallow marine environment. Zone II is marked by the dominance of marine diatoms, which are indicative of a marine environment. Freshwater diatoms are exclusive of Zone III, and are indicative of a fluvial environment with some marine influence. In the upper part of the core, a marine environment is recognized and only marine to marine-estuarine diatoms were identified. The malacological content obtained from these three stratigraphic cores encompassed 19 mollusk taxa, which were analyzed in detail according to the ecological and taphonomic aspects. Their taxonomic identity and diversity, and the application of them in paleoenvironmental studies are also addressed. The results show that two incised valleys were infilled by estuarine and marine to estuarine assemblages. This work is inserted in a project about the Paleogeographic Evolution of the Rio Grande do Sul coastal plain, and the study of biogenic assemblages are used to expand the knowledge about the evolution of the present coastal plain.

Sumário

Estrutura da Tese

A tese é composta por 06 capítulos e 01 anexo.

O capítulo 1 contém introdução, objetivos da tese e os avanços pretendidos, estado da arte do tema de tese, métodos de investigação utilizados e sumário integrador com o resumo dos principais resultados e suas conclusões.

O capítulo 2 é composto pelo artigo intitulado: **“*Biogenic zones of the core Mo, Lagoa dos Patos, Rio Grande do Sul State, Brazil*”**, cujo título em português corresponde a: **“Zonas biogênicas fósseis de testemunho extraído na Lagoa dos Patos, Rio Grande do Sul, Brasil”,** e tem como autores: Dehnhardt, B.A., Corrêa, I.C.S., Kotzian, C.B., Baitelli, R. & Santos-Fischer, C.B. dos. Este trabalho foi encaminhado para a Revista Pesquisas em Geociências da Universidade Federal do Rio Grande do Sul. O trabalho trata de um zoneamento qualitativo dos biogênicos reconhecidos.

O capítulo 3 apresenta o artigo: **“*Paleoenvironmental changes based on the analysis of Late Pleistocene/Holocene biogenics from the core Pa, Patos Lagoon, Palmares do Sul (Rio Grande do Sul State, Brazil)*”** com título em português: **“Mudanças paleoambientais (Pleistoceno Tardio/Holoceno) na Lagoa dos Patos, região de Palmares do Sul, a partir da análise biogênica de um testemunho de sondagem (Rio Grande do Sul, Brasil)”,** e tem como autores: Dehnhardt, B.A., Corrêa, I.C.S., Kotzian, C.B., Baitelli, R. & Santos-Fischer, C.B. dos. Este trabalho foi encaminhado para a Revista dos Anais da Acadêmia Brasileira de Ciências. O trabalho diz respeito a um zoneamento quantitativo dos biogênicos identificados.

O capítulo 4 diz respeito ao artigo: **“*Diversity and Taphonomic signatures of mollusk assemblages as tools for recognizing Quaternary transicional sedimentary environments in Southern***

***Brazilian coast*”,** cujo título em português corresponde a: **“Diversidade e assinaturas tafonômicas de associações de moluscos como ferramentas para reconhecer ambientes transicionais quaternários na costa sul do Brasil”**, tem como autores: Dehnhardt, B.A., Kotzian, C.B., Corrêa, I.C.S., Baitelli, R., Barros, C.E. & Bortolin, E.C. Este trabalho foi encaminhado para a Revista Palaios. O trabalho faz uma análise tafonômica dos moluscos aplicados como ferramentas no reconhecimento ambiental de preenchimento dos vales incisos.

No capítulo 5 consta uma síntese dos resultados obtidos nos três artigos.

No capítulo 6 encontram-se as referências bibliográficas mencionadas nos capítulos anteriores.

No anexo constam os comprovantes de submissão dos artigos que compõe os capítulos 2, 3 e 4.

Capítulo 1

1. Introdução

1.1. Objetivos

Identificar os grupos fossilíferos e classificar de acordo com a taxonomia apropriada.

Obter através do estudo malacológico e biogênicos associados de fósseis calcários e silicosos, ferramentas efetivas que possibilitem a identificação de evidências da evolução paleogeográfica da Planície Costeira do Rio Grande do Sul, corroborando com os estudos de geologia, principalmente de sísmica de alta resolução, que vêm sendo desenvolvidos na Lagoa dos Patos.

Determinar, interpretar e discutir os dados levantados através de informações paleoecológicas e paleoambientais com base nos biogênicos identificados, fornecendo o tipo de ambiente que caracteriza a associação.

1.2. Estado da Arte

A presente tese visa utilizar fósseis calcários e silicosos como ferramenta para contribuir em estudos que versam sobre a evolução paleogeográfica que ocorreu na Planície Costeira do Rio Grande do Sul durante o Quaternário. A área estudada é a Lagoa dos Patos, na sua porção imersa, mais especificamente, as regiões próximas às localidades de Bojuru, Mostardas e Palmares do Sul, onde foram obtidos três testemunhos denominados Bo, Mo e Pa respectivamente (Figura 1).

Até o momento pesquisas com biogênicos realizadas em testemunhos localizados no interior da Lagoa dos Patos podem ser consideradas inéditas.

Estes testemunhos têm sido estudados sob vários enfoques, mas os que incluem biogênicos podem ser destacados: Bortolin, 2011, Baitelli, 2012, Leite *et al*., 2013, Santos, 2015 e Santos-Fischer *et al*., 2016.

Muitas assembleias de moluscos encontradas na região da Planície Costeira do Rio Grande do Sul, em especial na Lagoa dos Patos, não chegaram a ter seu potencial aplicado para interpretações paleoambientais explorado adequadamente. Por exemplo, estudos recentes que apresentaram importantes interpretações à cerca da evolução ambiental na região da Lagoa dos Patos, com base em testemunhos (Bortolin, 2011; Baitelli, 2012) não chegaram a analisar a identidade e a ecologia da totalidade das espécies de moluscos encontradas. Aspectos tafonômicos das assembleias, que poderiam contribuir para as interpretações apresentadas, também não foram enfocados para esta região. Diante esta escassez se faz necessário analisar a identidade e a ecologia da totalidade das espécies de moluscos encontradas abordando também aspectos tafonômicos das assembleias, que poderiam contribuir para as interpretações apresentadas.

Neste contexto, tem-se como objetivo apresentar: i) uma revisão sobre o conhecimento da paleobiodiversidade dos moluscos encontrados em depósitos sedimentares Planície Costeira do Rio Grande do Sul, em especial os da região da Lagoa dos Patos; e ii) analisar de forma detalhada a diversidade, a ecologia e alguns aspectos tafonômicos das assembleias de moluscos, previamente estudadas por Bortolin (2011), Baitelli (2012), contribuindo para aprimorar a compreensão sobre a evolução paleoambiental da planície.

Através de uma análise preliminar nos testemunhos constata-se a ocorrência de representantes dos dois grandes reinos, o animal e o vegetal. Os organismos identificados no testemunho de Mostardas estão representados pelos seguintes grupos taxonômicos: moluscos (gastrópodes e bivalves), crustáceos (ostracodes) e protistas (foraminíferos e diatomáceas). Já os organismos identificados no testemunho de Palmares do Sul estão representados pelos seguintes grupos taxonômicos: equinodermas (espinhos), poríferos (espículas), moluscos (gastrópodes e bivalves), crustáceos (ostracodes e cirrípedes) e os protistas (foraminíferos e diatomáceas).

Uma compilação de publicações científicas sobre os macrofósseis e microfósseis reconhecidos na Lagoa dos Patos e áreas adjacentes também é apresentado no seguimento.

As pesquisas sobre foraminíferos realizadas na região versam sobre sistemática, bioestratigrafia, paleoecologia e distribuição geográfica. Dentre elas destacam-se os trabalhos de Closs & Barberena (1960, 1962), Closs (1962, 1966, 1967, 1970, 1971), Closs & Madeira (1962, 1967, 1971), Closs & Medeiros (1965), Closs & Medeiros (1967), Madeira-Falcetta (1974), Fernandes (1975), Thiesen (1975), Madeira-Falcetta *et al*. (1980 a, b), Carvalho (1980), Bertels *et al*. (1982), Boltovskoy *et al*. (1982, 1983), Godolphim *et al*. (1989), Leipnitz *et al.* (2006), Leão *et al*. (2007) e Ferreira *et al*. (2009).

Godolphim *et al*. (1989) identificaram uma associação macrofaunística que inclui fragmentos de equinodermas na região dos municípios de São Lourenço, Pelotas, Capão do Leão, Pedro Osório e Rio Grande.

Pesquisas sobre poríferos possuem enfoques voltados à sistemática, à biodiversidade, a exploração de espongilitos (para fins industriais e tecnológicos) e também são muito aplicados em estudos ambientais, tais como Volkmer-Ribeiro *et al*. (1988) e Volkmer-Ribeiro & Turcq (1996), Mostardeiro *et al*. (2003) e Zucon & Vieira (2011).

Referências sobre moluscos estudados especificamente na região da Lagoa dos Patos são encontradas nas pesquisas de Ihering (1885), na qual o autor fez uma descrição das espécies e as aplicou na estratigrafia. A utilização dos moluscos na estratigrafia também foi desenvolvida por Carvalho (1932), Martins (1952), Closs & Forti (1971) e Forti-Esteves (1986). Estudos sistemáticos, ambientais e paleoecológicos foram realizados por Forti (1969), Bianchi (1969), Closs (1970), Forti-Esteves (1974), Godolphim *et al*. (1989), Buchmann (2002), Wiggers (2003), Pimpão (2004), Lopes *et al*. (2011), Lopes (2012), Lopes & Simone (2012) e Oliveira (2012). Horizontes orgânicos e conchas de moluscos são submetidos a datações por radiocarbono nas pesquisas de Caron *et al*. (2007a, b), Lima (2008), Bortolin (2011), Caron *et al*. (2011), Baitelli (2012) e Lima *et al.* (2013). Estudos de assinaturas tafonômicas em moluscos foram efetuados por Ritter (2010a, b), Ritter & Erthal (2011), Ritter & Erthal (2013), Ritter *et al*. (2013), Ritter & Erthal (2015).

As pesquisas sobre ostracodes destacam estudos ambientais, sistemáticos, estratigráficos entre outros. Neste contexto, inserem-se os trabalhos de Pinto & Sanguinetti (1958), Pinto & Kotzian (1961), Pinto & Ornellas (1965), Pinto & Purper (1965), Pinto & Purper (1970), Pinto & Ornellas (1970), Ornellas (1974), Purper & Würdig-Maciel (1974), Ornellas & Fallavena (1978), Sanguinetti (1979), Bertels *et al*. (1982), Würdig (1983), Würdig (1984), Würdig & Freitas (1988), Godolphim *et al.* (1989), Müller (1989), Würdig *et al*. (1990), Sanguinetti *et al.* (1991), Sanguinetti *et al.* (1992), Würdig & Pinto (1994), Würdig *et al*. (1998), Carreño *et al*. (1999), Ceolin *et al*. (2011), Ramos *et al*. (2012), Leite *et al*. (2013), Manica *et al.* (2015), Bergue *et al*. (2016) e Manica & Coimbra (2016). Leite *et al*. (2013) pesquisaram ostracodes dos três testemunhos localizados na Lagoa dos Patos (Pa, Mo e Bo) e as identificações taxonômicas fornecidas pelos autores foram utilizadas como base para a realização deste presente trabalho.

Cirrípedes torácicos (formas sésseis adultas) ocorrem em ambientes estuarinos e marinhos, sendo encontrados desde a região entre marés até o mar profundo (Newman, 1996). As pesquisas com o grupo versam sobre sistemática, importância econômica, estudos biogeográficos e ecológicos. Destacam-se as pesquisas de Newman *et al*. (1969), Young (1994, 1995, 1999), Newman (1996), Pitombo & Young (2011), Carvalho *et al*. (2011) entre outros.

Ao longo dos anos, várias pesquisas com diatomáceas foram realizadas na Lagoa dos Patos em áreas localizadas tanto na Planície Costeira do Rio Grande do Sul quanto na plataforma continental sul-brasileira. A coleta do material utilizado para o estudo das diatomáceas, em geral, é oriunda do fitoplâncton e de sedimentos de superfície. Os principais assuntos abordados dizem respeito à caracterização sistemática, à frequência de ocorrência, ao habitat e ao hábito dos gêneros, a estudos ambientais (lacustres, estuarinos e marinhos) e ecológicos, à distribuição das espécies, à produção primária, a relações tróficas, a estudos evolutivos e estatísticos, entre outros. Entretanto, estudos baseados na análise de diatomáceas que ocorrem em testemunhos de sondagem são considerados raros. Destacam-se os seguintes trabalhos: Arejano & Medeanic (2007), Medeanic *et al.* (2009), Hermany (2009), Santos (2011), Hermany *et al.* (2013), Weschenfelder *et al*. (2014), Santos-Fischer (2015) e Santos-Fischer *et al.* (2016). Os procedimentos laboratoriais (Santos, 2012) e as identificações taxonômicas (Santos-Fischer, 2015; Santos-Fischer *et al.,* 2016) serviram como base para o desenvolvimento deste trabalho com as diatomáceas.

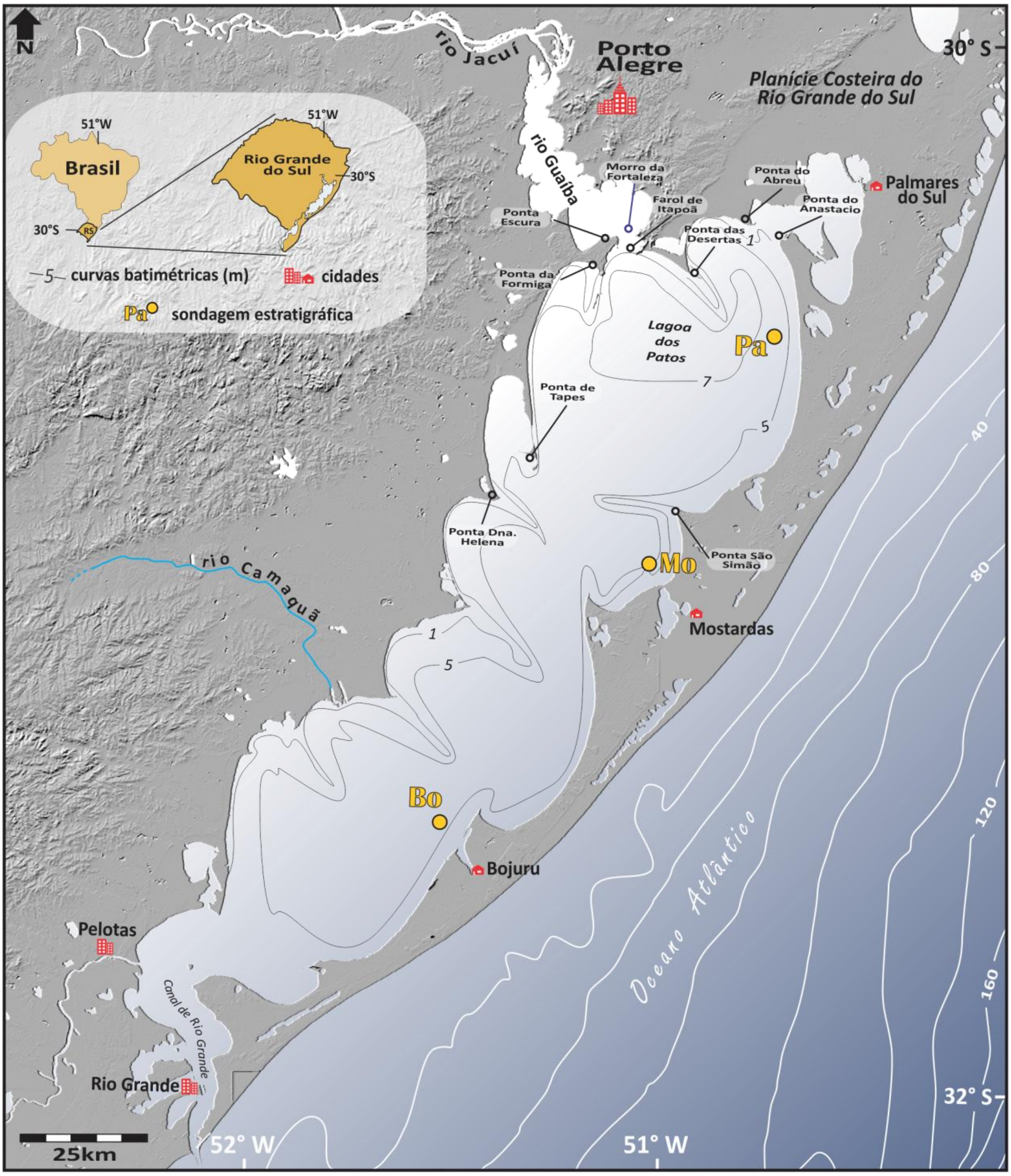

Figura 1 – Mapa de localização da área e dos testemunhos Bojuru (Bo), Mostardas (Mo) e Palmares do Sul (Pa), (modificado de Baitelli, 2012)

1.3. Materiais e Métodos

1.3.1. Coleta de Amostras

Para a realização deste trabalho foram utilizados testemunhos de sondagem. De sul para norte, os testemunhos estão localizados próximos às cidades de Bojuru (Bo) com 20 amostras, Mostardas (Mo) com treze amostras e de Palmares do Sul (Pa) com dezoito amostras (Tabela 1). Os testemunhos foram obtidos por ensaio de penetração dinâmica SPT (*SPT - Standard Penetration Test*). A amostragem foi feita de metro em metro com a extração da amostra realizada pela cravação do amostrador. A amostra recuperada representa em torno de 50 cm de espessura contínua do pacote sedimentar. A coleta deste material foi realizada por Bortolin (2011).

Tabela 1 - Localização dos testemunhos estudados, profundidade, lâmina d'água e total de amostras obtidas.

Localização	**Coordenadas**	**Comprimento (m)**	**Lâmina d'água (m)**	**Número de amostras**
Bojuru (Bo)	31º31'30''S 51º29'50''W	27,00	8,00	20
Mostardas (Mo)	31º00'25''S 51º00'10''W	29,50	7,30	13
Palmares do Sul (Pa)	30º32'52''S 50º42'54''W	28,5	6,00	18

1.3.2. Tratamento das Amostras

As amostras retiradas dos três testemunhos foram pesadas, acondicionadas em sacos plásticos, identificadas e etiquetas. A pesagem em balança de precisão Mark M214A resultou em torno de 50 g para análise macroscópica e de 10 g para análise microscópica de sedimentos não consolidados. Posteriormente, as amostras seguem para preparação em laboratório seguindo os seguintes passos para os cinco grupos taxonômicos (foraminíferos, equinodermas, poríferos, moluscos e crustáceos): desagregação da amostra em cápsulas de porcelana com água e aquecimento em estufa a temperatura de 60°C, sucessivas vezes até que o material desagregue totalmente; lavagem com água corrente em peneira de malha 0,062 mm para retirada do sedimento mais fino (silte e argila), no mínimo três vezes, até o clareamento da água de lavagem; inserção do sedimento novamente nas cápsulas de porcelana para secagem em estufa a temperatura máxima de 60°C; após secagem, procedeu-se a catação com pincel fino, selecionando os diferentes tipos de organismos e transferindo-os para as lâminas micropaleontológicas individualizadas para posterior classificação taxonômica.

A preparação das diatomáceas segue os padrões usuais do grupo e foram descritas no trabalho desenvolvido por Santos (2012).

1.3.3. Classificação Taxonômica

A identificação taxonômica para moluscos e organismos associados contou com o auxílio de estereomicroscópio com ocular de 10x e objetivas com aumentos de até 4x para a seleção dos espécimes. Esta identificação e comparação foram feitas por seus equivalentes atuais, tendo como base a consulta a atlas, catálogos, internet e bibliografia especializada, onde se destacam os trabalhos de: Shrock & Twenhofel (1953), Forti (1969), Closs & Forti (1971), Madeira-Falcetta *et al*. (1980 a,b), Kotzian & Eilert (1985), Abbott & Dance (1986), Forti-Esteves (1986), Rios (1994), Rios (2009), Thomé *et al.* (2010), o site Conquiliologistas do Brasil, Carvalho *et al.* (2011), Pitombo & Young (2011), Souza-Lima & Manso (2011) e Zucon & Vieira (2011).

Dados ecológicos sobre os táxons encontrados utilizados para interpretar a paleoecologia e o paleoambiente, baseiam-se em informações sobre táxons atuais, obtidos em diversos trabalhos dentre eles Würdig (1983), Roelofs (1984), Volkmer-Ribeiro *et al*. (1988), Walton & Sloan (1990), Mostardeiro *et al.* (2003), Coimbra *et al.* (2007), Talgatti *et al*. (2007), Rios (2009), Thomé *et al.* (2010), Carvalho *et al.*

(2011), Pitombo & Young (2011), Souza-Lima & Manso (2011), Zucon & Vieira (2011), Gonçalves (2012), entre outros.

Os ostracodes mencionados e utilizados neste trabalho têm como base a identificação proposta por Leite *et al*. (2013).

A identificação dos táxons em nível específico das diatomáceas foi consultada em obras pertinentes e foram elaboradas por Santos (2015).

Todo a material biogênico identificado encontra-se depositado em lâminas e fazem parte do acervo de amostras sedimentares da litoteca do Centro de Estudos de Geologia Costeira e Oceânica, Órgão Auxiliar do Instituto de Geociências da Universidade Federal do Rio Grande do Sul.

1.3.4. Análise Granulométrica

As análises granulométricas das amostras de sedimentos foram realizadas nos laboratórios do Centro de Estudos de Geologia Costeira e Oceânica, Órgão Auxiliar do Instituto de Geociências da Universidade Federal do Rio Grande do Sul, cuja classificação textural encontra-se detalhada em Shepard (1954) e a metodologia em Martins *et al*. (1987).

A descrição sedimentológica do testemunho Mo segue a fornecida por Bortolin (2011) e a descrição sedimentológica do testemunho Pa segue a fornecida por Baitelli (2012).

1.3.5. Análises Isotópicas

As análises isotópicas de δC^{13} e de δO^{18} utilizadas neste trabalho são de autoria de Baitelli (2012) assim como a datação por ^{14}C e foram realizadas as duas primeiras no laboratório de Geoquímica Isotópica, da Universidade Federal de Brasília (UnB) e as amostras para datação por ^{14}C foram enviadas ao laboratório Beta Analytic Inc, em Miami, Flórida.

2. Sumário Integrador

A malacofauna extraída de testemunho de sondagem no interior da Lagoa dos Patos é inédita. A tônica principal dos trabalhos aqui abordados envolve o conteúdo malacológico que ocorre em três testemunhos de sondagem obtidos na referida Lagoa. Os testemunhos estão localizados próximos às cidades de Bojuru, Mostardas e Palmares do Sul, municípios integrantes da Planície Costeira do Rio Grande do Sul e por esta razão receberam a identificação com base nas iniciais das respectivas cidades Bo, Mo e Pa.

A escolha deste grupo de microfósseis está relacionada à grande diversidade do grupo, à fácil identificação taxonômica e a ampla distribuição em regiões costeiras. As conchas dos moluscos são importantes instrumentos na ciência da paleontologia que pode ser aplicada tanto para o conhecimento na área geológica como na biológica.

Estes organismos são muito utilizados como indicadores nos estudos de estratos terrestres, datação da idade da Terra, distribuição geográfica, presença de petróleo (Thomé *et al*., 2010) e também em estudos tafonômicos mostrando-se importantes ferramentas nas interpretações paleoambientais tanto em ambientes límnicos como marinhos (Ritter, 2010a, b; Erthal *et al*., 2011; Ritter & Erthal, 2011).

Um total de dezenove táxons de moluscos foram registrados nos trabalhos sendo quinze em nível específico e quatro em nível genérico. Na mesma oportunidade foram feitos comentários a cerca do estado de preservação das conchas dos moluscos.

O trabalho identifica as associações de moluscos das classes Bivalvia e Gastropoda extraídos dos testemunhos e servirá como mais uma ferramenta para elucidar, sob o enfoque biogênico, esclarecimentos sobre a evolução da Planície Costeira do Rio Grande do Sul. A importância destes organismos se deve ao fato de que eles serem bons indicadores de informações paleoecológicas como temperatura, salinidade, etc (Forti-Esteves, 1974) e paleoambientais.

Nas últimas décadas vários estudos vêm sendo desenvolvidos na Planície Costeira do Rio Grande do Sul principalmente em relação a sistemas deposicionais aflorantes e pouco profundos com enfoque geológico cita-se Villwock (1972, 1984); Villwock *et al.* (1986); Villwock & Tomazelli (1995, 1998); Tomazelli *et al.* (2000); Dillenburg *et al.* (2004, 2006, 2009, 2013) entre outros.

No final da década de 80 pesquisas realizadas na Lagoa dos Patos demonstraram novas perspectivas de cunho geológico e biológico através dos trabalhos de: Martins *et al*. (1989), Toldo Jr. (1989), Cordeiro & Lorscheitter (1994), Toldo Jr. (1994), Toldo Jr. *et al*. (2000), Medeanic *et al.* (2001), Toldo Jr. *et al*. (1991, 2000, 2006), Corrêa *et al.* (2003, 2004), Weschenfelder (2005), Weschenfelder *et al.* (2005, 2008a, b, 2010a, b, 2014), Vasconcellos (2006), Baitelli *et al.* (2007), Pereira *et al.* (2009), Calliari *et al*. (2009, 2010), Bortolin (2011), Bortolin & Weschenfelder (2012, 2014), Baitelli (2012), Santos-Fischer (2015) e Santos-Fischer *et al.* (2016).

A aplicação de novas tecnologias, como a sísmica de alta frequência, passaram a ter um papel importante em função de apresentar resultados de subsuperfície. Sobre este aspecto vale salientar as pesquisas de Abreu & Calliari (2005), Weschenfelder (2005), Weschenfelder *et al*. (2008a, b, 2010a, b, 2014), Baitelli (2012), Corrêa *et al.* (2004, 2013, 2014), Bortolin & Weschenfelder (2012, 2014) e Santos-Fischer *et al.* (2016).

Desde 2000 um projeto sobre a Lagoa dos Patos vem se desenvolvendo no Centro de Estudos de Geologia Costeira e Oceânica, Órgão Auxiliar do Instituto de Geociências da Universidade Federal do Rio Grande do Sul, com a contínua coleta de testemunhos e realização de uma sequência sísmica de alta frequência em vários pontos da referida Lagoa.

Estes estudos revelaram que a região da planície costeira gaúcha, antes da formação atual da Lagoa dos Patos se achava muito drenada (Baitelli, 2012) e com o passar do tempo, durante o Quaternário, vários episódios de transgressões e regressões marinhas, umas maiores e outras menores ocorreram na região e terminaram por gerar marcas denominadas de paleocanais. Desde então, várias pesquisas têm sido propostas na tentativa de identificar estes paleocanais e de se saber a origem dos sedimentos que os preencheram.

Dando continuidade ao estudo sobre o entendimento do processo de evolução sedimentar da Planície Costeira do Rio Grande do Sul na sequência é desenvolvido um estudo específico sobre o testemunho de sondagem Mo com base em moluscos associados a ostracodes, foraminíferos e diatomáceas. É feito um zoneamento qualitativo com base nestes biogênicos onde se tem uma deposição sedimentar indicativa de ambiente marinho raso com alguma influência de água doce ou mixohalina.

No seguimento é apresentado um zoneamento quantitativo do testemunho de sondagem Pa onde além da malacofauna presente são analisados os biogênicos (foraminíferos, espinhos de equinodermas, espículas silicosas ostracodes, cirripédios e diatomáceas) que ocorrem associados sob o aspecto paleoecológico e paleoambiental. De acordo com estes organismos tem-se a indicação de um ambiente marinho raso para o referido testemunho.

Os moluscos dos três testemunhos estudados são analisados na sua identidade, diversidade e utilização em interpretações paleoambientais. Um estudo sobre a tafonomia também é desenvolvido e para tanto as conchas dos moluscos foram quantificadas quanto a: integridade, articulação das valvas (bivalves), integridade da ornamentação, integridade de brilho, marcas orgânicas e seleção de tamanho das conchas.

Este estudo, sobre o enfoque biogênico, representa mais uma ferramenta que com certeza vai se somar e fornecer mais informações e subsídios para o estudo do processo evolutivo que ocorreu na Planície Costeira do Rio Grande do Sul. Estas informações servirão para auxiliar na interpretação do modelo de formação e preenchimento sedimentar do sistema de paleodrenagem que ocorreu na região no Quaternário.

Capítulo 2

Biogenic Zones of the core Mo, Lagoa dos Patos, Rio Grande do Sul state, Brazil

Zonas Biogênicas do testemunho Mo, Lagoa dos Patos, Rio Grande do Sul, Brasil

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Resumo – Neste trabalho são inventariados os biogênicos: moluscos, foraminíferos, ostracodes e diatomáceas, encontrados no testemunho de sondagem Mo, localizado na região de Mostardas, parte imersa da Lagoa dos Patos. O testemunho Mo está localizado nas coordenadas 31º00’25”S e 51º00’10”W, possui 29,5 m de comprimento e encontra-se sob 7,30 m de lâmina d’água. Com base nos biogênicos identificados três zonas foram estabelecidas. A Zona I, (15,0-14,0 m de profundidade) caracterizada por diatomáceas de ambiente marinho a marinho mixohalino com influência marinha. A Zona II, (14,0-10,5 m de profundidade), onde ocorrem todos os biogênicos inventariados, e indicativa de ambiente marinho associado a espécies marinhas a marinhas mixohalinas e diatomáceas dulciaquícolas. E a Zona III (10,5-7,3 m de profundidade), com redução dos biogênicos caracterizada por organismos de diferentes ambientes associados como marinhos, mixohalinos, marinho mixohalinos e marinhos a marinhos mixohalinos, indicativa de ambiente marinho a marinho mixohalino com influência marinha. Ao mesmo tempo são fornecidos dados paleoecológicos e paleoambientais com base nos táxons reconhecidos. Evidências de pequenos pulsos entre os eventos de transgressão e regressão são observados ao longo de todo o testemunho, com base nos organismos registrados.

Palavras chave: Moluscos, Paleoambiente, Holoceno

Abstract – In this work the following biogenics are inventoried: mollusks, foraminifers, ostracods and diatoms, found in the core Mo, located in Mostardas, immerse portion of the Patos Lagoon. The core Mo lies at 31º00’25”S and 51º00’10”W, has 29.5 m length and was collected under 7.30 m water depth. Based on the identified biogenics, three zones have been proposed. The Zone I (15.0-14.0 m depth), composed exclusively of marine and mixohaline diatoms. The Zone II (14.0-10.5 m depth), where occurs all the biogenic inventoried and indicative of marine environment associated to marine to marine mixohaline and freshwater diatoms. The Zone III (10.5-7.3 m depth) records reduction of biogenics characterized by the association of organisms from different environments such as marine, mixohaline, marine-mixoaline and marine to mixohaline, indicating a marine to marine mixohaline with marine influence environment. Additionally, paleoecological and paleoenvironmental data based on the identified taxa are supplied. Evidences of small pulses between transgressive and regressive events along the core based on the organisms recorded.

Keywords: Mollusks, Paleoenvironment, Holocene

1 Introduction

Coastal plains occur along all Brazilian coast with regional peculiarities. They are basically discontinuous, narrow, and usually covered by poorly fossiliferous sands (Closs, 1970). The Rio Grande do Sul Coastal Plain, theme of this work, has been studied in the last few decades through detailed mapping, analysis of surface outcroppings, coring and cutting samples. The expansion of those research approaches, as well as the adoption of new techniques, are necessary to the acquisition of additional information on the region. In the last few years high resolution seismic studies have been carried out. In the beginning of the 21st century, seismic profiles were performed in the Patos Lagoon concomitant with corings. These cores have been studied under different approaches, being the analysis of biogenics one of them.

The first study on biogenics from the Patos Lagoon and adjacent areas was carried out by Ihering (1885) who described mollusk species and their stratigraphic application. Martins (1952) dated the fossil mollusks from some cores in the Pelotas Basin. Forti (1969) developed a mollusk-based stratigraphic study in cores from Cassino and Palmares do Sul. Closs (1970) analized samples from drillings carried out by Petrobras (Petróleo Brasileiro S.A.) in the Pelotas Basin, recording foraminifers, briozoans, a few brachiopods, abundant mollusks, and corals which were used for dating. Forti-Esteves (1974) published a paleoecologic study based on mollusk associations of two subsurface samples from Palmares do Sul and Cassino, and five additional localities in Santa Vitória do Palmar. Godolphim *et al.* (1989) determined paleoenvironments based on a macrofaunal assemblages composed of mollusks, echinoderms, briozoans and corals, and a microfaunal assemblage composed of ostracods and foraminifers in outrcrop samples from São Lourenço, Pelotas, Capão do Leão, Pedro Osório and Rio Grande.

The foraminifers in the Rio Grande do Sul Coastal Plain were studied by Closs (1962, 1966), Closs & Madeira (1968) and Boltovskoy *et al*. (1983). Several studies on this group in the Pelotas Basin, dealt with biostratigraphy, paleoecology and isotope analyses, e.g. Closs (1970), Thiesen (1975), Fernandes (1975), Madeira-Falcetta & Thiesen (1988), Giacomel *et al*. (2007), Coimbra *et al.* (2009), Zerfass (2009) and Silva *et al.* (2013). Foraminifers from the shelf and slope of the Rio Grande do Sul State were studied by Vicalvi (1977), Carvalho (1980), Madeira-Falcetta *et al.* (1980a), Rodrigues & Carvalho-Pires (1981) and Boltovskoy *et al.* (1982). Madeira-Falcetta *et al.* (1980b) associated the foraminifers and ostracods with sediments to interpret depositional environments in two cores from Palmares do Sul and Balneário Albatroz.

Ostracod studies in the Rio Grande do Sul Coastal Plain with both taxonomic and biostratigraphic purposes gave additional contribution to the knowledge on the sea-level changes in the Pelotas Basin (e.g. Sanguinetti, 1974, 1991, 1992; Ornellas, 1981; Carreño *et al.*, 1997, 1999; Ceolin *et al.*, 2011; Manica & Coimbra, 2013, 2015 and Manica, 2015). Ostracods from the Tramandaí lagoon system were studied by Würdig (1983) with emphasis on systematics, ecology and potential application to paleoecology. Leite *et al.* (2013) carried out a preliminary work on Quaternary ostracods from the immerse portion of the Patos Lagoon.

The research on fossil diatoms in the Rio Grande do Sul Coastal Plain is poorly developed. Palinological and other micropaleontological studies in different sites of this area, as well as in the continental shelf have recorded diatoms (Medeanic *et al.*, 2008; Weschenfelder *et al.*, 2008, 2014; Lima *et al.*, 2013; Corrêa *et al.*, 2013, 2014). Diatom-based paleoenvironmental studies were carried out in Cassino (Medeanic *et al.*, 2009), Peixe Lagoon (Santos, 2011), Itapeva Lagoon (Hermany *et al.*, 2013), Patos Lagoon (Santos, 2015; Santos-Fischer *et al.*, 2016) and in the continental shelf and slope (Santos-Fischer *et al.*, 2016).

The present study is a contribution to the improvement of the knowledge on the biogenics identification in the Patos Lagoon and adjacent areas. The study of the core Mo permitted more detailed data on the paleoenvironmental changes in the region, based on the diversity and paleoecology of the biogenics recorded. Additionally, biogenic zones are proposed aiming at a more comprehensive understanding on the paleoenvironmental evolution of the Patos Lagoon.

2 Study area description

The study area lies in the Rio Grande do Sul Coastal Province (Villwock, 1972, 1984; Urien & Martins, 1978; Villwock *et al*., 1986, 1994; Villwock & Tomazelli, 1995, 1998). This province comprises the sedimentary deposits of the Pelotas Basin and its adjacent basement (Villwock, 1972; 1984). Villwock & Tomazelli (1995) divided the Rio Grande do Sul State into two geomorphological domains: the High Lands (Sul-riograndense Plateau, Central Depression and Araucárias Plateau), and the Low Lands (Coastal Plain and Continental Shelf). The Pelotas Basin is a marginal basin that lies over both the pre-Cambrian basement and the volcanic sedimentary sequences of the Paraná Basin. According to Gamboa & Rabinowitz (1981), covers approximately 210.000 km² and originated from the tectonic movements of the South Atlantic opening during the Cretaceous. It is limited in the north by the Florianópolis High and in the south by the Polônio Cape (Urien & Martins, 1978). The basement of the Pelotas Basin is composed of rocks of the Sul-riograndense Shield and the Uruguayan Shield, which belong to the Mantiqueira Province (Almeida *et al*., 1981), as well as the volcano-sedimentary rocks of the Paraná Basin, that crop-out in the west region of the basin.

In the Rio Grande do Sul Coastal Plain, Villwock & Tomazelli (1995) described two depositional systems: (1) a fan delta system that corresponds to the transition between the High Lands of the Pelotas Basin basement and the sandy bar systems, and (2) a depositional system of lagoon-barrier type. The latter is the most representative for the present work. Villwock & Tomazelli (1995), Tomazelli *et al.* (2000) and Dillenburg *et al.* (2000, 2004, 2006, 2009, 2013) identified four lagoon-barrier depositional systems. Three of them are Pleistocene (barriers I, II and III) and one is Holocene (barrier IV) (Villwock, 1984; Villwock & Tomazelli, 1995). According to those authors, the formation of the sandy barrier systems resulted from high frequency sea-level oscillations which occurred during the Quaternary, and are in accordance to the global curves. The Pleistocene barriers are composed of fine to medium quartz-feldspar facies with rounded grains immersed into silt-clay matrix. The Patos-Mirim lagoons (Tomazelli *et al*., 2000) were established during the last Pleistocene system, which corresponds to the Barrier III, the area studied in this work. The sediments of this barrier are sandy facies of beach and shallow marine origin covered by aeolian ones.

The Patos Lagoon is the most representative morphological feature of the Rio Grande do Sul Coastal Plain. The main axis of the lagoon has about 180 km in NE-SW direction, including an estuarine region of approximately 60 km aligned to the coast between 30˚30'S and 32˚12'S, near to Rio Grande, where it connects to the Atlantic Ocean (Toldo Jr., 1994; Asmus, 1998; Calliari *et al*., 2009). It presents 240 km length, average width of 40 km, average depth of 6 m and surface area of approximately 10,000 km^2 (Baitelli *et al*., 2007). According to Asmus (1998), the central water body of the Patos Lagoon is composed by four elliptical cells which represent approximately 80% of the lagoon area, and its margins are dominated by freshwater marshes and sandy beaches. The estuarine portion in the south part of the lagoon has 971 km^2 (10% of the lagoon area), where occurs the influx of waters from the Atlantic Ocean through the Rio Grande channel (Figure 1).

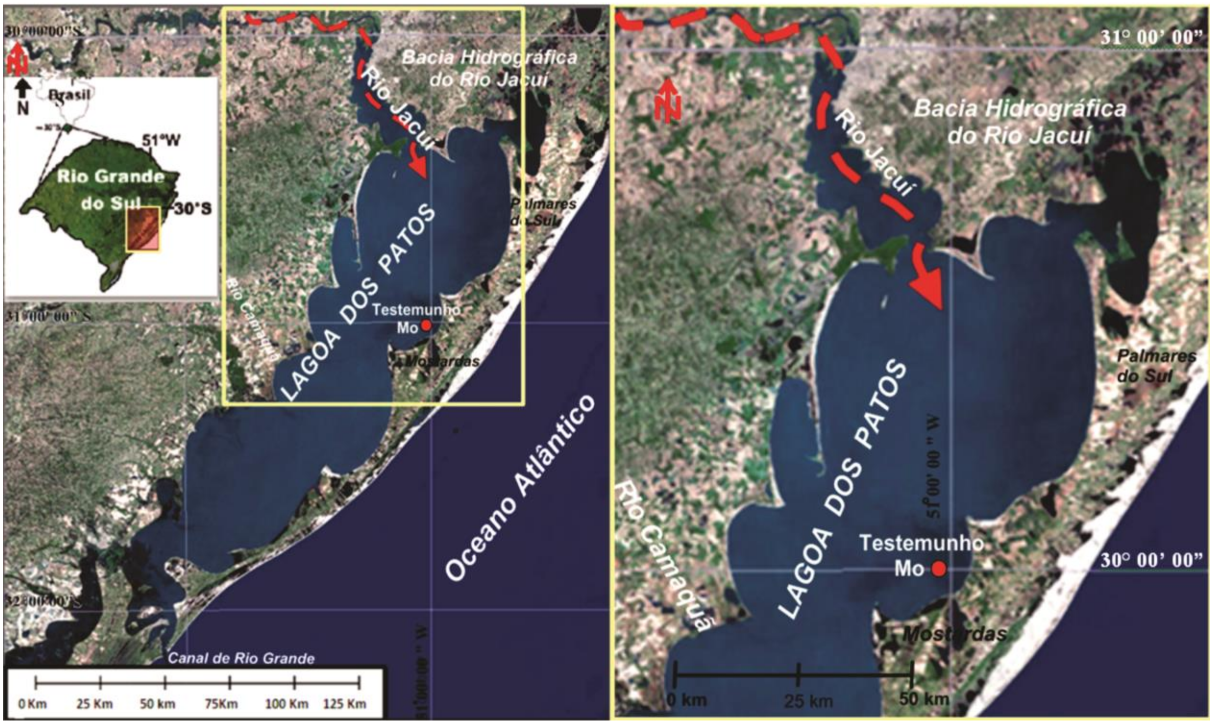

Figure 1 – Location map of the study area and the core Mo

Figura 1 – Mapa de localização da área de estudo e do testemunho Mo

3 Material and methods

3.1. The Core Mo

The core Mo was collected near Mostardas (31º00’25’’S; 51º00’10’’W) at 7.30 m water depth. The site was chosen based on the interpretation of the seismic records, and located with GPS system. The drilling method used was the Standard Penetration Test, SPT (Baitelli, 2012), resulting in the recuperation of a core with 29.5 m length and 3.9 cm diameter, wherein the sampling was performed each meter through the insertion of the sampler into 13 intervals. Each sample represents approximately 50 cm of the sedimentary package and their sedimentological descriptions follow Bortolin (2011), being fine sand (0.125–0.177 mm) the predominant class. Isotopic analyses of δC^{13} and δO^{18} and radiocarbon dating of ^{14}C were carried out in the biogenic material (Table 1) (Baitelli, 2012; Santos-Fischer *et al*., 2016).

Table 1 – ^{14}C, δC^{13} and δO^{18} analyses and location of the species in the core Mo

Tabela 1- Análises de ^{14}C, δC^{13} e δO^{18} e localização das espécies no testemunho Mo

Interval (m)	Conventional age (^{14}C yr BP)	Calibrated age (yr BP)	δC^{13}	δO^{18}	Material	Author
7,3-10,5	7420±40	7960-7680	-	-	*E. mactroides*	Santos-Fischer *et al*. (2016)
11,5-12,3	7.490 ± 50	7980-7750	- 0,6‰	- 0,873‰	*C. gayi*	Baitelli, 2012
13,4-13,5	7.260 ± 40	8160-7920	- 1,1‰	- 1,835‰	*C. gayi*	Baitelli, 2012

3.2. Preparation of the biogenics

The interval 29.0-15.0 m was barren, while in the six subsequent samples (15.0-7.3 m) biogenic material was recovered. The samples were weighed in a precision scale, being 50 g for the analysis of mollusks, and 10 g for foraminifers and ostracods. Sample preparation followed the usual protocols and afterwards the specimens were picked and stored in micropaleontologic slides for taxonomic classification under stereomicroscope. The diatoms were prepared according to Santos (2012) in permanent slides for study of the group in optical microscopy.

3.3. Taxonomic classification

The taxonomic classification of mollusks, ostracods and foraminifers was carried out under stereomicroscope with eypieces of 10x and objectives up to 4x. The identification of those biogenics was based on comparisons with recent co-specific specimens, as well as atlas, catalogues and publications. The scientific collection of micropaleontology of the Department of Paleontology and Stratigraphy, Institute of Geosciences, Federal University of Rio Grande do Sul, was also consulted for the mollusks identification. The mollusks taxonomy adopted follows Rios (2009); for the foraminifers, Madeira-Falcetta (1977) and Madeira-Falcetta *et al*. (1980a); for the ostracods, Leite *et al.* (2013), and for the diatoms, Santos (2015). Ecological information is provided for each species identified in order to characterize their respective paleoenvironment based on atualistic principles. The biogenic material studied in the present work was stored either in micropaleontological slides (mollusks, foraminifers and ostracods) or permanent slides (diatoms) and held at the sediment collections of the Center for Studies on Coastal and Oceanic Geology, Geosciences Institute, Federal University of Rio Grande do Sul.

4 Results and discussion

4.1. Biogenics of the core Mo

The interval 29.0-15.0 m, base of the core Mo, is barren. In the depths between 15.0 m and 7.3 m it were obtained six intervals with biogenics represented by mollusks, foraminifers, ostracods and diatoms. In the interval 15.0-14.0 m only marine to marine mixohaline and marine mixohaline diatoms were recorded, while in the remaining intervals the biogenic distribution is more homogeneous.

The mollusks are represented by *Tawera gayi* (Hupé, 1854), *Erodona mactroides* Bosc, 1908, *Heleobia australis* (Orbigny, 1842), *Turbonilla fasciata* (d'Orbigny, 1840), *Corbula* sp., *Adrana* sp., *Heleobia* sp., *Nucula semiornata* Orbigny, 1846, *Acteocina bidentata* (Orbigny, 1841), *Anomalocardia brasiliana* (Gmeli, 1791) and *Acteocina candei* (Orbigny, 1841).

The foraminifers identified are *Ammonia beccarii* (Linnaeus, 1758), *Elphidium discoidale* (Orbigny, 1839), *Orbulina universa* Orbigny, 1839 and *Candeina nitida* Orbigny, 1839. Only three ostracod species were identified, as follows: *Cyprideis multidentata* (Hartmann, 1955), *Cytheretta punctata* (Sanguinetti, 1979) and *Minicythere heinii* Ornellas, 1974.

The diatom assemblages recorded are composed, according to Santos (2015), by *Paralia sulcata* (Ehrenberg, 1838) Cleve, 1873, *Actinoptychus senarius* Ehrenberg, 1838, *Actinoptychus splendens* (Shadbolt, 1854) Ralfs *in* Pritchard, 1861, *Coscinodiscus radiatus* Ehrenberg 1840, *Cyclotella striata* (Kützing, 1844) Grunow, 1880, *Psammococconeis* *disculoides* (Hustedt, 1955) Garcia, 2001, *Thalassiosira oestrupii* (Ostenfeld, 1900) Proschkina-Lavrenko & Hasle, 1960, *Triceratium favus* Ehrenberg, 1839, *Eunotia* sp., *Pinnularia* sp., *Eunotia major* (Smith, 1856) Rabenhorst, 1864, *Fragilaria crassa* Metzeltin & Lange-Bertalot, 1998, *Gyrosigma* sp., *Achnanthes* sp., *Pinnularia borealis* Ehrenberg, 1843, *Encyonema* sp. and *Desikaneis gessneri* (Hustedt, 1987) Prasad, 1993.

4.2. Paleoecology of the biogenics

The palaecological interpretations are based on both living and fossil species according to several authors, e.g. Boltovskoy (1963, 1970, 1979), Bé & Tolderlund (1971), Madeira-Falcetta (1977), Bertels *et al.* (1982), Würdig (1983), Carreño *et al*. (1999), Coimbra *et al.* (2007), Medeanic *et al*. (2008), Rios (2009), Thomé *et al.* (2010) and Santos-Fischer *et al.* (2016).

4.2.1. Mollusks

The mollusk diversity in the core Mo is low, probably in consequence of the environmental variability prompted by the marine to fluvial sedimentation during the sea level change events. This result agrees with Renzi & Martinell (1979) who, studying Pliocene gastropods from Catalonia, Spain, demonstrated that the specific diversity is associated to the environmental stability. Few species are able to adapt to abrupt environmental changes, resulting, therefore, in diversity decrease. Those authors also concluded that diversity analyses must be performed not only vertically, but also horizontally, since important fluctuation may have happened in both. Margalef (1980) argues that in the study of fossil frequencies, environmental changes or instabilities correspond to low diversity. Diversity increases occur only if the stable conditions persist for a period sufficient for the development of a harmonic fauna. According to Veitenheimer-Mendes (1993), increases in the specific diversity of mollusks correspond to environmental stability, especially in terms of salinity and temperature.

Some taphonomic conclusions could be obtained from the core Mo, some species are represented by partially eroded specimens and showed bioerosion in all intervals, while rare specimens exhibited intact shells and predation marks.

Ecological parameters such as depth, salinity, substrate composition and temperature are influent, in variable degrees, on the occurrence of mollusk species (Forti-Esteves, 1974; Rios, 2009; Thomé *et al*., 2010; www.conchasbrasil.org.br/conquiliologia/). The analysis of the core Mo demonstrates that *A. bidentata*, *N. semiornata*, *T. gayi*, *A. candei* and *A. brasiliana* are typical of shallow marine environments, while *E. mactroides* and *H. australis*, of shallow estuarine environment (0-30 m depth).

The occurrence of *A. brasiliana* (12.3-11.5 m) is indicative of significant salinity variations. Studies on the influence of salinity in living specimens of this taxon were carried out by several authors, being Schaeffer-Noveli (1980) in Saco da Ribeira, São Paulo State, noteworthy. That author sustains that this species is eurythermic and euryhaline, and resistant to regional anoxic conditions. Leonel *et al.* (1983) demonstrated that the salinity range of the species varies from 17 to 42 psu, being the optimum around 22 psu. Monti *et al*. (1991) registered values between 17 to 38 psu, while Boehs *et al.* (2008), recorded its occurrence from the mouth of the Paranaguá Channel, Paraná State, whose average salinity is 30 psu, to upward sectors where it can be as low as 17 psu.

E. mactroides occurs in the intervals 14.0-13.0 m, 13.0-12.3 m, 11.5-10.5 m and 10.5-7.3 m. It can be considered an euryhaline species due to physiological adaptations that permit its thriving under broad salinity ranges, from estuaries (where the salinity is tide-influenced) up to lagoons, creeks and rivers (Forti-Esteves, 1974). Nonetheless, Abbott & Dance (1986) and Godolphim *et al.* (1989), consider it a mixohaline taxon, while Rios (1994) defines its salinity range from 7 to 20 psu.

H. australis occurs in the core Mo along the intervals 14.0-13.0 m, 13.0-12.3 m, 12.3-

11.5 m and 11.5-10.5 m. Though more common in mixohaline waters, its euryhaline character permits also its occurrence among marine algae in estuaries and dispersal throughout marine waters during the high tide (Forti-Esteves, 1974). Rios (1994) considers *H. australis* an estuarine species, and Silva (2003) observed size variation in living representatives of this gastropod and its wide distribution along the Rio Grande do Sul Coastal Plain, possibly influenced by coastal marine waters. This dispersal pattern, according to that author, results from the planktonic larvae (veliger) and its salinity tolerance, since the *Heleobia*’s veliger disperses according to the water masses. The smaller specimens of *H. australis* are more representative in the Mo core than the larger ones, and their size varies between 1.3 and 3.6 mm. This corroborates Silva’s (2003) results, which revealed that the size of this species in the Patos Lagoon ranges from 2.49 to 3.72 mm in mixohaline zones, and from 4.95 to 6.45 mm in limnic and estuarine zones. In relation to the bottom composition, species such as *A. brasiliana*, *E. mactroides*, *H. australis*, *N. semiornata*, *T. gayi*, *A. candei* and *A. bidentata* prefer sandy-clayed sediments (Forti-Esteves, 1974; Rios, 2009; Thomé *et al*., 2010).

4.2.2. Foraminifers

The foraminifers in the core Mo are well preserved and represented by the planktonic marine *O. universa* (11.5-10.5 m to 10.5-7.3 m) and *C. nitida* (11.5-10.5 m) and the benthic mixohaline *A. beccarii* and *E. discoidale* in the interval 15.0-14.0 m.

Studies on the temperature preferences in recent foraminifers indicate that *E. discoidale* is a typical warm water species (Boltovskoy, 1970), *C. nitida* a typical tropical warm water (20 to 30^{o}C) (Bé & Tolderlund, 1971) and *O. universa* as typical from tropical (20-30^{o}C) to subtropical waters (18-24^{o}C) (Boltovskoy, 1979). This demonstrates that temperatures at the deposition time of these carapaces were similar to the present ones.

Bertels *et al*. (1982) in their study on Quaternary foraminifers of a core in Palmares do Sul registered species typical from coastal mixohaline/euryhaline lagoon environments such as *A. beccarii* and *E. discoidale, Elphidium galvestonense*, *Elphidium excavatum,* as well as species typical of shallow marine environments.

In a study on recent foraminifers Madeira-Falcetta (1977) concluded that *A. beccarii* and *E. discoidale* are common in bays, estuaries and lagoons. *E. discoidale* is considered a typical inner shelf inhabitant (Boltovskoy *et al.*, 1980), yet it has been also recorded in lagoons and estuaries in southern Brazil, Uruguay and Argentina, especially, in the La Plata River, characterized by wide salinity variations (lower than 1 psu) and in the Mar Chiquita (1.8-34.4 psu) (Boltovskoy, 1957; 1963; Closs & Madeira, 1962; 1968; Lena & L'Hoste, 1975; Boltovskoy *et al.*, 1980; Ferrero, 2009).

Ferrero (2009) in her study on Late Pleistocene cores from the southern sector of the Mar Chiquita Lagoon, Argentina, identified *A. beccarii* as an eurobiont and oportunistic species with wide distribution and high abundance in the inner shelf, estuaries and marshes worldwide. Based on the aforementioned data the mixohaline foraminifers recorded in this study reveal a wide range of salinity and temperature. The co-occurrence of mixohaline and planktonic species also reinforces the sea level changes recorded in the fossiliferous part of the core, since the planktonic species live in oceanic waters.

4.2.3. Ostracods

The ostracod identified in the core Mo are the mixohaline *C. multidentata*, and the marine *C. punctata* and *M. heinii. C. multidentata* is absent only in the base of the core (15.0-14.0 m) and represented mostly by disarticulated carapaces with remains of soft parts, though some closed carapaces have also been found. *C. punctata*, on the other hand, is absent only in the upper portion of the core (15.0-7.3 m), while *M. heinii* occurs in the 13.0-12.3 m interval.

C. multidentata is the most abundant ostracod in the core Mo and the occurrence of both adult and juveniles indicates, probably, an autochthonous population. The population structure (adult-juvenile ratio) in ostracod assemblages permits to assess the proportion of autochthonous (Kontrovitz & Snyder, 1981). The juvenile carapaces are lighter than the adult ones and, therefore, more easily transported (Whatley, 1988). According to Kotzian & Eilert (1985) the genus *Cyprideis* is typical from coastal mixohaline environments, although Coimbra *et al.* (2007) sustain the opinion that it is a species with wide salinity ranges, including records in marine environments not only in Brazil, but in Argentina.

The intervals 14.0-13.0 m and 12.3-11.5 m, where *C. punctata* occurs, characterize a mixohaline environment. Carreño *et al.* (1999), studying the Neogene sea-level changes in the Pelotas Basin, registered *C. punctata* both in shallow marine and mixohaline environments. Bertels *et al*. (1982) based on the occurrence of the association *C. punctata*, *Kangarina* sp. and *Bensonia minipunctata*, defined the ostracods from a core in Palmares do Sul, Rio Grande do Sul State, as a shallow marine assemblage.

The species *M. heinii* occurs only in the interval 13.0-12.3 m, which corresponds to a mixohaline environment. Ornellas (1974) registered a transitional ostracod assemblage of mixohaline waters in the Tramandaí Lagoon estuary and another one in the mixohaline channel of the Patos Lagoon, which have connections with the Atlantic Ocean. Both associations are dominated by *M. heinii*, *Cyprideis* spp., *Perissocytheridea kroemmelbeini* and *Cytherura* sp. Bertels *et al*. (1982), also recorded typical mixohaline species such as *M. heinii* and *Cyprideis* sp., in Palmares do Sul.

Würdig (1983, 1988), Würdig & Freitas (1988) and Würdig *et al.* (1990), ostracod studies in the Tramandaí Lagoon, analyzed salinity and other environmental parameters, identifying four associations: polyhaline (18-35 psu), mesohaline (0.5-18 psu), oligohaline (< 3 psu), and limnic (0 psu). Those authors included in the polyhaline and mesohaline associatiations species typically mixohaline such as *M. heinii, Cyprideis riograndensis, C. salebrosa hartmanni*, *P. kroemmelbeini* and *Cytherura purperae*.

Although *C. punctata* and *M. heinii,* are typically shallow marine taxa (Würdig, 1983, 1988; Würdig & Freitas, 1988; Würdig *et al.*, 1990) they also occur in mixohaline waters

(Ornellas, 1974; Carreño *et al*., 1999). According to Coimbra *et al.* (2007), salinity is the most influential parameter on ostracods, being bottom composition, depth, temperature and pH of secondary influence on the distribution and abundance of species.

4.2.4. Diatoms

The diatoms occur along all the fossiliferous intervals of the core Mo. The marine species are *P. sulcata* and *A. splendens*, being the first one present in all the samples while the latter is restricted to the interval 14.0-13.0 m. *P. sulcata* is a reliable paleoenvironmental indicator due to its abundance, wide distribution and dissolution resistance compared to other species. *P. sulcata* usually occurs in marine and mixohaline waters of coastal zones (McQuoid & Nordberg, 2003). Ryu *et al*. (2008), however, argue that this species, per se, does not constitute an environmental indicator and the whole assemblage must be taken into account.

The marine to marine mixohaline species are *A. senarius*, *P. disculoides, T. favus, C. radiatus* and *T. oestrupii*. The marine mixohaline species *C. striata* was also registered and Santos (2015) even observed freshwater diatoms along the interval 14.0-10.5 m that are represented by *Eunotia* sp., *Pinnularia* sp., *Eunotia major*, *Fragilaria crassa*, *Gyrosigma* sp., *Achnanthes* sp., *Pinnularia borealis*, *Encyonema* sp. and *Desikaneis gessneri*. These diatoms are found very fragmented, rare, unusual and register one transported association, considered, probably, allochthonous (Weschenfelder *et al*., 2014).

The species *P. sulcata, C. striata, A. senarius, C. radiatus, P. disculoides* and *T. oestrupii* are considered planktonic euryhaline, usually recorded in marine deposits along coastal environments (Santos-Fischer *et al.*, 2016).

At the core top (10.5-7.3 m) the marine planktonic and marine to marine mixohaline species predominate associated to the marine mixohaline *C. striata*, which characterize a marine assemblage. The increasing incidence of the marine genus *Paralia* in Holocene sequences might indicate warmer and tropical climates (Santos-Fischer *et al*., 2016).

4.3. Biogenic zones of the core Mo

The distribution pattern of the biogenics in the core Mo allowed to identify three zones, hereafter named Zone I, Zone II and Zone III. The Zone I corresponds to the interval 15.0-14.0 m (Tab. 2), which represents the base of the fossiliferous section of the core. It is composed of marine, marine to marine mixohaline and marine mixohaline diatoms and mollusk shell fragments, while the remaining biogenics are absent. This zone indicates a marine trend due to the dominance of *P. sulcata* associated to marine and marine mixohaline species *P. disculoides*, *T. favus* and *A. senarius* and the marine mixohaline species *C. striata*.

Table 2 – Interval of occurrence of the biogenics with discrimination of the species, environment and zones. *freshwater diatoms were based on Santos (2015) used as reference.

Tabela 2 – Intervalo de ocorrência dos biogênicos com a discriminação das espécies, ambiente e zonas. *diatomáceas dulciaquícolas utilizadas como referência baseadas em Santos (2015).

Interval (m)	**Biogenics**	**Species**	**Environment**	**Zones**
Mo 10.5-7.3	Mollusk	*Heleobia* sp., *E. mactroides*	Mixohaline	III
	Foraminifer	*A. beccarii*, *E. discoidale*	Mixohaline	
		O. universa	Marine	
	Ostracod	*C. multidentata*	Mixohaline	
	Diatom	*P. sulcata*	Marine	
		A. senarius, *C. radiatus*, *P. disculoides*, *T. oestrupii*, *T. favus*	Marine to marine mixohaline	
		C. striata	Marine mixohaline	
Mo 11.5-10.5	Mollusk	*A. bidentata*, *A. candei*, *Corbula* sp., *N. semiornata*	Marine	II
		E. mactroides, *Heleobia* sp., *H. australis*	Mixohaline	
	Foraminifer	*E. discoidale*, *A. beccarii*	Mixohaline	
		O. universa, *C. nitida*	Marine	
	Ostracod	*C. multidentata*	Mixohaline	
		C. punctata	Marine	
	Diatom	*P. sulcata*	Marine	
		A. senarius, *C. radiatus*, *P. disculoides*, *T. oestrupii*, *T. favus*	Marine to marine mixohaline	
		C. striata	Marine mixohaline	
		**Pinnularia* sp.	*Freshwater	
Mo 12.3-11.5	Mollusk	*N. semiornata*, *T. gayi*, *Corbula* sp., *A. bidentata*, *A. brasiliana*	Marine	
		H. australis, *Heleobia* sp.	Mixohaline	
	Foraminifer	*A. beccarii*, *E. discoidale*	Mixohaline	
	Ostracod	*C. multidentata*	Mixohaline	
		C. punctata	Marine	
	Diatom	*P. sulcata*	Marine	
		A. senarius, *P. disculoides*, *T. favus*, *C. radiatus*, *T. oestrupii*	Marine to marine mixohaline	

		C. striata	Marine mixohaline	
		**Eunotia* sp., *Gyrosigma* sp., *Encyonema* sp., *D. gessneri*	*Freshwater	
Mo 13.0-12.3	Mollusk	*T. gayi, T. fasciata*	Marine	
		Heleobia sp., *H. australis, E. mactroides*	Mixohaline	
	Foraminifer	*A. beccarii, E. discoidale*	Mixohaline	
	Ostracod	*C. multidentata*	Mixohaline	
		C. punctata, M. heinii	Marine	
	Diatom	*P. sulcata*	Marine	
		A. senarius, P. disculoides, T. favus, C. radiatus, T. oestrupii	Marine to marine mixohaline	
		C. striata	Marine mixohaline	
		**Gyrosigma* sp., *Achnanthes* sp., *P. borealis, D. gessneri, Pinnularia* sp.	*Freshwater	
Mo 14.0-13.0	Mollusk	*T. gayi, T. fasciata, Corbula* sp., *Adrana* sp.	Marine	
		E. mactroides, H. australis, Heleobia sp.	Mixohaline	
	Foraminifer	*A. beccarii, E. discoidale*	Mixohaline	
	Ostracod	*C. multidentata*	Mixohaline	
		C. punctata	Marine	
	Diatom	*P. sulcata, A. splendens*	Marine	
		A. senarius, P. disculoides, T. favus, C. radiatus, T. oestrupii	Marine to marine mixohaline	
		C. striata	Marine mixohaline	
		**Eunotia* sp., *E. major, F. crassa, Gyrosigma* sp.	*Freshwater	
Mo 15.0-14.0	Diatom	*P. sulcata*	Marine	I
		A. senarius, P. disculoides, T. favus	Marine to marine mixohaline	
		C. striata	Marine mixohaline	

The Zone II includes the intervals 14.0-13 m, 13.0-12.3 m, 12.3-11.5 m and 11.5-10 m (Tab. 2), and registers the highest richness and diversity of the core, with the presence of all the biogenic elements. Some peculiarities are observed in this interval as, for instance, the presence of the marine mollusks *T. fasciata, T. gayi* and *Adrana* sp., restricted to the base of the zone, as well as of the marine diatom *A. splendens*. The freshwater diatoms are observed exclusively on this zone distributed in the four intervals (Santos, 2015): *Eunotia* sp., *E. major*, *F. crassa* and *Gyrosigma* sp. (14.0-13.0 m), *Gyrosigma* sp., *Achnanthes* sp., *P. borealis*, *D. gessneri* and *Pinnularia* sp. (13.0-12.3 m), *Eunotia* sp., *Gyrosigma* sp., *Encyonema* sp. and *D. gessneri* (13.3-11.5 m) and *Pinnularia* sp. (11.5-10.5 m). The ostracod *M. heinii* is recorded only in the interval 13.0-12.3 m. Toward the top of the Zone II are identified the marine biogenics *N. semiornata*, *A. bidentata*, *A. candei* and *O. nitida,* while *A. brasiliana* is restricted to the interval 12.3-11.5 m. The mixohaline bivalve *E. mactroides* is absent in this same interval. The mixohaline elements such as *H. australis*, *Heleobia* sp. (gastropods) and *C. multidentata* (ostracod) are present in all the intervals of the zone. The marine to marine mixoaline diatoms *A. senarius*, *P. disculoides*, *T. favus*, *C. radiatus*, *T. oestrupii*, *P. sulcata*, and the marine mixohaline diatom *C. striata* are common in all intervals of this zone. The marine mollusks of this zone are represented by *A. bidentata*, *A. candei*, *Corbula* sp., *N. semiornata*, *T. gayi*, *A. brasiliana*, *T. fasciata* and *Adrana* sp., all shallow waters dweelers, and also the mixohaline molluscs *E. mactroides*, *H. australis* and *Heleobia* sp. Those mollusks occur associated to the ostracods *C. punctata*, *M. heinii* and *C. multidentata* typical of mixohaline and coastal shallow waters, as well as the planktonic foraminifers *O. universa* and *C. nitida* and mixohaline *A. beccarii* and *E. discoidale*. These foraminifer species characterize a marine to shallow marine mixohaline environment.

The Zone III (10.5-7.3 m) (Tab. 2), is characterized by significant reduction of biogenics. However, the mixohaline mollusks *E. mactroides* and *Heleobia* sp., the foraminifers *A. beccarii* and *E. discoidale* (mixohaline) and *O. universa* (marine), and the mixohaline ostracode *C. multidentata* are recorded. In relation to the diatoms the marine to marine mixohaline *A. senarius*, *C. radiatus*, *P. disculoides*, *T. oestrupii*, *T. favus* and the marine mixohaline *C. striata* occur associated to the marine *P. sulcata* that indicates a marine to marine mixohaline environment, with stronger marine trend (Santos, 2015).

4.4. Evolutive Synthesis of the Core Mo

The interval 29.0-15.0 m of the core Mo is barren. The site of this core is related to the incise valley system of the Late Pleistocene/Holocene paleo-Jacuí River outflow and it is in the margin of the paleochannel (Weschenfelder *et al.*, 2008). According to the seismic analyses by Bortolin (2011), this interval corresponds to a sandy package with low granulometric variation, characterizing fluvial erosion. This indicates that the coastal deposits at the core base have been eroded, reworked and transported, and in part deposited again by rivers, composing the erosional surface. That author observed the first appearance of fossils at 15.0 m, though very fragmented and not identifiable. Shells of gastropods, bivalves and other fossils (ostracods, foraminifers and diatoms), and mollusk fragments are recorded between 14.0-7.3 m (Bortolin, 2011).

In the present study the interval 15.0-14.0 m (Zone I) records diatoms typically marine, marine to marine mixohaline and marine mixohaline, with predominance of *P. sulcata*. According to Ryu *et al*. (2008), the occurrence of this species would not ensure reliable paleoenvironmental characterization, but considering other species associated, it would be possible to infer a stronger marine influence. In this context it is also observed conspicuous environmental change compared to the barren portion of the core which is predominantly composed of homogeneous sandy package characterizing fluvial erosion (Bortolin, 2011). The base of the Zone II (14.0-13.0 m) records the only occurrence of the marine diatom *A. splendens,* which is an evidence of the transition from the marine-influenced environment of the Zone I toward a marine to marine mixohaline in the Zone II.

Another environmental variation in the core Mo is observed in the Zone II where the mixture of organisms from different environmental contexts indicates deposition under marine to marine mixohaline and freshwater conditions, as consequence of sea level changes. This mixture reinforces the marine and fluvial deposits observed by Baitelli (2012), and the proximity to a water body (paleo-Jacuí River), which influenced the coastal region.

Santos (2015) studying this same core recorded freshwater diatoms such as *Eunotia* sp., *E. major*, *F. crassa*, *Gyrosigma* sp., *Achnanthes* sp., *P. borealis*, *D. gessneri*, *Pinnularia* sp., and *Encyonema* sp. between 14.0-10.5 m, that, according to the present work corresponds to the Zone II. These taxa are usually found both in lotic and lentic environments in the Rio Grande do Sul coastal plain. The fragmentation and scarcity of frustules also reinforce proximity to a river system, the occurrence of transport and, consequently, the allochthonous character of the fossils as proposed by Santos (2015).

The biogenic material identified is typical from shallow coastal environments, which is in accordance to Baitelli (2012), who argues that the core Mo records shallow water deposits due to the closing of the north paleo-Jacuí River. The δC^{13} analyses in *T. gayi* supplied information on the continental influence which associated to the δO^{18} indicated low salinity conditions and a transgressive trend (Baitelli, 2012). The ages estimated to the mollusks in this zone are calibrated in 8.160-7.920 yr BP and 7.980-7.750 yr BP (Holocene) (Weschenfelder *et al*., 2014).

In the Zone III (10.5-7.3 m, top of the core), the diversity of biogenics decreases, especially mollusks. The fossils recorded are mixohaline mollusks, ostracods and foraminifers and a planktic foraminifer, probably transported during the several marine incursions. The diatoms from the Zone III have a pattern similar to the Zone I. *P. sulcata* is the most abundant species associated with the marine to marine mixohaline and marine mixohaline diatoms, which would indicate a marine to marine mixohaline environment with a marine trend to the Zone III. The mollusk shell used in the datation comes from this zone and the calibrated age obtained in it was 7.960-7.680 yr BP (Santos-Fischer *et al*., 2016) confirming the Holocene age for this sedimentary package.

Despite the homogeneity of the fossiliferous part of the core Mo, the organisms analyzed have different environmental characteristics. Marine, mixohaline, marine to marine mixohaline and marine mixohaline biogenics have been recorded. Some of those organisms have broad salinity ranges and, therefore, live in different environments. The marine taxa *A. brasiliana*, *C. punctata*, *M. heinii* and *P. sulcata,* for instance, are also found in mixohaline environments. In the same way, the typical mixohaline *E. mactroides* and *H. australis* characteristic of mixohaline environments, are also registered in coastal marine ones. In addition the diatoms *C. striata, A. senarius, C. radiatus, P. disculoides* and *T. oestrupii* are also considered euryhalines.

It is possible to observe in the six intervals herein studied several evidences of sea level changes from the core base toward the top. The most basal interval (15.0-14.0 m), composed exclusively by marine to marine mixohaline and marine mixohaline diatoms registers an environment with marine influence. In the four subsequent intervals (14.0-13.0 m, 13.0-12.3 m, 12.3-11.5 m and 11.5-10.5 m), marine mollusks occur associated to a low diversity of mixohaline ones. Moreover, marine and mixohaline foraminifers, marine and mixohaline ostracods, marine, marine to marine mixohaline, marine mixohaline and freshwater diatoms also reinforce the environmental changes.

During sea-level rising events (transgressions) the shallow water marine organisms predominate, while in the lowering sea-level events (regressions) the mixohaline organisms are predominant in the assemblages. In the subsequent interval of the core (10.5-7.3 m), the biogenics indicate a marine to marine mixohaline environment. The mixture of the marine, mixohaline, marine to marine mixohaline and marine mixohaline environments identified in the three zones of the core, in addition to the freshwater diatoms registered by Santos (2015), demonstrate the occurrence of short transgressive/regressive pulses in the Rio Grande do Sul coastal region, also recorded by Baitelli’s (2012) seismic study on the paleo-Jacuí River.

5 Conclusions

Evidences of short sea-level oscillation, or short pulses of regression and transgression in more significant events are observed in the zoning proposed in this work. Three zones are identified based on the analysis of biogenics (mollusks, foraminifers, ostracods and diatoms) characteristic of different environments (marine, mixohaline, marine mixohaline, marine to marine mixohaline and freshwater) along the core. The Zone I characterizes a marine to marine mixohaline environment with marine influence migrating toward the Zone II, with fluvial influence, and also interpreted as a marine to marine mixohaline environment. In the sequence, the Zone III registers again a marine to marine mixohaline environment with marine influence.

The data herein presented reinforce previous studies on the evolution of the Rio Grande do Sul Coastal Plain, which demonstrate that this region has been under influence of events of short amplitude of relative sea-level variation during the Holocene.

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Capítulo 3

1. **Título do trabalho:**

Paleoenvironmental changes based on the analysis of Late Pleistocene/Holocene biogenics from the core Pa, Patos Lagoon, Palmares do Sul (Rio Grande do Sul State, Brazil)

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4. **Palavras chave:**

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1. Abstract

This work presents a paleoecologic study on fossil biogenics from the core Pa, collected in the Patos Lagoon, near to Palmares do Sul. This core has 28.5 m length and was drilled at 30º32’52”S and 50º42’54”W, under 6 m water depth. Four biogenic zones (I, II, III and IV) were proposed characterizing different paleoenvironments between the Late Pleistocene and Holocene. The Zone I, at the base of the core, corresponds to the intervals 28.5-26.3 m and 21.0-20.5 m depth, being characterized by the occurrence of foraminifers, ostracods, mollusks, barnacles, echinoderms, sponges and diatoms and indicates a shallow marine environment. The Zone II occurs between 20.5-18.5 m and 16.5-16.0 m, and is characterized by the dominance of marine diatoms. In the Zone III, corresponding to the intervals 14.5-16.0 m to 11.0-11.5 m depth predominates marine, marine to marine mixohaline and freshwater diatoms, indicating a shallow fluvial environment with some marine influence. Lastly, in the Zone IV, between 10.5-10.0 m and 7.0-6.0 m, occur marine, marine to marine mixohaline and mixohaline diatoms, which characterize a marine environment. The results of this work suggest the occurrence of paleoenvironmental changes bonded to sea level oscillations, and subtropical climate during the deposition of the Pa core.

Keywords: Biogenic Zones, Paleoenvironments, South America, Brazil

2. Introduction

During the last few decades, researchers have taken different approaches on the study of Quaternary biogenics in the Patos Lagoon region. From the 1960 onwards, skeletal remains of many organisms began to be recorded in that area, providing not only palaeodiversity information, but paleoecological and biostratigraphical ones.

Foraminifers are amongst the most studied fossils groups in this region. Works published so far involved the taxonomy, biostratigraphy, paleoecoly and paleozoogeography of assemblages (e.g. Madeira-Falcetta et al. 1980a, Madeira-Falcetta et al. 1980b, Carvalho

1980, Bertels et al. 1982, Boltovskoy et al. 1982, Boltovskoy et al. 1983, Godolphim et al. 1989, Carreño et al. 1997, Mulitza et al. 1999, Leipnitz et al. 2006, Leão et al. 2007 and Ferreira et al. 2009).

Studies on ostracods have also dealt with involving paleocology, taxonomy and biostratigraphy (e.g. Bertels et al. 1982, Würdig 1983, Würdig 1984; Kotzian and Eilert 1985, Würdig and Freitas 1988, Müller 1989; Würdig et al. 1990, Würdig et al. 1998, Sanguinetti et al. 1991, Sanguinetti et al. 1992, Würdig and Pinto 1994, Carreño et al. 1999, Drozinski et al. 2003, Ceolin et al. 2011, Gonçalves 2012, Ramos et al. 2012, Manica and Coimbra 2013, Leite et al. 2013, Manica et al. 2015 and Bergue et al. 2016).

Mollusks have been recorded in the Patos Lagoon and adjacent areas since long ago. The first study was published by (Ihering 1885), who described new species and their stratigraphic application. Later on, this research was refined, among others, by (Closs and Forti 1971) and (Forti-Esteves 1986). Taxonomic and paleoenvironmental studies on mollusks were also published by (Godolphim et al. 1989), (Buchmann 2002), (Wiggers 2003), (Pimpão 2004), (Lopes et al. 2011), (Lopes and Simone 2012) and (Oliveira 2012). Organic layers and mollusk shells have also been used for radiocarbon dating (e.g. Caron et al. 2007a, Caron et al. 2007b, Lima 2008, Caron et al. 2011, Bortolin 2011, Baitelli 2012, Lima et al. 2013). More recently (Ritter 2010a), (Ritter 2010b), (Ritter and Erthal 2011), (Erthal et al. 2011) and (Ritter et al. 2013), launched the analysis of taphonomic signatures in the research of these assemblages and (Lopes 2012) with bioerosion and bioincrustation studies in this area.

Besides the fossil groups previously mentioned, there are also others which are poorly studied in this region due to their rarity or low abundance. Among them are the sponges, represented mostly by siliceous spicules. The diversity of this group is referred in studies aiming at the exploration of spongolites (for industrial application), and for paleoenvironmental purposes (Volkmer-Ribeiro et al. 1988, Volkmer-Ribeiro and Turq 1996). Echinoderms are also recorded in areas adjacent to the Patos Lagoon (Godolphim et al. 1989, Lopes 2009), being the studies on ophiuroids by (Absalão and Manso 1990), in the southernmost Brazilian coast, (Absalão 1990), in the Patos Laggon, and (Manso 1991), in the south-southeastern Brazil, the most relevant. Barnacles fragments are occasionally found associated to foraminifers and ostracods. This association was documented by (Madeira-Falcetta et al. 1980) and (Godolphim et al. 1989) in their studies on cores from Palmares do Sul region and Pelotas, respectively, both in the Rio Grande do Sul State. (Newman 1996) argues that thoracic cirripeds occur from the intertidal zone to the deep sea.

Diatoms are also important environmental proxies, despite the paucity of studies on fossil assemblages in the Patos Lagoon and adjacent areas. The works by (Arejano and Medeanic 2007), (Weschenfelder et al. 2008a, Weschenfelder et al. 2008b, Weschenfelder et al. 2014), (Medeanic et al. 2009), (Hermany 2009), (Santos 2011), (Santos 2015), (Hermany et al. 2013) and (Santos-Fischer et al. 2016) based on cores from different regions of the coastal plain, are the most significant. Those studies focused on the paleoenvironmental reconstructions (lacustrine, estuarine and marine), paleoecology (abundance) and geographic distribution of the species.

A preliminary analysis of the core Pa, collected in the Patos Lagoon (Palmares do Sul, Rio Grande do Sul State) revealed various biogenics, such as foraminifers, ostracods, mollusks, echinoderms, sponges (fragments and siliceous spicules), barnacles and diatoms in the Late Pleistocene–Holocene interval (Baitelli 2012). Due to the poor knowledge on biogenic groups in this region, the study of the core Pa constitutes an opportunity to improve our comprehension on the paleoenvironmental changes which took place in the Rio Grande do Sul Coastal Plain. The present work, therefore, analyzes the diversity and paleoecology of biogenics, erecting zones for the different stages of the paleoenvironmental evolution of the Patos Lagoon.

3. Description of the area

The Pelotas Basin originated from tectonic events related to the South Atlantic formation. It is classified as an open passive marginal basin and lies in the southernmost portion of the Brazilian margin, piling up approximately 12.000 m of continental, transitional and marine sediments. In the upper part of this sequence lies the Rio Grande do Sul Coastal Plain that represents a wide area of low lands with 33.000 km^2, characterized by a system of lakes and lagoons (Villwock and Tomazelli 1995).

In the Rio Grande do Sul Coastal Plain crop out two main depositional systems (Villwock and Tomazelli 1995). One of them is a system of alluvial fans which covers a continuous belt along the internal portion of the coastal plain, while the second one corresponds to four transgressive-regressive depositional systems of lagoon-barrier type. The latter represents sedimentary processes of marine transgression that took place during the Pleistocene (Barrier I, II and III) and Holocene (Barrier IV). Each barrier represents the maximum boundary of the trangressive event (Villwock and Tomazelli 1998, Tomazelli et al. 2000, Dillenburg et al. 2009). The Patos Lagoon was formed during the second transgressive-regressive cycle (Barrier II) (Villwock and Tomazelli 1995).

The Patos Lagoon has NE-SW orientation (Figure 1), parallel to the coast (Toldo Jr. 1994), between 30˚12'S and 32˚30'S (Asmus 1998). It presents 240 km length, average width of 40 km, and average depth of 6 m, covering an area of approximately 10.000 km^2, which corresponds roughly to one third of the Rio Grande do Sul Coastal Plain (Baitelli et al. 2007). This lagoon is divided into five sectors: central lagoon, estuary, Guaíba Lake, Tapes Bay and Casamento Lagoon (Asmus 1998). The central lagoon corresponds to approximately 80% of the lagoon and is bordered by freshwater marshes and sandy beaches. The estuary connects the lagoon to the Atlanctic Ocean through the Rio Grande Channel in the southern part of the lagoon, and represents 10% of the lagoon area (971 km^2) (Asmus 1998).

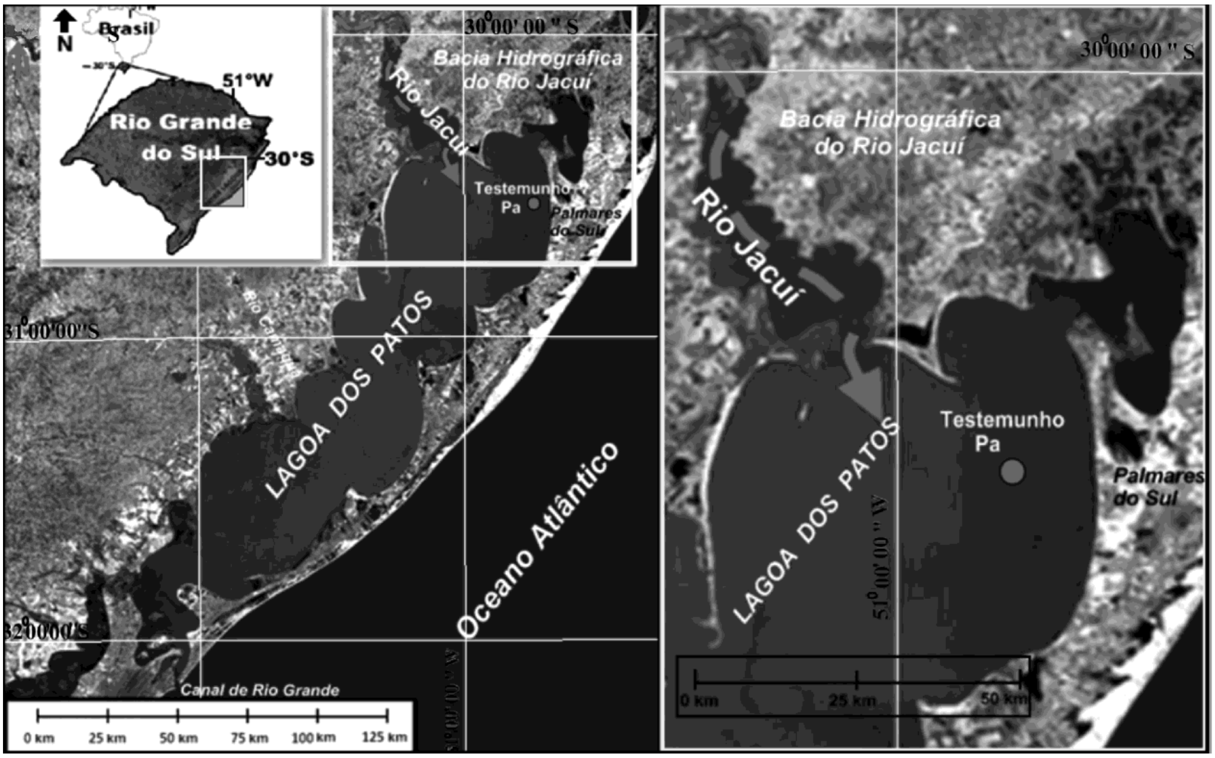

Figure 1 - Map of the study area showing location of the core Pa, near to Palmares do Sul, related to the Jacuí river drainage (delineation).

A broad drainage area of approximately 170.000 km^2 supplies freshwater to the Patos Lagoon. This water comes mostly from the Guaíba system, composed by the Jacuí, Sinos, Caí and Gravataí rivers and also from the Mirim Lagoon through the São Gonçalo Channel (Asmus 1998). Another freshwater source is the Camaquã River, which builds a deltaic system in the central portion of the eastern margin of the lagoon (Toldo Jr. et al. 2007). Due to the high volume of water provided by these drainages, the lagoon waters have low salinity (around 3 psu) and residence time of about 108 days (Toldo Jr. et al. 2007). The outflow oscillates around 4.800 m^3/s and the amplitude of the astronomical tide is 0.45 m. The saline wedge reaches, occasionally, up to 200 km northward, influenced by south winds, low level and spring tides (Martins et al. 1989; Toldo Jr. 1989). The drainage flux from the Guaíba Lake toward the Rio Grande Channel, exerts important influence on the sedimentation (Baitelli et al. 2007). According to the AMS (Accelerator Mass Spectrometry) ^{14}C dating of mollusk shells, the core Pa records the Late Pleistocene interval. However, (Baitelli 2012), based on

δC^{13} and δO^{18}, data suggest the age of 133.000 years BP which corresponds to the MIS 5e (Gibbard et al. 2010).

4. Materials and methods

4.1. Sampling

The core Pa was drilled using the SPT method (Standard Penetration Test) (Baitelli 2012) in the central-north sector of Patos Lagoon at 6.0 m water depth (30º32’52’’S; 50º42’54’’W), aiming at the investigation of the subsurface of the lagoon (Weschenfelder et al. 2014). It has 28.5 m length and 3.9 cm diameter. Eighteen samples were collected each meter by insertion, with continuous recuperation of about 50 cm. The sampling was performed to collect a homogeneous portion of sediments, which was stored in plastic vials.

The granulometric analysis of the samples was carried out at the Center for Coastal and Oceanic Geology Studies, Geosciences Institute, Federal University of Rio Grande do Sul, according to the methodology presented by (Martins et al. 1987) and textural classification by (Shepard 1954). The sedimentologic description follows (Baitelli 2012), being the fine fraction (<0.062 mm) the predominant in more than 90% of the 28.5-16.0 m interval, while the fine sand (0.125-0.250 mm) predominated in the interval 14.0-10.0 m (Figure 2).

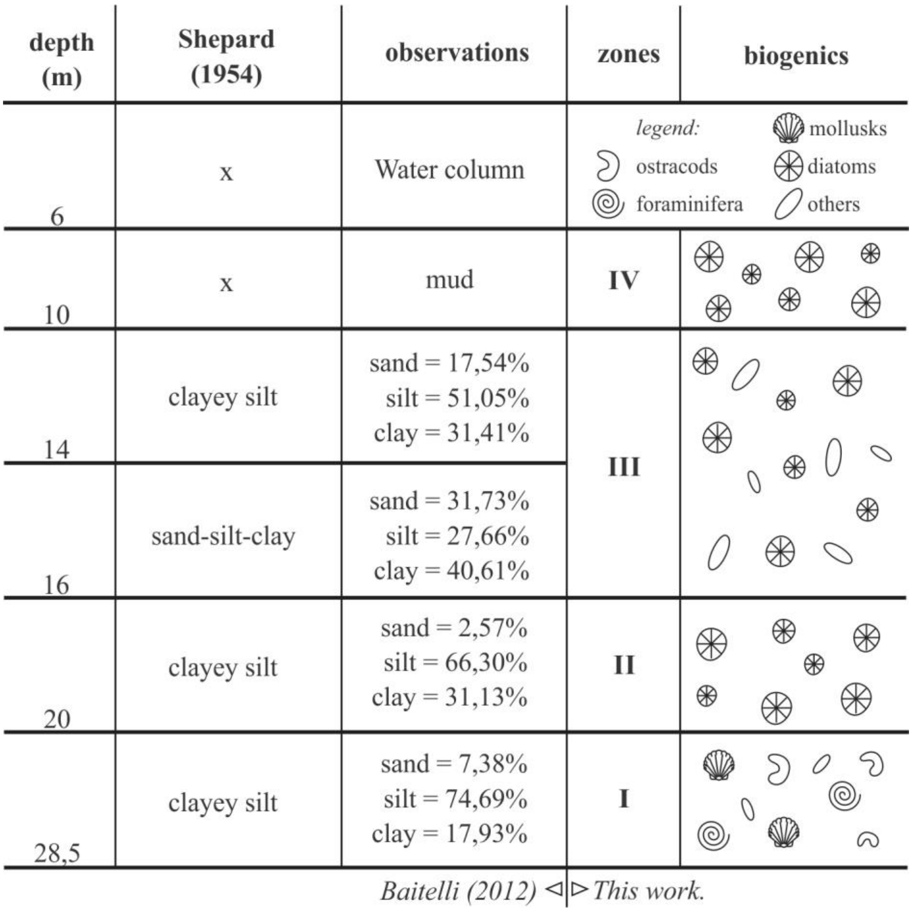

Figure 2 - Depth, sedimentologic profile (Shepard 1954), observation with percentage (sand, silt and clay), biogenic zones (I, II, III and IV) and symbols of biogenic content of the core Pa

4.2. Biologic proxies

Seven taxonomic groups were included in this study as biological proxies: foraminifers, ostracods, mollusks, echinoderms, sponges, barnacles and diatoms. Approximately 50 g of each sample were prepared for macrofossils and 10 g for microfossils. The specimens were picked out from the samples and stored in micropaleontological slides for analysis under stereomicroscope with eyepiece of 10x and objective of 4x. The diatoms were prepared in permanent slides according to the usual methodology, and identified according to the taxonomy proposed by (Santos-Fischer et al. 2016).

Two types of relative abundance analyses were carried out: (i) a general estimation for each taxa in each biogenic group, and (ii) a more specific calculation including each taxa recorded. Both estimations were obtained according to the following equation: relative abundance (RA)=N x 100/n, where N=total of individuals of each taxon in the sample, and n=total of individuals. Based on the percentage obtained for each taxon, they were classified in the following categories: dominant (> 50%), abundant (5-50%), uncommon (2-5%) and rare (< 2%). Taxa with lowest relative abundance (< 2%) were considered secondary and excluded of the biostratigraphic diagram, according to the statistic criterium adopted by Santos (2015) and (Santos-Fischer et al. 2016). The percentages obtained of each taxon were plotted in a biostratigraphic diagram using the program C2®, version 1.5 (Juggins 2003). The spacial distribution along the core are represented in the diagram, allowing the delimitation of biostratigraphic zones.

4.3. Taxonomic identification and ecological data

The foraminifers were identified according to (Madeira-Falcetta 1977) and (Madeira-Falcetta et al. 1980a), (Madeira-Falcetta et al. 1980b) and the ostracods according to (Leite et al. 2013). The identification of the mollusks was based on several sources (Forti 1969); (Closs and Forti 1971); (Abbott 1974); (Forti-Esteves 1984); (Abbott and Dance 1986); (Veitenheimer-Mendes 1993); (Lopes-Pitoni 1993); (Rios 1994), (Rios 2009); (Thomé et al. 2010) and the website *Conquiliologistas do Brasil*. The barnacles were compared to the taxonomic descriptions by (Shrock and Twenhfel 1953), (Carvalho et al. 2011) and (Pitombo and Young 2011). The identification of echinoderm spines and sponges (fragments and siliceous spicules) follow (Shrock and Twenhfel 1953), (Souza-Lima and Manso 2011) and (Zucon and Vieira 2011). The taxonomy of diatoms is based on (Santos 2015).

Ecological data of the taxa used for the palaeoenvironmental characterization are based on recent taxa, according to (Würdig 1983), (Roelofs 1984), (Volkmer-Ribeiro et al. 1988), (Walton and Sloan 1990), (Coimbra et al. 2007), (Talgatti et al. 2007), (Rios 2009), (Thomé et al. 2010), (Carvalho et al. 2011), (Pitombo and Young 2011), (Souza-Lima and

Manso 2011), (Zucon and Vieira 2011), among others.

5. Results

5.1. Description of the biostratigraphic zones

The relative abundance and spatial distribution allowed the statistical grouping of the taxa in four biostratigraphic zones (I-IV). The distribution of the taxa demonstrates that the biogenic associations are unevenly distributed. The diatom group is the only one that occurs in all intervals of the core. The others biogenic groups are distributed in five of the six intervals, mainly on the basis of the core. The siliceous spicules were recorded not only in the base but also in the interval 12.5-12.0 m (Zone III).

5.1.1. Zone I

The Zone I (Fig. 3) corresponds to the interval 28.5-26.3 m to 21.0-20.5 m, base of the core, and is characterized by the presence of all biogenic groups. In the interval 28.5-26.3 m, predominates the shallow marine species *Chione cancellata* (Linnaeus, 1767), *Nucula semiornata* Orbigny, 1846, *Boonea seminuda* (Adams, 1850) *Acteocina bidentata* (Orbigny, 1841), *Acteocina candei* (Orbigny, 1841) and *Finella dubia* (Orbigny, 1842). The mixohaline ostracod *Cyprideis multidentata* Hartmann, 1955, and the marine *Xestoleberis* sp. and *Propontocypris* sp., are also recorded, associated to echinoderm spines and fragments of sponges. The most representative diatoms are the marine *Actinoptychus splendens* (Shadbolt, 1854) Ralfs *in* Pritchard, 1861, *Actinoptychus vulgaris* Schumann, 1867 *Cymatosira belgica* Grunow, 1881, *Delphineis surirella* (Ehrenberg, 1840) Andrews, 1981, *Odontella atlantica* (Frenguelli, 1930) Sar, 2007, *Paralia sulcata (*Ehrenberg, 1838) Cleve, 1873, *Plagiogramma pulchellum* var. *pygmae* (Greville, 1859) Peragallo & Peragallo 1901; the marine to marine mixohaline species *Actinoptychus senarius* Ehrenberg, 1838, *Coscinodiscus radiatus* Ehrenberg, 1840, *Dimeregramma minor* (Gregory, 1857) Ralfs, 1861, *Psammococconeis disculoides* (Hustedt, 1955) Garcia, 2001, *Psammodictyon panduriformes* (Gregory, 1857), Mann, 1990, *Surirella fastuosa* Ehrenberg, 1843, *Thalassionema nitzschioides* (Grunow,

1881) Mereschkowsky, 1902 and *Thalassiosira oestrupii* (Ostenfeld, 1900) Proschkina-Lavrenko & Hasle, 1960, and the marine mixohaline species *Nitzschia lanceolata* Smith, 1853 and *Cyclotella striata* (Kützing, 1844) Grunow, 1880 (Fig. 5).

In the interval 26.3-26.0 m, the mollusks are the shallow marine *N. semiornata*, *Tawera gayi* (Hupé, 1854), *A. bidentata*, *A. candei* and *B. seminuda*. The ostracods are represented by the eurihaline species *C. multidentata*, and the marine *Xestoleberis* sp. The diatoms are represented by the marine species *A. splendens, A. vulgaris, C. belgica, D. surirella, O. atlantica, P. sulcata, P. pulchellum* var. *pygmae*; the marine to marine mixohaline species *A. senarius, C. radiatus, D. minor, P. disculoides, P. panduriformes, S. fastuosa, T. nitzschioides* and *T. oestrupii*, and the marine mixohaline species *N. lanceola* and *C. striata*. In the interval 26.0-23.5 m only diatoms are recorded, such as the marine species *A. splendens, C. belgica, D. surirella, O. atlantica, P. sulcata;* the marine to marine mixohaline species *A. senarius, Auliscus sculptus* (Smith, 1853), Ralfs, 1861, *D. minor, P. disculoides, P. panduriformes, S. fastuosa, T. nitzschioides* and *T. oestrupii;* and the marine mixohaline species *N. lanceola* and *C. striata*. In 23.5-23.0 m occur the shallow marine mollusks *A. candei*, *Adrana* sp., *N. semiornata* and *F. dubia* and the marine ostracods *Xestoleberis* sp. and *Cytheretta punctata* Sanguinetti, 1979. The diatoms are represented by the marine species *A. splendens, C. belgica, D. surirella, O. atlantica, P. sulcata*; the marine to marine mixohaline species *A. senarius, A. sculptus, C. radiatus, D. minor, P. disculoides, P. panduriformes, S. fastuosa, T. nitzschioides, T. oestrupii* and *Triceratium favus* Ehrenberg, 1839, and the marine mixohaline species *N. lanceola* and *C. striata*, (Fig. 5).

In the interval 23.0-21.0 m, are identified the shallow marine mollusks *T. gayi*, *F. dubia*, *Anadara notabilis* (Roding, 1798), *B. seminuda*, *A. candei* associated to the euryhaline bivalve *Ostrea equestris* Say, 1834, the barnacle *Chthamalus* sp., the mixohaline ostracod *C. multidentata* and the marine *Xestoleberis* sp. and *C. punctata*. The diatoms of this interval are the marine species *A. splendens, C. belgica, D. surirella, O. atlantica, P. sulcata*; the marine to marine mixohaline species *A. senarius, C. radiatus, D. minor, P. disculoides, P. panduriformes, S. fastuosa, T. oestrupii* and *T. favus*, and the marine mixohaline species *N. lanceola* and *C. striata*. Between 21.0-20.5 m occurs the euryhaline foraminifers *Ammonia beccarii* (Linnaeus, 1758) and *Elphidium discoidale* (d'Orbigny, 1839), associated to spicules of sponges. The diatoms are represented by the marine species *A. splendens, C. belgica, Coscinodiscus asteromphalus* Ehrenberg, 1844, *D. surirella, O. atlantica, P. sulcata, P. pulchellum* var. *pygmae*; the marine to marine mixohaline species *A. senarius, C. radiatus, D. minor, P. disculoides, P. panduriformes, S. fastuosa, T. oestrupii* and *T. favus*, and the marine mixohaline species *N. lanceola* and *C. striata*, (Fig. 5).

5.1.2. Zone II

The Zone II (18.5-20.5 m to 16.0-16.5 m) is dominated by marine diatoms (Fig. 4). In the interval 18.5-20.5 occurs the marine species *A. splendens, A. vulgaris, O. atlantica, P. sulcata*; the marine to marine mixohaline species *A. senarius, A. sculptus, C. radiatus, P. disculoides, T. oestrupii* and *T. favus*, and the marine mixohaline specie *C. striata*. The interval 18.5-18.0 m records the marine species *A. splendens, A. vulgaris, C. asteromphalus, D. surirella, P. sulcata,* and *P. pulchellum* var. *pygmae*; the marine to marine mixohaline species *A. senarius, C. radiatus, D. minor* and *T. favus* and the marine mixohaline specie *C. striata*, (Fig. 5).

In the interval 18.0-16.5 m occur the marine species *A. splendens, C. asteromphalus, P. sulcata,* and *P. pulchellum* var. *pygmae*; the marine to marine mixohaline species *A. sculptus, C. radiatus, D. minor, P. disculoides, P. panduriformes* and *T. favus* and the marine mixohaline specie *C. striata*. The interval 16.5-16.0 m is represented by the marine diatoms *A. splendens, A. vulgaris* and the marine specie *P. sulcata* and the freshwater diatom *Staurosirella pinnata* (Ehrenberg, 1843) Williams & Round, 1988; (Fig. 5).

	Foraminifers	*A. beccarii, E. discoidale*	Mixohaline	**Zone I**
21.0-20.5	**Diatoms**	*A. splendens, C. belgica, C. asteromphalus, D. surirella, O. atlantica, P. sulcata, P. pulchellum* var. *pygmae*	Marine	
		A. senarius, C. radiatus, D. minor, P. disculoides, P. panduriformes, S. fastuosa, T. oestrupii, T. favus	Marine to marine mixohaline	
		N. lanceola, C. striata	Marine mixohaline	
23.0-21.0	**Mollusks**	*C. gayi*, *F. dubia*, *A. notabilis*, *O. seminuda*, *A. candei*	Marine	
		O. esquestris	Mixohaline	
	Barnacles	*Chthamalus* sp.	Marine	
	Ostracods	*C. multidentata*	Mixohaline	
		Xestoleberis sp., *C. punctata*	Marine	
	Diatoms	*A. splendens, C. belgica, D. surirella, O. atlantica, P. sulcata*	Marine	
		A. senarius, C. radiatus, D. minor, P. disculoides, P. panduriformes, S. fastuosa, T. oestrupii, T. favus	Marine to marine mixohaline	
		N. lanceola, C. striata.	Marine mixohaline	
23.5-23.0	**Mollusks**	*A. candei*, *Adrana* sp., *N. semiornata, F. dubia*	Marine	
	Ostracods	*Xestoleberis* sp., *C. punctata*	Marine	
		A. splendens, C. belgica, D. surirella, O. atlantica, P. sulcata	Marine	
	Diatoms	*A. senarius, A. sculptus, C. radiatus, D. minor, P. disculoides, P. panduriformes, S. fastuosa, T. nitzschioides, T. oestrupii, T. favus*	Marine to marine mixohaline	
		N. lanceola, C. striata	Marine mixohaline	
26.0-23.5	**Diatoms**	*A. splendens, C. belgica, D. surirella, O. atlantica, P. sulcata;*	Marine	
		A. senarius, A. sculptus, D. minor, P. disculoides, P. panduriformes, S. fastuosa, T. nitzschioides, T. oestrupii	Marine to marine mixohaline	
		N. lanceola, C. striata.	Marine mixohaline	
26.3-26.0	**Mollusks**	*N. semiornata*, *C. gayi*, *A. bidentata*, *A. candei, O. seminuda*	Marine	
	Ostracods	*C. multidentata*	Mixohaline	
		Xestoleberis sp.	Marine	
	Diatoms	*A. splendens, A. vulgaris, C. belgica, D. surirella, O. atlantica, P. sulcata, P. pulchellum* var. *pygmae*	Marine	
		A. senarius, C. radiatus, D. minor, P. disculoides, P. panduriformes, S. fastuosa, T. nitzschioides, T. oestrupii	Marine to marine mixohaline	
		N. lanceola, C. striata.	Marine mixohaline	
28.5-26.3	**Mollusks**	*C. cancellata*, *N. semiornata*, *O. seminuda*, *A. bidentata, A. candei, F. dubia*	Marine	
	Ostracods	*C. multidentata*	Mixohaline	
		Xestoleberis sp., *Propontocypris* sp.	Marine	
	Diatoms	*A. splendens, A. vulgaris, C. belgica, D. surirella, O. atlantica, P. sulcata, P. pulchellum* var. *pygmae;*	Marine	
		A. senarius, C. radiatus, D. minor, P. disculoides, P. panduriformes, S. fastuosa, T. nitzschioides, T. oestrupii,	Marine to marine mixohaline	
		N. lanceolata, C. striata.	Marine mixohaline	

Figure 3 - Interval of occurrence of biogenic, with the identification of species and their respective environment in the Zone I

5.1.3. Zone III

The Zone III (Fig. 4) ranges the interval 16.0-14.5 m to 11.5-11.0 m and is characterized by both marine and freshwater diatoms, as well as the dominance of sponge spicules. In the interval 16.0-14.5 m are the diatoms marine *A. splendens, A. vulgaris, D. surirella, P. sulcata, P. pulchellum* var. *pygmae*; the marine mixohaline specie *C. striata*; the marine to marine mixohaline species *A. senarius, A. sculptus, D. minor* and *P. disculoides*. The freshwater diatoms, according to Santos (2015), are *Aulacoseira veraluciae* Tremarin, Torgan & Ludwig, 2014, *Cocconeis placentula* var. *euglypta* (Ehrenberg, 1836) Van Heurck, 1885, *Cyclotella meneghiniana* Kützing, 1844, *Eunotia major* (Smith, 1856) Rabenhrost, 1864, *Eunotia minor* (Kützing, 1844) Grunow, 1881, *Gomphonema paludosum*, Reichardt, 1999, *Luticola geoppertiana* (Bleish, 1861) Mann, 1990, *Pinnularia borealis* var. *rectangularis* Carlson, 1913 and *Ulnaria ulna* (Nitzsch, 1817) Compère, 2001; (Fig. 5).

In the interval 14.5-14.0 m (Fig. 4) are recorded by the marine species *A. splendens, A. vulgaris, P. sulcata, P. pulchellum* var. *pygmae*; the marine mixohaline specie *C. striata*; the marine to marine mixohaline species *A. sculptus* and *S. fastuosa*, and the freshwater species (according to Santos, 2015) *A. veraluciae, C. placentula* var. *euglypta*, *C. meneghiniana*, *E. major*, *L. geoppertiana*, *S. pinnata* and *U. ulna*. In 14.0-12.5 m, are registered the marine species *A. splendens, A. vulgaris, P. sulcata*, the marine mixohaline specie *C. striata*; the marine to marine mixohaline specie *T. oestrupii*, and the freshwater species *C. placentula* var. *euglypta*, *E. major* and *U. ulna*. Between 12.5-12.0 m occur sponge spicules and the marine species diatoms *A. splendens, A. vulgaris* and *P. sulcata*; the marine to marine mixohaline species *A. sculptus, P. panduriformes, P. disculoides* and *T. oestrupii*, and the freshwater species *C. placentula* var. *euglypta, E. major, L. geoppertiana* and *U. ulna*. Lastly, the interval 11.5-11.0 m is represented by the marine diatoms *A. splendens, A. vulgaris* and *P. sulcata*, the marine to marine mixohaline species *T. favus* and the freshwater specie (according to Santos, 2015) *Pinnularia* sp., (Fig. 5).

interval (m)	biogenics	species	environment	
7.0-6.0	**Diatoms**	*A. splendens, C. belgica, C. asteromphalus, D. surirella, P. sulcata, P. pulchellum* var. *pygmae*	Marine	**Zone IV**
		N. lanceola, C. striata	Marine mixohaline	
		A. senarius, A. sculptus, D. minor, P. disculoides, P. panduriformes, S. fastuosa, T. oestrupii, T. favus	Marine to marine mixohaline	
10.0-8.0	**Diatoms**	*A. splendens, D. surirella, P. sulcata*	Marine	
		C. striata	Marine mixohaline	
		A. senarius, A. sculptus, D. minor, P. disculoides, T. oestrupii	Marine to marine mixohaline	
10.5-10.0	**Diatoms**	*A. splendens, P. sulcata*	Marine	
		D. minor, P. disculoides	Marine to marine mixohaline	
11.5-11.0	**Diatoms**	*A. splendens, A. vulgaris, P. sulcata*	Marine	**Zone III**
		T. favus	Marine to marine mixohaline	
		**Pinnularia* sp.	*Freshwater	
12.5-12.0	**Diatoms**	*A. splendens, A. vulgaris, P. sulcata*	Marine	
		A. sculptus, P. panduriformes, P. disculoides, T. oestrupii	Marine to marine mixohaline	
		**C. placentula* var. *euglypta*, *E. major*, *L. geoppertiana, U. ulna.*	Marine	
14.0-12.5	**Diatoms**	*A. splendens, A. vulgaris, P. sulcata*	Marine	
		C. striata	Marine mixohaline	
		T. oestrupii	Marine to marine mixohaline	
		C. placentula var. *euglypta*, *E. major, U. ulna.*	Freshwater	
14.5-14.0	**Diatoms**	*A. splendens, A. vulgaris, P. sulcata, P. pulchellum* var. *pygmae*	Marine	
		C. striata	Marine mixohaline	
		A. sculptus, S. fastuosa	Marine to marine mixohaline	
		**A. veraluciae*, *C. placentula* var. *euglypta*, *C. meneghiniana*, *E. major*, *L. geoppertiana*, *S. pinnata, U. ulna*	*Freshwater	
16.0-14.5	**Diatoms**	*A. splendens, A. vulgaris, D. surirella, P. sulcata, P. pulchellum* var. *pygmae*	Marine	
		C. striata	Marine mixohaline	
		A. senarius, A. sculptus, D. minor, P. disculoides	Marine to marine mixohaline	
		**A. veraluciae*, *C. placentula* var. *euglypta*, *C. meneghiniana*, *E. major*, *E. minor*, *G. paludosum*, *L. geoppertiana*, *P. borealis* var. *rectangularis, U. ulna*	*Freshwater	
16.5-16.0	**Diatoms**	*A. splendens, A. vulgaris, P. sulcata*	Marine	**Zone II**
		**S. pinnata*	*Freshwater	
18.0-16.5	**Diatoms**	*A. splendens, C. asteromphalus, P. sulcata, P. pulchellum* var. *pygmae*	Marine	
		A. sculptus, C. radiatus, D. minor, P. disculoides, P. panduriformes, T. favus	Marine to marine mixohaline	
		C. striata	Marine mixohaline	
18.5-18.0	**Diatoms**	*A. splendens, A. vulgaris, C. asteromphalus, D. surirella, P. sulcata, P. pulchellum* var. *pygmae*	Marine	
		A. senarius, C. radiatus, D. minor, T. favus	Marine to marine mixohaline	
		C. striata	Marine mixohaline	
20.5-18.5	**Diatoms**	*A. splendens, A. vulgaris, O. atlantica, P. sulcata*	Marine	
		A. senarius, A. sculptus, C. radiatus, P. disculoides, T. oestrupii, T. favus	Marine to marine mixohaline	
		C. striata	Marine mixohaline	

Figure 4 - Interval of occurrence of biogenic, with the identification of species and their respective environment in the Zone II, Zone III and Zone IV. *freshwater diatoms were based on (Santos 2015) used as reference

5.1.4. Zone IV

This zone (Fig. 4) covers the interval 10.5-10.0 m to 7.0-6.0-m, and its main characteristic is the dominance of marine and marine mixohaline diatoms, as well as the complete absence of freshwater ones (Fig. 5). The marine diatoms *A. splendens* and *P. sulcata*, and the marine to marine mixohaline *D. minor* and *P. disculoides*, occur in the interval 10.5-10.0 m.

Along the interval 10.0-8.0 m are present the marine diatoms *A. splendens, D. surirella* and *P. sulcata*; the marine mixohaline specie *C. striata*, and the marine to marine mixohaline species *A. senarius, A. sculptus, D. minor, P. disculoides* and *T. oestrupii*. The interval 7.0-6.0 m records by the marine species *A. splendens*, *C. belgica*, *C. asteromphalus, D. surirella*, *P. sulcata*, *P. pulchellum* var. *pygmae*; the marine mixohaline species *N. lanceola* and *C. striata*, and the marine to marine mixohaline species *A. senarius, A. sculptus*, *D. minor*, *P. disculoides*, *P. panduriformes*, *S. fastuosa*, *T. oestrupii* and *T. favus. P. sulcata* and *A. splendens* are the dominant taxa, (Fig. 5).

5.2. Biogenic zones versus sedimentologic profile

The sedimentological analysis based on the granulometric data by (Baitelli 2012) show correspondence between the profile and the proposed zones (Figure 2). In the Zone I (28.5-20.5 m), clayey silt and sand occur in the following percentages: silt 74.69%, clay 17.93% and sand 7.38% (Baitelli 2012), according by (Shepard 1954) classification and all biogenic groups are identified (i.e. mollusks, foraminifers, ostracods, echinoderm spines, barnacles, sponges, both fragments and spicules, and diatoms). The shallow water mollusks and other biogenics indicate a marine environment. The Zone II (20.5-16.0 m) is composed by clayey silt with sand in the following percentages: silt 66.30%, clay 31.13% and sand 2.57% (Baitelli 2012), according by (Shepard 1954) classification. Only marine diatoms occur. In the Zone III (16.0-10.0 m) occurs clayey silt represented by: silt 51.05%, clay 31.41% sand and 17.54% (Baitelli 2012) according by (Shepard 1954) classification. The presence of siliceous spicules and predominantly freshwater diatoms indicate fluvial environment. Lastly, the Zone

IV (6.0-100 m) is composed of mud (Baitelli 2012) with marine diatoms.

The paleoenvironmental changes indicated by the biogenics correspond to the sedimentological composition of the core Pa. The zones I, II and III present the same granulometric description of clayey-silt with sand, although there is variation in the sedimentological composition, with either higher or lower incidence of sand, silt and clay. The zones I and II, for instance, have lower percentage of sand, which could indicate a low energy marine environment. In the Zone III, with higher percentage of sand, could be indicative of fluvial influence of higher energy. This hypothesis is supported by the register of fluvial diatoms exclusively in this interval. In the sequence there is a muddy deposit with marine, marine mixohaline, and marine to marine mixohaline diatoms which constitute the Zone IV which characterizes a marine environment.

6. Discussion

6.1. Ecological aspects of the biogenics

Foraminifers

The benthic foraminifers *A. beccarii* and *E. discoidale* live, presently, in coastal environments, such as bays, estuaries and lagoons (Madeira-Falcetta 1977). *Ammonia beccarii* thrives in a broad range of temperature and salinity (Schnitker 1974, Poag 1978, Walton and Sloan 1990). This species according to (Ferrero 2009) argues that predominated along the cores studied in the Mar Chiquita Lagoon (Argentina), associated to other species typical from lagoons and with wide occurrence in inner platforms around the world. Investigation on temperature preferences of living foraminifers, by (Boltovskoy 1970) revealed that *E. discoidale* is typical from warm waters. It occurs not only in inner shelves but also in lagoons and estuaries from Brazil, Uruguay and Argentina (Boltovskoy 1957, Boltovskoy 1963, Closs and Madeira 1962, Closs and Madeira 1967, Lena and L'Hoste 1975, Boltovskoy et al. 1980, Ferrero 2009). *Ammonia beccarii* and *E. discoidale* Quaternary foraminifers studied by (Bertels et al. 1982) in Palmares do Sul, were identified as species typical of coastal environments with mixohaline influence, being considered, therefore euryhaline species. The specimens herein identified as *A. beccarii* and *E. discoidale*, species typical of coastal environment with capacity to live in broad range of temperature and salinity, are in good preservation.

Ostracods

The ostracod species identified in the core Pa are represented by the euryhaline *C. multidentata* (the dominant ostracod) and the marine *Propontocypris* sp., *Xestoleberis* sp. and *C. punctata* (Leite et al. 2013). More than 30 specimens of *C. multidentata* of different instars were recorded, and its mixohaline characteristic is corroborated by previous studies (Kotzian and Eilert 1985, Ferrero 2009). This species was considered euryhaline in coastal regions from Brazil and Argentina (Coimbra et al. 2007). *C. punctata* recorded by (Carreño et al. 999) both in marine and mixohaline environments, in the Pelotas Basin, and (Bertels et al. 1982), in their study in Palmares do Sul argue that *C. punctata* is a shallow marine species. The ostracods recorded in this work are mostly represented by disarticulated carapaces with remains of soft parts, and a few closed carapaces.

Mollusks

At present, there are around 100 species of shallow water mollusks in Brazil (the website *Conquiliologistas do Brasil*). Shallow water marine mollusks occur, usually, in the intertidal and infralittoral zones (5-10 m depth). These organisms live in diversified environments, such as sandy/muddy beaches, mangrooves, rocky shores, tide pools and reefs (Forti-Esteves 1974, Rios 2009, Thomé et al. 2010).

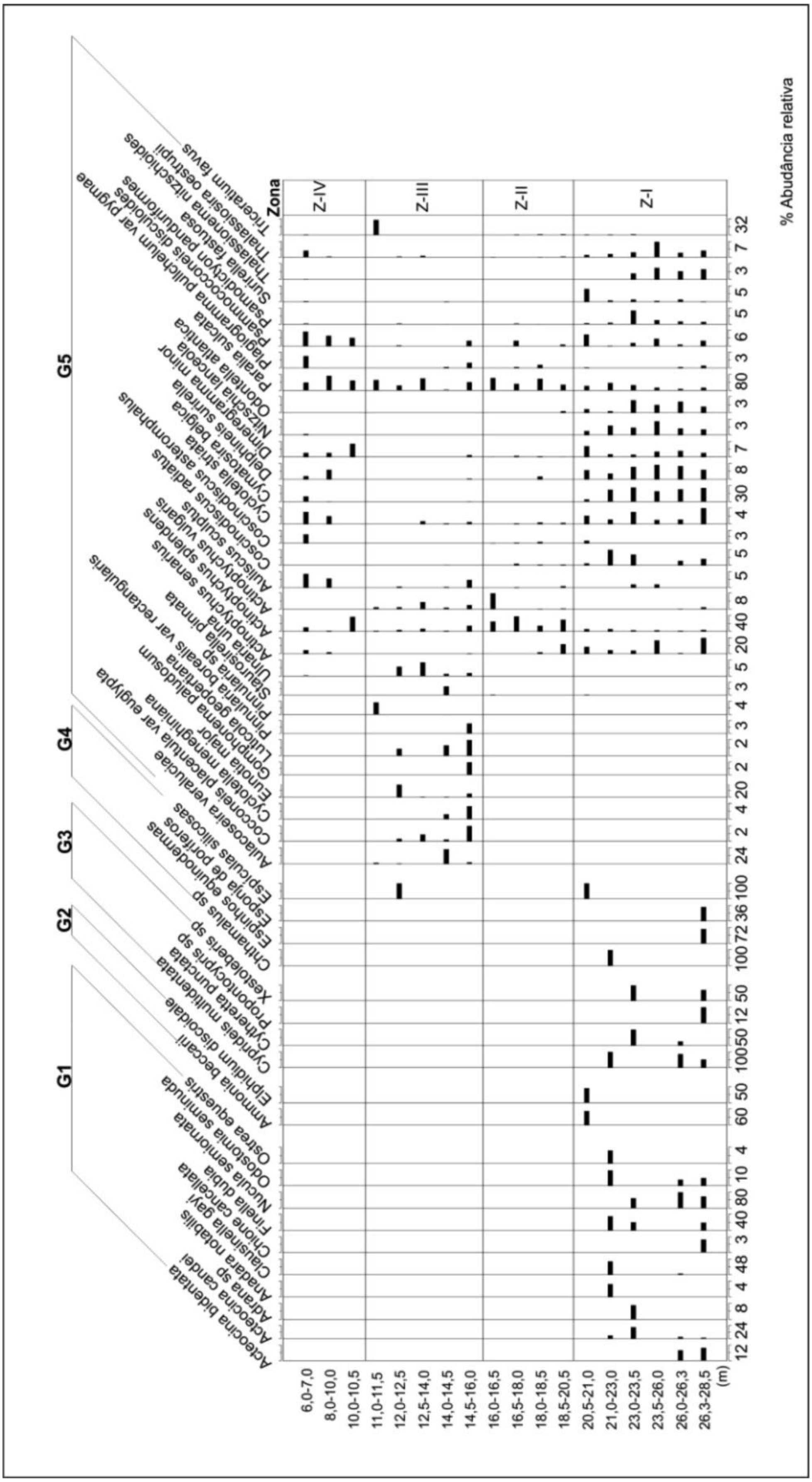

Figure 5 - Distribution of the biogenic groups and their relative abundance, divided in four biostratigraphic zones (I, II, III and IV).

The shallow water mollusks are represented in the core Pa by *C. cancellata*, *N. semiornata*, *B. seminuda*, *A. notabilis*, *O. esquestris* and *A. bidentata*, which are living species (the website *Conquiliologistas do Brasil*). The depth of occurrence of those species varies from 0 to 37 m (Forti-Esteves 1974, Rios 2009, Thomé et al. 2010). In terms of salinity, *O. esquestris* lives between 20 and 25 psu (Rios 2009), being able to thrive both in marine (where the average salinity is 35 psu) and estuarine environment (Godolphim et al. 1989).

Data on the temperature tolerance of mollusks are still scarce, though some studies have indicated the prefference of *F. dubia* for tropical and subtropical zones where the temperature is higher (Forti-Esteves 1974). *Chione cancellata* does not support cold temperatures (Gordilho 1998).

Barnacles, echinoderms and sponges

The barnacles are exclusively marine and sessile when adults (Carvalho et al. 2011). A specimen of *Chthamalus* was recorded in the core Pa. Species of this genus do not tolerate low salinities and are common in intertidal zone, both in protected areas and exposed to the action of waves (Pitombo and Young 2011).

The echinoderms are also exclusively marine and benthic. The dispersal occurs during the larval phase, which explains their wide geographic distribution, from the poles to the equator, and from the intertidal zone up to depths around 5000 m. The fossil record of this group is composed by the adults, whose endoskeleton permits preservation (Lima and Manso 2011). The core Pa records well preserved spines of echinoderms.

The sponges are benthic and sessile (when adults) marine invertebrates, which occur in all latitudes and depths. Some sponges, however, also live in freshwater and mixohaline environments. The spicules are part of their bodies, found either isolated or associated in the sediment (Zucon and Vieira 2011). Siliceous spicules are present in the core Pa, and the sponges identified are also represented by small fragments.

Diatoms

The diatoms are important biologic component of the primary production in coastal environments, and constitute photosynthetic microorganisms of noteworthy evolutionary success (Round et al. 1990, Mann 1999). This success is demonstrated by four main aspects: wide distribution in both marine and non-marine environments; high preservation potential; well defined salinity tolerance limits, and abundance in fine sediments.

Paralia sulcata, for instance, is observed along all the intervals of the core Pa, in consequence of the resistence of its frustule to dissolution, fragmentation and salinity changes. Moreover, it is classified as a ticoplanktonic species, which means that it can live both in the plankton and in the benthos (Roelofs 1984, Zong 1997, McQuoid and Hobson 1998, McQuoid and Nordberg 2003, Sawai et al. 2005, Gebühr et al. 2009, Santos-Fischer et al. 2016).

The occurrence of the freshwater diatoms *A. veraluciae* and *E. major* must be pointed up in this study. *Aulacoseira veraluciae* is recorded in both oligotrophic and eutrophic environments (Pagioro et al. 2005, Nogueira et al. 2006, Tremarin et al. 2014a). The genus *Aulacoseira* is widely recorded around the world and in tropical and subtropical regions of Brazil (Tremarin et al. 2011, Tremarin et al. 2012, Tremarin et al. 2013a, Tremarin et al. 2013b, Tremarin et al. 2014a, Tremarin et al. 2014b), including the Patos Lagoon. The genus *Eunotia* is particularly abundant in the epiphyton and metaphyton, both in oligotrophic and lotic environments (Tremarin et al. 2008). In the southern Brazil and Argentina, the genus *Eunotia* is commonly found in fluvial, lacustrine and lagoonal environments (Frenguelli 1923, Frenguelli 1924, Markgraf et al. 1986, Espinosa 1994, Torgan et al. 1999, Salomoni et al. 2006, Talgatti et al. 2007, Salomoni and Torgan 2008, Tremarin et al. 2008, Bicca and Torgan 2009, Hassan et al. 2009, Bicca et al. 2011, Durigon 2013, Santos-Fischer et al. 2016). Besides those taxa, *G. paludosum, L. geoppertiana, P. borealis* var. *rectangularis, Pinnularia* sp., *S. pinnata* and *U. ulna* are usually found in rivers, lakes and lagoons (Torgan et al. 1999).

In relation to the salinity, *P. sulcata* tolerates wide variation, being usually an indicator of marine conditions (Hendey 1964, Karentz and McIntire 1977, Navarro 1982, Vos and Wolf 1988, Stabell and Lange 1990, Cooper 1995a, Cooper 1995b, Zong 1997, McQuoid and Nordberg 2003). *Actinoptychus splendens* also tolerates wide variation of salinity, between 40-18 g/l (Navarro 1982, Hassan et al. 2009) and Cl 15,000-17,000 mg/l (Vos and Wolf 1988). The marine species *A. splendens* is commonly record in marine environments (Hendey 1964, Vos and Wolf 1988).

6.2. Environmental evolution of the core Pa

The Zone I, located at the base of the core Pa (28.5-20.5 m), registers fragments of sponges, siliceous spicules and shallow water mollusks (e.g. *C. cancellata, N. semiornata, B. seminuda, A. notabilis, O. equestris, T. gayi, F. dubia, A. candei* and *A. bidentata*). The marine ostracods *Propontocypris* sp., *Xestoleberis* sp. and *C. punctata* also indicate a marine environment at the base of the core. Although the ostracod *C. multidentata* and the foraminifers *E. discoidale* and *A. beccarii* are typically mixohaline, they occur also in shallow marine waters. Only the interval 23.5-260 m is barren for foraminifers, ostracods, mollusks, barnacles, echinoderm and sponges, yet diatoms occur. Among the diatoms are marine (e.g. *D. surirella*), marine to marine mixohaline (*A. senarius, T. oestrupii*) and marine mixohaline (e.g. *N. lanceola* and *C. striata*) species indicating marine and lagoonal/estuarine environments with some degree of variation in salinity (Santos-Fischer et al. 2016). In this zone, *P. sulcata* has the lowest relative abundance. Although the species is dominant in all samples, it presents an expressive increase from the base toward the top (Figure 3). The broad occurrence of this species in Pleistocene–Holocene deposits of the coastal plain, continental shelf and slope of the Rio Grande do Sul State was recorded in several studies (Weschenfelder et al. 2008b, Medeanic et al. 2009, Santos 2011, Santos 2015, Garcia et al. 2012, Lima et al. 2013, Santos-Fischer et al. 2016). The dominance of *P. sulcata* is also observed in several areas in South America (García-Rodriguez et al. 2001, García-Rodriguez et al. 2004a, García-Rodriguez et al. 2004b, Espinosa 2008, Escandell et al. 2009, Espinosa and Isla 2011, Escandell and Espinosa 2012, Fayó and Espinosa 2014).

The species *A. vulgaris, A. sculptus, P. pulchellum* var. *pygmae* and *T. favus* reach the lowest relative abundance, being occasionally almost absent. The relative abundance of *T. nitzschioides* is more constant only in the intervals near to the base (23.5-28.5 m) becoming absent upward. The Late Pleistocene sedimentation of the core Pa (i.e., its base) corresponds to a shallow marine environment.

The Zone II (20.5-16.0 m) differs from the previous one by the appearance of other taxa besides diatoms. The planktic marine diatoms are dominant, indicating a deepening trend and salinity increase. The most abundant taxa are the marine *A. splendens*, *A. vulgaris* and *P. sulcata*, followed by the marine to marine mixohaline *A. senarius* and *P. disculoides*. In this zone, the relative abundance of *P. sulcata* and *A. splendens* increases, followed by a conspicuous reduction or even absence of marine and marine mixohaline species as recorded in the Zone I (Figure 3). The freshwater diatom *S. pinnata* is recorded in the top of the Zone II (16.0-16.5 m), which can correspond to a transition to the Zone III with fluvial influence. The Zone II represents a marine environment characterized by the predominance of marine diatoms.

The Zone III (16.0-11.0 m) is represented exclusively by diatoms with the predominance of freshwater species (Santos 2015) over the marine, marine to marine mixohaline and marine mixohaline ones. The association with siliceous spicules of sponges suggests the transition from a shallow marine environment (similar to the Zone II) to a shallow environment influenced by river outflow. This environmental change is demonstrated by the dominance of benthic diatoms, differently from the zones I, II and IV, where predominate planktic diatoms (Santos 2015, Santos-Fischer et al. 2016). The fluvial influence in this zone is, possibly, related to the system of valleys and incise channels of the Jacuí River, as demonstrated in seismostratigraphic studies by (Baitelli 2012) and (Weschenfelder et al.

2014).

The siliceous spicules are observed in the Zone I and in the Zone III, in 21.0-20.5 m and 12.5-12.0 m, respectively. Sponges live both in marine and freshwater environments, which could explain their presence in the Zone I (marine) and in the Zone III (fluvial) belonging probably to distinct communities. Differently from the zones I and II which record the highest values of relative abundance and richness, the most representative marine diatoms the Zone III are *P. sulcata*, which persists as dominant species associated to the rare species, *A. splendens*, *A. vulgaris* and the marine to marine mixohaline *A. sculptus*. The most expressive occurrence of *T. favus* is in the interval 11.5-11.0-m, top of the Zone III, of fluvial influence. That species is characterized as a typical marine to marine mixohaline, and considered transitional to the Zone IV where the core presents again, dominance of marine diatoms. The Zone III, therefore, represents a shallow environment influenced by river discharge due to the presence of freshwater diatoms associated to marine to mixohaline benthic diatoms.

The Zone IV (10.5-6.0 m) is characterized by the dominance of marine to marine mixohaline diatoms which indicate the increasing marine influence associated to relative sea-level rise during the Late Holocene. This process caused the progressive transgression over the Rio Grande do Sul Coastal Plain, and the Maximum Transgressive (Middle Holocene). It is observed the absence of freshwater diatoms, becoming dominant the marine species *A. splendens, D. surirella, P. pulchellum var. pygmae* and *P. sulcata*, the marine to marine mixohaline *D. minor, A. sculptus* and *P. disculoides*, and the marine mixohaline *C. striata*. The species *P. sulcata* and *A. splendens* are the dominant, followed by *P. disculoides, A. sculptus, C. striata* and *D. minor.* The Zone IV composed exclusively by diatoms represents a marine environment due to presence of marine diatoms associated to others from marine mixohaline and marine to marine mixohaline environments.

Quaternary oscillations of the relative sea level in the Rio Grande do Sul Coastal Plain are represented in the core Pa by to the mixture of marine, estuarine and mixohaline organisms, concomitant to the transgressive/regressive that took place in this region (Villwock and Tomazelli 1995). Therefore, the biogenic material herein studied revealed paleoenvironmental changes along the core Pa that characterize deposition in shallow marine environment, at the base, followed by fluvial deposition in the middle part and, lastly, at the top, a shallow marine deposition. This is in accordance to the results by (Baitelli 2012), who based on seismic interpretations in the paleo-Jacuí River (same area of the core Pa), characterized the region as island-barrier system. The same study sustains, moreover, that the Jacuí River incise valley was filled both by fluvial and estuarine/shallow marine sedimentation during the transgressive/regressive events.

Oscillation in the relative sea-level was also recorded by (Santos-Fischer et al. 2016) in other sites of the Rio Grande do Sul Coastal Plain, including localities in the Patos Lagoon and the Barra Falsa channel (a former channel between the Patos Lagoon and the Atlantic Ocean), in Bojuru, south of the study area. The filling of the Barra Falsa who studied by (Weschenfelder et al. 2008b) based on palynomorphs (acritarchs and dinoflagellates) also concluded that the sedimentation is closely related to climatically-driven sea-level changes during the Holocene.

The temperature data supplied either by tropical/subtropical mollusks (*F. dubia*), or warm water ones such as *C. cancellata*, as well as the diatoms of the genus *Aulacoseira*, which preffer tropical to subtropical climates, suggest that the core Pa was located in a subtropical region.

7. Conclusions

The present work is inedit in terms of taxonomic identification of the biogenics from the longest core ever drilled in the Patos Lagoon. The four biostratigraphic zones herein proposed demonstrate clearly that the Rio Grande do Sul Coastal Plain faced intense environmental modifications, related to sea-level oscillations during the Late Quaternary.

Temperature data suggest a subtropical climate for the deposition interval of the core Pa.

The sedimentary deposition indicate that the base of the core Pa (Zone I) is characteristic of shallow marine environment during the Late Pleistocene, and older than 43.500 years BP. In the sequence there is a typically marine zone (Zone II). The subsequent portion (Zone III) indicates a change in the coastal environment, from marine to fluvial, with some marine influence. The increase in the marine influence during the early Holocene is clearly observed in the top of the core where a shallow marine environment is established again (Zone IV).

This work is a contribution to other research developed in the last decades on the sedimentary and environmental evolution of the Rio Grande do Sul Coastal Plain, bonded to transgression/regression Quaternary events.

8. Resumo

Este trabalho apresenta um estudo paleoecológico com biogênicos fósseis obtidos a partir do testemunho Pa coletado no interior da Lagoa dos Patos, próximo à cidade de Palmares do Sul, com 28,5 m de comprimento, 6,0 m de lâmina d’água e situado nas coordenadas 30º32’52”S e 50º42’54”W. É proposto um zoneamento com base no conteúdo fossilífero identificado composto por quatro zonas biogênicas (I, II, III e IV) indicando paleoambientes distintos, estabelecidos entre o Pleistoceno Tardio e o Holoceno. A base do testemunho, Zona I, compreende os intervalos de 28,5-26,3 m a 21,0-20,5 m de profundidade, e é caracterizada pela presença de foraminíferos, ostracodes, moluscos, cirripédios, equinodermos, poríferos e diatomáceas, indicando um ambiente marinho raso. A Zona II correspondente aos intervalos de 20,5-18,5 m a 16,5-16,0 m, e é dominada por diatomáceas marinhas. A Zona III compreende os intervalos de 16,0-14,5 m a 11,5-11,0 m de profundidade marcada pela presença de diatomáceas marinhas, marinhas a marinhas mixohalinas e de água doce indicando ambiente fluvial raso com alguma influência marinha. A Zona IV compreendida pelos intervalos de 10,5-10,0 m a 7,0-6,0 m é caracterizada pelo predomínio de diatomáceas marinhas, marinhas a marinhas mixohalinas e marinhas mixohalinas evidenciando um ambiente marinho. Os resultados sugerem que os paleoambientes registrados foram modificados em resposta às variações do nível relativo do mar na região e que a temperatura no período de deposição do testemunho Pa era característica de clima subtropical.

9. References

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Capítulo 4

DIVERSITY AND TAPHONOMIC SIGNATURES OF MOLLUSK ASSEMBLAGES AS TOOLS FOR RECOGNIZING QUATERNARY TRANSITIONAL SEDIMENTARY ENVIRONMENTS IN SOUTHERN BRAZILIAN COAST

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RRH: DIVERSITY AND TAPHONOMIC SIGNATURES OF MOLLUSK ASSEMBLAGES

LRH: DEHNHARDT ET AL.

Abstract. This study analyzes the diversity and taphonomic signatures of Quaternary mollusk assemblages from southern Brazilian coast, showing their role as important tools for recognizing the paleoenvironmental origin of sediments infilling some incised valleys. Mollusks were collected by means of drill holes conducted in three different and predefined paleovalleys. Based on the spatial distribution of present day mollusk assemblages, two different fossil assemblages were found. The predominance of *Heleobia australis* and/or *Erodona mactroides* characterized an estuarine and brackish water assemblage, similar to actual ones observed in estuarine proximal areas in southern Brazil. In turn, the predominance of some species that, in present days, are dominant in

estuarine distal areas, such as protected bays, large channels and some lagoons, influenced by marine waters (e.g., *Nucula semiornata, Finella dubia, Anomalocardia brasiliana*), characterized a brackish to marine assemblage. These assemblage, as well as their habitats are more common in northernmost regions of the Brazilian coast. Thus, a large variety of transitional and brackish water environments should have participated of the infilling of the paleovalleys studied. The taphonomic profile observed is also suggestive that mollusk assemblages are parautochthonous. As they also show evidences of reworking and time averaging in almost all depth intervals of the cores studied, they allow us to corroborate the findings of previous studies. The multitude of transgressive-regressive events that occurred during the overall Quaternary transgression, were related not only to climate changes but also to variations in the sedimentary and hydrological context of each paleovalley. Southern Brazilian coast landscape was environmentally more heterogeneous than it is today.

Keywords: Patos Lagoon; incised valleys; Rio Grande do Sul coastal plain; Late Pleistocene; Holocene.

INTRODUCTION

Mollusks is one of the most studied fossil groups in the coastal plain of the Rio Grande do Sul state (PCRS). The PCRS is a passive margin coast situated in the southernmost state (RS) of Brazil. The postglacial sea level history of the region started ca. 17,500 year BP when the sea level was positioned about 120–130 m below the present level. After that, it level rises rapidly until the Middle Holocene, when it started to slow down reaching its current position (Corrêa, 1996). Present days, this long and classic wave-dominated coast has a huge subtropical lagoon, the Patos Lagoon, partially enclosed by a broad and active sand barrier. Alluvial fans and four island-barrier systems comprise the main sedimentary deposits of the PCRS (Villwock and Tomazelli, 1995). Previous studies registered the occurrence of a diversified malacofauna in island-barrier deposits (e.g., Forti, 1969; Closs, 1970; Closs and

Forti, 1971; Forti-Esteves, 1974; Forti-Esteves, 1986; Lopes et al., 2011; Lopes, 2012; Lopes and Simone, 2012). The diversity of their mollusks assemblages helped to understand the paleoenvironmental evolution of the PCRS, providing important information related to changes in water temperature and salinity (Forti-Esteves, 1974; Caron et al., 2007; Bortolin, 2011; Baitelli, 2012; Lima et al., 2013). Some species were also used for carbon dating and isotopic analyses, collaborating for recognizing the timing of numerous sea-level oscillations that occurred during the overall Quaternary transgression (Bortolin, 2011; Baitelli, 2012; Weschenfelder et al., 2014).

Taphonomic signatures (shell damages produced after death) of mollusk assemblages can be as important as their diversity to recognize environmental factors operating in a wide array of marine and freshwater habitats. Differences among assemblages, concerning abundance or percentage values of shell fragmentation, corrasion (=physical and chemical damages; Parsons and Brett, 1991), incrustation, size selection, etc., can be related to differences in intensity or occurrence of some environmental factors. For instance, they can indicate differences among water velocity, temperature, depth and pH values, sediment grain size, as well as presence or absence of waves and predators, and time of exposition in water sediment interface, etc. (Best and Kidwell, 2000; De Francesco and Hassan, 2008). Thus, they can help to reveal, not only the habitat where an assemblage had lived or dead, but also where it was buried and eventually fossilized. They can also show evidences of post-morten transport and reworking (Kidwell and Bosence, 1991), helping to conclude if the sedimentary environment where fossil or dead assemblages are found corresponds to the environment occupied by life assemblages. Assemblages originated in different habitats, and spatially and/or temporally mixed, can also be recognized in fossil record by means of their taphonomic signatures, avoiding miss-interpretations (De Francesco and Hassan, 2008). Despite their importance for recognizing sedimentary environmental processes, studies focusing taphonomic signatures in mollusk assemblages from the PCRS are missing. Some studies about shell damages are available (Caron et al., 2011; Lopes et al., 2011) but quantitative analyses, focusing mollusk assemblages as the main tool for recognizing paleoenvironments, are scarce (Ritter and Erthal, 2011; Ritter et al., 2013).

In the last decade, high-resolution seismic studies revealed the existence of prominent river valleys and channels incised in the PCRS, especially at the Patos Lagoon region (Baitelli, 2012; Weschenfelder et al., 2014). These valleys were dug during regression events that occurred previously to the sea level highstand events of the Quaternary period. The sequence of sediments infilling incised valleys are associated with high rates of accommodation, and may show the complete record of transgressive events on continental shelves (Anderson and Rodriguez, 2008). In fact, a relatively well-diversified fossil content, constituted mainly by diatoms, cirripeds, ostracods and mollusks, have been registered in sediments infilling some paleoincisions of the PCRS. Fossils allowed recognize that fluvial and marine inputs interacted in a transitional landscape, characterizing estuarine environments (Bortolin, 2011, Baitelli, 2012; Leite et al., 2013; Weschenfelder et al., 2014; Santos-Fischer et al., 2016). Previous studies also suggested that sea level oscillations were not homogeneous along the coast, and that transitional environments were variable due to local differences in sedimentary input and hydrological context (Baitelli, 2012). However, studies about the diversity and taphonomic signatures of mollusk assemblages, which could help to characterize the environments and sedimentary processes, were missing.

In this study, the diversity and taphonomic signatures of mollusk assemblages recorded in three incised valleys from the PCRS were analyzed. Special attention was given to the spatial distribution of present day assemblages, instead of their species individually, in order to help recognizing different transitional settings. Diversity and Taphonomic signatures of mollusk assemblages were analyzed at each depth interval, in order to understand sedimentary processes involved in the origin of shell assemblages, and consequently in the origin of sediments infilling the incised valleys. This study aims to contribute to characterizing, spatially and temporally, the southern Brazilian coastal landscape.

Geologic Outline

The present physiography of the coastal plain and shelf is mainly the result of Quaternary high-frequency, glacio-eustatic, sea level changes (Villwock and Tomazelli, 1995; Corrêa, 1996; Baitelli, 2012; Weschenfelder et al., 2014). Also, the related continental shelf and slope are considered stable, subject to epirogenic movements and were shaped not only by sea level oscillations, but by local hydrodynamic conditions (Corrêa, 1987). Although several transgressive and regressive events have left their distinct topographic, depositional, erosional and sedimentary imprint, the present morphology of the PCRS, in general it shows an environmentally homogeneous landscape. The PCRS is characterized by a smooth morphology with a very gentle gradient (1.3-1.4 m/km), with and average width of 125 km. The coast is sandy, and high-energy wave-dominated, with tidal amplitude averages up to 40 cm (Toldo Jr., 2000). Its wide lowlands spanning ~33,000 km^2 is bordered by highlands to the west (Corrêa, 1987). Present day, few rivers cross the PCRS or run directly into the Atlantic Ocean. In turn, the remarkable physiographic feature in the coastal plain is the Patos Lagoon, which covers 10,000 km^2 NE-SW, with length of 240 km, and average width of 40 km and depth of 6 m (Toldo Jr., 2000; Figure 1). This huge and choked lagoon is separated from the ocean by a straight island-barrier deposit, and has only a single inlet, the Rio Grande channel, to exchange water with the sea. It receives freshwater from the Guaíba Hydrographic Basin (area ~200,000 km^2) and the main contributing rivers are the Jacuí, Taquari, and Camaquã, which flow into the lagoon. Thus, freshwater discharge contributes to the main circulation pattern (Toldo Jr., 2000).

The geology of the PCRS was strongly controlled by the sea level variations. Alluvial and island-barrier sedimentary deposits, originated in response to sea level changes, are the main depositional systems in southern Brazilian coast. According to Villwock and Tomazelli (1995), four island-barrier depositional systems can be recognized based on its

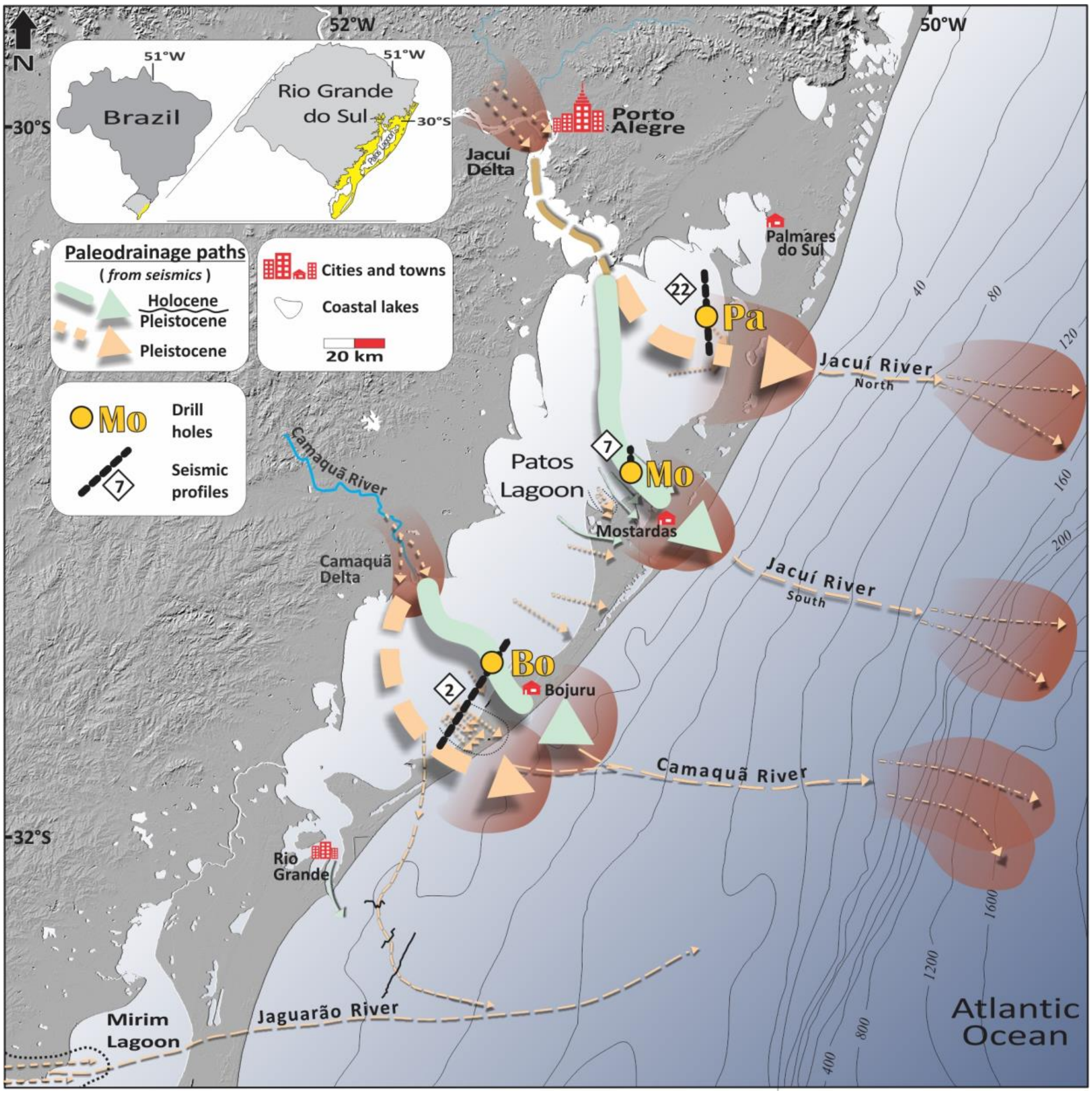


FIGURE 1 – Study area in the PCRS, showing the position of cores Bo (Bojuru), Mo (Mostardas) and Pa (Palmares) and of their related seismic profiles, and the inferred paths of ancient paleovalleys (adapted from Weschenfelder et al. 2014)

geomorphological and lithological patterns. Based on correlation between the sea level highstands and the major peaks of the oxygen isotope curves, the island-barrier systems are also related to Marine Isotope Stages (MIS). The oldest systems I, II and III was related to MIS 11, 9, 5e and 1 (I: 400,000 year BP, II: 325,000 year BP, III: 120,000 year BP), while the youngest system IV, is related to the LGM and the next interglacial cycle (MIS1), confirming the correlation between sea level oscillations and climate changes (Baitelli, 2012). However, in the last decade, the occurrence a different type sedimentary deposit in the PCRS was also confirmed. High-resolution seismic records (Bortolin, 2011; Baitelli, 2012; Weschenfelder et al., 2014) revealed the existence of prominent valleys and channels incised in the Patos Lagoon area (Fig. 1). These coastal valleys were incised before the installation of the actual coastal plain, during regression events occurring previously to the overall Quaternary transgression. Systematic mapping of the seismic surfaces allowed the establishment of three distinct sequences (S1, S2, S3), as well as of two distinct, non-contemporary, well-defined cut-and-fill incision events (Weschenfelder et al., 2014; Fig. 2). The filling of the younger incision system is mainly Holocene and its onset is related to the last main regressive event of the Pleistocene, when the sea level fell about 130 m below the actual position. The older incision and filling event is related to previous transgressive-regressive- events of the Middle and Late Pleistocene. Landwards, the paleoincisions are linked with present courses of the main rivers dissecting the area, such as Jacuí and Camaquã (Baitelli, 2012; Weschenfelder et al., 2014). Oceanwards, they are linked with features previously recognized in the continental shelf and slope by means of seismic and morphostructural studies (Corrêa 1994).

MATERIALS AND METHODS

Drill Holes Location and Geologic Characterization, And Sampling Methods

Three shallow stratigraphic cores were carried out in the Patos Lagoon interior (Fig. 1). Drillings cored in shallow water depths (6 to 8m), recovering up to 30 m sediments, and were performed using the Standard Penetration Test (SPT) equipment. The SPT uses a thick-walled sample tube, with internal diameter of cores of 34.9 mm, that is driven into the ground by blows from a gravity hammer. Samples were obtained meter by meter. However, differences concerning depth interval of each sample were common, because the first 50 cm of sediments was recovered by means of trough sample, while the following 50 cm was obtained by means of penetration. In other words, it was not always possible drilling equal amount of sediments or undisturbed samples. Both trough and penetration samples were stored in plastic bags, and conducted to the mineral collection of the Centro de Estudos em Geologia Costeira e Oceânica, Universidade Federal do Rio Grande do Sul (CECO/UFRGS).

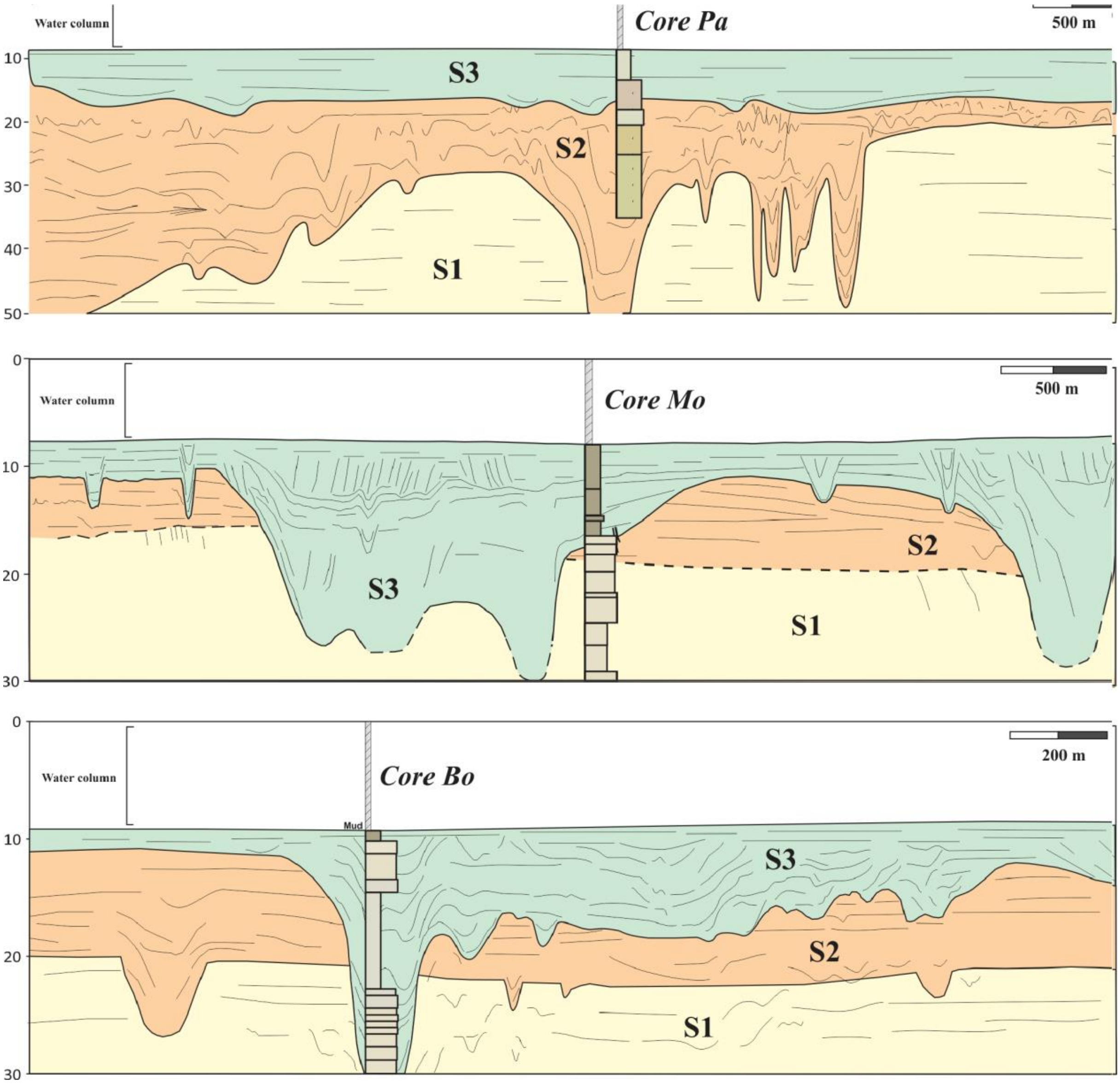


FIGURE 2 – Details of the main architectural elements of the seismic profiles and the position of the studied cores: a) profile 2, Core Bo; b) profile 7, Core Mo; and c) profile 22, Core Pa (adapted from Weschenfelder et al., 2014)

The studied cores were named Bojuru (Bo / 31º31’30’’S; 51º29’50’’W), Mostardas (Mo / 31º00’25’’S; 51º00’10’’W) and Palmares do Sul (Pa / 30º32’52’’S; 50º42’54’’W), according to the drilling site toponymy (Fig. 1). The location of the each core is coincident with different paleovalleys and seismic profiles (Fig. 2). The main features of the incised valley and infilling in the location of each core were previously studied (Bortolin, 2011; Baitelli, 2012; Weschenfelder et al., 2014; Santos-Fisher et al., 2016), as follows.

Core Bo is located according to the seismic profile 2, which extends for over 38 km along the eastern Patos Lagoon margin, in S-N direction. Various buried channels were identified along this profile. Near Core Bo, the largest paleochannel is about 1.5 km wide, the channel-fill is at least 20 m thick, and its sediments correspond to the sequence S3 (Fig. 2). This paleochannel represents an old and extinct course of the present Camaquã River. Carbon dating conducted with mollusk shells (7,640-7,430 to 11,500-10,240 cal yr BP) indicates that the infilling is Late Pleistocene – Holocene in age. The basal (27–20 m) and upper (13–9 m) portions of Core Bo are composed of fine sand, intercalated with a muddy middle portion (20–13 m), topped with muds (9–8 m) up to lagoon bottom. Core Mo is inserted in the seismic profile 7, which is about 10 km long, in a N-S direction, parallel to the eastern border of the Patos Lagoon. Prominent paleoincisions are identified in this seismic record, in which a large incised paleovalley and several paleochannels occur. In the location of Core Mo, the base of the incision correspond to the S1 and S2 sequences. The most prominent paleochannel is about 2 km wide, and its sedimentary filling is at least 20 m thick (S3). Core Mo is coincident with one of the two old and extinct course of the present Jacuí River. Carbon dating conducted with mollusk shells (7,640-7,430 to 11,500-10,240 cal yr BP), sampled in depth intervals coincident with a S3 incision, indicates that the infilling is Late Pleistocene – Holocene in age. The basal and middle portions (30–15 m) are composed of fine and very fine sand, and the upper part is essentially mud (15–7 m). Core Pa is inserted in the seismic profile 22, obtained in a NW-SE direction, almost parallel to eastern lagoonal margin, in water depths around 6 m. Core Pa correspond to a straight and small paleochannel, which is located near a large paleochannel that represent an old Pleistocene main course of the present Jacuí River. The smaller paleochannel sampled by Core Pa is coincident with S2 and S3 sequences.

Carbon dating conducted with mollusk shells collected in the basal portion of Core Pa showed ages > 43 ka, indicating infilling prior to the Late Pleistocene. Core Pa is composed by muddy silt from the bottom (29 m) up to the 10 m depth, and it is topped by a 4 m thick interval of mud (10–6 m) up to lagoon bottom.

Shell Sampling And Identification, And Diversity And Taphonomic Signature Analyses

About 50 gr of sediments was taken by chance from each sample (=depth interval) of each core. Sediments were soaked in porcelain capsules and heated at 60°C successively until the complete disaggregation of the sample, and washed through a 0.062 mm mesh. Mollusk shells were identified to species level whenever possible, and the identification was based on the extensive malacological literature available. All specimens showing intact or slightly broken shells were measured with the aid of a millimeter ocular lens (10x; precision = 0.1 mm). Bivalves were measured according their length (*sensu* Rios, 2009) and gastropods, according their height (*sensu* Abbott, 1974).

Ecological data about species recorded focused the following information: salinity (marine and brackish waters), substratum (sandy, muddy, rocky, algae, shells, wood), life habit (epifaunal, infaunal, borer, parasitic; free-living, attached, pelagic), water temperature (tropical-subtropical; subtropical-temperate) and water depth. The spatial distribution of the species in shallow transitional environments, along the Brazilian, and also in Uruguay and Argentina coasts, were based in present day living community studies. This procedure allow to recognizing different transitional environments, because individual species could inhabit a width range of habitats. Especially, it avoids using data based on mollusks found in palimpsests and reworked shells concentrations, which can be common in western South American coast (De Francesco and Hassan, 2008).

Some taphonomic signatures easily observable in minute mollusks shells were selected for study. Their definition was based on previous studies (Parsons and Brett, 1991; Best and Kidwell, 2000; Ritter et al., 2013); and their categories arbitrarily determined (Table 1). Shell damages were analyzed according to their percentages in each depth interval. Shell fragments (specimens showing ≥ 50% of shell surface broken) were not included in the analysis, except when calculating shell integrity percentage.

TABLE 1 – Taphonomic signatures studied

Taphonomic signature	Categories	Explanation
Shell integrity	Intact Broken Fragment	Not broken < 50% of shell broken > 50% of the shell broken
Articulation (only for bivalves)	Articulated Disarticulated	Closed or butterflied
Ornamentation integrity (= corrasion)	Intact Partial Eroded	100 – 80% preserved 80 – 50% preserved < 50% preserved
Luster (external shell surface)	Intact Lost	
Predation marks	Intact With predation marks	
Bioerosion marks	Intact With bioerosion marks	
Shell color integrity	Intact Altered	Original shell color preserved Original shell color lost or changed to secondary colors

Size selection was analyzed comparing the maximum and medium shell size measured for each species in each depth interval, with their maximum shell size recorded previously in the literature. Mollusk shell photos were taken with a digital camera. The studied specimens are stores in the sedimentary collection of the CECO, UFRGS.

RESULTS

Overall diversity and taphonomic signatures of mollusk assemblages

Nineteen species were recorded in the studied cores (Fig. 3). They were represented by eight gastropods (*Acteocina bidentata* (Orbigny, 1841), *Acteocina candei* (Orbigny, 1842), *Boonea seminuda* (C. B. Adams, 1837), *Bulla striata* Bruguìere, 1792, *Finella dubia* (Orbigny, 1842), *Heleobia australis* (Orbigny, 1835), *Heleobia* sp. and *Turbonilla fasciata* (Orbigny, 1840), and 11 bivalves (*Anomalocardia brasiliana* (Gmelin, 1791), *Anadara notabilis* (Röding, 1798), *Adrana* sp., *Caryocorbula caribaea* Orbigny, 1842, *Caryocorbula* sp., *Chione cancellata* (Linnaeus, 1767), *Erodona mactroides* Bosc, 1802, *Nucula semiornata* Orbigny, 1846, *Ostrea equestris* Say, 1834, *Ostrea* sp. and *Tawera gayi* (Hupé, 1854). Most of these mollusks is typically marine, occurs in shallow waters, and can be found in transitional environments located near freshwater settings, such as bays, estuaries, deltas, mangroves and lagoons (Table 2). Most of them also lives in tropical to subtropical Atlantic waters in South American coast, and is free-living epifaunal or infaunal mollusks, dwelling in sandy to muddy bottoms (Table 2). Two mollusks, *H. australis* and *E. mactroides*, are mainly inhabitants of estuaries and choked lagoons, where they can be very abundant, occurring in vegetated and lower salinity areas, and are frequently found associated (Arocena and Rodriguez, 2001; Fonseca and Netto, 2006; Rosa and Bemvenuti, 2006; Echeverria et al., 2010; Milessi et al., 2010; Barboza et al., 2012; Carcedo and Fiori, 2012). *Erodona mactroides* and *T. gayi* are not typical of tropical and subtropical waters. They have been recorded in the cooler waters (Table 2) of the Argentinean and Patagonic provinces (Palacio, 1982; Barroso et al., 2016). However, *E. mactroides* is restricted to the warmer waters in northward waters of the Argentinean Province (Colling et al., 2010), reaching the southern Brazilian coast. In general, the species registered were represented by specimens showing shell size smaller than that previously recorded for them in the literature (Table 2; Figs. 4, 5, 6). Their shells were also frequently fragmented or broken, and most bivalve shells were disarticulated (Fig. 3). However, richness, diversity, and dominant taxa, as well as the taphonomic signature percentages, varied among the studied cores, and among the different depth intervals of each core (Figs. 4, 5, 6).

Core Bojuru

A total of 11 taxa (four gastropods; seven bivalves) were registered (Fig. 4; Supplemental data). Two species was the typical inhabitants of present day estuaries in southern Brazil (*H.*

australis, *E. mactroides*), while the other ones can be found in other kinds of transitional habitats with restrict water circulation and/or riverine influence (e.g., bays, estuaries, lagoons, mangroves). Most of them occurs in South America tropical to subtropical waters, but *E. mactroides* and *T. gayi* are from cooler waters of the Argentinean Province. The interval Bo 13.0-12.0, near the top of the core, showed the highest richness (10) and abundance of intact or broken specimens (N=124). Only *A. bidentata*, a rare gastropod in the Core Bo, was not recorded in this interval. *H. australis* was dominant in the interval Bo 13.0-12.0, as well as along all core. Other intervals showed four or less species, as well as abundance smaller than that registered in interval Bo 13.0-12.0.

Broken shells and fragments predominated in intervals, and the intervals nearest the base (Bo 23.5-23.0 to 21.0-20.5) and the top (Bo 11.0-10.0 to 10.0-9.0) of the core contained only fragments (Supplemental data; Table 2; Fig. 4). The most basal intervals (Bo 27.0-26.0; 26.0-25.0) were sterile for mollusks. Gastropods showed higher number of intact shells than bivalves. The few broken gastropod specimens showed breaks mainly in the apex and aperture of their shells (e.g., *B. striata*, Fig. 3C), while the bivalves exhibited especially the hinge and the shell margin broken (e.g., *A. brasiliana* and *Ostrea* sp.; Fig. 3A, B). Only one specimen of *C. caribaea* (Bo 13.0-12.0) was represented by an articulated and intact shell. The largest specimens found reached a maximum of 8 mm of length. The majority did not reached half of the maximum shell size recorded for their species (Supplemental data; Table 2; Fig. 4), including specimens of minute species, such as *H. australis* (7.2 mm; Gaillard and Castellanos, 1976). This taphonomic condition also characterized the richest and most abundant interval Bo 13.0 -12.0. In intervals Bo 15.0-14.0 and Bo 19.0-18.0 some intact specimens, exceeding more than half of the maximum shell size registered for their species (Supplemental data) were found. However, they did not reach the maximum size too.

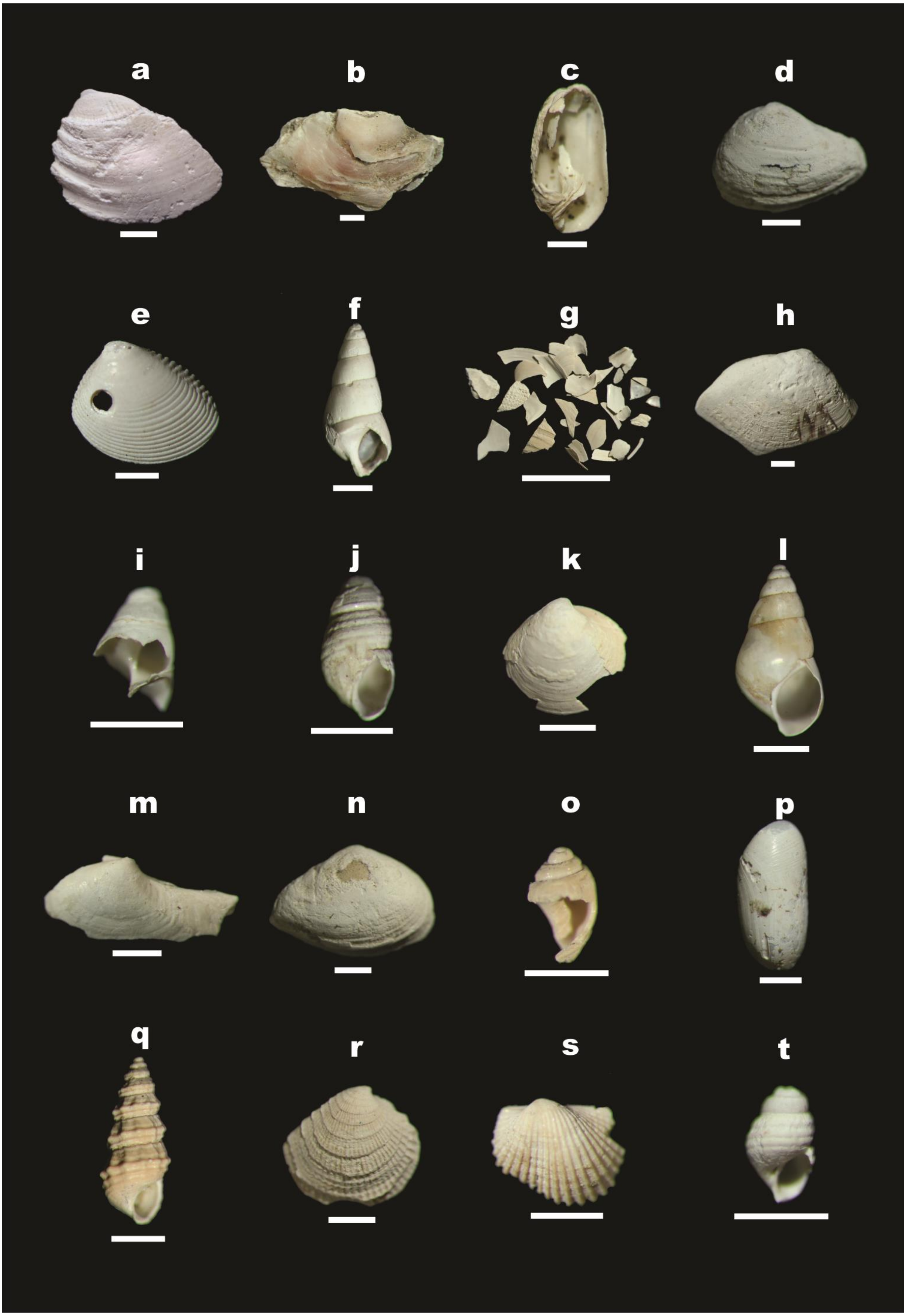


FIGURE 3 – Mollusk species and some taphonomic signatures registered in the studied cores. A) *A.brasiliana* (Bo 13.0-12.0 m): broken margin; B) *Ostrea* sp. (Bo 13.0-12.0 m):

broken shell, C) *B. striata* (Bo 13.0-12.0 m): broken shell, D) *C. caribaea* (Bo 13.0-12.0 m): bieroded shell, E) *N. semiornata* (Bo 13.0-12.0 m): predation signals, F) *Heleobia* sp. (Bo13.0-12.0 m): predation signals, G) molluks fragments (Mo 12.3-11.5 m), H) *E. mactroides* (Mo 10.5-7.3 m): broken margin, I) *H. australis* (Mo 11.5-10.5 m): broken aperture, J) *T. fasciata* (Mo 14.0-13.0 m): eroded shell, K) *T. gayi* (Mo 14.0-13.0 m): broken margin, L) *Heleobia* sp. (Mo 12.3-11.5 m): intact shell, M) *Adrana* sp. (Mo 14.0-13.0 m): broken margin, N) *Caryocorbula* sp. (Mo 12.3-11.5 m): bioeroded shell, O) *A. candei* (Pa 23.5-23.0 m): broken shell, P) *A. bidentata* (Pa 26.0-23.5 m): bioeroded shell, Q) *F. dubia* (Pa 28.5-26.3 m): intact shell, R) *C. cancellata* (Pa 28.5-26.3 m): intact shell, S) *A. notabilis* (Pa 23.0-21.0 m): intact shell, T) *B. seminuda* (Pa 28.5-26.3 m): broken apex. (Note: numbers in parentheses correspond to depth intervals of cores Bo, Mo and Pa; all scale bars = 1mm)

Along the Core Bo, most species were represented by specimens showing partially eroded shells (Fig. 3D) and luster totally lost (N=167; Fig. 3F). They were also represented mainly by bioeroded shells (Fig. 3D) in all intervals, and rare specimens showed intact shells (*T. gayi*), predation signals (*Heleobia* sp., Fig. 3F), including circular holes, possibly made by gastropods (*N. semiornata*, Fig. 3F). Luster was observed in the internal and external shell face of *A. brasiliana*, *Ostrea* sp., *B. striata* and *C. caribaea* (Fig. 3A, B, C, D).

Core Mostardas

Eleven species were registered (five gastropods/six bivalves) (Fig. 5; Supplemental data). Most species and specimens were represented by mollusks inhabiting shallow transitional environments, such as bays and estuarine areas, in tropical to subtropical waters. They can be found living in sandy (*N. semiornata*; Tallarico et al., 2014), muddy, or muddy sand substrates (*A. brasiliana*, Rodrigues et al., 2010; Santos et al., 2014; Maia et al., 2017), and also occur associated to algae (*T. fasciata*, Queiroz and Dias, 2010). Species of *Caryocorbula* and *Adrana* have been registered in bays and channels near river mouths

(Grillo et al., 1998; Soares-Gomes and Pires-Vanin, 2003; Denadai et al., 2014) (Table 2). In some intervals (Mo 10.5-7.3; Mo 13.0-12.3) species from subtropical to temperate waters predominated (*T. gayi* and *E. mactroides*). *Tawera gayi* is a very common species in the cool waters of all Argentinean coast (Gordillo, 2006), but its present day occurrence in southern Brazilian coast is poorly documented (Barroso et al., 2016).

TABLE 2 – Ecological data and maximum shell-size recorded for the studied species. (Environment: mar = marine, mix = exclusively estuarine, mar-mix = marine to brackish; Depth = water depth; WT = water temperature: Trop = Tropical; Sub = Subtropical; Temp = Temperate; Substrate; Life Habits: In=infaunal, Ep=epifaunal, Ot=others; and MSS= maximum shell size recorded in the literature). Note. Numbers in parentheses after the species name correspond to studies about living assemblages, as follows: 1 = Rios (2009); 2 = Gaillard and Castellanos (1976); 3 = Souza et al. (2013); 4 = Colling et al. (2010); 5 = Corte et al. (2017); 6 = Santos et al. (2014); 7 = Echeverría et al. (2010); 8 = Farrapeira et al. (2009); 9 = Oliveira (2011); 10 = Barroso et al. (2013); 11 = Tallarico et al. (2014); 12 = Barroso and Matthews-Cascon (2009); 13 = Boehs et al. (2004); 14 = Casares and Creed (2008); 15 = Rocha and Matthews-Cascon (2015); 16 = Soares-Gomez and Pires Vanin (2005); 17 = Soares-Gomes and Fernandes (2005); 18 = Creed and Kinupp (2011); 19= Gordillo (2006); 20 = Almeida et al. (2004); 21 = Denadai et al. (2000); 22 = Benkendorfer and Soares-Gomes (2009); 23 =Caetano et al. (2008); 24 = Ferreira et al. (2015); 25 = Fonseca and Netto (2006); 26 = Gandara-Martins and Almeida (2013); 27 = Garcia et al. (2007); 28 = Gonçalves et al. (1998); 29 = Grillo et al. (1998); 30 = Klein et al. (2001); 31 = Lima et al. (2017); 32 = Longo et al. (2014); 33 = Maia et al. (2017); 34 = Mendes et al. (2006); 35 = Neves et al. (2007); 36 = Neves et al. (2011); 37 = Neves et al. (2013); 38 = Ourives et al. (2011); 39 = Paiva (2001); 40 = Pimenta et al. (2009); 41 = Pires-Vanin et al. (2014); 42 = Queiroz and Dias (2014); 43 = Rollemberg et al. (2008); 44 = Soares-Gomes and

Pires-Vanin (2003); 45 = Arocena and Rodrigues (2001)

Species (live assemblage studies)	**Environment**	**Depth (m)**	**WT**	**Substrate**	**Life habits**	**MSS (mm)**
Gastropoda						
A. bidentata (19, 22, 24, 27, 35, 43)	mar	0 to 360 (1)	Trop-Sub (37)	sand, mud (22)	In (1)	4 (1)
A. candei (19, 22, 24, 26, 27, 41)	mar	0 to 8 (41)	Trop-Sub (1,41)	sand (41)	Ot(1)	4.5 (1)
B. striata (3, 10, 12, 13, 18, 19, 20, 21, 23, 24, 26, 42, 43)	mar	Intertidal (1)	Trop-Sub (1)	sand, mud (1,43)	In (1)	28 (1)
F. dubia (13, 14, 22, 32, 35, 38, 39, 41)	mar	0 to 11 (41)	Trop-Sub (1,41)	sand, algae (1,41)	Ep (3)	3 (1)
H. australis (7, 25, 26, 28, 35, 36, 37, 46)	mix	1 to 1.8 (25)	Trop-Sub (1)	sand, mud, algae (1)	Ep, In (1)	7.2 (2)
B. seminuda (40)	mar	Meso-littoral (40)	Trop-Sub (1,32)	sand, mud, shell banks (1,40)	Ot (1)	5 (1)
T. fasciata (42)	mar	intertidal, subtidal (1)	Trop-Sub (1)	mud (1)	In (1)	8 (1)
Bivalvia						
A. notabilis (10,16, 34)	mar	10 to 100 (16)	Trop-Sub (1)	sand, mud (1)	In (1)	66 (1)
A. brasiliana (5, 6, 10, 12, 13, 15, 18, 21, 23, 26, 29, 31, 33, 37, 41, 42, 43)	mar	10 to 20 (41)	Trop-Sub (15)	Sand, mud (43)	In (15)	34 (1)
C. cancellata (10, 11, 13, 15, 16, 18, 19, 21, 31, 37, 43, 44)	mar	10 to 100 (16)	Trop-Sub (16,)	ro, mud (45), sand (49)	In, Ep (15)	25 (1)
T. gayi (19,30)	mar	25 to 70 (1)	Sub-Temp (15,19)	sand, mud (1)	In (1)	35 (1)
C. caribaea (10, 13, 14, 16, 17, 20, 21, 26, 29, 30, 34, 39, 43, 44)	mar	45 to 60 (17)	Trop-Sub (16)	sand, mud (1,43)	In (1)	9 (1)
E. mactroides (4, 9, 21, 25, 45)	mix	Intertidal, subtidal (1)	Sub-Temp (1)	mud (1)	In (1)	28 (1)
N. semiornata (11, 14, 16, 20, 21, 23, 26, 29, 30, 34, 37, 41, 43, 44)	mar	4 to 44 (41)	Trop-Sub (1,41)	sand (43)	In (1)	6 (1)
O. equestris (8)	mix, mar	0 to 20 (1)	Trop-Sub (1,8)	rock (1)	Ep (1)	47 (1)

In most intervals, seven species were registered. In the top interval (Mo 10.5-7.3) the smaller values of richness and abundance were registered (2 and 7 respectively). In the core as a whole, as well as in most depth intervals, typically brackish and estuarine specimens predominated (*E. mactroides* and *H. australis*). However, in almost all intervals a similar number of exclusively brackish and marine to brackish species (Table 2) occurred. The top interval (Mo 10.5-7.3) contained the exclusively brackish species, *E. mactroides* and *H. australis*. *Heleobia* sp. or *H. australis* predominated in all intervals, except in the top interval (Mo 10.5-7.3), where *E. mactroides*, typical of muddy bottoms, predominated (Table 2; Fig. 5).

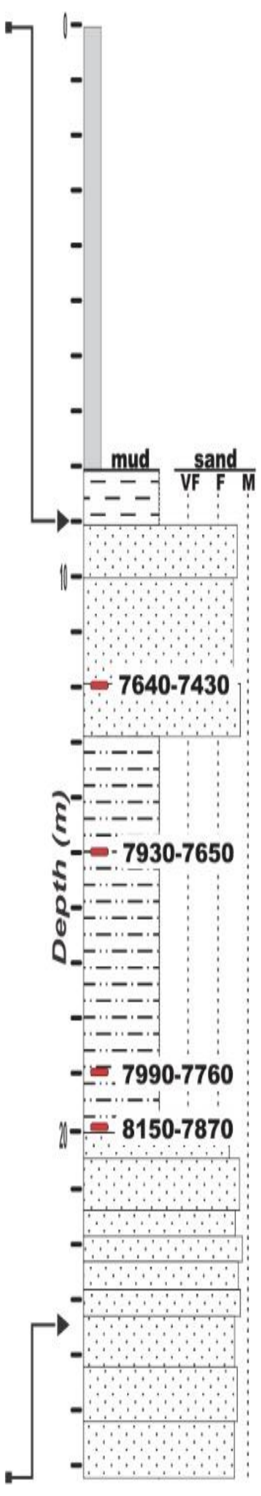
Depth	Mollusks	N (%)	MMSs	Bro (%)	Des (%)	Orn P (%)	Pred (%)	Bioe (%)	Core Bo
10.0-9.0	Frag. Indet.	16 (100)	---	16	0	0	0	0	
Subtotal		**16**		**16**	**0**	**0**	**0**	**0**	
11.0-10.0	Frag. Indet.	21 (100)	---	21	0	0	0	0	
Subtotal		**21**		**21**	**0**	**0**	**0**	**0**	
13.0-12.0	*A. brasiliana*	3 (1.28)	---	33.1	97.1	82.26	2.42	84.68	
	B. striata	1 (0.43)	2.7/2.7						
	T. gayi	6 (2.56)	4.2/3.4						
	C. caribaea	1 (0.43)	4.5/4.5						
	E. mactroides	1 (0.43)	8.1/8.1						
	H. australis	75 (32.05)	5.0/2.9						
	Heleobia sp.	14 (5.98)	6.8/3.4						
	O. equestris	2 (0.85)	5.2/3.5						
	Ostrea sp.	9 (3.85)	---						
	N. semiornata	12 (5.13)	2.7/3.1						
	Frag. Indet.	110 (47.01)	---						
Subtotal		**234**		**41**	**33**	**102**	**3**	**105**	
14.0-13.0	*A. brasiliana*	1 (2.70)	---	66.7	100.00	100.00	0	66.67	
	H. australis	1 (2.70)	---						
	N. semiornata	1 (2.70)	3.0/3.0						
	Frag. Indet.	34 (91.89)	---						
Subtotal		**37**		**2**	**2**	**3**	**0**	**2**	
15.0-14.0	*A. bidentata*	1 (4.16)	2.5/2.5	0	0.00	50.00	0	100.00	
	H. australis	7 (29.17)	4.3/2.6						
	Frag. Indet.	16 (66.67)	---						
Subtotal		**24**		**0**	**0**	**4**	**0**	**8**	
16.0-15.0	*T. gayi*	1 (5.55)	---	100.0	100.00	0	0	100.00	
	Ostrea sp.	1 (5.55)	---						
	Frag. Indet.	16 (88.90)	---						
Subtotal		**18**		**2**	**2**	**0**	**0**	**2**	
18.0-17.0	*N. semiornata*	1 (3.12)	---	100.0	100.00	75.00	0	50.00	
	H. australis	1 (3.12)	---						
	Ostrea sp.	2 (6.25)	---						
	Frag. Indet.	28 (87.51)	---						
Subtotal		**32**		**4**	**3**	**3**	**0**	**2**	
19.0-18.0	*H. australis*	2 (7.41)	4.0/3.7	0	0.00	100.00	0	100.00	
	Heleobia sp.	2 (7.41)	4.0/3.9						
	Frag. Indet.	23 (85.18)	---						
Subtotal		**27**		**0**	**0**	**4**	**0**	**4**	
20.5-19.0	*A. brasiliana*	2 (1.54)	8.2/8.2	40.9	100.00	81.82	0	86.36	
	T. gayi	2 (1.54)	3.7/3.7						
	Heleobia sp.	11 (8.46)	3.5/1.8						
	H. australis	7 (5.38)	3.1/2.1						
	Frag. Indet.	108 (83.08)	---						
Subtotal		**130**		**9**	**4**	**18**	**0**	**19**	
21.0-20.5	Frag. Indet.	14 (100.0)	---	0	0	0	0	0	
Subtotal		**14**		**0**	**0**	**0**	**0**	**0**	
22.0-21.0	Frag. Indet.	6 (100.0)	---	0	0	0	0	0	
Subtotal		**6**		**0**	**0**	**0**	**0**	**0**	
22.5-22.0	Frag. Indet.	11 (100.0)	---	0	0	0	0	0	
Subtotal		**11**		**0**	**0**	**0**	**0**	**0**	
23.0-22.5	Frag. Indet.	15 (100.0)	---	0	0	0	0	0	
Subtotal		**15**		**0**	**0**	**0**	**0**	**0**	
23.5-23.0	Frag. Indet.	5 (100.0)	---	0	0	0	0	0	
Subtotal		**5**		**0**	**0**	**0**	**0**	**0**	
Total		502		58	44	134	3	142	

FIGURE 4 – Sedimentological profile (adapted from Weschenfelder et al., 2014); richness of mollusk assemblages; abundance (N), frequency (%) and maximum and medium shell size (MMSs) of species; and percentage of some taphonomic signatures (Bro = broken shells, Des = disarticulated shells; Orn P = ornamentation partially preserved; Pred = predation signals; Bioe = bioeroded shells) per depth interval, in Bojuru (Bo) core. Note: subtotal values refer to

number of specimens used to calculate percentage values.

With the exception of the basal interval (Mo 14.0-13.0), in which intact shells predominated, fragments of unidentified mollusks were dominant in all intervals (Figs. 3G, 5; Supplemental data). Breaks on gastropod shells were observed in the apex and aperture regions (*H. australis*, *T. fasciata*; Fig.3I, J), while in some bivalve specimens (e.g., *E. mactroides*, *T. gayi*, and *Adrana* sp.) the hinge and shell margin were broken (Figs.3H, K, M). Most specimens of *Heleobia* showed intact shells (Fig. 3L; Supplemental data), while most bivalves showed disarticulated shells (Fig. 5). Only three specimens of *N. semiornata* (Mo 12.3-11.5) were found with closed and articulated valves (Supplemental data). All specimens, except those of *Heleobia* and *A. bidentata*, did not reach half of the maximum size that has been recorded for their species in the literature (Table 2, Fig. 5). Specimens of *Heleobia* and *A. bidentata* reached sizes proportionally larger than those of other species, but they also did not show the maximum size recorded in the literature (Supplemental data; Table 2). Most species was represented by partially eroded specimens (Fig. 3N), showing total loss of luster (N=273) in all intervals. Additionally, most species and their specimens showed bioerosion in all intervals, while rare specimens exhibited intact shells and predation marks (Supplemental data; Table 2; Fig. 5).

Core Palmares do Sul

Ten species were registered (four gastropods/six bivalves) (Fig. 6; Supplemental data). Richness was similar among the intervals, and varied from four to six species. However, the highest values were observed in the top (Pa 23.0-21.0) and basal (Pa 26.3-28.5 m) intervals, which also showed the highest abundance of specimens. Most species and specimens were represented by mollusks living in tropical to subtropical waters in Brazil. Only *T. gayi* was exclusive of subtropical to temperate waters. Also, most species and specimens were of mollusks that have been found living in shallow transitional environments, such as estuaries and bays with a complex of estuaries. They include, for exemple, *F. dubia* (Casares and Credd, 2008; Ourives et al., 2011; Neves et al 2013; Boehs et al., 2004; Pires-Vanin et al., 2014), *C. cancellata* (Barroso et al., 2013; Neves et al., 2013; Lima et al., 2017), and the fixed bivalve *O. equestris* (Farrapeira et al., 2009). *Finella dubia* have also been found associated to algae and organic matter (Boehs, 2004; Casares and Credd, 2008; Longo et al., 2014). In the basal interval (Pa 28.5-26.3), mollusks inhabitant of sandy bottoms predominated, due to the dominance of *N. semiornata* (Table 2; Fig. 6). In the top interval (Pa 23.0-21.0), the marine to brackish species, *T. gayi* and *F. dubia* were dominant.

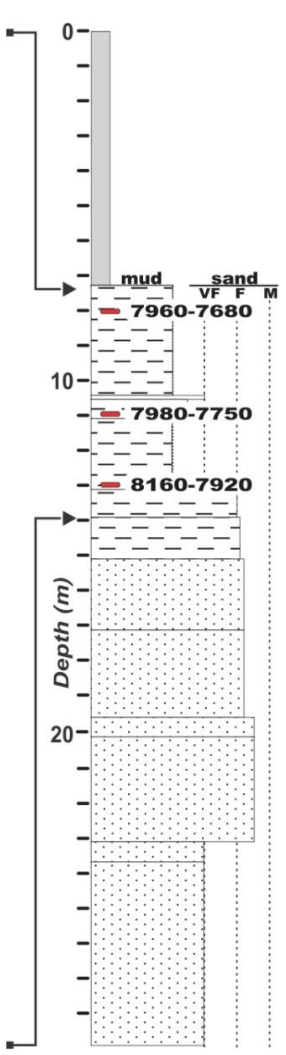
Depth	Mollusks	N (%)	MMSs	Bro (%)	Des (%)	Orn P (%)	Pred (%)	Bioe (%)	Core Mo
10.5-7.3	*E. mactroides*	5 (20.0)	6.4/5.2	28.6	100.00	71.43	0	100.00	
	Heleobia sp.	2 (8.00)	1.8/1.8						
	Frag. Indet.	18 (72.00)	---						
Subtotal		**25**		**2**	**5**	**5**	**0**	**7**	
11.5-10.5	*A. bidentata*	2 (2.86)	2.7/2.6	16.7	100.00	56.67	0	90.00	
	A. candei	1 (1.43)	2.5/2.5						
	Caryocorbula sp.	1 (1.43)	2.5/2.5						
	E. mactroides	1 (1.43)	4.7/4.7						
	H. australis	13 (18.57)	5.5/2.6						
	Heleobia sp.	6 (8.57)	3.5/2.9						
	N. semiornata	6 (8.57)	4.5/4.1						
	Frag. Indet.	40 (57.14)	---						
Subtotal		**70**		**5**	**8**	**17**	**0**	**27**	
12.3-11.5	*A. bidentata*	3 (1.47)	4.2/3.9	23.9	88.89	54.37	0	95.15	
	A. brasiliana	2 (0.98)	6.8/6.8						
	T. gayi	12 (5.88)	6.6/3.5						
	Caryocorbula sp.	2 (0.98)	5.8/5.4						
	H. australis	29 (14.21)	4.7/3.5						
	Heleobia sp.	44 (21.57)	6.1/2.0						
	N. semiornata	11 (5.39)	3.8/3.0						
	Frag. Indet.	101 (49.51)	---						
Subtotal		**204**		**23**	**24**	**56**	**0**	**98**	
13.0-12.3	*T. gayi*	4 (8.69)	3.9/3.5	33.3	100.00	61.90	4.76	95.24	
	E. mactroides	1 (2.17)	3.5/3.5						
	H. australis	1 (2.17)	2.8/2.8						
	Heleobia sp.	14 (30.43)	5.5/3.0						
	T. fasciata	1 (2.17)	1.4/1.4						
	Frag. Indet.	25 (54.35)	---						
Subtotal		**46**		**7**	**5**	**13**	**1**	**20**	
14.0-13.0	*Adrana* sp.	1 (0.55)	5.0/5.0	21.4	100.00	94.64	0	99.11	
	T. gayi	14 (7.69)	5.5/3.8						
	Caryocorbula sp.	6 (3.30)	5.4/5.0						
	E. mactroides	7 (3.85)	9.9/7.1						
	H. australis	34 (18.68)	5.6/3.1						
	Heleobia sp.	48 (26.38)	4.5/2.5						
	T. fasciata	2 (1.10)	2.5/2.2						
	Frag. Indet.	70 (38.46)	---						
Subtotal		**182**		**24**	**28**	**106**	**0**	**111**	
Total		**527**		**61**	**70**	**197**	**1**	**263**	

FIGURE 5 – Sedimentological profile (adapted from Weschenfelder et al., 2014); richness of mollusk assemblages; abundance (N), frequency (%) and maximum and medium shell size (MMSs) of species; and percentage of some taphonomic signatures (Bro = broken shells, Des

= disarticulated shells; Orn P = ornamentation partially preserved; Pred = predation signals; Bioe = bioeroded shells) per depth interval, in Mostardas (Mo) core. Note: subtotal values refer to number of specimens used to calculate percentage values

Core Palmares do Sul

Ten species were registered (four gastropods/six bivalves) (Fig. 6; Supplemental data). Richness was similar among the intervals, and varied from four to six species. However, the highest values were observed in the top (Pa 23.0-21.0) and basal (Pa 26.3-28.5 m) intervals, which also showed the highest abundance of specimens. Most species and specimens were represented by mollusks living in tropical to subtropical waters in Brazil. Only *T. gayi* was exclusive of subtropical to temperate waters. Also, most species and specimens were of mollusks that have been found living in shallow transitional environments, such as estuaries and bays with a complex of estuaries. They include, for exemple, *F. dubia* (Casares and Credd, 2008; Ourives et al., 2011; Neves et al 2013; Boehs et al., 2004; Pires-Vanin et al., 2014), *C. cancellata* (Barroso et al., 2013; Neves et al., 2013; Lima et al., 2017), and the fixed bivalve *O. equestris* (Farrapeira et al., 2009). *Finella dubia* have also been found associated to algae and organic matter (Boehs, 2004; Casares and Credd, 2008; Longo et al., 2014). In the basal interval (Pa 28.5-26.3), mollusks inhabitant of sandy bottoms predominated, due to the dominance of *N. semiornata* (Table 2; Fig. 6). In the top interval (Pa 23.0-21.0), the marine to brackish species, *T. gayi* and *F. dubia* were dominant.

All intervals contained fragments (Fig. 6; Supplemental data). Some specimens of *A. bidentata*, *A. candei*, *B.* s*eminuda* and *F. dubia* were broken in the shell apex and/or aperture. Specimens of *N. semiornata*, *T. gayi* and *Adrana* sp. Showed broken shell margins (Fig. 3O, T). Most bivalve shells were disarticulated, along the Core Pa as whole, and in each depth interval. Only one (1) specimen of *N. semiornata* (Pa 26.0-23.5) showed articulated and closed shell (Fig. 6; Supplemental data). With exception of the basal interval (Pa 28.5-26.3), the other ones contained specimens with shell size reaching at maximum half of the largest size previously recorded to their species (Table 2; Fig. 6).

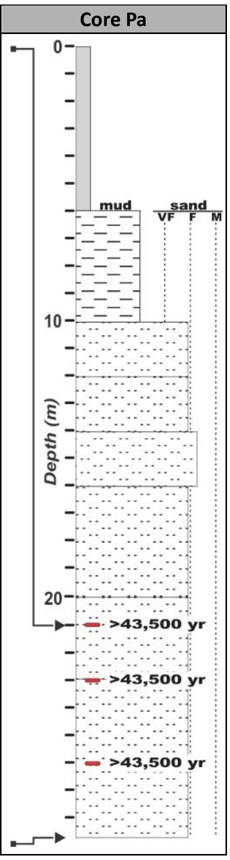
Depth	Mollusks	N (%)	MMSs	Bro (%)	Des (%)	Orn P (%)	Pred (%)	Bioe (%)	Core Pa
23.0-21.0	*A. candei*	2 (1.65)	1.1/1.0	16.1	100.00	96.77	0	96.77	
	A. notabilis	1 (0.83)	1.2/1.2						
	T. gayi	13 (10.74)	4.5/2.6						
	F. dubia	11 (9.09)	2.0/1.7						
	B. seminuda	3 (2.48)	0.9/0.6						
	O. equestris	1 (0.83)	3.3/3.3						
	Frag. Indet.	90 (74.38)	---						
Subtotal		**121**		**5**	**15**	**31**	**0**	**31**	
23.5-23.0	*Adrana* sp.	1 (1.35)	2.3/2.3	83.3	100.00	78.57	0.00	92.86	
	A. candei	3 (4.05)	1.9/1.5						
	F. dubia	3 (4.05)	2.1/2.0						
	N. semiornata	7 (9.46)	3.2/2.2						
	Frag. Indet.	60 (81.09)	---						
Subtotal		**74**		**20**	**8**	**11**	**0**	**13**	
26.0-23.5	*A. bidentata*	3 (6.52)	2.1/1.7	26.9	95.23	100.00	0.00	100.00	
	A. candei	1 (2.18)	1.2/1.2						
	T. gayi	1 (2.18)	2.3/2.3						
	N. semiornata	20 (43.47)	4.8/2.2						
	B. seminuda	1 (2.18)	1.0/1.0						
	Frag. Indet.	20 (43.47)	---						
Subtotal		**46**		**7**	**20**	**26**	**0**	**26**	
28.5-26.3	*A. bidentata*	7 (3.59)	2.9/2.1	30.3	100.00	50.00	1.54	95.45	
	A. candei	2 (1.03)	2.4/2.1						
	C. cancellata	1 (0.51)	3.6/3.6						
	F. dubia	8 (4.10)	4.0/2.5						
	N. semiornata	45 (23.07)	3.3/1.9						
	B. seminuda	3 (1.54)	2.1/1.8						
	Frag. Indet.	129 (66.16)	---						
Subtotal		**195**		**20**	**46**	**33**	**3**	**63**	
Total		**436**		**52**	**89**	**101**	**3**	**133**	

FIGURE 6 – Sedimentological profile (adapted from Weschenfelder et al., 2014); richness, richness of mollusk assemblages; abundance (N), frequency (%) and maximum and medium shell size (MMSs) of species; and percentage of some taphonomic signatures (Bro = broken shells, Des = disarticulated shells; Orn P = ornamentation partially preserved; Pred = predation signals; Bioe = bioeroded shells) per depth interval, in Palmares do Sul (Pa) core. Note: subtotal values refer to number of specimens used to calculate percentage values.

Most species was represented by partially eroded specimens also showing total loss of their shell luster (N=137) in all intervals. However, in the basal interval (Pa 28.5-26.3), *N. semiornata* was represented by shells by specimens showing intact shell ornamentation, with no signs of erosion (Supplemental data). Additionally, the nacre luster was preserved in the internal shell side of all specimens of *N. semiornata*, while the delicate ornamentation of the external shell side was also maintained in all specimens of *C. cancellata* and *A. notabilis* (Fig. 3Q, R, S). Most species and specimens showed evidences of bioerosion in their shells (Fig. 3P).

DISCUSSION

Main Transitional Environments and Sedimentary Processes Involved With The Infilling of The Incised Valleys

Although each species registered here had been recorded, individually, living in estuarine and/or frankly marine waters, they occurrence in species assemblages allow us to recognize two mollusk groups, related to estuarine environments. One assemblage is typical of brackish water environments, or proximal estuarine areas, and is compound by *H. australis* and *E. mactroides*. Present days, these species are commonly found associated, and are represented by abundant populations in brackish waters of proximal estuarine areas and choked lagoons (Arocena and Rodriguez, 2001; Echeverria et al., 2010; Milessi et al., 2010; Barboza et al., 2012; Carcedo and Fiori, 2012). They are also especially abundant in the few estuarine environments present in southern Brazilian coast (Fonseca and Netto, 2006; Rosa and Bemvenuti, 2006). The other assemblage is compound by many species, such as *N. semiornata, F. dubia, T. fasciata and A. brasiliana*, which can be found living associated in a variety of brackish to marine environments. This type of assemblage is more commonly registered northward from southern Brazil, where more diversified transitional environments occur, such as bays, channels, lagoons, as well as estuarine complexes (Grillo et al., 1998; Soares-Gomes and Pires-Vanin, 2003; Rodrigues, 2007; Queiroz and Dias, 2010; Rodrigues et al., 2010; Denadai et al., 2014; Santos et al., 2014; Tallarico et al., 2014; Maia et al., 2017).

The overall taphonomic profile is strongly suggestive that most shell damages were originated under the influence of freshwater influxes. The high percentages of corrasion and luster lost registered are typical of shells exposed to brackish or freshwater waters. The low pH of freshwater, or their acidic condition, promotes shell dissolution, which can also be intensified by freshwater percolation after their final burial (Kotzian and Simões, 2006; Erthal et al., 2011, 2015). The high percentage of fragments can also corroborate suggestive that freshwater influxes characterized the sedimentary environments. Studies conducted in brackish and freshwater environments have shown that the intense shell dissolution can facilitate shell breakage (Kotzian and Simões, 2006). In turn, bioerosion marks, which were very frequent in the studied specimens, are common in marine shell assemblages, but rare in freshwater assemblages (Kotzian and Simões, 2006). These finds could indicate that frankly shallow marine environments also participated of the infilling of the paleovalleys. In fact, shell fragments and broken shells were dominant in the assemblages studied. Shell break or fragmentation can be related to many factors, such as high energy environments, transport by currents and waves, and action of predators in marine environments (Best and Kidwell, 2000). Thus, the taphonomic profile observed evidences that the shell assemblages studied were exposed to both, freshwater and marine water influxes. In other words, after dead, mollusk shells should have remained exposed in water-sediment interface; possibly in their original brackish or brackish to marine environments.

The Standard Penetration Test (SPT) equipment used to drill the studies valleys does not allow to observe if brackish and brackish to marine assemblages occurred together or separately in each depth interval. Sediments of samples of each depth interval were disturbed. However, the shell size selection analysis helps to detect and corroborate the existence of two assemblages. It also allows understanding how the dead shell assemblages were formed. Shell size selection characterized all the assemblages analyzed. The shell size of almost all intact or slightly broken specimens never reached the maximum size previously assigned for their species in the literature. Size selection toward smaller specimens was also observed in minute species, whose shell size were not biased by the sampling method used (core diameter < 3.9 cm). Shell size selection has been related to shell transport by waves and currents. Previous studies have shown that shells are rarely transported far from their original habitat, and shell assemblages are usually parautochthonous (Kidwell and Bosence, 1991; Kidwell, 2001). As most bivalve shells were disarticulated, shell transport should have occurred after mollusk dead (Kidwell and Bosence, 1991). Thus, the overall taphonomic profile and especially the bioerosion marks on predominantly infaunal species shells clearly suggest that the shell assemblages remained for some time on the water sediment interface. In other words, shell assemblages are possibly reworked, containing shells from different generations, and also from different estuarine (proximal and distal) environments. The multitude of transgressive-regressive events occurring during the Quaternary history of the PCRS (Weschenfelder et al., 2014) should have been the main responsible for the reworking of the assemblages. Climatic changes should also be involved in sea level oscillations, because species such as *Tawera gayi*, present days living in the cooler waters of Patagonian Province (Gordillo, 2006), was common in many depth intervals.

Local Variations in the Transitional Environments and Sedimentary Processes Involved with the Infilling of Each Paleovalley

Although diversity and especially taphonomic signatures have been similar among the studied cores and their depth intervals, some differences were detected. These differences allow us to recognize differences in the emphasis with which brackish and brackish to marine environments, or proximal and distal estuarine areas, had participated of the sedimentary infilling of each paleovalleys studied. They also evidence that sea levels oscillations promoted by different factors than climatic changes and the overall Quaternary marine transgression helped to characterize the transitional environment of each paleovalley.

Late Pleistocene-Holocene Transitional Environments in the Core Bojuru Region

Only the middle unit (Bo 20.5-19.5 m to 13.0-12.0) of Core Bo contained identifiable shells. The brackish water species *H. australis* and *Heleobia* sp. were dominant in most depth intervals of this unit. As dominant species in dead or fossil assemblages are commonly dominant in their original life assemblages (Kidwell, 2001), *H. australis* and *Heleobia* sp.

should reflect the environments participating of the infilling of Core Bo. Thus, proximal estuarine environments, under significant influence of freshwater influxes, should have occupied the paleovalley, characterizing an important area in the landscape, at least during time interval embraced by sedimentary record of the core. However, numerous brackish to marine species that commonly dwell in estuarine distal areas also occurred in depth intervals of the middle unit. *Nucula semiornata* and *T. gayi* were frequent in the last interval (Bo 13.0-12.0), suggesting that sediments from environments nearest to marine settings had also participated subordinately of the landscape around the Core Bo region.

The simultaneous occurrence of both brackish and marine to brackish species in many depth intervals in Core Bo could be explained by the reworking of different shell assemblages. The overall taphonomic profile, which is homogeneous along all the middle unit, is suggestive that different assemblages (brackish and marine to brackish) were transported and/or reworked, and also time averaged. In some intervals, epifaunal species with attached life habit, such as *O. equestris* and *Ostrea* sp., occurred together with infaunal mollusks, reinforcing the reworked condition of the assemblages. As this condition occurs along ca. 8 meters of sediment, numerous transgressive-regressive events could explain the mixing of the assemblages. The occurrence of *T. gayi* in some intervals corroborate the occurrence of regressive pulses. Present day, this species lives preferentially in the cooler waters from the Patagonian Province (Gordillo, 2006).

The most basal depth intervals analyzed (Bo 27.0-26.0 to 21.0-20.5) as well as the top intervals (Bo 11.0-10.0 to Bo 10.0-9.0) of Core Bo contained only fragments. According to Weschenfelder et al. (2014), this basal unit corresponds to the early sedimentary infilling of the incised valley by fluvial deposits, influenced by both ocean and freshwater influxes, likewise an estuarine channel or inlet. As shell fragmentation can be related to shell transport by water currents and reworking, and also be result of freshwater action, this taphonomic profile corroborates that freshwater sedimentary deposits should have started the infilling of the paleochannel of the Camaquã River. Weschenfelder et al. (2014) also suggested that the sediments from the upper unit should correspond to the shallow marine and estuarine sediments related to the maximum transgressive and sea level highstand. In the upper interval (Bo 13.0-12.0), brackish to marine mollusk species were more diversified than in other intervals corroborating that distal estuarine environments, more influenced by marine waters, also characterized the region. The studies of Weschenfelder et al. (2014) and Leite et al. (2013) have registered estuarine species of diatoms and ostracods in the middle unit, corroborating our findings. In fact, the muddy sediments of the middle unit contrast with the fine sands of the upper and basal units, helping corroborate that sediments from proximal estuarine and low energy waters participated of its infilling.

Late Pleistocene-Holocene estuarine environments in the Core Mostardas region

Mollusks were found only in the upper unit (Mo 14.0-13.0 – Mo 10.5-7.0) of Core Mo. Typically brackish and estuarine species were common (*E. mactroides*) or predominated (*H. australis* and *Heleobia* sp.) in most depth intervals, as observed in Core Bo. Thus, sediments from estuarine proximal areas, should have had expressive participation in the infilling of the valley incised by the Jacuí River. However, brackish to marine species were more numerous than brackish species along almost all intervals. The formers were also more abundant in Core Mo than in Core Bo. The taxonomic composition and richness of assemblages, and the species proportional frequency were also homogeneous along the upper interval, allowing us to suggest that the participation of sediments from brackish to marine environments was more significant to the infilling of the paleochannel of Jacuí River, sampled by Core Mo, than to the paleochannel of Camaquã River, sampled by Core Bo. This result do not corroborate previous studies that emphasized the participation of sediments from brackish environments or estuarine proximal areas in the infilling of Core Mo (Baitelli, 2012). Only in the top interval (Mo 7.3-10.5), exclusively brackish and estuarine species (*E. mactroides* and *Heleobia* sp.) were assigned, indicating more expressive participation of freshwater influxes, i.e, of proximal estuarine conditions. The taphonomic signatures observed also corroborate that sediments from brackish to marine environments had more expressive participation in the infilling of Core Mo than in the infilling of Core Bo. In most depth intervals, the percentage of fragments and partial loss of ornamentation was high (> 50%), but lower than that registered for assemblages in Core Bo, suggesting smaller influence of freshwater. Bioerosion percentage was also slightly higher in Core Mo than in Core Bo. Bioerosion is more frequent in marine environments than in freshwater or brackish environments (Kotzian and Simões, 2006). The overall taphonomic profile of the assemblages was also homogeneous along the upper unit. Thus, the mixing of brackish with brackish to marine species in almost all intervals suggests that assemblages were reworked, and that multiple transgressive-regressive events were involved in the infilling of the valley incised by the Camaquã River.

Pleistocene transitional environments in the Core Palmares do Sul region

Mollusk assemblages were found only the basal unit of the core (Pa 28.5-26.3 to Bo 23.0-21.0). *Heleobia australis* and *E. mactroides,* the brackish water species commonly registered in southern Brazilian proximal areas of estuaries, were not recorded in all depth intervals of this core. The dominant species assigned, *N. semiornata* and *F. dubia*, are typical of estuarine environments nearest to the sea, and more influenced by marine waters. *Nucula semiornata* have been commonly recorded living in fine sand bottoms (Tallarico et al., 2014), while *F. dubia* have been registered associated to algal substrates (Casares and Credd, 2008; Longo et al., 2014). Living individuals of these species, as well as of other mollusks registered in Core Pa, are commonly found inhabiting Brazilian bays and channels delimitated by islands and the continent. They are also found near river mouths or estuarine complexes, dwelling in muddy to fine sand bottoms (Casares and Credd, 2008; Farrapeira et al., 2009; Ourives et al., 2011; Barroso et al., 2013; Neves et al 2013; Boehs et al., 2004; Pires-Vanin et al., 2014; Lima et al., 2017). Thus, our results corroborate previous studies suggesting that the infilling in the lower portion of the Core Pa was more influenced by marine than by predominantly brackish environments (Weschenfelder et al., 2014; Santos-Fisher et al., 2016). Additionally, some taphonomic signatures corroborate the higher influence of marine waters in the environments. The lower depth interval (Pa 28.5-26.3) contained the highest percentage of well preserved (70%) or intact shell ornamentation (32%), suggesting that freshwater influxes were not strong. Possibly, some specimens were preserved *in situ*, representing allochthonous assemblages. Previous studies also observed mollusk and ostracod specimens fossilized *in situ* in Core Pa (Leite et al., 2013). Thus, shallow marine coastal environments, related to distal estuarine areas, should have been the main responsible by sediments involved with the initial infilling of the Jacuí paleochannel sampled by Core Pa. Although mainly marine in origin, sediments related to proximal brackish environments may possibly have participated of this infilling. The total loss of luster and the high percentages of partially preserved shell ornamentation recorded are evidences that fossil assemblages was also submitted to the acidic conditions of freshwater, as previously discussed here.

Mollusk Assemblages As Tools For Recognizing Environmental Variations in The Quaternary Landscape of Southern Brazilian Coast

Present day, the southern Brazilian is coast can be considered a homogeneous landscape. It is characterized by a straight, long, sandy, high-energy and wave-dominated coast (Toldo Jr. et al., 2007). The few rivers running into the sea provide the scarce estuaries present in landscape. The position of the region near the cooler water marine Argentinean Province (Palacio, 1982, Barroso et al., 2016), determine the existence of a marine malacofauna more similar to those of Uruguayan and Argentinean coasts. Thus, the shallow marine malacofauna in southern Brazilian coast is less diversified than that registered in northward Brazilian regions (Rios, 2009; Barroso et al., 2016), which also shows a great variety of transitional landscapes.

Giving emphasis to diversity of assemblages, instead of ecological data of species separately, allow us recognizing the existence of two different mollusk fossil assemblages in the studied cores. The brackish water assemblage is similar to the present day and poorly diversified mollusk assemblages recorded in the few estuaries present in the PCRS (Fonseca and Netto, 2006; Rosa and Bemvenuti, 2006). The brackish to marine assemblage is more similar to assemblages registered in warmer regions of the Brazilian coast, and their species are not common in the colder waters of southern Brazil. The brackish to marine assemblages have been assigned in the neighbor coast of the Santa Catarina state (Klein et al., 2001; Almeida et al., 2004; Fonseca and Netto, 2006; Gandara-Martins and Almeida, 2013). This state is also affected by the cold waters from the Malvinas Current (Barroso et al., 2016), but presents a more environmentally heterogeneous coast. Thus, it is possible the scarcity of many species of brackish to marine assemblages in the modern southern Brazilian coast lays in its monotonous landscape. In other words, the Quaternary landscape of southern Brazilian coast should have been more heterogeneous than today, presenting a wide array of transitional environments, such as bays, channels, open lagoons, and numerous rivers mouths. Species typical of present days assemblages living in the fine-sand and wave-dominated coast of the Rio Grande do Sul state, or in its rivers, lakes and lagoons (Lanzer, 2001; Pfeifer and Pitoni, 2003; Rios, 2009; Sá et al. 2013), were not recorded here, helping to confirm that estuarine environments were the main source of the sediments infilling the studied paleovalleys.

Previous studies have also suggested that an indented shoreline should have characterized the Pleistocene-Holocene southern Brazilian coast (Jost, 1971; Baitelli, 2012). The multiple transgressive-regressive events that occurred during the overall transgression of the Quaternary should have driven these environmental changes in the southern Brazilian coastal landscape. These, sea levels oscillations were certainly related to the climatic changes (Weschenfelder et al., 2014). However, as emphasized by Baitelli (2012), others factors related to sea-level establishment, such as sedimentary input and hydrological context should have determined environmental differences along the southern Brazilian coast. Diversity and taphonomic signatures of mollusk assemblages corroborate that these changes were not homogeneous along in space and time. Our study shows that the middle unit of core Bo (7,640-7,430; 8,150-7,870 cal yr BP) and the upper unit of core Mo (7,960-7,680; 8,160-7,920 cal yr BP) contain mollusks with similar age. However, in Core Bo brackish water assemblages predominate, while in Core Mo brackish to marine assemblages predominate. In turn, in the Late Pleistocene sediments of Core Pa, brackish to marine assemblages were dominant. Briefly, our findings corroborate previous studies suggesting that the landscape of southern Brazilian coast was environmentally heterogeneous, characterized by variable marine transitional settings, and shaped by an interaction of sea level oscillation and different sedimentary inputs and hydrological context (Baitelli, 2012).

FINAL REMARKS

Although drill holes and SPT equipment does not constitute the best sampling method to recognize the complete mollusk diversity in a study area, the species here assigned are clearly representative of living assemblages from many modern Brazilian marine transitional environments. Two different fossil assemblages were found: a brackish water assemblage and a brackish to marine assemblage. Present day, the latter is found in estuarine distal areas, such as protected bays, large channels and some lagoons, influenced by marine waters. As these transitional environments are not present today in southern Brazilian wave-dominated coast, our results suggest that the shore line during Pleistocene to Holocene time was more heterogeneous than it is today. As the taphonomic signatures show evidences of reworking and time averaging in almost all depth intervals of the cores studied, they also allow us to relate the sedimentary deposits to sea-level oscillations. However, as different transitional environments seem to have occurred simultaneously along the coast during, they have been originated not only to climate changes. The multitude of transgressive-regressive events that shaped the southern Brazilian coast, during the overall Quaternary transgression, should have also be caused by variations in the sedimentary and hydrological context of each paleovalley. Southern Brazilian coast landscape was environmentally more heterogeneous than it is today.

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Supplemental Data - Diversidade e aspectos tafonômicos de moluscos encontrados no testemunho Palmares (Pa). Obs. N = abundânica de indivíduos inteiros ou quebrados; Epi = epibionte; End = endobionte; Out = outros (epibionte e endobionte / ectoparasito/endofauna e trato digestivo equinoderma); Trop = tropical; Sub = subtropical; Mar = marinho, Mix = mixohalino; L = lama; ArL/ArA = areia lamosa/areia com algas; Ar = areia;; Ar/Os/Me = areia com ostras / banco de ostras ou mexilhões; Roc = substrato duro; Tam max = tamanho máximo medido (mm); Tam max lit = tamanho máximo registrado na literatura (mm); Int Con= integridade das conchas (i = inteira; Q = quebrada; F = fragmentada); Art = articulação das valvas (D = desarticuladas; A = articuladas); Int Ornam = Integridade da Ornamentação (Int = integral; Parc = parcial; Erod = erodida); Marcas orgânicas (Int = intactas, Pred = predação; Bio = bioerosão).

Depth (m) Pa	**Mollusks**	**N (%)**	**Shell size mm**	**Shell Int**			**Art**		**Orn Int**			**Luster**		**Biol Marks**		
				Int	**Bro**	**Fra**	**D**	**A**	**Int (100-80%)**	**Par (80-50%)**	**Ero (<50%)**	**Int**	**Los**	**Int**	**Pred**	**Bioe**
23.0-21.0	*A. candei*	2 (1.65)	1.1	2	0		---	---	0	2	0		2	0	0	2
	A. notabilis	1 (0.83)	1.2	1	0		1	0	1	0	0		1	1	0	0
	T. gayi	13 (10.74)	4.5	9	4		13	0	0	13	0		13	0	0	13
	F. dubia	11 (9.09)	2.0	10	1		---	---	0	11	0		11	0	0	11
	B. seminuda	3 (2.48)	0.9	3	0		---	---	0	3	0		3	0	0	3
	O. equestris	1 (0.83)	3.3	1	0		1	0	0	1	0		1	0	0	1
	Frag. Indet.	90 (74.38)				90										
Subtotal		**121**		**26**	**5**	**90**	**15**	**0**								
23.5-23.0	*Adrana* sp.	1 (1.35)	2.3	0	1		1	0	1	0	0		1	1	0	0
	A. candei	3 (4.05)	1.9	2	1		---	---	0	3	0		3	0	0	3
	F. dubia	3 (4.05)	2.1	2	1		---	---	0	3	0		3	0	0	3
	N. semiornata	7 (9.46)	3.2	0	7		7	0	0	5	2		7	0	0	7
	Frag. Indet.	60 (81.09)			10	60			1							
Subtotal		**74**		**4**	**20**											
26.0-23.5	*A. bidentata*	3 (6.52)	2.1	0	3		---	---	0	3	0		3	0	0	3
	A. candei	1 (2.18)	1.2	1	0		---	---	0	1	0		1	0	0	1
	T. gayi	1 (2.18)	2.3	1	0		1	0	0	1	0		1	0	0	1
	N. semiornata	20 (43.47)	4.8	16	4		19	1	0	20	0		20	0	0	20
	B. seminuda	1 (2.18)	1.0	1	0		---	---	0	1	0		1	0	0	1
	Frag. Indet.	20 (43.47)				20										

Subtotal		**46**		**19**	**7**											
28.5-26.3	*A. bidentata*	7 (3.59)	2.9	5	2		---	---	0	6	1		7	0	1	6
	A. candei	2 (1.03)	2.4	2	0		---	---	0	2	0		2	0	0	2
	C. cancellata	1 (0.51)	3.6	1	0		1	0	1	0	0		1	0	0	1
	F. dubia	8 (4.10)	4.0	7	1		---	---	4	3	1		8	0	0	8
	N. semiornata	45 (23.07)	3.3	29	16		45	0	15	20	10		45	0	2	43
	B. seminuda	3 (1.54)	2.1	2	1		---	---	1	2	0		3	0	0	3
	Frag. Indet.	129 (66.16)				129										
Subtotal		**195**		**46**	**20**											
Total		**436**														

Capítulo 5

Síntese

O presente trabalho é inédito no que diz respeito ao estudo de biogênicos recuperados em testemunhos obtidos, no interior da Lagoa dos Patos, até o momento.

A delimitação das zonas bioestratigráficas propostas nos trabalhos relativos a Mostardas (Trabalho 1) e a Palmares do Sul (Trabalho 2), mostram as modificações paleoambientais que a Planície Costeira do Rio Grande do Sul sofreu ao longo do tempo. Estas mudanças estão relacionadas com as oscilações do nível do mar ocorridas durante o Quaternário tardio.

Para o testemunho Mo foram observados pequenos pulsos entre eventos maiores de transgressões e regressões identificados pelos diferentes ambientes observados através do zoneamento proposto onde três zonas biogênicas foram reconhecidas. São elas a Zona I de um ambiente marinho a marinho mixohalino com uma influência marinha, a Zona II, com influência fluvial, que também representa um ambiente marinho a marinho mixohalino e a Zona III que mostra novamente um ambiente marinho a marinho mixohalino com influência marinha.

No testemunho Pa são identificadas as Zonas I e II que caracterizam um ambiente marinho raso abrigado e de pouca energia, a Zona III indica um ambiente fluvial raso de maior energia com uma certa influência marinha e a Zona IV que retorna a um ambiente marinho raso abrigado de baixa energia.

As assinaturas tafonômicas analisadas nos moluscos dos testemunhos Bo, Mo e Pa (Trabalho 3), sugerem que as assembleias são parautóctones enquanto porcentagens elevadas de bioerosão e corrosão indicam que elas foram misturadas e retrabalhadas. Também são observadas que as mudanças ambientais ocorridas na região costeira gaúcha não ocorreram de forma homogênea no tempo e no espaço. E que o preenchimento sedimentar dos paleovales demarcados por interpretações sísmicas na região indicam duas assembleias distintas uma de água mixohalina e outra mixohalina a marinha.

Diante do exposto acima se constata que os objetivos propostos na presente tese foram plenamente atendidos tais como obter através das associações de fósseis calcários e silicosos, ferramentas efetivas que possibilitem a identificação de evidências da evolução paleogeográfica da Planície Costeira do Rio Grande do Sul, corroborando com os estudos de sísmica de alta frequência que vêm sendo realizados na área. Identificar os grupos fossilíferos e classificar na taxonomia apropriada. Caracterizar, interpretar e discutir os dados levantados, indicando o tipo de ambiente que caracteriza a associação identificada.

Esta pesquisa representa mais uma ferramenta para auxiliar no entedimento do processo de evolução sedimentar da Planície Costeira do Rio Grande do Sul que ocorreu no Quaternário tendo como foco principal a fração biogênica.

Capítulo 6

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Anexo

Assunto **[Pesq Geoc] Agradecimento pela Submissão**
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Para Beatriz Appel Dehnhardt <beatriz.dehnhardt@ufrgs.br>
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Agradecemos a submissão do seu manuscrito "Biogenic Zones of the core Mo, Lagoa dos Patos, Rio Grande do Sul state, Brazil" para Pesquisas em Geociências. Através da interface de administração do sistema, utilizado para a submissão, será possível acompanhar o progresso do documento dentro do processo editorial, bastanto logar no sistema localizado em:

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