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

PALEOECOLOGIA DE DIATOMÁCEAS COMO SUBSÍDIOS PARA O CONHECIMENTO DA EVOLUÇÃO PALEOGEOGRÁFICA DA REGIÃO COSTEIRA DO RIO GRANDE DO SUL, BRASIL

CRISTIANE BAHI DOS SANTOS

Porto Alegre – 2015

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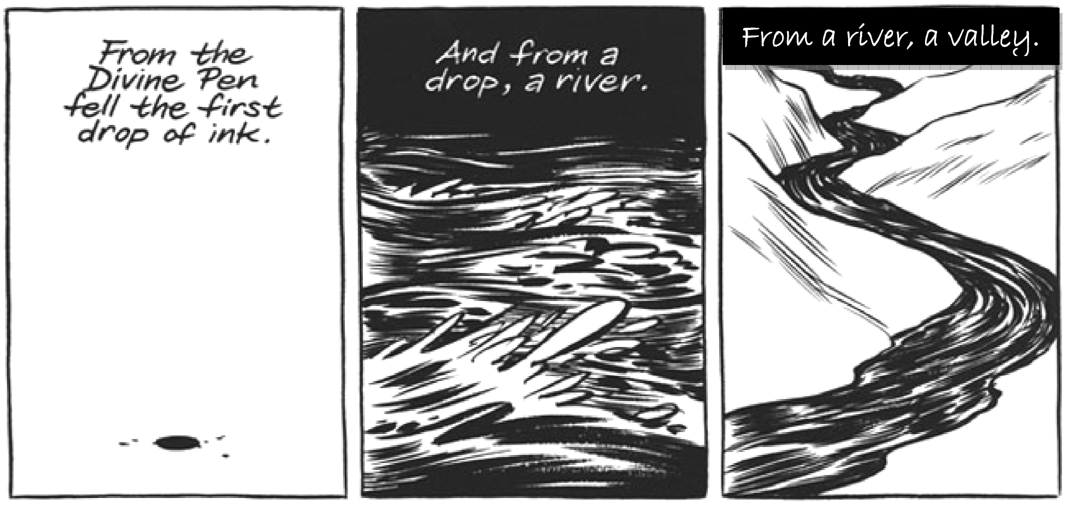

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RESUMO

A partir da premissa de que os estudos de sistemas fluviais de vales incisos desenvolvidos em sistemas lagunares são essenciais para o entendimento da influência das mudanças do nível do mar, na evolução de costas dominadas por ondas, uma abordagem multidisciplinar envolvendo sísmica de alta resolução e análise de diatomáceas é proposta. As diatomáceas encontradas em testemunhos, obtidos em distintos ambientes da zona costeira do Rio Grande do Sul, e amostras superficiais coletadas no interior da Lagoa dos Patos, fornecem a base para a realização de detalhadas interpretações paleogeográficas, paleoambientais e paleoecológicas da região costeira do Sul do Brasil. Três sistemas de vales e canais incisos, identificados através de mapeamentos sistemáticos de superfícies sísmicas no interior da Lagoa dos Patos, fazem parte da estratigrafia desta área costeira. Superfícies erosionais bem definidas são relacionadas a dois dos maiores períodos de rebaixamento do nível do mar ocorrendo simultaneamente aos estágios isotópicos marinhos 6 e 2. Os elementos arquiteturais sismoestratigráficos revelam proeminentes vales incisos de até 10 km de largura com preenchimento sedimentar de até 40 m de espessura. Os testemunhos foram relacionados aos perfis sísmicos com a finalidade de complementar as interpretações a partir dos registros sísmicoestratigráficos obtidos. A posterior integração destes dados aos registros de diatomáceas fornece uma base fundamental na determinação da natureza do preenchimento sedimentar de sistemas subtropicais incisos dos rios Jacuí e Camaquã. Diatomáceas fósseis e modernas são comparadas através de análises estatísticas multivariadas, que sugerem mudanças na composição e distribuição espacial dos *taxa* em distintos ambientes da zona costeira do Rio Grande do Sul. O *taxon* marinho *Paralia sulcata* é dominante em todos os testemunhos, ocorrendo continuamente desde o Pleistoceno tardio até o Holoceno, mas esta espécie é considerada rara nas comunidades atuais. As espécies dulciaquícolas ocorrem continuamente, sendo registradas em baixas densidades em períodos anteriores e posteriores ao último evento glacial e durante o Holoceno, em contraste com o máximo regressivo, quando são encontradas em altas densidades. A distribuição espacial de diatomáceas atuais é controlada pelo gradiente de salinidade, ação dos ventos e fatores climáticos fortementes influenciados pelos eventos El Niño/La Niña. Atualmente, os sedimentos do fundo da Lagoa dos Patos são dominados por espécies dulciaquícolas planctônicas *Aulacoseira veraluciae e Aulacoseira* sp.2 seguidas da espécie marinha-estuarina *Cyclotella litoralis*. As diatomáceas mais representativas são destacadas como excelentes indicadores de mudanças ambientais que incluem salinidade, composição sedimentar e ativo transporte através dos sistemas de vales incisos. Adicionalmente são fornecidos consistentes resultados e percepções sobre a evolução costeira e as condições hidrodinâmicas lagunares durante o Pleistoceno tardio e Holoceno, que contrastam com a configuração costeira moderna. Este estudo sugere que a Planície Costeira foi profundamente dissecada por sistemas de vales e canais incisos antes da implantação da paisagem costeira atual.

ABSTRACT

Starting with the assumption that studies of the incised valleys and channels systems in lagoonal systems are essential for understand the influence of sea-level changes related to evolution of wave-dominated coasts, a multidisciplinary approach based on high-resolution seismic and diatom analysis is proposed. Diatom assemblages found in cores obtained in distinct environments of the Rio Grande do Sul coastal zone and surface samples collected in the Patos Lagoon, provided a basis for detailed interpretations of paleogeography, paleoenvironment and paleoecology of the southern Brazilian coast. Three incised valleys systems, previously identified by systematic mapping of the seismic surfaces in the Patos Lagoon interior are part of the stratigraphy of this coast. Well-defined erosional surfaces related to the two major lowstands, concomitant with Marine Isotope Stages 6 and 2. The seismostratigraphic architectural elements show former prominent valleys up to 10 km wide, infilled with at least 40 meters thick sediments. Core data were related with seismic profiles in order to complement the seismostratigraphic records interpretations obtained. The subsequent integration of these data to diatom records provided a strong basis for determining the nature of infilling of subtropical incised valleys systems from Jacuí and Camaquã River. Fossil and modern diatoms are combined by multivariate statistical analyses that suggest changes in diatom composition and spatial distribution of abundant taxa in different environments of the Rio Grande do Sul coastal zone. The marine specie *Paralia sulcata* is dominant in all stratigraphic cores analyzed occurring continuously from Late Pleistocene to Holocene, but it is rare in modern communities. Non-marine assemblages also occurring continuously, but they are found in very low densities before and after the Last Glacial Maximum and during the Holocene, in contrast with lowstand maximum, when they are found in high densities. The spatial distribution of modern associations is controlled by salinity gradient, wind action, and climate forcing strongly related to El Niño Southern Oscillation and La Niña activity. The bottom sediments of Patos Lagoon are dominated by freshwater taxa *Aulacoseira veraluciae* and *Aulacoseira* sp.2, followed by marine-estuarine species of *Cyclotella litoralis*. The most representative diatoms are highlighted as excellent indicators of environmental changes, including salinity, sediment composition and active transport by incised valleys systems. In addition, are provided consistent outcomes and insights about coastal evolution and lagoonal hydrodynamic conditions during Late Pleistocene and Holoceno, in contrast to the modern configuration. The results suggest that the coastal plain was deeply dissected before the installation of the actual landscape.

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I- INTRODUÇÃO

1. Tema de estudo

Um vale inciso pode ser definido como uma superfície erosional com truncamento de antigos estratos; uma justaposição de estratos fluviais e/ou estuarinos em depósitos marinhos (Van Wagoner *et al.*, 1990). A definição de Zaitlin *et al.* (1994) relaciona vales incisos a um baixo topográfico alongado, erodido fluvialmente que é mais largo que um simples canal. Estes são caracterizados por uma mudança brusca de fácies deposicionais à jusante, delimitadas por um limite de sequências regional geralmente localizado nas partes mais basais do vale. De acordo com Van Wagoner *et al.* (1990) o conceito de limite de sequências implica em exposição subaérea e erosão simultânea associada ao rejuvenescimento fluvial e uma mudança de fácies à jusante. Os sistemas de vales e canais incisos são feições estratigráficas do Quaternário costeiro preservados em planícies costeiras e plataformas continentais mundiais (Zaitlin *et al.*, 1994; Dalrymple *et al.*, 1994, 2006; Blum *et al.*, 2013).

Diversos sistemas de vales incisos foram desenvolvidos durante o Pleistoceno tardio e preenchidos durante o Holoceno (Dalrymple *et al.*, 1994, 2006; Zaitlin *et al.*, 1994; Zhang e Li, 1998; Blum e Törnqvist, 2000; Chaumillon e Weber, 2006; Chaumillon *et al.*, 2008; Gibling *et al.*, 2011). A erosão fluvial é peça fundamental envolvida nos processos de incisão e na criação de espaço de acomodação e preenchimento sedimentar. Estes processos podem ser controlados por diversos fatores incluindo glacio-eustasia, elevação tectônica, mudanças climáticas e aumento de descarga fluvial (Dalrymple *et al.*, 1992, 1994, 2006; Blum, 1993; Zaitlin *et al.*, 1994; Boyd *et al.*, 2006; Dalrymple, 2006; Blum *et al.*, 2013).

Em um contexto paleoambiental, os sistemas de vales incisos representam um complexo singular que preservam não somente o registro de uma ampla variedade de ambientes deposicionais~~,~~ como também armazenam relevantes informações sobre as mudanças paleogeográficas e paleoclimáticas ocorridas no tempo e no espaço. Em geral os sistemas desenvolvidos em planícies costeiras de baixa declividade são preenchidos por areias de granulometria fina e sedimentos lamosos de origem fluvial, estuarina e marinha (Zaitlin *et al.*, 1994), favorecendo a preservação de microfósseis, incluindo diatomáceas. As diatomáceas podem ser consideradas um dos principais componentes biológicos envolvidos na produção primária de ambientes costeiros e constituem um dos microrganismos fotossintéticos de maior sucesso ecológico-evolutivo (Round *et al*., 1990; Mann, 1999). Este sucesso refere-se a quatro implicações principais: (1) devido à ampla distribuição de espécies em ambientes continentais e marinhos; (2) a alta preservação no registro sedimentar, possibilitando a identificação em nível específico, a partir da morfologia e das medidas de comprimento e largura de frústulas silicosas; (3) por possuírem limites de tolerância bem definidos quanto à salinidade e (4) pela elevada abundância em sedimentos de granulometria fina.

Estudos interdisciplinares têm enfatizado o uso destes marcadores biológicos como indicadores de mudanças de salinidade, geralmente associadas às oscilações do nível do mar (Espinosa, 1988, 1994, 2001, 2008; Zong, 1992; Long e Shennan, 1998; Zong e Horton, 1999; García-Rodríguez *et al*., 2001, 2004 a,b; Espinosa *et al*., 2003, 2012; García-Rodríguez, 2006; Zong *et al*., 2010 a,b,c; Espinosa e Isla, 2011; Fayó e Espinosa, 2014, entre outros). Entretanto, as investigações paleoecológicas baseadas em comunidades de diatomáceas fósseis como descritoras paleoambientais realizadas na zona costeira do Rio Grande do Sul (RS) são raras (Medeanic *et al*., 2009; Santos, 2011; Hermany *et al*., 2012) se comparadas aos estudos de comunidades modernas presentes em sedimentos costeiros atuais (Garcia-Baptista e Baptista, 1992; Garcia-Baptista, 1993; Garcia, 1999, 2006, 2010; Garcia e Odebrecht, 2008; Garcia e Souza, 2008; Garcia e Talgatti, 2008, 2011; Medeanic *et al*., 2008; Bergesch *et al*., 2009; Silva *et al*., 2010; Santos, 2011; Garcia *et* al., 2012; Talgatti *et al*., 2014).

Diversas análises preliminares de diatomáceas fósseis, depositadas em sedimentos provenientes de testemunhos de sondagem, foram realizadas em distintos ambientes da zona costeira do RS (Medeanic *et al*., 2001; Clerot, 2004; Arejano, 2006; Arejano e Medeanic, 2007; Caron, 2007; Lima, 2007; Medeanic *et al*., 2008, 2009; Weschenfelder *et al*., 2008 a, 2014; Corrêa *et al*., 2013, 2014 a,b; Lima *et al*., 2013). Entretanto nos estudos referidos, poucos indivíduos foram identificados em nível genérico e específicos e geralmente são associados aos palinomorfos, ostracodes e microfósseis calcários, com a finalidade principal de inferir mudanças gerais de salinidade ao longo de vales incisos, sedimentos lagunares e estratigrafia da barreira arenosa.

As diatomáceas fósseis são organismos determinantes na análise do preenchimento e proveniência sedimentar de vales-reservatórios (Ta e Nguyen, 2000; Ta *et al.*, 2001, 2002 a,b; Nguyen *et al.*, 2000, 2010; Mallinson *et al.*, 2005; Culver *et al.*, 2008; Tjallingii *et al.*, 2010; Nakanishi *et al.*, 2011; Yoshida *et al.*, 2011; Zong *et al.*, 2012), sendo comumente associados a foraminíferos e palinomorfos (Nguyen *et al.*, 2000, 2010; Ta *et al.*, 2000, 2001, 2002 a,b; Mallinson *et al.*, 2005). Os estudos desenvolvidos no delta do rio Mekong, localizado no Sul do Vietnam, constituem bons exemplos de associações de fácies sedimentares relacionadas aos dados de diatomáceas fósseis, utilizados na determinação de paleoambientes (Nguyen *et al.*, 2000, 2010; Ta *et al.*, 2000, 2001, 2002 a,b). A dominância de diatomáceas marinhas planctônicas indicam embaiamentos abertos registrados em áreas costeiras japonesas e vietnamitas (Nguyen e Kobayashi, 1996, 1997; Ta e Nguyen, 2000). Neste contexto, abundantes espécies marinhas e salobras são frequentemente indicadoras de associações típicas de ambientes rasos com uma relativa influência de água doce enquanto que o aumento expressivo de espécies dulciaquícolas encontradas em meio às comunidades salobras e marinhas, são geralmente associadas às fácies arenosas e siltosas características de frentes deltaicas.

As contribuições de Mallinson *et al.* (2005) e Culver *et al.* (2008) realizadas em áreas costeiras da Carolina do Norte (Estados Unidos) e no delta do rio Pearl (Sul da China), desenvolvido por Zong *et al.* (2012), representam os estudos de caso que mais se aproximam ao presente trabalho devido à integração de dados sísmicos ao registro de diatomáceas. Mallinson *et al.* (2005) utiliza espécies de diatomáceas de água doce à salobras, depositadas na parte basal do vale, como indicadoras de um ambiente de baixa salinidade. A dominância de diatomáceas marinhas e salobras é relacionada a uma laminação de lama e areia, indicando o desenvolvimento de um ambiente marinho raso. No trabalho de Culver *et al.* (2008) os registros de diatomáceas são utilizados como subsídios na reconstrução paleoambiental e paleogeográfica holocênica de Outer Banks (Carolina do Norte), bem como na determinação da natureza do preenchimento sedimentar do vale inciso do rio Roanoke. A reconstrução paleoambiental holocênica do delta do rio Pearl é apresentada por Zong *et al.* (2012). No referido estudo, a integração entre os registros sísmicos, sedimentares e de microfósseis, fornecem evidências sobre as interações entre a subida do nível do mar, a topografia antecedente, a descarga sedimentar na bacia e o preenchimento de vales incisos.

2. Objetivos

2.1. Objetivo geral

O objetivo principal deste trabalho é elucidar a natureza e a proveniência dos sedimentos depositados no interior de sistemas fluviais incisos, previamente registrados em estudos sismoestratigráficos desenvolvidos na zona costeira do RS, a partir da análise detalhada de diatomáceas fósseis presentes nos sedimentos, fortemente influenciadas pelas oscilações do nível do mar e mudanças climáticas ocorridas durante o Quaternário tardio.

2.2. Objetivos específicos

1. Integrar e correlacionar unidades sismoestratigráficas aos dados paleoecológicos de diatomáceas fósseis a fim de identificar possíveis mudanças paleoambientais ocorridas em resposta às oscilações do nível do mar durante o Pleistoceno tardio e o Holoceno;
2. Classificar e caracterizar os paleoambientes em função da salinidade, da composição sedimentar, da distribuição espacial de espécies e da composição das associações fósseis;
3. Comparar associações fósseis e modernas como subsídios para a interpretação de sequências fósseis, bem como identificar espécies análogas modernas;
4. Aplicar técnicas de estatística multivariada no estudo de comunidades de diatomáceas fósseis e atuais utilizadas, com a finalidade de auxiliar nas interpretações paleoecológicas e paleoambientais;
5. Identificar espécies indicadoras de mudanças ambientais, incluindo salinidade, composição sedimentar e transporte por sistema de vales e canais incisos;
6. Estabelecer uma correlação entre paleocanais e feições geomorfológicas preservadas na planície costeira;

7. Demonstrar a relevância e a aplicabilidade de associações de diatomáceas fósseis na determinação da natureza e proveniência de registros sedimentares e apresentar um modelo evolutivo de preenchimento de vales e canais incisos;
8. Fornecer novos dados que possam ser futuramente incorporados a estudos paleogeográficos, paleoecológicos e paleoambientais desenvolvidos da zona costeira do RS e ambientes análogos.

A partir do cumprimento do objetivo geral e dos objetivos específicos desta pesquisa, pretende-se obter respostas para algumas questões científicas aqui levantadas:

1. As diatomáceas fósseis constituem bons indicadores biológicos utilizados na determinação e na caracterização da natureza e proveniência dos preenchimentos sedimentares de vales e canais incisos?
2. Os resultados obtidos permitem um maior detalhamento sobre os eventos regressivos e transgressivos que ocorreram durante o Pleistoceno tardio e Holoceno?
3. As condições hidrodinâmicas observadas no sistema lagunar atual são semelhantes àquelas observadas durante o Pleistoceno tardio e Holoceno?
4. As comunidades de diatomáceas fósseis e atuais possuem uma distribuição espacial homogênea em distintos ambientes da zona costeira do RS?
5. Os sistemas de paleovales e paleocanais atuaram como barreiras geográficas isolando diferentes espécies de diatomáceas ao longo do tempo? Pode-se atribuir a proveniência destas espécies associadas a drenagens fluviais distintas?

3. Organização da tese

Esta Tese de Doutorado está estruturada em torno de artigos científicos de acordo com a Resolução 2/98 do Programa de Pós-graduação em Geociências da Universidade Federal do Rio Grande do Sul – PPGGEO/UFRGS. Os artigos foram submetidos à publicação em periódicos indexados internacionais. Deste modo, as sessões de resultados e discussões estão expostas ao longo de três artigos.

O capítulo I abrange a introdução geral que contém o estado da arte, os objetivos da tese e os avanços pretendidos com este estudo;

O capítulo II apresenta uma breve contextualização sobre o tema de estudo e uma síntese dos estudos sismoestratigráficos e investigações baseadas na análise de diatomáceas realizadas em distintas áreas na zona costeira do RS, ambos pertinentes para a justificativa e relevância do presente estudo.

O capítulo III trata de uma breve contextualização geológica e descrição da área de estudo;

O capítulo IV descreve os métodos empregados na elaboração desta tese, incluindo a aquisição de dados sismoestratigraficos e sedimentológicos, nas datações radiométricas, na análise de diatomáceas fósseis e modernas e nas análises estatísticas empregadas na ordenação, classificação e sumarização dos *taxa* mais representativos.

O capítulo V refere-se ao artigo "*The relationship between a modern geomorphologic feature and a Late Pleistocene/Holocene incised valley system: an example from Southern Brazilian coast*", que foi submetido para o **Journal Geologica Acta**. O artigo demonstra por meio da integração de registros sísmicos e de diatomáceas, evidências sobre a estreita ligação entre a feição geomorfológica Barra Falsa e o paleocurso do rio Camaquã. Durante o Holoceno, este canal comportou-se como um *inlet* submetido a sucessivos regimes de aberturas e fechamentos até o máximo transgressivo, quando a costa foi completamente afogada em resposta à subida do nível do mar. Após 2.100 anos AP, o canal é fechado e um ambiente lagunar-estuarino é desenvolvido.

O capítulo VI apresenta o artigo "*Diatom assemblages play a key role in determining the nature of sedimentary records from the subtropical Southern Brazilian coast*", submetido a publicação na revista **Marine Geology**. O trabalho constitui um exemplo de correlação paleoecológica e sismoestratigráfica na inferência de paleoambientes gerados durante o Pleistoceno tardio e Holoceno, relacionados ao desenvolvimento e preenchimento sedimentar dos sistemas de vales incisos do rio Jacui. A partir da integração dos dados de diatomáceas interligados a três unidades sismoestratigraficas, preestabelecidas em estudos anteriores, é apresentado um modelo paleoevolutivo e paleoambiental da área costeira central e norte da Planície Costeira do RS.

O Capitulo VII apresenta o artigo *“Paleoenvironmental insights into the Quaternary evolution of the Southern Brazilian coast based on fóssil and modern diatom assemblages”* submetido para publicação no revista **Palaeogeography, Palaeoclimatology, Palaeoecology**. O trabalho apresenta um panorama paleoambiental da zona costeira do Rio Grande do Sul desde o Pleistoceno tardio, incluindo o Holoceno até a configuração costeira atual. Nove testemunhos de sondagem, obtidos em distintos ambientes da zona costeira, e treze amostras superficiais, coletados no interior da Lagoa dos Patos, fornecem um sólido embasamento para as interpretações e percepções sobre aspectos evolutivos desta costa. A influência das variações do nível do mar, o desenvolvimento de vales fluviais incisos e barreiras arenosas, são evidenciados como principais atuantes na transformação da paisagem e na distribuição espacial de diatomáceas.

O Capitulo VIII apresenta as considerações finais integrando os temas aqui abordados e suas principais conclusões seguidas do capitulo IX que traz as referências completas dos capítulos I, II, III, IV e VII. As referências dos capítulos V, VI e VII encontram-se listadas nos artigos desenvolvidos. Por fim, estão dispostos os anexos da tese.

II- CONTEXTUALIZAÇÃO DO TEMA DE ESTUDO

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1. Generalidades sobre vales incisos

Os primeiros modelos de vales incisos basearam-se na evolução pleistocênica tardia e holocênica do baixo curso do rio Mississipi, Estados Unidos (Fisk, 1944) e Somme Valley na França (Lamothe, 1918). Após estes modelos, uma ampla variedade de modelos conceituais e experimentais, relacionados às respostas do sistema fluvial em relação às mudanças glacio-eustáticas do nível do mar, é desenvolvida (Payton *et al*., 1977; Vail *et al*., 1977; Jervey, 1988; Posamentier e Vail, 1988, entre outros). Devido aos elementos arquiteturais dos vales (geometria) estarem associados à acumulação de hidrocarbonetos em rochas-reservatório e pela riqueza do registro das oscilações do nível do mar, os vales fluviais incisos ganharam importância no desenvolvimento da Estratigrafia de Sequências (Van Wagoner *et al*., 1990; Zaitlin e Schultz 1990; Shanley e McCabe, 1991, 1993; Dalyrmple *et al*., 1992, 2006; Allen e Posomentier, 1993, 1994; Schumm *et al*., 1993; Zaitlin *et al*., 1994; Blum e Törqvist, 2000; Boyd *et al*., 2006; Bhattacharya, 2011; Gibling *et al*., 2011; Holbrook e Bhattacharya, 2012; Blum *et al*., 2013, entre outros), com destaque para o conjunto de artigos apresentados na conferência da *American Association of Petroleum Geologists* (AAPG) em 1992, publicados pela *Society for Sedimentary Research* (SEPM) por Dalrymple *et al*. (1994).

Zaitlin *et al*. (1994) propuseram uma subdivisão longitudinal baseado na organização deposicional e estratigráfica para o preenchimento de vales incisos. Três segmentos foram reconhecidos: (1) uma deposição de fácies fluviais e estuarinas sobrepostas na porção distal do vale; (2) um estuário afogado e (3) uma deposição dominada por sedimentos fluviais sem a influência marinha na porção proximal do sistema. A presença ou ausência de múltiplas superfícies erosionais (adicionais ao limite de sequências principal) pode ser utilizada como um critério de classificação quanto ao preenchimento de vales incisos (Zaitlin *et al*., 1994). Similarmente, a localização regional e espacial dos sistemas de vales em planícies costeiras, plataformas e taludes continentais, podem ser um parâmetro de classificação. De acordo com Zaitlin *et al*. (1994) os sistemas de vales e canais podem ser classificados em dois grupos distintos: vales de planícies costeiras (*Coastal Plain valleys)* e montanhosos (*Piedmont valleys*) (Fig. 1).

Os vales que se encontram confinados em planícies costeiras e que não ultrapassaram a linha de máxima queda do nível do mar, são geralmente preenchidos durante um ciclo regressivo-transgressivo, associados ao tipo simples de preenchimento. Estes vales de planícies costeiras geralmente são preenchidos por sedimentos de granulometria fina, reciclados de ambientes costeiros. De acordo com Boyd *et al.* (2006) estes sistemas, além de serem dominados por sedimentos fluviais e estuarinos, incluem estratos deltaicos, superfícies geradas pela incisão fluvial, estuário afogado e superfície de ravinamento. Neste modelo, sedimentos marinhos estão depositados na porção estuarina do preenchimento. Em algumas áreas costeiras modernas os vales incisos são preenchidos e soterrados por sedimentos deltaico-aluviais holocênicos de pouca expressividade e em outras áreas, no lugar do vale afogado existe um estuário afogado. Em contraponto, os paleovales montanhosos, que cortam as plataformas continentais, ocorrem entre o limite de linha de costa durante o máximo transgressivo e a margem continental. Este tipo de vale geralmente está associado com a deposição de sedimentos de granulometria grossa.

De acordo com Van Wagoner *et al.* (1990) a formação de vales segue distintas fases relacionadas à erosão de sedimentos precedida ou ocorrendo concomitantemente com o transpasse de sedimentos em direção às partes mais distais da bacia (na planície costeira e/ou plataforma continental) em resposta à queda do nível do mar. Dois modelos de suprimento e transpasse de sedimentos para bacias marginais foram propostos por Blum e Törqvist (2000): o modelo "aspirador de pó" (*vaccum cleaner*) e o "correia transportadora" (*conveyor belt*). O primeiro refere-se à transferência de todo o sedimento para as partes mais distais da bacia produzindo profundas incisões fluviais. O segundo diz respeito a uma extensa rede de drenagem fluvial como mecanismo de transporte contínuo de sedimentos sem a necessidade de formação de incisões fluviais proeminentes e sem o completo transpasse de sedimentos durante a queda do nível do mar. Experimentos de Blum e Törqvist (2000) sugerem que o modelo de "correia transportadora" contribui com maior volume de sedimentos transportados para bacias marginais quando comparado ao primeiro modelo. Apesar do modelo "aspirador de pó" ter suas bases nos estudos de Fisk (1944), os modelos propostos para o baixo vale do rio Mississipi indicam claramente que o completo transpasse sedimentar não se aplica corretamente para este sistema. Estudos de caso similares demonstraram a contrariedade a este modelo (Stanley e Warne, 1993; Blum *et al.*, 1995; Saucier, 1996; Amorosi *et al.*, 1999; Blum e Törqvist, 2000; Blum e Womack, 2009).

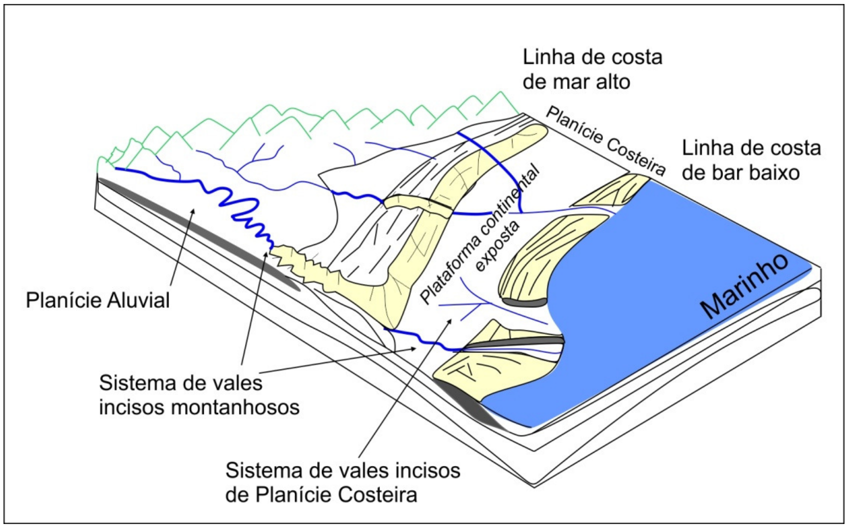


Figura 1**.** Modelo esquemático de dois tipos de vales incisos, classificados quanto à localização na área costeira: vales montanhosos (*Piedmont valleys*) e de planície costeira (*Coastal Plain valleys*), propostos por Zaitlin *et al*. (1994).

2. Trabalhos sismoestratigráficos realizados na zona costeira do RS

Estudos sismoestratigráficos realizados na Planície Costeira do RS revelam a presença de distintos sistemas de vales incisos e canais associados às principais drenagens fluviais atuantes na região (Weschenfelder, 2005; Weschenfelder *et al.*, 2008 a,b, 2010 a,b, 2014; Baitelli, 2012). Através da integração e correlação dos dados de estudos sísmicos e morfoestruturais, tornou-se possível inferir os limites destas incisões em áreas da plataforma continental do RS (Martins *et al.*, 1996; Abreu e Calliari, 2005; Corrêa *et al.*, 2007, 2013, 2014 a), interligadas por uma complexa rede de paleodrenagens ativadas em períodos de exposição subaérea e quedas do nível do mar (Corrêa, 1990, 1994).

As contribuições de Weschenfelder *et al*. (2008 a,b, 2010 a,b, 2014) e Baitelli (2012) constituem um excelente exemplo de integração de registros sísmicos de alta resolução e frequência (3,5 e 7 kHz) a dados sedimentológicos, micropaleontológicos e radiocarbônicos de testemunhos de sondagem obtidos no interior da Lagoa dos Patos, utilizados no mapeamento e reconhecimento de elementos arquiteturais de distintos sistemas de paleovales e paleocanais incisos. Os principais avanços no conhecimento destes sistemas incluem:

(1) O estabelecimento de um modelo evolutivo do paleocanal holocênico da Barra Falsa, associado à drenagem do rio Camaquã. Cinco unidades litológicas são relacionadas às principais mudanças paleoambientais e paleogeográficas da planície costeira média do RS, relacionados às oscilações do nível do mar (Weschenfelder *et al.*, 2008 a);

(2) Distintos eventos de incisão e preenchimento dos sistemas de vales incisos dos rios Camaquã e Jacuí estão associados aos estágios isotópicos marinhos (MIS) 6-5 e 2-1 (Weschenfelder *et al.*, 2008 b);

(3) Um complexto sistema de rede de drenagem, responsável pelo transpasse de sedimentos das partes mais proximais se estendendo pela planície costeira e plataforma continental, subaeriamente expostas durante eventos de regressão forçada, desempenhou um papel importante na arquitetura marginal, na distribuição de fácies e no espaço de acomodação (Weschenfelder *et al.*, 2010 a);

(4) Através de estudos sísmicos e morfoestruturais previamente realizados na zona costeira do RS, a drenagem fluvial do rio Camaquã pôde ser conectada, à jusante, por sistemas de paleocanais localizados na plataforma e no talude continental. À montante, a drenagem foi escavada diretamente no prisma costeiro depositado durante eventos transgressivos Quaternários (Weschenfelder *et al.*, 2010 b);

(5) Os elementos arquiteturais identificados nos perfis sísmicos obtidos na porção norte da Lagoa dos Patos foram associados à antiga drenagem do rio Jacuí. Um modelo de evolução paleogeográfica da região de Palmares do Sul foi sugerido a partir da integração de dados sísmicos, associações macrofaunísticas e dados isotópicos de oxigênio (Baitelli, 2012);

(6) Três unidades sismoestratigráficas (S1, S2, S3) delimitadas por dois limites de sequências (S1-S2, S2-S3) são reconhecidas e associadas a três distintos e não contemporâneos sistemas de paleovales e paleocanais incisos dos rios Camaquã e Jacuí (Weschenfelder *et al.*, 2014).

CAPÍTULO III- ÁREA DE ESTUDO

III- ÁREA DE ESTUDO

1. Breve contexto geológico e caracterização da área de estudo

A área de estudo encontra-se inserida no contexto geológico da Província Costeira do RS (Villwock, 1972, 1984; Urien e Martins, 1978; Villwock *et al*., 1986, 1994; Villwock e Tomazelli, 1995; Tomazelli e Villwock, 2000). De acordo com Villwock (1972, 1984) esta província abrange os depósitos sedimentares da Bacia de Pelotas e o embasamento adjacente. Villwock e Tomazelli (1995) reconheceram distintas divisões geomorfológicas que caracterizam a província costeira: terras altas (Planalto Sul-Rio-Grandense, Depressão Central e Planalto das Araucárias) e terras baixas (Planície Costeira e Plataforma Continental). A Bacia de Pelotas é uma bacia marginal apoiada sobre o embasamento pré-Cambriano e sequências sedimentares e vulcânicas da Bacia do Paraná, ocupando uma área de aproximadamente 210.000 km^2 (Gamboa e Rabinowitz, 1981). A formação desta bacia está vinculada a movimentos tectônicos que ocasionaram a abertura do oceano Atlântico Sul no Cretáceo. Esta bacia é delimitada ao Norte pelo Alto de Florianópolis e ao Sul, pelo Alto do Cabo Polônio (Urien e Martins, 1978), (Fig. 2). O embasamento é constituído pelas rochas do Escudo Sul-Rio-Grandense e do Escudo Uruguaio, pertencente à Província da Mantiqueira (Almeida *et al*., 1981) e pelas rochas vulcano-sedimentares da Bacia do Paraná, aflorantes na região oeste da bacia marginal. A evolução desses sistemas está firmada na variação glacio-eustática do nível do mar como observado por Villwock e Tomazelli (1995).

1.1. Sistemas deposicionais costeiros

Os sistemas deposicionais identificados na planície costeira do RS correspondem a fácies sedimentares classificadas e agrupadas de acordo com Villwock e Tomazelli (1995) em: (1) sistema de Leques Aluviais e (2) sistemas deposicionais do tipo Laguna-barreira. O sistema de Leques Aluviais do tipo "*fan delta"* correspondem à transição entre as terras altas do Embasamento da Bacia de Pelotas e os sistemas de barreiras arenosas. Posteriormente, Tomazelli e Villwock (2000) subdividiram o sistema de leques em: (1) leques alimentados pelo Escudo pré-Cambriano e (2) leques alimentados pelo Planalto de acordo com as características texturais, estruturais, composicionais dependentes da area fonte. Os sistemas de leques alimentados pelo escudo, formados a partir da erosão sobre as rochas ígneas e metamórficas do Escudo, ocorrem na margem oeste da planície. O sistema de leques alimentados pelo Planalto está associado às encostas do Planalto da Serra Geral, formados pelas rochas vulcânicas e sedimentares da Bacia do Paraná localizados na região norte da planície costeira. Entretanto, os sistemas deposicionais do tipo Laguna-barreira são mais relevantes para o presente estudo. A seguir são apresentados alguns aspectos gerais referentes aos quatro sistemas bem estudados e classificados por Villwock *et al*. (1986), Villwock e Tomazelli (1995), Tomazelli e Villwock (2000), Dillenburg *et al*. (2000, 2004, 2006, 2013) e Dillenburg e Hesp (2009).

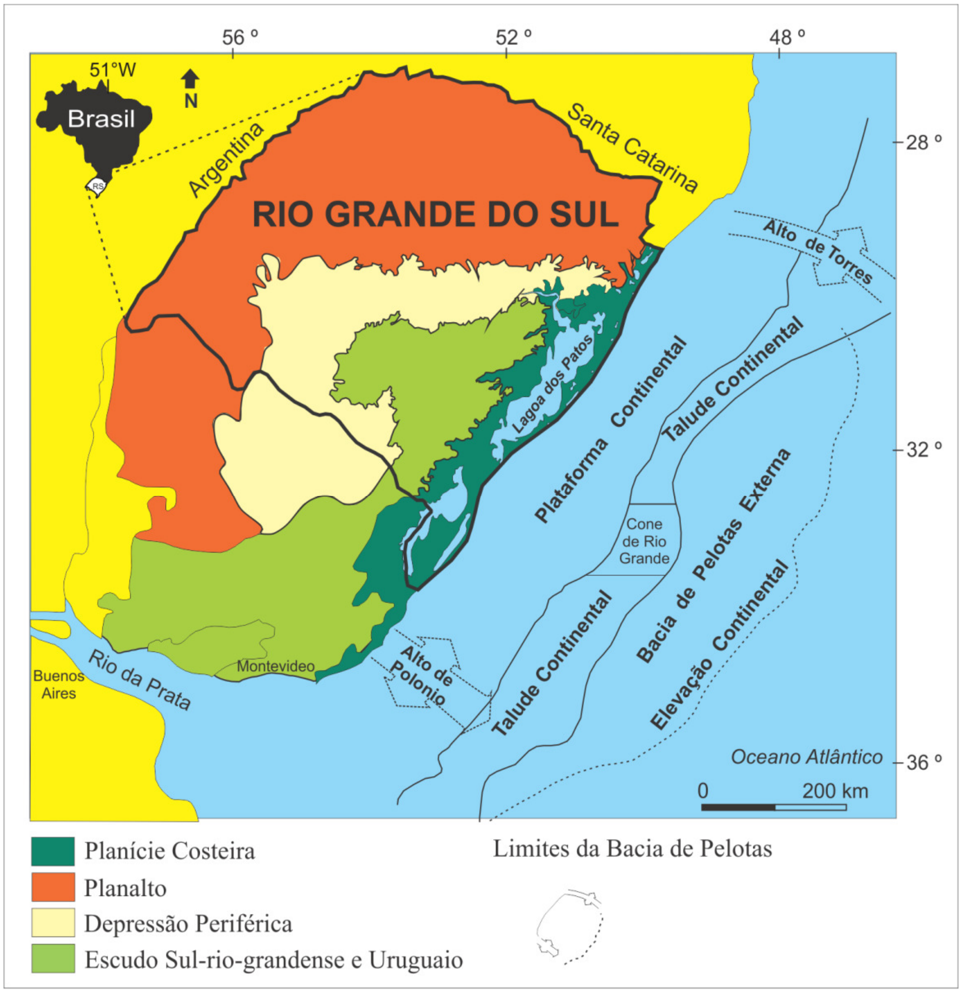


Figura 2. Mapa da Província Fisiográfica do RS e principais estruturas geológicas da Bacia de Pelotas e do Embasamento (modificado de Urien e Martins, 1978).

Três sistemas deposicionais do tipo Laguna-barreira pleistocênicos e um sistema holocênico, atualmente ativo, foram distinguidas nesta região desde os últimos 400.000 anos AP (Villwock *et al.*, 1986; Villwock e Tomazelli, 1995). Devido à ausência de evidências consistentes sobre a influência da neotectônica atuando ao longo desta área costeira, o estabelecimento de sistemas de barreiras arenosas é atribuído às oscilações de alta frequência do nível do mar durante o Quaternário, que são consistentes com as curvas globais existentes. Embora Delaney (1962) tenha atribuído a formação de barreiras costeiras aos movimentos tectônicos verticais, as mais consistentes evidências da ação neotectônica podem ser encontradas em áreas costeiras localizadas nas regiões sudeste e nordeste do país (Suguio e Martin 1996; Barreto *et al.*, 2002; Bezerra *et al.*, 2003).

As idades dos sistemas variam desde 400, 325, 125 e 6-7 mil anos AP ao recente, correlacionados com os estágios isotópicos marinhos (MIS) 11, 9, 5 e 1 (Villwock e Tomazelli, 1995), (Fig. 3). De acordo com esses autores as fácies sedimentares dos sistemas de barreiras pleistocênicos são compostas por areias quartzo-feldspáticas de granulação fina a médias, com grãos bem arredondados e com um elevado conteúdo em matriz síltico-argilosa. Estas fácies refletem uma deposição sedimentar em um ambiente de retrobarreira. O sistema lagunar I (MIS 11) encontra-se preservado na porção noroeste da planície costeira (Barreira das Lombas) em uma orientação NE-SW com extensão aproximada de 250 km e largura média entre 5-10 km. A evolução do sistema Laguna-Barreira II (MIS 9) corresponde ao primeiro estágio de desenvolvimento do Complexo de Barreiras Múltiplas (Villwock, 1984) que devido à individualização isolou uma extensa planície ocupada atualmente pelo Sistema Lagunar Patos-Mirim (Tomazelli e Villwock, 2000). O último sistema pleistocênico formado durante o MIS 5 foi responsável pela implantação do Sistema Lagunar Patos-Mirim. Os sedimentos da Barreira III consistem em fácies arenosas de origem praial e marinho raso, cobertos por sedimentos eólicos. O sistema Laguna-Barreira IV foi intensamente estudado por Dillenburg *et al.* (2000, 2004, 2006, 2013); Clerot (2004), Caron (2007, 2014), Dillenburg e Hesp (2009), Lima *et al.* (2013), entre outros. Este sistema ativo corresponde à praia oceânica moderna, desenvolvido durante o Holoceno em consequência ao último evento transgressivo pós-glacial (MIS 1) (Villwock *et al.*, 1986; Villwock e Tomazelli, 1994; Tomazelli e Villwock, 2000). Este sistema ocupa o espaço de retrobarreira entre a barreira holocênica e pleistocênica (sistema III).

1.2. Área de estudo

Dentro deste contexto geológico, a área de estudo engloba distintos ambientes do talude, da plataforma continental e da planície costeira. O talude e a plataforma continental ocupam a parte submersa da Bacia de Pelotas. O talude continental caracteriza-se por apresentar uma forma convexa com declividades suaves em torno de 2º que diminui para 1º, onde o talude inferior passa a assumir uma forma de cone. Este é amplo e irregular na forma e relevo, apresentando cânions e canais submarinos (Martins *et al*., 1972) relacionados à uma complexa rede fluvial de drenagem (Corrêa, 1990, 1994). A plataforma continental do RS é caracterizada por apresentar baixos gradientes (variando entre 1,3 e 1,4 m/km) e largura média de 125 km (que aumenta gradualmente em direção ao sul) com uma zona de quebra observada em torno da isóbata de 170 m (Martins, 1984). O gradiente de declividade é suave (1:1000) aumentando em direção ao talude continental (Martins *et al*., 1972). Este ambiente é dominado por sedimentos relíquias, depositados em condições de mar baixo, onde a linha de costa estava posicionada aproximadamente -120/-130 m abaixo do nível atual (Corrêa, 1986; Corrêa 1990, 1996; Corrêa e Toldo Jr.,1998). De acordo com Martins *et al*. (1996) um complexo sistema de ambientes transicionais foram desenvolvidos na planície costeira pleistocênica. Ambos ambientes de plataforma e talude continentais são considerados tectonicamente estáveis, sujeitos a movimentos epirogênicos e formados pelas oscilações do nível do mar e condições hidrodinâmicas locais (Corrêa, 1987).

A Planície Costeira do RS ocupa a parte emersa da Bacia de Pelotas e representa o típico modelo de costa dominada por ondas. É considerada uma das mais extensas planícies costeiras do mundo ocupando aproximadamente 33.000 km^2, ocupada em grande parte por sistemas lacustres e lagunares. Neste contexto, os sedimentos de quatro sistemas deposicionais não contemporâneos do tipo Laguna-barreira encontram-se expostos. Estes sistemas foram desenvolvidos em resposta aos ciclos transgressivo-regressivos induzidos pela glácio-eustasia

(Villwock *et al*., 1986; Villwock e Tomazelli, 1995; Tomazelli e Villwock, 2000; Dillenburg e Hesp, 2009).

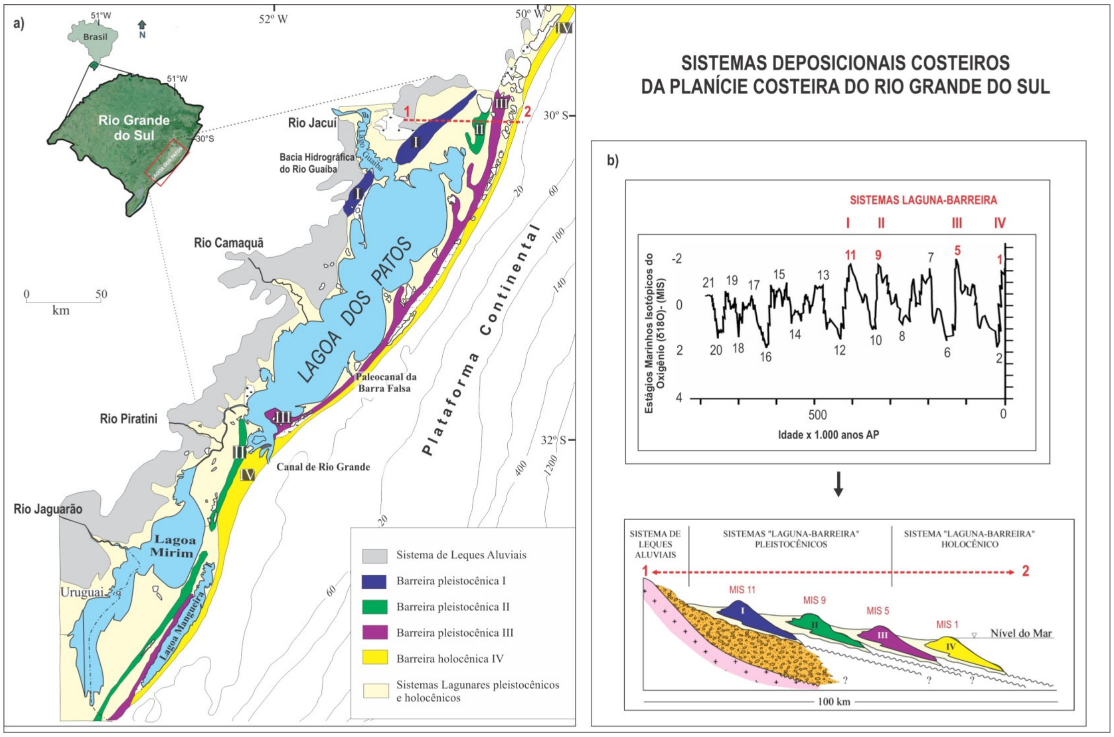


Figura 3. Mapa geológico simplificado dos sistemas deposicionais costeiros identificados na Planície Costeira do RS (a) e os sistemas Laguna-barreira (b) correlacionados aos estágios Marinhos Isotópicos do Oxigênio (MIS) a partir dos dados de Imbrie *et al*. (1984) (modificados de Villwock, 1984 e Tomazelli e Villwock, 2000).

A feição geomorfológica mais representativa desta costa é uma ampla laguna subtropical rasa (com profundidade média de 6 m), considerada o maior sistema lagunar estrangulado do mundo (10.000 km^2 de extensão), representando também uma das mais importantes reservas hídricas da América do Sul (Fig. 4a). O eixo principal da Lagoa dos Patos estende-se além de 180 km em uma direção NE-SW, incluindo uma região estuarina que possui 60 km de extensão (Calliari *et al*., 2009). Apesar da ampla extensão que o sistema lagunar ocupa na planície costeira, somente o canal de Rio Grande é responsável pelas trocas hídricas com o Oceano Atlântico atualmente. Ambas as margens e o fundo lagunar são influenciados pela energia de ondas que podem atingir 1,6 m de altura. Os sedimentos arenosos são predominantes nas áreas marginais cobrindo aproximadamente 60% da área total e no interior do corpo lagunar encontram-se os sedimentos lamosos com espessuras de até 6 m (Toldo Jr. *et al*., 2000). A direção da corrente longitudinal é claramente bidirecional e regular nas direções SW-NE (Jung e Toldo Jr., 2012). A maré astronômica é semidiurna próxima ao canal de entrada da laguna, com amplitude média de 0,47 m. Em geral exercendo pouca influência na dinâmica sedimentar da região costeira e plataforma interna adjacente (Garcia, 1997). O regime de micromarés deve-se à proximidade a um ponto anfidrômico do Atlântico Sul associado com a largura da plataforma continental e o caráter retilíneo e regular da linha de costa (Weschenfelder, 2005).

A Lagoa dos Patos recebe água doce através da Bacia Hidrográfica do Rio Guaíba que tem uma área de aproximadamente 200.000 km^2. As principais drenagens fluviais são provenientes dos rios Jacuí e Taquari que fluem ao longo da bacia hidrográfica e a drenagem do rio Camaquã, desaguando na região sul da laguna. A bacia do rio Jacuí apresenta 710 km de extensão e é responsável pela drenagem de uma área aproximada de 71.600 km^2. Esta bacia caracteriza-se pelo intenso uso da terra para fins de geração de energia e agricultura (FEPAM, 2010). A bacia do rio Camaquã tem uma superfície de 24.000 km^2, que nesta atual configuração, apresenta um sistema deltaico intralagunar na porção central da laguna. Toldo Jr. *et al.* (2000) mensuraram a descarga média de 4.800 m^3/s na saída do canal de Rio Grande. Marques e Möller (2009) estimaram a descarga média anual de água doce no interior do sistema lagunar em 2.400 m^3/s, sendo o rio Jacuí considerado o maior contribuinte de água doce no sistema, com uma descarga de 801 m^3/s, seguido pelos rios Taquari (452 m^3/s) e Camaquã com aproximadamente 400 m^3/s (Vaz, 2003 e Vaz *et al.*, 2006). O conjunto dessas drenagens converge para a laguna, cujos picos extremos de descarga, para o ambiente oceânico adjacente, podem atingir valores de 16.000 m^3 (Marques, 2005). Uma vez que o clima desta região é fortemente influenciado pelos fenômenos de El Niño/La Niña (Grimm *et al.*, 1998, 2000; Fernandes *et al.*, 2002), altos valores de descarga fluvial foram registrados (8.000 e 12.000 m^3/s) em épocas de El Niño (Möller *et al.*, 1996). Em geral, baixos valores são registrados durante o verão (700 m^3/s) em contraponto aos altos valores que podem atingir 3.000 m^3/s durante a primavera (Möller *et al.*, 2001). Um estudo recente desenvolvido no sistema fluvial do rio Guaíba sugere que a descarga média anual de sólidos em suspensão transportados da Bacia Hidrográfica do Rio Guaíba para a Lagoa dos Patos corresponde a $1,1 \times 10^6$ toneladas/ano de 400.000 m^3, correspondendo a uma média anual de suprimento sedimentar de 0,11 kg/m^2 (Andrade Neto *et al.*, 2012).

A hidrodinâmica lagunar é fortemente influenciada pela descarga fluvial e a ação de ventos (Möller e Fernandes, 2010) que atuam nos processos de salinização e desalinização (Möller e Castaing, 1999). A ação dos ventos pode controlar a circulação estuarina dentro do sistema lagunar. Intrusões marinhas são favorecidas em períodos de altas temperaturas, baixa precipitação e pela direção predominante SW que propiciam um aumento de salinidade no estuário. Intrusões de águas doces são relacionadas à baixa salinidade geradas pela alta taxa de precipitação e ventos predominantes na direção NE (Möller e Castaing, 1999). De acordo com Marques (2012) a descarga de água doce contribui para o padrão de circulação, mistura e trocas com as águas marinhas, bem como o transporte de sedimentos em suspensão ao longo da zona costeira, que podem variar mensalmente, sazonalmente ou em longas escalas de tempo (Marques *et al.*, 2010, 2011).

CAPÍTULO IV- METODOLOGIA

IV- METOLOGIA

1. Dados sísmicos e sedimentares

Este estudo foi desenvolvido principalmente a partir de dados sísmicos de alta resolução e frequência (3,5 e 7,0 kHz), de registros sedimentares de quatro testemunhos de sondagem obtidos em duas campanhas de coleta de dados realizadas em dezembro de 2002 e janeiro de 2010, previamente publicados em trabalhos anteriores (Weschenfelder, 2005; Weschenfelder *et al.*, 2008 a,b, 2010 a,b, 2014; Bortolin, 2011; Baitelli, 2012). Os materiais e métodos envolvidos na aquisição geofísica podem ser revistos em Weschenfelder (2005).

2. Amostragem

2.1. Testemunhos

Os testemunhos de sondagem foram obtidos em distintos ambientes da zona costeira do RS: no interior da Lagoa dos Patos (Bo, Mo, Pa, T15, T19), na extensão do canal da Barra Falsa (B2, TBJ-02), na Lagoa do Peixe (T9), na plataforma continental externa (T103) e no talude continental (T22), (Fig. 4 b). O testemunho TBJ-02 analisado previamente por Medeanic e Dillenburg (2001) foi utilizado como informação complementar nas idades radiocarbônicas (Tabela 1).

Os testemunhos B2, Bo, Mo e Pa foram obtidos por ensaio de penetração dinâmica SPT (*SPT - Standard Penetration Test*). Bo, Mo e Pa foram coletados em profundidades de até 30 m a partir da superfície lagunar (em lâmina d'água de ~7 m de profundidade) e o testemunho B2 foi obtido na planície costeira, com recuperação sedimentar de ~ 30 m. As perfurações foram realizadas por sondagem à percussão, com a circulação de água e lama bentonítica para a estabilização. O primeiro metro de perfuração foi revestido com tubo de 63,5 mm de diâmetro. A extração das amostras foi realizada com cravação de amostrador padrão de 34,9 mm de diâmetro interno e 50,8 mm de diâmetro externo (Weschenfelder, 2005). As amostragens foram realizadas em intervalos de metro a metro.

Os testemunhos rasos foram obtidos na região norte da Lagoa dos Patos: T15 e T19 (Toldo Jr. *et al.*, 1991, mais detalhes em Toldo Jr. e Martins, 1988) e na Lagoa do Peixe: T09 (Arejano, 2006), os quais foram coletados por um testemunhador a vibração. A metodologia utilizada na amostragem dos testemunhos restantes está sumarizada no trabalho de Martins *et al.*, 1987 (T103 e T22). Todas as amostras encontram-se armazenadas no Centro de Estudos de Geologia Costeira e Oceânica do Instituto de Geociências da Universidade Federal do Rio Grande do Sul – CECO/IGEO-UFRGS.

2.2. Amostras superficiais de sedimentos do fundo da Lagoa dos Patos

Um total de 39 amostras superficiais foram obtidas ao redor dos testemunhos Bo, Mo e Pa com um amostrador ~~de~~ busca-fundo , tipo *Van Veen*, e de arraste, em distâncias cerca de 500 e 1000 m a partir do local dos testemunhos de sondagem. As amostragens foram obtidas nos quadrantes Norte (N), Sul (S), Leste (E) e Oeste (W). Dentre estas, somente 13 foram selecionadas para a análise de diatomáceas: B2, B3, B4, B6, M3, M5, M9, M12, Pa3, Pa5, Pa6, Pa8, Pa13 (Tabela 2, Fig. 4c-e).

3. Análise sedimentológica

As análises granulométricas das amostras de sedimentos coletados nos testemunhos de sondagem e amostras superficiais foram realizadas no laboratório do Centro de Estudos de Geologia Costeira e Oceânica do Instituto de Geociências da Universidade Federal do RS – CECO/IGEO-UFRGS, a partir da metodologia descrita por Martins *et al.*, (1987) e a classificação textural segundo Shepard (1954).

4. Datação radiométrica

Conchas de moluscos fósseis e sedimentos ricos em matéria orgânica foram coletados e processados com a finalidade de obter informações sobre as condições paleoambientais e na determinação do efeito reservatório do carbono pelo método radiocarbônico (^{14}C) através da técnica *Accelerator Mass Spectrometry* (AMS). As idades radiocarbônicas foram determinadas pelo laboratório Beta Analytic Inc., Flórida, Estados Unidos e pela Universidade Federal da Bahia (amostras dos testemunhos T15 e T19). As datações são apresentadas com idades ^{14}C convencionais e calibradas através das correções da razão $^{13}C/^{14}C$ (Tabela 3).

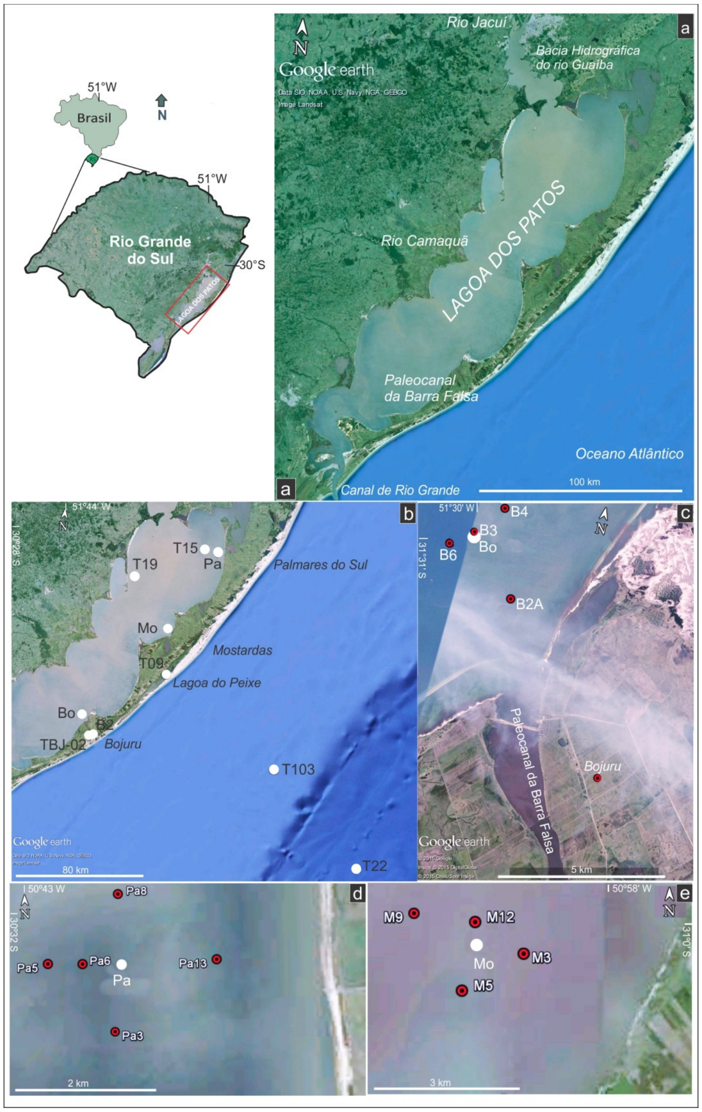


Figura 4. Mapa de localização da área de estudo e das sondagens estratigráficas obtidas no interior da Lagoa dos Patos (Bo, Mo, Pa, T15 e T19), na Lagoa do Peixe (T09), no prolongamento do paleocanal da Barra Falsa (B2, TBJ-02), na plataforma continental (T103) e no talude continental (T22) e das amostras superficiais coletadas ao redor das sondagens Bo (B2A, B3, B4, B6), Mo (M3, M5, M9, M12) e Pa (Pa3, Pa5, Pa6, Pa8, Pa13).

5. Análise de Diatomáceas

5.1. Preparação química

Para a análise de diatomáceas, as subamostras de sedimentos foram tratadas com uma solução aquosa de Ácido Clorídrico (HCl) a 10 % para a retirada de carbonatos e com a solução de Hidróxido de Potássio (KOH) diluído a 5 % utilizado para a remoção de ácidos húmicos e matéria orgânica. Após as lavagens com água destilada para a retirada dos reagentes químicos, alíquotas de 0,5 ml do extrato de diatomáceas foram diluídas em 6 ml de água destilada e colocados em uma lamínula de vidro que posteriormente foram expostas à temperatura ambiente até a completa secagem do material. Depois de secas as lamínulas foram montadas em lâminas de vidro utilizando a resina Naphrax® como meio de inclusão entre lâmina e lamínula, para a montagem de lâminas permanentes. A resina Naphrax foi utilizada por apresentar um alto índice de refração (1,74).

5.2. Eficiência amostral e abundância relativa

As amostras foram analisadas com um microscópio de luz refletida Zeiss® para a contagem e determinação da abundância relativa de indivíduos. Foram contadas até 600 valvas a partir da eficiência amostral de acordo com Pappas e Stoermer (1996). A eficiência amostral foi obtida através do método de curva de saturação que consiste na estabilização da curva representativa entre a eficiência amostral e o número de indivíduos. Este método consiste não somente na inclusão de espécies frequentes, mas também na inclusão de espécies raras. Para assegurar uma maior confiabilidade de contagem de valvas em lâminas permanentes, atingiu-se a eficiência amostral de no mínimo 95% através da seguinte fórmula expressa por: eficiência amostral (EF) = 1 – NSP/NI, onde: NSP= número de espécies e NI= número de indivíduos

A estimativa média de contagem de valvas para abundância relativa foi obtida através do cálculo expresso através da seguinte fórmula: abundância relativa (AR) = Nx100/ n, onde: AR = Abundância relativa, N = Número total de organismos de cada *taxon* na amostra e n = Número total de organismos. A partir dos percentuais obtidos para a abundância relativa (%), os *taxa* foram classificados de acordo com as seguintes categorias: dominante > 50 %, abundante: 5 a 50 %, incomum (pouco abundante): 1 a 5 % e raro: < 1 %. Os resultados foram plotados em diagramas bioestratigráficos usando o software C2® (versão 1.5; Juggins, 2003).

5.3. Classificação ecológica dos *taxa* de diatomáceas

Para a identificação dos *taxa* a nível específico, foram consultadas obras específicas como Iconographia Diatomologica, Biblioteca Diatomologica, Diatom Research e Proceedings of Internacional Diatom Congress, bem como as obras clássicas de Peragallo e Peragallo (1897-1908); Hendey (1964) e Patrick e Reimer

(1966). O sistema de classificação adotado segue Round *et al.* (1990) e Medlin e Kaczmarska (2004). Aspectos ecológicos relacionados ao hábito e habitat para os *taxa* identificados foram verificados através da revisão de literatura estrangeira nas obras de Peragallo e Peragallo (1897-1908); Hustedt (1930, 1956, 1957); Hendey (1964); Patrick e Reimer (1966); Patrick (1977); Vos e De Wolf (1988, 1993, 1994); Round *et al.*, *(*1990); Denys (1991 a,b); Denys e De Wolf (1999) e nacionais, nas obras de: Flôres (1997); Torgan (1997); Garcia (1999); Torgan *et al.*, (1999); Ferrari (2004); Bigunas (2005); Salomoni *et al.*, (2006); Bicca *et al.*, *(*2011); Laux e Torgan (2011); Santos (2011); Silva *et al.*, *(*2011); Tremarin *et al.*, *(*2009, 2014), entre outros.

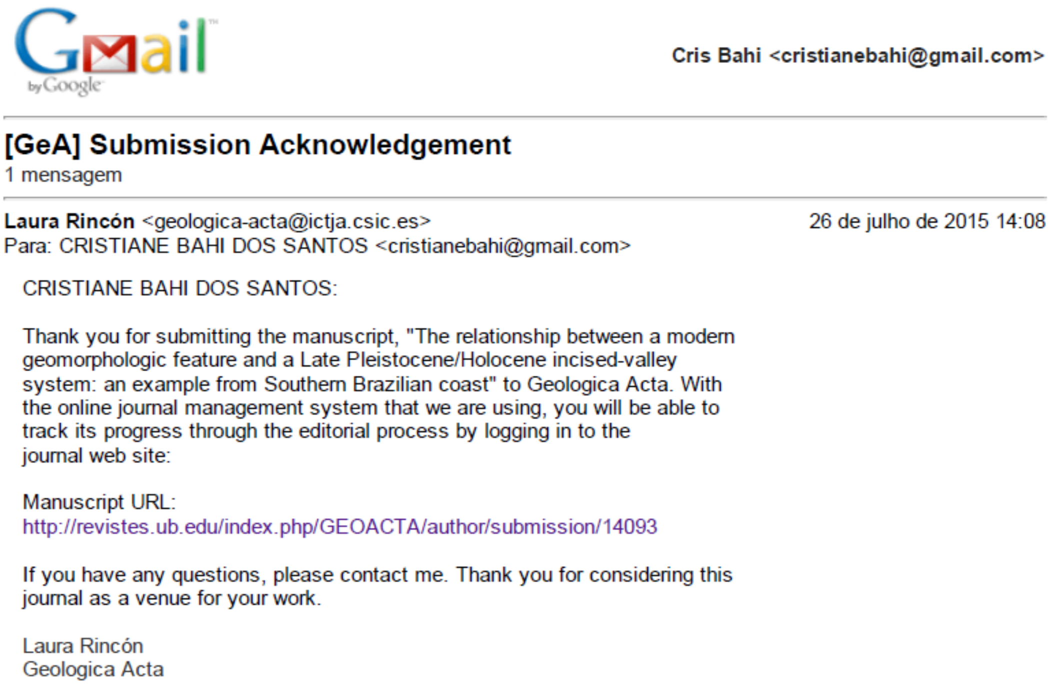
6. Análises estatísticas

Distintas técnicas estatísticas multivariadas amplamente utilizadas na análise de dados ecológicos de comunidades de diatomáceas foram empregadas para a identificação dos padrões de distribuição e composição de *taxa* de diatomáceas em diferentes ambientes da zona costeira do RS. A análise dos Componentes Principais (PCA) foi usada para sumarizar as informações paleoecológicas por meio de indivíduos que se destacaram quanto à abundância relativa nas comunidades fósseis e modernas. Utilizou-se também a Análise de Correspondência Detrítica (DCA) e Análise Canônica de Correspondência (CCA) para a ordenação dos *taxa*, através do programa PAST$^{®}$ (versão 3.06), (Hammer *et al.*, 2001). A análise de Cluster Hierarquico, utilizando o método Ward com intervalos baseados na distância Euclidiana ao quadrado, foi realizada por meio do programa SPSS$^{®}$ (versão AMOS 18), (Arbuckle, 2009), foi utilizada para a unificação dos grupos distribuídos em clusters.

O critério de seleção dos *taxa* de diatomáceas baseou-se na frequência de ocorrência (≥ a quatro amostras) e em valores de abundância relativa maiores que 1 % (≤ a duas amostras). Os dados ambientais de areia, silte e argila e a matriz de espécies relativas aos mais frequentes e abundantes espécimes foram utilizados na obtenção estatística. O teste de Monte Carlo de significância ($p < 0,05$) foi aplicado para indicar a significância dos dados e averiguar a validação e adequação dos métodos estatísticos empregados nas distintas análises.

CAPÍTULO V

THE RELATIONSHIP BETWEEN A MODERN GEOMORPHOLOGIC FEATURE AND A LATE PLEISTOCENE/HOLOCENE INCISED-VALLEY SYSTEM: AN EXAMPLE FROM SOUTHERN BRAZILIAN COAST



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[GeA] Submission Acknowledgement

1 mensagem

Laura Rincón <geologica-acta@ictja.csic.es>
Para: CRISTIANE BAHI DOS SANTOS <cristianebahi@gmail.com>

26 de julho de 2015 14:08

CRISTIANE BAHI DOS SANTOS:

Thank you for submitting the manuscript, "The relationship between a modern geomorphologic feature and a Late Pleistocene/Holocene incised-valley system: an example from Southern Brazilian coast" to Geologica Acta. With the online journal management system that we are using, you will be able to track its progress through the editorial process by logging in to the journal web site:

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Laura Rincón
Geologica Acta

V- THE RELATIONSHIP BETWEEN A MODERN GEOMORPHOLOGIC FEATURE AND A LATE PLEISTOCENE/HOLOCENE INCISED-VALLEY SYSTEM: AN EXAMPLE FROM SOUTHERN BRAZILIAN COAST

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ABSTRACT

The main signatures of the southern Brazilian coast are four barrier systems (formed since MIS 11) and a large subtropical lagoon, which is considered the world's most choked lagoon. Three wave-dominated incised-valleys systems with erosional surfaces related to the two major lowstands, concomitant with MIS 6 and 2 are part of the stratigraphy of this coast. However, the origins of the modern geomorphological features preserved in the coastal plain were not completely elucidated. Core data integration, diatom analysis and seismic records provided a 12,000-yr history of the Camaquã River incised-channel evolution. The Holocene is typified by a stronger influence of marine deposition related to the maintenance of distinct inlets through the paleolagoon system. Drastic environmental changes due to sea-level influence and distinct hydrodynamic conditions after the Last Glacial Maximum were identified. An estuarine environment collapsed in response to rapid sea-level rise prior to 11,500 -10,240 cal yr BP. A drowned coast occurred between 8,420-7,430 cal yr BP. The barrier system became more continuous allowing the progressive development of Patos Lagoon. High marine influence is observed between 3,370 cal yr BP to at least 2,150 yr BP. The inlet closure and final valley-fill sometime after 2,000 yr BP. Important insights about the lagoon's hydrodynamics are presented.

Keywords: Diatoms, Seismic, Sea-level changes, South America, Incised-channel, Barra Falsa channel

1. INTRODUCTION

Incised-valley systems and buried channels are well-studied features of Quaternary stratigraphy, and they are preserved on many coastal plains and continental shelves worldwide (Zaitlin et al., 1994; Dalrymple et al., 2006; Blum et al., 2013). They are characterized by a fluvially eroded valley system that is generally larger than a single channel (Van Wagoner et al., 1990; Schumm, 1993) that developed during the Late Pleistocene, when sea-level fell, and back-filled during the Holocene in response to the sea-level rise (Dalrymple et al., 1994; Zhang and Li, 1998; Blum and Törnqvist, 2000; Catuneanu et al., 2009; Gibling et al., 2011). Most studies of incised-valleys systems are concentrated in estuarine environments (Dalrymple et al., 1994, 2006; Zaitlin et al., 1994). However, studies performed in coastal lagoons have an important bearing on sequence stratigraphic models and concepts (Mallinson et al., 2005; Tesson et al., 2005; Culver et al., 2008; Féniès et al., 2010, Ferrer et al., 2010; Raynal et al., 2010; Sabatier et al., 2010; Cooper et al., 2012).

Coastal landscapes are result of multiple interactions including local environmental controls, tectonic disturbance, climate changes and sea-level oscillations. Since no consistent evidence of local influence of neotectonism acting southern Brazilian coast, the present coastal physiography is result of Quaternary high-frequency sea-level oscillations (Villwock et al., 1986; Corrêa, 1996; Corrêa and Toldo Jr. 1998). The knowledge of the seismic stratigraphy of southern Brazilian coastal zone is relatively recent (Abreu and Calliari, 2005; Weschenfelder et al., 2008 a,b, 2010 a,b, 2014; Baitelli, 2012; Corrêa et al., 2004, 2013, 2014 a). Several studies suggest that the fluvial drainages occurring in the region maintained a relatively fixed position during the Quaternary (Leinz, 1948; Villwock et al., 1986; Tomazelli and Villwock, 2000). However, the origins of the modern geomorphological features preserved in the coastal plain and their relationship with incised-valleys and channels were not completely elucidated.

Knowing that fossil diatom assemblages can be associated with the seismic analysis to determine the infilling nature of the incised-valleys and channels fill (Ta et al., 2001; Mallinson et al., 2005; Culver et al., 2008; Nguyen et al., 2010; Zong et al., 2012). This case study addresses a 12,000-yr history of an incised-valley channel developed in the southern Brazilian coast that preserves a complete Holocene sequences, obtained in a modern lagoon. The goal is to provide simple and consistent outcomes about the close relationship between a geomorphologic heritage and a prominent Late Pleistocene/Holocene incised-valley channel. Our results suggest that the coastal plain was deeply dissected before the installation of the actual landscape. We also compare fossil and modern diatom taxa using common multivariate statistical technique to aid our interpretation; abundant diatom taxa are good indicators of environmental changes.

2. GEOLOGIC SETTING

The southern Brazilian coastal plain is wave dominated and characterized by wide lowlands spanning ~ 33,000km^2. A broad barrier-lagoon system and a subtropical lagoon are the most remarkable physiographic features in the present coastal plain (Fig. 5a). The Barra Falsa channel is an important geomorphologic feature on the southern margin of the lagoon (Fig.5b, c). It is located at approximately 87km northernmost of the present Rio Grande channel and it partially cross cuts the Pleistocene sand barrier (Toldo Jr. et al., 1991). Patos Lagoon is considered the world largest choked lagoon (10,000km^2; 240 km long). The main axis of the lagoonal system extends over 180km in a NE–SW direction, while the estuarine area is 60km long (Calliari et al., 2009). Both the bottom and margins of the lagoon are influenced by waves up to 1.6m (Toldo Jr. et al., 2000). The astronomical tide is semi-diurnal; near the channel entrance, the mean amplitude is 0.47m (Garcia, 1997). Patos Lagoon has a huge surface area but only a single inlet, the Rio Grande channel, which exchanges water with the Atlantic Ocean.

Patos Lagoon receives freshwater supply from the Guaíba River Hydrographic Basin (GHB), which has an area of ~200,000km^2. The main contributing Rivers are the Jacuí and Taquari, which flow throughout the GHB, and the Camaquã River, which flows into the southern region of the lagoon. The Camaquã River basin has a surface of 24,000km^2 and is currently creating a delta system in the central portion of the western margin of the lagoon. According to Vaz et al., (2006) the mean annual water discharge from the Camaquã River is 307m^3/s. However, the mean annual discharge of freshwater into Patos Lagoon is 2,400m^3/s (Marques and Möller, 2009). A recent study performed in the Guaíba fluvial system suggested that the mean annual suspended solids discharge from GHB towards the lagoon corresponds to 1.1 x 10^6 t/yr, of about 400,000m^3 (2,650 kg/m^3) of sediments. This correspond a yearly sediment supply rate of 0.11kg/m^{-2} (Andrade Neto et al., 2012).

3. METHODS

3.1. Seismic surveys

Geophysical data comprises high resolution 3.5kHz seismic reflection sections conducted in the Patos Lagoon interior resulting in approximately one thousand kilometers (see Weschenfelder et al., 2014). Navigation was archived using a DGPS system linked to the sub-bottom profiler used to determine the location and track of transects. The GeoAcoustics subbottom profiler composed of GeoPulse transmitter (5430A), 132B transducer array, GeoPro processor system and the SonarWiz® acquisition software were used. The dataset was saved in digital SEG-Y format. Architectural elements are identified according to the general terms established by the seismostratigraphic analysis approach. A constant sound velocity of 1,650m/s was applied for integrating the cores (depth in meters) with the seismic profiles (depth in milliseconds).

3.2. Sampling and Dating

Two stratigraphic cores were collected in order to inspect the subsurface stratigraphy of Patos Lagoon and extension of the Barra Falsa channel (Fig. 5b and Table 4). Four surface samples obtained around core Bo were used to compare fossil and modern deposition (Fig. 5c, Table 5). A total of 74 samples were collected for diatom analysis. Fossil mollusc shells and organic muds were collected and processed to obtain information about the paleoenvironmental conditions and to determine potential carbon reservoir effects for radiocarbon dating. Accelerator mass spectrometry (AMS) dates were obtained by Beta Analytic Inc., Miami, FL, USA (Table 6). Also, core TBJ-02, which was analyzed by Medeanic and Dillenburg (2001) was correlated with core B2 and was used for supplementary radiocarbon dates. The general characteristics and textural classification for both core and surface samples were based on Shepard (1954).

3.3. Diatom Analysis

Diatom sub-samples were treated with an aqueous solution of 10 % HCl and 5 % KOH. After rinsing with distilled water, diatom extracts were dried onto coverslips and mounted on microscope slides using Naphrax®, which is a permanent mounting resin with a high refractive index. The samples were analyzed with a transmitted light Zeiss® microscope. Relative abundances of fossil diatom assemblages were calculated based upon counts of at least 600 valves and 80 % efficiency sampling based on Pappas and Stoermer (1996). Diatom taxa were then classified according to the following categories based on upon relative abundance: dominant (> 50 %), abundant (5 % to 50 %), uncommon (1 % to 5 %) and rare (< 1 %). The results were plotted in biostratigraphic diagrams using the software program C2® (version 1.7.6; Juggins, 2003). Detrended Correspondence Analysis (DCA) using the software program PAST® (version 3.06), (Hammer et al., 2001) were used to analyze fossil and modern assemblages. Both fossil and modern diatom taxa were selected based on two criteria: (1) frequency of occurrence in at least one sample; (2) relative abundance greater than 1 %. Monte Carlo significance test indicated that the ordination diagram is significant ($p < 0.05$), validating the adequacy of the statistical method.

4. RESULTS

4.1. Seismic analysis

Three incised-valleys systems were associated with the most important drainage systems occurring in the study area (Weschenfelder et al., 2008 a,b; 2010 a,b, 2014). The systematic mapping of three seismic units (S1, S2, S3) allowed identification of two well-defined erosional surfaces related to the two major lowstands concomitant with MIS 6 and 2 (sequence boundary S1-S2 and S2-S3).Three stratigraphic cores collected in order to inspect the subsurface stratigraphy and groundtruth the seismic records interpretations were related to seismic profiles 22, 7 and 2 from Jacuí and Camaquã rivers (Weschenfelder et al., 2014). However, we have analyzed one seismic section from Camaquã River (profile 2; core Bo). Geophysical data of profile 2 comprise a largest paleochannel and multiple buried secondary channels related with Late Pleistocene/Holocene deposition. Seismic profile extended for over 38 km along the Patos Lagoon margin. It was obtained in a southwest-to-northeast direction, in water depths of approximately 6m. The main channel has about 1.5km wide, and the channel-fill was at least 20-m-thick sediments of unit S3.

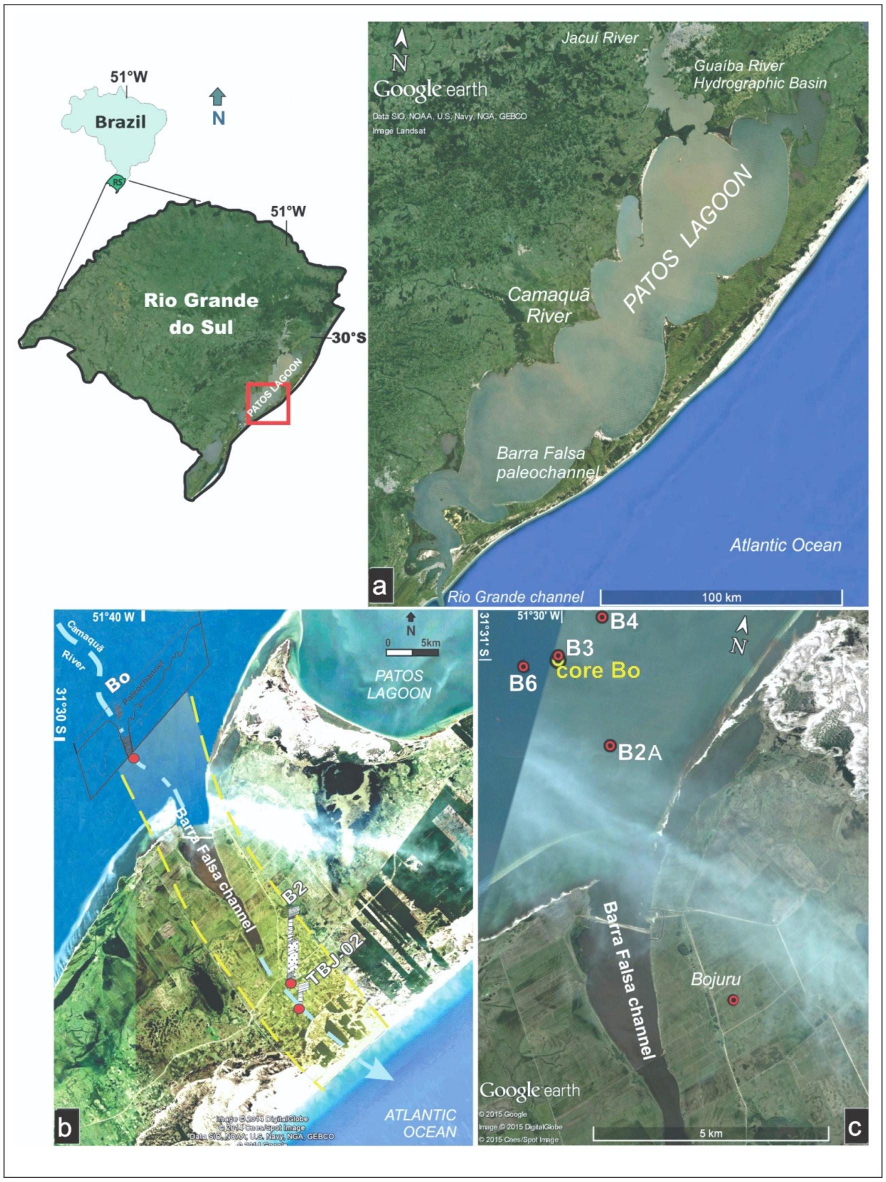

Figure 5. Location map of the southern Brazilian coast (a) showing position of cores (b) and surface samples (c) used in this study (see also tables 4,5).

4.2. Diatom Stratigraphy

Core B2

A total of 65 diatom taxa were recorded in core B2 (Table 7). The marine taxon (*Paralia sulcata*) was considered dominant (77 %), followed by the freshwater taxon *Pinnularia* sp.1 (16 %) and other minor species: *Triceratium favus* (2 %), *Eunotia* sp., (1.5 %) and *Psammococconeis disculoides* (1.2 %). The rest of the assemblage was classified as rare. Benthic assemblages represented a total of 74 %, followed by the planktonic assemblages (26 %) in core B2. From the distribution and salinity tolerances of the fossil diatoms, we divided core B2 into nine diatom zones (DZ I-IX), (Fig. 6). Non-marine diatom taxa are recorded in DZ I, II, IV, VI and IX. The most representative are *Pinnularia* sp.1 (ranging from 4.2 to 80 %), *Eunotia* sp. (ranging from 0.1 to 20 %), *Pinnularia* sp (5 %), *Planothidium* sp (1.2 %) and other rare species ranging from 0.1 to 1 %, including *Cocconeis placentula* var. *euglypta*, *Cymbella* sp.1, *Cymbella* sp.2, *Eunotogramma matogrossiana*, *Gomphonema* sp, *Gomphonema* sp.2. Marine assemblage is related to the dominance of *P. sulcata* accompanied by *A. kitonii*, *Cocconeis distans*, *C. radiatus*, *D. minor*, *Eunotogramma laevis*, *Podosira stelligera*, *P. disculoides*, *T. oestrupii* and *T. favus*, followed by other minor marine species, including *C. litoralis*, *C. striata*, *Dimeregramma marinum*, *T. americana* and *T. nitzschioides*.

Core Bo

Only one diatom zone was observed in core Bo (Fig. 7). Planktonic assemblages composed 67% of the taxa, followed by benthic assemblages (33 %). Diatom assemblages were composed of marine and marine-brackish taxa distributed throughout the core, indicating a marine depositional environment. A total of 24 diatom taxa were recorded in core Bo. *Paralia sulcata* (83 %) was dominant, followed by the abundant taxa *Triceratium favus* (6 %) and *Actinoptychus splendens* (5 %) and the uncommon *Aulacodiscus kitonii* (3 %). Species with less than 1 % representation were not graphed in the diagrams; however, they were classified as rare (see Table 7 for more details)

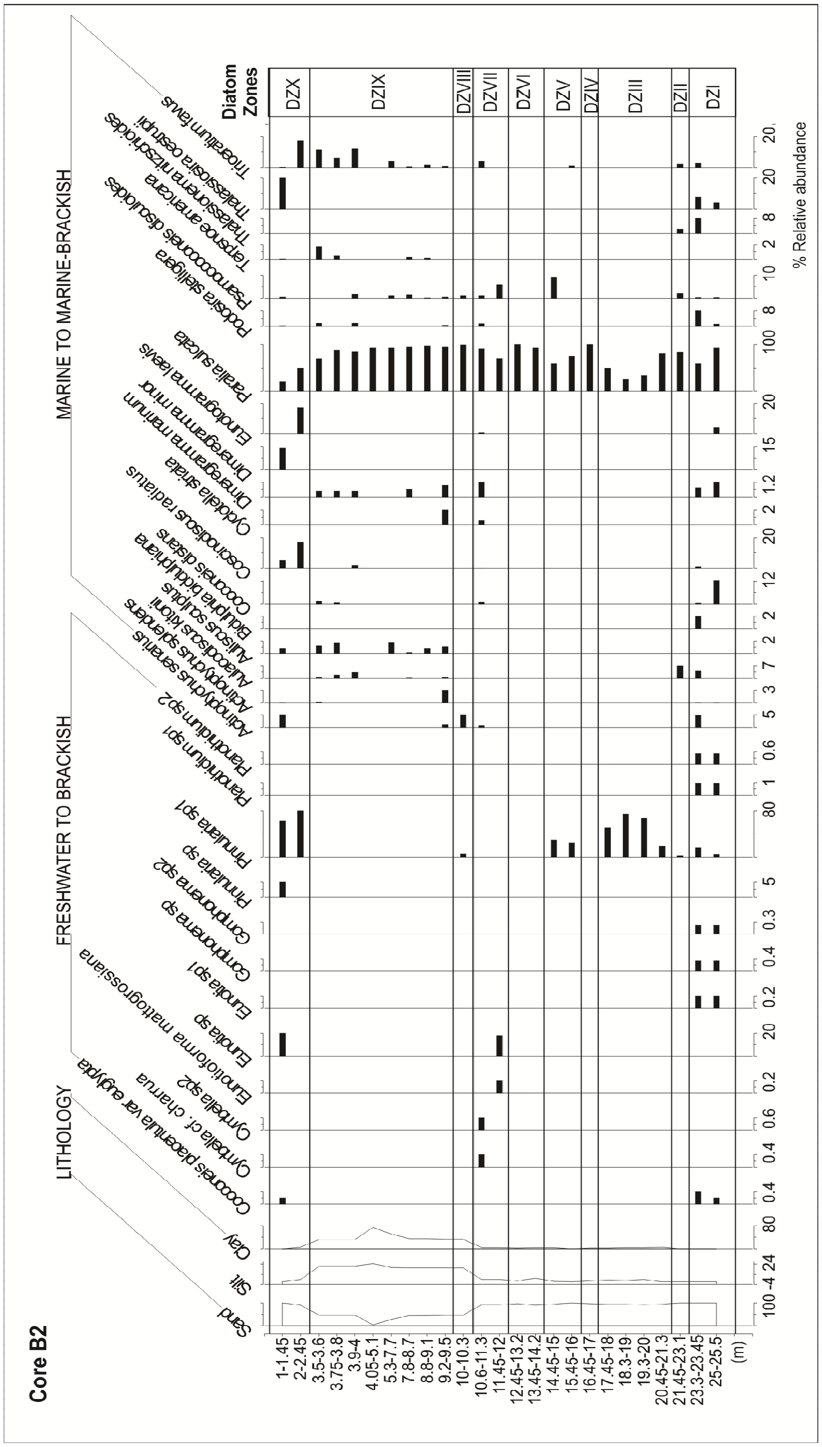

Figure 6. Spatial distribution of fossil diatom assemblages present in core B2.Ten diatom zones (DZ I-X) associated to the most representative diatom taxa are shown. Diatom assemblages are dominated by marine taxon *Paralia sulcata* and other marine species with suggest high marine influence during Holocene. Fluvial influence of the Camaquã River is related to freshwater taxon *Pinnularia* sp.1. The Barra Falsa channel behaved as an inlet submitted to successive openings and closures (DZ I-VIII, X) until the complete drowning coast (DZ IX).

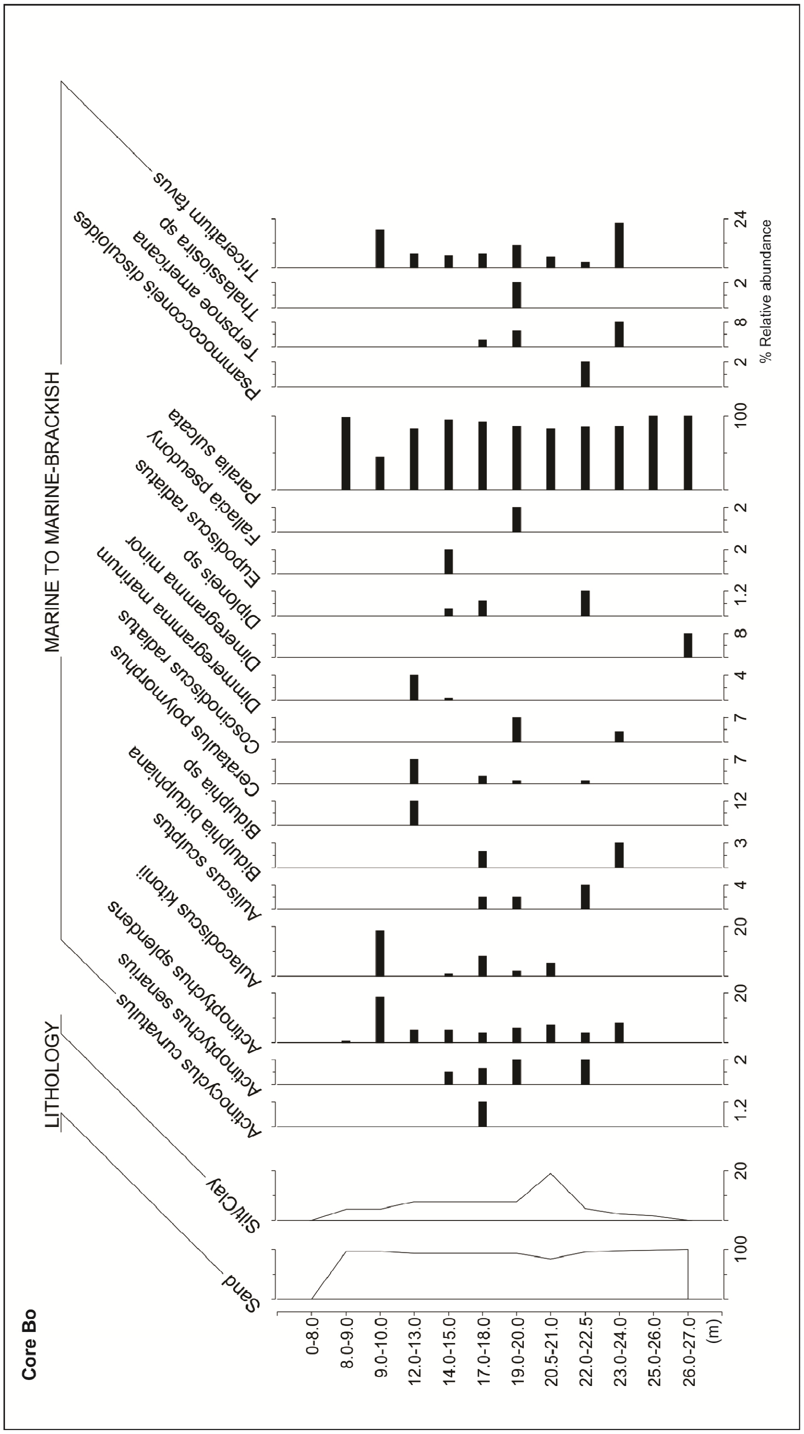

Figure 7. Spatial distribution and composition of fossil diatom assemblages recorded in core sediments of the Patos Lagoon interior (core Bo). Diatom assemblages have indicated that the channel was filled by marine sediments. Only one diatom zone is recorded associated to the most representative marine to marine-brackish taxa. The marine taxa *Paralia sulcata* is dominant accompanied by *Actinoptychus senarius*, *Actinoptychus splendens*, *Aulacodiscus kitonii* and *Triceratium favus*.

4.3. Comparing fossil and modern diatom assemblages

Modern diatom assemblages are represented by a total of 35 diatom taxa (see Table 7). The most representative taxa are *Cyclotella litoralis* (34.5 %), *Actinocyclus normanii* (13.6 %), *Aulacoseira veraluciae* and *Aulacoseira* sp.2 (12 %), *P. sulcata* (9 %), *Staurosirella martyi* (5 %), *Fallacia* sp. (4 %), *A. senarius* (3 %), *Catenula adhaerens* and *Thalassiosira* sp.2 (1.7 %), followed by other rare species. Fossil and modern diatom taxa are combined by Detrended Correspondence Analysis (DCA) which shows a clear separation among assemblages in ordination space. The most abundant diatom taxa and their relationship with core and surface samples are shown (Fig. 8). The eigenvalues of the first two DCA axis are 0.73 (axis 1) and 0.14 (axis 2).

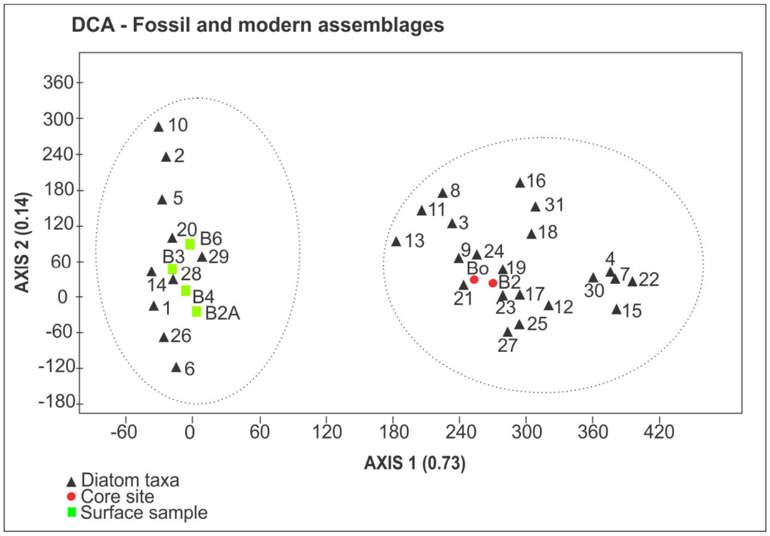

Figure 8. DCA ordination plot of the most abundant diatom taxa occurring in core and surface sediments of Patos Lagoon and extension of the Barra Falsa channel. The clear separation among fossil and modern assemblages in ordination space with surface samples completely isolated from those of core sites is shown. Red dots correspond to core sites B2 and Bo and green squares are associated with surface samples B2A, B3, B4 and B6. Diatom taxa are linked to black triangle and numbered from 1 to 31: 1. *Actinocyclus normanii*, 2. *Actinoptychus senarius*, 3. *Actinoptychus splendens*, 4. *Aulacodiscus kitonii*, 5. *Aulacoseira veraluciae*, 6. *Aulacoseira* sp..2, 7. *Auliscus sculptus*, 8. *Biddulphia biddulphiana*, 9. *Biddulphia* sp., 10. *Catenula adhaerens*, 11. *Cerataulus polymorphus*, 12. *Cocconeis disculoides* var. *euglypta*, 13. *Coscinodiscus radiatus*, 14. *Cyclotella litoralis*, 15. *Cyclotella striata*, 16. *Cymatosira belgica*, 17. *Dimeregramma marinum*, 18. *Dimeregramma minor*, 19. *Eunotia* sp., 20. *Fallacia* sp., 21. *Paralia sulcata*, 22. *Pinnularia* sp., 23. *Pinnularia* sp.1., 24. *Psammococconeis disculoides*, 25. *Podosira stelligera*, 26. *Staurosirella martyi*, 27. *Terpsinoë americana*, 28. *Thalassiosira* sp., 29. *Thalassiosira* sp.2., 30. *Thalassionema nitzschioides*, 31. *Triceratium favus*.

The core sites clustered on the right side of diagram are related to dominance of marine to marine/brackish diatom taxa *A. splendens*, *A. kitonii*, *A. sculptus*, *Biddulphia biddulphiana*, *Biddulphia* sp., *C. distans*, *Cerataulus polymorphus*, *C.*

radiatus, *C. striata*, *C. belgica*, *D. marinum*, *D. minor*, *P. sulcata*, *Podosira stelligera*, *P. disculoides*, *Terpsinoë americana*, *T. nitzschioides* and *T. favus* and freshwater diatom taxa *Eunotia* sp., *Pinnularia* sp., and *Pinnularia* sp.1. Surface samples are associated with the left side of the diagram. Sites located around core Bo (B2A, B3, B4 and B6) are characterized by freshwater taxa *A. veraluciae*, *Aulacoseira* sp.2, *S. martyi* and brackish taxon *A. normanii*. Marine to marine-brackish taxa are associated with *A. senarius*, *C. litoralis*, *Fallacia* sp., *Thalassiosira* sp., and *Thalassiosira* sp.2.

5. DISCUSSION

5.1. Diatom proxies applied to determine the nature of incised-valley systems fill

Fine-grained and muddy sediments are usually related to infilling of coastal plain incised-valleys due to low gradient coastal plain (Zaitlin et al., 1994).Because diatom assemblages are especially abundant in fine-grained and muddy coastal sediments, paleoecological studies based on diatom-inferred play key a role of determination of nature of sedimentary records deposited in valley-containers. Ta et al. (2001) described an incised-valley sequence from the Mekong River Delta, southern Vietnam, based on sedimentary facies and changes in fossil foraminifera and diatom assemblages. They identified nine sedimentary units related to sea-level oscillations during the Late Pleistocene and Holocene. Mallinson et al. (2005) integrated seismic analysis with fossil foraminifera and diatom data to provide a model of the northern North Carolina coastal system evolution. The succession of lithofacies and seismic facies indicated a history of valley-fill at the Albemarle Embayment during the Late Neogene and Quaternary periods. Similarly, Culver et al. (2008) provided the reconstruction of the paleoenvironment in the Late Pliocene to Holocene sedimentary record based on the foraminifera, diatom and pollen analyses from nine cores from the northern Outer Banks, east of Albemarle Sound, North Carolina. The diatom assemblages indicated marine, brackish and freshwater environments from Roanoke River incised valley fill. Nguyen et al. (2010) reconstructed a Holocene initiation of the Mekong River Delta based on sedimentary facies, diatom and foraminifera analyses and radiocarbon dating of the DT1 core. Sedimentary-diatom/foraminifera data provided the upward-deepening succession from marsh/intertidal flat to subtidal-inner bay facies and successions from pro-delta to intertidal flat-floodplain related to Holocene sea-level changes. Similarly, Zong et al. (2012) reconstructed a Holocene history of the Pearl River Delta based on sediment cores obtained from one of the main paleovalleys in the basin, combined with radiocarbon dating, to provide evidence for the interactions between sea-level rise, antecedent topography and sedimentary discharge within the deltaic basin since the Last Glacial Maximum.

In southern Brazilian coast, studies based on diatom records applied to the evolution of the incised-valley systems are scarce and incomplete (Weschenfelder et al., 2008 a, 2014; Corrêa et al., 2013, 2014 a). These studies included few diatom taxa that were associated with palynomorph and ostracoda which were used to infer general changes in salinity. The most paleoecological studies performed in the coastal plain are based on palynomorph records (Medeanic et al., 2000, 2001, 2003, 2010; Medeanic and Dillenburg, 2001; Weschenfelder et al., 2008 a; Medeanic and Corrêa, 2010) and studies based on diatom-inferred presence in the core sediments are considered rare (Medeanic et al., 2009; Santos, 2011, 2015; Hermany et al., 2013). This scarcity of paleoenvironmental studies is more contrasting compared to studies performed in South America where diatom proxies provided a strong paleoecological basis for paleoenvironmental reconstructions (Bracco et al., 2005; Espinosa, 1988, 1994, 2001, 2008; Espinosa et al., 2003, 2012; García-Rodríguez et al., 2001, 2004 a,b; García-Rodríguez and Witkoswki, 2003; García-Rodríguez, 2006, 2012; Vilanova et al., 2006; Escandell et al., 2009; Espinosa and Isla, 2011; Hassan et al., 2011; Escandell and Espinosa, 2012; Fayó and Espinosa, 2014).

5.2. A general climate scenario in the southern Brazilian coastal plain during the Holocene

Several climate proxies have shown that the Holocene climate was influenced by opposite hemispheric trends of solar insolation, which decrease in the Northern and increase in the southern Hemisphere (Cruz et al., 2007; LeGrande and Schmidt, 2008; Cheng et al., 2009; Wanner et al., 2011). Speleothem data associated with $\delta^{18}O$ ratios from southeastern and southern Brazil, suggest a long-term variation in mean precipitation from the last glacial to the Holocene, due to the southern hemisphere summer insolation (Cruz et al., 2007). The southern Brazilian coastal area experienced relatively humid conditions and lower than present day temperatures during the early Holocene (Medeanic and Dillenburg, 2001; Medeanic et al., 2001; Weschenfelder et al., 2008a). Pollen records from lagoon sediments in the coastal plain provided consistent evidence of climatic conditions alternating between humid and dry periods during the middle to late Holocene (Medeanic et al., 2003, 2010, Medeanic, 2006; Medeanic and Corrêa, 2010). According to Weschenfelder et al (2008b), there was evidence of a humid climate at radiocarbon age 8,620 ± 170 ^{14}C yr BP, which caused a decrease in the size of freshwater marshes and an increase in xerophylous and halophylous herbaceous plants in the southern Brazilian coast. At the same time, the marine influence on the coast increased, as was inferred from the appearance of marine palynomorphs in coastal lagoons sediments. A decrease in the incidence of pollen and spores was related to an increase in the amplitude of the sea-level rise.

Similar records were observed in South America. According to Violante and Parker (2004), the Post-Glacial deposition in the La Plata River and adjacent marine and coastal regions in Argentina was deposited in the context of a significant climate change related to sea-level rise. The paleoclimatic conditions were characterized by a transition between arid and cool at 18,000-8,500 years BP, followed by humid subtropical conditions between 8,500-3,500 yr BP (Iriondo and Garcia, 1993; Krohling and Iriondo, 1999). In Uruguay, both dry and humid conditions were observed during the early Holocene (Bracco et al., 2005; Iriarte 2006; García-Rodríguez, 2012).

5.3. Camaquã River incised-valley system evolution

The valley sedimentation is controlled by sea-level oscillations

In accordance with global sea-level curves, based upon the eustatic relative sea-level prediction of Corrêa (1996), sea-level was positioned 130 m below the present level during Last Glacial Maximum. The coastline was positioned at a distance of ~ 130 km seaward of the present position and the present inner shelf surface was sub-aerially exposed, subjected to high erosion and fluvial incision during MIS 2. An incision in the Pleistocene sedimentation was generated, and the Camaquã River and other rivers in the coastal plain were bypassed along the channels being deposited in distal parts of the basin. Sediment transport fed a complex of delta systems installed on the shelf edge during the sea-level lowstand.

Coarse sands formed beach ridges and fine sands were deposited on the inner shelf, whereas muddy sands were deposited on the outer shelf and the upper slope (Corrêa and Toldo Jr., 1998).

The southern Brazilian coast was progressively drowned due to a rapid sea-level rise at a rate of 2.0cm/yr from 17,500 to 16,000 yr BP. Layers of fine sand over the inner shelf, intercalated with medium sands originating from estuaries or delta systems that may have been related to incised-valley systems, were deposited in the paleoshoreline (Corrêa and Toldo Jr., 1998). Changes in sea-level rise speed were observed from 16,000 – 11,000 yr BP, when sea-level rise went from 2cm/yr to 0.6 cm/yr, and as result, muddy sands of the pre-littoral environment were deposited. Two major bathymetric breaks on the shelf preserved as marine terraces at depths of -80/-90 and -60/-70m (Corrêa, 1996). During early Holocene, sea-level rose on average by about 1.6cm/yr from 11,000-6,000 yr BP. Three sea-level stabilization occurring at 11,000/9,000/8,000 year BP are recorded. A peat layer recorded on the continental shelf at depth of -60m is attributed to deposits from the Camaquã or Jaguarão River at 12,540-12,150 cal yr BP (10,460 ± 40 ^{14}C BP, BETA 343479) are recorded by Corrêa et al., (2014 b).

Extensive seismic records from Camaquã River incised-valley system were presented by Weschenfelder et al., (2008 a,b, 2010 a,b, 2014), which provided an excellent information about valley system. Unit S2 was cut by the streams, and the resulting valleys and channels were filled by sequence S3 during the Holocene (Fig. 9a, b). Unit S3 partially cut the Pleistocene unit S2 as a consequence of paleochannel development during the Late Pleistocene/Holocene. A stratigraphic core (Bo) collected in the exact location of the Camaquã incised channel (Fig. 9c), appointed by seismic records, and a large marine/marine-brackish deposit was correlated with unit S3. A previous 7kHz seismic reflection section obtained across the actual intralagoonal Camaquã River Delta revealed the presence of one incised-valley (which has about 2 km wide, filled with more than 10-m thick sediments) and multiple buried channels (1 km wide and up to 7-m thick sediments). The buried paleochannels were infilled with a thick sedimentary package with no clear evidence of channel cutting due to the Camaquã River channel. Two placer deposits in Bojuru have been related to Camaquã River. The first deposit is related to deltaic sediments reworked by coastal processes during sea-level highstands (Dillenburg et al., 2004) and the second placer has similar characteristics to the first, but it is located where two seismic profiles are intercepted (seismic profile 1 and 2), (see Weschenfelder et al., 2010 a,b for more details). The geomorphologic feature the Barra Falsa channel was hypothesized as an inlet between Patos Lagoon and the Atlantic Ocean by Toldo Jr. et al., (1991, 2000) as a Holocene inlet. When the axis of this inlet is extended into the lagoon it intercepts the seismic profile 2, where one prominent paleochannel occurs (Weschelfelder et al., 2010 a).

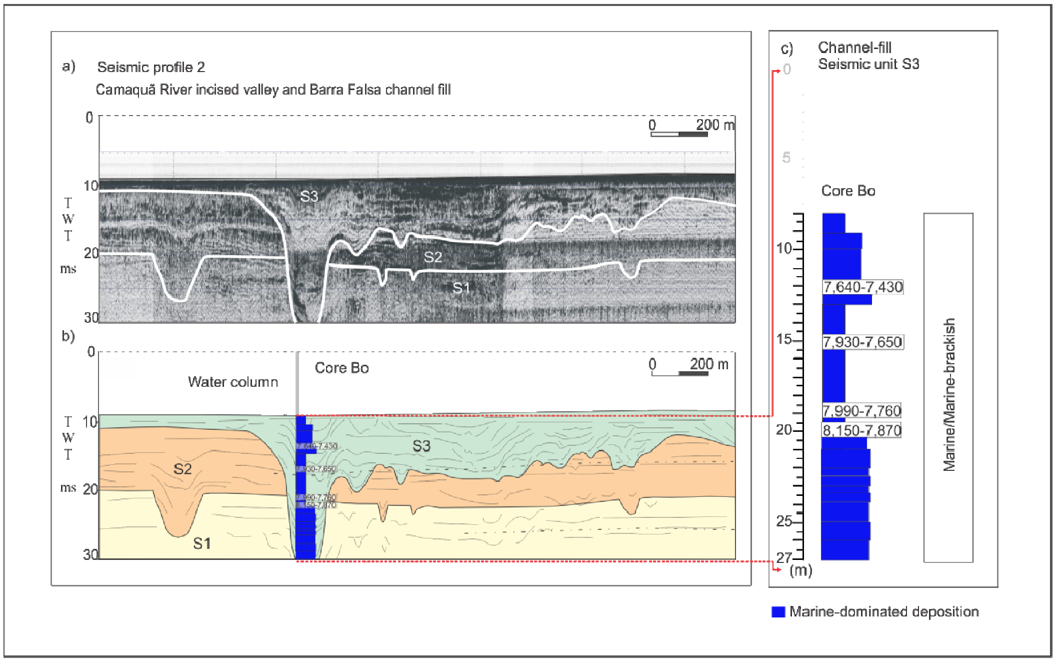

Figure 9. Seismic profile 2 is related to the Late Pleistocene/Holocene incision from Camaquã River (A, B). The relationship between three seismo-depositional units S1, S2 and S3 established by Weschenfelder et al., (2014), (a, b) and the position of core Bo (b, c) are shown. TWT: Two-Way Traveltime (in milliseconds).

The channel incision is a natural part of landscape evolution and inlets have a fundamental importance in coastal systems by virtue of sand barrier maintenance and development (see Mallinson et al., 2008). The river incision can be attributed to numerous factors including geomorphologic, climatic and hydrological reasons (Schumm, 1993). Several studies have demonstrated the significance of paleoinlets in the coastal geomorphology. The relationship between paleoinlets and geomorphologic features along the Outer Banks of North Carolina coast was evidenced by Fisher (1962) and Smith (2006).

Pleistocene paleochannels in coastal areas of southeastern Virginia and Cape Hatteras were widely studied (Riggs et al., 1996; Thieler et al., 2001; Mallinson et al., 2005; Miselis and McNinch, 2006). The most importance of establishment and maintenance of inlets is related to the interchange of freshwater and marine within an estuarine system. In microtidal coasts for example, they act as outlets for freshwater source that flows into the transitional environments from the rivers; wide barrier islands can be observed (see Mallinson et al., 2008 for a review). The Barra Falsa channel is an ancient fluvial channel from the Camaquã River (Toldo Jr. et al., 1991; Weschenfelder et al., 2008 a,b, 2010 a,b, 2014) which behaved as an inlet submitted to successive openings and closures until the complete drowning coast. Three main phases of the Camaquã incised-valley system evolution are presented: (1) an estuarine system collapsed in response to sea-level rise, (2) a drowned coast, (3): final valley-fill and inlet closure related to estuarine deposition with high marine influence. The evolutionary model discussed here is similar to studies performed in the Albemarle Sound-North Carolina (Mallinson et al., 2005; Culver et al., 2008) and Gulf of Lions, Mediterranean Sea on the French coast (Ferrer et al., 2010; Raynal et al., 2010).

Phase I: an estuarine system collapsed in response to a sea-level rise – core B2

The changing speed of sea-level rising allowed the estuarine deposition of sand and sand-mud at interval of 25.5-21.45m (DZ I). Freshwater assemblages were composed of *Cocconeis placentula* var. *euglypta*, *Eunotia* sp.2, *Fragillaria* sp., *Gomphonema* sp., *Gomphonema* sp.2 and *Pinnularia* sp.1, Marine-brackish and marine assemblages were also present, indicating the high marine influence on the system indicating a marine-estuarine environment prior to 11,500 - 10,240 cal yr BP (9,400 ± 140 ^{14}C yr BP, BETA185455). Changes in the valley sedimentation were observed and associated with the alternation between estuarine and marine deposition. This phase corresponded to periods of instability in the system.

An abrupt decrease in diatom assemblages was observed at an interval of 21.30 – 12m, and the estuarine deposition was partially interrupted. Only the freshwater *Pinnularia* sp.1 and *P. sulcata* and *Psammococconeis disculoides* persisted in this sequence (DZ II-VII). Intercalated influxes of the marine *P. sulcata* were observed in diatom zones DZ IV, V, related to successive openings and closures inlet until the complete drowning coast. An increase of fluvial influence was recorded at an interval of 11.45-10 m and was more closely linked to sand deposition in DZ VII. Non-marine taxa in the sequence were composed of *C. placentula* var. *euglypta*, *Cymbella* cf. *charrua*, *Cymbella* sp.2, *Eunotioforma mattogrossiana*, *Eunotia* sp., and *Pinnularia* sp.1., accompanied with marine and marine-brackish taxa illustrated in Figure 2. This oscillatory deposition between fluvial and marine observed by diatom data, can be related to the palynomorph analysis performed by Weschenfelder et al., (2008a). According to these authors, six stages were identified and related to the general environmental conditions in the Bojuru area during the Holocene. Stages I-III was related to an environment impacted by both the ocean and fluvial influence from the Camaquã River and may be indicative of climate changes during the Holocene.

Phase II: a drowned environment as a consequence of sea-level rise – cores B2 and Bo

Sea waters drowned the southern Brazilian coastal plain, and marine assemblages were deposited in the valley. According to Harvey (2006), a rapid sea-level rise after the Last Post-Glacial Maximum and subsequent period of middle to late Holocene stability had a dramatic effect on coastlines worldwide. Changes in the sediment supply, coastline landward migration and coastal adjustments to a new equilibrium with modern coastal processes were the main effects of sea-level changes. There was an estuarine environment with a fluvial influence interrupted and replaced by a drowned estuarine system at the interval between 9.5 and 3.5m (core B2). This abrupt increase in marine and marine-brackish diatom taxa and complete disappearance of freshwater diatoms was interpreted as submergence and transgressive deepening of the marine environment at an interval between 8,420-7,930 cal yr BP (7,370 ± 150 ^{14}C yr BP, BETA 146844). This phase corresponded to a drowned estuarine system that developed in response to a large flooding event in the middle Holocene. The effects of sea-level oscillations can be observed in both transgressive sequences of cores B2 and Bo.

A large transgressive package composed of silt and clay sediments within fine sands was present in core B2. The sedimentary data showed an average of fine sand levels of 34.8 %, followed by clay (45.2 %) and silt (20 %). Marine and marine-brackish assemblages were indicative of marine deposition in the middle/upper part of core B2 prior to 8,500 years BP, indicating high marine influence (DZ VIII). Considerable decreases in sand levels and abrupt increases in clay and silt were observed at the interval of 8,420-7930 cal yr BP (7,370 ± 150^{14}C yr BP, BETA 146844). Marine taxa deposited in the marine mud were composed of *A. sculptus*, *P. sulcata*, *P. disculoides* and *T. favus*. However, this was a temporary phase in the system. At the same time that sand levels were reestablished, a significant decrease in marine taxa was observed in the period directly after 8,420-7,930 cal yr BP (7,370 ± 150^{14}C yr BP, BETA146844), which we interpreted as the Mid-Holocene High Stand (MHHS) period, when the system was drowned by sea waters.

Toldo Jr. et al., (2000) estimated that the Holocene sedimentation in Patos Lagoon started at approximately 8,000 yr BP with an average deposition rate of 0.75mm/yr, supported by a stratigraphic correlation with a relative sea-level prediction from Corrêa (1996). A large transgressive package composed of fine sand intercalated within a muddy middle portion, was associated with marine and marine-brackish diatom assemblages deposited in periods before 8,150-7,870 cal yr BP (7,590 ± 30^{14}C yr BP, BETA 359871) and after 7,640 -7,430 cal yr BP (7,130 ± 40 ^{14}C yr BP, BETA 294867) in core Bo (see Fig. 8). Out of the 22 diatom taxa recorded in core Bo, 18 were similar to assemblages of core B2. Thus, a core correlation between radiocarbon dating and diatom assemblages was made (Fig. 10). Similar results were obtained by a diatom analysis performed by Santos (2015) in distinct environments of the southern Brazilian coastal zone, where several marine transgressive depositions were recorded.

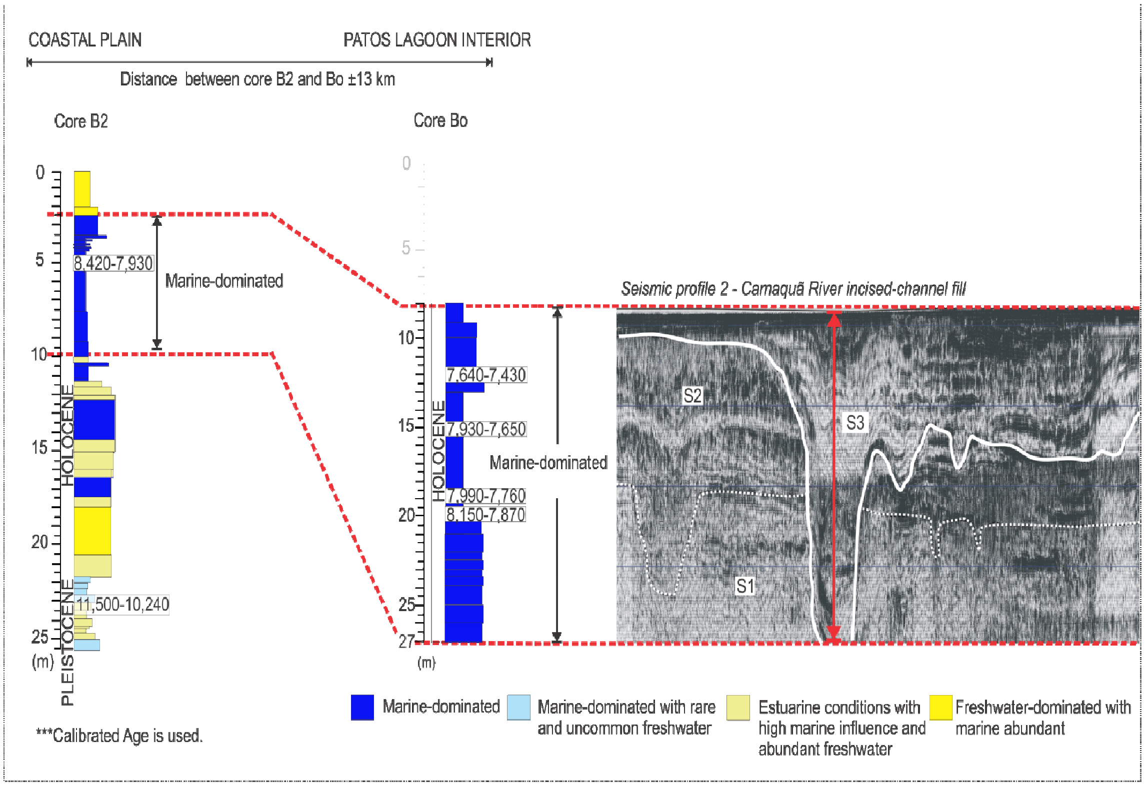

Figure 10. Diatom data, core data integration and seismic record are associated to perform a correlation between core B2 and Bo. A large incised-channel recognized in profile 2 is filled with marine and marine-brackish sediments during the Holocene. The channel-fill is associated with a drowned coast established prior to 8,500 years BP to after 7,640-7,430 cal years BP.

Phase III – Final channel fill: core B2

The active sand barrier system has been the focus of several studies, however the studies performed by Dillenburg et al., (2000, 2004, 2006, 2013) and Dillenburg and Hesp (2009) are emphasized here. In the Bojuru region, near to the core sites B2 and Bo, the sand barrier is classified as a retrogradational/transgressive model submitted to a long-term erosional trend (Dillenburg, 2004; Dillenburg and Hesp, 2009). According to these researchers, it was formed approximately 7,000 ^{14}C yr BP. The sea-level fell up to 2 m after 5,500 cal years BP and the barrier was subjected to long-term erosion caused by high wave energy. The coastal barrier receded approximately 2 km, and large amounts of sand were transported landwards (Dillenburg et al., 2004). The outcropping of lagoonal muds and peats on the backshore recorded by Dillenburg et al. (2000) is indicative of a long-term erosional trend in this sector of the southern Brazilian coast, suggesting the seaward position of the Bojuru sand barrier after the Holocene maximum. Lagoonal-estuarine deposits were accumulated at the rear of the barrier in an interbarrier depression and the macrofaunistic association of *Anomalocardia brasiliensis*, *Tagelus plebeus*, *Bulla striata*, *Olivella* sp., *Heleobia* sp., and *Pittar* sp.,it has radiocarbon dates of 3,220 and 3,370 cal years BP, which were recorded by Dillenburg et al. (2004).

Relative sea-level curves for the middle/late Holocene were proposed for distinct sectors of Brazilian coast (Corrêa, 1996; Angulo and Lessa, 1997; Angulo et al., 1999, 2006; Martin et al., 2003). Most evidence suggested that from the onset of the Holocene, the relative sea-level rose rapidly until ca 7,000 years BP, when it reached the current level. A Holocene barrier-lagoon is responsible to progressive closure of Patos Lagoon. Between 5,000 - 6,000 yr BP, the sea-level was positioned 5 - 6m above the present level (Corrêa, 1996). Afterwards, the sea-level progressively fell until returning to the current position (Corrêa, 1996). According to Medeanic and Corrêa (2010), the presence of scolecodonts and a great number of fungal palynomorphs indicated a decrease in the water level of the southern Brazilian coastal lagoons during marine regressive stages. The decrease in pollen and spores may have been related to lower temperatures and dry climate as a result of the end of the marine transgression at 4,940 ± 80 ^{14}C yr BP. Two negative sea-level fluctuations were recorded during the intervals of 4,000-3,500 yr BP and 2,300-2,000 yr BP.

After the flooding maximum an abrupt shift from marine muddy deposition to sand-dominated deposition was observed in the upper part of the core B2 (DZ X). Our results suggest the high contribution of freshwater flora observed in the upper part of core B2 represented by the dominance of *Pinnularia* sp.1 (ranging from 80 to 62 %) and *Eunotia* sp., followed by other minor freshwater species. Marine assemblages are also recorded in the upper part of core B2. *P. sulcata* is considered abundant (ranging from 50 to 20 %), followed by other marine species indicating a marine influence.

Toldo Jr. et al., (1991) described the presence of a acrofaunistic association present in five cores collected in the north region of Patos Lagoon, with ages ranging from 2,080-2,450 ^{14}C yr BP. This marine/marine-brackish assemblage deposition was composed of *Macra isabelleana*, *Erodona mactroides* and *Heleobia australis*, indicating an estuarine environment with high marine influence. The researches have been attributed the marine influence to the Barra Falsa channel. However, a palynological study performed by Cordeiro and Lorsheitter (1994) from one shallow core of 2.26 m length obtained in the northern part of the lagoon suggest no evidence of marine transgression after 4,000 yr BP, when a gradual decrease in marine components is recorded from the base to the top of core T25. According to these authors, it contradicts the results of Toldo Jr. et al., (1991) who recorded a marine influence in core obtained on the northern and mid-portions of the lagoon from microfossil association and the close relationship with incised-channels. However, Santos (2015) has analyzed two cores from Toldo Jr. et al., (1991) which both reveal a strong marine influence at around 2400 – 2150 yr BP (T19 and T15). Most marine and marine-brackish assemblages present in both core T15 and T19 were similar to the diatom assemblages identified in nine stratigraphic cores analyzed, contradicting the results of Cordeiro and Lorsheitter (1994). The traditional application of hydrofluoric acid (HF) in the extraction of palynomorphs from sediments is widely used to elimination of silica materials. In order to preserve siliceous organisms remains from palynomorph analysis, such as silicoflagellate and diatoms from coastal sediments, the use of HF was avoided in many studies performed in the southern Brazilian coast (Medeanic and Dillenburg, 2001; Medeanic et al., 2001, 2003, 2008, 2009, 2010; Weschenfelder et al., 2008 a; Medeanic and Corrêa, 2010; Corrêa et al., 2013).

The use of HF in the extraction of palynomorphs from sediments of Patos Lagoon by Cordeiro and Lorsheitter (1994) may have affected the global paleoenvironmental scenario. The strong marine influence observed by Toldo Jr., (1991) in the northeast area of Patos Lagoon is also related to the Jacuí incised-valley systems (Baitelli, 2012; Weschenfelder et al., 2014; Santos, 2015). Marine-estuarine macrofaunistic associations recorded by Toldo et al. (1991) (in the north part of the lagoon) and Dillenburg et al. (2004) (in the south part of the lagoon) and the diatom analyses performed in core T19, T15, B2 and Bo showed strong paleontological evidence of the marine environment established in the estuarine-paleolagoon at the interval of 3,370 cal years BP to at least 2,150 yr BP.

The modern coastal configuration displays a large lagoon system, with a fresh to oligohaline water regime, enclosed by a large barrier system that occupies the entire length of its coast. In this context, only the Rio Grande channel is responsible for water exchanges with the Atlantic Ocean. DCA results show a clear division among fossil assemblages and modern communities in ordination space, with surface samples completely isolated from those of core sites (see Fig. 8). Planktonic forms are dominant (60 %), usually correlated with sand sediments (65 %). Fossil assemblages have analogues in the modern configuration of Patos Lagoon. Modern communities are characterized by high abundance of *C. litoralis*, followed by *A. normanii*, *A. veraluciae*, *Aulacoseira* sp and *P. sulcata*. The brackish diatom *A. normanii* and the marine/marine-brackish taxon *C. litoralis* are considered rare in both cores B2 and Bo. The marine taxa *P. sulcata* is uncommon to abundant in modern sediments (ranging from 4.6 to 12 %), in contrast with fossil associations where it is dominant. The freshwater taxa *A. veraluciae* and *Aulacoseira* sp.2 are not recorded in fossil sequences related to the Camaquã River (B2, Bo), because they are closely linked to Jacuí River during Late Pleistocene (Santos, 2015). The absence of *Aulacoseira* species in sediments of core B2 and Bo, suggest that the Barra Falsa channel and other incised-valleys acted as geographic barrier isolating distinct diatom assemblages during the Holocene.

High-resolution seismic records obtained in the Patos Lagoon inlet (Rio Grande channel) by Corrêa et al. (2004) displayed transgressive and regressive structures commonly associated with coastal barriers, beach ridges and foredune-ridges. Three seismic units were recognized throughout the 18-m-thick sediments. Unit I, at the base of the sequence, displayed seismic surfaces probably related to the Pleistocene. Unit II corresponded to the Hummocky clinoforms reflective model, which is related to the deposition of a shallow environment building in a wave-dominated and tide-dominated process. A muddy deposition in a low energy environment was related to the last regressive event of the late Holocene (Unit III). The mapping of the barrier structures helped to understand the evolution and migration of the modern lagoon inlet. However, seismic data do not show structures of incised valleys and buried paleochannels as shown by Weschenfelder et al. (2008 a,b; 2010 a,b; 2014), suggesting that the Rio Grande channel is a modern inlet. Also, several coastal lagoons and lakes became separated from the ocean during the final stages of the Holocene regression in South America (Iriondo and Garcia, 1993; García-Rodríguez et al., 2004 a,b; Bracco et al., 2005; del Puerto et al., 2006; García-Rodríguez, 2012).

6. CONCLUSIONS

High-resolution seismic records, core data sets and diatom paleoecology enhance the knowledge of Holocene stratigraphy and evolution of the Southern Brazilian coast. Because channel incision is part of landscape evolution and inlets have a fundamental importance in coastal systems by virtue of sand barrier maintenance and development. Holocene sea-level oscillations and its impact on coastal environments provide an excellent framework to understand changes in the evolution of wave-dominated coasts worldwide. The strong linkage between the origin of coastal plain incised-valley systems and their subsequent back-filling during base-level fluctuations was highlighted.

In the setting considered in this study, we show that diatom analysis combined with seismic records provided consistent evidence of the main environmental changes that this coast was submitted to during the Holocene. Our results provided simple and consistent outcomes and insights about the lagoon-environment hydrodynamic conditions during the Holocene. The Holocene is typified by a stronger influence of marine deposition related to the maintenance of distinct inlets through the lagoon; in contrast, in the actual configuration only one modern channel is responsible for water exchanges with the open ocean. The prominent incised-channel can be related to the modern geomorphologic feature Barra Falsa. This fluvial incision was active during the maximum lowstand of the Late Pleistocene and progressively filled during the subsequent Holocene transgression. The Barra Falsa channel behaved as an inlet submitted to successive openings and closures until the complete drowning coast.

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8. REFERENCES

Abreu, J.G.N., Calliari, L.J. 2005. Paleocanais da plataforma continental interna do Rio Grande do Sul: evidências de drenagem fluvial pretérita. Revista Brasileira de Geofísica, 23(2): 123-132.

Andrade Neto, J.S., Rigon, L.T., Toldo Jr., E.E., Schettini, C.A.F., 2012. Descarga sólida em suspensão do sistema fluvial do Guaíba, RS, e sua variabilidade temporal. Pesquisas em Geociências, 39: 161- 171.

Angulo, R.J., Giannini, P.C.F., Suguio, K., Pessenda, L.C.R., 1999. Relative sea-level changes in the last 5500 years in southern Brazil, Laguna–Imbituba region, Santa Catarina State based on vermetid ^{14}C ages. Marine Geology, 159: 323-339.

Angulo, R.J., Lessa, G.C., 1997. The Brazilian sea-level curves: a critical review with emphasis on the curves from the Paranaguá and Cananeia regions. Marine Geology, 140: 141-166.

Angulo, R.J., Lessa, G.M., Souza, M.C., 2006. A critical review of mid- to late-Holocene sea-level fluctuations on the eastern Brazilian coastline. Quaternary Science Review, 25: 486-506.

Baitelli, R., 2012. Evolução Paleogeográfica do Sistema de Paleodrenagem do Rio Jacuí na Planície Costeira do Rio Grande do Sul (PhD Thesis) Universidade Federal do Rio Grande do Sul, Brasil. http://hdl.handle.net/10183/56850.

Blum M., Martin J., Milliken K., Garvin M., 2013. Paleovalley systems: Insights form Quaternary analogs and experiments. Earth-Science Reviews, 116: 128-169.

Blum, M.D., Törnqvist, T.E., 2000. Fluvial responses to climate and sea-level change: A review and look forward. Sedimentology, 47(1): 2-48.

Bracco, R., Inda, H., Del Puerto, L., Castiñeira, C., Sprechmann, P., García-Rodríguez, F., 2005. Relationships between Holocene sea-level variation, trophic development and climate change in Negra Lagoon, southern Uruguay. Journal of Paleolimnology, 33: 252-262.

Calliari,L.J., Winterwerp, J.C., Fernandes, E., Cuchiara, D., Vinzon, S.B., Sperle, M, Holland, K.T. 2009. Fine grain sediment transport and deposition in the Patos Lagoon-Cassino beach sedimentary system. Continental Shelf Research, 29(3): 515-529.

Catuneanu, O., et al., 2009. Towards the standardization of sequence stratigraphy. Earth-Science Reviews, 92: 1-33.

Cheng, H., Edwards, R.L., Broecker, W.S., Denton, G.H., Kong, X., Wang, Y., Zhang, R., Wang, X., 2009. Ice age terminations. Science, 326: 248–252.

Cooper, J.A., Green, A.N., Wright, I.N., 2012. Evolution of and incised valley coastal plain estuary under low sediment supply: a ‘give-up’ estuary. Sedimentology, 59 (3): 899-916.

Cordeiro, S.L., Lorscheitter, M.L., 1994. Palynology of Lagoa dos Patos sediments, Rio Grande do Sul, Brazil. Journal of Paleolimnology, 10(1) : 35-42.

Corrêa, I.C.S., 1996. Les variations du niveaux de la mer durant les-erniers 17.500 ans BP: l’example de la plate-forme continentale du Rio Grande do Sul-Brasil. Marine Geology, 130: 163-178.

Correâ, I.C.S., Aliotta, S., Weschenfelder, J. 2004. Estrutura e evolução dos cordões arenosos pleistocênicos no canal de acesso à Laguna dos Patos, Brasil. Pesquisas em Geociências, 31(2): 69-78.

Corrêa, I. C.S., Medeanic, S., Weschenfelder, J., Toldo Jr. E.E., Nunes, J.C., Baitelli, R., 2014a. The palaeo-drainage of the La Plata River in southern Brazil continental shelf. Revista Brasileira de Geofísica, 32 (2): 259-271.

Corrêa, I. C.S., Medeanic, S., Weschenfelder, J., Toldo Jr. E.E., Nunes, J.C., Baitelli, R., Santos, C. B. dos., 2013. Registro sedimentario del antiguo canal de desembocadura del Río de La Plata en la plataforma continental del sur de Brasil. Revista Mexicana de Ciencias Geológicas, 30(1): 51-64.

Corrêa, I.C.S., Toldo Jr, E.E., 1998. The Sea-level Stabilization in The Rio Grande do Sul Continental Shelf, Brazil. Anais da Academia Brasileira de Ciências, 70 (2): 213-219.

Corrêa, I.C.S., Weschenfelder, J., Toldo Jr., E.E., Baitelli, R., Santos, C.B.dos., 2014b. Turfa na plataforma continental do Sul do Brasil. Comunicações Geológicas, 101: 721-724.

Cruz, F.W., Burns, S.J., Jercinovic, M., Karmann, I., Sharp, W.D.,Vuille, M., 2007. Evidence of rainfall variations in southern Brazil from trace element ratios (Mg/Ca and Sr/Ca) in a late Pleistocene stalagmite, Geochimica et Cosmochimica Acta, 71: 2250– 2263.

Culver, J.S., Farrell, K.M., Mallinson, J.D., Horton, B.P., Willard, D.A., Thieler, E.R., Riggs, S.R., Snyder, S.W., Wehmiller, J.F., Bernhardt, C.E., Hillier, C., 2008. Micropaleontologic record of late Pliocene and Quaternary paleoenvironments in the northern Albermarle Embayment, North Carolina, USA. Palaeogeography, Palaeoclimatology, Palaeoecology, 264: 54-77.

del Puerto, L, García-Rodríguez, F., Inda H., Bracco, R., Castiñeira, C., J.B., Adams, J.B., 2006. Paleolimnological evidence of Holocene paleoclimatic changes in Lake Blanca, southern Uruguay, Journal of Paleolimnology, 36: 151-163.

Dalrymple, R.W., Boyd, R., Zaitlin, B.A. (eds.), 1994. Incised-Valley Systems: Origin and Sedimentary Sequences. Society for Sedimentary Geology Special Publication 51, Tulsa, Oklahoma.

Dalrymple, R.W., Leckie, D.A., Tillman, R. (eds.), 2006. Incised valleys in Time and Space. Society for Sedimentary Geology Special Publication, 85, Tulsa, Oklahoma.

Dillenburg, S.R., Barboza, E.G., Tomazelli, L.J., Rosa, M. L.C.C., Maciel, G.S., 2013. Aeolian deposition and barrier stratigraphy of the transition region between a regressive and transgressive barrier: an example from southern Brazil. Journal of Coastal Research, 65: 464-469.

Dillenburg, S.R., Hesp, P.A. (eds.), 2009. Geology and Geomorphology of Holocene Coastal Barriers of Brazil. Lectures Notes in Earth Sciences, Springer, Berlin, 390p.

Dillenburg, S.R., Roy, P.S., Cowell, P.J., Tomazelli, L.J., 2000. Influence of antecedent topography on coastal evolution as tested by the shoreface translation-barrier model (STM). Journal Coastal Research, 16: 71-81.

Dillenburg, S.R., Tomazelli, L.J., Barboza, E.G., 2004. Barrier evolution and placer formation at Bujuru southern Brazil. Marine Geology, 203: 43-56.

Dillenburg, S.R., Tomazelli, L.J., Hesp, P.A., Barbosa, E.G., Clerot, L.C.P., Silva, D.B., 2006. Stratigraphy and evolution of a prograded, transgressive dunefield barrier in southern Brazil. Journal of Coastal Research, SI 39(1): 132-135.

Escandell, A., Espinosa, M.A. (eds.), 2012. Evolución paleoambiental de estuarios mesomareales de Patagonia. Editorial académica española, 83 p.

Escandell, A., Espinosa, M.A., Isla, F.I., 2009. Diatomeas como indicadoras de variaciones de salinidad durante el Holoceno tardío en el río Negro, Patagonia Norte, Argentina. Ameghiniana, 46: 461–468.

Espinosa M.A. 1988. Paleoecologia de diatomeas del estuario del Rio Quequén (Prov. de Buenos Aires, Argentina). Thalassas, 6: 33–44.

Espinosa M.A. 1994. Diatom paleoecology of the Mar Chiquita lagoon delta, Argentina. Journal of Paleolimnology, 10:17–23.

Espinosa M.A. 2001. Reconstruccíon de paleoambientes holocenos de la costa de Miramar. (provincia de Buenos Aires, Argentina) basada en diatomeas. Ameghiniana, 38: 27–34.

Espinosa, M.A., 2008. Diatoms of Patagonia and Tierra del Fuego. In: Rabassa, J. (ed.). Late Cenozoic of Patagonia and Tierra del Fuego. Developments in Quaternary Sciences, 11: 383–392.

Espinosa, M.A., De Francesco, C.G., Isla, F.I., 2003. Paleoenvironmental reconstruction of Holocene coastal deposits from the southeastern Buenos Aires province, Argentina. Journal of Paleolimnology, 29: 49-60.

Espinosa, M.A., Hassan, G., Isla, F., 2012. Diatom-inferred salinity changes in relation to Holocene sea-level fluctuations in estuarine environments of Argentina. Alcheringa: An Australasian Journal of Palaeontology, 36: 373-386.

Espinosa, M.A., Isla, F., 2011. Diatom and sedimentary record during the Mid-Holocene evolution of the San Blas estuarine complex, Northern Patagonia, Argentina. Ameghiniana, 48 (4): 411-423.

Fayó, R., Espinosa, M.A., 2014. Reconstrucción paleoambiental de la Planicie Costera de Mar Chiquita (Provincia de Buenos Aires, Argentina) Durante el Holoceno, Basada em Diatomeas. Ameghiniana, 51 (6): 510-528.

Féniès, H., Lericolais, G., Posamentier, H.W., 2010. – Comparison of wave- and tide-dominated incised valleys: specific processes controlling systems tract architecture and reservoir geometry, In : Chaumillon, E., Tessier, B., Reynaud, J.W.(eds.). French incised valleys and estuaries. – Bulletin de la Société géologique de France, 181(2): 171-181.

Ferrer, P., Benabdellouahed, M., Certain, R., Tessier, B., Barusseau, J-P., Bouchette, F., 2010. The Late Holocene sediment infilling and beach barrier dynamics of the Thau Lagoon (Gulf of Lions, Mediterranean Sea, SE France). Bulletin de la Socièté Geologique de France, 181(2) : 197-209.

Fisher, J.J., 1962. Geomorphic Expression of Former Inlets along the Outer Banks of North Carolina. Unpublished M.S. Thesis, University of North Carolina, Chapel Hill, North Carolina, 120p.

Garcia, C.A.E., 1997. Hydrographic Characteristics. In: Seeliger, U., Odebrecht, C., Castello, J.P. (eds.). Subtropical Convergence Environments - The Coast and Sea in the Southwestern Atlantic. Springer Verlag, 18-20.

García-Rodríguez, F., 2006. Inferring paleosalinity changes using the chrysophyte cyst to diatom ratio in coastal shallow temperate/subtropical lagoons influenced by sea-level changes, Journal of Paleolimnology, 36:165-173.

García-Rodríguez, F., 2012. South America, Holocene Coastal Lagoons. In: Fairbridge, R.W., Herschy, R.W. (eds.), Encyclopedia of Lakes and Reservoirs, Geology, Hydrology and Paleolimnology. Springer Verlag, Berlin, 723-724.

García-Rodríguez, F., Del Puerto, L., Inda, H., Castiñeira, C., Bracco, R., Sprechmann, P., Scharf, B., 2001. Preliminary paleolimnological study of Rocha lagoon, SE Uruguay. Limnologica, 31: 221-228.

García-Rodríguez, F., Metzeltin, D., Sprechmann, P., Trettin, R., Stams, G., Beltrán-Morales, L.F., 2004a. Upper Pleistocene and Holocene paleosalinity and trophic state changes in relation to sea-level variation in Rocha Lagoon, southern Uruguay. Journal of Paleolimnology, 32: 117-135.

García-Rodríguez, F., Sprechmann, P., Metzeltin, D., Scafati, L., Melendi, D.L., Volkheimer, W., Mazzeo, N., Hiller, A., Von Tümpling Jr., W. Scasso, F., 2004b. Holocene trophic state changes in relation to sea-level variation in Lake Blanca, SE Uruguay. Journal of Paleolimnology, 31: 99-115.

García-Rodríguez, F.,Witkowski, A., 2003. Inferring sea-level variation from relative percentages of *Pseudopodosira kosugii* in Rocha lagoon, SE Uruguay. Diatom Research, 18: 49-59.

Gibling M.R., Fielding C.R., Sinha R. 2011. Alluvial valleys and alluvial sequences: towards a geomorphic assessment. In: Davidson, S., Leleu, S., North, C. (eds.). From River to Rock Record: The Preservation of Fluvial Sediments and Their Subsequent Interpretation, SEPM Special Publication, 97: 423-447.

Hammer, O., Harper, D.A.T., Rian, P.D., 2001. Past: Palaeonthological statistics software package for education and data analysis. Version. 1.37.

Harvey, N., 2006. Holocene coastal evolution: Barriers, beach ridges and tidal flats of the South Australia. Journal of Coastal Research, 22: 90-99.

Hassan, G.S., Espinosa, M.A., Isla, F.I., 2011. Fluctuaciones de salinidad durante el holoceno en la laguna costera de Mar Chiquita (Provincia de Buenos Aires): una aproximación cuantitativa basada en diatomeas. Ameghiniana, 48: 496–507.

Hermany, G., Souza, P.A., Torgan, L.C., 2013. Paleoecologia do sistema Pinguela-Palmital-Malvas, Holoceno da Bacia de Pelotas, RS, Brasil: uma abordagem focada na utilização de análises multivariadas para obtenção de diatomáceas descritoras. Pesquisas em Geociências, 40 (1): 31-49.

Iriarte, J., 2006. Vegetation and climate change since 14,810 C-14 yr BP in southeastern Uruguay and implications for the rise of early Formative societies. Quaternary Research, 65: 20-32.

Iriondo, M.H., Garcia, N.O., 1993. Climatic variations in the Argentina plains during the last 18.000 years. Palaeogeography, Palaeoclimatology, Palaeoecology, 101: 209-220.

Juggins, S., 2003. C2 software for ecological and palaeoecological data analysis and visualization, version 1.5. Newcastle University, Newcastle.

Krohling, D.M., Iriondo, M.H., 1999. Upper Quaternary palaeoclimates of the Mar Chiquita area, North Pampa, Argentina. Quaternary International, 57/58: 149-163.

LeGrande, A.N., Schmidt, G.A., 2008. Ensemble, water isotope-enabled, coupled general circulation modeling insights into the 8.2 ka event: Paleoceanography, 23, doi: 10.1029/2008PA001610.

Leinz, V., 1948. A fossa do Camaquã no Passo do Mendonça, R.G.S. Mineração e Metalurgia, 73(13): 21-22.

Mallinson, D., Riggs, S.R., Thieler, E.R., Foster, D.S., Culver, S.J., Corbett, D.R., Farrell, K.,Wehmiller, J.F., 2005. Late Neogene evolution of the northeastern North Carolina coastal system: filling the Albemarle Embayment. Marine Geology, 217: 97-117.

Mallinson, D.J., Riggs, S.R., Culver, S.J., Ames, D.V., Walsh, J.P., Smith, C.W. (eds.), 2008. Past, Present and Future Inlets of the Outer Banks Barrier Islands, North Carolina. East Carolina University Printing Press, Greenville, NC. 28 p.

Marques, W. C., O.O. Möller, 2009.Variabilidade temporal em longo período da descarga fluvial e níveis de água da Lagoa dos Patos, Rio Grande do Sul, Brasil, Revista Brasileira de Recursos Hídricos, 13: 155–163.

Martin, L., Dominguez, J.M.L., Bittencourt, A.C.S.P., 2003. Fluctuating Holocene sea-levels in Eastern and Southeastern Brazil: evidence from multiple fossil and geometric indicators. Journal of Coastal Research, 19: 101-124.

Medeanic, S., 2006. Freshwater algal palynomorph records from the Holocene deposits in the coastal plain of Rio Grande do Sul. Review of Palaeobotany and Palynology, 141: 83-101.

Medeanic, S., Corrêa I.C.S., 2010. Climatic changes in the coastal plain of the Rio Grande do Sul state in the Holocene: palynomorph evidences. Pan-American Journal of Aquatic Sciences, 5: 287-297.

Medeanic, S., Corrêa, I.C.S., Weschenfelder, J., 2008. Resultados preliminares sobre as diatomáceas dos sedimentos superficiais do fundo da Laguna dos Patos. Gravel, 6 (1): 15-25.

Medeanic, S., Dillenburg, S.R., 2001. The Early Holocene palaeoenvironment history of the Tramandaí Lagoon (RS, Brazil). In: V Reunião do Quaternário Ibérico, I Congresso do Quaternário de Paises de Línguas Ibéricas 6, Actas, Lisboa, Portugal, 402-405.

Medeanic, S., Dillenburg, S.R., Toldo Jr, E.E., 2001. Novos dados palinológicos da transgressão marinha pós-glacial em sedimentos da Laguna dos Patos. Revista Universidade Guarulhos, 6: 64-76.

Medeanic, S., Hirata, F., Dillenburg, S.R., 2010. Algal Palynomorphs Response to Environmental Changes in the Tramandai Lagoon, Southern Brazil, and Climatic Oscillations in the 20th Century. Journal of Coastal Research, 26: 726-735.

Medeanic, S., Jankovská, V., Dillenburg, S.R., 2003. The implications of green algae (Chlorophyta) for palaeoecological reconstruction of the Holocene lagoon system in the Tramandai Lagoon region, Rio Grande do Sul, Brazil. Acta Palaeobotanica, 43: 113-123.

Medeanic, S., Toigo-Marques, M., Ashraf, A.R., 2000. The use of fossil algae for the palaeoenvironment reconstruction during the Late Holocene in the Maquiné River Valley, RS, Brazil. Revista da Universidade de Guarulhos, Geociências (Special publication), 168-172.

Medeanic, S., Torgan, L.C., Clerot, L.C.P., Santos, C.B. dos., 2009. Holocene Marine Transgression in the Coastal Plain of Rio Grande do Sul, Brazil: Palynomorph and Diatom Evidence. Journal of Coastal Research, 25: 224-233.

Miselis, J.L., McNinch, J.E., 2006. Calculating shoreline erosion potential using nearshore stratigraphy and sediment volume: Outer Banks, North Carolina. Journal of Geophysical Research, 111, F02019.

Nguyen, V.L., Ta, T.K.O., Saito, Y., 2010. Early Holocene initiation of the Mekong River delta, Vietnam, and the response to Holocene sea-level changes detected from DT1 core analyses. Sedimentological Geology, 230: 146-155.

Pappas, J. L., Stoermer, E.F., 1996. Quantitative method for determining a representative algal sample count. Journal of Phycology, 32: 693-696.

Raynal, O., Bouchette, F., Certain, R., Sabatier, P., Lofi, J., Seranne, M., Dezileau, L., Briqueu, L., Ferrer, P., Courp, T., 2010. Holocene evolution of a Languedocian Lagoonal environment controlled by inherited coastal morphology (Northern Gulf of Lions, France). Bulletin de la Socièté Geologique de France, 181 (2) : 211-224.

Riggs, S.R., Snyder, S.W., Hine, A.C., Mearns, D.L., 1996. Hard-bottom morphology and relationship to the geologic framework: mid-Atlantic continental shelf. Journal of Sedimentary Research, 66 (4): 830–846.

Sabatier, P., Dezileau, L., Barbier, M., Raynal, O., Lofi, J., Briqueu, L., Condomines, M., Bouchette, F., Certain, R., Van Grafenstein, U., Jorda, C., Blanchemanche, P., 2010. Late-Holocene evolution of coastal lagoon in Gulf of Aigues Mortes (South of France), Bulletin de la Socièté Geologique de France , 181(1): 27-36.

Santos, C.B.dos., 2011. Assembléias de diatomáceas em sedimentos holocênicos no extremo sul do Brazil: reconstruções paleoambientais. Dissertation (Master Degree) 116f. Programa de Pós-graduação em Geociências, Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil.

Santos, C.B. dos., 2015. Paleoecologia de diatomáceas como subsídios para o conhecimento da evolução paleogeográfica da região costeira do Rio Grande do Sul, Brasil. Unpublished PhD Thesis. 221f. Programa de Pós-graduação em Geociências, Universidade Federal do Rio Grande do Sul, Porto Alegre, Brasil.

Schumm, S.A., 1993. River response to base-level change: Implications for sequence stratigraphy. Journal of Geology, 101: 279-294.

Shepard, F.P., 1954. Nomenclature based on sand-silt-clay ratios. Journal of Sedimentary Petrology, 24 (3): 151-158.

Smith, C.W., 2006. Lithologic, Geophysical, and Paleoenvironmental Framework of Relict Inlet Channel-Fill and Adjacent Facies: North Carolina Outer Banks. Unpublished M.S. Thesis, East Carolina University, Greenville, NC, 267 p.

Ta, T.M.O., Nguyen, V.L., Tateishi, M., Kobayashi, I., Saito, Y., 2001. Sedimentary facies, diatom and foraminifer assemblages in a late Pleistocene/Holocene incised-valley sequence from the Mekong River delta, Bentre Province, southern Vietnam: the BT2 core. Journal of Asian Earth Sciences, 20: 83-94.

Tesson, M., Labaune, C. and Gensous, B., 2005. Small rivers contribution to the Quaternary evolution of a Mediterranean littoral system: The western gulf of Lion, France. Marine Geology, 223: 299-311.

Thieler, E.R., Pilkey Jr., O.H., Cleary, W.J., Schwab, W.C., 2001. Modern sedimentation on the shoreface and inner continental shelf at Wrightsville Beach, North Carolina, U.S. A. Journal of Sedimentary Research, 71: 958–970.

Toldo Jr., E.E., Ayup Zouain, R.N., Corrêa, I.C.S., Dillenburg, S.R., 1991. Barra Falsa: Hipótese de um paleocanal holocênico de comunicação entre a Laguna dos Patos e o Oceano Atlântico. Pesquisas, 18 (2): 99-103.

Toldo Jr., E.E., Dillenburg, S.R., Corrêa, I.C.S., Almeida, L.E.S.B., 2000. Holocene Sedimentation in Patos Lagoon Lagoon, Rio Grande do Sul, Brazil. Journal of Coastal Research, 16(3): 816-822.

Tomazelli, L.J.,Villwock, J.A., 2000. O Cenozóico no Rio Grande do Sul: Geologia da Planície Costeira. In: Holz, M., De Ros, L.F., (eds.). Geologia do Rio Grande do Sul. Edição CIGO/UFRGS, Porto Alegre, Rio Grande do Sul, 375-406.

Van Wagoner, J.C., Mitchum, R.M., Campion, K.M., Rahmanian, V.D., 1990. Siliciclastic Sequence Stratigraphy in Well Logs, Cores, and Outcrops: Concepts for High-Resolution Correlation of Time and Facies: American Association of Petroleum Geologists, Methods in exploration series 7.

Vaz, A. C., Möller Jr., O.O., Almeida, T. L. de., 2006. Análise quantitativa da descarga dos rios afluentes da Lagoa dos Patos. Atlântica, 28: 13-23.

Vilanova, I., Prieto, A.R., Epinosa, M.A., 2006. Paleoenvironmental evolution and sea-level fluctuations along the southeastern Pampa grasslands coast of Argentina during the Holocene. Journal of Quaternary Sciences, 21(3): 227-242.

Violante, R.A., Parker, G., 2004. The post-last glacial maximum transgression in the de la Plata River and adjacent inner continental shelf, Argentina. Quaternary International, 114: 167-181.

Villwock, J.A., Tomazelli, L.J., Loss, E.L., Dehnhardt, E.A., Horn Fo., N.O., Bachi, F.A., Dehnhardt, B.A., 1986. Geology of the Rio Grande do Sul Coastal Province. In: Rabasa, J. (ed.), Quaternary of South America and Antarctic Peninsula. Balkema Publishers, Rotterdam, 4-11.

Wanner, H., Beer, J., Bütikofer, J., Crowley, T., Cubasch, U., Flückiger, J., Goosse, H., Grosjean, M., Joos, F., Kaplan, J.O., Küttel, M., Müller, S.A., Prentice, I.C., Solomina, O., Stocker, T.F., Tarasov, P., Wagner, M., Widmann, M., 2008. Mid- to late Holocene climate change: an overview. Quaternary Science Reviews, 27: 1791–1828.

Weschenfelder, J., Baitelli, R., Corrêa, I.C.S., Bortolin, E.C., Santos, C.B.dos., 2014. Quaternary incised valleys in southern Brazil coastal zone. Journal of South American Earth Sciences, 55: 83-93.

Weschenfelder, J., Corrêa, I.C.S., Aliotta, S., Baitelli, R. 2010a. Paleochannels related to late Quaternary sea-level changes in southern Brazil. Brazilian Journal of Oceanography, 58: 35-44.

Weschenfelder, J., Corrêa, I.C.S., Toldo Jr., E.E., Baitelli, R., 2008a. Paleocanais como indicativo de eventos regressivos quaternários no nível do mar no sul do Brasil. Revista Brasileira de Geofísica, 3(26): 367-375.

Weschenfelder, J., Corrêa, I.C.S., Toldo Jr., E.E., Baitelli R., 2010b. A drenagem pretérita do Rio Camaquã na costa do Rio Grande do Sul. Pesquisas em Geociências, 37 (1): 13-23.

Weschenfelder, J., Medeanic, S., Corrêa, I.C.S., Aliotta, S., 2008b. Holocene palaeoenvironment of the Bojuru region, Southern Brazil. Journal of Coastal Research, 24: 99-109.

Zaitlin, B.A., Dalrymple, R.W., Boyd, R., 1994. The stratigraphic organisation of incised valley systems associated with relative sea-level change. In: Dalrymple, R.W., Boyd, R.J., Zaitlin, B.A., (eds.), Incised Valley Systems: Origin and Sedimentary Sequences, Society for Sedimentology Geology (Special Publication) 51: 45-60.

Zhang, G.J., Li, C.X., 1998. Sources of sediments filling the Qiantangjiang-estuary incised valley since last glaciation: Chinese Science Bulletin, 43 (15): 1280-1284.

Zong, Y., Huang, K., Yu, F., Zheng, Z., Switzer, A., Huang, G., Wang, N., Tang, M., 2012. The role of sea-level rise, monsoonal discharge and the palaeo-landscape in the early Holocene evolution of the Pearl River delta, southern China.Quaternary Science Reviews, 54: 77-88.

CAPÍTULO VI

DIATOM ASSEMBLAGES PLAY A KEY ROLE IN DETERMINING THE NATURE OF SEDIMENTARY RECORDS FROM THE SUBTROPICAL SOUTHERN BRAZILIAN COAST

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VI- DIATOM ASSEMBLAGES PLAY A KEY ROLE IN DETERMINING THE NATURE OF SEDIMENTARY RECORDS FROM THE SUBTROPICAL SOUTHERN BRAZILIAN COAST

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1. ABSTRACT

The stratigraphy of southern Brazilian coast is marked by three incised valley systems with erosional surfaces related to two major lowstands, concomitant with Marine Isotope Stages (MIS) 6 and 2. An evolutionary model of two distinct and non-contemporary valleys from a subtropical drainage is proposed. Seismic profiles, core data sets and diatom records are used to determine the nature of infilling. Seismo-depositional units were subdivided into sub-units; these show distinct phases of valley evolution. The basin sedimentation occurred in a marine-dominated embayment environment prior to 43,500 yr BP. A Pleistocene sand barrier is responsible for progressive blockage of the river mouth. An abrupt shift from marine-dominated to estuarine-fluvial deposition is recorded during the Last Glacial Maximum. A sea-level drop of 130 m allowed new incisions in the coastal plain. The main fluvial drainage was not re-incised during MIS 2 and it was shifted to a new connection with Atlantic Ocean, occupying a deep incision ~50 km south of the older incision. The Holocene transgressive postglacial event drowned the Late Pleistocene incisions, infilling the incised valleys with marine and estuarine sediments. The active barrier system became more continuous and a large lagoon developed as result of complete closure by sands from the barrier lagoon, which closed the secondary former inlets. Fossil and modern diatom assemblages are compared by multivariate statistical analysis that suggests changes in diatom composition and spatial distribution. Our results provide insights about coastal evolution and lagoonal hydrodynamic conditions during Late Pleistocene and Holocene, in contrast to the modern configuration.

Keywords: Diatoms, Seismic, Sea-level changes, Late Pleistocene, Patos Lagoon, Incised valleys

2. INTRODUCTION

Incised valley systems are features commonly developed during Late Pleistocene lowstands and back-filled during highstands in response to the sea-level rise (Blum and Törnqvist, 2000; Gibling et al. 2011; Blum et al. 2013). The increase of the high-resolution seismic studies of Late Quaternary stratigraphy and its relationship to sea-level oscillations may have an important bearing on sequence stratigraphic models and concepts (Zaitlin et al.1994; Dalrymple, 2006; Dalrymple et al. 2006; Blum et al. 2013). Studies of the incised valleys and channels in lagoonal systems are essential for understand the influence of sea-level and climate changes related to evolution of wave-dominated coasts (Mallinson et al. 2005; Tesson et al. 2005; Culver et al. 2008; Ferrer et al. 2010; Raynal et al. 2010; Sabatier et al. 2010). Analysis of the seismic stratigraphy of incised valley systems of the southern Brazilian coast has been increasing through the last decade (Abreu and Calliari, 2005; Weschenfelder et al. 2008 a, b, 2010 a, b, 2014; Baitelli, 2012; Corrêa et al. 2013, 2014a). The observed valley architectures have been correlated chronologically with coastal deposits of Pleistocene barrier systems, identified along the coast, related to Marine Isotope Stages (MIS) 7 and 5e (Villwock et al. 1986; Dillenburg et al. 2004). Two erosional surfaces have been associated with the two major lowstands, concomitant with the MIS 6 and 2 (Weschenfelder et al. 2014).

Diatoms are one of the most important biological markers living in terrestrial and marine environments relevant for source-to-sink studies. As a result of the low gradient of coastal plains, Fine-grained and muddy sediments typically infill incised valley systems (Zaitlin et al. 1994). Because diatom assemblages are especially abundant in fine-grained and muddy coastal sediments, paleoecological studies based on diatom inferences play key a role in determining the environment of these deposits (Ta and Nguyen, 2000; Ta et al. 2001, 2002 a, b; Nguyen et al. 2000, 2010; Mallinson et al. 2005; Culver et al. 2008; Tjallingii et al. 2010; Nakanishi et al. 2011; Yoshida et al. 2011; Zong et al. 2012; Santos, 2015). Prior preliminary studies of fossil diatoms in this region investigated a distinct area of the southern Brazilian coastal plain and shelf (Weschenfelder et al. 2008 b, 2014; Corrêa et al. 2013, 2014 a). These studies noted a few diatom taxa that were associated with pollen and ostracoda records; the fossil diatoms were used to infer general changes in salinity along four incised valley systems. Fossil diatom assemblages have rarely been applied to help reconstruct the evolution of the southern Brazilian coast , which strongly contrasts with studies performed in other South America coastal areas, where diatom data often is a major component of the paleoenvironmental reconstructions (Bracco et al. 2005; Espinosa, 1988, 1994, 2001, 2008; Espinosa et al. 2003, 2012; Espinosa and Isla, 2011; Fayó and Espinosa, 2014; García-Rodríguez, 2006, 2012; García-Rodríguez et al. 2001, 2004 a,b; García-Rodríguez and Witkoswki, 2003; Vilanova et al. 2006).

The impact of Quaternary sea-level oscillations on the wave-dominated coast provides an opportunity to explore fluvial and marine inputs interacting within barrier systems. A multidisciplinary approach including seismic records, core data integration and diatom analysis is used to enhance the knowledge of Late Pleistocene and Holocene stratigraphy and evolution of southern Brazilian coast. In this study, abundant diatom taxa are correlated with seismo-depositional units and core data sets to reveal environmental changes, including salinity, fluvial adjustment and active transport by incised valleys. Our results demonstrate that diatom assemblages play key role in determining the nature of these sedimentary records. Fossil and modern diatom taxa are compared by means of common multivariate statistical technique that is widely used in diatom studies. We also provide insights about hydrodynamic conditions of the lagoon during the Late Pleistocene and Holocene through to present day conditions.

3. GEOLOGIC SETTING

3.1. Modern Coastal Configuration

The southern Brazilian coastal plain is wave dominated and characterized by wide lowlands spanning ~33,000 km^2. Four well-defined barrier systems have been preserved along this coast for at least the last 400,000 years (Villwock et al. 1986; Villwock and Tomazelli, 1995; Tomazelli and Villwock, 2000). The active barrier-lagoon system that occupies the 625 km length of this coast and the warm-temperate shallow lagoon are the most remarkable physiographic features in the actual coastal plain. Patos Lagoon is considered the world largest choked lagoon (10,000 km^2; 240 km long). The main axis of the lagoonal system extends over 180 km in a NE–SW direction, including an estuarine area that is 60 km long (Calliari et al. 2009). Both the bottom and margins of the lagoon are influenced by medium- to high-energy waves up to 1.6 m (Toldo Jr. et al. 2000). The astronomical tide is semi-diurnal; near the channel entrance, the mean amplitude is 0.47 m (Garcia, 1997). Patos Lagoon has a huge surface area but only a single inlet, the Rio Grande channel, which exchanges water with the Atlantic Ocean.

Patos Lagoon receives freshwater from the Guaíba River Hydrographic Basin (GHB), which has an area of ~ 200,000 km^2, and is a primary source of freshwater to the lagoon. The main contributing rivers are the Jacuí and Taquari, which flow through the GHB, and the Camaquã River, which flows into the southern region of the lagoon. The Jacuí River basin is 710 km long, draining an area of 71,600 km^2. This basin is characterized by intense land use for agriculture and energy generation (FEPAM, 2010). The Camaquã River basin has a surface of 24,000 km^2 and is currently creating a delta system in the central portion of the western margin of the lagoon. According to Vaz et al. (2006) the mean annual water discharge from the Jacuí River is 801 m^3/s, followed by the Taquari River (452 m^3/s) and the Camaquã River (307 m^3/s). However, the mean annual discharge of freshwater into Patos Lagoon is 2,400m^3/s (Marques and Möller, 2009). A recent study performed in the Guaíba fluvial system suggest that the mean annual suspended solids discharge from GHB towards the lagoon corresponds to 1.1 x 10^6 t/yr, about 400,000 m^3 (2,650 kg/ m^3) of sediments. This corresponds to a yearly sediment supply rate of 0.11 kg/m^2 (Andrade Neto et al. 2012).

4. MATERIALS AND METHODS

4.1. Seismic Surveys

Geophysical data comprises two very high resolution 3.5 kHz seismic reflection profiles conducted in Patos Lagoon, resulting in approximately one thousand kilometers of seismic data (see Weschenfelder et al. 2014). Navigation used a DGPS system linked to a sub-bottom profiler to determine the location and to track the transects. A GeoAcoustics sub-bottom profiler composed of GeoPulse transmitter (5430A), 132B transducer array, GeoPro processor system and the SonarWiz® acquisition software were used. The dataset was saved in digital SEG-Y format. 7 kHz seismic records obtained with a Raytheon shallow seismic system during a previous cruise were also used (see more details in Toldo Jr. et al. 2000). A constant sound velocity in water (1,500 m/s) and sediment (1,650 m/s) were applied for integrating the cores (depth in meters) with the seismic profiles (depth in milliseconds).

4.2. Sampling and Dating

Two stratigraphic cores were collected in order to inspect the subsurface stratigraphy of Patos Lagoon (Fig. 11a-b). Nine surface samples obtained around both cores were used to compare fossil and modern deposition (Fig. 11 c-d), (Table 8, 9). A total of 104 samples were collected for diatom analysis. Fossil mollusc shells were collected and processed to obtain information about the paleoenvironmental conditions and to determine potential carbon reservoir effects for radiocarbon dating. Accelerator mass spectrometry (AMS) dates were obtained by Beta Analytic Inc., Miami, FL, USA (Table 10). The general characteristics and textural classification for both core and surface samples were based on Shepard (1954).

4.3. Diatom Analysis

Diatom sub-samples were treated with an aqueous solution of 10% HCl and 5% KOH. After rinsing with distilled water, diatom extracts were dried onto coverslips and mounted on microscope slides using Naphrax®, which is a permanent mounting resin with a high refractive index. Samples were analyzed with a transmitted light Zeiss® microscope. Relative abundances of fossil diatom assemblages were calculated based upon counts of at least 600 valves and 80 % efficiency sampling based on Pappas and Stoermer (1996). Diatom taxa were then classified according to the following categories based upon relative abundance: dominant: > 50 %, abundant: 5 to 50 %, uncommon: 1 to 5 %, and rare: < 1 %. The results were plotted in biostratigraphic diagrams using the software program C2® (version 1.5; Juggins, 2003).

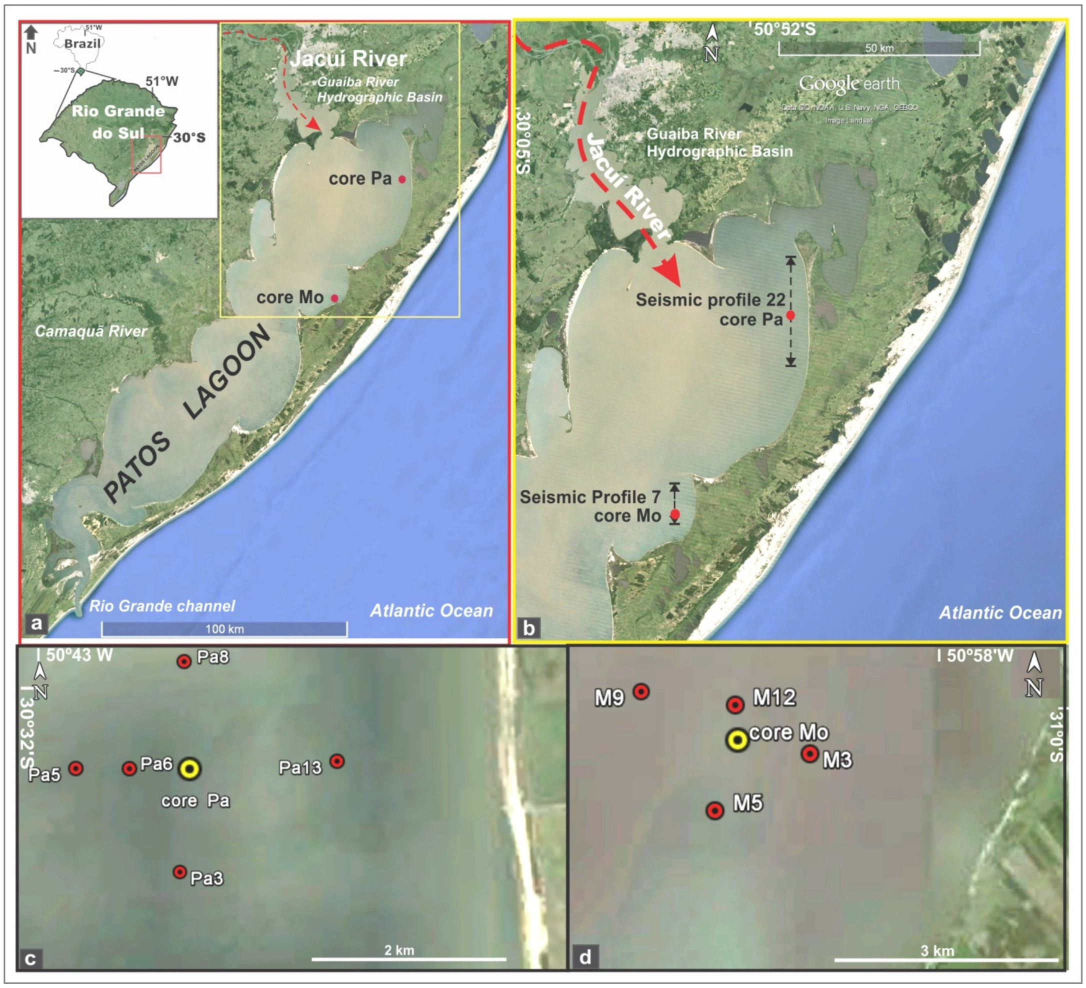

Figure 11. Locality map of southern Brazilian coast detailing the major fluvial drainage from Jacuí River (dashed red arrow) which flows through the Guaíba River Hydrographic Basin (GHB), seismic sections described in the study (dashed black arrows), core sites (a, b) and surface samples analyzed (c, d).

4.4. Statistical Analysis

Multivariate statistical techniques for analyzing ecological data of diatom assemblages were used to identify distribution patterns and composition of diatom taxa across distinct sites in Patos Lagoon interior. Detrended Correspondence Analysis (DCA) using the software program PAST® (version 3.06), (Hammer et al. 2001) was used to analyze fossil and modern assemblages. Fossil and modern diatom taxa were selected based on two criteria: (1) frequency of occurrence in at least one sample; (2) relative abundance greater than 1 %. Monte Carlo significance test indicated that the ordination diagram was significant ($p < 0.05$), validating the adequacy of the statistical method.

5. RESULTS

5.1. Seismic Analysis

Three incised valley systems were associated to the most important drainage systems occurring in the study area. Three main seismic units (S1, S2, S3) were selected on the basis of their acoustic, architecture and sedimentary characteristics according to general terms established by a seismostratigraphic analysis approach (see Baitelli, 2012; Weschenfelder et al. 2014). The systematic mapping of the seismic surfaces allowed the establishment of two well-defined erosional surfaces related to the two major lowstands concomitant with MIS 6 and 2 (sequence boundary S1-S2 and S2-S3).Three stratigraphic cores collected in order to inspect the subsurface stratigraphy and groundtruth the seismic interpretations were related to seismic profiles 22, 7 and 2 from Jacuí and Camaquã Rivers (Weschenfelder et al. 2014). We have analyzed two seismic profiles from Jacuí River (profile 22; core Pa and profile 7; core Mo).

Geophysical data of profile 22 comprise a broad valley with single channels related to Late Pleistocene deposition. This seismic profile extended for over 27 km along the eastern margin of Patos Lagoon. It was obtained in a northwest-to-southeast direction, in water depths of approximately 6 m. The main channel is about 3.5 km wide, and located between 20-30 m below the present water level of Patos Lagoon. Seismic profile 7 is about 10 km long and it was obtained in a north-to-south direction parallel to the eastern border of the lagoon, in water depths of approximately 5 m. The largest valley and buried channels were identified along the seismo-depositional sequence S3. The prominent channel visible in profile 7 was approximately 2 km wide, and the channel fill sediments were at least 20 m thick-in sequence S3.

5.1.1. Late Pleistocene Diatom Stratigraphy of Unit S2: seismic profile 22, core Pa

A total of one hundred and ninety-nine diatom taxa were associated with the Late Pleistocene and Holocene valley fill sediments. Benthic diatoms represent 69% of the total assemblage (Table 11). Marine and marine-brackish taxa were dominant

(83 %) in transgressive sediments. Non-marine assemblages were abundant in sediments related to the high fluvial influence during lowstand. The most abundant diatom taxa were: *P.sulcata* (38 %), *A. splendens* (12 %), *C. belgica* (8 %), *A. senarius* (4.4 %), *T. favus* (2.3 %), *D. minor* (1.6 %), *P. disculoides* (1.6 %), *A. veraluciae* (1.5 %), *Eunotia major* (1.5 %). The rest of the assemblage was classified as uncommon and rare. From the distribution and salinity tolerances of the fossil diatoms it was possible to divide core Pa into five diatom zones (DZ I-V), (Fig. 12, 13). The diatom zones are correlated with five seismic sub-units (Fig. 14).

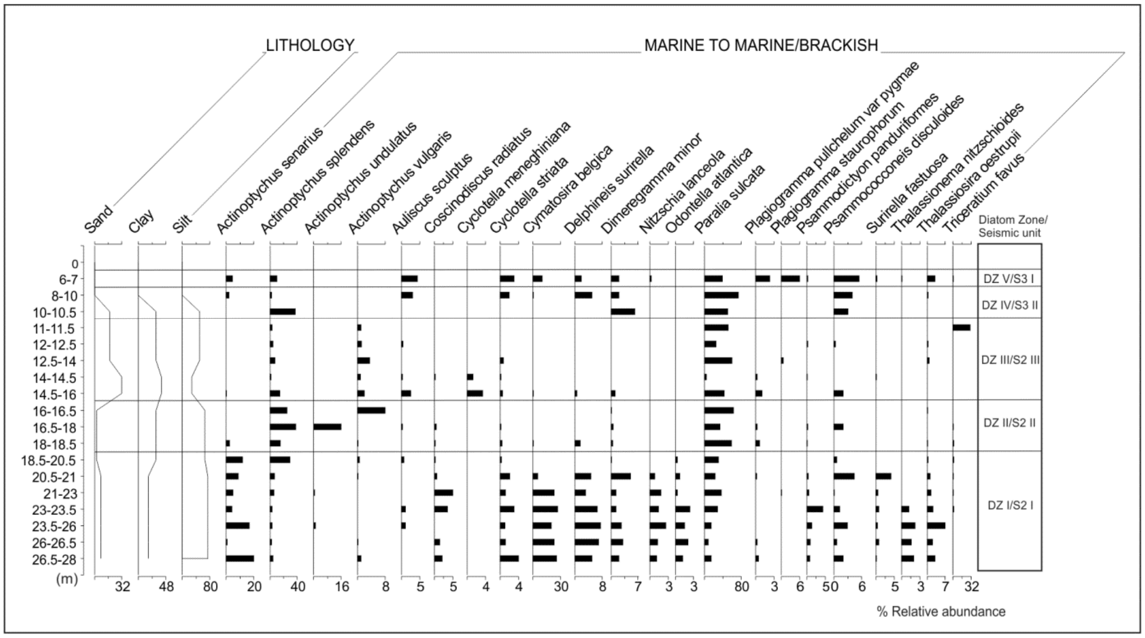

Figure 12. Diatom diagram showing the spatial distribution of the most representative marine and marine-brackish diatom taxa occurring in core Pa. Five diatom zones are recognized (DZ I-V) related with seismic sub-units deposited during Late Pleistocene (S2 I-III) and Late Pleistocene/Holocene (S3 I-II). Diatom zones DZ I-II are related with high marine influence prior to 43,500 yr BP until the LGM. An abrupt shift to estuarine-fluvial deposition is related to decrease of marine influence during MIS 2 (DZ III). Note that the marine taxa *Paralia sulcata* occurs continuously from Late Pleistocene to Holocene. After the LGM, the marine-dominated deposition is reestablished (DZ IV, V).

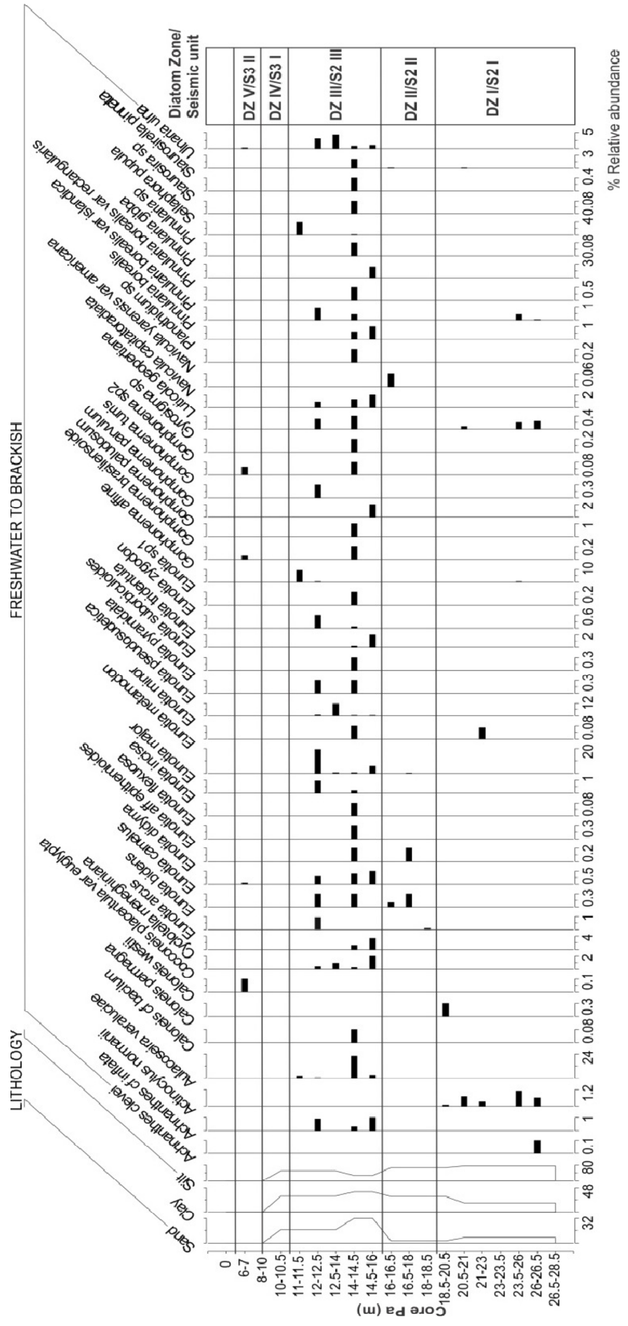

Figure 13. Diatom diagram showing the spatial distribution of non-marine diatom taxa occurring in core Pa. Five diatom zones are defined (DZ I-V). Changes in diatom composition and distribution allowed a correlation between five seismic sub-units deposited during Late Pleistocene (S2 I-III) and Late Pleistocene/Holocene (S3 I-II). Note that non-marine diatom taxa occur almost continuously from samples older than 43,500 yr BP (DZ I/S2 I) to DZ III/S2 III), but in very low density. An abrupt shift to estuarine-fluvial deposition reLated with substantial freshwater influence observed during MIS 2 (DZ III/S2 III). After the LGM, non-marine taxa are absent returning only in DZ V/S3 II).

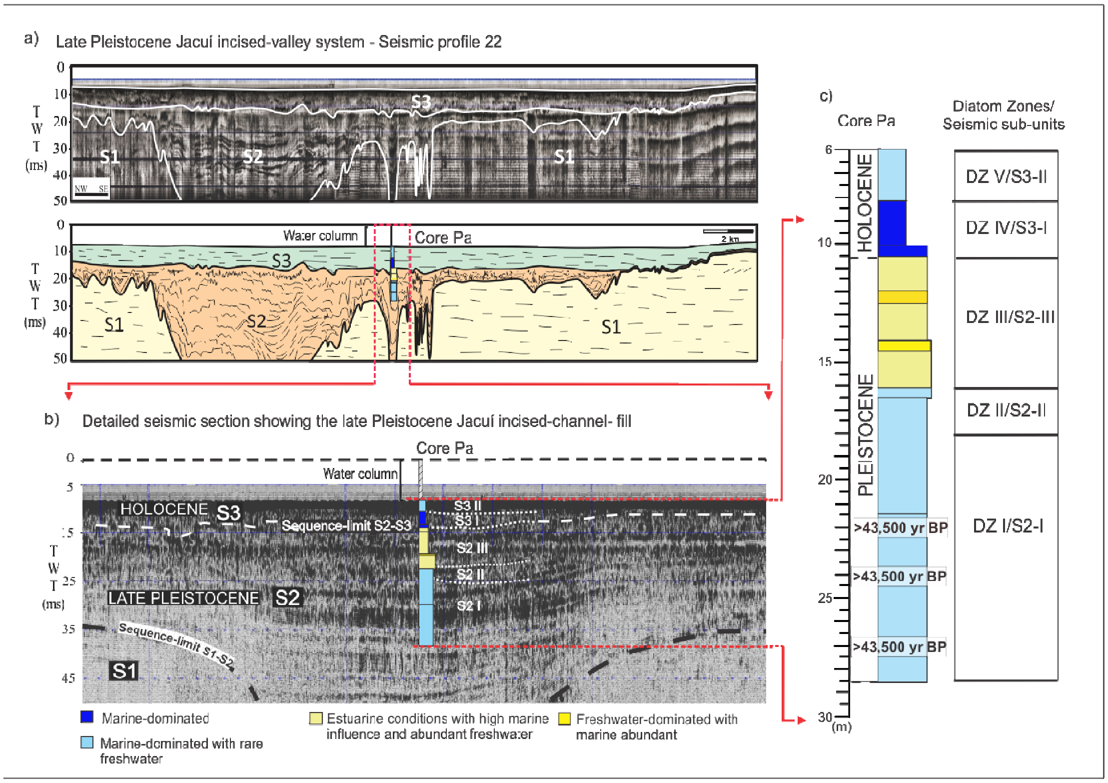

Figure 14. Correlation between core data integration, seismic and diatom records from core Pa (1a-c). Detailed diatom interpretation provides information about nature of valley fill during Late Pleistocene and Holocene. Unit S2 and S3 are subdivided into sub-units (S2 I-III and S3 I-II; white dashed lines) related with distinct diatom zones (DZ I-V), (1b-c). Marine-dominated deposition with rare freshwater is related to S2 I-III in contrast with sub-unit S2-III which has an estuarine-fluvial deposition during MIS 2. Sub-unit S3-I corresponds a drowned coast followed by a marine-dominated with rare non-marine diatom taxa (sub-unit S3-II) deposited during MIS 1. TWT: Two-Way Traveltime in milliseconds (m/s).

5.1.1.1. Diatom zone I, sub-unit S2 I (28.50 -18.5 m)

High frequency and abundance of marine/marine-brackish diatoms (> 94 %) suggests that the basin was a relatively open-marine embayment, strongly influenced by marine waters. The marine taxa *Paralia sulcata* was abundant (31 %), associated with *Actinoptychus splendens* (13.2 %), *Cymatosira belgica* (13 %), *Actinoptychus senarius* (7 %), *Delphineis surirella* (4%) and other minor species typical of marine environments. Non-marine taxa also occurred in very low densities (ranging from 0.04 to 1.2 %), interpreted as allochthonous components occurring from interval of 28.5 to 18.5 m. The brackish planktonic taxa *A. normanii* was the most representative taxon, accompanied by rare diatom taxa including *Achnanthes clevei*, *Caloneis permagna*, *Eunotia metamodon*, *Gyrosigma* sp. and *Pinnularia borealis*. Benthic forms were dominant; in this context the base of the Late Pleistocene sedimentation occurred in a relatively shallow marine-dominated environment with a very minor fluvial contribution.

5.1.1.2. Diatom zone II, sub-unit S2 II (18.5 – 16 m)

Marine assemblages in this unit were dominated by planktonic forms. The most abundant diatom taxa were *P. sulcata* (39 %) and *A. splendens* (29 %) followed by *A. senarius* (6.3 %), *A. undulatus* (5 %) and *A. vulgaris* (5 %) associated with silt and clay (97.43 %). The marine influence was greater than the previously stages of the basin sedimentation however the transport of non-marine diatom taxa was not affected. Freshwater diatom taxa were recorded occurring continuously but in very low densities. They were represented by rare diatoms: *Eunotia arcus*, *E. camelus*, *Eunotia* aff. *epithemioides* and *Navicula capitatoradiata*.

5.1.1.3. Diatom zone III, sub-unit S2-III (16 – 11 m)

Diatom zone III is related to the emergence of non-marine assemblages in an estuarine environment, evidenced by high abundances of *Aulacoseira veraluciae*, *Eunotia major*, *E. minor* and *Eunotia* sp., accompanied by uncommon taxa including *Cocconeis disculoides* var. *euglypta*, *Cyclotella meneghiniana*, *E. subarcuatoides*, *Gomphonema paludosum*, *Luticola geoppertiana*, *Pinnularia borealis* var. *rectangularis*, *Pinnularia* sp. and *Staurosirella martyi*. Rare non-marine species were composed of diatom taxa commonly found in terrestrial environments reached densities greater than 20 % of total assemblages. Two peaks of highest freshwater influence were recorded at intervals of 14.5-14 m and 12.5-12 m. Marine and marine-brackish taxa also occurred. The most abundant diatom was *P. sulcata*, which was associated with the planktonic taxa *A. splendens*, *A. vulgaris*, *T. favus* and *A. sculptus*.

5.1.2. Late Pleistocene/Holocene Diatom Stratigraphy of unit S3: seismic profile 22, core Pa

5.1.2.1. Diatom zone IV (10.5 – 8 m), sub- unit S3-I

Marine deposition was reestablished in this sequence, which is evidenced by the disappearance of brackish and freshwater diatom taxa from the assemblages. The most representative marine and marine-brackish taxa in this sequence were: *P.*

sulcata (54 %), *A. splendens* (16.3 %), *Psammococconeis disculoides* (4.2 %), *C. belgica* (4 %), *D. minor* (3.4 %) and *Auliscus sculptus* (3 %).

5.1.2.2. Diatom zone V (6 – 7 m), sub- unit S3-II

In contrast to sub-unit S2-III, a very minor fluvial influence was observed in the interval between 6 to 7 m. Non-marine assemblages were rare because there was very low diatom abundance in this sequence. This interval is composed of: *E. camelus*, *Gomphonema affine*, *G. turris* and *Ulnaria ulna*, followed by brackish taxa *Caloneis westii*. Some marine influences were still active in the valley; the marine diatom taxa that were most representative of this included: *P. sulcata* (39 %), *C. belgica* (10 %), *P. staurophorum* (6 %), *A. sculptus* (4.5 %), *C. striata* (3 %), *T. oestrupii* (3 %), *Lyrella lyra* (2.4 %), *P. pulchellum* var. *pygmae* (2.3 %).

5.1.3. Late Pleistocene/Holocene Diatom Stratigraphy of unit S3: seismic profile 7, core Mo

The lowest and middle part of the core Mo was composed of fine sand silt and fine sands deposited in the margin of the channel during Pleistocene (Units S1 and part of S2), which had no diatom valves present from the interval between 29.95 to 14 m; this was probably related to the dominance of sand deposition (~93 %). A total of eighty-two diatom taxa were recorded in the core Mo; these were distributed into two diatom zones (DZ I-II) correlated to seismo-depositional unit S3 (Fig. 15-17). Benthic forms were dominant (68 %) and the marine tycoplanktonic taxa *P. sulcata* was dominant and associated with *C. striata* and *A. senarius* which were abundant, followed by other minor species considered uncommon and rare (see Table 11).

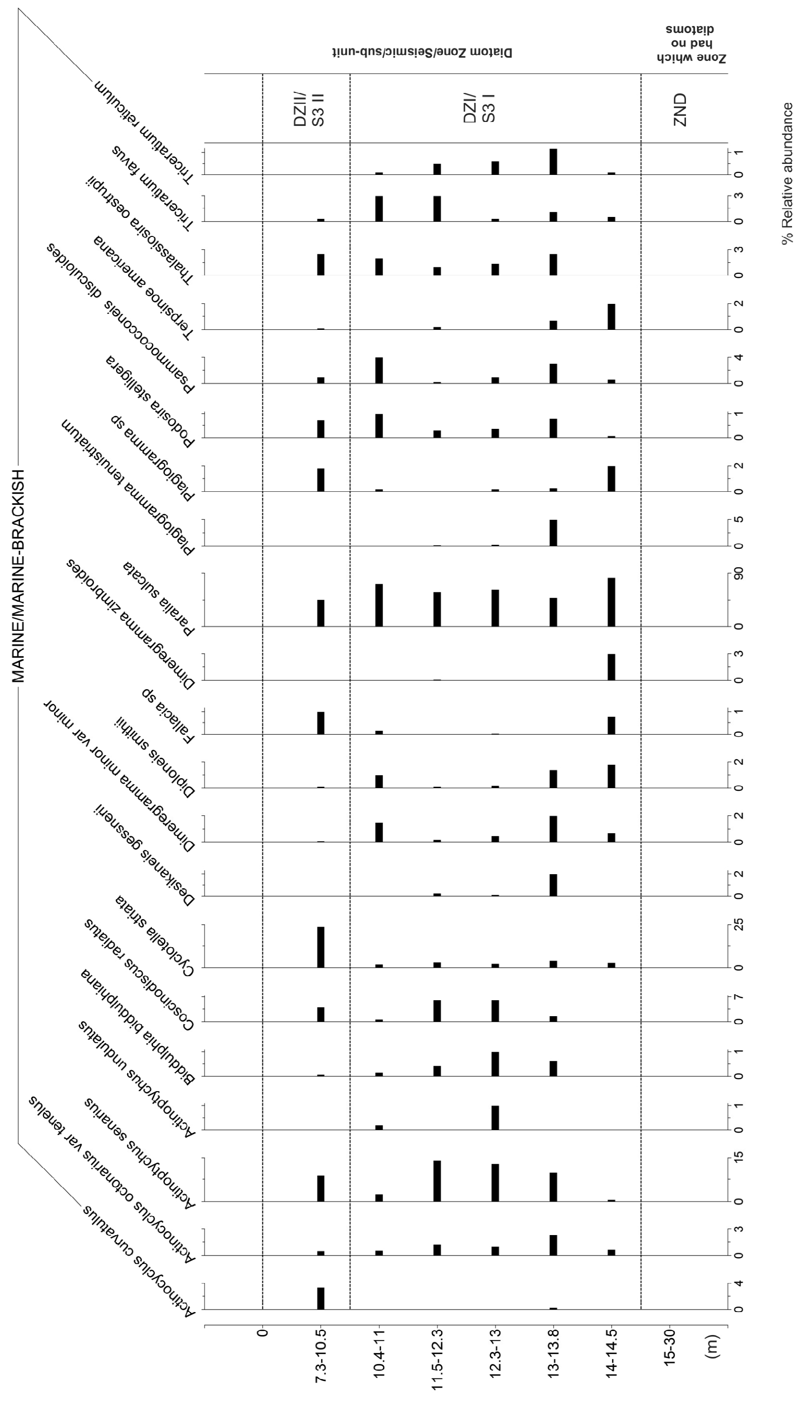

Figure 15. Diatom diagram showing the spatial distribution of the most representative marine and marine-brackish diatom taxa occurring in core Mo. Similarly to core Pa, diatom zones (DZ I-II) are related with seismic sub-units (S3 I-II). One zone which had no diatoms present (ZND) is related with deposition of Pleistocene sands (see Fig. 7). Marine-dominated deposition is recorded in DZ I-II/S3 I-II related with a rapid sea-level rise during Holocene

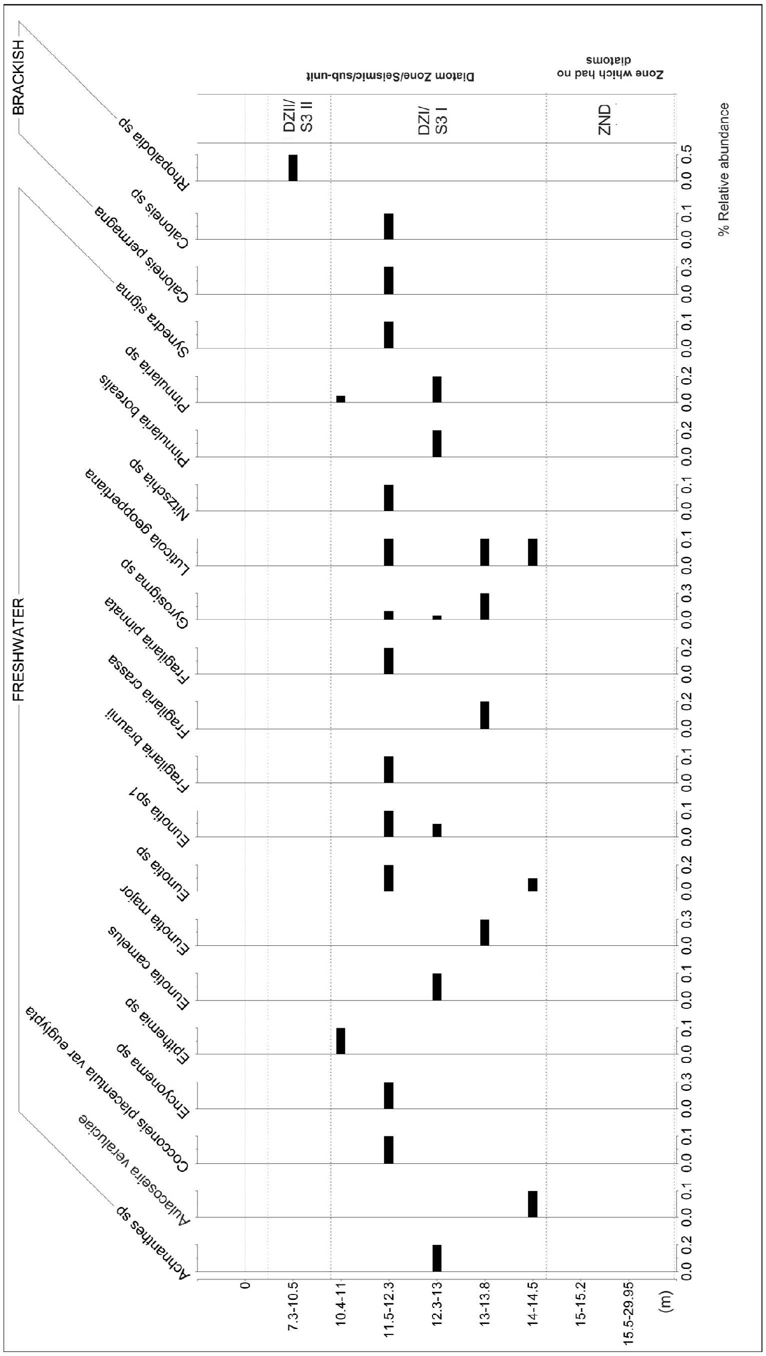

Figure 16. Diatom diagram showing the spatial distribution of non-marine diatom taxa occurring in core Mo. Similarly to core Pa, diatom zones (DZ I- II) are related with seismic sub-units (S3 I-II). One zone which had no diatoms present (ZND) is related with deposition of Pleistocene sands (see Fig. 16). Note that a marine-dominated deposition with rare non-marine taxa is recorded in DZ I/S3 I followed by a zone which freshwater diatom taxa are absent.

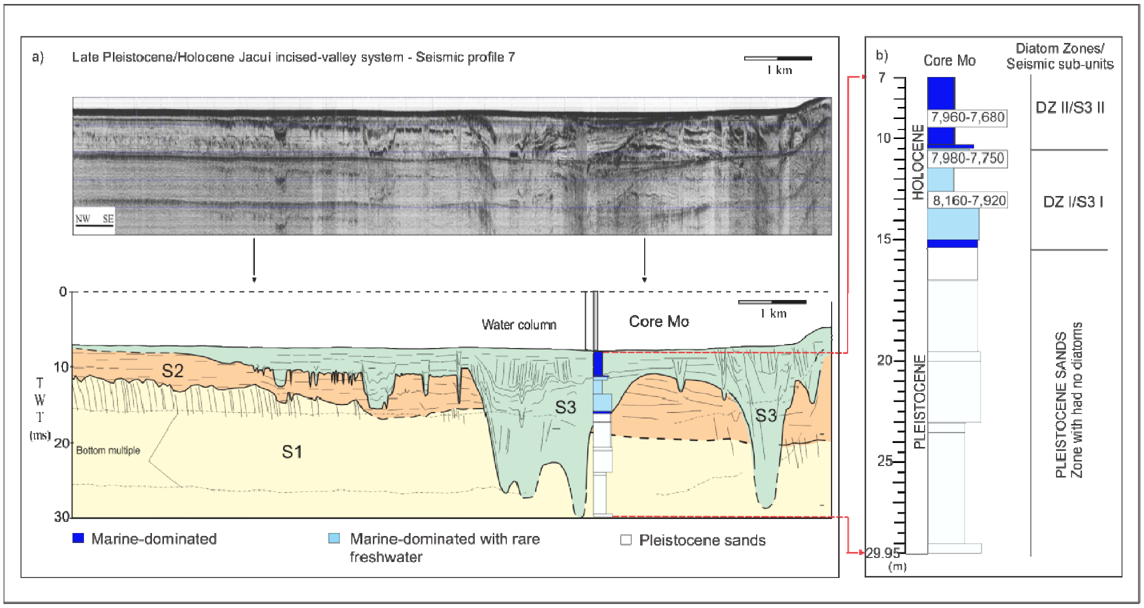

Figure 17. Correlation between seismic reflection and diatom records from core Mo (1a-b). Detailed diatom analysis provides information about nature of valley fill during Holocene. A zone which has no diatom present is related to deposition of Pleistocene sands (ZND). Unit S3 is subdivided in two sub-units (S3 I-II), related with diatom zones DZ I and II, (1b). Marine-dominated deposition with rare freshwater is related to S3 I in contrast with sub-unit S3 II which has a deposition of marine and marine-brackish diatom taxa in the uppermost part of the valley. TWT: Two-Way Traveltime in milliseconds (m/s).

5.1.3.1. Diatom zone I, seismic sub-unit S3 I (15.2 – 10.4 m)

Marine diatoms were dominant in the assemblages of this sequence (99.3 %), followed by freshwater (0.5 %) and brackish (0.2 %) diatom taxa. The most abundant taxa observed were *Paralia sulcata* (49 %) and *Actinoptychus senarius* (6.1 %) associated with *C. striata* (4.8 %), *C. radiatus* (2.3 %), *P. disculoides* (1.2 %), *T. oestrupii* (1.2 %). Non-marine assemblages were rare, occurring in very low percentages (ranging from 0.03 to 0.1 %).

5.1.3.2. Diatom zone II, seismic sub-unit S3 II (10.4- 7.3 m)

Diatom zone II indicated the dominance of marine deposition; planktonic diatom forms included *P. sulcata* (46 %), *C. striata* (24 %), *A. senarius* (9 %), *C. radiatus* (4 %), *Actinocyclus curvatulus* (3.4 %) and *T. oestrupii* (2.5 %), followed by other minor marine and marine/brackish taxa.

5.2. Comparing fossil and modern assemblages

A total of 51 modern diatom taxa were identified from the bottom sediments of Patos Lagoon (see Table 11for more details). Sites around core Pa (Pa3, Pa5, Pa6, Pa8, Pa13) were related to silt and clay deposition (89 %) in contrast with sites around core Mo (M3, M5, M9, M12) which were associated with sand deposition (66 %). Planktonic forms were dominant in both sites; the most representative diatom taxa were: *A. veraluciae*, *Aulacoseira* sp.2, *C. litoralis*, *A. normanii* and other minor species. DCA analysis of the diatom data revealed a clear separation between fossil and modern assemblages in ordination space, with surface samples completely isolated from those of the core sites (Fig. 18).

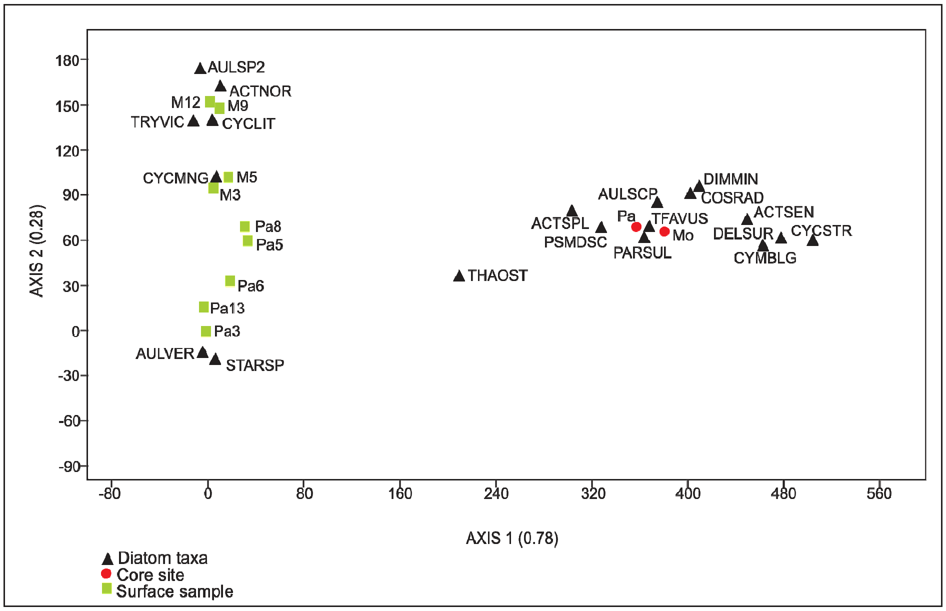

Figure 18. Fossil and modern diatom taxa are combined by means of DCA ordination. A clear separation among assemblages in ordination space is recorded. Surface samples are completely isolated from those of core sites indicating distinct environmental conditions. ACTNOR: *Actinocyclus normanii*, ACTSEN: *Actinoptychus senarius*, ACTSPL: *Actinoptychus splendens*, AULVER: *Aulacoseira veraluciae*, AULSP.2: *Aulacoseira* sp.2, AULSCP: *Auliscus sculptus*, COSRAD: *Coscinodiscus radiatus*, CYCLIT: *Cyclotella litoralis*, CYCMEN: *Cyclotella meneghiniana*, CYCSTR: *Cyclotella striata*, CYMBELG: *Cymatosira belgica*, DELSUR: *Delphineis surirella*, DIMMIN: *Dimeregramma minor*, PARSUL: *Paralia sulcata*, PSAMDC: *Psammococconeis disculoides*, STARSP: *Staurosira* sp., THAOST: T*halassiosira oestrupii*, TFAVUS: *Triceratium favus*, TRYVIC: *Tryblionella victoriae*.

The eigenvalues of the first two DCA axis were 0.78 (axis 1) and 0.20 (axis 2). The core sites Pa and Mo, clustered on the right side of diagram, were related to the high values along DCA axis 1, associated to the dominance of marine species: *A. senarius*, *A. splendens*, *A. sculptus*, *C. radiatus*, *C. striata*, *C. belgica*, *D. surirella*, *D. minor*, *P. sulcata*, *P. disculoides* and *T. favus*. Surface samples were associated with the low values along DCA axis 1, related to freshwater diatom taxa *A. veraluciae*, *Aulacoseira* sp.2, *C. meneghiniana*, *Staurosira* sp., followed by brackish taxa *A. normanii* and *T. victoriae*. Marine/marine-brackish taxa were represented by the planktonic diatom *C. litoralis*. The marine/marine-brackish *T. oestrupii* was positioned on the center of diagram with similar abundances (ranging from 1.2 to 1.5 %) related to core Pa, Mo and site Pa13. Bottom sediments from Patos Lagoon were dominated by *A. veraluciae* recorded in sites Pa3 and Pa13 (ranging from 80-85 %). It is abundant in samples Pa6, Pa8 and M3 (ranging from 40-48%). *Aulacoseira* sp.2., is dominant in M9 and M12 (ranging from 56-57 %) and it is considered abundant (ranging from 16-34 %) in Pa5 and M5.

6. DISCUSSION

6.1. A coast strongly influenced by sea-level oscillations

The present physiography of the southern Brazilian coast is mainly a result of Quaternary high-frequency glacio-eustatic, relative sea-level changes (Corrêa, 1986, 1996; Villwock et al. 1986; Villwock and Tomazelli, 1995; Tomazelli and Villwock, 2000). Three Pleistocene and one Holocene barrier-lagoon systems have been distinguished in this region (Villwock et al. 1986; Villwock and Tomazelli, 1995; Tomazelli et al. 2000) correlated with Marine Isotope Stages (MIS) from Imbrie et al. (1984). Sedimentary facies of the Pleistocene systems are composed of fine to medium grain quartz-feldspar sands, well-rounded with a silty-clay matrix. These facies reflect sediment deposition in a back-barrier environment (Villwock and Tomazelli, 1995). Since there is no consistent evidence of the local influence of neotectonism acting along the southern Brazilian coast, establishment of barrier systems must be a consequence of Quaternary high-frequency sea-level oscillations consistent with global sea-level changes. Delaney (1962) attributed the formation of coastal barriers to vertical tectonic movements. The most consistent evidence of neotectonics has been found in the southeastern and northeastern Brazilian coasts (Suguio and Martin 1996; Barreto et al. 2002; Bezerra et al. 2003).

Several areas of South America were subjected to cooler temperatures and greater aridity during the Late Pleistocene (Ledru et al. 1996; Turcq et al. 1997; Behling, 1998), accompanied by a gradual increase in humidity in both tropical and subtropical regions from 45,000 to 25,000 yr BP (Ledru, 1993; Van der Hammen and Absy, 1994; Ledru et al. 1996). High-resolution studies suggest a strong influence of the *El Niño-Southern Oscillation* (*ENSO*) as component of the climate in South America ranging back until at least MIS 8 (Oberhänsli et al. 1990; Beaufort et al.

2001; Tudhope et al. 2001; Marwan et al. 2003). Paleoclimate conditions along the southern Brazilian coast may have been affected by *El Niño* events during Late Pleistocene. Modern climate conditions of subtropical Brazil are strongly influenced by ENSO activity (Grimm et al. 1998, 2000; Fernandes et al. 2002).

6.1.1. Late Pleistocene deposition (profile 22 -seismo-depositional unit S2, core Pa)

Onset of fluvial incision of Jacuí River valley occurred during the Early Pleistocene. It has been excavated principally since the middle Pleistocene during sea-level lowstands created by the maximum extent of Wisconsin Glaciation and continued until the Holocene highstand period (Weschenfelder et al. 2014). According to Baitelli (2012), high-frequency sea-level oscillations from 241,000 to 201,000 yr BP, were not effective at drowning the valley and the Jacuí River continued cutting into barrier systems I and II. The southern Brazilian coast was exposed sub-aerially and subjected to high erosion rates and fluvial incision during MIS 6. The observed valley architectures have been correlated with deposits of Pleistocene barrier systems that formed in association with MIS 7 and 5e (Villwock et al. 1986; Dillenburg et al. 2004). Downstream, the incisions can be extended through the continental shelf and slope by means of morphostructural data (Corrêa, 1994; Martins et al. 1996; Corrêa et al. 2007, 2013, 2014). The fluvial-shelf sedimentary bypassing system is linked by a wide fluvial-drainage network complex recorded by Corrêa (1994).

Sediments of the seismic-depositional sub-unit S2-I (28.50 – 18.5 m) were deposited into an environment with a highly marine influence. Marine muddy silt deposits are associated with dominance of marine diatom assemblages (> 94 %). The marine taxa *P. sulcata* is abundant usually accompanied by *A. splendens*, *A. senarius*, *C. radiatus*, *C. belgica*, *D. surirella* and other minor species. Greater relative abundances of *P. sulcata* and *C. belgica* indicate a relatively open-marine embayment. Similar dominance of marine conditions in samples older than 43,500 yr BP were also evidenced by Baitelli (2012) who recorded a marine microfossil assemblage in the lowest section of core Pa. Similarly, Leite et al. (2013) reported the occurrence of marine/marine-brackish ostracoda taxa: *Xestoleberis* sp., *Propontocypris* sp., *Cyprideis multidentata* and *Cytheretta punctata*. The occurrence of non-marine diatom taxa in very low densities is interpreted as an allochthonous component, present in an environment partially occupied by a discontinuous Pleistocene sand-barrier. Diatom analyses performed by Santos (2015) show the strong relationship between core Pa and core sediments from the outer shelf and continental slope, associated with active transport of fine terrestrial sediments. Both stratigraphic cores displayed highly fragmented benthic frustules from freshwater taxa indicating transport from the Jacuí River during the Pleistocene.

During the Pleistocene, the marine influence was greater than the previous stages of basin sedimentation, however the transport of non-marine diatom taxa was not affected in sub-unit S2-II (18.5 – 16 m). Marine planktonic forms were primarily associated with silt and clay deposition (97.43 %). The marine taxa *P. sulcata* and *A. splendens* were most abundant in the assemblages, followed by *A. senarius*, *A. undulatus* and *A. vulgaris*. Freshwater diatom taxa are recorded occurring continuously in this section, but in very low density. The high abundance of *P. sulcata* is recorded towards the ingression and isolation contacts of the sedimentary sequences in coastal sediments of northwest Scotland (Zong, 1997). Along the southern Brazilian coast, the dominance of the species in open-marine embayment partially occupied by sand barriers, submitted to high marine influence is highlighted. In addition, studies based on seismic stratigraphy performed on marine embayments have been made by Mallinson et al. (2005), Culver et al. (2008) and Green et al. (2015).

Sediments from the Pleistocene sand barrier system III (whose formation is related to MIS 5e) are responsible for the progressively blockage of the Jacuí River inlet. There is no paleontological evidence of complete drainage closure during the previous stages of the valley evolution (seismic unit S2). If it was closed during previous stages of sedimentation, a progressive increase of freshwater influence could be expected. However, the marine-dominated deposition suggests clearly that at this time, the Jacuí inlet was not totally closed by sands from the barrier system III, as demonstrated by Weschenfelder et al. (2014). As expected, after that only estuarine conditions occur, and abundant freshwater and marine/marine-brackish assemblages are recorded. Baitelli (2012) recorded the presence of a strong reflector located between 10 – 15 m deep, and suggested that this is evidence of both fluvial and marine deposition.

An abrupt shift from marine-dominated to estuarine-fluvial deposition is suggested by the decrease of marine species in sub-unit S2-III (16 – 11 m). This is marked by the development of a sand barrier, which extended across the marine embayment, forcing to a new coastal configuration of more lagoonal-estuarine conditions. Three intervals of substantial fluvial influence were recorded. The first interval is represented by *A*. *veraluciae*, *E*. *major*, *C*. *meneghiniana*, *G*. *paludosum*, *C*. *placentula* var. *euglypta*, which are commonly found in terrestrial environments, reaching abundances greater than 20 % of total assemblage between 16 to 14.5 m. The second stage is related to the most important and highest fluvial contribution of the Jacuí River associated with MIS 2. Sand concentrations went from 2.57 to 31.7 % and non-marine assemblages accounted a total of 74 % of all diatom species (14.5 – 14 m). The freshwater taxa *A*. *veraluciae*, *Aulacoseira* sp.2, *P*. *borealis*, *S*. *martyi* and other minor species commonly found in terrestrial environments were found mixing with rare marine taxa *P*. *sulcata* (4 %) and *A*. *splendens* (1.6 %), accompanied by *C*. *radiatus*, *A*. *sculptus* and *T*. *favus* (ranging from 0.08 to 0.2 %). Afterwards, a third interval of the highest freshwater influence comprising a total of 60 % of all diatom assemblages was recorded in the interval between 12.5 – 12 m, accompanied by an increase of *P*. *sulcata* (25 %). Planktonic diatom taxa were a much less important component, with benthic assemblages indicating a shallow estuarine-fluvially environment. In addition, Lopes et al. (2010) recorded fossil mammal teeth from *Hippidion principale*, *Stegomastodon waringi* and *Toxodon platensis* in deposits from the Pleistocene barrier system III, in the south area of the coastal plain. These fossils had ages ranging from 42,000 to 33,000 yr BP, indicating more recent deposition than the estimated age of the sand barrier associated with the fluvial contribution from Chuí Creek.

In accordance with global sea-level curves, based upon the eustatic relative sea-level prediction of Corrêa (1996), sea-level was positioned 130 m below the present level during Last Glacial Maximum (LGM). The coastline was positioned at a distance of ~ 130 km seaward of the present position during MIS 2. However, sea-level oscillations alone could not explain the abrupt changes in valley sedimentation. According to Blum and Hattier-Womack (2009) sea-level oscillations have a low direct influence on rates of sediment supply and delivery to the shelf and slope. Sediment supplied by unglaciated fluvial systems would have been 20-50 % less under a glacial maximum climate, in contrast to interglacial highstands, when the sediment yields are maximized. Blum and Törnqvist (2000) compared the valley incision and complete sediment bypass to a *vacuum cleaner model* for sediment supply. This model derives all sediments from distal parts of the basin that promoted the excavation of an incised valley at the basin margin, as observed in the Gulf of Mexico coast (Blum et al. 1995; Blum and Straffin, 2001; Anderson et al. 1996) and southern Australia (Hill et al. 2009). However, mathematical experiments from Blum and Hattier-Womack (2009) suggest that during the LGM only 60-70 % of the total sediment discharged by fluvial drainage is deposited on the shelf-margin area and the rest is dispersed directly to the slope (30-40 %).

With respect to our results, the position of the coastline in response to sea-level change is of greater importance. During lowstands, sea-level falls to the mid-shelf (more basin-ward), forcing river systems to extend and shorelines to migrate across emergent shelves, accompanied by fluvial incision though highstandprisms. Opposite conditions occur in periods of sea-level rise, which force the channel length to shorten, river mouth and shoreline to back step and flood the shelves (Blum and Törqvist, 2000). The present inner shelf surface was exposed sub-aerially, subjected to high erosion rates and fluvial incision during the LGM. Wide incisions in the coastal plain were trigged by forced regression event during the Wisconsin glaciation. The Late Pleistocene/Holocene valleys represented an important fluvial-shelf sediment bypassing system. This coast was deeply dissected before the implantation of the modern landscape. According to Corrêa and Toldo Jr., (1998) coarse sands formed beach ridges along the southern Brazilian paleo-shoreline, and fine sands were deposited on the inner shelf. Muddy sands were deposited on the outer shelf and the upper slope. Fine-grained and muddy sediments are usually related to infilling of the coastal plain incised valleys because of the low gradient of the coastal plain (Zaitlin et al. 1994).

Sedimentary signatures of the maximum lowstand are preserved in two seismic profiles regarding younger drainages from Jacuí and Camaquã rivers, profiles 7 and 2, respectively. Both seismic profiles have shown deep incisions of at least 30 m in unit S3. However, the main drainage of the Jacuí River (Late Pleistocene sedimentation) was not re-incised during MIS 2 and the drainage was shifted to a new connection with Atlantic Ocean, occupying a new incision generated during MIS 2 (seismic profile 7), located ~50 km south of the older incision. The causes of river avulsions are not yet understood, but may be associated with coastal subsidence, changes in fluvial discharge and channel capacity, neotectonics, climate changes, and channel blockage by sediments (Harwood and Brown, 1993; Schumm et al. 1996; Jones and Harper, 1998; Ethridge et al. 1999; Stouthamer and Berensen, 2000; Aslan et al. 2005). FitzGerald et al. (1986) attributed the migration of drainage divides to wind action that generates currents, augmenting the tidal currents in back-barrier deposits in a barrier island configuration.

6.1.2. Late Pleistocene/Holocene deposition of unit S3

Layers of fine sand were deposited in the paleo-shoreline over the inner shelf, intercalated with medium sands originating from estuaries or deltas systems transported by the incised valleys. After the LGM, this coast was drowned by rapid (2.0 cm/yr) sea-level rise from 17,500 to 16,000 yr BP. Muddy sands of the pre-littoral environment were deposited on the shelf in response to a decrease in the rate of sea-level rise (from 2 cm/yr to 0.6 cm/yr) from 16,000 to 11,000 yr BP (Corrêa and Toldo Jr., 1998). Bathymetric breaks on the shelf were preserved as marine terraces at depths of -80/-90 m and -60/-70 m (Corrêa, 1996). Sea-level rose on average by ~1.6 cm/yr from 11,000 to 6,000 yr BP during the early Holocene. Three sea-level stabilizations are recorded by Corrêa (1996) at around 11,000 yr BP (-60/-70 m), 9,000 yr BP (-32/-45 m) and 8,000 yr BP (-20/-25 m). Corrêa et al. (2014 b) recorded a peat layer on the shelf at depth of -60 m deposited at around 12,540-12,150 cal yr BP (10,460 ± 40 ^{14}C yr BP, BETA 343479).

Combined time-series analyses of δ^{18}O and elemental ratios of speleothems suggest that long-term variations in mean precipitation in subtropical Brazil during the Last Glacial and Holocene period are modulated by changes in southern hemisphere summer insolation. Cheng et al. (2009) and Cruz et al. (2007) have suggested that the intensified summer monsoon in South America is related to meltwater pulses in the North Atlantic (LeGrande and Schmidt, 2008). Several climate proxies have shown that the Holocene climate was influenced by opposite hemispheric trends of insolation (Wanner et al. 2011). The southern Brazilian coast experienced relatively humid conditions and lower than present day temperatures during early Holocene (Medeanic and Dillenburg, 2001; Medeanic et al. 2001; Weschenfelder et al. 2008 a).

Intercalated climatic conditions between humid and dry periods during the middle to late Holocene were observed by Medeanic et al. (2003, 2010) and Medeanic and Corrêa (2010). More humid conditions were related to a decrease in the size of freshwater marshes and an increase in xerophylous and halophylous herbaceous plants in coastal areas of Rio Grande do Sul (RS) at around 8,620 ± 170 ^{14}C yr BP (Weschenfelder et al. 2008a).

Rising sea-level during the early-middle Holocene was responsible for progradation and development of a sand barrier. The Holocene barrier has been focused upon in many studies from southern Brazilian coast, however the studies performed by Dillenburg et al. (2000, 2004, 2006, 2013) and Dillenburg and Hesp, (2009) are emphasized here. The sand barrier occurring in the study area, where core sites Pa and Mo are located, is considered an aggradational/stationary model inserted into the subsector from Dunas Altas to the Lagarmazinho areas (Dillenburg et al. 2013). Marine ingressions caused the inland migration of a large Holocene sand barrier formed in the study area approximately 11,280 – 10,510 cal years BP (Dillenburg and Hesp, 2009).

The Holocene transgressive postglacial event drowned the Late Pleistocene incisions, infilling the incised valleys with marine and marine-estuarine sediments. Based upon the eustatic relative sea-level prediction of Corrêa (1996), Toldo Jr. et al. (2000) estimated that the Holocene sedimentation in Patos Lagoon started at around of 8,000 yr BP, with an average deposition rate of 0.75 mm/yr. This is in agreement with marine sequences recorded in core sediments from distinct environments of the coastal plain and Patos Lagoon interior (Santos, 2015). Core Pa has a marine-dominated deposit (Diatom zone IV, sub-unit S3-I) inferred by the dominance of *P. sulcata* associated with *A. splendens*, *P. disculoides*, *C. belgica*, *D. minor* and *A. sculptus*, followed by a marine-dominated deposit with very low fluvial influence (sub-unit S3- II). The most representative marine diatom taxa are *P. sulcata*, *C. belgica* and *P. staurophorum* followed by uncommon and rare marine to marine-brackish taxa. The lowest part of core Mo has a thin (0.5 m) marine-dominated deposition, followed by a 4.8-m thick marine-dominated package with uncommon and rare freshwater taxa, deposited prior to 8,160 – 7,920 until 7,980 – 7,750 cal years BP (Diatom zone I, sub-unit S3- I). Marine assemblages are dominant in the sequence (99.3 %) related to an increase of fine sands and muddy deposition. *P. sulcata* is associated with *A. senarius*, *C. striata* and other minor species. Non-marine diatom taxa are rare, occurring in very low percentages (ranging from 0.03 to 0.1 %). Only after that, a marine-dominated deposition occurs at around 7,960 – 7,680 cal years BP (sub-unit S3-II) associated with marine planktonic forms of *P. sulcata*, *C. striata*, *A. senarius*, *C. radiatus*, *A. curvatulus* and *T. oestrupii*, commonly found in marine sequences of southern Brazilian coast (Santos, 2015).

Relative sea-level curves have been proposed for distinct sectors of the Brazilian coast. They are related to a submergence phase established prior to 7,000 yr BP until the maximum highstand, followed by a discontinuous drop in sea-level (Angulo and Lessa, 1997; Martin et al. 2003; Angulo et al. 1999, 2006). Based upon the eustatic sea-level curve of Corrêa (1996), two negative sea-level fluctuations occurred at the interval between 4,000 – 3,500 yr BP and 2,300 – 2,000 yr BP. After that, sea-level progressively fell, until returning to the present position (Corrêa, 1996).

Marine-estuarine macrofaunistic deposits accumulated at the rear of the barrier in an inter-barrier depression of sand barrier are indicative of marine influence in sediments ranging in age from 3,220 and 3,370 cal years BP (Dillenburg et al. 2004). Similarly, Toldo Jr., et al. (1991) recorded a microfossil association present in five stratigraphic cores obtained in the north region of Patos Lagoon, suggesting a highly marine influence attributed to the Barra Falsa channel in ages ranging from 2,080 – 2,450 ^{14}C yr BP. Recently a diatom analysis performed by Santos (2015) in two cores from Toldo Jr. et al. (1991) revealed a strong marine influence closely linked to the Jacuí River incised-valley system (Baitelli, 2012; Weschenfelder et al. 2014). The barrier became more continuous after the late Holocene lowstand and the contours of the Patos Lagoon were developed due complete closure by sands of the barrier-lagoon system. Several former inlets from the Jacuí and Camaquã rivers were closed. However, a relatively modern lagoonal-estuarine inlet located to the south known as Rio Grande channel remains active in the actual configuration (Corrêa et al. 2004). Similar conditions of estuaries and lagoons that became enclosed since the middle Holocene are recorded in South America (Iriondo and Garcia, 1993; Espinosa et al. 2003; García-Rodríguez et al. 2004a, Bracco et al. 2005; García-Rodríguez, 2012).

Fossil and modern diatom assemblages were clearly divided in ordination space. DCA results show surface samples isolated from those of core sites, indicating changes in diatom distribution and composition. However, fossil assemblages have analogues that constitute the most ecologically successful taxa, which have persisted in the environments of coastal plain. Similar results were obtained by Santos (2015) that combined fossil and modern diatom taxa by means of multivariate statistical techniques applied in distinct sediments of southern Brazilian coastal zone.

The marine taxa *P. sulcata* occurs continuously from the Late Pleistocene to present-day conditions. In samples older than 43,500 yr BP and in periods near to the LGM, the species is found in low abundance (reaching 4-8 %) due to a strong freshwater influence. Abrupt changes in relative abundances of *P. sulcata* may be caused by a decrease of marine influence and cooler temperatures as observed during the LGM, since that *P. sulcata* has been related to relatively warm climates (Stabell, 1980; Karpuz and Schrader, 1990). During the Holocene, *P. sulcata* is dominant in marine sequences because conditions were more humid and warm, promoting a substantial increase in populations of *Paralia* (see Santos, 2015). This observation enhances the knowledge of paleoecology of *Paralia* species found in coastal areas subjected to a strong marine influence during the Quaternary, because the paleoecology (ecology) of the species is not fully understood (see McQuoid and Hobson 1998; McQuoid and Norberg, 2003; Gebühr et al. 2009; Garcia et al. 2012).

Modern deposition is associated with high abundances of the freshwater taxa *Aulacoseira veraluciae* and *Aulacoseira* sp.2 along with the brackish diatom *Actinocyclus normanii* and the marine/marine-brackish species *Cyclotella litoralis*. The marine taxa *P. sulcata*, which is dominant in fossil sequences, is recorded in low densities in modern sediments of the Patos Lagoon. Surface samples collected around core Pa are mostly silt and clay because of the proximity to fluvial drainages from the Guaíba Hydrographic Basin. However, spatial distribution of modern associations seems to be controlled by a combination of salinity gradient, wind action, and climate forcing strongly influenced by El Niño Southern Oscillation (ENSO) activity (Santos, 2015).

7. IMPLICATIONS AND CONCLUSIONS

By integrating seismic profiles, core data sets, and diatom stratigraphy, seismic units can be associated with distinct environmental scenarios of two non-contemporary valley fills from the Late Pleistocene to Holocene.

1. The Late Pleistocene is typified by the strong influence of marine deposition in samples older than 43,500 years BP until the beginning of the LGM (seismic sub-unit S2 I-II) associated with an open-marine embayment. Non-marine diatom taxa were recorded occurring continuously, but in very low density, interpreted as allochthonous components; transported from terrestrial environments.
2. Strong seismic reflectors are associated with an abrupt shift from marine-dominated to substantial estuarine-fluvial deposition (sub-unit S2-III). Since no consistence evidence of local influence of neotectonism acting southern Brazilian coast exists, there are several possible explanations for the changes in valley sedimentation: (1) the development of well-defined sand barrier which extends across the marine embayment followed by establishment of lagoonal-estuarine conditions; (2) the effects of ENSO activity during Late Pleistocene in South America, regionally associated with a reduction in the abundance of marine species; (3) a sea-level drop of 130 m below the present level coupled with shelf exposure and intense erosion during maximum lowstand.
3. Wide incisions in the coastal plain were trigged by forced regression event during the Wisconsin glaciation. The Late Pleistocene/Holocene valleys represented an important fluvial-shelf sediment bypassing system. The Late Pleistocene valley was not re-incised and the drainage was shifted to a new connection with Atlantic Ocean, occupying a new incision (Unit S3). After the LGM, the Holocene transgressive postglacial event drowned the Late Pleistocene incisions, infilling the incised valleys (sub-unit S3 I-II).
4. The Late Pleistocene and Holocene sediments differ strongly from the modern sediments. Fossil and modern diatom assemblages were clearly divided in DCA ordination space, indicating changes in diatom distribution and composition. This is no doubt directly related to distinct hydrological conditions and paleogeographic configuration from those observed today.

5. The characterization of the source-to-sink of terrigenous sediments interacting due to sea-level fluctuations, are essential to understand the sedimentary records preserved on incised valleys systems. Diatom assemblages have greater potential for contributing to source-to-sink studies made especially in transitional environments. They are important not only through the environmental reconstructions, sea-level and climate changes, but also through tracking the transport and provenance of fine-grained sediments.
6. The marine taxa *P. sulcata* is an excellent indicator of sea-level changes. It occurred continuously from the Late Pleistocene to present-day conditions. Low densities were recorded during LGM related to cooler temperatures and increase of freshwater influence. During the Holocene, *P. sulcata* is dominant in marine sequences because conditions were more humid and climate was warmer. In modern sediments of Patos Lagoon, which are dominated by the freshwater taxa, the marine diatom *P. sulcata* is found in low density. Our results enhance the knowledge about the paleoecology of *Paralia* species found in coastal areas worldwide.
7. The evolutionary model presented here provides a framework for understanding the processes that regulate deposition within valleys located in coastal plains, enhancing the importance of multidisciplinary approach in determining the nature of sedimentary records

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9. REFERENCES

Abreu, J.G.N., Calliari, L.J. 2005. Paleocanais da plataforma continental interna do Rio Grande do Sul: evidências de drenagem fluvial pretérita. Revista Brasileira de Geofísica, 23(2): 123-132.

Anderson, J.B., Abdulah, K., Sarzalejo, S., Siringin, F., Thomas, M.A., 1996. Late Quaternary sedimentation and high-resolution sequence stratigraphy of the East Texas Shelf, in: De Batist, M., Jacobs, P. (Eds.) Geology of Siliciclastic Shelf Seas. Geologic Society of London Special Publication 117, pp. 95-124.

Andrade Neto, J.S., Rigon, L.T., Toldo Jr., E.E., Schettini, C.A.F., 2012. Descarga sólida em suspensão do sistema fluvial do Guaíba, RS, e sua variabilidade temporal. Pesquisas em Geociências, 39: 161- 171.

Angulo, R.J., Giannini, P.C.F., Suguio, K., Pessenda, L.C.R., 1999. Relative sea-level changes in the last 5500 years in southern Brazil, Laguna–Imbituba region, Santa Catarina State based on vermetid ^{14}C ages. Marine Geology, 159: 323-339.

Angulo, R.J., Lessa, G.C., 1997. The Brazilian sea-level curves: a critical review with emphasis on the curves from the Paranaguá and Cananeia regions. Marine Geology, 140: 141-166.

Angulo, R.J., Lessa, G.M., Souza, M.C., 2006. A critical review of mid- to Late-Holocene sea-level fluctuations on the eastern Brazilian coastline. Quaternary Science Review, 25: 486-506.

Aslan, A., Autin, W.J., Blum, M.D., 2005. Causes of river avulsion: insights from the Late Holocene avulsion history of the Mississippi River, USA. Journal of Sedimentary Research, 75: 650–664.

Baitelli, R., 2012. Evolução Paleogeográfica do Sistema de Paleodrenagem do Rio Jacuí na Planície Costeira do Rio Grande do Sul (PhD thesis) Universidade Federal do Rio Grande do Sul, Brasil (2012), available in the website: http://hdl.handle.net/10183/56850.

Barreto, A.M.F., Bezerra, F.H.R., Suguio, K., Tatumi, S.H., Yee, M., Paiva, R.P., Munita, C.S., 2002. Late Pleistocene marine terrace deposits in northeastern Brazil: sea-level change and tectonic implications. Palaeogeography, Palaeoceanography, Paleoecology, 179: 57-69.

Beaufort, L., de Garidel-Thoron, T., Mix, A.C., Pisias, N.G., 2001. ENSO-like forcing on oceanic primary production during the late pleistocene. Science, 293: 2440–2444.

Behling, H. (1998). Late Quaternary vegetational and climatic changes in Brazil. Review of Palaeobotany and Palynology, 99(2): 143-156.

Bezerra, F.H.R., Barreto, A.M.F., Suguio, K., 2003. Holocene sea-level history on the Rio Grande do Norte State coast, Brazil. Marine Geology, 196:73-89.

Blum, M.D., Hattier-Womack, J., 2009. Climate change, sea-level change, and fluvial sediment supply to deepwater depositional systems: a review, in: External Controls on Deepwater Depositional Systems, Kneller, B.C., McCaffrey, W.D., Martinsen, O.J., (Eds.), SEPM Special Publication, 93, pp. 15-39.

Blum, M., Martin, J., Milliken, K., Garvin, M., 2013. Paleovalley systems: Insights form Quaternary analogs and experiments. Earth-Science Reviews, 116: 128-169.

Blum, M.D., Morton, R.A., Durbin, J.M., 1995. "Deweyville" terraces and deposits of the Texas Gulf Coastal Plain. Transactions of the Gulf Coast Association of Geological Societies, 45: 53-60.

Blum, M.D., Straffin, E.C., 2001. Fluvial response to external forcing: examples from the Massif Central of France, the Texas Coastal Plain (USA), the Sahara of Tunisia, and the Lower Mississippi Valley (USA), in: Maddy, D. and Macklin, M. A. (Eds.) River Basin Sediment Systems: Archives of Environmental Change. Balkema Press. pp.195-228.

Blum, M.D., Törnqvist, T.E., 2000. Fluvial responses to climate and sea-level change: A review and look forward. Sedimentology, 47(1): 2-48.

Bracco, R., Inda, H., Del Puerto, L., Castiñeira, C., Sprechmann, P., García-Rodríguez, F., 2005. Relationships between Holocene sea-level variation, trophic development and climate change in Negra Lagoon, southern Uruguay. Journal of Paleolimnology, 33: 252-262.

Calliari,L.J., Winterwerp, J.C., Fernandes, E., Cuchiara, D., Vinzon, S.B., Sperle, M, Holland, K.T. 2009. Fine grain sediment transport and deposition in the Patos Lagoon-Cassino beach sedimentary system. Continental Shelf Research, 29(3): 515-529.

Cheng, H., Edwards, R.L., Broecker, W.S., Denton, G.H., Kong, X., Wang, Y., Zhang, R., Wang, X., 2009. Ice age terminations. Science, 326: 248–252.

Corrêa, I.C.S., 1986. Evidence of sea-level fluctuation on the Rio Grande do Sul continental shelf, Brazil. Quaternary of South America and Antarctic Peninsula, 40: 237-249.

Corrêa, I.C.S., 1994. Interpretation Morphostructurale de la Plate-Forme Continentale du Rio Grande do Sul, a partir de l'Analise Cartographique. Notas Técnicas, 7 :3-26.

Corrêa, I.C.S., 1996. Les variations du niveaux de la mer durant lês derniers 17.500 ans BP: l'example de la plate-forme continentale du Rio Grande do Sul-Brèsil. Marine Geology, 130: 163-178.

Correâ, I.C.S., Aliotta, S., Weschenfelder, J. 2004. Estrutura e evolução dos cordões arenosos pleistocênicos no canal de acesso à Laguna dos Patos, Brasil. Pesquisas em Geociências, 31(2): 69-78.

Corrêa, I. C.S., Medeanic, S., Weschenfelder, J., Toldo Jr. E.E., Nunes, J.C., Baitelli, R. 2014a. The paleo-drainage of the La Plata River in southern Brazil Continental Shelf. Revista Brasileira de Geofísica, 32 (2): 259-271.

Corrêa, I. C.S., Medeanic, S., Weschenfelder, J., Toldo Jr. E.E., Nunes, J.C., Baitelli, R., Santos, C. B. dos., 2013. Registro sedimentario del antiguo canal de desembocadura del Río de La Plata en la plataforma continental del sur de Brasil. Revista Mexicana de Ciencias Geológicas, 30(1): 51-64.

Corrêa, I.C.S., Toldo Jr, E.E., 1998. The Sea Level Stabilization in The Rio Grande do Sul Continental Shelf, Brazil. Anais da Academia Brasileira de Ciências, 70 (2): 213-219.

Corrêa, I.C.S., Weschenfelder, J., Toldo Jr., E.E., Baitelli, R., Santos, C.B.dos., 2014b. Turfa na plataforma continental do Sul do Brasil. Comunicações Geológicas, 101: 721-724.

Cruz, F.W., Burns, S.J., Jercinovic, M., Karmann, I., Sharp, W.D.,Vuille, M., 2007. Evidence of rainfall variations in southern Brazil from trace element ratios (Mg/Ca and Sr/Ca) in a late Pleistocene stalagmite, Geochimica et Cosmochimica Acta, 71: 2250– 2263.

Culver, J.S., Farrell, K.M., Mallinson, J.D., Horton, B.P., Willard, D.A., Thieler, E.R., Riggs, S.R., Snyder, S.W., Wehmiller, J.F., Bernhardt, C.E., Hillier, C., 2008. Micropaleontologic record of Late Pliocene and Quaternary paleoenvironments in the northern Albermarle Embayment, North Carolina, USA. Palaeogeography, Palaeoclimatology, Palaeoecology, 264: 54-77.

Dalrymple, R.W., 2006. Incised valleys in time and space: introduction to the volume and an examination of the controls on valley formation and filling, in: Dalrymple, R.S., Leckie, D.A., Tillman, R., (Ed.), Incised valleys in Time and Space. SEPM Special Publication 85, pp. 5-12.

Dalrymple, R.W., Boyd, R., Zaitlin, B.A., 1994. Incised-Valley Systems: Origin and Sedimentary Sequences. Society for Sedimentary Geology Special Publication 51, Tulsa, Oklahoma.

Dalrymple, R.W., Leckie, D.A., Tillman, R., 2006. Incised valleys in Time and Space. Society for Sedimentary Geology Special Publication 85, Tulsa, Oklahoma.

Delaney, P.J.V. 1962. Quaternary Geologic History of the Coastal Plain of Rio Grande do Sul, Brazil. South American Coastal Studies Technical Report, 10 (Part A), 1-63.

Dillenburg, S.R., Barboza, E.G., Tomazelli, L.J., Rosa, M. L.C.C., Maciel, G.S., 2013. Aeolian deposition and barrier stratigraphy of the transition region between a regressive and transgressive barrier: an example from southern Brazil. Journal of Coastal Research, 65: 464-469.

Dillenburg, S.R., Hesp, P.A., 2009. Geology and Geomorphology of Holocene Coastal Barriers of Brazil. Springer, Lecture Notes in Earth Sciences, 107, Berlin, Germany.

Dillenburg, S.R., Roy, P.S., Cowell, P.J., Tomazelli, L.J., 2000. Influence of antecedent topography on coastal evolution as tested by the shoreface translation-barrier model (STM). Journal Coastal Research, 16: 71-81.

Dillenburg, S.R., Tomazelli, L.J., Barboza, E.G., 2004. Barrier evolution and placer formation at Bujuru southern Brazil. Marine Geology, 203: 43-56.

Dillenburg, S.R., Tomazelli, L.J., Hesp, P.A., Barbosa, E.G., Clerot, L.C.P., Silva, D.B., 2006. Stratigraphy and evolution of a prograded, transgressive dunefield barrier in southern Brazil. Journal of Coastal Research, SI 39(1): 132-135.

Espinosa M.A. 1988. Paleoecologia de diatomeas del estuario del Rio Quequén (Prov. de Buenos Aires, Argentina). Thalassas, 6: 33–44.

Espinosa M.A. 1994. Diatom paleoecology of the Mar Chiquita lagoon delta, Argentina. Journal of Paleolimnology, 10:17–23.

Espinosa M.A. 2001. Reconstruccio´n de paleoambientes holocenos de la costa de Miramar. (provincia de Buenos Aires, Argentina) basada en diatomeas. Ameghiniana, 38: 27–34.

Espinosa, M.A., 2008. Diatoms of Patagonia and Tierra del Fuego. En: J. Rabassa (Ed.), Late Cenozoic of Patagonia and Tierra del Fuego. Developments in Quaternary Sciences, 11: 383–392.

Espinosa, M.A., De Francesco, C.G., Isla, F.I., 2003. Paleoenvironmental reconstruction of Holocene coastal deposits from the southeastern Buenos Aires province, Argentina. Journal of Paleolimnology, 29: 49-60.

Espinosa, M.A., Hassan, G., Isla, F., 2012. Diatom-inferred salinity changes in relation to Holocene sea-level fluctuations in estuarine environments of Argentina. Alcheringa: An Australasian Journal of Palaeontology, 36: 373-386.

Espinosa, M.A., Isla, F., 2011. Diatom and sedimentary record during the Mid-Holocene evolution of the San Blas estuarine complex, Northern Patagonia, Argentina. Ameghiniana, 48 (4): 411-423.

Ethridge, F.G., Skelly, R.L., Bristow, C.S., 1999, Avulsion and crevassing in the sandy, braided Niobrara River: complex response to base-level rise and aggradation, in: Smith, N.D., Rogers, J., (Eds.). Fluvial Sedimentology VI: International Association of Sedimentologists, Special Publication, 28: 179–191.

Fayó, R., Espinosa, M.A., 2014. Reconstrucción paleoambiental de la Planicie Costera de Mar Chiquita (Provincia de Buenos Aires, Argentina) Durante el Holoceno, Basada em Diatomeas. Ameghiniana, 51(6): 510-528.

Fepam, 2010. *Qualidade das Águas da Bacia Hidrográfica do Rio Jacuí*. Available in the website: http://www.fepam.rs.gov.br/qualidade/qualidadejacui/jacui.asp.

Fernandes, E.H.L., Dyer, K.R., Möller, O.O., Niencheski, L.F.H., 2002. The Patos Lagoon hydrodynamics during an El Niño event (1998).Continental Shelf Research, 22: 1699-1713.

Ferrer, P., Benabdellouahed, M., Certain, R., Tessier, B., Barusseau, J-P., Bouchette, F., 2010. The Late Holocene sediment infilling and beach barrier dynamics of the Thau Lagoon (Gulf of Lions, Mediterranean Sea, SE France). Bulletin de la Socièté Geologique de France, 181(2): 197-209.

Fitzgerald, P.G., M. Sandiford, P.J. Barrett, and A.J.W. Gleadow., 1986. Asymmetric extension association with uplift and subsidence of the Transantarctic Mountains and Ross Embayment, Earth Planetary Science Letters, 81: 67-78.

Fornel, R.; Cordeiro-Estrela, P. and De Freitas, T.R.O. 2010. Skull shape and size variation in Ctenomys minutus (Rodentia: Ctenomyidae) in geographical, chromosomal polymorphism, and environmental contexts. Biological Journal of Linnean Society, 101:705-720.

Garcia, C.A.E., 1997. Hydrographic Characteristics, in: Seeliger, U., Odebrecht, C., Castello, J.P. (Eds.) Subtropical Convergence Environments - The Coast and Sea in the Southwestern Atlantic. Springer Verlag, pp. 18-20.

Garcia, M., Talgatti, D.M., Souza-Mozimann, R., Laudares-Silva, R., 2012. Morphology and distribution of *Paralia* Heiberg (Coscinodiscophyceae) in southern Brazil. Iheringia Série Botânica, 67 (2): 225-235.

García-Rodríguez, F., 2006. Inferring paleosalinity changes using the chrysophyte cyst to diatom ratio in coastal shallow temperate/subtropical lagoons influenced by sea-level changes, Journal of Paleolimnology, 36:165-173.

García-Rodríguez, F., 2012. South America, Holocene Coastal Lagoons, in: Fairbridge, R.W., Herschy, R.W. (Eds.), Encyclopedia of Lakes and Reservoirs, Geology, Hydrology and Paleolimnology. Springer Verlag, Berlin, pp. 723-724.

García-Rodríguez, F., Del Puerto, L., Inda, H., Castiñeira, C., Bracco, R., Sprechmann, P., Scharf, B., 2001. Preliminary paleolimnological study of Rocha lagoon, SE Uruguay. Limnologica, 31: 221-228.

García-Rodríguez, F., Metzeltin, D., Sprechmann, P., Trettin, R., Stams, G., Beltrán-Morales, L.F., 2004a. Upper Pleistocene and Holocene paleosalinity and trophic state changes in relation to sea-level variation in Rocha Lagoon, southern Uruguay. Journal of Paleolimnology, 32: 117-135.

García-Rodríguez, F., Sprechmann, P., Metzeltin, D., Scafati, L., Melendi, D.L., Volkheimer, W., Mazzeo, N., Hiller, A., Von Tümpling Jr., W. Scasso, F., 2004b. Holocene trophic state changes in relation to sea-level variation in Lake Blanca, SE Uruguay. Journal of Paleolimnology, 31: 99-115.

García-Rodríguez, F.,Witkowski, A., 2003. Inferring sea-level variation from relative percentages of *Pseudopodosira kosugii* in Rocha lagoon, SE Uruguay. Diatom Research, 18: 49-59.

Gebühr C., Wiltshire K.H., Aberle N., van Beusekom J.E.E.,Gerdts G., 2009. Influence of nutrients, temperature, light and salinity on the occurrence of Paralia sulcata at Helgoland Roads, North Sea. Aquatic Biology, 7: 185-197.

Gibling M.R., Fielding C.R., Sinha R. 2011. Alluvial valleys and alluvial sequences: towards a geomorphic assessment, in*:* Davidson S., Leleu S., North C. (Eds.) From River to Rock Record: The Preservation of Fluvial Sediments and Their Subsequent Interpretation, SEPM Special Publication, 97, pp. 423-447.

Green, A.N., Cooper, J.A.G., Wiles, E.A., De Lecea, A.M., 2015. Seismic architecture, stratigraphy and evolution of a subtropical marine embayment: Maputo Bay, Mozambique. Marine Geology, doi: 10.1016/j.margeo.2015.06.005.

Grimm, A.M., Ferraz, S.E.T., Gomes, J., 1998. Precipitation Anomalies in Southern Brazil associated with “El Niño” and “La Niña” Events. Journal of Climate,11: 2863-2880.

Grimm, A.M., Bartros, V.R., Doyle, M. E., 2000. Climate variability in Southern South America associated with “El Niño” and “La Niña”events. Journal of Climate,13(1): 35-58.

Hammer, O., Harper, D.A.T., Rian, P.D.,2001. Past: Palaeonthological statistics software package for education and data analysis. Version. 1.37.

Harwood, K., Brown, A.G., 1993, Fluvial processes in a forested anastomosing river; flood partitioning and changing flow patterns: Earth Surface Processes and Landforms, 18: 741–748.

Hill, P.J., De Deckker, P., Von der Borch, C., Murray-Wallace, C.V., 2009. Ancestral Murray River on the Lacepede Shelf, southern Australia: Late Quaternary migrations of a major river outlet and strandline development. Australian Journal of Earth Sciences, 56: 135–157

Imbrie, J., Hays, J.D., Martinson, D.G., McIntyre, A., Mix, A.C., Morley, J.J., Pisias, N.G., Prell, W.L., Shackleton, N.J., 1984. The orbital theory of Pleistocene climate: support from a revised chronology of the marine ^{18}O record, in: Berger, A.L., Imbrie, J., Hays, J., Kukla, G., Saltzman, B. (Eds.), Milankovitch and Climate 1. Reidel, Boston, pp. 269-305.

Iriondo, M.H., Garcia, N.O., 1993. Climatic variations in the Argentina plains during the last 18.000 years. Palaeogeography, Palaeoclimatology, Palaeoecology, 101: 209-220.

Jones, L.S., Harper, J.T., 1998, Channel avulsions and related processes, and large-scale sedimentation patterns since 1875, Rio Grande, San Luis Valley, Colorado: Geological Society of America, Bulletin, 110: 411–421

Juggins, S., 2003. C2 software for ecological and palaeoecological data analysis and visualization, version 1.5. Newcastle University, Newcastle.

Karpuz, N.K., Schrader, H., 1990. Surface sediment diatom distribution and Holocene paleotemperature variations in the Greenland, Iceland and Norwegian Sea. Paleoceanography, 5: 557-580.

Ledru, M.P., 1993. Late Quaternary evironmental and climatic changes in Central Brazil. Quaternary Research, 39: 90-98.

Ledru, M.P., Braga, P.I.S.; Soubiès, F., Martin, L., Suguio, K., Turcq, B., 1996. The last 50,000 years in neotropics (Southern Brazil): evolution of vegetation and climate. Paleogeography,Paleoclimatology, Paleoecology, 123: 239-259.

LeGrande, A.N., Schmidt, G.A., 2008. Ensemble, water isotope-enabled, coupled general circulation modeling insights into the 8.2 ka event: Paleoceanography, 23, doi: 10.1029/2008PA001610.

Leite, A.M., Barbalho, F., Weschenfelder, J., Pinto, R.L., 2013. Ostracodes do quaternario da Laguna dos Patos, RS. Paleontolia em Destaque, Boletim Informativo Sociedade Brasileira de Paleontololgia, Nesp, 132p.

Lopes, R.P., Kinoshita, A., Figueiredo, A.M.G., Baffa, O., Buchmann, F.S.C., 2010. ESR dating of Pleistocene mammal teeth and its implications for the biostratigraphy and geologic evolution of the Rio Grande do Sul coastal plain, southern Brazil. Quaternary International, 212(2): 213-222.

Mäder, G., Fregonezi, J. N., Lorenz-Lemke, A. P., Bonatoo, S. L.. Freitas, L. B., 2013.Geological and climatic changes in quaternary shaped the evolutionary history of *Calibrachoa heterophylla*, an endemic South-Atlantic species of petunia. BMC Evolutionary Biology, 13, 178: doi:10.1186/1471-2148-13-178.

Mallinson, D., Riggs, S.R., Thieler, E.R., Foster, D.S., Culver, S.J., Corbett, D.R., Farrell, K.,Wehmiller, J.F., 2005. Late Neogene evolution of the northeastern North Carolina coastal system: filling the Albemarle Embayment. Marine Geology, 217: 97-117.

Marques, W. C., O.O. Möller, 2009.Variabilidade temporal em longo período da descarga fluvial e níveis de água da Lagoa dos Patos, Rio Grande do Sul, Brasil, Rev. Bras. Recursos Hídricos, 13: 155–163.

Martin, L., Dominguez, J.M.L., Bittencourt, A.C.S.P., 2003. Fluctuating Holocene sea-levels in Eastern and Southeastern Brazil: evidence from multiple fossil and geometric indicators. Journal of Coastal Research 19: 101-124.

Martins, L.R., Urien, C.M., Corrêa, I.C.S., Martins, I.R., 1996. Late Quaternary processes along the Rio Grande do Sul continental shelf (southern Brazil). Notas Técnicas, 9: 62-68.

Marwan, N., Trauth, M.H., Vuille, M., Kurths, J. 2003. Comparing modern and Pleistocene ENSO-like influences in NW Argentina using nonlinear time series analysis methods. Climate Dynamics, 21: 317-326.

McQuoid, M.R., Hobson, L.A., 1998. Assessment of palaeoenvironmental conditions on Southern Vancouver Island, British Columbia, Canada, using the marine tychopankter *Paralia sulcata* Diatom Research, 13: 311–321.

McQuoid, M.R., Nordberg, K ., 2003. The diatom Paralia sulcata as an environmental indicator species in coastal sediments. Estuarine Coastal and Shelf Sciences, 56: 339–354.

Medeanic, S., Corrêa I.C.S., 2010. Climatic changes in the coastal plain of the Rio Grande do Sul state in the Holocene: palynomorph evidences. Pan-American Journal of Aquatic Sciences, 5: 287-297.

Medeanic, S., Dillenburg, S.R., 2001. The Early Holocene palaeoenvironment history of the Tramandaí Lagoon (RS, Brazil), in: V Reunião do Quaternário Ibérico, I Congresso do Quaternário de Paises de Línguas Ibéricas 6, Actas, Lisboa, Portugal, pp. 402-405.

Medeanic, S., Dillenburg, S.R., Toldo Jr, E.E., 2001. Novos dados palinológicos da transgressão marinha pós-glacial em sedimentos da Laguna dos Patos. Revista Universidade Guarulhos, 6: 64-76.

Medeanic, S., Hirata, F., Dillenburg, S.R., 2010. Algal Palynomorphs Response to Environmental Changes in the Tramandai Lagoon, Southern Brazil, and Climatic Oscillations in the 20th Century. Journal of Coastal Research, 26: 726-735.

Medeanic, S., Jankovská, V., Dillenburg, S.R., 2003. The implications of green algae (Chlorophyta) for palaeoecological reconstruction of the Holocene lagoon system in the Tramandai Lagoon region, Rio Grande do Sul, Brazil. Acta Palaeobotanica, 43: 113-123.

Nakanishi, T., Tanabe, S., Kimura, K., Nakashima, R., Uchiyama, M., Shibata, M., 2011. Sedimentary facies, diatom assembleages, physical properties and radiocarbon ages of the latest Pleistocene to Holocene incised-valley fills under the southern Nakagawa Lowland, Kanto Plain, Japan. Bulletin of the Geological Survey of Japan, 62 (1/2): 3-46.

Nguyen, V.L., Ta, T.K.O., Tateishi, M., 2000. Late Holocene depositional environments and coastal evolution of the Mekong River Delta, Southern Vietnam. Journal of Asian Earth Science, 18: 427-439.

Nguyen, V.L., Ta, T.K.O., Saito, Y., 2010. Early Holocene initiation of the Mekong River delta, Vietnam, and the response to Holocene sea-level changes detected from DT1 core analyses. Sedimentary Geology, 230: 146-155.

Oberhänsli, H., Heinze, P., Diester-Haass, L., Wefer, G., 1990. Upwelling off Peru during the last 430,000 years and its relationship to the bottom-water environment, as deduced from coarse grain-size distributions and analyses of benthic foraminifers at holes 679D, 680B, and 681B, LEG 112, in: Suess, E.,Von Huene, R., (Eds.), Proc Ocean Drilling Program. Scientific Results, 112: 369–382.

Pappas, J. L., Stoermer, E.F., 1996. Quantitative method for determining a representative algal sample count. Journal of Phycology, 32: 693-696.

Raynal, O., Bouchette, F., Certain, R., Sabatier, P., Lofi, J., Seranne, M., Dezileau, L., Briqueu, L., Ferrer, P., Courp, T., 2010. Holocene evolution of a Languedocian Lagoonal environment controlled by inherited coastal morphology (Northern Gulf of Lions, France). Bulletin de la Socièté Géologique de France, 181(2) : 211-224.

Sabatier, P., Dezileau, L., Barbier, M., Raynal, O., Lofi, J., Briqueu, L., Condomines, M., Bouchette, F., Certain, R., Van Grafenstein, U., Jorda, C., Blanchemanche, P., 2010. Late-Holocene evolution of coastal lagoon in Gulf of Aigues Mortes (South of France), Bulletin de la Société Géologique de France,181(1): 27-36.

Santos, C.B. dos., 2015. Paleoecologia de diatomáceas como subsídios para o conhecimento da evolução paleogeográfica da região costeira do Rio Grande do Sul, Brasil. (PhD thesis), 221p. Programa de Pós-graduação em Geociências. Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil.

Schumm, S.A., Erskine, W.D.,Tilleard, J.W., 1996. Morphology, hydrology, and evolution of the anastomosing Ovens and King Rivers, Victoria, Australia: Geological Society of America, Bulletin, 108: 1212–1224.

Shepard, F.P., 1954. Nomenclature based on sand-silt-clay ratios. Journal of Sedimentary Petrology, 24 (3): 151-158.

Stabell, B., 1980. Holocene shorelevel displacement in Telemark, southernNorway. Norsk Geologisk Tidsskrift, 60: 71–81.

Stouthamer, E., Berendsen, H.J.A., 2000, Factors controlling the Holocene avulsion history of the Rhine–Meuse Delta (The Netherlands): Journal of Sedimentary Research, 70: 1051–1064.

Suguio K and Martin L. 1996. The role of neotectonics in the evolution of the Brazilian coast. Geonomos, 4(2): 45-53.

Ta, T.K.O., Nguyen, V.L., 2000. Diatom - indicator of sedimentary environments and sealevel changes in Late Pleistocene–Holocene. Journal of Science of the Earth, 22: 226-233.

Ta, T.M.O., Nguyen, V.L., Tateishi, M., Kobayashi, I., Saito, Y., 2001. Sedimentary facies, diatom and foraminifer assemblages in a Late Pleistocene/Holocene incised-valley sequence from the Mekong River delta, Bentre Province, southern Vietnam: the BT2 core. Journal of Asian Earth Sciences, 20: 83-94.

Ta, T. M.O., Nguyen, V.L., Tateishi, M., Kobayashi, I., Tanabe, S., Saito, Y. 2002a.

Holocene delta evolution and sediment discharge of the Mekong River, southern Vietnam. Quaternary Science Reviews, 21:1807–1819.

Ta, T.K.O., Nguyen, V.L., Tateishi, M., Iwao, K., Saito, Y., 2002b. Sediment facies and Late Holocene progradation of the Mekong River Delta in Bentre Province, southern Vietnam: an example of a tide- and wave-dominated delta. Sedimentary Geology, 152 (7): 313-325.

Tesson, M., Labaune, C. and Gensous, B., 2005. Small rivers contribution to the Quaternary evolution of a Mediterranean littoral system: The western gulf of Lion, France. Marine Geology, 223: 299-311.

Tjallingii, R., Stattegger, K., Wetzel, A., Phach, P.V., 2010. Infilling and flooding of the Mekong River incised-valley during deglacial sea-level rise. Quaternary Science Reviwes, 29: 1432-1444.

Toldo Jr., E.E., Ayup Zouain, R.N., Corrêa, I.C.S., Dillenburg, S.R., 1991. Barra Falsa: Hipótese de um paleocanal holocênico de comunicação entre a Laguna dos Patos e o Oceano Atlântico. Pesquisas, 18(2): 99-103.

Toldo Jr., E.E., Dillenburg, S.R., Corrêa, I.C.S., Almeida, L.E.S.B., 2000. Holocene Sedimentation in Patos Lagoon Lagoon, Rio Grande do Sul, Brazil. Journal of Coastal Research, 16(3): 816-822.

Tomazelli, L.J.,Villwock, J.A., 2000. O Cenozóico no Rio Grande do Sul: Geologia da Planície Costeira, in: Holz, M., De Ros, L.F., (Eds.). Geologia do Rio Grande do Sul. Edição CIGO/UFRGS, Porto Alegre, Rio Grande do Sul, pp. 375-406.

Tudhope, A.W., Chilcott, C.P., McCulloch, M.T., Cook, E.R., Chappell, J., Ellam, R.M., Lea, D.W., Lough. J.M., Shimmield, G.B., 2001.Variability in the El Niño Southern Oscillation through a glacial-interglacial cycle. Science, 291: 1511–1517.

Turcq, B., Pressinotti, M.M.M., Martin, L., 1997. Paleohydrology and paleoclimate of past 33,000 years at the Tamanduá River, Central Brasil. Quaternary Research, 47: 284-294.

Van der Hammen, T., Absy, M.L., 1994. Amazonia during the Last Glacial. Palaeogeography Palaeoclimatology Palaeoecology, 109: 247-261.

Vaz, A. C., Möller Jr., O.O., Almeida, T. L. de., 2006. Análise quantitativa da descarga dos rios afluentes da Lagoa dos Patos. Atlântica, 28: 13-23.

Vilanova, I., Prieto, A.R., Epinosa, M.A., 2006. Paleoenvironmental evolution and sea-level fluctuations along the southeastern Pampa grasslands coast of Argentina during the Holocene. Journal of Quaternary Sciences, 21(3): 227-242.

Villwock, J.A., Tomazelli, L.J., 1995. Geologia costeira do Rio Grande do Sul. Porto Alegre: UFRGS, Notas Técnicas, 8: 1-45.

Villwock, J.A., Tomazelli, L.J., Loss, E.L., Dehnhardt, E.A., Horn Fo., N.O., Bachi, F.A., Dehnhardt, B.A., 1986. Geology of the Rio Grande do Sul Coastal Province, in: Rabasa, J. (Ed.), Quaternary of South America and Antarctic Peninsula. Balkema Publishers, Rotterdam, pp. 4-11.

Wanner, H., Beer, J., Bütikofer, J., Crowley, T., Cubasch, U., Flückiger, J., Goosse, H., Grosjean, M., Joos, F., Kaplan, J.O., Küttel, M., Müller, S.A., Prentice, I.C., Solomina, O., Stocker, T.F., Tarasov, P., Wagner, M., Widmann, M., 2008. Mid- to late Holocene climate change: an overview. Quaternary Science Reviews, 27: 1791–1828.

Weschenfelder, J., Baitelli, R., Corrêa, I.C.S., Bortolin, E.C., Santos, C.B.dos., 2014. Quaternary incised-valleys in southern Brazil coastal zone. Journal of South American Earth Sciences, 55: 83-93.

Weschenfelder, J., Corrêa, I.C.S., Aliotta, S., Baitelli, R. 2010a. Paleochannels related to Late Quaternary sea-level changes in southern Brazil. Brazilian Journal of Oceanography, 58: 35-44.

Weschenfelder, J., Corrêa, I.C.S., Toldo Jr., E.E., Baitelli, R., 2008a. Paleocanais como indicativo de eventos regressivos quaternários no nível do mar no sul do Brasil. Revista Brasileira de Geofísica, 3(26): 367-375.

Weschenfelder, J., Corrêa, I.C.S., Toldo Jr., E.E., Baitelli R., 2010b. A drenagem pretérita do Rio Camaquã na costa do Rio Grande do Sul. Pesquisas em Geociências, 37 (1):13-23.

Weschenfelder, J., Medeanic, S., Corrêa, I.C.S., Aliotta, S., 2008b. Holocene palaeoenvironment of the Bojuru region, Southern Brazil. Journal of Coastal Research, 24: 99-109.

Yoshida, M., Inoue, H., Hoyanagi, K., Yanagisawa, Y., Oishi, M., Yoshida, H., 2011. High-resolution sequence stratigraphy in an incised-valley system on the basis of sedimentary organic matter, sulfur content and fossil diatom: an example from Miocene to Pliocene Tatsunokuchi Formation, Iwate Prefecture, Northeast Japan. Journal of the Sedimentological Society of Japan ,70 (2): 63-79.

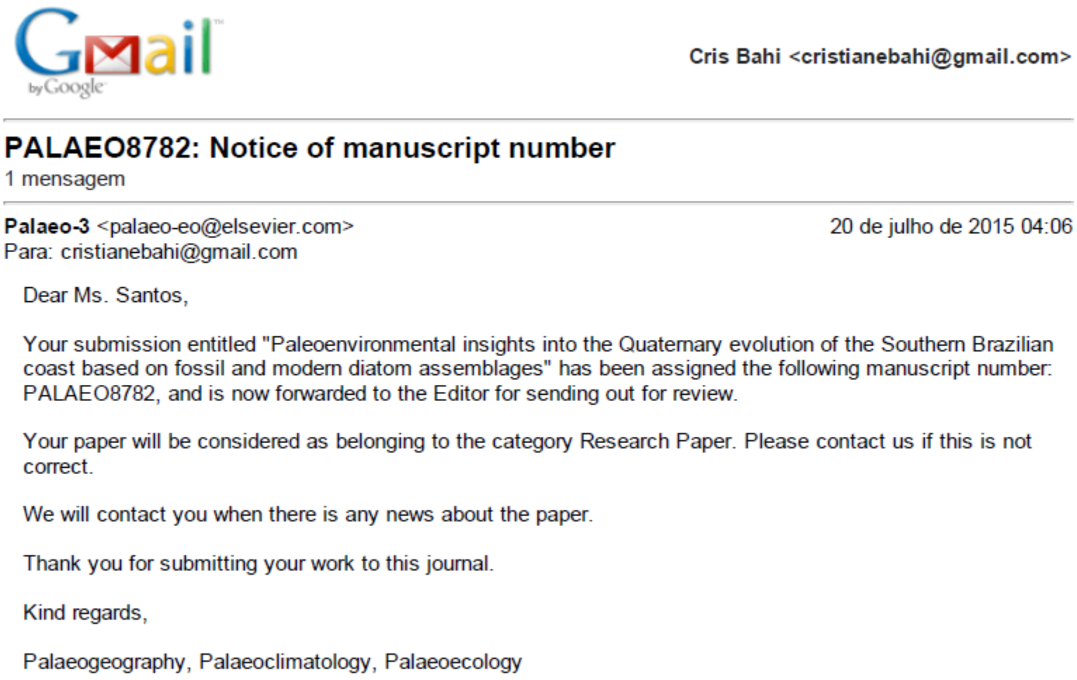
Zaitlin, B.A., Dalrymple, R.W., Boyd, R., 1994. The stratigraphic organisation of incised-valley systemsassociated with relative sea-level change. In: Dalrymple, R.W., Boyd, R.J., Zaitlin, B.A., (Eds.), Incised Valley Systems: Origin and Sedimentary Sequences, Society for Sedimentology Geology (Special Publication) 51, pp.45-60.

Zong ,Y., 1997. Implications of *Paralia sulcata* abundance in Scottish isolation basins. Diatom Research, 12: 125–150.

Zong, Y., Huang, K., Yu, F., Zheng, Z., Switzer, A., Huang, G., Wang, N., Tang, M., 2012. The role of sea-level rise, monsoonal discharge and the palaeo-landscape in the early Holocene evolution of the Pearl River delta, southern China.Quaternary Science Reviews, 54: 77-88.

CAPÍTULO VII

PALEOENVIRONMENTAL INSIGHTS INTO THE QUATERNARY EVOLUTION OF THE SOUTHERN BRAZILIAN COAST BASED ON FOSSIL AND MODERN DIATOM ASSEMBLAGES



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VII- PALEOENVIRONMENTAL INSIGHTS INTO THE QUATERNARY EVOLUTION OF THE SOUTHERN BRAZILIAN COAST BASED ON FOSSIL AND MODERN DIATOM ASSEMBLAGES

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1. ABSTRACT

Diatom assemblages provide strong basis for detailed interpretations of paleoceanography and diatom paleoecology of the southern Brazilian coast. They can reflect changes in sediment production and transport providing additional insights into coastal evolution. Nine stratigraphic cores obtained in the coastal plain, shelf and continental slope and thirteen bottom samples of the Patos Lagoon provide an excellent opportunity to use a paleoecological approach to study detailed Quaternary environmental changes in the southern coasts. In the interval studied, the basin sedimentation occurred in a marine-dominated environment related to humid periods prior to 43,500 years BP. *Paralia sulcata* is dominant in the cores, occurring continuously from Late Pleistocene to Holocene, but is rare in the modern communities. Freshwater assemblages occurred continuously but in very low density during Pleistocene. Abrupt changes in sedimentation are recorded and a shallow-estuarine environment developed during Last Glacial Maximum. Sea-level rose rapidly (~ 2.0 cm/yr) during Holocene, which is responsible for the progressive drowning of the coast. Marine-dominated sequences are identified in distinct areas of the coastal plain. The spatial distribution of modern associations is controlled by salinity gradient, wind action, and climate forcing strongly related to El Niño Southern

Oscillation (ENSO) activity. Three hyaline zones are identified related to *Aulacoseira veraluciae*, *Aulacoseira* sp.2 and *Cyclotella litoralis*.

Keywords: Diatom, Sea-level change, Late Pleistocene, Holocene, Seismic, Patos Lagoon, South America

2. INTRODUCTION

Sedimentary systems occurring along the southern Brazilian coast are a consequence of Quaternary high-frequency, glacio-eustatic, relative sea-level oscillations consistent with global sea-level changes (Corrêa, 1986, 1996; Villwock et al. 1986; Villwock and Tomazelli, 1995; Tomazelli and Villwock, 2000). This classic wave-dominated coast mantles a large shallow choked lagoon system. Patos Lagoon is strongly influenced by wind action and fluvial discharge (Möller et al. 2001; Möller and Fernandes, 2010; Marques, 2012, 2014). During El Niño events the NE winds are dominant; they enhance precipitation (Möller and Fernandes, 2010), which increases the freshwater influence by flushing the estuarine area (Garcia, 1997; Barros and Marques, 2012; Marques, 2012) and affects the spatial distribution and composition of organisms (Odebrecht and Abreu, 1998; Garcia et al. 2001, 2003, Odebrecht et al. 2005, 2010).

Diatoms are the main biological component of primary production in coastal systems and are considered one of the most successful groups of photosynthetic micro-organisms (Round et al. 1990; Mann, 1999). Preliminary microfossil investigations including observations of fossil diatoms, analyzed a distinct area of the southern Brazilian coastal plain and shelf (Medeanic et al. 2008; Weschenfelder et al. 2008a, 2014; Lima et al. 2013; Corrêa et al. 2013, 2014a,b). However, these studies included few diatom taxa that were associated with palynomorph and other microfossil records, which were used to infer changes in salinity along incised-valleys systems and barrier stratigraphy. Paleoecological studies based on diatom-inferred environmental changes are considered rare in this region (Medeanic et al. 2009; Santos, 2011, 2015; Hermany et al. 2013) compared to diatom analysis from modern sediments. The study of modern diatoms communities recorded in surface sediments of the coastal plain are restricted to the taxonomic composition and distribution of diatom taxa (Garcia-Baptista, 1993; Garcia-Baptista and Baptista, 1992; Garcia, 2006, 2010; Garcia and Souza, 2008; Garcia and Talgatti, 2008, 2011; Medeanic et al. 2008; Bergesch et al. 2009; Garcia and Odebrecht, 2008; Silva et al. 2010; Talgatti et al. 2014). However, the information provided by these ecological studies was not applied to interpret the fossil sequences and they did not attempt to produce detailed paleoecological information about environmental shifts in a dynamic scenario linked to sea-level changes.

This paper assesses the composition and distribution of fossil assemblages recorded in distinct environments of the southern Brazilian coast. Quaternary sea-level oscillations and its impact on coastal environments provide an excellent framework to explore fluvial and marine inputs interacting in the coastal plain transitional systems. We apply common multivariate statistical techniques to the fossil diatom assemblages from these sites to aid our interpretation. We also compare fossil and modern diatom taxa; abundant diatom taxa are highlighted as excellent indicators of environmental changes, including salinity, sediment composition and transport by incised-valleys systems. The goal is to provide simple and consistent outcomes and insights about the lagoon-environment hydrodynamic conditions during Late Pleistocene and Holocene, and contrast them against the modern coastal configuration.

3. GEOLOGIC AND OCEANOGRAPHIC OUTLINE

The southern Brazilian continental shelf is characterized by a low gradient (1.3 -1.4 m/km) and an average width of 125 km, gradually increasing southward, with a break zone around the 170 m isobath (Martins, 1984). The gradient of declivity is quite soft (1:1,000), increasing toward the continental slope. The slope has a convex form with declivities between1:40 a 1:60. It is wide and irregular in relief, with several canyons and submarine channels that appear related to fluvial drainage (Martins et al. 1972). Both the shelf and continental slope are considered stable, subject to epirogenic movements and shaped by sea-level oscillations and local hydrodynamic conditions (Corrêa, 1987).

The southern Brazilian coastal plain is wave dominated and characterized by wide lowlands spanning ~33,000 km^2. A broad barrier-lagoon system and a large warm, temperate shallow lagoon are the most remarkable physiographic features in the actual coastal plain. Patos Lagoon is considered the world largest choked lagoon

(10,000 km^2; 240 km long), representing one of the main water sources of South America. The main axis of the lagoonal system extends over 180 km in a NE–SW direction, including an estuarine area that is 60 km long (Calliari et al. 2009). Both the bottom and margins of the lagoon are influenced by medium- to high-energy waves up to 1.6 m (Toldo Jr. et al. 2000). The longshore current direction is clearly bidirectional and highly regular towards both SW and NE (Jung and Toldo Jr., 2012). The astronomical tide is semi-diurnal; near the channel entrance, the mean amplitude is 0.47 m (Garcia, 1997). Patos Lagoon has a huge surface area but only a single inlet, the Rio Grande channel, which exchanges water with the Atlantic Ocean. The Barra Falsa channel is the principal feature on the southeast margin of the lagoon, in the Bojuru area. The Barra Falsa is located 87 km north of the present Rio Grande channel, at the southeast margin of the lagoon and it partially cross cuts the Pleistocene sand barrier (Toldo Jr. et al. 1991).

Patos Lagoon receives freshwater from the Guaíba Hydrographic Basin (GHB), which has an area of ~200,000 km^2, and is a primary contributor of freshwater to the lagoon. The main contributing rivers are the Jacuí and Taquari, which flow through the GHB, and the Camaquã River, which flows into the southern region of the lagoon. The Jacuí River basin is 710 km long, draining an area of 71,600 km^2. This basin is characterized by intense land use for agriculture and energy generation (FEPAM, 2010). The Camaquã River basin has a surface of 24,000 km^2 and is currently creating a delta system in the central portion of the western margin of the lagoon. According to Vaz et al. (2006) the mean annual water discharge from the Jacuí River is 801 m^3/s, followed by the Taquari River (452 m^3/s) and the Camaquã River (307 m^3/s). However, the mean annual discharge of freshwater into Patos Lagoon is 2,400m^3/s (Marques and Möller, 2009). A recent study performed in the Guaíba fluvial system suggest that the mean annual suspended solids discharge from GHB towards the lagoon corresponds to 1.1 x 10^6 t/yr, of about 400,000 m^3 (2,650 kg/ m^3) of sediments. This corresponds a yearly sediment supply rate of 0.11 kg/m^2 (Andrade Neto et al. 2012).

The actual climate conditions in the southern Brazilian coast, including Patos Lagoon and adjacent areas, are strongly influenced by ENSO activity (Grimm et al. 1998, 2000; Fernandes et al. 2002) and the South Atlantic Convergence Zone (SACZ). Interannual variability of rainfall is also related to anomalies in sea surface temperature (SST). According to Möller et al. (2001) the seasonal averages of water discharge is variable with low values (700 m^3/s) recorded during summer and high values (up to 3,000 m^3/s) recorded during spring. Peak values of 8,000 and 12,000 m^3/s, can be observed during El Niño events (Möller et al. 1996). The lagoonal hydrodynamics is influenced both by fluvial discharge and the action of the winds (Möller and Fernandes, 2010) actuating in the salinization and desalination processes (Möller and Castaing, 1999). Wind action is to the primary control on estuarine circulation. Marine intrusions are favored during periods of higher temperatures, lower precipitation, and SW wind action, which increases the salinity of the estuary. Freshwater inputs are associated with lower salinity ranges related to high precipitation and winds from the NE (Möller and Castaing, 1999). NE winds typically dominate throughout most of the year while SW winds increase during fall and winter as frontal systems become frequent (Möller et al. 2001). According to Marques (2012) freshwater discharge contributes to the circulation pattern, the mixing and exchange process, and the transport of suspended sediments along the coastal zone varying from monthly, seasonal, and longer time scales (Marques et al. 2010, 2011).

4. MATERIALS AND METHODS

4.1 Sampling and Dating

Stratigraphic cores were obtained in some environments in the Rio Grande do Sul (RS) coastal zone: in the Patos Lagoon interior (cores Bo, Mo, Pa, T15, T19), extension of the Barra Falsa channel (core B2, TBJ-02), Peixe Lagoon (core T9), shelf (T103) and continental slope (T22), (Fig. 19 a,b). Core TBJ-02, which was analyzed by Medeanic and Dillenburg (2001), was correlated with core B2 and was used for supplementary radiocarbon dates (Table 12). A total of 39 surface samples were obtained around the cores Bo, Mo and Pa at a distance of 500 to 1000 m away from core sites, following the four cardinal directions: North (N), South (S), East (E) and West (W). Only 13 of these were selected for diatom analysis: B2, B3, B4, B6, M3, M5, M9, M12, Pa3, Pa5, Pa6, Pa8, Pa13 (Table 13, Fig. 19 c-e). Fossil mollusc shells present in the core samples were collected and processed to obtain information about the paleoenvironmental conditions and to determine potential carbon reservoir effects for radiocarbon dating. Accelerator mass spectrometry (AMS) dates were obtained by Beta Analytic Inc., Miami, FL, USA and Federal University of Bahia (cores T19, T15), (Table 14). The general characteristics and textural classifications for both core and surface samples were based on Shepard (1954).

4.2 Diatom analysis

Diatom sub-samples were treated with an aqueous solution of 10% HCl and 5% KOH. After rinsing with distilled water, diatom extracts were dried onto coverslips and mounted on microscope slides using Naphrax®, which is a permanent mounting resin with a high refractive index. Samples were analyzed with a transmitted light Zeiss® microscope. Relative abundances of fossil diatom assemblages were calculated based upon counts of at least 600 valves and 80 % efficiency sampling based on Pappas and Stoermer (1996). Diatom taxa were then classified according to the following categories based upon relative abundance: dominant: >50%, abundant: 5 to 50%, uncommon: 1 to 5%, and rare: < 1%. The results were plotted in biostratigraphic diagrams using the software program C2® (version 1.5; Juggins, 2003).

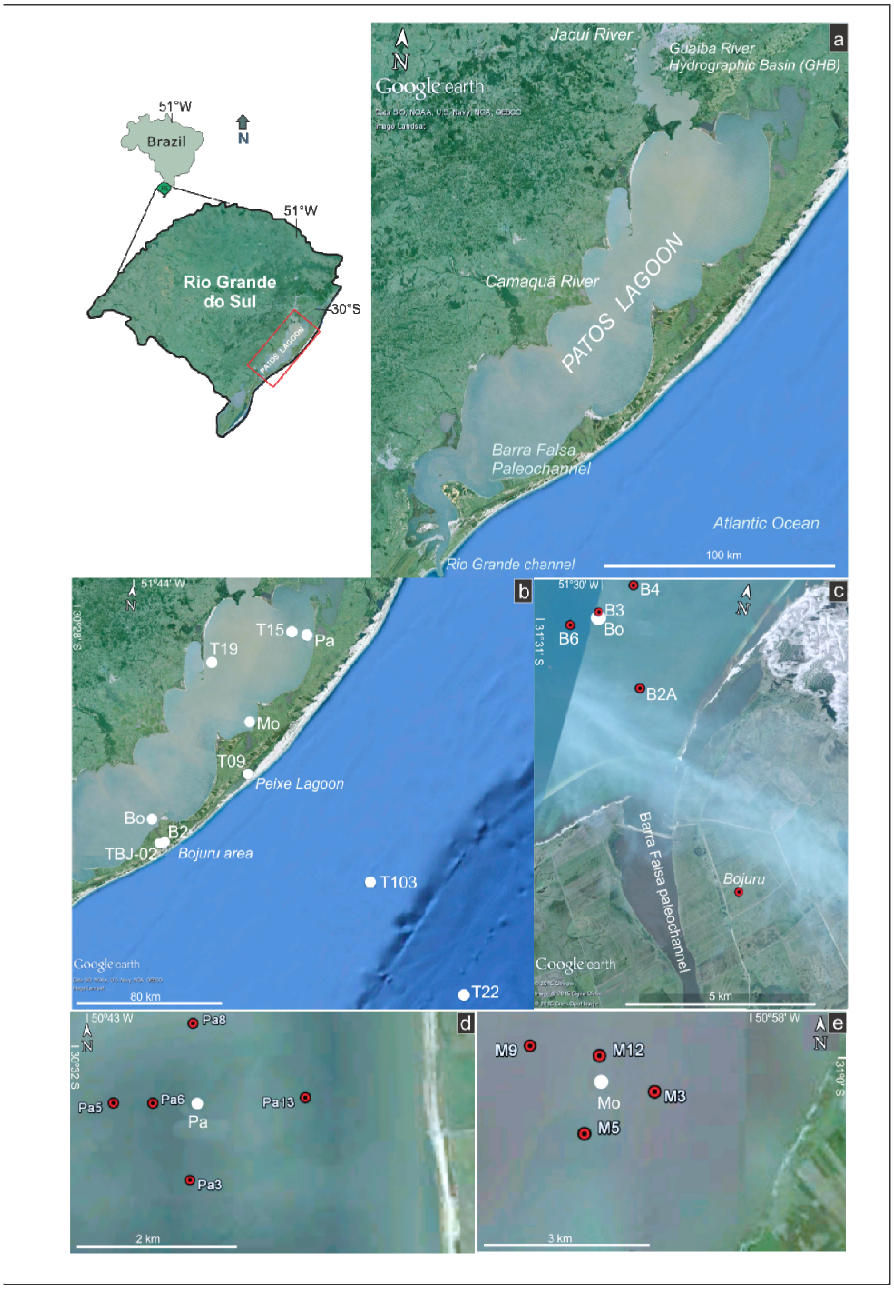

Figure 19. Location map of the southern Brazilian coast showing position of cores and surface samples used in this study (see also tables 12, 14).

4.3 Statistical analyses

Multivariate statistical techniques for analyzing ecological data of diatom assemblages were used to identify distribution patterns and composition of diatom taxa across distinct sites in the southern Brazilian coast. Principal Component Analysis (PCA) was used to summarize the paleoecological information by means of principal individuals in fossil assemblages. Detrended Correspondence Analysis

(DCA) and Canonical Correspondence Analysis (CCA) ordination, using the software program PAST$^{®}$ (version 3.06), (Hammer et al. 2001) were used to analyze fossil and modern assemblages. Hierarchical cluster analysis, using the Ward's Method with intervals based on Square Euclidian Distance, using the computer program SPSS$^{®}$ (version AMOS 18), (Arbuckle, 2009) was used to unify diatom groups. Both fossil and modern diatom taxa were selected based on two criteria: (1) frequency of occurrence in at least four samples; (2) relative abundance greater than 1 % in at least two samples. The environmental data of sand and silt/clay and species matrix of the most frequently and abundant occurring diatom species were used to perform statistical analyses commonly used in diatom proxies. Monte Carlo significance test indicated that the ordination diagram is significant ($p < 0.05$), validating the adequacy of the statistical methods.

5. RESULTS

5.1 Statistical analyses applied to fossil and modern assemblages

A total of 296 diatom taxa were identified (Table 15) and 232 of these species these were recorded only in core sediments, and nine diatom taxa were recorded only in surface samples; 55 occurred in both core and surface sediments. Diatom associations recorded in modern communities are displayed in Table 16.

5.1.1 Principal components of fossil assemblages: ordination and reduction

Due to the high diversity of the diatom taxa in fossil associations the PCA analysis was used to summarize the paleoecological information by means of principal individuals in diatom assemblages. The main criteria of ordination and reduction were based on the frequency of occurrence in at least four samples and abundance greater than 1%. Out of 287 fossil diatom taxa identified in core sediments, only 22 of them are considered in the analyses. The extraction method was based on principal components and minimum eigenvalues (> 0.1) with varimax normalized rotation were used to define the most representative groups of diatom assemblages. Five axes of the principal components analysis (Fossil Groups G1-G5) were recognized, accounting a total of 94.6 % of the cumulative variance (Table 17). The most important temporal trends in fossil diatom assemblages are displayed in Figure 20.

Fossil Group 1 (G1) is mainly composed of *C. radiatus* (marine/marine-brackish, euryhaline) and *A. veraluciae* (freshwater planktonic) followed by *Aulacoseira* sp.2, *P. borealis*, *S. martyi* and *T. granulata*. It represents a mixing between freshwater and marine inputs typical of estuarine conditions (cumulating 31.3 % of the total variance). Highest relative contribution of Group 1 is related to the presence of freshwater taxa related to MIS 2, closely linked to incised-valleys systems. During the Holocene, the contribution of G1 is related to the marine/marine-brackish taxa *C. radiatus*. After 2,000 yr BP, the increase of G1 is related to progressively more estuarine influence resulting from sea-level fall and closure of channels that have remained active through the Late Holocene. In the modern coastal configuration, both *A. veraluciae* and *Aulacoseira* sp.2 are dominant and abundant in the bottom sediments of Patos Lagoon.

Fossil Group 2 (G2) is indicative of marine conditions, suggesting submergence and deepening of coastal environments, and it is strongly related to sea-level oscillations after the Last Glacial Maximum (LGM). The group occurs continuously from the Late Pleistocene to the late Holocene (explained by a total of 53 % of cumulative variance). During the Pleistocene, *P. sulcata* is associated with *C. striata*, *C. litoralis*, *P. nitidus*, *P. panduriforme* and *T. nitzschioides*. Also, both taxa are considered abundant in marine environments of the outer shelf and the continental slope. Very low contribution of *P. sulcata* are observed during LGM (4 %). However, the dominance of this species in the southern Brazilian coast is associated mainly with the Holocene, when very high percentages are recorded. At around 11,500-10,240 cal years BP, *P. sulcata* is accompanied by *T. nitzschioides*. Afterwards, high contribution of G2 is related mainly to *P. sulcata* (ranging from 20 to 100 %). In the present-day conditions, the abundance of G2 is associated to *C. litoralis* and *P. sulcata* (reaching a total of 25.4 % of relative abundance).

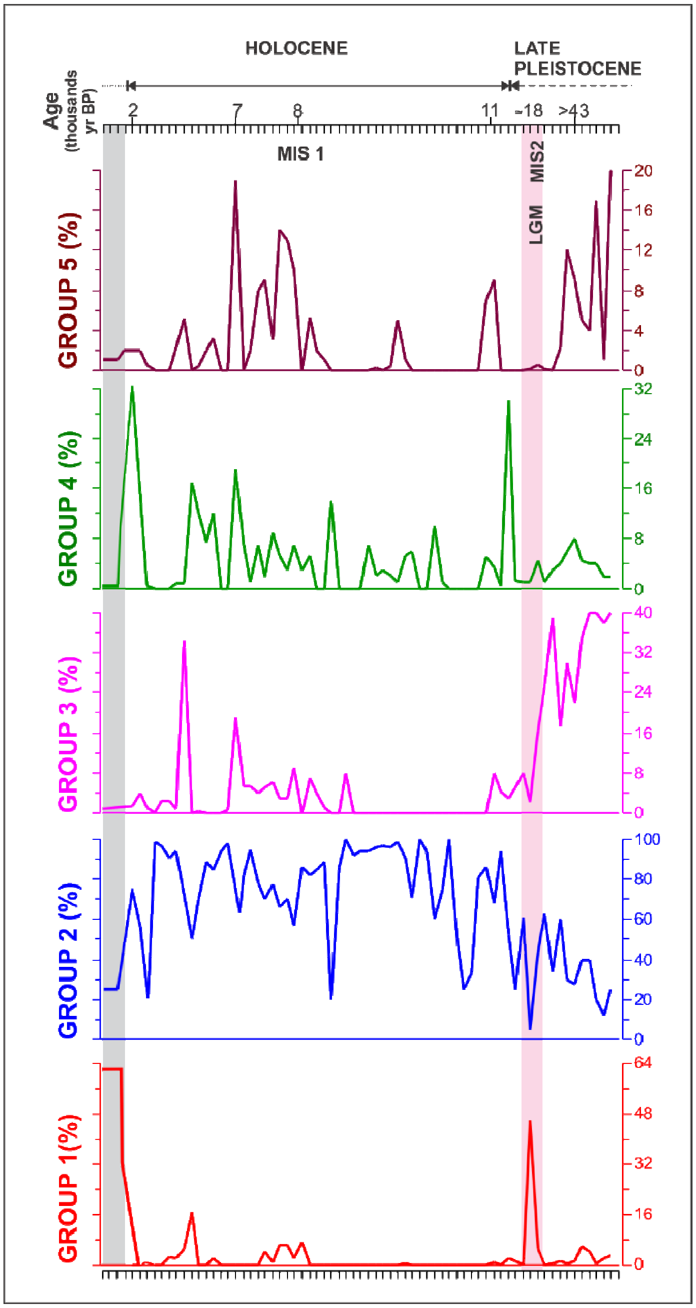

Figure 20. Diagram showing the relative contribution of five diatom groups established from the PCA analysis from Late Pleistocene to late Holocene (> 43,500 yr BP to 2,150 yr BP) based on stratigraphic cores obtained in distinct environments of southern Brazilian coast. Modern diatom data are used to infer changes in the actual coastal configuration (grey shadding). The Last Glacial Maximum (~18,000 yr BP) is indicted by pink shadding (See Table 17).

Fossil Group 3 (G3) explains 84.2 % of the total variance and it is composed by marine/marine-brackish euryhaline species, such as *A. splendens*, *C. belgica*, *D. surirella* and *D. minor*. The highest relative contribution of *A. splendens* and *C. belgica* occurs in ages greater than 43,500 yr BP indicating pelagic conditions and rising sea level. G3 is absent in a part of the early to middle-Holocene. The highest contribution of G3 occurs before the Mid-Holocene High Stand (MHHS), related to occurrence of *A. splendens*, *D. minor* and *D. surirella*. Afterwards, very low contributions of G3 are recorded.

The presence of *A. sculptus*, *P. disculoides*, *T. oestrupii* and *T. favus* in the *Fossil Group* 4 (G4) is explaining by a total of 84.9 % cumulative variance. Similar to G2, it occurs continuously from the Pleistocene to the Holocene. In samples older than 43,500 yr BP, both diatom taxa are abundant and only *T. oestrupii* is recorded in the outer shelf. The highest contribution of G4 occurs after the LGM and before 11,500-10,240 cal years BP, closely linked to the occurrence of *P. disculoides*, *T. oestrupii* and *T. favus*. Between 8,420-7,930 and after 7,640-7,430 cal years BP, they are abundant; although near the flooding maximum (MHHS) very low contributions are recorded. Around 2,150 yr BP, very high contributions of *P. disculoides* and *T. favus* are associated with the initial stage of estuarine conditions with a high marine influence in Patos Lagoon. In the present-day configuration, the G4 is rare.

Fossil Group 5 (G5) is composed of the planktonic marine/marine-brackish taxa *A. kitonii* and *A. senarius*, which explain a total of 92.2 % of the cumulative variance. High contributions of *A. senarius* are observed during the Late Pleistocene in samples older than 43,500 yr BP. However, near the LGM, very low percentages are recorded. Afterwards, it is accompanied by *A. kitonii* and several peaks are recorded. High contributions are observed ~ 7,000 yr BP. The marine taxa *A. kitonii* is absent during the late Holocene and only *A. senarius* has persisted in the bottom sediments of the modern Patos Lagoon.

5.1.2 Diatom distribution and sediment composition

The correlation between fossil diatom distribution and sediment composition was determined through Canonical Correspondence Analysis (Fig. 21). The first CCA axis 1= 0.2 (97.24 %) explains a large diatom taxa variance due to environmental variables in comparison to axis 2= 0.0005 (2.76 %). The silt and clay sediments, core sites located in the outer shelf (T103), slope (T22), Patos Lagoon (core Pa) and thirteen diatom taxa (positively related to axis 1) are clustered on the right side of the CCA diagram. Diatom species associated with the northeast margin of Patos Lagoon are *A. splendens*, *C. belgica*, *D. surirella* and *T. oestrupii*. The association of *C. litoralis*, *P. panduriforme*, *T. nitzschioides* and *P. nitidus* is linked to outer shelf (T103). Diatom taxa occurring in continental slope (T22) are *Aulacoseira* sp.2, *C. radiatus*, *P. borealis*, *S. martyi*, and *T. granulata*. On the other hand, the left side of the CCA diagram clustered core sites located in the interior of Patos Lagoon (Mo, Bo), the coastal plain (B2) and sand deposition, which are linked to CCA axis 2. Diatom taxa associated with sand deposition are *A. veraluciae*, *A. sculptus*, *C. striata*, *P. sulcata*, *P. disculoides*, *T. favus* (positively related to CCA axis 2), followed by *A. senarius*, *A. kitonii* and *D. minor*, core sites Mo, Bo and B2 (negatively related to axis 2). Core sites T09, T15 and T19 were not included in the CCA analysis due to absence of detailed lithology data.

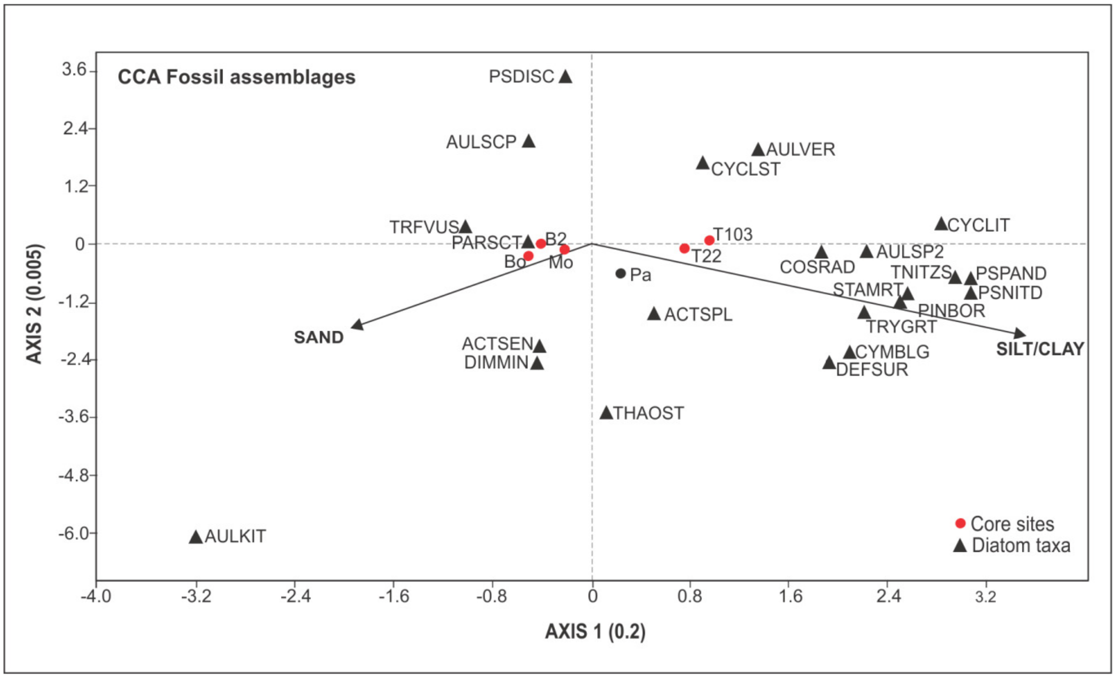

Figure 21. Ordination diagram generated by canonical correspondence analysis (CCA). Fossil diatom taxa (black triangle) and core sites (red dots) are combined with sand and silt/clay deposition. ACTSEN: *Actinoptychus senarius*, ACTSPL: *Actinoptychus splendens*, AULKIT: *Aulacodiscus kitonii*, AULVER: *Aulacoseira veraluciae*, AULSP.2: *Aulacoseira* sp.2, AULSCP: *Auliscus sculptus*, COSRAD: *Coscinodiscus radiatus*, CYCLIT: *Cyclotella litoralis*, CYCLST: *Cyclotella striata*, CYMBLG: *Cymatosira belgica*, DEFSUR: *Delphineis surirella*, DIMMIN: *Dimeregramma minor*, PARSCT: *Paralia sulcata*, PINBOR: *Pinnularia borealis*, PSNITD: *Psamodiscus nitidus*, PSDISC: *Psammococconeis disculoides*, PSPAND: *Psammodyction panduriforme*, STAMRT: *Staurosirella martyi*, TNITZS: *Thalassionema nitzschioides*, THAOST: *Thalassiosira oestrupii*, TRFVUS: *Triceratium favus*, TRYGRT: *Tryblionella granulata*.

5.1.3 Comparing fossil and modern assemblages

The CCA analysis does not explain that the spatial distribution of modern diatom taxa is related to sediment composition. However, both DCA and cluster analysis of the diatom data revealed a clear separation between fossil and modern assemblages in ordination space, with surface samples completely isolated from those of the core sites (Fig. 22). The eigenvalues of the first two DCA axis are 0.78 (axis 1) and 0.20 (axis 2). The core sites clustered on the right side of diagram are related to dominance of marine to marine/brackish diatom taxa *A. splendens*, *A. kitonii*, *A. sculptus*, *C. radiatus*, *C. litoralis*, *C. striata*, *C. belgica*, *D. surirella*, *D. minor*, *P. sulcata*, *P. nitidus*, *P. disculoides*, *T. nitzschioides*, *T. oestrupii*, *T. favus* and *T. granulata*. Also, the presence of the fresh-brackish taxa *P. borealis* is recorded. Surface samples are associated with the left side of the diagram.

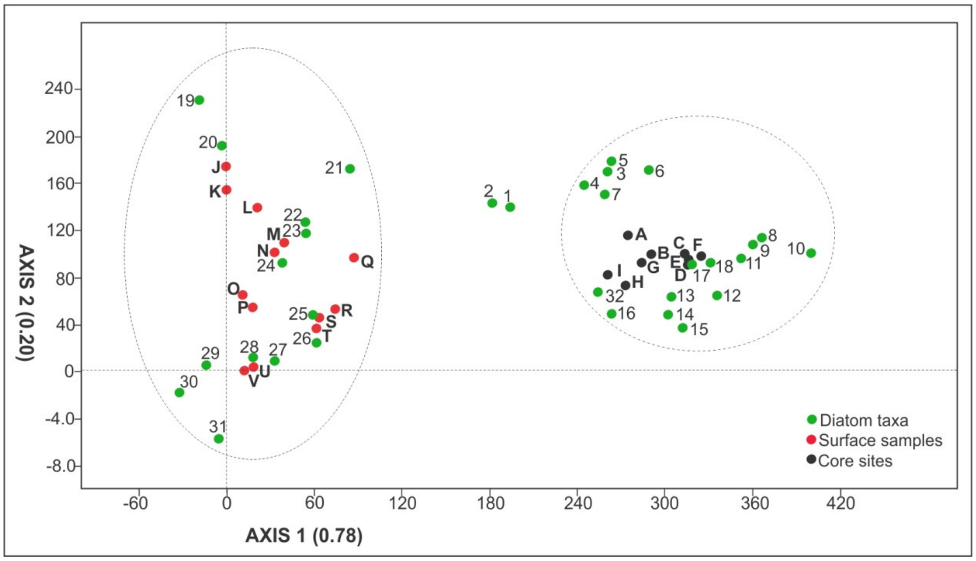

Figure 22. DCA ordination plot of the most abundant diatom taxa occurring in distinct environments of the southern Brazilian coast. The clear separation among fossil and modern assemblages in ordination space with surface samples completely isolated from those of core sites is shown. Black dots correspond to core sites A-I (black bold): **A** (Pa), **B** (Mo), **C** (Bo), **D** (B2), **E** (T09), **F** (T15), **G** (T19), **H** (T103), **I** (T22). Red dots are related to surface samples J-V (black bold): **J** (Pa3), **K** (Pa13), **L** (Pa6), **M** (Pa5), **N** (Pa8), **O** (M3), **P** (M5), **Q** (B6), **R** (B3), **S** (B3), **T** (B2A), **U** (M9), **V** (M12). Diatom taxa are linked to green dots and numbered from 1 to 31: 1. *Actinoptychus senarius*, 2. *Psammodictyon panduriforme*, 3. *Thalassiosira oestrupii;* 4. *Pinnularia borealis*, 5. *Cymatosira belgica*, 6. *Delphineis surirella*, 7. *Actinoptychus splendens*, 8. *Triceratium favus*, 9. *Psammococconeis disculoides*, 10. *Aulacodiscus kitonii*, 11. *Auliscus sculptus*, 12. *Cyclotella striata*, 13. *Tryblionella granulata*, 14. *Coscinodiscus radiatus*, 15. *Psamodiscus nitidus*, 16. *Thalassionema nitzschioides*, 17. *Paralia sulcata*, 18. *Dimeregramma minor*, 19. *Staurosira* sp., 20. *Aulacoseira veraluciae*, 21. *Catenula adhaerens*, 22. *Fallacia* sp., 23. *Staurosirella martyi*, 24. *Thalassiosira* sp.2., 25. *Grammatophora* sp., 26. *Cyclotella litoralis*, 27. *Actinocyclus normanii*, 28. *Thalassiosira* sp., 29. *Cyclotella meneghiniana*, 30. *Tryblionella victoriae*, 31. *Aulacoseira* sp.2, 32. *Actinoptychus vulgaris*.

Sites located around core Bo (B2A, B3, B4, B6) and around core Mo (M9, M12) are characterized by *A. normanii*, *Aulacoseira* sp.2, *C. adhaerens*, *C. litoralis*, *Fallacia* sp., *Grammatophora* sp., *S. martyi* and *Thalassiosira* sp. The freshwater diatom *A. veraluciae* and *Staurosira* sp., are closely linked to sites around core Pa (Pa 3, Pa5, Pa6, Pa8, Pa13) while *C. meneghiniana*, *Thalassiosira* sp.2 and *T. victoriae*, are related to sites located around core Mo (M3, M5). Two marine/marine-brackish diatom taxa *A. senarius* and *P. panduriforme* are clustered around the center of diagram and are related to both core sites and surface samples. Similarly to DCA analysis, hierarchical cluster analysis yielded two main ecological groups with surface samples completely isolated from those of the core sites. The most abundant diatom taxa and their relationship with core and surface samples are shown (Fig. 23). The northern area of Patos Lagoon is dominated by the freshwater planktonic taxa *A. veraluciae*, and the central area is mainly dominated by *Aulacoseira* sp.2. The southern area is dominated by *Aulacoseira* sp.2 and *C. litoralis*, which are abundant (see Table 16, Fig 24).

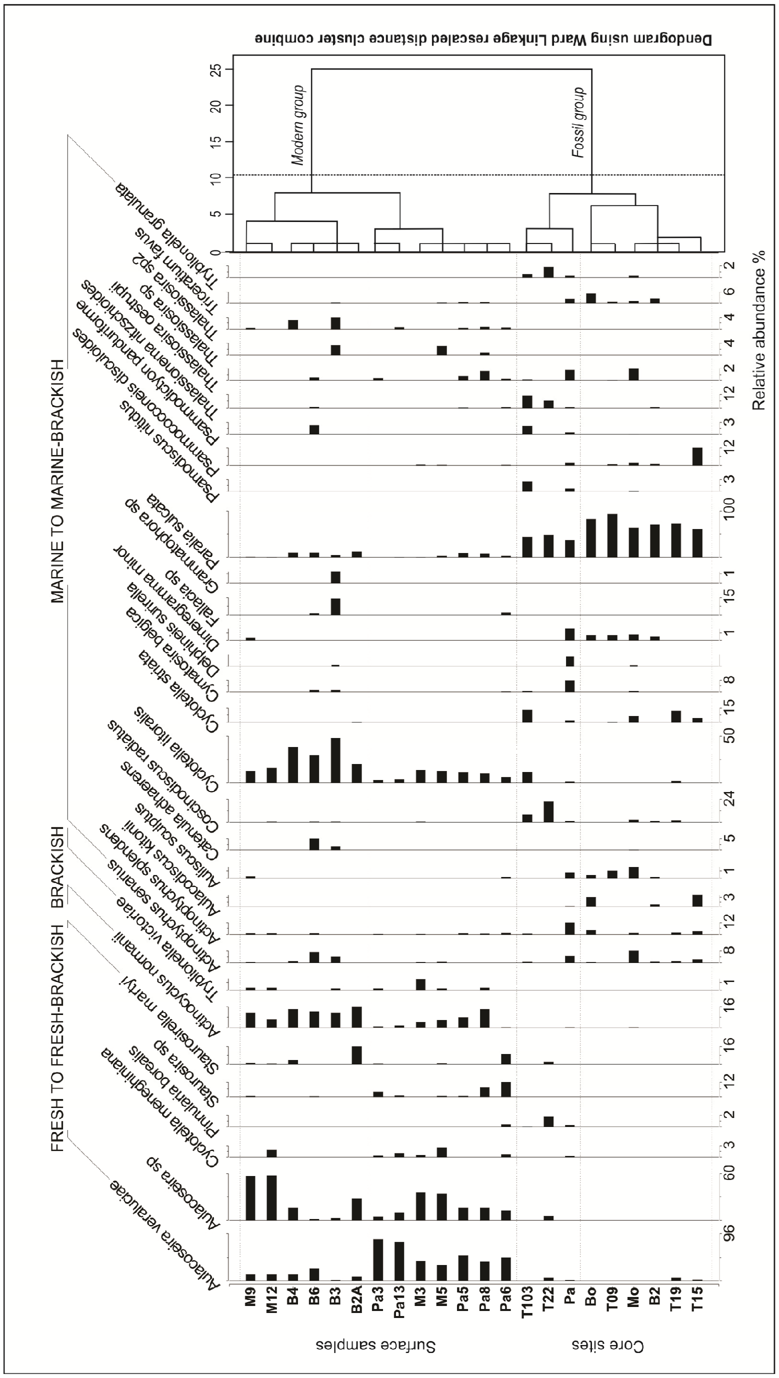

Figure 23. . Fossil and modern diatom assemblages are combined by means of hierarchical cluster analysis. The clear separation between cores sites and surface samples is shown. The marine taxa *Paralia sulcata* is dominant in core sites while that *Aulacoseira veraluciae*, *Aulacoseira* sp.2 and *Cyclotella litoralis* are abundant in the surface samples.

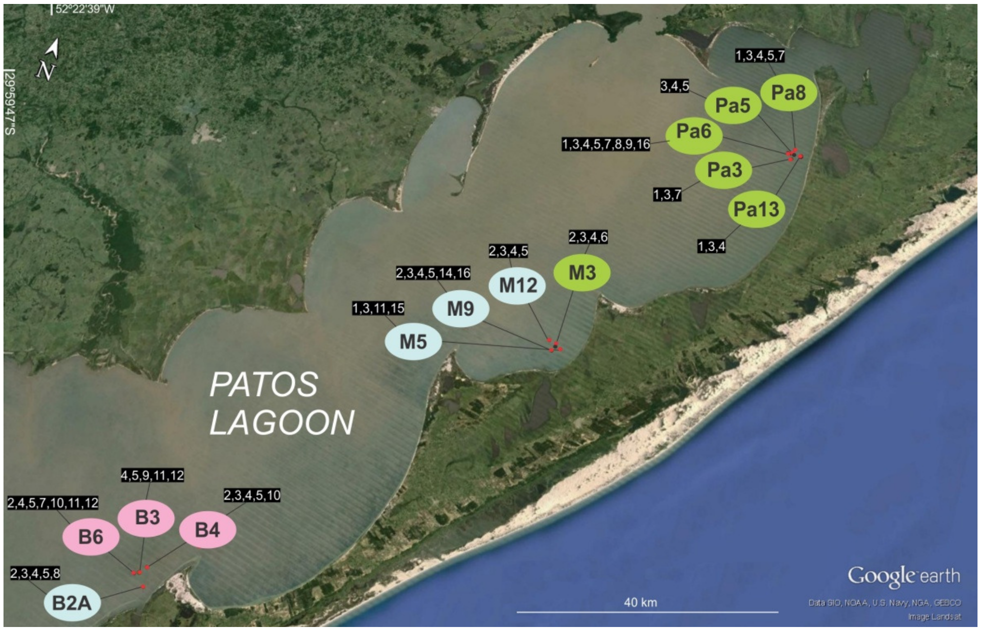

Figure 24. The spatial distribution of modern diatoms present in sediments of Patos Lagoon. Three hyaline zones are proposed: (1) the northern margin of the lagoon is dominated by *Aulacoseira veraluciae* (green balloon); (2) *Aulacoseira* sp.2 (blue balloon) is dominant in the central area and (3) a mixing between *Aulacoseira* sp.2 and *Cyclotella litoralis* (blue and pink balloon) is observed in the south area of the lagoon. Diatoms associated to the most important taxa are numbered from 1to 16: 1. *Aulacoseira* sp.2, 2. *Aulacoseira veraluciae*, 3. *Cyclotella litoralis*, 4. *Actinocyclus normanii*, 5. *Paralia sulcata*, 6. *Cyclotella meneghiniana*, 7. *Staurosira* sp., 8. *Staurosirella martyi*, 9. *Fallacia* sp, 10. *Catenula adhaerens*, 11. *Actinoptychus senarius*, 12. *Thalassiosira* sp.2, 13. *Psammodictyon panduriforme*, 14. *Thalassiosira* sp., 15. *Tryblionella victoriae*, 16. *Actinoptychus splendens*.

6. DISCUSSION

6.1. Major factors controlling the composition and distribution of fossil assemblages

Most diatom species found in the southern Brazilian coast are polyhalobous and euryhaline. According to Soeijs (1999) this ecological characteristic is indicative of environments with fluctuating salinity regimes and reflects their ability to adapt to changes in salinity levels rather than representing their salinity optima. Coastal dynamics are highly sensitive to changes in the rate of sea-level rise, especially on low-gradient shelves such as southern Brazilian coast. This coast is mainly result of Quaternary high-frequency relative sea-level oscillations (Corrêa, 1986, 1996; Villwock et al. 1986; Tomazelli and Villwock, 2000). Since no consistent evidence of local influence of neotectonism acting in this coast, establishment of barrier systems are related to sea-level oscillations occurring at least MIS 11. Three Pleistocene and one active barrier have been distinguished in the region (Villwock et al. 1986).

Three incised-valley systems were recognized and associated with the most important drainage systems in the coastal area (Weschenfelder et al. 2008 a,b; 2010 a,b; 2014, Baitelli, 2012). Two major erosional surfaces interpreted as sequence boundaries S1-S2 and S2-S3 were assigned to the two major lowstands, concomitant with Marine Oxygen Isotope (MIS) 6 and 2 (Weschenfelder et al. 2014). Three stratigraphic cores were obtained in Patos Lagoon (Pa, Mo and Bo) related to seismic profiles 22, 7 and 2, respectively (Fig. 25).

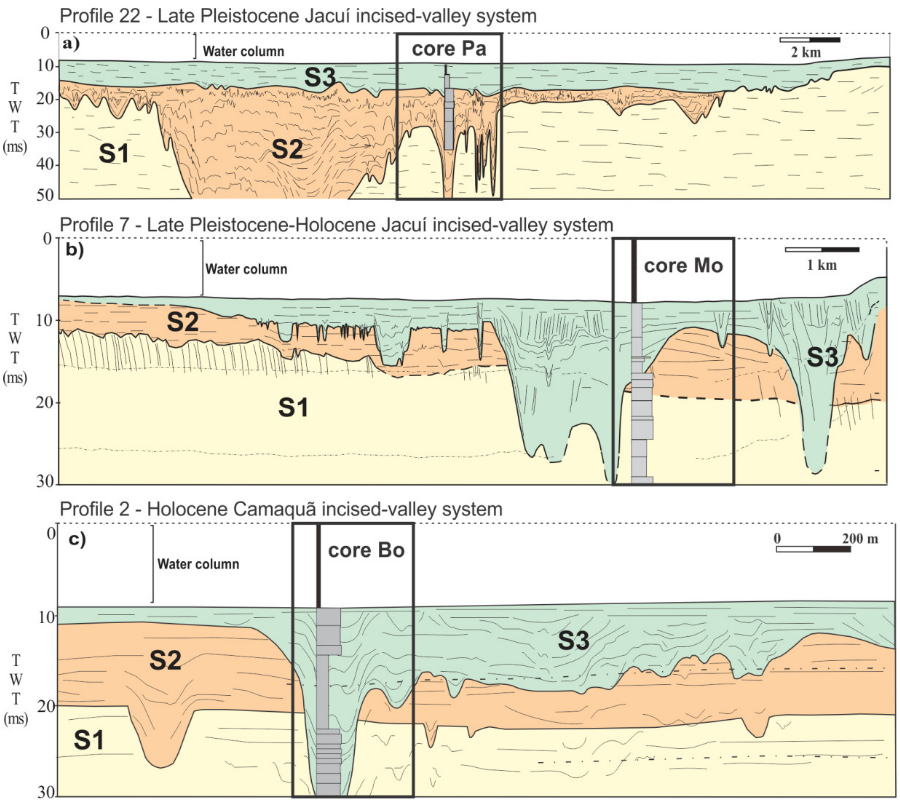

Figure 25. Schematic stratigraphic configuration of three incised-valleys systems of southern Brazilian coast based on seismic data from Weschenfelder et al., (2014). The relationship between three seismo-depositional units S1, S2 and S3 related to three seismic profiles (a-c) and the position of cores analyzed in the present study are shown. (a) Seismic profile 22 is related to the Late Pleistocene Jacuí incised-valley system and core Pa; (b) profile 7 is related to the Late Pleistocene/Holocene Jacuí incised-valley system and core Mo; (c) seismic profile 2 is related to the Holocene incised-channel from the Camaquã River and core Bo. TWT: Two-Way Traveltime (in milliseconds).

Because incised-valley systems are considered good sedimentary-containers, most shifts between fluvial and marine deposition are driven by sea-level oscillations (Zaitlin et al. 1994; Dalrymple, 2006; Blum et al. 2013). The application of fossil diatom assemblages may be associated with the seismic analysis to determine the infilling nature of the incised-valley systems fill. Detailed paleoecological information about the nature of incised-valleys systems from Jacuí and Camaquã River based on diatom-inferred was made by Santos (2015). Allochthonous taxa present in marine environments provide ecological information about adjacent environments from coastal area. In southern Brazilian coast changes in diatom distribution are driven by proximity to streams, sediment composition, sea-level oscillations and climate changes. Fossil diatom assemblages provide strong basis for detailed interpretations of paleoceanography and diatom paleoecology of the southern Brazilian coast. Nine stratigraphic cores obtained in the coastal plain, shelf and continental slope provide an excellent opportunity to use a paleoecological approach to study detailed environmental changes. Four kinds of deposition are identified associated with nine stratigraphic cores (Pa, Mo, Bo, T15, T19, B2, T09, T22, T103) obtained in distinct environments of the southern Brazilian coast (Fig. 26). The Late Pleistocene deposition is linked to core Pa, T22 and T103. Holocene sequences are relatated to core B2, Bo, Mo, T09, T15 and T19.

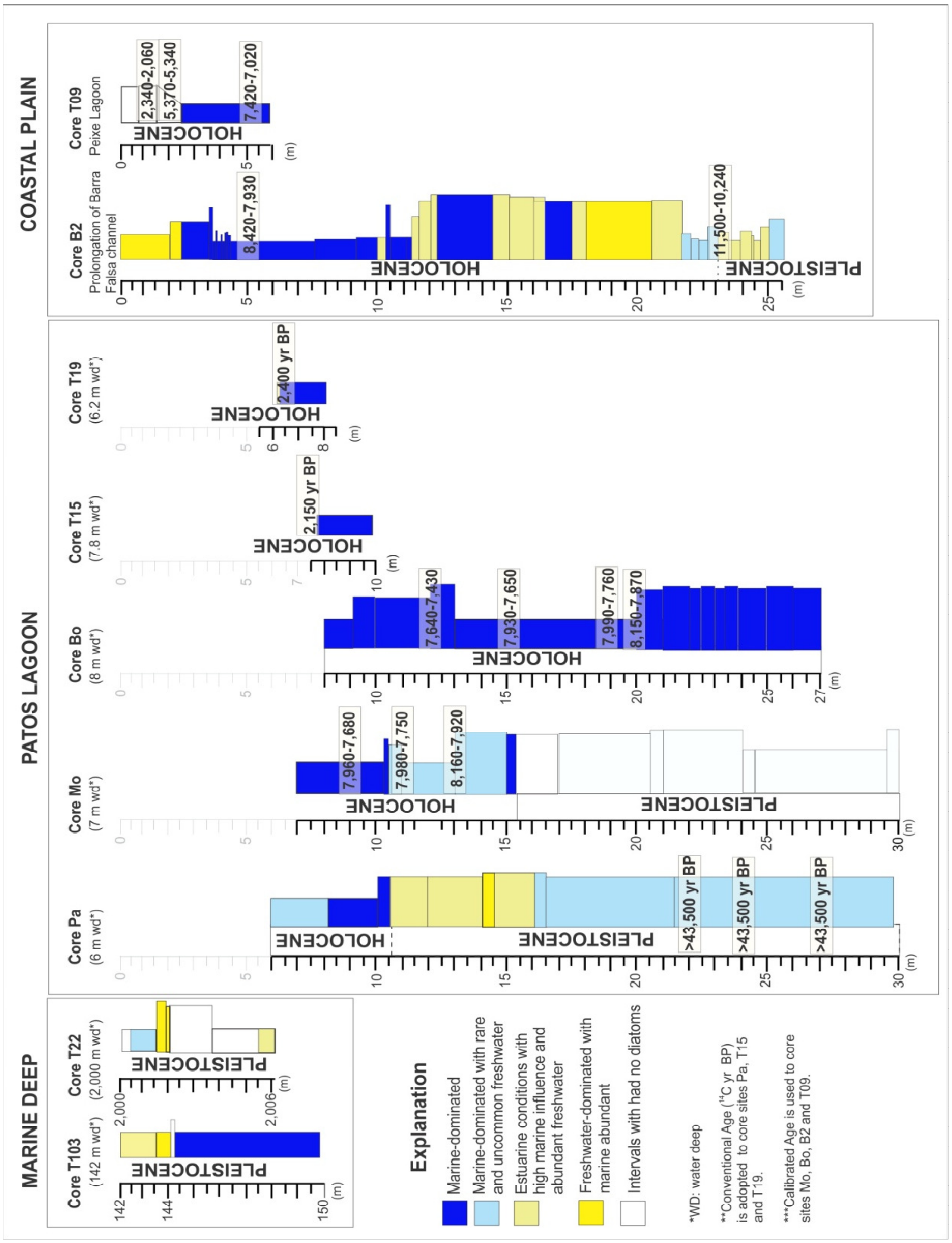

Figure 26. A general paleoecological scenario of the southern Brazilian coast based on diatom assemblages from Late Pleistocene to Holocene is shown. Distinct core fills are recorded based on diatom records and core data integration. Five cores are related to the Patos Lagoon interior (Pa, Mo, Bo, T15 and T19). Two cores are related to the marine deep environments of the outer shelf (T103) and continental slope (T22). Core sites in the coastal plain obtained in the prolongation of the Barra Falsa channel (B2) and Peixe Lagoon (T09).

6.2 Late Pleistocene deposition – core Pa

During the Late Pleistocene, all fossil groups (G1 to G5) were recorded in samples older than 43,500 yr BP. The greatest contributions observed were from G3, followed by lesser contributions from groups G2 and G5, indicated a marine-dominated environment. Greater relative abundances of *C. belgica* indicate open-marine lagoonal conditions; it is commonly accompanied by *P. sulcata*, *A. senarius*, *A. splendens*, *A. sculptus*, *C. radiatus*, *C. striata*, *D. surirella*, *D. minor*, *P. disculoides*, *P. panduriforme*, *T. nitzschioides*, *T. oestrupii* and *T. favus*. Similar dominance of marine conditions in samples older than 43,500 yr BP were also evidenced by Baitelli (2012) who recorded a marine microfossil assemblage in the lowest section of core Pa, comprised of *Acteocina candei*, *Anadara notabilis*, *A. ovalis*, *Clausinella gayi*, *Cylichna bidentada*, *Odostomia seminuda* and *Nucula semiornata*.

Non-marine diatom taxa also occur in very low concentrations (ranging from 0.04 to 0.5 %), interpreted as allochthonous components that occur within the interval from 28.5 to 16 m. According to Vos and De Wolf (1988), the influx of allochthonous components in relatively low energy environments should be small, as observed in core Pa. Benthic frustules of freshwater taxa have been fragmented, indicating active transport from the Jacuí River. Similar scenarios are recorded in the Pleistocene sediments from the outer shelf (T103) and the continental slope (T22), clustered by CCA. They have been associated with fine terrestrial silt and clay sediments deposited during the Pleistocene. Benthic forms are dominant, in this context, at the base of the Late Pleistocene indicating a relatively shallow and open marine-dominated environment with a very low fluvial contribution.

6.2.1 Abrupt changes on coastal sedimentation near to the Last Glacial Maximum

Cooler temperatures and greater aridity were dominant in South America during the Late Pleistocene (Ledru et al. 1996; Turcq et al. 1997; Behling, 1998; Behling et al. 1998) accompanied by a gradual increase in humidity in both tropical and subtropical South America from 45,000 to 25,000 years BP (Ledru, 1993; Van der Hammen and Absy, 1994; Ledru et al. 1996). Several high-resolution climate studies suggest a strong influence of the ENSO during the Late Pleistocene. Oberhänsli et al. (1990) recorded strong impacts of the ENSO during MIS 8 and 6. Tudhope et al. (2001) suggested that ENSO has been a persistent component of the climate in the region for at least 130,000 yr BP. It is responsible for controlling rainfall and atmospheric circulation which affect the hydrology of many rivers in South

America (Pasquini and Depetris, 2007). Marwan et al. (2003) suggests that a strong relationship exists between rainfall and ENSO in Argentina ~30,000 yr BP, where similar conditions have persisted in the modern climate. Similarly, Beaufort et al. (2001) suggests that ENSO impacted marine sediments from the Pacific Ocean at least 30,000 yr BP.

An abrupt shift from marine-dominated to estuarine-fluvial deposition is related to the substantial decrease of marine fossil groups G2 to G5, associated with the submergence of the freshwater group G1. Three stages of substantial fluvial influence from Jacuí River are recorded at interval of 16- 14.5 m, 14.5-14 m and 12.5-12 m. The freshwater taxa *A. veraluciae*, *Aulacoseira* sp.2, *P. borealis* and *S. martyi* are associated with rare freshwater species not displayed in PCA groups, including *C. placentula* var. *euglypta*, *C. meneghiniana*, *Eunotia major* and *Gomphonema paludosum*. They are mixing with uncommon marine taxa *P. sulcata* (4 %) and *A. splendens* (1.6 %) and rare marine taxa *C. radiatus*, *A. sculptus* and *T. favus* (ranging from 0.08 to 0.2 %).

Based upon the eustatic relative sea-level prediction of Corrêa (1996), sea-level was positioned 130 m below the present level during the maximum lowstand (MIS 2) in accordance with global sea-level curves. According to Corrêa and Toldo Jr. (1998) during the LGM, coarse sands formed beach ridges along the southern Brazilian paleoshoreline, fine sands were deposited on the inner shelf, whereas, muddy sands were deposited on the outer shelf and the upper slope.The present inner shelf surface was exposed sub-aerially, subjected to high erosion rates and fluvial incision during the LGM (see seismic profiles 7 and 2; fluvial incisions in the unit S3). However, the main drainage of the Late Pleistocene Jacuí River was not re-incised during MIS 2 and the drainage was shifted to a new connection with Atlantic Ocean, occupying a new incision generated during MIS 2 (seismic profile 7).

6.3 Late Pleistocene/Holocene deposition

After the LGM, this coast was drowned due to a rapid (2.0 cm/yr) sea-level rise from 17,500 to 16,000 yr BP. During this period layers of fine sand were deposited in the paleoshoreline over the inner shelf, intercalated with medium sands originating from estuaries or deltas systems transported by incised-valleys. Incised-valleys and distributary channels along the southern Brazilian coast became an estuary and were filled with marine and fluvial sediments as a consequence of sea-level rise. Muddy sands of the pre-littoral environment were deposited on the shelf in response to a decrease (from 2 cm/yr to 0.6 cm/yr) in the rate of sea-level rise from 16,000 – 11,000 yr BP (Corrêa and Toldo Jr., 1998), which led to the development of two major bathymetric breaks on the shelf. These were preserved as marine terraces at depths of -80/-90 m and -60/-70 m. Holocene deposition is related to the establishment of two incised-valley systems filled with marine sediments, a modern lagoon which is progressively enclosed by a large sand barrier system and development of many coastal lakes and lagoons on distinct areas of the coastal plain. During the early Holocene, sea-level rose on average by about 1.6 cm/yr from 11,000 to ~6,000 yr BP. Three sea-level stabilizations are recorded by Corrêa (1996): at depths of -60/-70 m (at around 11,000 yr BP), between -32/-45 m (9,000 yr BP) and -20/-25 m (8,000 yr BP).

Several climate proxies have shown that the Holocene climate was influenced by opposite hemispheric trends of solar insolation, which decrease in the Northern and increase in the southern Hemisphere (Wanner et al. 2011). According to Cheng et al. (2009) the intensified summer monsoon in South America is related with meltwater pulses in the North Atlantic (LeGrande and Schmidt, 2008). Speleothem data associated with $\delta^{18}O$ ratios from southeastern and southern Brazil, suggest a long-term variation in mean precipitation from the last glacial to the Holocene, due to the southern hemisphere summer insolation (Cruz, 2006; Cruz et al. 2007). Combined time-series analyses of $\delta^{18}O$ and elemental ratios of speleothems suggest that long-term variations in mean precipitation in subtropical Brazil during the last glacial period and Holocene are modulated by changes in the southern hemisphere summer insolation. Rainfall excess in the region during the Late Pleistocene and especially at the LGM is strongly linked to Northern Hemisphere glacial boundary conditions (Cruz et al. 2007).

The southern Brazilian coastal zone experienced relatively humid conditions and lower than present day temperatures during the early Holocene (Medeanic and Dillenburg, 2001; Medeanic et al. 2001; Weschenfelder et al. 2008a). Palynomorph records from lagoonal sediments in the coastal plain provided strong evidence of climatic conditions alternating between humid and dry periods during the middle to late Holocene (Medeanic et al. 2003, 2010, Medeanic and Corrêa, 2010). According to Weschenfelder et al. (2008a), there was evidence of a humid climate at radiocarbon age 8,620 ± 170 ^{14}C yr BP, which caused a decrease in the size of freshwater marshes and an increase in xerophylous and halophylous herbaceous plants in the southern Brazilian coast. Similar climate conditions were recorded in South America (Iriondo and Garcia, 1993; Krohling and Iriondo, 1999). In the Uruguay coast, both dry and humid conditions were observed during the early Holocene (Bracco et al. 2005; Iriarte, 2006; García-Rodríguez, 2012).

6.3.1 A drowned coast (core Bo, B2, Pa, Mo, T09)

CCA shows the relationship between diatom distribution and sediment composition of three core sites located in Patos Lagoon (Mo, Bo) and the extension of the Barra Falsa channel (B2). The marine/marine-brackish taxa *A. senarius*, *A. kitonii*, *A. sculptus*, *D. minor*, *P. sulcata*, *P. disculoides* and *T. favus* are closely linked to sand deposition during the Holocene. Both cores preserved similar marine flooding sequences deposited prior to 8,400 yr BP (see Fig 26). Dominance of the marine taxa *P. sulcata* occurs throughout the Holocene in the sediments of the southern Brazilian coast, when very high percentages are recorded. This species is related to rising in sea-level and increasing salinity.

Between 11,000 to around 8,000 yr BP increased abundances of *P. sulcata*, *A. splendens*, *C. striata*, *P. disculoides* and *T. favus* persisted in the sequences associated with marine/marine-brackish planktonic taxa *A. senarius*, *A. sculptus* and *P. nitidus*, indicating drowning of coast due to a rising sea-level. During the Holocene, the contribution of the PCA fossil group 1 is related to the marine/marine-brackish taxa *C. radiatus*. The dominance of the G2 is related to marine tycoplanktonic taxa *P. sulcata*. G3 is absent in a part of the early to middle-Holocene. High contributions of group 1 are observed before the last flooding maximum, related to *A. splendens* followed by *D. minor* and *D. surirella*. Between 8,420-7,930 and after 7,640-7,430 cal years BP, the marine/marine-brackish taxa *P. disculoides*, *T. oestrupii* and *T. favus* are abundant, although closer to the flooding maximum (MHHS) very low contributions are recorded. High contributions of G5 are observed ca 7,000 years BP, related to the relative abundance of *A. senarius*.

Based on the stratigraphic correlation and relative sea-level curve of the southern Brazilian shelf proposed by Corrêa (1996), Toldo Jr. et al. (2000) estimated that the Holocene sedimentation in Patos Lagoon started ~8,000 yr BP, with an average deposition rate of 0.75 mm/yr. This is in agreement with marine sequences recorded in cores Bo, Mo and Pa. Core Bo has a thick marine package (21 m) deposited in the Patos Lagoon interior before 8,150-7,870 and after 7,640-7,430 cal years BP. Core Pa has a 2.5-m thick marine deposit followed by a 2 m marine-dominated deposit with rare freshwater influences. Similarly, the lowest part of core Mo has a thin (0.5 m) marine-dominated deposition followed by a 4.8-m thick marine-dominated deposit with uncommon and rare freshwater taxa (at interval between 15-10.5 m), deposited before 8,160-7,920 until 7,980-7,750 cal years BP. Only after that, marine-dominated deposition is reestablished from 10.5-7 m at around 7,960-7,680 cal years BP. Also, the high marine influence is observed in distinct environments of coastal plain. A 7.5-m thick marine transgressive package is deposited before and after 8,420-7,930 cal years BP., in the extension of the Barra Falsa channel (core B2). Similarly, the sediments of Peixe Lagoon (core T09) are composed by a homogeneous marine package deposited from 7,420-7,020 to 5,370-5,340 cal years BP (see Santos, 2011).

Rising sea level coupled with longshore current during the early and middle Holocene were responsible for progradation and development of a sand barrier. The Holocene barrier has been the focus of several studies, however the studies performed by Dillenburg et al. (2000, 2004, 2006, 2013) and Dillenburg and Hesp (2009) are emphasized here. The localization of the core sites Pa, Mo and T09 are insered to the subsector from Dunas Altas to the Lagarmazinho area when the sand barrier is considered as an aggradational/stationary model (Dillenburg et al. 2013). In the Bojuru region, near to the core sites B2 and Bo, the sand barrier is classified as a retrogradational/transgressive model submitted to a long-term erosional trend (Dillenburg, 2004). Relative sea-level curves have been proposed for distinct sectors of the Brazilian coast.

The general trend is related to the submergence phase, established at least 7,000 yr until at around 5,100 yr BP, followed by a discontinuous drop in sea-level (Martin et al. 2003; Angulo et al. 2006). Two negative sea-level fluctuations during interval of 4,000 – 3,500 yr BP and 2,300 – 2,000 yr BP. Afterwards, sea level progressively fell, until returning to the current position (Corrêa, 1996). However, the marine-dominated deposition is recorded in both core Bo, Mo, Pa, T09, T15 and T19.

Core samples from T15 and T19 indicate marine conditions between 2,400 and 2,150 yr BP. The marine taxa *P. sulcata* is dominant, accompanied by diatom taxa from G2-G5: *A. senarius*, *A. splendens*, *A. sculptus*, *C. radiatus*, *C. striata*, *P. disculoides* and *T. favus*. High contribution of freshwater flora is observed only in the upper part of core B2 and an estuarine deposition is recorded in the top of core T19, related with modern deposition (see Fig. 8). After 2,400 yr BP, estuarine conditions are inferred from core T19 based upon abundant freshwater taxa including *A. veraluciae* and *Aulacoseira* sp.2 (uncommon). The marine taxon *P. sulcata* is abundant (31 %) accompanied by other marine species including *C. litoralis*, *C. striata*, *A. splendens* and *A. senarius*.

The strong marine influence observed by Toldo Jr. (1991) in the northeast area of Patos Lagoon is also related to the Jacuí incised-valley systems (Baitelli, 2012; Weschenfelder et al. 2014). The incised-valley systems established along this coast have acted as geographic barriers that have isolated diatom communities as observed by Santos (2015). The freshwater taxa *Aulacoseira veraluciae* and *Aulacoseira* sp.2 are related to the Jacuí incised-valley systems while *Pinnularia* sp.1 is exclusively related to the Camaquã incised-valley system, active from the Late Pleistocene to the Holocene. Similar correlations with incised-valleys were observed in a study about evolution of the skull shape of *Ctenomys minutus* (Rodentia-Ctenomyidae), based on an isolation-by-distance model that was shaped by selection and geological evolution of the coastal plain (Fornel et al. 2010). Similarly, Mäder et al. (2013) suggests that the geographic clades of *Calibrachoa heterophylla*, an endemic South-Atlantic species of petunia, formed when the coastal plain was deeply dissected by incised-valley systems acting as geographic barriers.

After the late Holocene lowstand, the barrier system became more continuous and Patos Lagoon developed as a result of complete closure by sands from the large barrier-lagoon, which closed the secondary former inlets from the Jacuí and Camaquã rivers. However, a single inlet located to the south (Rio Grande channel) remains active in the present-day configuration. High-resolution seismic records obtained in the lagoon inlet by Corrêa et al. (2004) do not shows structures of incised-valleys and buried paleochannels, suggesting that the Rio Grande channel is a relatively modern lagoonal-estuarine inlet. Also, estuaries and coastal lagoons that have become enclosed since middle Holocene are recorded in several areas of

South America at least ~3,000-1,000 ^{14}C yr BP (Iriondo and Garcia, 1993; Espinosa et al. 2003; García-Rodríguez et al. 2004a; Bracco et al. 2005; García-Rodríguez, 2012).

6.4 Modern configuration of the Patos Lagoon

DCA results show a clear division among fossil assemblages and modern communities in ordination space, with surface samples completely isolated from those of core sites as observed in Figure 4 and 5. Planktonic forms are dominant (66 %), usually correlated with silt- and clay-rich sediments (56 %). Modern diatom communities in Patos Lagoon may be influenced by the salinity gradient and climate forcing. Sediment composition seems like a minor environment variable affecting the spatial distribution, because the modern climate conditions in the southern Brazilian coast is strongly influenced by ENSO activity (Grimm et al. 1998, 2000; Fernandes et al. 2002). The Southern Oscillation Index (SOI) values indicate that the sampling period on January 2010 was included in a weak/moderate ENSO activity (see http://www.bom.gov.au/climate/current/soihtm1.shtml for more details).

Our results suggest that the both marine and freshwater diatom taxa are recorded in bottom sediments of Patos Lagoon during ENSO period. According to Garcia et al. (2001) during ENSO events, intense precipitation and freshwater discharge are associated with a reduction in the abundance of marine species. The most representative taxa are *A. veraluciae*, *Aulacoseira* sp.2, *C. litoralis*, *A. normanii*, *P. sulcata*, *S. martyi*, *Staurosira* sp. and *Fallacia* sp. The dominance of freshwater diatom taxa is observed in the northeast and south margin of the lagoon, related to the proximity of the Jacuí and Camaquã rivers. The increase of the freshwater taxa *A. veraluciae* occurs from the southwest to the northeast; *Aulacoseira* sp is most abundant in the southern region.

A marine influence is abundant in the southwest sites as illustrated in Figure 6; the most important diatom taxa are *C. litoralis* (ranging from 13-48 %), *A. normanii* (ranging from11-16 %) and *Paralia sulcata* (4.6-12 %). However, Medeanic et al. (2008) recorded the presence of marine diatoms in sites located in the southwest and south areas of Patos Lagoon during a weak/moderated ENSO activity (with a SOI value of -10.6 on December 2002). A strong marine influence was indicated by the dominance of *Actinocyclus*, *Actinoptychus*, *Auliscus*, *Diploneis*, *Paralia sulcata*, *Terpsinoë* and *Triceratium*. Short-term changes in the phytoplankton composition are related to salinity oscillations, driven primarily by changing wind regimes (Torgan, Tundisi and Niencheski, 2002; Torgan, Pillar and Niencheski, 2006; Fujita and Odebrecht, 2007; Abreu et al. 2010; Odebrecht et al. 2010). The spatial salinity distribution of Patos Lagoon shows distinct patterns in drought and wet periods. Large spatial salinity variations, from 0 to 31 psu, were recorded in the southern 90 km of the lagoon, mostly indicative of oligohaline conditions. A slow northward marine influence has been observed; oligohaline waters reached approximately 180 km from the mouth of Patos Lagoon during the rainy season (Odebrecht et al. 2005).

Fossil assemblages have analogues in the modern configuration of Patos Lagoon and they constitute the most successful diatom taxa which have persisted in a coast subjected to drastic sea-level and climate changes. The most successful diatom taxa *Paralia sulcata* occurs continuously from the Late Pleistocene to present-day (ranging from 4 to 100 %). Two periods of low density occur in samples older than 43,500 yr BP and during the LGM (4-8 %). Afterwards it is dominant, with the exception of three periods: after 11,000 yr BP, at around 8,400 yr BP and between 2,400 and 4,000 yr BP. Also, *P. sulcata* is found in sediments of outer shelf and continental slope (ranging from 7-93 %). In the modern Patos Lagoon, *P. sulcata* is found in eight surface samples in the northeast, south and southwest area of the lagoon (ranging from 0.1 to 12 %). The species is more abundant in sites located relatively near to the Rio Grande channel: B2A (12 %), B4 and B6 (10 %). Very low density is recorded in surface samples located in the south and northeast area: Pa3 (0.1 %), M12 (0.7 %), M3 and Pa13 (0.8 %).

The genus *Paralia* is reported from sediments of the Late Cretaceous (Sims and Crawford, 2002). The great ecological success of *P. sulcata* has been attributed to a heavily silicified frustule, which preserves well in coastal environments that are submitted to extreme hydrodynamic conditions. The presence of the species has been related to relatively warm climates (Stabell, 1980; Karpuz and Schrader, 1990). Also, it is abundant in fine-grained and organic-rich sediments (Roelofs 1984, Zong 1997, McQuoid and Hobson 1998), especially in estuarine systems and marine environments (Bérard-Thérriault et al. 1999; McQuoid and Nordberg 2003; Sawai et al. 2005; Gebühr et al. 2009) and is indicative of isolated basins (Zong, 1997). In coastal areas of South America, the dominance of the diatom taxon *P. sulcata* is highlighted (García-Rodríguez et al. 2001; García-Rodríguez et al. 2004 a,b; Espinosa, 2008; Escandell et al. 2009; Hassan et al. 2011; Espinosa and Isla, 2011; Escandell and Espinosa, 2012; Fayó and Espinosa, 2014). In southern Brazilian coast, *P. sulcata* was found in Holocene marine sediments from extension of the Barra Falsa channel (Weschenfelder et al. 2008a), Cassino Beach (Medeanic et al. 2009), Peixe Lagoon (Santos, 2011), Hermenegildo beach (Lima et al. 2013). In modern sediments from Peixe Lagoon, the decrease in this species was attenuated by increases in the brackish diatom *Paralia fenestrata* as observed by Santos (2011). Also, the marine taxa *P. sulcata* is associated with distinct environments such as the coastal shelf, lakes, lagoons, and streams (see Torgan et al. 1999). A recent review of the morphology and distribution of *P. sulcata* and *P. fenestrata* in distinct environments of the southern Brazil was made by Garcia et al. (2012).

Diatom assemblages can reflect changes in sediment production and transport, providing additional insights into the paleogeographic setting of a study area, shifts in hydrographic conditions, and long-term climate changes and sea-level oscillations. The main properties of ecological communities that can determine the response to environment changes are resistance to changes and the ability to return to previous states after an environment perturbation (Holling, 1986; Pimm, 1991). The freshwater taxa *A. veraluciae* and *Aulacoseira* sp.2 occurring from samples older than 43,500 yr BP is closely related to the Jacuí River drainage (core Pa). During the Holocene they are absent in the lagoonal system due to a drowning coast. Only after 2,400 yr BP, the species *A. veraluciae* is recorded in greater abundances in the sediments of Patos Lagoon. The genus *Aulacoseira* is reported from non-marine sediments with ages older than 65 Ma, in the Lameta Formation (*upper* Cretaceous), India (Ambwani et al. 2003). It has been widely documented worldwide and specifically in tropical and subtropical Brazil, where an extensive review of the *Aulacoseira* species was made by Tremarin et al. (2011, 2012, 2013a, b, 2014 a,b). In southern Brazil, the occurrence of the species is reported from south area of Patos Lagoon, Pinguela-Palmital-Malvas Lake System (described as *Aulacoseira* aff. *agassizii*; Hermany et al. 2013).

7. CONCLUSIONS

Fossil assemblages from subtropical southern Brazilian coast have changed due to local and global effects of climate variability and sea-level oscillations, reflecting the relative instability recorded in diatom populations. The application of the PCA, CCA and DCA analyses combined with fossil and modern diatoms, obtained from distinct sites along the southern Brazilian coast, provide consistent evidence of the main environmental changes that this coast was subjected to from the Late Pleistocene to present-day conditions. The relationship between sediment composition and spatial distribution of fossil and modern assemblages are presented. The influence of sand and silt/clay deposition seems more significant during the Late Pleistocene and the Holocene than observed today. However, the distribution of the fossil assemblages was strongly linked to sea-level oscillations and climate changes that control this coastal environment in a more dynamic scenario than in the modern coastal configuration.

Our results provide consistent insights about the lagoonal-environment hydrodynamic conditions prior to 43,500 yr BP. The comparison between fossil and modern assemblages by means of DCA analysis results in the recognition of modern analogs, which were used to interpret the modern configuration of this coast. The marine diatom *Paralia sulcata* is the most ecological successful taxa, occurring continuously from Late Pleistocene to present-day sediments; it is considered an excellent indicator of long-term and short period oscillations in sea-level. The freshwater taxa *Aulacoseira veraluciae* and *Aulacoseira* sp.2 were considered the most important diatom taxa for detecting a fluvial influence from the Jacuí River during the Late Pleistocene. After the LGM they are absent, returning only after 2,400 yr BP.

By observing the changes in relative abundance and the spatial distribution patterns of diatom species, we concluded that in the past the southern Brazilian coast displayed a different coastal configuration from those observed today. Two main diatom assemblages were strongly linked to distinct and non-contemporary incised-valley systems which acted as geographic barriers isolating distinct diatom assemblages. The freshwater *Aulacoseira veraluciae* and *Aulacoseira* sp.2 have been related to sediments from the Jacuí River since the Late Pleistocene, while the deposition of *Pinnularia* sp.1 is exclusively related to the Camaquã River during the

Holocene. In the modern coastal configuration, a shallow lagoonal system is enclosed by a large and continuous active barrier-lagoon system that occupies the entire length of its coast. Only one modern channel is responsible for water exchanges with the open ocean; in contrast, the Late Pleistocene and Holocene are typified by a stronger influence of marine deposition related to the establishment and maintenance of distinct inlets through the lagoon. The modern Patos Lagoon is dominated by both *Aulacoseira veraluciae* and *Aulacoseira* sp.2, and the marine taxa *P. sulcata* is considered rare. The spatial distribution of the modern diatom taxa deposited in the bottom sediments are not controlled by deposition of sand and silt/clay, but rather they seem more likely to be influenced by El Niño (La Niña) events, which control the lagoon's hydrodynamics and salinity.

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9. REFERENCES

Abreu, P. C., Bergesch, M., Proenca, L.A., Garcia, C.A.E., Odebrecht, C., 2010. Short- and long-term chlorophyll a variability in the shallow microtidal Patos Lagoon estuary,southern Brazil. Estuaries and Coasts 33: 554–569.

Ambwani, K., Sahni, A., Kar, R.K., Dutta, D., 2003. Oldest known non-marine diatoms (Aulacoseira) from the uppermost Cretaceous Deccan Intertrappean beds and Lameta Formation of India. Micropaleontolology 46(2): 67–71.

Andrade Neto, J.S., Rigon, L.T., Toldo Jr., E.E., Schettini, C.A.F., 2012. Descarga sólida em suspensão do sistema fluvial do Guaíba, RS, e sua variabilidade temporal. Pesquisas em Geociências 39: 161-171.

Angulo, R.J., Lessa, G.M., Souza, M.C., 2006. A critical review of mid- to Late-Holocene sea-level fluctuations on the eastern Brazilian coastline. Quaternary Science Review 25: 486-506.

Arbuckle, J.L., 2009. Amos 18 user's guide. Amos Development Corporation, Chicago.

Arejano, T., 2006. Geografia e evolução holocênica do sistema lagunar da Lagoa do Peixe, litoral médio do Rio Grande do Sul, Brasil. (Tese Doutorado). Universidade Federal do Rio Grande do Sul, Instituto de Geociências, Porto Alegre.

Baitelli, R., 2012. Evolução Paleogeográfica do Sistema de Paleodrenagem do Rio Jacuí na Planície Costeira do Rio Grande do Sul (Unpublished PhD Thesis) Universidade Federal do Rio Grande do Sul, Brasil (2012), available in the website: http://hdl.handle.net/10183/56850.

Barros, G.P., Marques, W.C., Kirinus, E.de P., 2014. Influence of the freshwater discharge on the hydrodynamics of Patos Lagoon, Brazil. International Journal of Geosciences 5: 925-942.

Beaufort, L., de Garidel-Thoron, T., Mix, A.C., Pisias, N.G., 2001. ENSO-like forcing on oceanic primary production during the late pleistocene. Science 293: 2440–2444.

Behling, H., 1998. Late Quaternary vegetational and climatic changes in Brazil. Review of Palaeobotany and Palynology, 99(2): 143-156.

Behling, H., Negret, A.J., Hooghiemstra, H., 1998. Late Quaternary vegetational and climatic change in the Popayan region, southern Colombian Andes. Journal of Quaternary Sciences 13: 43– 53.

Bérard-Therriault, L., Poulin, M., Bossé, L., 1999. Guide d'identification du phytoplancton marin de l'estuaire et du golfe du Saint-Laurent, incluant également certains protozoaires. Publication spéciale canadienne des sciences halieutiques et aquatiques, 128 : 1–387.

Bergesh, M., Garcia, M., Odebrecht, C., 2009. Diversity and morphology of *Skeletonema* species in southern Brazil, southwestern Atlantic Ocean. Journal of Phycology, 45: 1348-1352.

Blum, M., Martin, J., Milliken, K., Garvin, M., 2013. Paleovalley systems: Insights form Quaternary analogs and experiments. Earth-Science Reviews, 116: 128-169.

Bracco, R., Inda, H., Del Puerto, L., Castiñeira, C., Sprechmann, P., García-Rodríguez, F., 2005. Relationships between Holocene sea-level variation, trophic development and climate change in Negra Lagoon, southern Uruguay. Journal of Paleolimnology, 33: 252-262.

Calliari,L.J., Winterwerp, J.C., Fernandes, E., Cuchiara, D., Vinzon, S.B., Sperle, M, Holland, K.T. 2009. Fine grain sediment transport and deposition in the Patos

Lagoon-Cassino beach sedimentary system. Continental Shelf Research, 29(3): 515-529.

Cheng, H., Edwards, R.L., Broecker, W.S., Denton, G.H., Kong, X., Wang, Y., Zhang, R., Wang, X., 2009. Ice age terminations. Science, 326: 248–252.

Corrêa, I.C.S., 1986. Evidence of sea-level fluctuation on the Rio Grande do Sul continental shelf, Brazil. Quaternary of South America and Antarctic Peninsula, 40: 237-249.

Corrêa, I.C.S.,1987. Sedimentos superficiais da plataforma e talude continental do Rio Grande do Sul. Pesquisas, 19: 95–104.

Corrêa, I.C.S., 1996. Les variations du niveaux de la mer durant lês derniers 17.500 ans BP: l'example de la plate-forme continentale du Rio Grande do Sul-Brasil. Marine Geology, 130: 163-178.

Correâ, I.C.S., Aliotta, S., Weschenfelder, J. 2004. Estrutura e evolução dos cordões arenosos pleistocênicos no canal de acesso à Laguna dos Patos, Brasil. Pesquisas em Geociências, 31(2): 69-78.

Corrêa, I. C.S., Medeanic, S., Weschenfelder, J., Toldo Jr. E.E., Nunes, J.C., Baitelli, R. 2014a. The paleo-drainage of the La Plata River in southern Brazil Continental Shelf. Revista Brasileira de Geofísica, 32(2): 259-271.

Corrêa, I. C.S., Medeanic, S., Weschenfelder, J., Toldo Jr. E.E., Nunes, J.C., Baitelli, R., Santos, C. B. dos., 2013. Registro sedimentario del antiguo canal de desembocadura del Río de La Plata en la plataforma continental del sur de Brasil. Revista Mexicana de Ciencias Geológicas, 30(1): 51-64.

Corrêa, I.C.S., Toldo Jr, E.E., 1998. The Sea Level Stabilization in The Rio Grande do Sul Continental Shelf, Brazil. Anais da Academia Brasileira de Ciências, 70(2): 213-219.

Corrêa, I.C.S., Weschenfelder, J., Toldo Jr., E.E., Baitelli, R., Santos, C.B.dos., 2014b. Turfa na plataforma continental do Sul do Brasil. Comunicações Geológicas, 101: 721-724.

Cruz, F.W., Burns, S.J., Jercinovic, M., Karmann, I., Sharp, W.D.,Vuille, M., 2007. Evidence of rainfall variations in southern Brazil from trace element ratios (Mg/Ca and Sr/Ca) in a late Pleistocene stalagmite, Geochimica et Cosmochimica Acta, 71: 2250– 2263.

Cruz, F.W., Burns, S.J., Karmann, I., Sharp, W.D., Vuille, M., 2006. Reconstruction of regional atmosphere circulation features during the late Pleistocene in subtropical Brazil from oxygen isotope composition of speleothems. Earth and Planetary Science Letters, 248: 494–506.

Dalrymple, R.W., 2006. Incised valleys in time and space: introduction to the volume and an examination of the controls on valley formation and filling, in: Dalrymple, R.S., Leckie, D.A., Tillman, R., (Eds.), Incised valleys in Time and Space. SEPM Special Publication 85, pp. 5-12.

Dillenburg, S.R., Barboza, E.G., Tomazelli, L.J., Rosa, M. L.C.C., Maciel, G.S., 2013. Aeolian deposition and barrier stratigraphy of the transition region between a regressive and transgressive barrier: an example from southern Brazil. Journal of Coastal Research, 65: 464-469.

Dillenburg, S.R., Hesp, P.A., 2009. Geology and Geomorphology of Holocene Coastal Barriers of Brazil. Springer, Lecture Notes in Earth Sciences 107, Berlin.

Dillenburg, S.R., Roy, P.S., Cowell, P.J., Tomazelli, L.J., 2000. Influence of antecedent topography on coastal evolution as tested by the shoreface translation-barrier model (STM). Journal Coastal Research, 16: 71-81.

Dillenburg, S.R., Tomazelli, L.J., Barboza, E.G., 2004. Barrier evolution and placer formation at Bujuru southern Brazil. Marine Geology, 203: 43-56.

Dillenburg, S.R., Tomazelli, L.J., Hesp, P.A., Barbosa, E.G., Clerot, L.C.P., Silva, D.B., 2006. Stratigraphy and evolution of a prograded, transgressive dunefield barrier in southern Brazil. Journal of Coastal Research SI, 39(1): 132-135.

Escandell, A., Espinosa, M.A., Isla, F.I. 2009. Diatomeas como indicadoras de variaciones de salinidad durante el Holoceno tardio en el estuario del rio Negro, Patagonia Norte, Argentina. Ameghiniana, 46: 461-468.

Escandell, A., Espinosa, M.A., 2012. Evolución paleoambiental de estuarios mesomareales de Patagonia. Las diatomeas como indicadores ambientales durante el Holoceno en la costa norpatagónica argentina. Editorial Academica Espanola.Verlag, Alemania, 83 p.

Espinosa, M.A., 2008. Diatoms of Patagonia and Tierra del Fuego. En: J. Rabassa (Ed.), Late Cenozoic of Patagonia and Tierra del Fuego. Developments in Quaternary Sciences, 11: 383–392.

Espinosa, M.A., De Francesco, C.G., Isla, F.I., 2003. Paleoenvironmental reconstruction of Holocene coastal deposits from the southeastern Buenos Aires province, Argentina. Journal of Paleolimnology, 29: 49-60.

Espinosa, M.A., Isla, F., 2011. Diatom and sedimentary record during the Mid-Holocene evolution of the San Blas estuarine complex, Northern Patagonia, Argentina. Ameghiniana, 48 (4): 411-423.

Fayó, R., Espinosa, M.A., 2014. Reconstrucción paleoambiental de la Planicie Costera de Mar Chiquita (Provincia de Buenos Aires, Argentina) Durante el Holoceno, Basada em Diatomeas. Ameghiniana, 51(6): 510-528.

Fepam, 2010. Qualidade das Águas da Bacia Hidrográfica do Rio Jacuí. Available at page: http://www.fepam.rs.gov.br/qualidade/qualidadejacui/jacui.asp

Fernandes, E.H.L., Dyer, K.R., Möller, O.O., Niencheski, L.F.H., 2002. The Patos Lagoon hydrodynamics during an El Niño event (1998).Continental Shelf Research, 22: 1699-1713.

Fornel, R.; Cordeiro-Estrela, P. and De Freitas, T.R.O. 2010. Skull shape and size variation in Ctenomys minutus (Rodentia: Ctenomyidae) in geographical, chromosomal polymorphism, and environmental contexts. Biological Journal of Linnean Society, 101: 705-720.

Fujita, C.C.O., Odebrecht, C., 2007. Short term variability of chlorophyll a and phytoplankton composition in a shallow area of the Patos Lagoon estuary (Southern Brazil). Atlântica, 29(2): 93-107.

Garcia, A.M., Raseira, M.B., Vieira, J.P., Winemiller, K.O., Grimm., A.M., 2003. Spatiotemporal variation in shallow-water freshwater fish distribution and abundance in a large subtropical coastal lagoon. EnvironmentalBiology of Fishes, Netherlands, 68: 215-228.

Garcia, A.M., Vieira, J.P., Winemiller, K.O., 2001. Dynamics of the shallow-water fish assemblage of the Patos Lagoon estuary (Brazil) during cold and warm ENSO episodes. Journal of Fish Biology, 59: 1218-1238.

Garcia, C.A.E., 1997. Hydrographic Characteristics. In: Seeliger, U., Odebrecht, C., Castello, J.P. (Ed.) Subtropical Convergence Environments - The Coast and Sea in the Southwestern Atlantic. Springer Verlag, pp. 18-20.

Garcia, M., 2006. The transfer of Fragilaria obtusa Husted to the genus Staurosira Ehrenberg (Bacillariophyceae). Phycological Research, 54 (2): 87-93.

Garcia, M., 2010. A new diatom genus: *Rimoneis* M. Garcia (Fragilariaceae, Bacillariophyceae): a new hyaline araphid genus base on observations of frustules from Southern Brazil. Diatom, 26: 1-9.

Garcia, M., Odebrecht, C., 2008. Morphology and ecology of the planktonic diatom *Palmerina hardmaniana* (Greville) Hasle in southern Brazil. Biota Neotropica, 8(2): 85-90.

Garcia, M., Souza, V.F. de., 2008. *Amphora tumida* Hustedt (Bacillariophyceae) from southern Brazil. Iheringia Série Botânica, 63(1): 139-143.

Garcia, M., Talgatti, D.M., 2008. The Diatom *Anorthoneis dulcis* Hein from Southern Brazil: morphology and ecology. Research Letters in Ecology, 1-5.

Garcia, M., Talgatti, D.M., 2011. Morfologia e distribuição de *Catenula adhaerens* Mereschkowsky (Bacillariophyceae) no sul do Brasil. Iheringia Série Botânica, 66(1): 99-108.

Garcia, M., Talgatti, D.M., Souza-Mosimann, R., Laudares-Silva, R., 2012. Morphology and distribution of Paralia Heiberg (Coscinodiscophyceae) in southern Brazil. Iheringia Série Botânica, 67(2): 225-235.

Garcia-Baptista, M., 1993. Observations on the genus *Hantzschia* at a sandy beach in Rio Grande do sul, Brazil. Diatom Reseach, 8(1): 23-27.

Garcia-Baptista, M., Baptista, L.R.M., 1992. Algas psâmicas de Jardim Beira-Mar, Capão da Canoa, Rio Grande do Sul, Brasil. Revista Brasileira de Biologia, 52(2): 325-342.

García-Rodríguez, F., 2012. South America, Holocene Coastal Lagoons, in: Fairbridge, R.W., Herschy, R.W. (Eds.), Encyclopedia of Lakes and Reservoirs, Geology, Hydrology and Paleolimnology. Springer Verlag, Berlin, pp. 723-724.

García-Rodríguez, F., Del Puerto, L., Inda, H., Castiñeira, C., Bracco, R., Sprechmann, P., Scharf, B., 2001. Preliminary paleolimnological study of Rocha lagoon, SE Uruguay. Limnologica, 31: 221-228.

García-Rodríguez, F., Metzeltin, D., Sprechmann, P., Trettin, R., Stams, G., Beltrán-Morales, L.F., 2004a. Upper Pleistocene and Holocene paleosalinity and trophic state changes in relation to sea-level variation in Rocha Lagoon, southern Uruguay. Journal of Paleolimnology, 32: 117-135.

García-Rodríguez, F., Sprechmann, P., Metzeltin, D., Scafati, L., Melendi, D.L., Volkheimer, W., Mazzeo, N., Hiller, A., Von Tümpling Jr., W. Scasso, F., 2004b. Holocene trophic state changes in relation to sea-level variation in Lake Blanca, SE Uruguay. Journal of Paleolimnology, 31: 99-115.

Gebühr, C., Wiltshire, K.H., Aberle, N., van Beusekom, J.E.E., Gerdts, G., 2009. Influence of nutrients, temperature, light and salinity on the occurrence of Paralia sulcata at Helgoland Roads, North Sea . Aquatic Biology , 7: 185–197.

Grimm, A.M., Ferraz, S.E.T., Gomes, J., 1998. Precipitation Anomalies in Southern Brazil associated with “El Niño” and “La Niña” Events. Journal of Climate, 11: 2863-2880.

Grimm, A.M., Bartros, V.R., Doyle, M. E., 2000. Climate variability in Southern South America associated with “El Niño” and “La Niña”events. Journal of Climate, 13(1): 35-58.

Hammer, O., Harper, D.A.T., Rian, P.D.,2001. Past: Palaeonthological statistics software package for education and data analysis. Version. 1.37.

Hermany, G., Souza, P.A., Torgan, L.C., 2013. Paleoecologia do sistema Pinguela-Palmital-Malvas, Holoceno da Bacia de Pelotas, RS, Brasil: uma abordagem focada na utilização de análises multivariadas para obtenção de diatomáceas descritoras. Pesquisas em Geociências, 40 (1): 31-49.

Holling, C.S., 1986. Resilience of ecosystems; local surprise and global change, in: Sustainable Development of the Biosphere, Clark, W.C., Munn, R.E., (Eds.) Cambridge University Press, Cambridge, pp. 292-317.

Iriarte, J., 2006. Vegetation and climate change since 14,810 C-14 yr BP in southeastern Uruguay and implications for the rise of early Formative societies. Quaternary Research, 65: 20-32.

Iriondo, M.H., Garcia, N.O., 1993. Climatic variations in the Argentina plains during the last 18.000 years. Palaeogeography, Palaeoclimatology, Palaeoecology, 101: 209-220.

Juggins, S., 2003. C2 software for ecological and palaeoecological data analysis and visualization, version 1.5. Newcastle University, Newcastle.

Jung, G.B., Toldo JR., E.E. 2012. Análise qualitativa da direção da corrente longitudinal entre 2004 e 2008 na praia de Tramandaí, RS, Brasil.. Revista Brasileira de Geomorfologia, 13: 51-56.

Karpuz, N.K., Schrader, H., 1990. Surface sediment diatom distribution and Holocene paleotemperature variations in the Greenland, Iceland and Norwegian Sea. Paleoceanography, 5: 557-580.

Krohling, D.M., Iriondo, M.H., 1999. Upper Quaternary palaeoclimates of the Mar Chiquita area, North Pampa, Argentina. Quaternary International, 57/58: 149-163.

Ledru, M.P., 1993. Late Quaternary evironmental and climatic changes in Central Brazil. Quaternary Research, 39: 90-98.

Ledru, M.P., Braga, P.I.S.; Soubiès, F., Martin, L., Suguio, K., Turcq, B., 1996. The last 50,000 years in neotropics (Southern Brazil): evolution of vegetation and climate. Paleogeography, Paleoclimatology, Paleoecology, 123: 239-259.

LeGrande, A.N., Schmidt, G.A., 2008. Ensemble, water isotope-enabled, coupled general circulation modeling insights into the 8.2 ka event: Paleoceanography 23, doi: 10.1029/2008PA001610.

Lima, L.G., Dillenburg, S.R., Medeanic, S., Barboza, E.G., Rosa, M.L.C.C., Tomazelli, L.J., Dehnhardt, B.A. and Caron, F. 2013. Sea-level rise and sediment budget controlling the evolution of a transgressive barrier in southern Brazil. Journal of South American Earth Sciences, 42: 27-38.

Mäder, G., Fregonezi, J. N., Lorenz-Lemke, A. P., Bonatoo, S. L.. Freitas, L. B., 2013.Geological and climatic changes in quaternary shaped the evolutionary history of *Calibrachoa heterophylla*, an endemic South-Atlantic species of petunia. BMC Evolutionary Biology, 13:178.

Mann, D.G., 1999. The species concept in diatoms (Phycological Reviews 18). Phycologia, 38: 437–495.

Marques, W. C., O.O. Möller, 2009.Variabilidade temporal em longo período da descarga fluvial e níveis de água da Lagoa dos Patos, Rio Grande do Sul, Brasil, Rev. Bras. Recursos Hídricos, 13: 155–163.

Marques, W.C., Fernandes, E.H., Moraes, B.C., Möller, O.O., Malcherek, A., 2010. The dynamics of Patos Lagoon suspendeds sediment plume and its contribution for the deposition pattern in the Southern Brazilian inner shelf. Journal of Geophysical Research115, C10045.

Marques, W.C., Fernandes, E.H., Rocha, L.A.O., 2011. Straining and advection contributions to the mixing process of the Patos Lagoon estuary, Brazil. Journal of Geophysical Research 116, C03016.

Marques, W.C., 2012. The Temporal Variability of the Freshwater Discharge and Water Levels at the Patos Lagoon,Brazil. International Journal of Geosciences, 3: 758-766.

Marques, W.C., Stringari, C.E., Eidt, R.T.,2014. The Exchange Processes of the Patos Lagoon Estuary—Brazil: A Typical El Niño Year versus a Normal Meteorological Conditions Year. Advances in Water Resource and Protection, 2: 11-19.

Martin, L., Dominguez, J.M.L., Bittencourt, A.C.S.P., 2003. Fluctuating Holocene sea-levels in Eastern and Southeastern Brazil: evidence from multiple fossil and geometric indicators. Journal of Coastal Research, 19: 101-124.

Martins, I.R., 1984. Aspectos da oceanografia física do Atlântico Sul. Pesquisas, 16: 76–90.

Martins, L.R., Villwock, J.A., Martins, I.R., 1972. Estudo preliminar sobre a distribuição faciológica da plataforma Continental Brasileira. Pesquisas, 1:51-56.

Marwan, N., Trauth, M.H., Vuille, M., Kurths, J. 2003. Comparing modern and Pleistocene ENSO-like influences in NW Argentina using nonlinear time series analysis methods. Climate Dynamics, 21: 317-326.

McQuoid, M.R., Hobson, L.A., 1998. Assessment of palaeoenvironmental conditions on Southern Vancouver Island, British Columbia, Canada, using the marine tychopankter *Paralia sulcata*. Diatom Research, 13: 311–321.

McQuoid, M.R., Nordberg, K., 2003. The diatom Paralia sulcata as an environmental indicator species in coastal sediments. Estuarine, Coastal and Shelf Sciences, 56: 339–354.

Medeanic, S., Corrêa I.C.S., 2010. Climatic changes in the coastal plain of the Rio Grande do Sul state in the Holocene: palynomorph evidences. Pan-American Journal of Aquatic Sciences, 5: 287-297.

Medeanic, S., Corrêa, I.C.S., Weschenfelder, J., 2008. Resultados preliminares sobre as diatomáceas dos sedimentos superficiais do fundo da Laguna dos Patos. Gravel, 6(1): 15-25.

Medeanic, S., Dillenburg, S.R., 2001. The early Holocene palaeoenvironment history of the Tramandaí Lagoon (RS, Brazil). In: V Reunião do Quaternário Ibérico, I

Congresso do Quaternário de Paises de Línguas Ibéricas 6, Actas, Lisboa, Portugal, pp. 402-405.

Medeanic, S., Dillenburg, S.R., Toldo Jr, E.E., 2001. Novos dados palinológicos da transgressão marinha pós-glacial em sedimentos da Laguna dos Patos. Revista Universidade Guarulhos, 6: 64-76.

Medeanic, S., Hirata, F., Dillenburg, S.R., 2010. Algal Palynomorphs Response to Environmental Changes in the Tramandai Lagoon, Southern Brazil, and Climatic Oscillations in the 20th Century. Journal of Coastal Research, 26: 726-735.

Medeanic, S., Jankovská, V., Dillenburg, S.R., 2003. The implications of green algae (Chlorophyta) for palaeoecological reconstruction of the Holocene lagoon system in the Tramandai Lagoon region, Rio Grande do Sul, Brazil. Acta Palaeobotanica, 43: 113-123.

Medeanic, S., Torgan, L.C., Clerot, L.C.P., Santos, C.B. dos., 2009. Holocene Marine Transgression in the Coastal Plain of Rio Grande do Sul, Brazil: Palynomorph and Diatom Evidence. Journal of Coastal Research, 25: 224-233.

Möller, O.O., Castaing, P., 1999. Hydrological characteristics of the estuarine area of Patos Lagoon (301S, Brazil), in: Perillo, G.M.E., Piccolo, M.C., (Eds.), Estuaries of South America (their Geomorphology and Dynamics)—Environmental Science. Springer, Berlin, pp. 83–100.

Möller, O.O., Castaing, P., Salomon, J.C., Lazure, P., 2001. The influence of local and non-local forcing effects on the sub tidal circulation of Patos Lagoon. Estuaries, 24: 297-311.

Möller, O.O., Fernandes, E.,2010. Hidrologia e Hidrodinâmica, in: Seelinger, U. and Odebrecht, C. (Eds.), O Estuário da Lagoa dos Patos: Um século de transformações, FURG, Rio Grande, pp. 17-30.

Möller, O.O., Lorenzzetti, J.A., Stech, J.L., Mata, M.M., 1996. The summertime circulation and dynamics of Patos Lagoon. Continental Shelf Research, 16: 355-351.

Oberhänsli, H., Heinze, P., Diester-Haass, L., Wefer, G., 1990. Upwelling off Peru during the last 430,000 years and its relationship to the bottom-water environment, as deduced from coarse grain-size distributions and analyses of benthic foraminifers at holes 679D, 680B, and 681B, LEG 112, in: Suess E,von Huene R (Eds.), Proc Ocean Drilling Program. Scientific Results, 112: 369–382.

Odebrecht, C., Abreu, P.C. 1998. Microalgas, in: Ecossistemas Costeiro e Marinho do Extremo Sul do Brasil (Seeliger, U., Odebrecht, C.,Castello, J.P. (Eds.), Editora Ecoscientia, Rio Grande, pp. 36-40.

Odebrecht, C, Abreu, P.C., Bemvenuti, C.E., Copertino, M., Muelbert, J. H., Vieira, J. P., Seeliger, U., 2010. The Patos Lagoon Estuary, Southern Brazil: Biotic responses to natural and anthropogenic impacts in the last decades (1979-2008), in:

Kennish, M. J., Paerl, H.W. (Eds.). Coastal Lagoons: critical habitats of environmental change. Boca Raton, Florida, pp. 433-455

Odebrecht, C., Abreu, P.C., Möller Jr., O.O., Niencheski, L.F., Proença, L.A., Torgan, L.C., 2005. Drought Effects on Pelagic Properties in the Shallow and Turbid Patos Lagoon, Brasil. Estuaries, 28(5): 675-685.

Pappas, J. L., Stoermer, E.F., 1996. Quantitative method for determining a representative algal sample count. Journal of Phycology, 32: 693-696.

Pasquini, A.I., Depetris, P.J., 2007. Discharge trends and flow dynamics of South American rivers draining the southern Atlantic seaboard: An overview. Journal of Hydrology, 333: 85-399.

Pimm, S.L., 1991. The balance of nature? Ecological issues in the conservation of species and communities. Chicago: The University of Chicago Press.

Roelofs, A.K., 1984. Distributional patterns and variation of valve diameter of Paralia sulcata in surface sediments of Southern British Columbia Inlets. Estuarine Coastal Shelf Sciences, 18: 165–176.

Round, F.E., Crawford, R.M., Mann, D.G., 1990. Diatoms. Cambridge University Press, Cambridge.

Santos, C.B.dos., 2011. Assembléias de diatomáceas em sedimentos holocênicos no extremo sul do Brazil: reconstruções paleoambientais. M.Sc. Dissertation, Universidade Federal do Rio Grande do Sul, Porto Alegre, Brasil. Available in the website: http://hdl.handle.net/10183/32700 .

Santos, C.B. dos., 2015. Paleoecologia de diatomáceas como subsídios para o conhecimento da evolução paleogeográfica da região costeira do Rio Grande do Sul, Brasil (PhD thesis), 221p Programa de Pós-graduação em Geociências,. Universidade Federal do Rio Grande do Sul, Porto Alegre, Brasil.

Sawai, Y., Nagumo, T., Toyoda, K., 2005. Three extant species of Paralia (Bacillariophyceae) along the coast of Japan. Phycologia, 44: 517–529.

Shepard, F.P., 1954. Nomenclature based on sand-silt-clay ratios. Journal of Sedimentary Petrology, 24(3): 151-158.

Silva, J.G. da; Torgan, L.C., Cardoso, L.S., 2010. Diatomáceas (Bacillariophyceae) em marismas no sul do Brasil. Acta Botanica Brasilica, 24: 935-947.

Sims, P.A., Crawford, R.M., 2002. The morphology and taxonomy of the marine centric diatom genus Paralia. II. Paralia crenulata, P. fausta and the new species, P. hendeyi. Diatom Research, 17: 363-382.

Snoeijs, P., 1999. Diatoms and environmental change in brackish waters, in: Stoermer E.F., Smol J.P., (Eds), The Diatoms: Applications for the Environmental and Earth Sciences. Cambridge University Press, London, pp. 298–333.

Stabell, B., 1980.Holocene shorelevel displacement in Telemark, southernNorway. Norsk Geologisk Tidsskrift, 60: 71–81.

Talgatti, D.M., Bertolli, L.M., Torgan, L.C., 2014. Seminavis recta comb. nov. et stat. nov.: morphology and distribution in salt marshes from southern Brazil. Fottea, Olomouc, 14(2): 141-148.

Toldo Jr., E.E., Ayup Zouain, R.N., Corrêa, I.C.S., Dillenburg, S.R., 1991. Barra Falsa: Hipótese de um paleocanal holocênico de comunicação entre a Laguna dos Patos e o Oceano Atlântico. Pesquisas, 18(2): 99-103.

Toldo Jr., E.E., Dillenburg, S.R., Corrêa, I.C.S., Almeida, L.E.S.B., 2000. Holocene Sedimentation in Patos Lagoon Lagoon, Rio Grande do Sul, Brazil. Journal of Coastal Research, 16(3): 816-822.

Tomazelli, L.J.,Villwock, J.A., 2000. O Cenozóico no Rio Grande do Sul: Geologia da Planície Costeira, in: Holz, M., De Ros, L.F., (Eds.). Geologia do Rio Grande do Sul. Edição CIGO/UFRGS, Porto Alegre, Rio Grande do Sul, pp. 375-406.

Torgan, C. T., Becker, V., Prates, H. M., 1999. Checklist das diatomáceas (Bacillariophyta) de ambientes de aguas continentais e costeiros do Estado do Rio Grande do Sul, Brasil. Iheringia, Série Botânica, 52: 89-144.

Torgan, L.C., Pillar,V.D., Niencheski, L.F., 2006. Phytoplankton Associations of a Coastal Lagoon in South of Brazil. Journal of Coastal Research, 39: 1149-1151.

Torgan, L.C., Tundisi, J.G., L.F., Niencheski., 2002. Seasonal variation of planktonic diatoms in Patos Lagoon, southern Brasil. In: John, J., (Ed.). Proceedings of 15th Diatom Symposium. Ganmer Verlag, Lichtenstein, 459-470.

Tremarin, P.I., Loverde-Oliveira, S.M., Ludwig, T.A.V., Torgan, L.C., 2011. Ultrastructure and distribution of Aulacoseira gessneri (Hustedt) Simonsen (Diatomeae). Diatom Research, 26(2): 189–197.

Tremarin, P.I., Ludwig T.A.V. e Torgan, L.C., 2012. Ultrastructure of Aulacoseira brasiliensis sp. nov. (Coscinodiscophyceae) and comparison with related species. Fottea, 12(2): 171–188.

Tremarin, P.I., Paiva, R.S., Ludwig, T.A.V., Torgan, L.C., 2013a. Aulacoseira calypsi sp. nov. (Coscinodiscophyceae) from an Amazonian lake, northern Brazil. Phycological Research, 61: 292–298.

Tremarin, P.I., Ludwig, T.A.V., Torgan, L.C., 2013b. Morphological variation and distribution of the freshwater diatom Aulacoseira ambigua (Grunow) Simonsen in Brazilian continental environments. Iheringia, Série Botânica, 68(1): 139–157.

Tremarin, P.I., Ludwig T.A.V. e Torgan, L.C., 2014a. Four new Aulacoseira species (Coscinodiscophyceae) from Matogrossense Pantanal, Brazil. Diatom Research, 69(2): 183–199.

Tremarin, P.I., Ludwig, T.A.V., Torgan, L.C., 2014b. Aulacoseira veraluciae sp. nov. (Coscinodiscophyceae, Aulacoseiraceae): a common freshwater diatom from Brazil. Phytotaxa, 184(4): 208-222.

Tudhope, A.W., Chilcott, C.P., McCulloch, M.T., Cook, E.R., Chappell, J., Ellam, R.M., Lea, D.W., Lough. J.M., Shimmield, G.B., 2001.Variability in the El Niño Southern Oscillation through a glacial-interglacial cycle. Science, 291: 1511–1517.

Turcq, B., Pressinotti, M.M.M., Martin, L., 1997. Paleohydrology and paleoclimate of past 33,000 years at the Tamanduá River, Central Brasil. Quaternary Research, 47: 284-294.

Van der Hammen, T., Absy, M.L., 1994**.** Amazonia during the Last Glacial. Palaeogeography Palaeoclimatology Palaeoecology, 109: 247-261.

Vaz, A. C., Möller Jr., O.O., Almeida, T. L. de., 2006. Análise quantitativa da descarga dos rios afluentes da Lagoa dos Patos. Atlântica, 28: 13-23.

Villwock, J.A., Tomazelli, L.J., 1995. Geologia costeira do Rio Grande do Sul. Porto Alegre: UFRGS, Notas Técnicas, 8: 1-45.

Villwock, J.A., Tomazelli, L.J., Loss, E.L., Dehnhardt, E.A., Horn Fo., N.O., Bachi, F.A., Dehnhardt, B.A., 1986. Geology of the Rio Grande do Sul Coastal Province, in: Rabasa, J. (Ed.), Quaternary of South America and Antarctic Peninsula. Balkema Publishers, Rotterdam, pp. 4-11.

Vos, P.C., Wolf, H. de., 1988. Methodological aspects of palaeoecological diatom research in coastal areas of the Netherlands, Geologie en Mijnbouw, 67: 31-40.

Wanner, H., Beer, J., Bütikofer, J., Crowley, T., Cubasch, U., Flückiger, J., Goosse, H., Grosjean, M., Joos, F., Kaplan, J.O., Küttel, M., Müller, S.A., Prentice, I.C., Solomina, O., Stocker, T.F., Tarasov, P., Wagner, M., Widmann, M., 2008. Mid- to late Holocene climate change: an overview. Quaternary Science Reviews, 27: 1791–1828.

Weschenfelder, J., Baitelli, R., Corrêa, I.C.S., Bortolin, E.C., Santos, C.B.dos., 2014. Quaternary incised-valleys in southern Brazil coastal zone. Journal of South American Earth Sciences, 55: 83-93.

Weschenfelder, J., Corrêa, I.C.S., Aliotta, S., Baitelli, R. 2010a. Paleochannels related to Late Quaternary sea-level changes in southern Brazil. Brazilian Journal of Oceanography, 58: 35-44.

Weschenfelder, J., Corrêa, I.C.S., Toldo Jr., E.E., Baitelli, R., 2008b. Paleocanais como indicativo de eventos regressivos quaternários no nível do mar no sul do Brasil. Revista Brasileira de Geofísica, 3(26): 367-375.

Weschenfelder, J., Corrêa, I.C.S., Toldo Jr., E.E., Baitelli R., 2010b. A drenagem pretérita do Rio Camaquã na costa do Rio Grande do Sul. Pesquisas em Geociências, 37(1): 13-23.

Weschenfelder, J., Medeanic, S., Corrêa, I.C.S., Aliotta, S., 2008a. Holocene palaeoenvironment of the Bojuru region, Southern Brazil. Journal of Coastal Research, 24: 99-109.

Zaitlin, B.A., Dalrymple, R.W., Boyd, R., 1994. The stratigraphic organisation of incised-valley systemsassociated with relative sea-level change, in: Dalrymple, R.W., Boyd, R.J., Zaitlin, B.A., (Eds.)., Incised Valley Systems: Origin and Sedimentary Sequences, Society for Sedimentology Geology (Special Publication), Tulsa, 51, pp.45-60.

Zong ,Y., 1997. Implications of *Paralia sulcata* abundance in Scottish isolation basins. Diatom Research, 12: 125–150

CAPÍTULO VIII

CONSIDERAÇÕES FINAIS E CONCLUSÕES

VIII- CONSIDERAÇÕES FINAIS E CONCLUSÕES

Estudos sismoestratigráficos de alta resolução e frequência (3,5 e 7,0 kHz), realizados em registros sísmicos do interior da Lagoa dos Patos, revelaram proeminentes sistemas de vales e canais fluviais incisos associados às drenagens pretéritas dos rios Camaquã e Jacuí (Weschenfelder, 2005; Weschenfelder *et al*., 2008 a,b; 2010 a,b, 2014; Baitelli, 2012). Esses estudos permitiram o reconhecimento de elementos arquiteturais de vales e canais fluviais formados durante os estágios marinhos isotópicos (MIS) 6 e 2, sendo preenchidos durante os estágios subsequentes MIS 5-1. A partir dessas novas interpretações de natureza sismo-estratigráficas, três testemunhos de sondagem foram coletados com a finalidade de analisar o substrato sedimentar da Lagoa dos Patos, auxiliando na interpretação evolutiva dos sistemas de vales incisos e ambientes deposicionais costeiros associados.

A disponibilidade de dados sísmicos, geocronológicos e sedimentológicos dos testemunhos de sondagem, forneceram uma excelente oportunidade para a realização do estudo da natureza dos preenchimentos sedimentares de três vales incisos dos rios Camaquã e Jacuí, inferidos a partir da análise taxonômica e paleoecológica de diatomáceas fósseis. Adicionalmente, foram realizadas as análises de diatomáceas em sedimentos de testemunhos obtidos em distintos ambientes da planície costeira, plataforma continental externa e talude continental, bem como em amostras superficiais coletadas no interior da Lagoa dos Patos. Esta abordagem multidisciplinar permitiu não somente ampliar o conhecimento evolutivo desta região costeira, fortemente relacionada às oscilações do nível do mar durante o Pleistoceno tardio e o Holoceno, como também ressaltou a influência climática atuante no sistema lagunar moderno alterando a composição e distribuição espacial de diatomáceas ao longo do tempo.

A partir do tema central desta tese, envolvendo o preenchimento sedimentar de sistemas subtropicais de vales incisos dos rios Camaquã e Jacuí, dois artigos foram gerados:

O primeiro artigo apresenta a estreita ligação entre a feição geomorfológica conhecida como Barra Falsa e o paleocanal inciso do rio Camaquã. Após o último evento glacial (MIS 2), este canal comportou-se como um *inlet* submetido a sucessivos regimes de aberturas e fechamentos até o máximo transgressivo, quando extensas áreas da planície costeira foram afogadas em resposta à rápida elevação do nível do mar (MIS 1). Em torno de 2.100 anos AP, o canal foi fechado e um ambiente lagunar-estuarino foi estabelecido devido ao desenvolvimento e migração de dunas. Este estudo de caso demonstra a importância do estabelecimento e desenvolvimento de sistemas incisos na geomorfologia costeira regional, como observado em outras áreas costeiras (Fisher, 1962; Riggs *et al.*, 1996; Thieler *et al.*, 2001; Mallinson *et al.*, 2005; Miselis e McNinch, 2006; Smith, 2006). O modelo de evolução proposto é semelhante aos estudos realizados em Albemarle Sound na Carolina do Norte (Mallinson *et al.*, 2005; Culver *et al.*, 2008) e Gulfo de Lions, no mar Mediterrâneo na costa francesa (Ferrer *et al.*, 2010; Raynal *et al.*, 2010).

O segundo artigo constitui um exemplo de correlação paleoecológica e sismoestratigráfica na inferência de paleoambientes gerados durante o Pleistoceno tardio e Holoceno, relacionados ao desenvolvimento de distintos sistemas de vales incisos do rio Jacui. A análise de diatomáceas permitiu a subdivisão de duas unidades sismoestratigráficas, pré-definidas em estudos anteriores (S2 e S3), em cinco diferentes subunidades (S2 I, II e III e S3 I e II) fortemente relacionadas às oscilações do nível do mar. A sedimentação da bacia ocorreu em um grande embaiamento costeiro/marinho em idades superiores à 43.500 anos AP. Entretanto, os dados de diatomáceas mostram que esta deposição marinha foi substituída por uma deposição fluvial, ocorrendo em períodos próximos à última glaciação pleistocênica (Ultimo Glacial Máximo – MIS 2). Esta mudança brusca de sedimentação pode ser atribuída ao bloqueio de sedimentos à jusante do rio Jacuí por sedimentos da barreira arenosa pleistocênica, à queda do nível do mar de aproximadamente 130 m abaixo do atual associados aos eventos climáticos *El Niño/La Niña*. Durante o Holoceno, a transgressão pós-glacial afogou as incisões pleistocênicas, preenchendo os vales incisos com sedimentos marinho-estuarinos (MIS 1).

Os resultados das análises de diatomáceas realizadas em sedimentos de nove testemunhos de sondagem realizados no interior da Lagoa dos Patos e da Lagoa do Peixe, na plataforma e no talude continental, permitiram a elaboração de um terceiro artigo que visou apresentar dados inéditos sobre o conhecimento paleoecológico e paleoambiental da região costeira do Rio Grande do Sul desde o Pleistoceno tardio aos dias atuais. As comunidades de diatomáceas fósseis e atuais foram comparadas através de análises estatísticas multivariadas (PCA, CCA, DCA) e análise de cluster, amplamente utilizadas em estudos paleoambientais. Estas análises sugerem mudanças na composição e distribuição espacial dos *taxa* de diatomáceas ao longo do tempo em distintos ambientes da planície costeira, plataforma continental externa e talude continental do Rio Grande do Sul. Foram evidenciados os efeitos das oscilações do nível do mar, das mudanças climáticas e do transporte e isolamento geográfico de distintos *taxa* de diatomáceas devido ao estabelecimento de sistemas de vales incisos implantados na planície costeira. Um total de nove testemunhos e treze amostras superficiais coletadas no interior da Lagoa dos Patos fornece um sólido embasamento para as interpretações e novos percepções sobre os aspectos evolutivos desta área costeira.

A partir do desenvolvimento dos artigos acima citados, algumas significativas conclusões são apresentadas:

1. O estudo do preenchimento de vales incisos e paleocanais, através de sísmica e estudos bioestratigráficos, são bons parâmetros para a compreensão das mudanças causadas pela evolução de ambientes fluviais durante o Pleistoceno tardio e o Holoceno.
2. As oscilações do nível do mar foram enfatizadas como o principal mecanismo atuante na formação e preenchimento de vales incisos e na distribuição espacial de diatomáceas fósseis em distintos ambientes da zona costeira do Rio Grande do Sul.
3. A análise de diatomáceas, combinadas com registros sísmicos, forneceu consistentes evidências das principais mudanças ambientais às quais, distintos ambientes desta área costeira foram submetidos durante o Pleistoceno e Holoceno, possibilitando um avanço no conhecimento paleoecológico, paleogeográfico e evolutivo.
4. A sedimentação pleistocênica tardia é tipificada pela grande influência marinha registrada em amostras mais antigas que 43.500 anos AP até o Máximo Glacial (sub-unidade sísmica S2 I e II). As diatomáceas fósseis não marinhas foram registradas ocorrendo continuamente, mas em baixa densidade, interpretadas

como componentes alóctones, transportadas de ambientes fluviais. Posteriormente, a sedimentação marinha é substituída pelo aumento da influência fluvial (sub-unidade S2 III).

5. A sedimentação holocênica é tipificada pela influência da deposição marinha relacionada a manutenção de distintos *inlets* ao longo da Lagoa dos Patos (sub-unidades S3 I e II), em contraste com a configuração atual, aonde somente um canal é responsável pelas trocas de água com o Oceano Atlântico.
6. As diatomáceas fósseis de água doce registradas em ambientes da plataforma continental externa e talude continental são compatíveis com as amostras provenientes do rio Jacuí, corroborando com os registros de trabalhos morfoestruturais realizados na plataforma continental do Rio Grande do Sul, aonde as paleodrenagens fluviais podem ser conectadas por redes de drenagem à jusante. Os *taxa* de diatomáceas dulciaquícolas registrados nestes ambientes evidenciam o ativo transporte fluvial ocorrido em épocas pretéritas.
7. O proeminente paleocanal inciso do rio Camaquã pode ser relacionado à moderna feição geomorfológica Barra Falsa. Esta incisão fluvial permaneceu ativa durante o máximo rebaixamento do nível do mar durante a Última glaciação pleistocênica tardia, sendo preenchido durante a subsequente transgressão holocênica. Neste contexto, o paleocanal da Barra Falsa comportou-se como um *inlet* submetido a sucessivas aberturas e fechamentos até o completo afogamento desta área costeira. Esta herança geomorfológica corresponde ao remanescente canal de ligação entre o sistema lagunar e o oceano Atlântico como observado por diversos estudos realizados anteriormente.
8. Os resultados mostram que as oscilações do nível do mar, as mudanças nos padrões deposicionais e sedimentares aliados às condições climáticas causaram relevantes mudanças na composição e distribuição espacial de diatomáceas fósseis durante o Pleistoceno tardio e o Holoceno.
9. As comunidades de diatomáceas modernas depositadas nos sedimentos de fundo da Lagoa dos Patos parecem ser influenciadas pelos regimes de ventos, pelas mudanças no padrão de salinidade, pelo regime de descarga fluvial, pelos eventos climáticos *El Niño* e *La Niña* e pela configuração lagunar atual que apresenta somente um canal de ligação com o oceano.

10. A aplicação de análises estatísticas multivariadas (DCA, PCA, CCA) e análise de cluster, combinadas ao registro de diatomáceas, obtidos em diferentes ambientes da zona costeira do Rio Grande do Sul, fornecem consistentes evidências das principais mudanças paleoambientais pleistocênicas e holocênicas. Mudanças no padrão de distribuição espacial e na composição de comunidades de diatomáceas estão relacionadas a distintas condições paleogeográficas e hidrológicas das que são observadas atualmente na configuração costeira moderna.
11. A comparação entre comunidades por meios da análise de DCA permitiu o reconhecimento de espécies análogas modernas que foram utilizadas como ferramentas adicionais na interpretação paleoecológica e paleoambiental.
12. A espécie marinha *Paralia sulcata* é considerada como a espécie de maior sucesso ecológico-evolutivo, diferindo especialmente dos demais *taxa* registrados. Esta espécie ocorre continuamente desde o Pleistoceno tardio até a sedimentação atual, sendo considerada uma espécie indicadora de mudanças de salinidade relacionadas às oscilações do nível do mar e condições hidrológicas diversas.
13. As diatomáceas de água doce registradas em sedimentos pleistocênicos e holocênicos foram consideradas os *taxa* mais importantes na detecção da influência fluvial dos rios Camaquã e Jacuí.
14. Os sistemas de vales incisos dos rios Camaquã e Jacuí foram responsáveis pelo isolamento geográfico dos *taxa Aulacoseira veraluciae* e *Aulacoseira* sp.2 que são exclusivamente relacionadas à drenagem do rio Jacuí, enquanto que o *taxon Pinnularia* sp.1 está relacionada ao rio Camaquã. Devido ao isolamento, os *taxa* não foram registrados ocorrendo juntos no intervalo estudado, evidenciando a importância de vales incisos na distribuição e isolamento genético e geográfico, concordando com diversos estudos paleogeográficos e paleontológicos realizados na região de estudo.
15. Os estudos baseados em diatomáceas fósseis são fundamentais na determinação da natureza e proveniência sedimentar contidos em sistemas fluviais incisos.

CAPÍTULO IX- REFERÊNCIAS

IX- REFERÊNCIAS

ABREU, J. G.N.; CALLIARI, L.J. Paleocanais da platamarforma continental interna do Rio Grande do Sul: evidências de drenagem fluvial pretérita. **Revista Brasileira de Geofísica**, v. 23, n.2. p. 123-132, 2005.

ALLEN, G. P.; POSAMENTIER, H. W. Sequence stratigraphy and facies model of an incised valley fill: the Gironde Estuary, France. **Journal of Sedimentary Petrolology**, v. 63, p. 378-391, 1993.

ALLEN, G.P.; POSAMENTIER, H. W. Transgressive facies and sequence architecture in mixed tide and wave-dominated incised valleys: example from the Gironde estuary, France. In: DALRYMPLE, R;W; BOYD, R.J; ZAITLIN, B.A. (Ed.), **Incised valley systems : Origin and sedimentary Sequences**. Tulsa: SEPM, 1994. . p. 285-301. (Society for Sedimentology Geology Special Publication, 51).

ALMEIDA, F.F.M. DE.; HASUI, Y.; PONÇANO, W.L.; DANTAS, A.S.L.; CARNEIRO, C.D.R.; MELO, M.S. DE; BISTRICHI, C.A. **Mapa Geológico do Estado de São Paulo** São Paulo: Instituto de Pesquisas Tecnológicas. 126 p, 1981, Escala 1:500.000.

AMOROSI, A.; COLALONGO, M. L.; FUSCO, F.; PASINI, G.; FLORINI, F. Glacio-eustatic control of continental shallow marine cyclicity from Late Quaternary deposits of the Southeastern Po Plain, northern Italy. **Quaternary Research**, v. 52, p. 1-13, 1999.

ANDRADE NETO, J.S.; RIGON, L. T.; TOLDO JR., E. E.; SCHETTINI, C. A.F. Descarga sólida em suspensão do sistema fluvial do Guaíba, RS, e sua variabilidade temporal. **Pesquisas em Geociências**, v. 39, p. 161- 171, 2012.

ARBUCKLE, J.L., 2009. **Amos 18 user's guide**. Amos Development Corporation, Chicago, 654p.

AREJANO, T. **Geografia e evolução holocênica do sistema lagunar da Lagoa do Peixe, litoral médio do Rio Grande do Sul, Brasil**. 2006. 94 f. Tese de Doutorado (Doutorado em Geociências). Instituto de Geociências, Programa Pós-Graduação em Geociências, Universidade Federal do Rio Grande do Sul, Instituto de Geociências, Porto Alegre.

AREJANO, T.; MEDEANIC, S. Evolução do sistema lagunar da Lagoa do Peixe; os dados palinológicos e de diatomáceas. In: XI CONGRESSO DA ASSOCIAÇÃO BRASILEIRA DE ESTUDOS DO QUATERNÁRIO ABEQUA. Belém do Pará, PA, **Anais...** , Belém, 2007, (CD-ROM)

BAITELLI, R. **Evolução Paleogeográfica do Sistema de Paleodrenagem do Rio Jacuí na Planície Costeira do Rio Grande do Sul**. 2012,147 f. Tese (Doutorado em Geociências)- Instituto de Geociências, Programa de Pós-Graduação em Geociências, Universidade Federal do Rio Grande do Sul, Porto Alegre. http://hdl.handle.net/10183/56850.

BARRETO, A. M.F.; BEZERRA, F. H.R.; SUGUIO, K.; TATUMI, S. H.; YEE, M.; PAIVA, R. P.; MUNITA, C. S. Late Pleistocene marine terrace deposits in northeastern Brazil: sea-level change and tectonic implications. **Palaeogeography, Palaeoceanography, Paleoecology**, v. 179, p. 57-69, 2002.

BHATTACHARYA, J. P. Sequence stratigraphy of fluvial–deltaic wedges: a 20 year perspective from the Cretaceous Interior Seaway of North America. **Sedimentology**, v. 58, p. 120–169, 2011.

BERGESH, M.; GARCIA, M.; ODEBRECHT, C. Diversity and morphology of *Skeletonema* species in southern Brazil, southwestern Atlantic Ocean. **Journal of Phycology**, v. 45, p. 1348-1352, 2009.

BEZERRA, F. H.R., BARRETO, A. M.F., SUGUIO, K. Holocene sea-level history on the Rio Grande do Norte State coast, Brazil. **Marine Geology**, v. 196, p.73-89, 2003.

BICCA, A. B.; TORGAN, L. C.; SANTOS, C. B. dos. Eunotiaceae (Eunotiales, Bacillariophyta) em ambientes lacustres na Planície Costeira do Sul do Brasil. **Revista Brasileira de Botânica,** v. 34, p. 1-19, 2011.

BIGUNAS, P. I. **Diatomáceas (Ochrophyta) do Rio Guaraguaçu, Litoral do Paraná, Brasil.** 2005. 494f. Dissertação (Mestrado em Botânica) – Setor de Ciências Biológicas,Universidade Federal do Paraná, Curitiba.

BLUM, M. D. Genesis and architecture of incised valley fill sequences: a Late Quaternary example from the Colorado River, Gulf Coastal Plain of Texas. In: WEIMER, P; POSAMENTIER, H.W. (Ed). **Siliciclastic Sequence Stratigraphy: Recent Developments and Applications.** 1993, p. 259-283. (Memoir of the American Association of Petrology Geology, 58).

BLUM, M. D., HATTIER-WOMACK, J. Climate change, sea-level change, and fluvial sediment supply to deepwater depositional systems: a review. In: KNELLER, B.C; MCCAFFREY, W.D; MARTINSEN, O.J., (Ed.). **External Controls on Deepwater Depositional Systems**. Tulsa: SEPM, 2009, p. 15-39. (Society for Sedimentary Geology Special Publication, 93).

BLUM M. D., MARTIN J., MILLIKEN, K.; GARVIN, M. Paleovalley systems: Insights form Quaternary analogs and experiments. **Earth-Science Reviews**, 116: 128-169, 2013.

BLUM, M. D., MORTON, R. A., DURBIN, J. M. "Deweyville" terraces and deposits of the Texas Gulf Coastal Plain. Transactions of the Gulf Coast. **Association of Geological Societies,** v. 45, 53-60, 1995.

BLUM, M. D., TÖRNQVIST, T.E. Fluvial responses to climate and sea-level change: A review and look forward. **Sedimentology**, v. 47, n. 1, p.2-48, 2000.

BORTOLIN, E. C. **Análise sismo-estratigráfica no estudo evolutivo de paleocanais da Planície Costeira do Rio Grande do Sul**. 2011, 51f. Trabalho de Conclusão do Curso de Geologia, Instituto de Geociências da Universidade Federal do Rio Grande do Sul, IGEO/UFRGS, Porto Alegre. 2011.

BOYD, R.; DALRYMPLE, R. W.; ZAITLIN, Brian A. **Estuarine and Incised-Valley Facies Models.** Tulsa: SEPM, 2006, p. 171-235. Society for (Sedimentary Geology. Special Publication, 84).

CALLIARI, L. J.; WINTERWERP, J.C.; FERNANDES, E.; CUCHIARA, D.; VINZON, S.B., SPERLE, M. HOLLAND, T. Fine grain sediment transport and deposition in the Patos Lagoon-Cassino beach sedimentary system. **Continental Shelf Research**, v. 29, n.3, p. 515-529. 2009.

CARON F. **Depósitos sedimentares associados à desembocadura do Arroio Chuí (Planície Costeira do Rio Grande do Sul e suas relações com as variações do nível do mar durante o Holoceno.** 2007, 81f. Dissertação (Mestrado em Geociências), Programa de Pós-Graduação em Geociências - Universidade Federal do Rio Grande do Sul (PPGGEO-UFRGS), Porto Alegre. 2007. http://www.lume.ufrgs.br/handle/10183/8813.

______. **Estratigrafia e evolução da barreira costeira holocênica na região de Santa Vitória do Palmar, sul da planície costeira do Rio Grande do Sul**. 2014, 172f. Tese (Doutorado em Geociências). Programa de Pós-Graduação em

Geociências - Universidade Federal do Rio Grande do Sul (PPGGEO-UFRGS), Porto Alegre. 2014.http://www.lume.ufrgs.br/handle/10183/88625

CHAUMILLON, E.; PROUST, J J-N.; MENIER, D.; WEBER, N. Incised valley morphologies and sedimentary-fills within the inner shelf of the Bay of Biscay (France): a synthesis. **Journal of Marine Systems**, v. 72, p.383-396, 2008.

CHAUMILLON, E.; WEBER, N. Spatial variability of modern incised valleys on the French Atlantic coast: comparison between the Charente (Pertuis d'Antioche) and the Lay-Sèvre (Pertuis Breton) incised valleys. In: DALRYMPLE, R.W; LECKIE, D.A.; TILLMAN, R.W. (Ed.). **Incised valleys in time and space.** 2006, p. 57-85. Tulsa: SEPM. 2006. (Society for Sedimentary Geology Special Pub.lication 85).

CLEROT, L.C.P. **Estudo da Bareira IV na Região do Cassino, Rio Grande – RS: Evolução e Caracterização como Reservatório**. 2004, 75f. Dissertação (Mestrado em Geociências), Programa de Pós-Graduação em Geociências da Universidade Federal do Rio Grande do Sul, Porto Alegre. 2004.

CORRÊA, I.C.S. Evidence of sea-level fluctuation on the Rio Grande do Sul continental shelf, Brazil. **Quaternary of South America and Antarctic Peninsula**, v. 40, p. 237-249. 1986.

______.Sedimentos superficiais da plataforma e talude continental do Rio Grande do Sul. **Pesquisas**, v. 19, p. 95–104, 1987.

______.Analyse morphostructurale et evolution paleogeographique de la plateforme continentale atlantique sud-bresilienne (Rio Grande do Sul – Brasil). 1990, 314 f. Doctorate Universite de Bordeaux I. Doctorate. France, Bordeaux. 1990.

______.Interpretation Morphostructurale de la Plate-Forme Continentale du Rio Grande do Sul, a partir de l'Analise Cartographique. **Notas técnicas**, v.7,p. 3-26, 1994.

______.Les variations du niveaux de la mer durant lês derniers 17.500 ans BP: l'example de la plate-forme continentale du Rio Grande do Sul-Brasil. **Marine Geology,** v. 130, p. 163-178, 1996.

CORRÊA, I.C.S.; MEDEANIC, S.; WESCHENFELDER, J.; TOLDO JR. E.E.; NUNES, J.C.; BAITELLI, R. The palaeo-drainage of the La Plata River in southern Brazil continental shelf. **Revista Brasileira de Geofísica**, v. 32, n. 2, p. 259-271, 2014a.

CORRÊA, I. C.S.; MEDEANIC, S.; WESCHENFELDER, J.; TOLDO JR. E. E.; NUNES, J. C.; BAITELLI, R.; SANTOS, C. B. dos. Registro sedimentario del antiguo canal de desembocadura del Río de La Plata en la plataforma continental del sur de Brasil. **Revista Mexicana de Ciencias Geológicas**, v. 30, n. 1, p. 51-64, 2013.

CORRÊA, I. C.S.; TOLDO JR, E. E.The Sea-level Stabilization in The Rio Grande do Sul Continental Shelf, Brazil. **Anais da Academia Brasileira de Ciências**, v. 70, n. 2, p. 213-219, 1998.

CORRÊA, I. C.S.; TOLDO JR, E. E.; WESCHENFELDER, J.; BAITELLI, R.; AYUP-ZOUAIN, R. N.; DEHNHARDT, B., A.; MARTINS, L.R.S. Plataforma e Talude Continental do Rio Grande do Sul: síntese dos conhecimetos. In: IANUZZI, R.; FRANTZ, J.C. (Ed.). **50 anos de Geologia**: **Instituto de Geociências. Porto Alegre, IGEO/UFRGS**, Porto Alegre: 2007, p. 341-353. Ed. da Universidade/ UFRGS.

CORRÊA, I.C.S.; WESCHENFELDER, J.; TOLDO JR., E. E.; BAITELLI, R.; SANTOS, C. B.dos.Turfa na plataforma continental do Sul do Brasil. **Comunicações Geológicas**, v. 101, p. 721-724, 2014b.

CULVER, S. J.; FARRELL, K. M.; MALLINSON, D. J.; HORTON, B. P.; WILLARD, D. A.; THIELER, R. E.; RIGGS, S. R.; SNYDER, S. W.; WEHMILLER, J. F.; BERNHARDT, C. E.; HILLIER, C. Micropaleontologic record of late Pliocene and Quaternary paleoenvironments in the northern Albermarle Embayment, North Carolina, USA. **Palaeogeography, Palaeoclimatology, Palaeoecology**, v. 264, p. 54-77, 2008.

DALRYMPLE, R.W., 2006. Incised valleys in time and space: introduction to the volume and an examination of the controls on valley formation and filling, In: Dalrymple, R.S.; Leckie, D.A.; Tillman, R., (Ed.). **Incised valleys in Time and Space**. Tulsa: SEPM , 2006, p. 5-12. (Special Publication 85).

DALRYMPLE, R. W.; BOYD, R.; ZAITLIN, B. A. **Incised-Valley Systems: Origin and Sedimentary Sequences**. Tulsa: SEPM, 1994. (Society for Sedimentary Geology Special Publication 51).

DALRYMPLE, R. W; LECKIE, D. A.; TILLMAN, R. I**ncised valleys in Time and Space.** SEPM, 2006. (Society for Sedimentary Geology Special Publication 85).

DALRYMPLE, R. W.; ZAITLIN, B. A.; BOYD, R. Estuarine facies models: conceptual basis and stratigraphic implications. **Journal of Sedimentary Petrololgy** v. 62, p.1130–1146, 1992.

DELANEY, P.J.V. Quaternary Geologic History of the Coastal Plain of Rio Grande do Sul, Brazil. **South American Coastal Studies Technical Report**, v.10 (Part A), p. 1-63, 1962.

DENYS, L. A check-list of the diatoms in the Holocene deposits of the western Belgian coastal plain with a survey of their apparent ecological requirements. I. Introduction, ecological code and complete list. **Belgische Geolgische Dienst van België, Professional Paper**,v. 246: p. 1-41, 1991a.

DENYS, L. A check-list of the diatoms in the Holocene deposits of the western Belgian coastal plain with a survey of their apparent ecological requirements. II. Centrales**. Belgische Geolgische Dienst van België, Professional Paper**, v. 247, p.1-92. 1991b.

DENYS, L.; de WOLF; H. Diatoms as indicators of coastal paleo-environments and relative sea-level change. In: **The Diatoms: Applications for the Environmental and Earth Sciences.** STOERMER, E.F.; SMOL, J.P. (Ed.), Cambridge: 1999, p. 277-297. Cambridge University Press

DILLENBURG, S. R.; BARBOZA, E. G.; TOMAZELLI, L. J.; ROSA, M. L. C.C., MACIEL, G. S. Aeolian deposition and barrier stratigraphy of the transition region between a regressive and transgressive barrier: an example from southern Brazil. **Journal of Coastal Research**, v. 65, p. 464-469, 2013.

DILLENBURG, S. R.; HESP, P. A. **Geology and Geomorphology of Holocene Coastal Barriers of Brazil.** Springer: Lecture Notes in Earth Sciences 107, Berlin, 2009, 390p.

DILLENBURG, S .R., ROY, P. S.; COWELL, P.J.; TOMAZELLI, L. J. Influence of antecedent topography on coastal evolution as tested by the shoreface translation-barrier model (STM). **Journal Coastal Research**, v. 16, p. 71-81, 2000.

DILLENBURG, S. R.; TOMAZELLI, L. J.; BARBOZA, E. G. Barrier evolution and placer formation at Bujuru southern Brazil. **Marine Geology**, v. 203, p.43-56, 2004.

DILLENBURG, S. R.; TOMAZELLI, L. J.; HESP, P. A.; BARBOSA, E. G.; CLEROT, L. C.P.; SILVA, D.B. Stratigraphy and evolution of a prograded, transgressive dunefield barrier in southern Brazil. **Journal of Coastal Research SI**, v. 39, n. 1,p. 132-135, 2006.

ESPINOSA M. A. Paleoecologia de diatomeas del estuario del Rio Quequén (Prov. de Buenos Aires, Argentina). **Thalassas**, v. 6, p. 33–44, 1988.

______.Diatom paleoecology of the Mar Chiquita lagoon delta, Argentina. **Journal of Paleolimnology**, v. 10,p. 17–23, 1994.

______.Reconstruccio´n de paleoambientes holocenos de la costa de Miramar. (provincia de Buenos Aires, Argentina) basada en diatomeas. **Ameghiniana**, v. 38, p. 27–34, 2001.

______. Diatoms of Patagonia and Tierra del Fuego. In: RABASSA, J. (Ed.). **Late Cenozoic of Patagonia and Tierra del Fuego**. Argentina, 2008, p. 383-392. (Developments in Quaternary Sciences, v. 11).

ESPINOSA, M. A.; DE FRANCESCO, C. G.; ISLA, F.I. Paleoenvironmental reconstruction of Holocene coastal deposits from the southeastern Buenos Aires province, Argentina. **Journal of Paleolimnology**, v. 29, p. 49-60, 2003.

ESPINOSA, M. A.; HASSAN, G.; ISLA, F. Diatom-inferred salinity changes in relation to Holocene sea-level fluctuations in estuarine environments of Argentina. **Alcheringa: An Australasian Journal of Palaeontology**, v. 36, p. 373-386, 2012.

ESPINOSA, M.; A., ISLA, F. Diatom and sedimentary record during the Mid-Holocene evolution of the San Blas estuarine complex, Northern Patagonia, Argentina. **Ameghiniana**, v. 48, n. 4,p. 411-423, 2011.

FAYÓ, R.; ESPINOSA, M. A. Reconstrucción paleoambiental de la Planicie Costera de Mar Chiquita (Provincia de Buenos Aires, Argentina) Durante el Holoceno, Basada em Diatomeas. **Ameghiniana,** v. 51, n. 6, 510-528, 2014.

FEPAM, 2010. **Qualidade das Águas da Bacia Hidrográfica do Rio Jacuí**. Disponível em: http://www.fepam.rs.gov.br/qualidade/qualidadejacui/jacui.asp

FERNANDES, E. H.L.; DYER, K. R.; MÖLLER, O. O.; NIENCHESKI, L. F. H. The Patos Lagoon hydrodynamics during an El Niño event (1998). **Continental Shelf Research**, v. 22, p.1699-1713, 2002.

FERRARI, F. **Diatomoflórula (Bacillariophyta) dos rios Ívaí, São João e Patos. Bacia hidrográfica do rio Ívaí (alto curso), Prudentópolis, PR**. 2004, 288f.

Dissertação (Mestrado em Botânica) – Setor de Ciências Biológicas da Universidade Federal do Paraná, Curitiba. 2004.

FERRER, P.; BENABDELLOUAHED, M.; CERTAIN, R.; TESSIER, B., BARUSSEAU, J-P.; BOUCHETTE, F. The Late Holocene sediment infilling and beach barrier dynamics of the Thau Lagoon (Gulf of Lions, Mediterranean Sea, SE France). **Bulletin de la Socièté Geologique de France**, v. 181, n. 2, p. 197-209, 2010.

FISHER, J.J., 1962. **Geomorphic Expression of Former Inlets along the Outer Banks of North Carolina.** 1962, 120 f. Thesis (Master Degree), University of North Carolina, Chapel Hill, North Carolina. 1962.

FISK, H. N. Geological investigation of the alluvial valley of the lower Mississippi River: **Technical Report, Mississippi River Committee, Vicksburg, Mississippi**, 1944.

FLÔRES, T.L. **Inventário florístico das diatomáceas (Bacillariophyta) do Banhado do Taim, Rio Grande do Sul, Brasil.** 1997, 390f. Dissertação (Mestrado em Botânica)- Setor de Ciências Biológicas da Universidade Federal do Paraná, Curitiba. 1997.

GAMBOA, L. A. P., RABINOWITZ, P.D. The Rio Grande Fracture Zone in the western South Atlantic and its tectonic implications. **Earth and Planetary Science Letters**, v. 52, p. 410-418, 1981.

GARCIA, C. A. E., 1997. Hydrographic Characteristics. In: SEELIGER, U., ODEBRECHT, C., CASTELLO, J.P. (Ed.). **Subtropical Convergence Environments . The Coast and Sea in the Southwestern Atlantic.** Springer Verlag, p.118-20.

GARCIA, M. **Considerações sobre a flora de diatomáceas psâmicas de Tramandaí (RS), Porto Belo (SC), Rhossili e Port Erin (Reino Unido).** 1999, 500f. Tese (Doutorado em Botânica). Instituto de Botânica, Universidade Federal do Rio Grande do Sul, Porto Alegre. 1999.

______.The transfer of Fragilaria obtusa Husted to the genus Staurosira Ehrenberg (Bacillariophyceae). **Phycological Research** v. 54, n. 2, p. 87-93, 2006.

______.A new diatom genus: *Rimoneis* M. Garcia (Fragilariaceae, Bacillariophyceae): a new hyaline araphid genus base on observations of frustules from Southern Brazil. **Diatom**, v.26, p. 1-9, 2010.

GARCIA, M.; ODEBRECHT, C., 2008. Morphology and ecology of the planktonic diatom *Palmerina hardmaniana* (Greville) Hasle in southern Brazil. **Biota Neotropica**, v.8, n.2, 85-90, 2008.

GARCIA, M.; SOUZA, V. F. de. *Amphora tumida* Hustedt (Bacillariophyceae) from southern Brazil. **Iheringia Série Botânica**, v. 63, n.1, p. 139-143, 2008.

GARCIA, M.; TALGATTI, D. M. The Diatom *Anorthoneis dulcis* Hein from Southern Brazil: morphology and ecology. **Research Letters in Ecology**, p. 1-5, 2008.

______.Morfologia e distribuição de *Catenula adhaerens* Mereschkowsky (Bacillariophyceae) no sul do Brasil. **Iheringia Série Botânica**, v. 66, n.1, 99-108, 2011.

GARCIA, M.; TALGATTI, D. M.; SOUZA-MOSIMANN, R; LAUDARES-SILVA, R. Morphology and distribution of Paralia Heiberg (Coscinodiscophyceae) in southern Brazil. **Iheringia Série Botânica**, v.67, n.2, p. 225-235, 2012.

GARCIA-BAPTISTA, M. Observations on the genus *Hantzschia* at a sandy beach in Rio Grande do sul, Brazil. **Diatom Reseach,** v. 8, n.1, p. 23-27, 1993.

GARCIA-BAPTISTA, M.; BAPTISTA, L. R.M. Algas psâmicas de Jardim Beira-Mar, Capão da Canoa, Rio Grande do Sul, Brasil. **Revista Brasileira de Biologia**, v. 52, n.2, p.325-342, 1992.

GARCÍA-RODRÍGUEZ, F. Inferring paleosalinity changes using the chrysophyte cyst to diatom ratio in coastal shallow temperate/subtropical lagoons influenced by sea-level changes**, Journal of Paleolimnology,** v. 36, p.165-173, 2006.

GARCÍA-RODRÍGUEZ, F.; DEL PUERTO, L.; CASTIÑEIRA, C.; INDA, H.; BRACCO, R.; SPRECHMANN, P.; SCHARF, B.W. Preliminary paleolimnological study of Rocha lagoon, SE Uruguay. **Limnologica**, v. 31, p. 221-228, 2001.

GARCÍA-RODRÍGUEZ, F.; METZELTIN, D.; SPRECHMANN, P.; TRETTIN, R.; STAMS, G.; BELTRÁN-MORALES, L. F. Upper Pleistocene and Holocene paleosalinity and trophic state changes in relation to sea-level variation in Rocha Lagoon, southern Uruguay. **Journal of Paleolimnology**, v. 32, p.117-135, 2004a.

GARCÍA-RODRÍGUEZ, F.; SPRECHMANN, P.; METZELTIN, D., SCAFATI, L.; MELENDI, D. L.; VOLKHEIMER, W.; MAZZEO, N.; HILLER, A.; VON TÜMPLING JR., W.; SCASSO, F. Holocene trophic state changes in relation to sea-level variation in Lake Blanca, SE Uruguay. **Journal of Paleolimnology**, v. 31, p. 99-115, 2004b.

GIBLING, M.R., FIELDING, C.R.; SINHA; R. Alluvial valleys and alluvial sequences: towards a geomorphic assessment. **From River to Rock Record: The Preservation of Fluvial Sediments and Their Subsequent Interpretation**. In: DAVIDSON, S.; LELEU, S.; NORTH, C. (Ed.). Tulsa, SEPM, 2011, p. 423-447. (Special Publication, 97).

GRIMM, A. M.; BARTROS, V. R.; DOYLE, M. E. Climate variability in Southern South America associated with “El Niño” and “La Niña”events. **Journal of Climate**,v. 13, n.1, p. 35-58, 2000.

GRIMM, A. M.; FERRAZ, S. E.T.; GOMES, J. Precipitation Anomalies in Southern Brazil associated with “El Niño” and “La Niña” Events. **Journal of Climate,** v.11, p. 2863-2880, 1998.

HAMMER, O.; HARPER, D.A.T.; RIAN, P.D. **Past: Palaeonthological statistics software package for education and data analysis**. Version. 1.37. 2001. 243p.

HERMANY, G.; SOUZA, P. A.; TORGAN, L. C. 2013. Paleoecologia do sistema Pinguela-Palmital-Malvas, Holoceno da Bacia de Pelotas, RS, Brasil: uma abordagem focada na utilização de análises multivariadas para obtenção de diatomáceas descritoras. **Pesquisas em Geociências**, v. 40, n.1, p. 31-49, 2013.

HENDEY, I. N. **An introductory account of the smaller algae of British coastal waters – V.Bacillariophyceae (Diatoms).** Fischery Investigations Series, London: Her Majesty’s Stationery Office, 4, n. 5, 317 p, 1964.

HOLBROOK, J. M.; BHATTACHARYA, J.P. Reappraisal of the sequence boundary in time and space: Case and considerations for an SU (subaerial unconformity) that is not a sediment bypass surface, a time barrier, or an unconformity: Earth-Science Reviews, v. 113, n. 3-4, p. 271-302, 2012.

HUSTEDT, F. Bacillariophyta (Diatomaceae). In:PASCHER, A. (Ed.), **Die Süsswaser-flora Mitteleuropas**, 10. Fischer, G, Jena, 1930, 466p.

______.Diatomeen aus dem lago de Maracaibo in Venezuela. Ergebnisse der deutschen limnogischen **Venezuela-Expedition 1952,** v.1, p. 93-140, 1956.

______.Die Diatomeenflora des Flubsystems der Weser im Gebiet der Hansestadt Bremen. **Abhandlungen Naturwissenschaftlicher Verein zu Bremen**, v. 34, n.3, p.181-440, 1957.

IMBRIE, J.; HAYS, J.D.; MARTINSON, D. G.; MCINTYRE, A..; MIX, A. C.; MORLEY, J. J.; PISIAS, N. G.; PRELL, W. L.; SHACKLETON, N. J., The orbital theory of Pleistocene climate: support from a revised chronology of the marine ^{18}O record. In: BERGER, A.L., IMBRIE, J., HAYS, J., KUKLA, G., SALTZMAN, B. (Ed.), **Milankovitch and Climate, 1**, Reidel, Boston, 1984, pp. 269-305.

JERVEY, M. T. Quantitative Geological modeling of siliciclastic rock sequences and their seismic expression In: WILGUS, C.K.; BRUCE, S.; HASTINGS, H., POSAMENTIER, H.; VAN WAGONER, J., ROSS, C.A.; CHRISTOPHER, S.T. (Ed.). **Sea-level Changes: An integrated aproach.** Tulsa, SEPM, 1988, p. 47-69. (Society for Sedimentology Geology Special Publication 42).

JUGGINS, S. **C2 software for ecological and palaeoecological data analysis and visualization,** version 1.5. Newcastle University, Newcastle, 73p, 2003.

JUNG**,** G. B., TOLDO JR**.,** E. E. Análise qualitativa da direção da corrente longitudinal entre 2004 e 2008 na praia de Tramandaí, RS, Brasil. **Revista Brasileira de Geomorfologia**, v. 13, p. 51-56, 2012.

LAUX, M.; TORGAN, L. C. Diatomáceas com plastídios no plâncton da foz dos rios do Delta do Jacuí, sul do Brasil: um complemento à taxonomia tradicional. **Iheringia Série Botânica**, v. 66, p.109-132, 2011.

LAMOTHE, G. L. de. Les anciennes nappes alluviales et lignes de Rivage du basin de la Somme et leurs rapports avec celles de la Meditarranee occidentals, **Bulletin de la Société Géologique de la France**, v.18, p. 3-58, 1918.

LIMA, L. G. **Estratigrafia e evolução da Barreira holocênica na praia do Hermenegildo(RS)**. 2007, 78f. Dissertação (Mestrado em Geociências), Programa de Pós-Graduação em Geociências - Universidade Federal do Rio Grande do Sul (PPGGEO-UFRGS), Porto Alegre. 2007.

LIMA, L. G.; DILLENBURG, S. R.; MEDEANIC, S.; BARBOZA, E. G.; ROSA, M. L.C.C.; TOMAZELLI, L. J.; DEHNHARDT, B. A.; CARON, F. Sea-level rise and sediment budget controlling the evolution of a transgressive barrier in southern Brazil. **Journal of South American Earth Sciences**, v. 42, p.27-38, 2013.

LONG, A. J.; SHENNAN, I. Models of rapid relative sea-level change in Washington and Oregon, USA. **The Holocene**, v. 8, p.129–42, 1998.

MALLINSON, D.; RIGGS, S. R.; THIELER, R.; CULVER, S. J.; FARRELL, K.; FOSTER, D. S.; CORBETT, R. D.; HORTON, B.; WEHMILLER, J.F. Late Neogene evolution of the northeastern North Carolina coastal system: filling the Albemarle Embayment. **Marine Geology**, v. 217, p. 97-117, 2005.

MANN, D. G. The species concept in diatoms (Phycological Reviews 18). **Phycologia,** v. 38, p. 437 – 495, 1999.

MARQUES, W. C. 2005. **Padrões de variabilidade temporal nas forçantes da circulação e seus efeitos na dinâmica da Lagoa dos Patos**, **Brasil.** 2005. Dissertação (Mestrado em Oceanografia) Universidade do Rio Grande, Rio Grandedo Sul, Brasil.

MARQUES, W. C. The Temporal Variability of the Freshwater Discharge and Water Levels at the Patos Lagoon,Brazil. **International Journal of Geosciences**, v.3, p.758-766, 2012.

MARQUES, W. C.; FERNANDES, E. H.; MORAES, B. C.; MÖLLER, O. O.; MALCHEREK, A. 2010. The dynamics of Patos Lagoon suspendeds sediment plume and its contribution for the deposition pattern in the Southern Brazilian inner shelf. **Journal of Geophysical Research,** v.115, p. C10045, 2010.

MARQUES, W. C.; FERNANDES, E. H.; ROCHA, L. A.O. Straining and advection contributions to the mixing process of the Patos Lagoon estuary, Brazil. **Journal of Geophysical Research**, v. 116, p. C03016, 2011.

MARQUES, W. C., MÖLLER, O.O. 2009.Variabilidade temporal em longo período da descarga fluvial e níveis de água da Lagoa dos Patos, Rio Grande do Sul, Brasil, **Revista Brasileira de Recursos Hídricos**, v. 13, p. 155–163, 2009.

MARTINS, I. R. Modelo Sedimentar do Cone de Rio Grande. **Pesquisas**, v.16, p. 91-189, 1984.

MARTINS, L. R., MELO, U., FRANÇA, A.M.C., SANTANA, C.I., MARTINS, I. R. 1972. Distribuição Faciológica da Margem Continental Sulriograndense. Congresso Brasileiro de Geologia, 26, Anais 2: 115-132, Belém, Brasil.

MARTINS, I. R.; TOLDO JR., E. E.; GRUBER, N. L.S. Descrição de Testemunhos da Plataforma Continental Sul-brasileira - GEOMAR VII, **Notas técnicas**, v.5, p. 1-158, 1987.

MARTINS, L. R.; URIEN, C. M.; CORRÊA, I. C. S.; MARTINS, I. R. Late Quaternary processes along the Rio Grande do Sul continental shelf (southern Brazil). **Notas Técnicas**, v.9, p.62-68, 1996.

MEDEANIC, S.; CORRÊA, I. C.S.; WESCHENFELDER, J. Resultados preliminares sobre as diatomáceas dos sedimentos superficiais do fundo da Laguna dos Patos. **Gravel**, v.6, n. 1,p. 15-25, 2008.

MEDEANIC, S.; DILLENBURG, S. R. 2001. The Early Holocene palaeoenvironment history of the Tramandaí Lagoon (RS, Brazil). In: V REUNIÃO DO QUATERNÁRIO IBÉRICO, I CONGRESSO DO QUATERNÁRIO DE PAISES DE LÍNGUAS IBÉRICAS 6, Lisboa, Portugal, **Actas** p. 402-405, Lisboa, 2001.

MEDEANIC, S.; DILLENBURG, S. R.; TOLDO JR, E. E. Novos dados palinológicos da transgressão marinha pós-glacial em sedimentos da Laguna dos Patos. **Revista Universidade Guarulhos**, v. 6, p. 64-76, 2001.

MEDEANIC, S.; TORGAN, L. C.; CLEROT, L. C.P.; SANTOS, C. B. dos. Holocene Marine Transgression in the Coastal Plain of Rio Grande do Sul, Brazil: Palynomorph and Diatom Evidence. **Journal of Coastal Research**, v. 25, p. 224-233, 2009.

MEDLIN, L.; KACZMARSKA, I. 2004. Evolution of the Diatoms: V. Morphological and Cytological Support for the Major Clades and a Taxonomic Revision. **Phycologia,** v. 43, n. 3, p. 245-270.

MISELIS, J.L.; MCNINCH, J.E. Calculating shoreline erosion potential using nearshore stratigraphy and sediment volume: Outer Banks, North Carolina. **Journal of Geophysical Research**, v.111, p.F02019, 2006.

MÖLLER, O. O.; CASTAING, P. 1999. Hydrological characteristics of the estuarine area of Patos Lagoon (301S, Brazil) In: PERILLO, G.M.E.; PICCOLO, M.C., (Ed.), **Estuaries of South America (their Geomorphology and Dynamics).** Springer, Berlin, 1999, p. 83-100. Environmental Science.

MÖLLER, O. O.; CASTAING, P.; SALOMON, J-C., LAZURE, P. The influence of local and non-local forcing effects on the sub tidal circulation of Patos Lagoon. **Estuaries**, v. 24, p. 297-311, 2001.

MÖLLER, O. O.; FERNANDES, E. Hidrologia e Hidrodinâmica. In: SEELINGER, U.; ODEBRECHT, C. (Ed.), **O Estuário da Lagoa dos Patos: Um século de transformações,** FURG, Rio Grande, 2010, p 17-30.

MÖLLER, O. O.; LORENZZETTI, J. A.; STECH, J. L.; MATA, M. M.1996. The summertime circulation and dynamics of Patos Lagoon. **Continental Shelf Research**, v.16, p. 355-351, 1996.

NAKANISHI, T.; TANABE, S.; KIMURA, K.; NAKASHIMA, R.; UCHIYAMA, M.; SHIBATA, Y. Sedimentary facies, diatom assembleages, physical properties and radiocarbon ages of the latest Pleistocene to Holocene incised-valley fills under the southern Nakagawa Lowland, Kanto Plain, Japan. **Bulletin of the Geological Survey of Japan**, v. 62, n.1/2, p.3-46, 2011.

NGUYEN, V. L.; KOBAYASHI, I. Holocene diatom flora and sedimentary environment ofthe Echigo Plain, central Honshu, JapanFPart 1: the analysis ofFukushim a-gata well core. **Scientific Report of Niigata University,** 11, 13–33, 1996.

NGUYEN, V. L.; KOBAYASHI, I. Diatom flora and paleoenvironment ofLate Pleistocene and Holocene deposits ofLake Kamo, Sado Island, **Central Japan. Scientific Report of Niigata University**, v.12, p.51–83, 1997.

NGUYEN, V. L.; TA, T. K. O.; TATEISHI, M. Late Holocene depositional environments and coastal evolution of the Mekong River Delta, Southern Vietnam. **Journal of Asian Earth Science**, v.18, p. 427-439, 2000.

NGUYEN, V. L.; TA, T. K. O.; SAITO, Y. Early Holocene initiation of the Mekong River delta, Vietnam, and the response to Holocene sea-level changes detected from DT1 core analyses. **Sedimentary Geology**, v. 230, p.146-155, 2010.

PATRICK, R. Ecology of freshwater diatoms. In: WERNER, D. (Ed.). **The Biology of Diatoms.** University California Press, 1977, p. 284-332.

PATRICK, R.; REIMER, C. The diatoms of the United States exclusive of Alaska and Hawaii” **Philadelphia: Academy of Natural Sciences, Monograph,** v. 13, n.1, 1966. 410p

PAPPAS, J. L.; STOERMER, E. F. Quantitative method for determining a representative algal sample count. **Journal of Phycology,** v. 32, p. 693-696, 1996.

PAYTON, C. E. Seismic stratigraphy - Applications to hydrocarbon Exploration, in: **The American Association of Petroleum Geologists AAPG memoir,** v. 26, 516 pp, 1977.

PERAGALLO, H.; PERAGALLO, M. **Diatomées marines de France et des districts maritimes voisins.** Micrographe-Éditeur, à Grez-sur-Loing (S.-et-M.). 491 pp., Atlas, 1897-1908., 137p.

POSAMENTIER H. W.; VAIL, P. R. 1988. Eustatic controls on clastic deposition II—Sequence and systems tract models, In: WILGUS, C.K.; BRUCE, S.; HASTINGS, H., POSAMENTIER, H.; VAN WAGONER, J., ROSS, C.A.; CHRISTOPHER, S.T. (Ed.). **Sea-level Changes: An integrated aproach.** Tulsa, SEPM, 1988, p. 125-154. (Society for Sedimentology Geology Special Publication 42).

RAYNAL, O.; BOUCHETTE, F.; CERTAIN, R.; SABATIER, P.; LOFI, J.; SERANNE, M.; DEZILEAU, L.; BRIQUEU, L.; FERRER, P.; COURP, T. Holocene evolution of a Languedocian Lagoonal environment controlled by inherited coastal morphology (Northern Gulf of Lions, France). **Bulletin de la Sociètè Geologique de France**, v. 181, n. 2, p. 211-224, 2010.

RIGGS, S.R.; SNYDER, S.W.; HINE, A.C.; MEARNS, D.L. Hard-bottom morphology and relationship to the geologic framework: mid-Atlantic continental shelf. **Journal of Sedimentary Research**, v. 66, n. 4, p.830–846. 1996.

ROUND, F. E.; CRAWFORD, R. M.; MANN, D. G., 1990. **Diatoms**. Cambridge University Press, Cambridge, 760p.

SALOMONI, S. E.; ROCHA, O.; CALLEGARO, V. L. M.; LOBO, E. A. 2006. Diatomáceas epilíticas como indicadoras no rio Gravataí, Rio Grande do Sul, Brasil. **Hydrobiologia**, v. 559, n.1, p. 233-246, 2006.

SANTOS, C. B.dos. Assembléias de diatomáceas em sedimentos holocênicos no extremo sul do Brazil: reconstruções paleoambientais. 2011,129 f. Dissertação (Mestrado em Geociências), Programa de Pós-Graduação em Geociências da

Universidade Federal do Rio Grande do Sul, Porto Alegre. 2011. http://hdl.handle.net/10183/32700 .

SAUCIER, R. T. A contemporary appraisal of some key Fishian concepts with emphasis on Holocene meander belt formation and morphology. **Engineering Geology**, v.45, p.67-86,1996.

SCHUMM, S. A. 1993. River response to base-level change: Implications for sequence stratigraphy. **Journal of Geology**, v.101, p. 279-294, 1993.

SHANLEY, K. W.; MCCABE, P. J. 1991. Predicting facies architecture through sequence stratigraphy: and example from the kaiparowits plateau. Utah. **Geology**, v.19, p. 742-745, 1991.

______. Alluvial architecture in a sequence stratigraphic framework: a case stury from the upper cretaceous of southern Utah, USA. In: FLINT, S.S.; BRYANT, D.I. (Ed.). **Quantitative modelling of clastic hydrocarbon reservoirs and outcrop analogs**. 1993, p. 21-55. (International Association of Sedimentologists Special Publication, 15).

SHEPARD, F. P. Nomenclature based on sand-silt-clay ratios. **Journal of Sedimentary Petrology**, 24, n. 3, p. 151-158, 1954.

SILVA, J. G da.; TORGAN, L. C.; CARDOSO, L. S. Diatomáceas (Bacillariophyceae) em marismas no sul do Brasil. **Acta Botanica Brasilica**, v. 24, p. 935-947, 2010.

SMITH, C.W., 2006. **Lithologic, Geophysical, and Paleoenvironmental Framework of Relict Inlet Channel-Fill and Adjacent Facies: North Carolina Outer Banks.** 2006, 267 f. Thesis (Master Degree), East Carolina University, Greenville, North Carolina.

STANLEY, D. J., WARNE, A. G.Sea level and initiation of Predynastic culture in the Nile delta: **Nature**, v. 363, p. 435–438, 1993.

SUGUIO, K.; MARTIN, L.. The role of neotectonics in the evolution of the Brazilian coast. **Geonomos**, v.4, n. 2, p. 45-53, 1996.

TA, T. K. O.; NGUYEN, V. L. Diatom - indicator of sedimentary environments and sealevel changes in Late Pleistocene–Holocene. **Journal of Science of the Earth**, v. 22, p. 226-233, 2000**.**

TA, T. K.O.; NGUYEN, V. L.; TATEISHI, M.; KOBAYASHI, I.; SAITO, Y. Sedimentary facies, diatom and foraminifer assemblages in a Late Pleistocene/Holocene incised-valley sequence from the Mekong River delta, Bentre Province, southern Vietnam: the BT2 core. **Journal of Asian Earth Sciences**, v. 20, p. 83-94, 2001.

TA, T.K.O.; NGUYEN, V. L; TATEISHI, M.; KOBAYASHI, I.; TANABE, S; SAITO, Y. Holocene delta evolution and sediment discharge of the Mekong River, southern Vietnam. **Quaternary Science Reviews**, v. 21, p. 1807–1819, 2002a.

TA, T. K. O.; NGUYEN, V. L.; TATEISHI, M.; KOBAYASHI, I.; SAITO, Y.; NAKAMURA, T. Sediment facies and Late Holocene progradation of the Mekong River Delta in Bentre Province, southern Vietnam: an example of a tide- and wave-dominated delta. **Sedimentary Geology**, v. 152, n. 7, 313-325, 2002b.

TALGATTI, D. M.; BERTOLLI, L. M.; TORGAN, L. C. Seminavis recta comb. nov. et stat. nov.: morphology and distribution in salt marshes from southern Brazil. **Fottea, Olomouc**, v. 14, n. 2, p. 141-148, 2014.

THIELER, E.R.; PILKEY JR. O.H.; CLEARY, W.J.; SCHWAB, W.C. Modern sedimentation on the shoreface and inner continental shelf at Wrightsville Beach, North Carolina, U.S. A. **Journal of Sedimentary Research**, v. 71, p. 958–970, 2001.

TJALLINGII, R.; STATTEGGER, K.; WETZEL, A.; PHACH, P V. Infilling and flooding of the Mekong River incised-valley during deglacial sea-level rise. **Quaternary Science Reviwes**, v. 29, p. 1432-1444, 2010.

TOLDO JR., E. E.; AYUP ZOUAIN, R. N.; CORRÊA, I. C.S.; DILLENBURG, S. R. 1991. Barra Falsa: Hipótese de um paleocanal holocênico de comunicação entre a Laguna dos Patos e o Oceano Atlântico. **Pesquisas**, v.18 n. 2, p. 99-103, 1991.

TOLDO JR., E. E.; DILLENBURG, S. R.; CORRÊA, I. C.S.; ALMEIDA, L. E.S.B. Holocene Sedimentation in Patos Lagoon Lagoon, Rio Grande do Sul, Brazil. **Journal of Coastal Research**, v. 16, n. 3, p. 816-822, 2000.

TOLDO JR., E. E.; MARTINS, R. R. Testemunhador Vibrador. **Pesquisas**, v. 21, p. 5-10, 1988.

TOMAZELLI, L. J.; VILLWOCK, J. A. 2000. O Cenozóico no Rio Grande do Sul: Geologia da Planície Costeira, In: HOLZ, MICHEL., DE ROS, L.F., (Ed.). **Geologia do Rio Grande do Sul.** Porto Alegre, 2000, p. 375-406. Edição CIGO/UFRGS.

TORGAN, L. C. **Estrutura e dinâmica da comunidade fitoplanctônica na Laguna dos Patos, Rio Grande do Sul, Brasil, em um ciclo anual**. 1997, 284f. Tese (Doutorado em Ciências– Ecologia e Recursos Naturais) – Centro de Ciências Biológicas e de Saúde, Universidade Federal de São Carlos, São Carlos. 1997.

TORGAN, L. C.; BECKER, V.; PRATES, H. M. Checklist das diatomáceas (Bacillariophyta) de ambientes de aguas continentais e costeiros do Estado do Rio Grande do Sul, Brasil. **Iheringia, Série Botânica**, v. 52, p. 89-144, 1999.

TREMARIN, P. I.; FREIRE, E. G.; BERTOLLI, L. M.; LUDWIG, T. A.V. Catálogo das diatomáceas (Ochrophyta-Diatomeae) continentais do estado do Paraná. **Iheringia, Série Botânica**, v. 64, n. 2, p: 79-107, 2009.

TREMARIN, P. I.; LUDWIG, T.; A.V.; TORGAN, L. C. *Aulacoseira veraluciae* sp. nov. (Coscinodiscophyceae, Aulacoseiraceae): a common freshwater diatom from Brazil. **Phytotaxa**, v.184, n. 4, p. 208-222, 2014.

URIEN, C. M.; MARTINS, L. R. **Structural and Physiographic Map of Eastern South America and Western South Atlantic.** Porto Alegre, CECO/UFRGS. Série Mapas 03. 1978.

VAIL, P. R.; MITCHUM, R. M.; THOMPSON, S. Seismic stratigraphy and global changes of sea level, part 4: global cycles of relative changes of sea level. **Memoir of the American Association of Petroleum Geologists**, v. 26, p. 83–97, 1977.

VAN WAGONER, J.C.; MITCHUM, R. M.; CAMPION, K. M.; RAHMANIAN, V. D. Siliciclastic Sequence Stratigraphy in Well Logs, Cores, and Outcrops: concepts for High-resolution Correlation of Time and Facies, 1990. **American Association of Petroleum Geologists, Methods in exploration series**, 7, 55p.

VAZ, A. C. **Efeito da descarga de água doce em processos ocorrentes no estuário da Lagoa dos Patos**. 2003, 68f. Monografia do curso de Oceanologia da Fundação Universidade do Rio Grande, 68pp. Rio Grande do Sul, Brasil, 2003.

VAZ, A. C.; MÖLLER JR.; O.O., ALMEIDA, T. L. de. Análise quantitativa da descarga dos rios afluentes da Lagoa dos Patos. **Atlântica,** v. 28, p. 13-23, 2006.

VILLWOCK, J. A. 1972. **Contribuição à geologia do Holoceno da Província Costeira do Rio Grande do Sul.** 1972, 113f. Dissertação (Mestrado em Geociências). Programa de Pós-Graduação em Geociências da Universidade Federal do Rio Grande do Sul, Porto Alegre, UFRGS. 1972.

______. Geology of the Coastal Province of Rio Grande do Sul, Southern Brazil. A Synthesis. **Pesquisas**, v. 16, p. 5-49, 1984.

VILLWOCK, J. A.; TOMAZELLI, L. J. Geologia costeira do Rio Grande do Sul. Porto Alegre: UFRGS, **Notas Técnicas**, v. 8, p. 1-45, 1995.

VILLWOCK, J. A.; TOMAZELLI, L. J.; LOSS, E. L.; DEHNHARDT, E. A.; BACHI, F. A.; DEHNHARDT, B. A.; GODOLPHIM, M.F.; HORN Fº, N. O. 1994. **Mapa Geológico da Província Costeira do Rio Grande do Sul** Porto Alegre, CECO, Instituto de Geociências, Universidade Federal do Rio Grande do Sul, 1994. Escala 1: 1.000.000.

VILLWOCK, J. A.; TOMAZELLI, L. J.; LOSS, E.L.; DEHNHARDT, E.A., HORN FO., N. O.; BACHI, F. A.; DEHNHARDT, B. A. . Geology of the Rio Grande do Sul Coastal Province. In: RABASA, J. (Ed.), **Quaternary of South America and Antarctic Peninsula,** Balkema Publishers, Rotterdam, 1986, p. 4-11.

VOS, P. C.; DE WOLF, H.. 1988. Methodological aspects of paleo-ecological diatom research in coastal areas of the Netherlands**.** **Geologie en Mijnbouw,** v. 67, p. 31-40.

VOS, P. C.; DE WOLF, H. Diatoms as a tool for reconstructing sedimentary environments in coastal wetlands; methodological aspects. **Hydrobiologia**, v. 269/270, p. 285-296. 1993.

______.Paleoenvironmental research on diatoms in early and middle Holocene deposits in central north Holland (The Netherlands). **Netherlands Journal of Aquatic Ecology ,** v. 28, p. 97-115, 1994.

WESCHENFELDER, J. **Processos sedimentares e variação do nível do mar na região costeira do Rio Grande do Sul, Brasil**. Porto Alegre. 2005, 130p. Tese de Doutorado, Programa de Pós-graduação em Geociências. Instituto de Geociências. Universidade Federal do Rio Grande do Sul, Porto Alegre, 2005.

WESCHENFELDER, J.; BAITELLI, R.; CORRÊA, I C.S.; BORTOLIN, E.C.; SANTOS, C. B.dos. Quaternary incised-valleys in southern Brazil coastal zone. **Journal of South American Earth Sciences** , v. 55, p. 83-93, 2014.

WESCHENFELDER, J.; CORRÊA, I. C.S.; ALIOTTA, S.; BAITELLI, R.. Paleochannels related to Late Quaternary sea-level changes in southern Brazil. **Brazilian Journal of Oceanography,** v. 58, p. 35-44, 2010a.

WESCHENFELDER, J.; CORRÊA, I. C.S.; TOLDO JR., E. E.; BAITELLI, R. Paleocanais como indicativo de eventos regressivos quaternários no nível do mar no sul do Brasil. **Revista Brasileira de Geofísica**, v. 3, n. 26, p. 367-375, 2008b.

WESCHENFELDER, J.; CORRÊA, I. C.S.; TOLDO JR., E. E.; BAITELLI, R.. A drenagem pretérita do Rio Camaquã na costa do Rio Grande do Sul. **Pesquisas em Geociências**, v. 37, n. 1, p. 13-23, 2010b.

WESCHENFELDER, J.; MEDEANIC, S.; CORRÊA, I.C.S.; Aliotta, S. Holocene palaeoenvironment of the Bojuru region, Southern Brazil. **Journal of Coastal Research**, v. 24, p. 99-109, 2008a.

YOSHIDA, M., INOUE, H., HOYANAGI, K., YANAGISAWA, Y., OISHI, M., YOSHIDA, H., 2011. High-resolution sequence stratigraphy in an incised-valley system on the basis of sedimentary organic matter, sulfur content and fossil diatom: an example from Miocene to Pliocene Tatsunokuchi Formation, Iwate Prefecture, Northeast Japan. **Journal of the Sedimentological Society of Japan** , v.70, n.2, p.63-79.

ZAITLIN, B.A., DALRYMPLE, R.W., BOYD, R. The stratigraphic organisation of incised-valley systemsassociated with relative sea-level change, In: DALRYMPLE, R.W., BOYD, R.J., ZAITLIN, B.A., (Ed.). **Incised Valley Systems: Origin and Sedimentary Sequences**. Tulsa, SEPM, 1994, p. 45-60. (Society for Sedimentology Geology Special Publication, 51).

ZAITLIN, B.A., SCHULTZ, B.C. 1990. Wave-influenced estuarine sand bodys, Senlac heavy oil pool. Saskatchewan, Canada. In: BARWIS, J.H.; MCPHERSON, J.G.; STUDLICK, J.R.J. (Ed.) **Sandstone Petroleum Reservoirs**. New York, Springer-Verlag, 1990, p.363-387.

ZHANG, G.J.; LI, C.X. Sources of sediments filling the Qiantangjiang-estuary incised valley since last glaciation: **Chinese Science Bulletin**, v. 43, n. 15, 1280-1284, 1998.

ZONG, Y. Postglacial stratigraphy and sea-level changes in the Han River Delta, China. **Journal of Coastal Research**, v.8, p. 1-28, 1992.

ZONG, Y.Q.; HORTON, B.P. Diatom-based tidal-level transfer functions as an aid in reconstructing Quaternary history of sea-level movements in the UK. **Journal of Quaternary Science**, v. 14, p.153–67, 1999.

ZONG, Y.; YU, F.; LLOYD, J.M.; HUANG, G.; YIM, W.W. S. Diatoms from the Pearl River estuary, China and their suitability as water salinity indicators for coastal environments. **Marine Micropaleontology,** v. 75, p. 38-49, 2010a.

ZONG, Y.; YU, F.; HUANG, G.; LLOYD, J.M.; YIM, W.W.S. Sedimentary evidence of Late Holocene human activity in the Pearl River delta, China. **Earth Surface Processes and Landforms**, v. 35, p.1095-1102, 2010b.

ZONG, Y.; YU, F.; HUANG, G.; LLOYD, J.M.; YIM, W.W.S. The history of water salinity in the Pearl River estuary, China, during the Late Quaternary. **Earth Surface Processes and Landforms**, v. 35, p.1221-1233, 2010c.

ZONG, Y.; HUANG, K.; YU, F.; ZHENG, Z.; SWITZER, A.; HUANG, G.; WANG, N.; TANG, M. The role of sea-level rise, monsoonal discharge and the palaeo-landscape in the early Holocene evolution of the Pearl River delta, southern China. **Quaternary Science Reviews,** v. 54, p. 77-88, 2012.

ANEXOS

ANEXOS

Tabela 1. Dados dos testemunhos de sondagem analizados no presente estudo.

Testemunho	Coordenadas	Profundidade (m)	Ambiente	Referência
B2	31°38’S/51°26’W	25,2	Planície costeira	Weschenfelder *et al*. (2008 b)
Bo	31º31’S/51º29’W	27,0	Lagoa dos Patos	Weschenfelder *et al*. (2014)
TBJ-02	31º38’S/51º25’W	5,50	Planície costeira	Medeanic *et al*. (2001)
T9	31º15’15”S/50º58’19”W	5,90	Lagoa do Peixe	Arejano (2006)
Mo	31º00’25”S/51º00’10”W	29,9	Lagoa dos Patos	Weschenfelder *et al*. (2014)
Pa	30º32’52”S/50º42’54”W	28,0	Lagoa dos Patos	Weschenfelder *et al*. (2014)
T15	30º32’12”S/50º47’18”W	2,30	Lagoa dos Patos	Toldo Jr. *et al*. (1991)
T19	30º41’23”S/51º10’50”W	2,05	Lagoa dos Patos	Toldo Jr. *et al*. (1991)
T103	31°43’16”S/50°12’24”W	6,70	Plataforma continental externa	Martins *et al*. (1978)
T22	32°13’24”S/49°35’30”W	6,09	Talude continental	Martins *et al*. (1978)

Tabela 2. Dados das amostragens superficiais do fundo da Lagoa dos Patos obtidas ao redor dos furos de sondagem Bo, Mo e Pa.

Amostra	Coordenadas	Profundidade da coluna d’água (m)	Amostrador	Sedimento
B2A	31º32’S/51º28’W	5,00	Draga de arraste	Areia
B3	31º31’S/51º29’W	7,50	*Van Veen*	Lama arenosa
B4	31º30’S/51º29’W	7,00	Draga de arraste	Areia
B6	31º31’S/51º30’W	7,65	*Van Veen*	Lama arenosa
M3	31º00’S/50º59’W	5,35	Draga de arraste	Areia
M5	31º00’S/51º0’W	6,35	Draga de arraste	Areia siltosa
M9	31º00’S/51º1’W	6,20	*Van Veen*	Lama
M12	31º00’S/51º00’W	6,30	*Van Veen*	Areia siltosa
Pa3	30º33’S/50º42’W	7,15	Draga de arraste	Lama
Pa5	30º32’S/50º43’W	7,35	*Van Veen*	Lama
Pa6	30º32’S/50º43’W	7,15	*Van Veen*	Lama
Pa8	30º32’S/50º42’W	7,05	*Van Veen*	Lama
Pa13	30º32’S/50º42’W	6,65	*Van Veen*	Lama arenosa

Tabela 3. Dados de datação radiocarbônica (^{14}C) de sedimentos biodetríticos e lamosos de amostras dos testemunhos de sondagem analisados neste estudo.

Testemunho/Amostra e Profundidade (m)	**Número BETA**	**Idade Convencional (^{14}C anos AP)**	**Idade Calibrada (cal anos AP)**	**Material datado**
Pa (21,0)	305998	> 43.500	-	Conchas
Pa (23,0)	305999	> 43.500	-	Conchas
Pa (26,0)	298209	> 43.500	-	Conchas
Mo (8,00)	360370	7.420 ± 40	7.960 – 7.680	Conchas
Mo (11,0)	298208	7.490 ± 50	7.980 - 7.750	Conchas
Mo (13,0)	294869	7.650 ± 40	8.160 - 7.920	Conchas
B2 (23,2)	185455	9.400 ± 140	11.500 - 10.240	Lama orgânica
TBJ-02 (3,30)	146844	7.370 ± 50	8.420 - 7.930	Lama orgânica
Bo (12,0)	294867	7.130 ± 40	7.640 - 7.430	Conchas
Bo (15,0)	359870	7.380 ± 40	7.930 - 7.650	Conchas
Bo (19,0)	294868	7.500 ± 40	7.990 - 7.760	Conchas
Bo (20,0)	359871	7.590 ± 30	8.150 - 7.870	Conchas
T9 (2,71-2,91)	204665	4.840 ± 70	5.370 – 5.340	Lama orgânica
T9 (5,15-5,35)	204666	6.630 ± 80	7.420 – 7.020	Lama orgânica
T19 (0,49-0,52)	Indisponível	2.400	-	Conchas
T15 (0,12-0,15)	Indisponível	2.150	-	Conchas

Table 4. Data from cores analyzed in this study.

Core	Coordinates	Length (m)	Environmental	Reference
B2	31°38' S/51°26'W	25.2	Extension of the Barra Falsa channel	Weschenfelder et al. (2008b)
Bo	31º31'S /51º29'W	27.0	Lagoa dos Patos interior	Weschenfelder et al. (2014)
TBJ-02	31º38'S /51º25'W	5.5	Extension of the Barra Falsa channel	Medeanic et al. (2001)

Table 5. Data from surface samples collected in the Patos Lagoon interior.

Sample	Coordinates	Water depth (m)	Sampler	Sample
B2A	31º32'S/51º28'W	5.00	Dredge	Sand
B3	31º31'S/51º29'W	7.50	Van Veen	Mud sand
B4	31º30'S/51º29'W	7.00	Dredge	Sand
B6	31º31'S/51º30'W	7.65	Van Veen	Mud sand

Table 6. AMS dates from stratigraphic cores obtained in the Patos Lagoon interior and extension of the Barra Falsa**.**

Core Interval (m)	Sample	Conventional Age (^{14}C yr BP)	Calibrated Age (cal yr BP)	Material
B2 (23.2)	BETA 185455	9,400 ± 140	11,500 - 10,240	Organic mud
Bo (12.0)	BETA 294867	7,130 ± 40	7,640 - 7,430	Shells
Bo (15.0)	BETA 359870	7,380 ± 40	7,930 - 7,650	Shells
Bo (19.0)	BETA 294868	7,500 ± 40	7,990 - 7,760	Shells
Bo (20.0)	BETA 359871	7,590 ± 30	8,150 - 7,870	Shells
TBJ-02 (3.30)	BETA 146844	7,370 ± 50	8,420 - 7,930	Organic mud

Table 7. List of diatom taxa recovered in each core site and surface samples from Patos Lagoon interior and extension of the Barra Falsa channel. The ecological parameters of life form (P: planktonic and B: benthic) and salinity (S): freshwater (F), brackish (B), marine-brackish (MB), marine to marine-brackish (M/MB) and marine (M) are displayed.

DIATOM TAXA	L	S	Bo	B2	B2A	B3	B4	B6
Actinocyclus curvatulus Janisch	P	M		X				
Actinocyclus normanii (Gregory) Hustedt	P	B			X	X	X	X
Actinoptychus senarius (Ehrenberg) Ehrenberg	P	M/MB	X	X		X	X	X
Actinoptychus splendens (Shadbolt) Ralfs	P	M	X	X				X
Amphicocconeis disculoides (Hustedt) Stefano e Marino	B	M/MB				X		X
Asteromphalus flabellatus (Brébisson) Greville	P	M				X		X
Aulacodiscus kitonii Arnot	P	M	X	X				
Aulacoseira veraluciae Tremarin, Torgan e Ludwig	P	F			X	X	X	X
Aulacoseira sp.2	P	F			X	X	X	X
Auliscus sculptus (Smith) Ralfs	P	M/MB	X	X				
Biddulphia antediluviana (Ehrenberg) Van Heurck	P	M	X					
Biddulphia pulchella Gray	P	M	X	X				
Catenula adhaerens Mereschkowsky	B	MB				X		X
Cerataulus smithii Ralfs	P	M	X					
Cocconeis distans Gregory	B	M		X				
Cocconeis placentula var. *euglypta* (Ehrenberg) Van Heurck	B	FB		X				
Cocconeis sp.	B	B	X					
Coscinodiscus curvatulus Grunow	P	M	X					
Coscinodiscus radiatus Ehrenberg	P	M/MB	X	X		X		X
Cyclotella litoralis Lange and Syvertsen	P	M/MB		X	X	X	X	X
Cyclotella striata (Kützing) Grunow	P	MB		X				
Cyclotella striata var. *baltica* (Grunow) Håkansson	P	M/MB			X	X	X	X
Cymatosira belgica Grunow	T	M		X		X		X

Table 7 (Continued)

DIATOM TAXA	**L**	**S**	**Bo**	**B2**	**B2A**	**B3**	**B4**	**B6**
Cymbella charrua Metzeltin, Lange-Bertalot and García-Rodríguez	B	B		X				
Cymbella sp.	B	B		X				
Delphineis surirella (Ehrenberg) Andrews	B	M				X		
Desikaneis gessneri (Hustedt) Prasad	B	M				X		X
Diadesmis confervacea Kützing	B	FB		X				
Dimeregramma maculatum (Cleve) Frenguelli	B	M	X	X				
Dimeregramma marinum (Gregory) Ralfs	B	M	X	X				
Dimeregramma minor (Gregory) Ralfs	B	M/MB	X	X				
Dimeregramma minor var. *minor* (Gregory) Ralfs	B	M/MB	X	X				
Dimeregramma minor var. *nana* (Gregory) Ralfs	B	M/MB		X				
Diploneis didyma (Ehrenberg) Ehrenberg	B	MB					X	X
Diploneis gruendleri (Schmidt) Cleve	B	M		X				
Diploneis ovalis (Hilse) Cleve	B	MB				X		
Diploneis smithii (Brébisson) Cleve	B	MB				X		
Diploneis sp.	B	M/MB		X		X		
Eunotia bilunaris (Ehrenberg) Schaarschmidt	B	F		X				
Eunotia mattogrosiana Kociolek, Burliga and Salomoni	B	F		X				
Eunotogramma laevis Grunow	B	M/MB		X				
Eunotogramma marinum (Smith) Peragallo	B	M		X				X
Eupodiscus radiatus Bailey	P	M	X					
Fallacia pseudony Hustedt	B	MB	X	X				
Fallacia sp.	B	MB		X				
Fallacia sp.1	B	MB				X		X
Fragillaria sp.	B	F		X				
Frustulia neomundana Lange-Bertalot and Rumrich	B	F		X				
Frustulia aff. *saxonica* Rabenhorst	B	F		X				

Table 7 (Continued)

DIATOM TAXA	L	S	Bo	B2	B2A	B3	B4	B6
Frustulia sp.	B	F		X				
Gomphonema sp.	B	F		X				
Gomphonema sp.2	B	F		X				
Grammatophora angulosus var. *islandica* (Ehrenberg) Grunow	B	M		X		X		
Hantzschia sp.	B	F		X				
Hippodonta hungarica (Grunow) Lange-Bertalot, Metzeltin and Witkowski	B	F		X				
Hyalodiscus radiatus (O'Meara) Grunow	P	MB				X		X
Lyrella lyra (Ehrenberg) Karajeva	P	M		X				
Nitzschia sp.	B	B		X				
Opephora pacifica (Grunow) Petit	B	M	X	X				
Opephora schwartzii (Grunow) Petit and Pelletan	B	M		X				
Paralia sulcata (Ehrenberg) Cleve	T	M	X	X	X	X	X	X
Petroneis granulata (Bailey) Mann	B	MB		X		X		
Pinnularia sp.1	B	F		X				
Pinnularia sp.2	B	F		X				
Pinnularia sp.3	B	F		X				
Pinnularia sp.4	B	F		X				
Placoneis sp.	B	F		X				
Placoneis sp.1	B	F		X				
Plagiogramma interruptum (Gregory) Ralfs	B	M/MB		X				
Plagiogramma pulchellum var. *pygmaea* (Greville) Peragallo and Peragallo	B	M	X	X				
Planothidium sp.	B	B		X				
Planothidium sp.1	B	B		X				
Planothidium sp.2	B	B		X				
Pleurosira laevis (Ehrenberg) Compère	P	B		X				
Podosira stelligera (Bailey) Mann	P	M	X	X				

Table 7 (Continued)

DIATOM TAXA	L	S	Bo	B2	B2A	B3	B4	B6
Psammococconeis disculoides (Hustedt) Garcia	P	M/MB	X	X				
Psammodictyon panduriforme (Gregory) Mann	B	M/MB						X
Rhopalodia sp.	B	B		X				
Rhopalodia sp.1	B	B						X
Sellaphora pupula (Kützing) Mereschkovsky	B	FB		X				
Sellaphora sp.	B	F		X				
Staurosira sp.	B	FB						X
Shionodiscus oestrupii (Ostenfeld) Alverson, Kang and Theriot	P	M						
Staurosirella martyi (Héribaund) Round	B	B			X	X	X	X
Staurosirella pinnata (Ehrenberg) Williams and Round	B	FB			X		X	
Surirella fastuosa Ehrenberg	B	M/MB		X				
Terpsinoë americana (Bailey) Ralfs	P	M/MB	X	X				
Thalassiosira eccentrica (Ehrenberg) Cleve	P	M/MB				X		
Thalassionema nitzschioides (Grunow) Mereschkowsky	P	M/MB		X		X		X
Thalassiosira sp.	P	M/MB	X			X		
Thalassiosira sp.3	P	M/MB				X	X	
Triceratium favus Ehrenberg	P	M/MB	X	X		X		
Tryblionella granulata (Grunow) Mann	B	M/MB		X				
Tryblionella victoriae Grunow	B	B				X		

Table 8. Data from cores analyzed in this study.

Core	Coordinates	Depth (m)	Environmental	Reference
Mo	31º00’25”S /51º00’10”W	29.95	Patos Lagoon	Weschenfelder
Pa	30º32’52”S /50º42’54”W	28.50	interior	et al. (2014)

Table 9. Data from surface samples collected in the Patos Lagoon.

Sample	Coordinates	Water depth (m)	Sampler	Sample
M3	31º00’S/50º59’W	5.35	Dredge	Sand
M5	31º00’S/51º0’W	6.35	Dredge	Sand mud
M9	31º00’S/51º1’W	6.20	Van Veen	Muddy
M12	31º00’S/51º00’W	6.30	Van Veen	Sand mud
Pa3	30º33’S/50º42’W	7.15	Grab	Muddy
Pa5	30º32’S/50º43’W	7.35	Van Veen	Muddy
Pa6	30º32’S/50º43’W	7.15	Van Veen	Muddy
Pa8	30º32’S/50º42’W	7.05	Van Veen	Muddy
Pa13	30º32’S/50º42’W	6.65	Van Veen	Mud sand

Table 10. AMS dates from stratigraphic cores obtained in the Patos Lagoon interior.

Core	Depth (m)	Sample	Conventional Age (^{14}C yr BP)	Calibrated Age (cal yr BP)
Mo	8	BETA 360370	7,420 ± 40	7,960 – 7,680
Mo	11	BETA 298208	7,490 ± 50	7,980 –7,750
Mo	13	BETA 294869	7,650 ± 40	8,160 –7,920
Pa	21	BETA 305998	> 43,500	-
Pa	23	BETA 305999	> 43,500	-
Pa	26	BETA 298209	> 43,500	-

Table 11. List of diatom taxa recovered in each core site and surface samples from Patos Lagoon analyzed in this study. The ecological parameters of life form (P: planktonic and B: benthic) and salinity (S): freshwater (F), brackish (B), marine-brackish (MB), marine to marine-brackish (M/MB) and marine (M) are displayed.

DIATOM TAXA	L	S	Pa	Mo	M3	M5	M9	M12	Pa3	Pa5	Pa6	Pa8	Pa13
Achnanthes clevei Grunow	B	FB	X										
Achnanthes delicatula (Kützing) Grunow	B	B	X										
Achnanthes inflata (Kützing) Grunow	B	FB	X			X							
Achnanthes sp	B	FB		X									
Actinocyclus curvatulus Janisch	P	M	X	X									
Actinocyclus normanii (Gregory) Hustedt	P	B	X	X	X	X	X	X	X	X	X	X	X
Actinocyclus octonarius Ehrenberg	P	M/MB	X										
Actinocylus octonarius var. *crassus* (Smith) Hendey	P	M/MB	X										
Actinocyclus octonarius var. *minuta* (Pantoksec) Hajós	P	M/MB	X										
Actinocyclus octonarius var. *tenellus* (Brébisson) Hendey	P	M/MB	X	X									
Actinocyclus oculatus Jousé	P	M/MB	X										
Actinoptychus biformis Brun	P	M/MB	X										
Actinoptychus senarius (Ehrenberg) Ehrenberg	P	M/MB	X	X	X	X	X						
Actinoptychus splendens (Shadbolt) Ralfs(Shadbolt) Ralfs	P	M	X	X	X		X	X	X	X	X	X	
Actinoptychus subtilis Ehrenberg	P	M/MB	X										
Actinoptychus undulatus (Bailey) Ralfs	P	M/MB	X	X									
Actinoptychus vulgaris Schumann	P	M	X					X					
Actinoptychus sp	P	M/MB	X										
Amphicocconeis disculoides (Hustedt) Stefano and Marino	B	M/MB	X	X	X	X					X		
Anaulus minutus Grunow	P	M	X	X									
Anorthoneis hyalina Hustedt	P	M	X	X									
Ardissonea formosa (Hantzsch) Grunow	B	M	X										

Table 11 (Continued)

DIATOM TAXA	L	S	Pa	Mo	M3	M5	M9	M12	Pa3	Pa5	Pa6	Pa8	Pa13
Aulacodiscus kitonii Arnot	P	M	X	X									
Aulacodiscus sp	P	M	X										
Aulacoseira veraluciae Tremarin, Torgan and Ludwig	P	F	X	X	X	X	X	X	X	X	X	X	X
Aulacoseira sp.2	P	F	X		X	X	X	X	X	X	X	X	X
Auliscus caelatus var. *latecostata* Schmidt	P	M	X										
Auliscus caelatus var. *strigillata* Schmidt	P	M	X										
Auliscus sculptus (Smith) Ralfs	P	M/MB	X	X			X				X		
Auliscus sp	P	M	X										
Biddulphia antediluviana (Ehrenberg) Van Heurck	P	M	X	X									
Biddulphia pulchella Gray	P	M	X	X									
Caloneis bacilum (Grunow) Cleve	B	B	X										
Caloneis permagna (Bailey) Cleve	B	B		X									
Caloneis westii (Smith) Hendey	B	B	X										
Caloneis sp	B	FB		X									
Campylodiscus grevillei (Smith) Grunow	P	M		X									
Catenula adhaerens Mereschkowsky	B	MB	X	X									
Catenula sp	B	MB	X										
Cerataulus californicus Schmidt	P	M	X										
Cerataulus smithii Ralfs	P	M	X										
Cocconeis distans Gregory	B	M	X	X									
Cocconeis fluminensis (Grunow) Peragallo and Peragallo	B	M	X										
Cocconeis latecostata Hustedt	B	M	X										
Cocconeis placentula var. *euglypta* (Ehrenberg) Van Heurck	B	FB	X	X			X		X		X		
Cocconeis placentula var. *lineata* (Ehrenberg) Van Heurck	B	FB	X										
Cocconeis pseudomarginata Gregory	B	M	X	X									
Coscinodiscus asteromphalus Ehrenberg	P	M	X						X				

Table 11 (Continued)

DIATOM TAXA	L	S	Pa	Mo	M3	M5	M9	M12	Pa3	Pa5	Pa6	Pa8	Pa13
Coscinodiscus curvatulus Grunow	P	M	X						X				
Coscinodiscus cf. *gigas* Ehrenberg	P	M				X		X	X				
Coscinodiscus oculus-iridis (Ehrenberg) Ehrenberg	P	M	X										
Coscinodiscus radiatus Ehrenberg	P	M/MB	X	X	X			X					
Craticula cuspidata (Kützing) Mann	B	F	X										
Cyclotella choctawhatcheeana Prasad	P	B/M	X										
Cyclotella litoralis Lange and Syvertsen	P	M/MB	X	X	X	X	X	X	X	X	X	X	X
Cyclotella meneghiniana Kützing	P	FB	X		X	X		X	X		X		X
Cyclotella striata (Kützing) Grunow	P	MB	X	X									
Cyclotella striata var. *baltica*(Grunow) Håkansson	P	M/MB			X	X	X	X	X	X	X	X	X
Cyclotella cubiculata Sar, Sunensen and Lavigne	P	MB	X										
Cyclostephanos dubius (Fricke) Round	P	F	X								X		
Cymatonitzschia marina (Lewis) Simonsen	B	M	X	X									
Cymatosira belgica Grunow	T	M	X	X							X		
Cymatosira lorenziana Grunow	P	M	X										
Delphineis livingstonii Prasad	B	M	X										
Delphineis surirella (Ehrenberg) Andrews	B	M	X	X									
Desikaneis gessneri (Hustedt) Prasad	B	M	X	X									
Diadesmis confervacea Kützing	B	FB	X										
Discostella stelligera (Cleve and Grunow) Houk and Klee	P	F	X										
Dimeregramma distans (Gregory) Ralfs	B	M/MB									X		
Dimeregramma fulvum (Gregory) Ralfs	B	M	X										
Dimeregramma maculatum (Cleve) Frenguelli	B	M	X	X									
Dimeregramma marinum (Gregory) Ralfs	B	M	X	X									
Dimeregramma minor (Gregory) Ralfs	B	M/MB	X	X			X						
Dimeregramma minor var. *minor* (Gregory) Ralfs	B	M/MB	X										

Table 11 (Continued)

DIATOM TAXA	L	S	Pa	Mo	M3	M5	M9	M12	Pa3	Pa5	Pa6	Pa8	Pa13
Dimeregramma minor var. *nana* (Gregory) Ralfs	B	M/MB	X										
Dimeregramma zimbroides Garcia	B	M/MB	X	X									
Dimeregramma sp	B	M/MB	X										
Diplomenora cocconeiformis (A.Schmidt) Blazé	B	M	X										
Diploneis bombus (Ehrenberg) Ehrenberg	B	MB	X	X									
Diploneis didyma (Ehrenberg) Ehrenberg	B	MB		X			X						
Diploneis gruendleri (Schmidt) Cleve	B	M	X	X									
Diploneis suborbicularis var. *intermedia* (Gregory) Cleve	B	M/MB	X										
Diploneis interrupta (Kützing) Cleve	B	M/MB	X										
Diploneis litoralis var. *clathrata* Ostrup	B	M	X										
Diploneis ovalis (Hilse) Cleve	B	MB	X			X							
Diploneis smithii (Brébisson) Cleve	B	MB	X	X	X			X		X	X		
Diploneis smithii var. *rhombica* Mereschkowsky	B	MB	X	X									
Diploneis sp	B	M/MB	X			X						X	
Encyonema cf. *vulgare* Krammer	B	F	X										
Encyonema sp	B	F		X									
Epithemia argus (Ehrenberg) Kützing	B	F	X										
Epithemia epithemioides Hustedt	B	F	X										
Epithemia sp	B	F		X									
Eunotia bidens Ehrenberg	B	F	X										
Eunotia camelus Ehrenberg	B	F	X	X									
Eunotia didyma Hustedt	B	F	X										
Eunotia incisa Smith	B	F	X										
Eunotia major (Smith) Rabenhorst	B	F	X	X									
Eunotia minor (Kützing) Grunow	B	F	X										
Eunotia monodon Ehrenberg	B	F	X										

Table 11 (Continued)

DIATOM TAXA	L	S	Pa	Mo	M3	M5	M9	M12	Pa3	Pa5	Pa6	Pa8	Pa13
Eunotia pectinalis (Kützing) Rabenhorst	B	F	X										
Eunotia pyramidata Hustedt	B	F	X										
Eunotia pyramidata var. *monodon* Krasske	B	F	X										
Eunotia subarcuatoides Alles, Nörpel and Lange-Bertalot	B	F	X										
Eunotia tridentula Ehrenberg	B	F	X										
Eunotia zygodon Ehrenberg	B	F	X										
Eunotia sp	B	F	X	X		X							
Eunotia sp.1	B	F	X	X									
Eunotia sp.2	B	F	X										
Eunotogramma laevis Grunow	B	M/MB	X	X					X				
Eunotogramma marinum (Smith) Peragallo	B	M	X	X									
Eupodiscus radiatus Bailey	P	M	X										
Fallacia pseudony Hustedt	B	MB	X	X									
Fallacia nummularia (Greville) Mann	B	MB	X										
Fallacia pygmaea (Kützing) Stickle and Mann	B	MB	X										
Fallacia shoemaniana Foged	B	MB	X										
Fallacia tenera (Hustedt) Mann	B	MB	X	X									
Fallacia sp	B	MB	X										
Fallacia sp.1	B	MB									X		
Fragillaria braunii Hustedt	B	F		X									
Fragillaria crassa Metzeltin and Lange-Bertalot	B	F		X									
Fragillaria sp	B	F	X										
Gemellodiscus micronodosus Suto	P	M	X										
Glyphodesmis intermedius Gregory	B	M	X	X									
Gomphonema brasilensoide Lange-Bertalot	B	F	X										
Gomphonema paludosum Reichardtii	B	F	X										

Table 11 (Continued)

DIATOM TAXA	L	S	Pa	Mo	M3	M5	M9	M12	Pa3	Pa5	Pa6	Pa8	Pa13
Gomphonema turris var. *brasiliense* (Fricke) Frenguelli	B	F	X										
Gomphonema sp.1	B	F	X										
Gomphonema sp.2	B	F	X										
Gomphonema sp.3	B	F	X										
Gomphonema sp.4	B	F	X										
Gomphonema sp.5	B	F	X										
Gomphonema sp.6	B	F									X		
Grammatophora angulosus var. *islandica* (Ehrenberg) Grunow	B	M	X										
Grammatophora oceanica Ehrenberg	B	M	X										
Gyrosigma sp	B	F		X									
Gyrosigma sp.1	B	F	X										
Gyrosigma sp.2	B	F	X										
Hantzschia sp.1	B	F				X							
Hyalodiscus radiatus (O'Meara) Grunow	P	MB	X		X				X	X	X	X	
*Hyalodiscus subtilis*Bailey	P	MB		X									
Koizumia adaroi (Azpeitia Moros) Yanagisawa	B	M	X										
Lyrella interrupta (Ehrenberg) Round	P	M	X										
Lyrella lyra (Ehrenberg) Karajeva	P	M	X	X									
Luticola geoppertiana (Bleish) Mann	B	FB	X										
Luticola mutica (Kützing) Mann	B	FB		X									
Luticola simplex Metzeltin, Lange-Bertalot and García-Rodríguez	B	FB	X										
Navicula capitatoradiata Germain	B	F	X										
Navicula yarensis var. *americana* Grunow	B	F	X										
Navicula sp	B	F	X								X		
Neohuttonia reichardtii (Grunow) Hustedt	B	M/MB	X										X
Nitzschia brevissima Grunow	B	MB	X										

Table 11 (Continued)

DIATOM TAXA	L	S	Pa	Mo	M3	M5	M9	M12	Pa3	Pa5	Pa6	Pa8	Pa13
Nitzschia lanceola Smith	B	MB	X										
Nitzschia sp	B	B	X	X									
Nitzschia sp.1	B	B				X							
Odontella atlantica (Frenguelli) Sar	P	M	X	X									
Opephora pacifica (Grunow) Petit	B	M	X	X									
Opephora schwartzii (Grunow) Petit and Pelletan	B	M	X	X						X			
Paralia fenestrata Nagumo and Sawai	T	B	X										
Paralia sulcata (Ehrenberg) Cleve	T	M	X	X	X	X	X	X	X	X	X	X	X
Paralia sp	T	M	X										
Peltophora catholica Garcia	B	M	X	X									
Petroneis granulata (Bailey) Mann	B	MB	X	X									
Petroneis humerosa (Brébisson and Smith) Stickle and Mann	B	MB	X										
Petroneis marinum (Ralfs) Mann	B	M	X										
Perissonoë antediluviana Ehrenberg	P	M	X										
Pinnularia acoricola Hustedt	B	FB	X										
Pinnularia borealis Ehrenberg	B	FB	X	X							X		
Pinnularia borealis var. *islandica* Krammer	B	FB	X										
Pinnularia borealis var. *rectangularis* Carlson	B	FB	X										
Pinnularia divergens Smith	B	F	X										
Pinnularia gibba Ehrenberg	B	FB	X										
Pinnularia cf. *microstaurum* (Ehrenberg) Cleve	B	FB	X										
Pinnularia sp	B	F	X	X									
Pinnularia sp.1	B	F	X										
Placoneis sp	B	F	X										
Plagiogramma pulchellum var. *pygmaea* (Greville) Peragallo and Peragallo	B	M	X	X									

Table 11 (Continued)

DIATOM TAXA	L	S	Pa	Mo	M3	M5	M9	M12	Pa3	Pa5	Pa6	Pa8	Pa13
Plagiogramma rostratum Stein	B	M/MB	X										
Plagiogramma staurophorum (Gregory) Heiberg	B	M/MB	X										
Plagiogramma tenuistriatum Cleve	B	M/MB	X	X									
Plagiogramma sp	B	M/MB		X									
Plagiogramma sp.1	B	M/MB	X										
Plagiogramma sp.2	B	M/MB	X										
Planothidium rostratum (Østrup) Lange-Bertalot	B	B	X										
Planothidium sp	B	B	X										
Planothidium sp.3	B	B						X				X	
Podosira stelligera (Bailey) Mann	P	M	X	X			X						
Psamodiscus nitidus (Gregory) Round and Mann	P	M	X	X									
Psammococconeis brasiliensis Garcia	P	M/MB	X										
Psammococconeis disculoides (Hustedt) Garcia	P	M/MB	X										
Psammodictyon panduriforme (Gregory) Mann	B	M/MB	X	X									
Pseudodimeregramma sp	B	M/MB	X										
Rhaphoneis amphiceros (Ehrenberg) Ehrenberg	B	MB	X										
Rhaphoneis castracanei Grunow	B	MB		X									
*Rhaphoneis*sp	B	MB	X										
Rhopalodia gibberula (Ehrenberg) Müller	B	B		X									
Rhopalodia sp	B	B	X										
Sellaphora pupula (Kützing) Mereschkovsky	B	FB	X						X				
Stauroneis sp	B	F	X										
Stauroneis sp.1	B	F	X										
Staurosira sp	B	FB	X			X	X		X	X	X	X	X
Staurosirella martyi (Héribaund) Round	B	B	X	X	X	X			X				X
Staurosirella pinnata (Ehrenberg) Williams and Round	B	FB	X			X	X	X	X		X		X

Table 11 (Continued)

DIATOM TAXA	L	S	Pa	Mo	M3	M5	M9	M12	Pa3	Pa5	Pa6	Pa8	Pa13
Surirella fastuosa Ehrenberg	B	M/MB		X									
Surirella fastuosa var. *cuneata* Witt	B	M/MB	X										
Surirella fastuosa var. *recedens* (Schmidt) Cleve	B	M/MB	X										
Surirella sp	B	M/MB				X					X	X	
Synedra sigma Kützing	B	F		X									
Tabularia fasciculata (Agardh) Williams e Round	B	B	X										
Terpsinoë americana (Bailey) Ralfs	P	M/MB	X	X									
Thalassiosira eccentrica (Ehrenberg) Cleve	P	M/MB					X	X	X	X	X	X	X
Thalassionema nitzschioides (Grunow) Mereschkowsky	P	M/MB	X	X					X	X	X		
Thalassionema pseudonitzschioides (Schuette and Schrader) Hasle	P	M/MB	X										
Thalassiosira oestrupii (Ostenfeld) Hasle	P	M/MB	X	X				X	X	X	X	X	
Thalassiosira simonsenii Hasle and Fryxell	P	M/MB	X										
Thalassiosira sp.1	P	M/MB	X										
Thalassiosira sp.2	P	M/MB	X										
Thalassiosira sp.3	P	M/MB					X			X	X	X	X
Thalassiosira sp.4	P	M/MB				X						X	
Trachyneis aspera (Ehrenberg) Cleve	B	M	X	X									
Trachyneis sp	B	M	X										
Triceratium distinctum Janish	P	M	X										
Triceratium dubium Brightwell	P	M	X										
Triceratium favus Ehrenberg	P	M/MB	X	X		X				X		X	
Triceratium reticulum (Ehrenberg) Boyer	P	M	X	X									
Trigonium alternans (Bailey) Mann	P	M	X										
Tryblionella granulata (Grunow) Mann	B	M/MB	X	X								X	
Tryblionella victoriae Grunow	B	B			X	X	X	X	X				

Table 11 (Continued)

DIATOM TAXA	L	S	Pa	Mo	M3	M5	M9	M12	Pa3	Pa5	Pa6	Pa8	Pa13
Ulnaria ulna (Nitzsch) Compère	B	FB	X										

Table 12. Data from cores analyzed in this study.

Core	Coordinates	Depth (m)	Environment	Reference
B2	31°38’S/51°26’W	25.2	Coastal plain	Weschenfelder et al. (2008b)
Bo	31º31’S/51º29’W	27.0	Patos Lagoon	Weschenfelder et al. (2014)
TBJ-02	31°38’S/51°25’W	5.50	Coastal plain	Medeanic et al. (2001)
T9	31º15’15”S/50º58’19”W	5.90	Peixe Lagoon	Arejano (2006)- *Unpublished*
Mo	31º00’25”S/51º00’10”W	29.9	Patos Lagoon	Weschenfelder et al. (2014)
Pa	30º32’52”S/50º42’54”W	28.0	Patos Lagoon	Weschenfelder et al. (2014)
T15	30º32’12”S/50º47’18”W	2.30	Patos Lagoon	Toldo Jr. et al. (1991)
T19	30º41’23”S/51º10’50”W	2.05	Patos Lagoon	Toldo Jr. et al. (1991)
T103	31°43’16”S/50°12’24” W	6.70	Outer Shelf	Martins et al. (1978)
T22	32°13’24”S/49°35’30”W	6.09	Continental Slope	Martins et al. (1978)

Table 13. AMS dates from stratigraphic cores obtained in the Patos Lagoon interior, extension of the Barra Falsa channel and Peixe Lagoon.

Core/Depth (m)	Sample	Conventional Age (^{14}C yr BP)	Calibrated Age (cal yr BP)	Material
Pa (21.0)	BETA 305998	> 43,500	-	Shells
Pa (23.0)	BETA 305999	> 43,500	-	Shells
Pa (26.0)	BETA 298209	> 43,500	-	Shells
Mo (8.00)	BETA 360370	7,420 ± 40	7,960 – 7,680	Shells
Mo (11.0)	BETA 298208	7,490 ± 50	7,980 - 7,750	Shells
Mo (13.0)	BETA 294869	7,650 ± 40	8,160 - 7,920	Shells
B2 (23.2)	BETA 185455	9,400 ± 140	11,500 - 10,240	Organic mud
TBJ-02 (3.30)	BETA 146844	7,370 ± 50	8,420 - 7,930	Organic mud
Bo (12.0)	BETA 294867	7,130 ± 40	7,640 - 7,430	Shells
Bo (15.0)	BETA 359870	7,380 ± 40	7,930 - 7,650	Shells
Bo (19.0)	BETA 294868	7,500 ± 40	7,990 - 7,760	Shells
Bo (20.0)	BETA 359871	7,590 ± 30	8,150 - 7,870	Shells
T9 (2.71-2.91)	BETA 204665	4,840 ± 70	5,370 – 5,340	Organic mud
T9 (5.15-5.35)	BETA 204666	6,630 ± 80	7,420 – 7,020	Organic mud
T19 (0.49-0.52)	Not Available	2,400	-	Shells
T15 (0.12-0.15)	Not Available	2,150	-	Shells

Table 14. Data from surface samples collected in the Patos Lagoon interior.

Sample	Coordinates	Water depth (m)	Sampler	Sample
B2A	31º32'S/51º28'W	5.00	Dredge	Sand
B3	31º31'S/51º29'W	7.50	Van Veen	Mud sand
B4	31º30'S/51º29'W	7.00	Dredge	Sand
B6	31º31'S/51º30'W	7.65	Van Veen	Mud sand
M3	31º00'S/50º59'W	5.35	Dredge	Sand
M5	31º00'S/51º0'W	6.35	Dredge	Sand mud
M9	31º00'S/51º1'W	6.20	Van Veen	Muddy
M12	31º00'S/51º00'W	6.30	Van Veen	Sand mud
Pa3	30º33'S/50º42'W	7.15	Grab	Muddy
Pa5	30º32'S/50º43'W	7.35	Van Veen	Muddy
Pa6	30º32'S/50º43'W	7.15	Van Veen	Muddy
Pa8	30º32'S/50º42'W	7.05	Van Veen	Muddy
Pa13	30º32'S/50º42'W	6.65	Van Veen	Mud sand

Table 15. List of diatom taxa recovered in each core site and surface samples from southern Brazilian coast (1) Pa, (2) Mo, (3) Bo, (4) T15, (5) T19, (6) B2, (7) T09, (8) T103, (9)T22, (10) B2A, (11) B3, (12) B4, (13)B6, (14) M3, (15) M5, (16) M9, (17) M12, (18) Pa3, (19) Pa5, (20) Pa6, (21) Pa8, (22) Pa13. The ecological parameters of life form (P: planktonic and B: benthic) and salinity (S): freshwater (F), brackish (B), marine-brackish (MB), marine to marine-brackish (M/MB) and marine (M) are displayed.

DIATOM TAXA	**L**	**S**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Achnanthes clevei Grunow	B	FB	X																					
Achnanthes delicatula (Kützing) Grunow	B	B	X																					
Achnanthes inflata (Kützing) Grunow	B	FB	X														X							
Achnanthes sp	B	FB		X																				
Actinocyclus curvatulus Janisch	P	M	X	X				X	X															
Actinocyclus normanii (Gregory) Hustedt	P	B	X	X			X					X	X	X	X	X	X	X	X	X	X	X	X	X
Actinocyclus octonarius Ehrenberg	P	M/MB	X																					
Actinocylus octonarius var. *crassus* (Smith) Hendey	P	M/MB	X																					
Actinocyclus octonarius var. *minuta* (Pantoksec) Hajós	P	M/MB	X																					
Actinocyclus octonarius var. *tenellus* (Brébisson) Hendey	P	M/MB	X	X						X														
Actinocyclus oculatus Jousé	P	M/MB	X																					
Actinoptychus biformis Brun	P	M/MB	X																					
Actinoptychus senarius (Ehrenberg) Ehrenberg	P	M/MB	X	X	X	X	X	X	X	X			X	X	X	X	X	X						
Actinoptychus splendens (Shadbolt) Ralfs(Shadbolt) Ralfs	P	M	X	X	X	X	X	X	X	X					X	X		X	X	X	X	X	X	
Actinoptychus subtilis Ehrenberg	P	M/MB	X																					
Actinoptychus undulatus (Bailey) Ralfs	P	M/MB	X	X																				
Actinoptychus vulgaris Schumann	P	M	X				X		X										X					
Actinoptychus sp	P	M/MB	X																					
Amphicocconeis disculoides (Hustedt) Stefano and Marino	B	M/MB	X	X		X							X		X	X	X					X		
Amphora copulata (Kützing) Schoeman and Archibald	B	MB							X															
Amphora forcimen Grunow	B	MB							X															

Table 15 (Continued)

DIATOM TAXA	L	S	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Amphora lineata Gregory	B	MB							X															
Amphora proteus Gregory	B	M/MB							X															
Amphora pseudoproteus Wachicka and Gaiser	B	MB							X															
Amphora sp	B	MB							X															
Amphora sp.2	B	MB							X															
Amphora sp.3	B	MB							X															
Anaulus minutus Grunow	P	M	X	X					X															
Anorthoneis hyalina Hustedt	P	M	X	X					X															
Anorthoneis eurystoma Cleve	P	M							X															
Ardissonea formosa (Hantzsch) Grunow	B	M	X																					
Asteromphalus flabellatus (Brébisson) Greville	P	M								X			X		X									
Aulacodiscus kitonii Arnot	P	M	X	X	X			X	X															
Aulacodiscus sp	P	M	X																					
Aulacoseira veraluciae Tremarin, Torgan and Ludwig	P	F	X	X			X				X	X	X	X	X	X	X	X	X	X	X	X	X	X
Aulacoseira sp.2	P	F	X				X				X	X	X	X	X	X	X	X	X	X	X	X	X	X
Auliscus caelatus var. *latecostata* Schmidt	P	M	X																					
Auliscus caelatus var. *strigillata* Schmidt	P	M	X																					
Auliscus sculptus (Smith) Ralfs	P	M/MB	X	X	X	X	X	X	X									X				X		
Auliscus sp	P	M	X																					
Auliscus sp.1	P	M							X															
Biddulphia antediluviana (Ehrenberg) Van Heurck	P	M	X	X	X																			
Biddulphia pulchella Gray	P	M	X	X	X			X																
Caloneis bacilum (Grunow) Cleve	B	B	X																					
Caloneis permagna (Bailey) Cleve	B	B		X																				
Caloneis westii (Smith) Hendey	B	B	X																					
Caloneis sp	B	FB		X																				
Campylodiscus grevillei (Smith) Grunow	P	M		X																				

Table 15 (Continued)

DIATOM TAXA	L	S	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Catenula adhaerens Mereschkowsky	B	MB	X	X					X				X		X									
Catenula sp	B	MB	X																					
Cerataulus californicus Schmidt	P	M	X																					
Cerataulus smithii Ralfs	P	M	X		X																			
Cocconeis distans Gregory	B	M	X	X		X		X																
Cocconeis fluminensis (Grunow) Peragallo and Peragallo	B	M	X																					
Cocconeis latecostata Hustedt	B	M	X																					
Cocconeis pediculus Ehrenberg	B	F							X															
Cocconeis placentula var. *euglypta* (Ehrenberg) Van Heurck	B	FB	X	X				X										X		X		X		
Cocconeis placentula var. *lineata* (Ehrenberg) Van Heurck	B	FB	X																					
Cocconeis pseudomarginata Gregory	B	M	X	X																				
Cocconeis scutelum Ehrenberg	B	B							X															
Cocconeis sp	B	B			X				X															
Coscinodiscus asteromphalus Ehrenberg	P	M	X																	X				
Coscinodiscus curvatulus Grunow	P	M	X		X		X		X											X				
Coscinodiscus cf. *gigas* Ehrenberg	P	M															X		X	X				
Coscinodiscus marginatus var. *curvato striata* Grunow	P	M							X															
Coscinodiscus oculus-iridis (Ehrenberg) Ehrenberg	P	M	X						X															
Coscinodiscus obscurus Schmidt	P	M							X															
Coscinodiscus radiatus Ehrenberg	P	M/MB	X	X	X		X	X	X	X	X		X		X	X			X					
Craticula cuspidata (Kützing) Mann	B	F	X																					
Cyclotella choctawhatcheeana Prasad	P	B/M	X						X															
Cyclotella litoralis Lange and Syvertsen	P	M/MB	X	X			X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Cyclotella meneghiniana Kützing	P	FB	X													X	X		X	X		X		X
Cyclotella striata (Kützing) Grunow	P	MB	X	X				X	X	X														

Table 15 (Continued)

DIATOM TAXA	L	S	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Cyclotella striata var. *baltica*(Grunow) Håkansson	P	M/MB				X	X					X	X	X	X	X	X	X	X	X	X	X	X	X
Cyclotella cubiculata Sar, Sunensen and Lavigne	P	MB	X																					
Cyclostephanos dubius (Fricke) Round	P	F	X						X													X		
Cymatonitzschia marina (Lewis) Simonsen	B	M	X	X																				
Cymatosira belgica Grunow	T	M	X	X				X	X	X			X		X							X		
Cymatosira lorenziana Grunow	P	M	X																					
Cymbella charrua Metzeltin, Lange-Bertalot and García-Rodríguez	B	B						X																
Cymbella sp.1	B	B						X																
Cymbella sp.2	B	B						X																
Cymbella sp.3	B	B							X															
Delphineis livingstonii Prasad	B	M	X						X															
Delphineis surirella (Ehrenberg) Andrews	B	M	X	X					X				X											
Desikaneis gessneri (Hustedt) Prasad	B	M	X	X					X				X		X									
Diadesmis confervacea Kützing	B	FB	X					X																
Discostella stelligera (Cleve e Grunow) Houk and Klee	P	F	X																					
Dimeregramma distans (Gregory) Ralfs	B	M/MB							X													X		
Dimeregramma fulvum (Gregory) Ralfs	B	M	X																					
Dimeregramma maculatum (Cleve) Frenguelli	B	M	X	X	X			X	X															
Dimeregramma marinum (Gregory) Ralfs	B	M	X	X	X			X	X															
Dimeregramma minor (Gregory) Ralfs	B	M/MB	X	X	X			X	X									X						
Dimeregramma minor var. *minor* (Gregory) Ralfs	B	M/MB	X		X			X	X															
Dimeregramma minor var. *nana* (Gregory) Ralfs	B	M/MB	X					X	X															
Dimeregramma zimbroides Garcia	B	M/MB	X	X																				
Dimeregramma sp	B	M/MB	X																					
Diplomenora cocconeiformis (A.Schmidt) Blazé	B	M	X																					
Diploneis bombus (Ehrenberg) Ehrenberg	B	MB	X	X			X																	

Table 15 (Continued)

DIATOM TAXA	**L**	**S**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Diploneis didyma (Ehrenberg) Ehrenberg	B	MB		X										X	X			X						
Diploneis gruendleri (Schmidt) Cleve	B	M	X	X				X																
Diploneis suborbicularis var. *intermedia* (Gregory) Cleve	B	M/MB	X						X															
Diploneis interrupta (Kützing) Cleve	B	M/MB	X																					
Diploneis litoralis var. *clathrata* Ostrup	B	M	X																					
Diploneis ovalis (Hilse) Cleve	B	MB	X										X				X							
Diploneis smithii (Brébisson) Cleve	B	MB	X	X			X			X			X			X			X		X	X		
Diploneis smithii var. *rhombica* Mereschkowsky	B	MB	X	X																				
Diploneis weissflogii (Schmidt) Cleve	B	M							X															
Diploneis sp	B	M/MB	X					X					X				X						X	
Ehrenbergia granulosa (Grunow) Witkowski, Lange-Bertalot and Metzeltin	P	F							X															
Encyonema cf. *vulgare* Krammer	B	F	X																					
Encyonema sp	B	F		X																				
Epithemia argus (Ehrenberg) Kützing	B	F	X																					
Epithemia epithemioides Hustedt	B	F	X																					
Epithemia odebrechtiana Metzeltin and Lange-Bertalot	B	F								X														
Epithemia sp	B	F		X																				
Eunotia bidens Ehrenberg	B	F	X																					
Eunotia bilunaris (Ehrenberg) Schaarschmidt	B	F						X																
Eunotia camelus Ehrenberg	B	F	X	X																				
Eunotia didyma Hustedt	B	F	X							X														
Eunotia incisa Smith	B	F	X																					
Eunotia major (Smith) Rabenhorst	B	F	X	X																				
Eunotia mattogrosiana Kociolek, Burliga and Salomoni	B	F						X																
Eunotia minor (Kützing) Grunow	B	F	X																					

Table 15 (Continued)

DIATOM TAXA	L	S	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Eunotia monodon Ehrenberg	B	F	X																					
Eunotia pectinalis (Kützing) Rabenhorst	B	F	X																					
Eunotia pyramidata Hustedt	B	F	X																					
Eunotia pyramidata var. *monodon* Krasske	B	F	X																					
Eunotia subarcuatoides Alles, Nörpel and Lange-Bertalot	B	F	X																					
Eunotia tridentula Ehrenberg	B	F	X																					
Eunotia zygodon Ehrenberg	B	F	X																					
Eunotia sp	B	F	X	X			X			X	X						X							
Eunotia sp.1	B	F	X	X																				
Eunotia sp.2	B	F	X							X														
Eunotia sp.3	B	F																						
Eunotogramma laevis Grunow	B	M/MB	X	X				X	X											X				
Eunotogramma marinum (Smith) Peragallo	B	M	X	X				X	X						X									
Eunotogramma rostratum Hustedt	B	M/MB							X															
Eupodiscus radiatus Bailey	P	M	X		X				X															
Fallacia pseudony Hustedt	B	MB	X	X	X			X																
Fallacia nummularia (Greville) Mann	B	MB	X																					
Fallacia pygmaea (Kützing) Stickle and Mann	B	MB	X																					
Fallacia shoemaniana Foged	B	MB	X																					
Fallacia tenera (Hustedt) Mann	B	MB	X	X																				
Fallacia sp	B	MB	X					X		X														
Fallacia sp.1	B	MB											X		X							X		
Fragillaria braunii Hustedt	B	F		X																				
Fragillaria crassa Metzeltin and Lange-Bertalot	B	F		X																				
Fragillaria sp	B	F	X					X	X	X														
Frustulia neomundana Lange-Bertalot and Rumrich	B	F						X																
Frustulia aff. *saxonica* Rabenhorst	B	F						X																

Table 15 (Continued)

DIATOM TAXA	L	S	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Frustulia sp	B	F						X																
Gemellodiscus micronodosus Suto	P	M	X																					
Glyphodesmis distans (Gregory) Grunow	B	M							X															
Glyphodesmis intermedius Gregory	B	M	X	X																				
Gomphonema brasilensoide Lange-Bertalot	B	F	X																					
Gomphonema paludosum Reichardtii	B	F	X																					
Gomphonema turris var. *brasiliense* (Fricke) Frenguelli	B	F	X																					
Gomphonema sp	B	F						X		X	X													
Gomphonema sp.1	B	F	X																					
Gomphonema sp.2	B	F	X					X																
Gomphonema sp.3	B	F	X																					
Gomphonema sp.4	B	F	X																					
Gomphonema sp.5	B	F	X																					
Gomphonema sp.6	B	F																				X		
Grammatophora angulosus var. *islandica* (Ehrenberg) Grunow	B	M	X					X					X											
Grammatophora oceanica Ehrenberg	B	M	X				X																	
Gyrosigma sp	B	F		X						X														
Gyrosigma sp.1	B	F	X																					
Gyrosigma sp.2	B	F	X																					
Halamphora aponina (Kützing) Levkov	B	B							X															
Hantzschia sp	B	F						X			X													
Hantzschia sp.1	B	F															X							
Hippodonta hungarica (Grunow) Lange-Bertalot, Metzeltin e Witkowski	B	F						X																
Hyalodiscus radiatus (O'Meara) Grunow	P	MB	X										X		X	X				X	X	X	X	
*Hyalodiscus subtilis*Bailey	P	MB		X																				

Table 15 (Continued)

DIATOM TAXA	L	S	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Hyaloneis hyalinum (Hustedt) Amspoker	B	M							X															
Koizumia adaroi (Azpeitia Moros) Yanagisawa	B	M	X																					
Lyrella clavata (Greville) Mann	P	M							X															
Lyrella clavata var. *indica* (Gregory) Mann	P	M							X															
Lyrella interrupta (Ehrenberg) Round	P	M	X																					
Lyrella lyra (Ehrenberg) Karajeva	P	M	X	X				X	X															
Lyrella sp	P	M							X															
Lyrella sp.1	P	M							X															
Luticola geoppertiana (Bleish) Mann	B	FB	X																					
Luticola mutica (Kützing) Mann	B	FB		X																				
Luticola simplex Metzeltin, Lange-Bertalot and García-Rodríguez	B	FB	X																					
Navicula capitatoradiata Germain	B	F	X																					
Navicula caribaea Cleve	B	MB							X															
Navicula yarensis var. *americana* Grunow	B	F	X																					
Navicula sp	B	F	X																			X		
Neohuttonia reichardtii (Grunow) Hustedt	B	M/MB	X						X															X
Nitzschia brevissima Grunow	B	MB	X																					
Nitzschia lanceola Smith	B	MB	X																					
Nitzschia sp	B	B	X	X				X																
Nitzschia sp.1	B	B															X							
Odontella atlantica (Frenguelli) Sar	P	M	X	X																				
Opephora olsenii Moller	B	M							X	X														
Opephora pacifica (Grunow) Petit	B	M	X	X	X			X	X															
Opephora schwartzii (Grunow) Petit and Pelletan	B	M	X	X				X	X												X			
Opephora sp	B	M							X															
Opephora sp.1	B	M							X															

Table 15 (Continued)

DIATOM TAXA	L	S	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Opephora sp.2	B	M							X															
Paralia fenestrata Nagumo and Sawai	T	B	X						X															
Paralia sulcata (Ehrenberg) Cleve	T	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Paralia sulcata f. *coronata* (Ehrenberg) Grunow	T	M							X															
Paralia sp	T	M	X						X															
Peltophora catholica Garcia	B	M	X	X					X															
Petroneis granulata (Bailey) Mann	B	MB	X	X				X	X				X											
Petroneis humerosa (Brébisson and Smith) Stickle and Mann	B	MB	X																					
Petroneis marinum (Ralfs) Mann	B	M	X						X															
Perissonoë antediluviana Ehrenberg	P	M	X																					
Pinnularia acoricola Hustedt	B	FB	X																					
Pinnularia borealis Ehrenberg	B	FB	X	X						X	X											X		
Pinnularia borealis var. *islandica* Krammer	B	FB	X																					
Pinnularia borealis var. *rectangularis* Carlson	B	FB	X																					
Pinnularia divergens Smith	B	F	X																					
Pinnularia gibba Ehrenberg	B	FB	X																					
Pinnularia cf. *microstaurum* (Ehrenberg) Cleve	B	FB	X																					
Pinnularia cf. *rectangulata* (Gregory) Rabenhorst	B	FB							X															
Pinnularia sp	B	F	X	X					X															
Pinnularia sp.1	B	F	X					X																
Pinnularia sp.2	B	F						X		X														
Pinnularia sp.3	B	F						X																
Pinnularia sp.4	B	F						X																
Pinnularia sp.5	B	F																						
Placoneis sp	B	F	X																					
Placoneis sp.1	B	F						X																

Table 15 (Continued)

DIATOM TAXA	L	S	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Plagiogramma interruptum (Gregory) Ralfs	B	M/MB						X																
Plagiogramma pulchellum var. *pygmaea* (Greville) Peragallo and Peragallo	B	M	X	X	X			X	X															
Plagiogramma rostratum Stein	B	M/MB	X				X		X															
Plagiogramma staurophorum (Gregory) Heiberg	B	M/MB	X						X															
Plagiogramma tenuistriatum Cleve	B	M/MB	X	X					X															
Plagiogramma sp	B	M/MB		X					X															
Plagiogramma sp.1	B	M/MB	X						X															
Plagiogramma sp.2	B	M/MB	X																					
Plagiogramma sp.3	B	M/MB							X															
Planothidium rostratum (Østrup) Lange-Bertalot	B	B	X																					
Planothidium sp	B	B	X					X		X														
Planothidium sp.1	B	B						X																
Planothidium sp.2	B	B						X																
Planothidium sp.3	B	B							X										X				X	
Pleurosira laevis(Ehrenberg) Compère	P	B						X																
Podosira stelligera (Bailey) Mann	P	M	X	X	X			X	X	X								X						
Pravifusus sp	B	M							X															
Psamodiscus nitidus (Gregory) Round and Mann	P	M	X	X					X															
Psammococconeis brasiliensis Garcia	P	M/MB	X						X															
Psammococconeis disculoides (Hustedt) Garcia	P	M/MB	X		X	X		X	X															
Psammodictyon panduriforme (Gregory) Mann	B	M/MB	X	X						X					X									
Pseudodimeregramma sp	B	M/MB	X																					
Pseudostaurosira subsalina (Hustedt) Morales	B	M/MB							X															
Rhaphoneis amphiceros (Ehrenberg) Ehrenberg	B	MB	X																					
Rhaphoneis castracanei Grunow	B	MB		X																				
*Rhaphoneis*sp	B	MB	X																					

Table 15 (Continued)

DIATOM TAXA	**L**	**S**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Rhopalodia gibberula (Ehrenberg) Müller	B	B		X																				
Rhopalodia rumrichae Krammer	B	B							X															
Rhopalodia sp	B	B	X					X																
Rhopalodia sp.1	B	B									X				X									
Sellaphora pupula (Kützing) Mereschkovsky	B	FB	X					X												X				
Sellaphora sp	B	F						X																
Stauroneis sp	B	F	X																					
Stauroneis sp.1	B	F	X																					
Staurosira sp	B	FB	X												X		X	X		X	X	X	X	X
Shionodiscus oestrupii (Ostenfeld) Alverson, Kang and Theriot	P	M							X															
Staurosirella martyi (Héribaund) Round	B	B	X	X					X		X	X	X	X	X	X	X			X				X
Staurosirella pinnata (Ehrenberg) Williams and Round	B	FB	X									X		X			X	X	X	X		X		X
Surirella fastuosa Ehrenberg	B	M/MB		X				X																
Surirella fastuosa var. *cuneata* Witt	B	M/MB	X																					
Surirella fastuosa var. *recedens* (Schmidt) Cleve	B	M/MB	X																					
Surirella sp	B	M/MB															X					X	X	
*Synedra sigma*Kützing	B	F		X																				
Tabularia fasciculata (Agardh) Williams and Round	B	B	X																					
Terpsinoë americana (Bailey) Ralfs	P	M/MB	X	X	X			X	X															
Terpsinoë musica Ehrenberg	P	B																						
Thalassiosira eccentrica (Ehrenberg) Cleve	P	M/MB											X					X	X	X	X	X	X	X
Thalassiosira ferrelineata Hasle and Fryxell	P	M/MB							X															
Thalassionema nitzschioides (Grunow) Mereschkowsky	P	M/MB	X	X				X		X	X		X		X					X	X	X		
Thalassionema pseudonitzschioides (Schuette and Schrader) Hasle	P	M/MB	X						X		X													
Thalassionema sp	B	M/MB							X															

Table 15 (Continued)

DIATOM TAXA	L	S	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Thalassiosira oestrupii (Ostenfeld) Hasle	P	M/MB	X	X					X	X									X	X	X	X	X	
Thalassiosira simonsenii Hasle and Fryxell	P	M/MB	X																					
Thalassiosira sp	P	M/MB			X				X				X											
Thalassiosira sp.1	P	M/MB	X																					
Thalassiosira sp.2	P	M/MB	X						X															
Thalassiosira sp.3	P	M/MB											X	X				X			X	X	X	X
Thalassiosira sp.4	P	M/MB															X						X	
Trachyneis aspera (Ehrenberg) Cleve	B	M	X	X																				
Trachyneis sp	B	M	X																					
Triceratium distinctum Janish	P	M	X																					
Triceratium dubium Brightwell	P	M	X																					
Triceratium favus Ehrenberg	P	M/MB	X	X	X	X	X	X	X	X			X				X				X		X	
Triceratium reticulum (Ehrenberg) Boyer	P	M	X	X					X															
Trigonium alternans (Bailey) Mann	P	M	X																					
Tryblionella granulata (Grunow) Mann	B	M/MB	X	X				X		X	X												X	
Tryblionella victoriae Grunow	B	B											X			X	X	X	X	X				
Ulnaria ulna (Nitzsch) Compère	B	FB	X																					

Table 16. Ecological information of the modern communities preserved in modern surface sediments of Patos Lagoon. The relative abundance (RA %) of the most representative taxa occurring in thirteen sites and respective ecological associations are shown.

Site	Diatom taxa	RA %	Diatom associations
B2A	*Aulacoseira* sp.2	28	*C. litoralis*, *A. normanii*, *S. martyi*, *P. sulcata*, *A. veraluciae*.
B3	*C. litoralis*	48	*Fallacia* sp., *A. normanii*, *P. sulcata*, *A. senarius*, *Thalassiosira* sp.2, *Thalassiosira* sp, *Aulacoseira* sp.2, *C. adhaerens*.
B4	*Aulacoseira* sp.2	56	*A. veraluciae*, *C. litoralis*, *A. normanii*, *P. sulcata*
B6	*C. litoralis*	30	*A. veraluciae*, *A. normanii*, *P. sulcata*, *A. senarius*, *C. adhaerens*, *Staurosira* sp., *Thalassiosira* sp.2, *P. panduriforme*
M3	*A. veraluciae*	41	*Aulacoseira* sp.2, *C. litoralis*, *A. senarius*, *Tryblionella victoriae*
M5	*Aulacoseira* sp.2	34	*A. veraluciae*, *C. litoralis*, *A. normanii*, *P. sulcata*, *Thalassiosira* sp,*C. meneghiniana*
M9	*Aulacoseira* sp.2	56	*A. veraluciae*, *C. litoralis*, *A. normanii*, *P. sulcata*
M12	*Aulacoseira* sp.2	57	*C. litoralis*, *A. veraluciae*, *A. normanii*, *C. meneghiniana*
Pa3	*A. veraluciae*	85	*Aulacoseira* sp.2, *Staurosira* sp *and C. litoralis*
Pa5	*Aulacoseira* sp.2	16	*Cyclotella litoralis*, *Paralia sulcata*, *A. normanii*
Pa6	*A. veraluciae*	48	*Aulacoseira* sp.2, *Staurosira* sp, *C. litoralis*, *S. martyi*, *P. sulcata*, *Fallacia* sp, *A. normanii*, *A. splendens*
Pa8	*A. veraluciae*	40	*Aulacoseira* sp.2, *A. normanii*, *C. litoralis*, *Staurosira* sp, *P. sulcata*
P13	*A. veraluciae*	80	*Aulacoseira* sp.2, *C. litoralis*, *A. normanii*

Table 17. The results of the varimax component matrix with Kaiser Normalization (rotated method), variance and communalities (CM) of each fossil diatom taxa used in the PCA analysis. Bold values indicate the correlation between diatom taxa and five principal components (Group G1, G2, G3, G4, G5).

DIATOM TAXA	G1	G2	G3	G4	G5	CM.
Actinoptychus senarius	-,198	-,171	,479	,103	**,714**	,818
Actinoptychus splendens	-,110	-,008	**,923**	,167	-,090	,900
Aulacodiscus kitonii	-,269	-,222	,026	-,097	**-,745**	,687
Aulacoseira veraluciae	**,694**	-,143	-,147	-,309	,177	,651
Aulacoseira sp.2	**,969**	-,112	-,158	-,140	-,034	,997
Auliscus sculptus	-,206	-,213	-,013	**,907**	,242	,969
Coscinodiscus radiatus	**,937**	,230	-,192	,064	,038	,974
Cyclotella litoralis	-,093	**,975**	-,113	-,158	,036	,997
Cyclotella striata	-,217	**,639**	-,296	-,109	,507	,812
Cymatosira belgica	,003	,089	**,961**	-,019	,074	,937
Delphineis surirella	,002	,033	**,966**	-,016	,095	,944
Dimeregramma minor	-,322	-,299	**,840**	-,204	-,027	,941
Paralia sulcata	-,490	**-,583**	-,510	-,174	-,257	,937
Pinnularia borealis	**,987**	-,065	,044	-,102	-,063	,994
Psamodiscus nitidus	-,076	**,982**	,086	-,107	,010	,990
Psammococconeis disculoides	-,090	-,089	-,045	**,975**	,130	,986
Psammodictyon panduriforme	-,076	**,983**	,073	-,107	,009	,989
Staurosirella martyi	**,983**	-,094	-,043	-,096	-,074	,993
Thalassionema nitzschioides	,444	**,847**	-,167	-,151	-,062	,969
Thalassiosira oestrupii	-,126	-,084	-,079	**,710**	,589	,880
Triceratium favus	-,231	-,193	,039	**,893**	-,270	,962
Tryblionella granulata	**,956**	,151	,016	-,142	,042	,958
Eigenvalues	6.894	4.774	4.427	2.588	1.603	-
Variance (%)	31.335	21.700	20.123	11.763	7.285	-
Cumulative variance (%)	31.335	53.035	73.158	84.921	92.206	-