

A MIDDLE PLEISTOCENE MARINE MOLLUSCAN ASSEMBLAGE FROM THE SOUTHERN COASTAL PLAIN OF RIO GRANDE DO SUL STATE, BRAZIL

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ABSTRACT – A marine molluscan assemblage is described from four fossil concentrations in the Coastal Plain of Rio Grande do Sul State, southern Brazil. The concentrations were found at the same stratigraphic interval, some 7.5 m above present sea-level, in a layer deposited in a shallow marine environment during the penultimate marine transgression around 230 ka BP and currently exposed along the banks of Chuí Creek, located some 11 km landwards of the present coastline. The assemblage is composed of a mixture of highly fragmented, unidentifiable shells and well-preserved bivalves and gastropods. Many bivalve remains are complete, including juveniles and thin-shelled taxa, lacking signs of abrasion or bioerosion. The origin of the shell concentrations is interpreted as a short-term depositional event, generated by storms, in shallow water settings under a marine transgressive regime. The predominant taxa in the assemblage are infaunal, stenohaline bivalves that inhabit shallow sandy bottoms, with few gastropods and epifaunal organisms. Most of the taxa have living representatives today in the southern Brazilian coast, indicating a mixture of Argentinean and Caribbean (or Brazilian) malacological provinces. The presence of taxa that are not found living in the coast of Rio Grande do Sul today (*Anomalocardia brasiliana*, *Chione paphia*, *C. cancellata*, *Anadara brasiliana* and *Arcinella brasiliana*), suggests warmer oceanographic conditions coinciding with past sea-level highstands, also indicated by similar taxa found in fossil concentrations in the Uruguayan and Argentinean coasts. A discussion of the stratigraphic position, age and correlation of this assemblage with other outcrops is also presented.

Key words: Chuí Creek, Barrier System II, Pleistocene, fossil assemblage, paleobiogeography, paleoenvironment.

RESUMO – Aqui é descrita uma assembleia de moluscos marinhos a partir de quatro concentrações fossilíferas encontradas na Planície Costeira do Estado do Rio Grande do Sul, Brasil. As concentrações foram encontradas na mesma posição estratigráfica, aproximadamente 7,5 m acima do nível atual do mar, em uma camada depositada em ambiente marinho raso durante a penúltima transgressão marinha em torno de 230 ka AP e atualmente exposta nas barrancas do Arroio Chuí, localizado aproximadamente 11 km da linha de costa atual. A assembleia é composta por uma mistura de conchas altamente fragmentadas, não identificáveis, bem como bivalves e gastrópodes bem preservados. Muitos bivalves são completos, incluindo juvenis e táxons de conchas finas, sem sinais de abrasão ou bioerosão. A origem dessas concentrações é interpretada como evento deposicional de curta duração, gerado por tempestade, em águas rasas sob regime marinho transgressivo. Os táxons predominantes na assembleia são bivalves estenohalinos infaunais que habitam fundos arenosos rasos, com poucos gastrópodes e organismos epifaunais. A maioria dos táxons ainda habita a costa sul do Brasil, indicando uma mistura das províncias malacológicas Argentina e Caribenha (ou Brasileira). A presença de táxons que não são encontrados vivendo atualmente na costa do Rio Grande do Sul (*Anomalocardia brasiliana*, *Chione paphia*, *C. cancellata*, *Anadara brasiliana* e *Arcinella brasiliana*), sugere condições oceanográficas mais quentes, coincidentes com máximos transgressivos marinhos no passado, também indicadas por concentrações fósseis encontradas em depósitos do Holoceno nas costas da Argentina e Uruguai. A posição estratigráfica, idade e correlação desta assembleia com outros afloramentos são discutidas.

Palavras-chave: Arroio Chuí, Sistema Barreira II, Pleistoceno, assembleia fóssil, paleobiogeografia, paleoambiente.

INTRODUCTION

The southernmost portion of the Brazilian coast comprises the Coastal Plain of Rio Grande do Sul State (CPRS), a geomorphological unit formed by successive sea-level oscillations during the Neogene and Quaternary (Tomazelli *et al.*, 2000). The CPRS is known for the presence of several deposits of marine fossils, located both on the continental shelf (Figueiredo, 1975) and in continental areas landwards of the Present-day coastline. The latter were studied by several authors (Bianchi, 1969; Closs & Forti, 1971; Forti Esteves, 1974; Godolphim *et al.*, 1989), but focusing mostly on the taxonomic composition of the fossil assemblages, rather than their stratigraphic or paleoecologic significance. From the Santa Vitória do Palmar County, in the southern CPRS, Closs & Forti (1971) described several fossil marine mollusks, found in four outcrops in continental areas, including the Chuí Creek. These fossils, however, were described without any indication of their stratigraphic origin, and probably represent material that was found out of their original depositional setting, reworked by erosive processes resulting from fluvial activity.

During recent surveys in the Chuí Creek, four concentrations of marine fossil shells were found on their original stratigraphic position, at the base of the banks of the creek. These concentrations were briefly described by Lopes & Simone (2012), but the focus of that study was mostly on the presence of molluscan taxa previously not found in fossil deposits of the CPRS. Herein an expanded report on these concentrations is presented which encompasses the systematics, taphonomy, paleoenvironmental and stratigraphic implications of these concentrations, plus a discussion regarding the fossil shells reported by Closs & Forti (1971). **Institutional abbreviations.** FURG, Universidade Federal do Rio Grande, Rio Grande, Brazil; MZUSP, Museu de Zoologia da Universidade de São Paulo, São Paulo, Brazil.

GEOLOGICAL SETTING

The CPRS is formed by sediments accumulated in the coastal area of southern Brazil after the break-up of South America and Africa, during the Late Cretaceous. These sediments filled up the Pelotas Basin, the southernmost marginal sedimentary basin in the Brazilian coast (Closs, 1970). During the Late Quaternary, four major sea-level transgressions correlated to interglacial phases reworked the uppermost portion of the basin. Each marine highstand produced a long sandy barrier system along the coastline, with associated coastal lagoons located landwards. They are referred to as Barrier-Lagoon Systems I, II, III and IV, and were correlated to marine isotope stages 11, 9, 5 and 1, respectively, following the oxygen ($\delta^{18}\text{O}$) curves of Imbrie *et al.* (1984, in Villwock & Tomazelli, 1995).

The Chuí Creek flows subparallel to the coastline in a NE-SW direction between the Pleistocene barriers II and III, through the plain that is part of the Lagoon System III (Figures 1A, B). In its lower course, the creek makes a southeastwards turn following the Chuí faulting zone before reaching the

Atlantic Ocean. The creek channel was originally shallow, but was further excavated for agricultural purposes in the early 1960s. At that time, a marine deposit found beneath sediments that contain remains of Pleistocene mammals was exposed (Figure 1C). Soliani (1973) correlated the marine layer to the “Chuí Formation” of Delaney (1965), and named the overlying fossiliferous layer as “Santa Vitória Formation”. Under the chronostratigraphic scheme proposed for the description of the geology of the CPRS by Villwock *et al.* (1986), which replaced the classical lithostratigraphic scheme of Delaney (1965), the marine sediments are identified as shallow marine facies deposited during the sea-level highstand that originated the Barrier System II and underlies the youngest sediments of Lagoon System III (Lopes *et al.*, 2011; Rosa, 2012).

The marine deposit consists of laminated (parallel and cross stratified), well-sorted, well-rounded and mature sand. The sand is essentially composed of quartz and contains small amounts (less than 10%) of heavy minerals and carbonate fragments of biogenic origin; the uppermost centimeters of this layer are reddish due to iron oxide coating resulting from subaerial exposure. Ichnofossils *Ophiomorpha nodosa* and *Rosselia* sp. are commonly found (Lopes *et al.*, 2001), and indicate shallow coastal waters (Weimer & Hoyt, 1964; Frey *et al.*, 1978; Pollard *et al.*, 1993; Nara, 2002). Some 2 m of this facies remain exposed above the creek bed; its total thickness is of at least 10 m, based on direct observation of drilling activities made for building purposes near the creek. The marine sand deposit is covered by a sediment layer containing the mammalian remains and generated in fluvial systems (Lopes *et al.*, 2009). The oldest age for a fossil mammal tooth obtained by ESR dating (226 ± 35 kyr BP) indicates that the marine facies below corresponds to the marine isotope stage (MIS) 7 (Lopes *et al.*, 2010), a conclusion also reinforced by ESR datings on shells from this facies (Lopes *et al.*, 2012). The layer with mammalian remains is covered by silty loam probably of loessic origin (Lopes *et al.*, 2011); the uppermost portion of the sedimentary sequence is composed of organic matter-rich sand and clay, containing fossil remains indicative of wetland environments and archaeological structures (Schmitz *et al.*, 1997).

MATERIAL AND METHODS

Previous descriptions of fossils of marine mollusks found in the Chuí Creek were presented by Closs & Forti (1971) and Forti Esteves (1974). The fossils described by those authors were collected in four different outcrops: on the bridge over Chuí Creek (sample E3, Figure 1B); on dredged sediments piled near the road between the town of Santa Vitória do Palmar and Hermenegildo Beach (sample E4, not shown in the figure); some 4 km to the south of the town of Chuí, in the Brazilian-Uruguayan border (samples E1 and E2), and some 50 km to the northeast of the town of Santa Vitória (sample E5, also not in the figure).

During the field work on the creek in 2010, when the water table was very low due to a drought, a concentration of fossil marine shells (M002) was found exposed at the

base of the right bank of the creek (Figures 1C, D), some 2 km to the north of the bridge on the road between the town of Santa Vitória do Palmar and Hermenegildo Beach. Two other concentrations (M001 and M004) were identified in the left and right banks, respectively, at the same stratigraphic position of M002, but some 600 m to the north of the bridge. The specimens collected from these outcrops were the basis for the paper by Lopes & Simone (2012); later, a fourth concentration (M003) was found in the left bank some tens of meters to the south of M002.

The term “concentration” is used here to designate a densely-packed shell accumulation *sensu* Kidwell & Holland (1991). Each concentration is formed by a densely packed (*sensu* Kidwell & Holland, 1991), decimeter-thick thick layer (Figure 1D) of clustered and chaotically-oriented shells; smaller specimens are found nested within larger ones. Above this layer shell remains are scarce and disperse in the sandy matrix until disappearing above approximately 15 cm upwards. A remarkable feature found in M003 is an ichnofossil *Ophiomorpha nodosa* that vertically crosses the shell concentration (Figure 1E). The total lateral extension of each concentration is as yet unknown, because the adjacent banks remain covered by alluvium. The physical proximity of approximately 20 m between the outcrops M001 (in the left bank) and M004 (in the right bank) suggests that both may represent the same accumulation. The outcrop M001 is visible on a gully transversal to the left margin of the creek, which shows that the fossil shell concentration extends into the subsurface for at least 10 m eastwards of the creek.

The bulk samples collected from each outcrop were washed and particles smaller than 2 mm were separated by using a sieve, in order to remove fragments that are not considered bioclasts *sensu* Kidwell & Holland (1991); identifiable specimens were hand picked among the remaining fragments. Identification was based on the compendia of Brazilian seashells (Rios 1994, 2009) and comparison with reference specimens from MZUSP and FURG.

RESULTS

Taxonomic composition of the assemblage

Although most of the remains are unidentifiable fragments, a total of 710 specimens were identified to the species level (Table 1; Figures 2, 3). All four concentrations are composed of predominantly the same taxa; the exceptions are taxa represented by a single individual. Besides the previously unrecorded species described by Lopes & Simone (2012), six other taxa not found before in this assemblage were collected in the outcrop M003, namely the gastropods *Buccinanops duartei* (Figure 2D), *B. gradatus* (Figure 2E) and *Terebra gemmulata* (Figure 2H) and the bivalves *Anadara chemnitzii* (Figure 3B) *A. brasiliiana* (Figure 3C) and *Erodona mactroides* (Figure 3F). Two other bivalve species previously unrecorded as fossils in the CPRS were found in the outcrop M001: *Cyrtopleura lanceolata* (Figure 3G) and *Semele purpurascens* (Figure 3Y).

The analysis of the shells shows a predominance of bivalves (95% of the specimens) over gastropods, both in

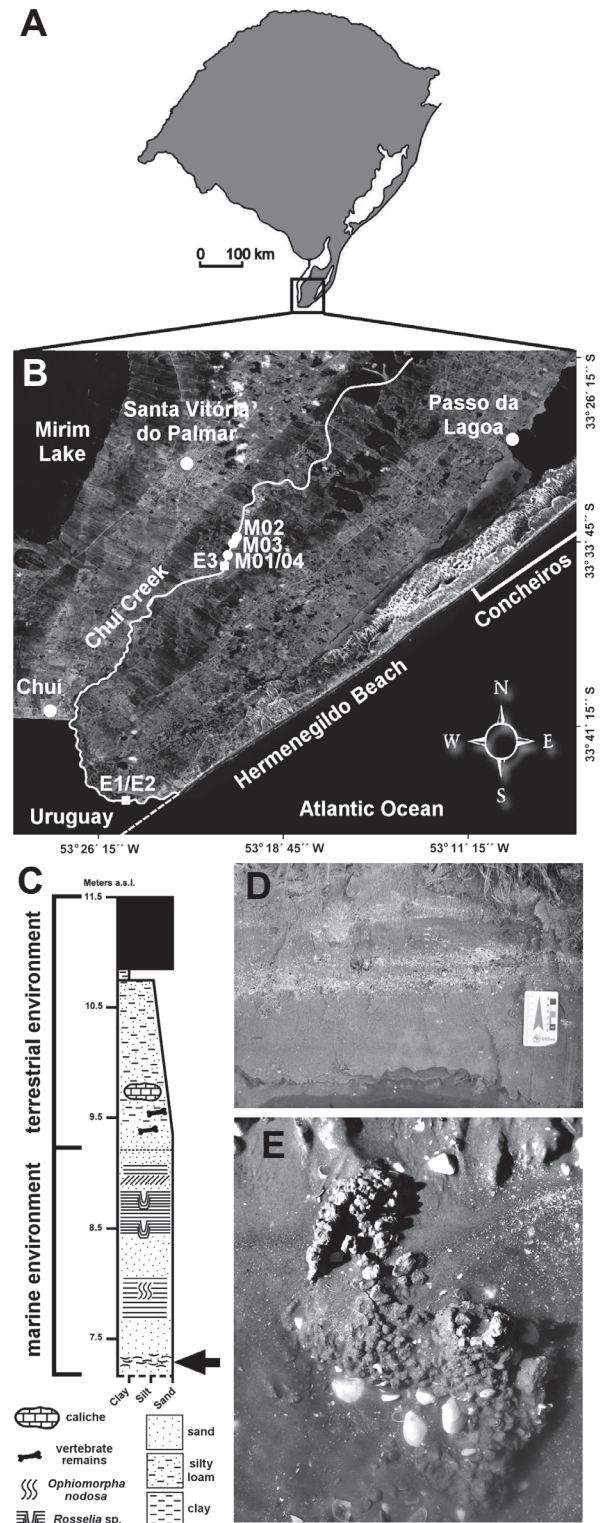


Figure 1. A, location of Chuí Creek, in the southern part of the CPRS. B, satellite image of Chuí Creek, showing outcrops M001, 002, 003 and 004 (the sources of the material described here), E1, E2 and E3 (sources of the shells described by Closs & Forti, 1971), and other localities with fossil shell concentrations (Passo da Lagoa and Concheiros). C, stratigraphic sequence exposed along the banks of Chuí Creek, with the position of the shells indicated by arrow (from Lopes & Simone, 2012). D, detail of the shell concentration exposed at the base of the banks in the outcrop M002 (scale = 50 mm). E, gallery of a callianassid crustacean (ichnofossil *Ophiomorpha nodosa*) associated with the shells at the outcrop M003.

Table 1. Molluscan taxa found in the concentrations.

Class GASTROPODA	
Order VETIGASTROPODA	
Family FISSURELLIDAE	
<i>Diodora patagonica</i> (d'Orbigny, 1847) (Figure 2A)	
Family TROCHIDAE	
<i>Tegula patagonica</i> (d'Orbigny, 1840) (Figure 2B)	
Order CAENOGASTROPODA	
Family CALYPTRAEIDAE	
<i>Bostrycapulus odites</i> (Collin, 2005) (Figure 2C)	
Family Nassariidae	
<i>Buccinanops duartei</i> (Klappenbach, 1961) (Figure 2D)	
<i>Buccinanops gradatus</i> (Deshayes, 1844) (Figure 2E)	
Family VOLUTIDAE	
<i>Zidona dufresnei</i> (Donovan, 1823) (Figure 2F)	
<i>Adelomelon brasiliana</i> (Lamarck, 1811) (Figure 2G)	
Family TEREBRIDAE	
<i>Terebra gemmulata</i> (Kiener, 1839) (Figure 2H)	
Family OLIVIDAE	
<i>Olivancillaria carcellesi</i> (Klappenbach, 1965) (Figure 2I)	
<i>Olivancillaria urceus</i> (Röding, 1798) (Figure 2J)	
<i>Olivancillaria deshayesiana</i> (Duclos, 1857) (Figure 2K)	
Family CONIDAE	
<i>Lamniconus lemniscatus carcellesi</i> (Martins, 1945) (Figure 2L)	
Class BIVALVIA	
Order ARCOIDA	
Family ARCIDAE	
<i>Lunarca ovalis</i> (Bruguière, 1789) (Figure 3A)	
<i>Anadara chemnitzii</i> (Philippi, 1851) (Figure 3B)	
<i>Anadara brasiliana</i> (Lamarck, 1819) (Figure 3C)	
Order MYOIDA	
Family NOETIIDAE	
<i>Noetia bisulcata</i> (Lamarck, 1819) (Figure 3D)	
Family CORBULIDAE	
<i>Corbula caribaea</i> (d'Orbigny, 1842) (Figure 3E)	
Family ERODONIDAE	
<i>Erodona mactroides</i> (Bosc, 1802) (Figure 3F)	
Family PHOLADIDAE	
<i>Cyrtopleura lanceolata</i> (d'Orbigny, 1846) (Figure 3G)	
Family GLYCYMERIDIDAE	
<i>Glycymeris longior</i> (Sowerby, 1833) (Figure 3H)	
Order OSTREOIDA	
Family PLICATULIDAE	
<i>Plicatula gibbosa</i> (Lamarck, 1801) (Figure 3I)	
Family OSTREIDAE	
<i>Ostrea puelchana</i> (d'Orbigny, 1841) (Figure 3J)	
<i>Ostrea equestris</i> (Say, 1834) (Figure 3K)	
<i>Crassostrea rhizophorae</i> (Guilding, 1828) (Figure 3L)	
Family PECTINIDAE	
<i>Chlamys tehuelchus</i> (d'Orbigny, 1846) (Figure 3M)	
Order VENEROIDA	
Family CHAMIDAE	
<i>Arcinella brasiliana</i> (Nicol, 1953) (Figure 3N)	
Family CARDIIDAE	
<i>Trachycardium muricatum</i> (Linné, 1758) (Figure 3O)	
Family VENERIDAE	
<i>Anomalocardia brasiliana</i> (Gmelin, 1791) (Figure 3P)	
<i>Chione cancellata</i> (Linné, 1767) (Figure 3Q)	
<i>Chione paphia</i> (Linné, 1767) (Figure 3R)	
<i>Pitar rostratus</i> (Koch, 1844) (Figure 3S)	
<i>Amiantis purpuratus</i> (Lamarck, 1818) (Figure 3T)	
Family MACTRIDAE	
<i>Macra</i> cf. <i>guidoi</i> (Signorelly & Scarabino, 2010) (Figure 3U)	
<i>Macra janeiroensis</i> (E.A. Smith, 1915) (Figure 3V)	
<i>Macra isabelleana</i> (d'Orbigny, 1846) (Figure 3W)	
<i>Macra marplatensis</i> (Doello-Jurado, 1949) (Figure 3X)	
Family SEMELIDAE	
<i>Semele purpurascens</i> (Gmelin, 1791) (Figure 3Y)	

species richness and total number of individuals (Table 2). The remains include mostly sandy bottom dwellers that inhabit the intertidal to infralittoral zone. Most of the species are stenohaline; the only taxon that usually inhabits brackish waters is *Erodona mactroides*, represented by two individuals. The gastropods and some bivalves are epifaunal, but most bivalves are infaunal taxa. All the gastropods found in the assemblage are taxa that live today in the southern Brazilian shelf, except for *Lamniconus lemniscatus carcellesi* (Figure 2L), a taxon that currently does inhabit Argentinean and Uruguayan waters but is not found in Brazil (Rios, 1994, 2009; Lopes & Simone, 2012). The bivalves *Anadara brasiliana* (Figure 3B), *Arcinella brasiliana* (Figure 3M), *Anomalocardia brasiliana* (Figure 3O), *Chione cancellata* (Figure 3P) and *C. paphia* (Figure 3Q) are not recorded among living molluscan assemblages of the coast of Rio Grande do Sul (e.g. Absalão, 1991; Borzone, 1988; Capitoli, 2002; Wigger & Veitenheimer-Mendes, 2003; Pimpão, 2004), although found living in other areas of the Brazilian coast.

Of the 37 species recorded, 12 belong to the Caribbean/Brazilian malacological province and 13 to the Argentinean; 10 occur on both Argentinean and Caribbean provinces and 2 occur on both Argentinean and Magellanic provinces (Figure 4).

Preservation

The shells were divided in two groups, according to their state of preservation: Group I is composed of highly abraded, unidentifiable and sometimes corroded and/or bioeroded fragments, and Group II, composed of 710 specimens, either complete (85% of the total) or incomplete (15%). The term incomplete is used here to describe specimens that although broken, still have at least 50% of the shell preserved.

All specimens are white-colored and without periostracum, except for a few *Chlamys tehuelchus* (Figure 3L) and two ostreids that exhibit traces of the original color pattern, and the *Tegula patagonica* (Figure 2B), that exhibits traces of the original color and the pearly internal lining. The complete fossils of Group II do not exhibit signs of abrasion; the corrosion seen in 45.3% of these fossils (Figure 5A) was probably caused by exposure to acidic water. Good preservation is observed even among fragile shells, such as those of small juvenile individuals and thin-shelled taxa (e.g. *Macra janeiroensis*).

All bivalves are represented by disarticulated valves, except for six *Corbula caribaea* that were found with valves still closed articulated. Signs of bioerosion can be seen on 32% of the shells; one specimen of *Macra janeiroensis* exhibits a *Caulostrepsis* ichnofossil (Figure 5B) and one specimen of *Pitar rostratus* exhibits ichnofossil *Entobia* (Figure 5C). Ichnogenera *Pennatichnus* or *Maeandropolydora* have not been observed on the bivalves, although these are common in shells from other fossil concentrations of the CPRS (see discussion below). On the other hand, eight specimens, including five ostreids, exhibit ichnofossils *Oichnus* (Figure 5D) that are virtually absent among fossils found in other localities of CPRS (Lopes, 2008; Lopes, 2012).

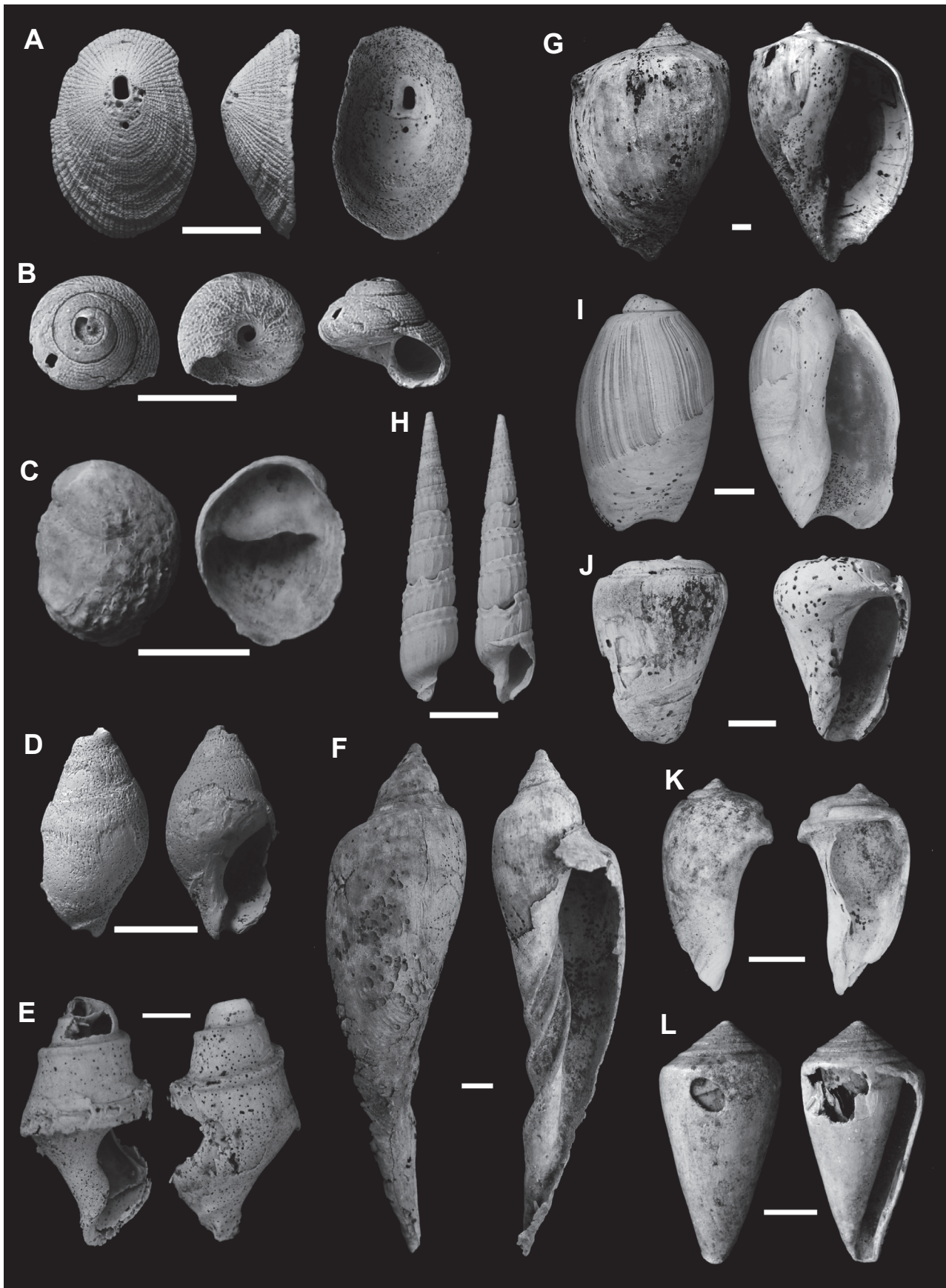


Figure 2. Gastropod taxa from Chuí Creek. **A**, *Diodora patagonica*; **B**, *Tegula patagonica*; **C**, *Bostrycapulus odites*; **D**, *Buccinanops duartei*; **E**, *Buccinanops gradatus*; **F**, *Zidona dufresnei*; **G**, *Adelomelon brasilliana*; **H**, *Terebra gemmulata*; **I**, *Olivancillaria carcellesi*; **J**, *Olivancillaria urceus*; **K**, *Olivancillaria deshaysiana*; **L**, *Lamniconus lemniscatus carcellesi*. Scale bars = 10 mm.



Figure 3. Bivalve taxa from Chuí Creek. **A**, *Lunarca ovalis*; **B**, *Anadara chemnitzii*; **C**, *Anadara brasiliensis*; **D**, *Noetia bisulcata*; **E**, *Corbula caribaea*; **F**, *Erodona mactroides*; **G**, *Cyrtopleura lanceolata*; **H**, *Glycymeris longior*; **I**, *Plicatula gibbosa*; **J**, *Ostrea puelchana*; **K**, *Ostrea equestris*; **L**, *Crassostrea rhizophorae*; **M**, *Chlamys tehuelchus*; **N**, *Arcinella brasiliensis*; **O**, *Trachycardium muricatum*; **P**, *Anomalocardia brasiliensis*; **Q**, *Chione cancellata*; **R**, *Chione paphia*; **S**, *Pitar rostratus*; **T**, *Amiantis purpuratus*; **U**, *Mactra* cf. *guidoi*; **V**, *Mactra janeiroensis*; **W**, *Mactra isabelleana*; **X**, *Mactra marplatensis*; **Y**, *Semele purpurascens*. Scale bars = 10 mm.

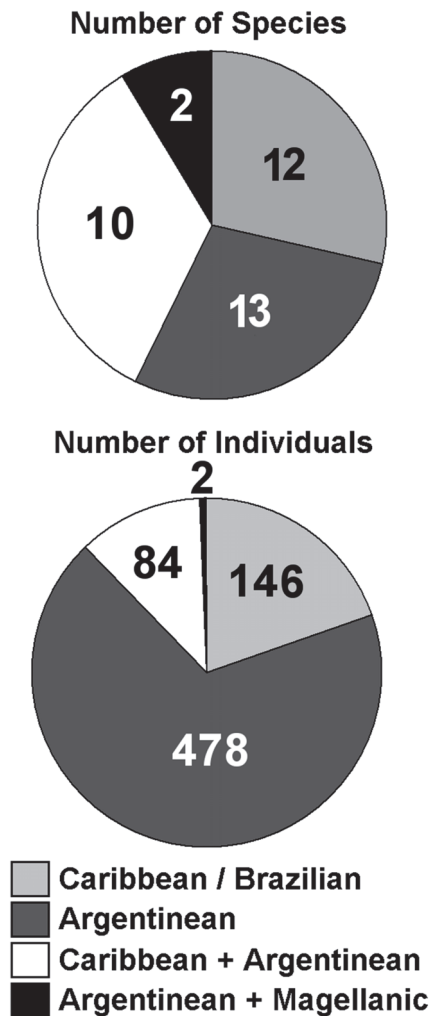


Figure 4. Relative percentages of taxa belonging to the Caribbean/Brazilian, Argentinean and Magellanic malacological provinces.

One ostreid (Figure 5E) and one pectinid (Figure 3L) exhibit ovoid borings (*cf.* ichnogenus *Gastrochaenolites* sp.); another ostreid exhibit several borings of *Entobia* and *Caulostrepsis* (Figure 5F).

Most of the gastropods are poorly preserved in comparison to the bivalves. The specimens of *Zidona dufresnei* (Figure 2F) and most *Adelomelon brasiliense* (Figure 2G) are broken; both taxa also exhibit signs of corrosion and ichnofossils *Entobia* and *Caulostrepsis*. The only other gastropod that exhibit bioerosion by *Entobia*, *Caulostrepsis* and also *Pennatichnus* is one specimen of *Olivancillaria urceus* (Figure 2J). The latter also exhibits traces tentatively assigned to the ichnogenus *Clionoides* sp. (Lopes, 2012).

DISCUSSION

Taphonomy

The assemblage from Chuí Creek is composed of well-preserved remains, concentrated together with highly fragmented and abraded unidentifiable shells. Good preservation may result of less exposure time in the

taphonomically active zone (TAZ, *sensu* Davies *et al.*, 1989a,b), while longer exposure times cause the destruction of more fragile shells, such as juveniles, small and thin-shelled taxa, and result in highly abraded and corroded specimens (Driscoll, 1970; Brandt, 1989; Davies *et al.*, 1989a,b; Kidwell, 1989). A survey among complete specimens of the most abundant bivalves (*Amiantis purpuratus*, *Pitar rostratus* and *Mactra janeiroensis*) shows that these include elements of all ontogenetic stages (Figure 6), with a predominance of juveniles. If the transport took longer time or the burial of these remains was delayed, it would be unlikely that the shells of juvenile individuals, more fragile in comparison to adults, would have been preserved. Studies have shown that shells of juveniles are more readily destroyed by currents, waves and dissolution, thus are often underrepresented in fossil concentrations (Cummins *et al.*, 1986; Kidwell, 1989; Kidwell & Bosence, 1991).

The estimated time of survival of shells in nearshore environments is shorter than in the shelf (Flessa & Kowalewski, 1994; Carroll *et al.*, 2003; Krause *et al.*, 2010) due to continuous mechanical reworking by waves and chemical dissolution while exposed on the water-sediment interface or buried within the zone affected by bioturbation. Because the sedimentation rates are usually lower than the rates of chemical destruction (dissolution) of the shells (Davies *et al.*, 1989b), the good preservation seen in many specimens indicates either an elevated rate of sedimentation during their final burial, or that these specimens have died shortly before burial, thus were exposed on the TAZ for a brief interval. Most of the bivalves found here are infaunal (spend most of their lives buried in the sediment), so it is likely that these could have died and remained articulated within the sediment, which prevented biogenic or mechanical reworking, until their removal and disarticulation by a storm event, after which the remains would have been buried under a thick sediment layer below the TAZ (depth of final burial, or DFB, *sensu* Olszewski, 2004). The presence of at least one *Ophiomorpha nodosa* preserved in association with the fossil concentration M003 (Figure 2E), plus six individuals of *Corbula caribaea* and several yet undescribed ostracods found with the valves still closed, reinforce the interpretation that the assemblage has not been reworked since their burial.

The specimens that are broken, bioeroded and/or corroded probably remained in the TAZ for longer periods. Among Holocene molluscan assemblages from Argentina, Aguirre & Farinatti (1999a) observed that infaunal bivalves (*e.g.* *Mactra isabelleana*, *Pitar rostratus*) are better preserved than epifaunal taxa. Lazo (2004) found similar results for the bivalve *Protothaca stamina*, which exhibits both infaunal and epifaunal behavior. The poor preservation among the larger gastropod shells (*Adelomelon brasiliense* and *Zidona dufresnei*) could have resulted from transportation of these specimens from their living areas (between 15 and 77 m in depth according to Rios, 1994) to the shoreline. Although predation is also a possible source of breakage of shells (Cate & Evans, 1994; Alexander & Dietl, 2003; Zuschin *et al.*, 2003), no conclusive evidence of such activity was identified

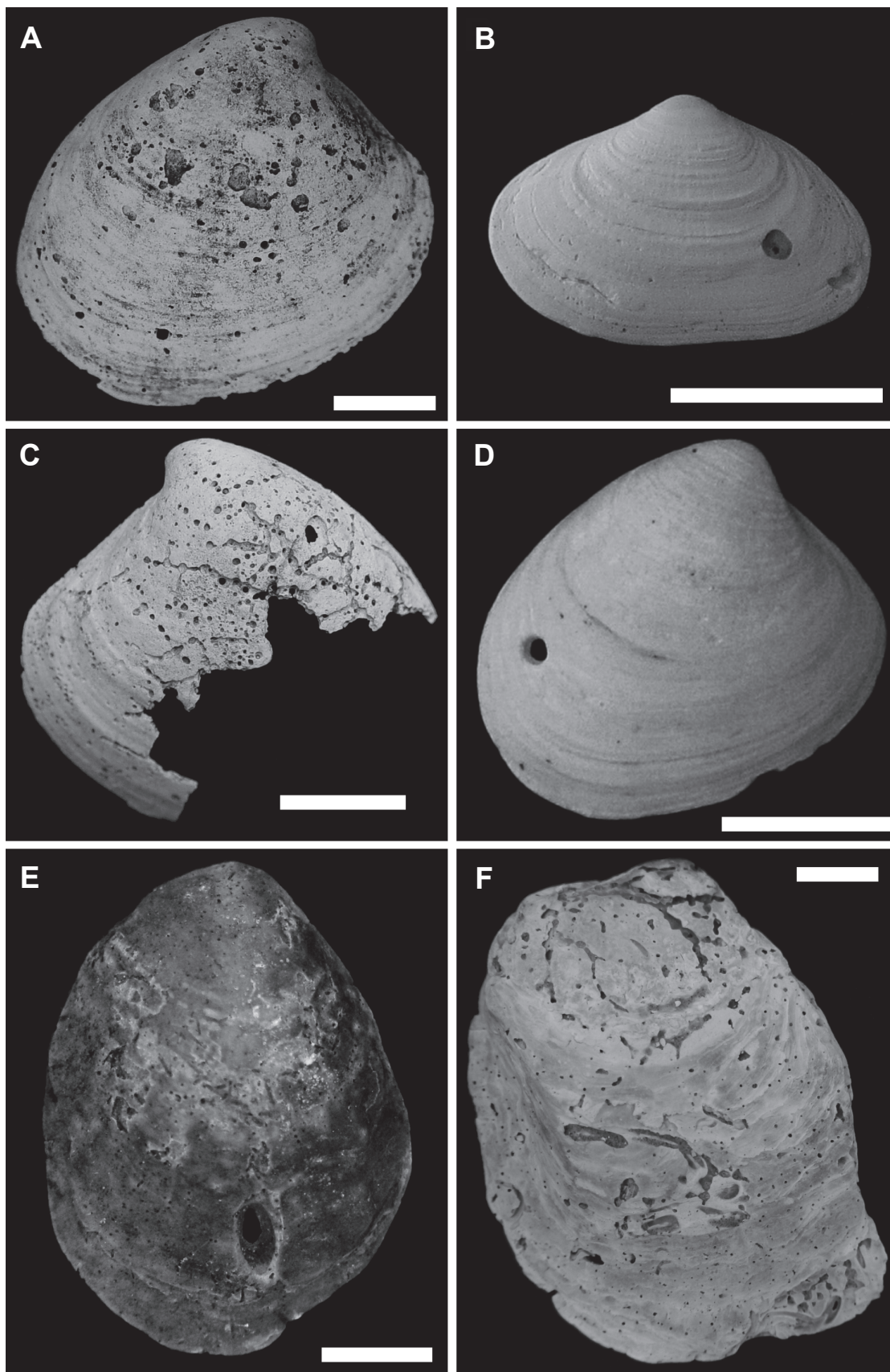


Figure 5. A, *Pitar rostratus* showing signs of corrosion. B, *Mactra janeiroensis* with borings of the ichnogenus *Caulostrepsis* sp. (on the right side of the photo). C, incomplete specimen of *P. rostratus* with *Entobia* sp. borings. D, juvenile of *P. rostratus* with boring made by predatory gastropod (ichnogenus *Oichnus* sp.). E, ostreid with boring produced by mytilid bivalve (ichnogenus *Gastrochaenolites* cf. *torpedo*). F, ostreid with *Caulostrepsis* and *Entobia*. Scale bars = 10 mm.

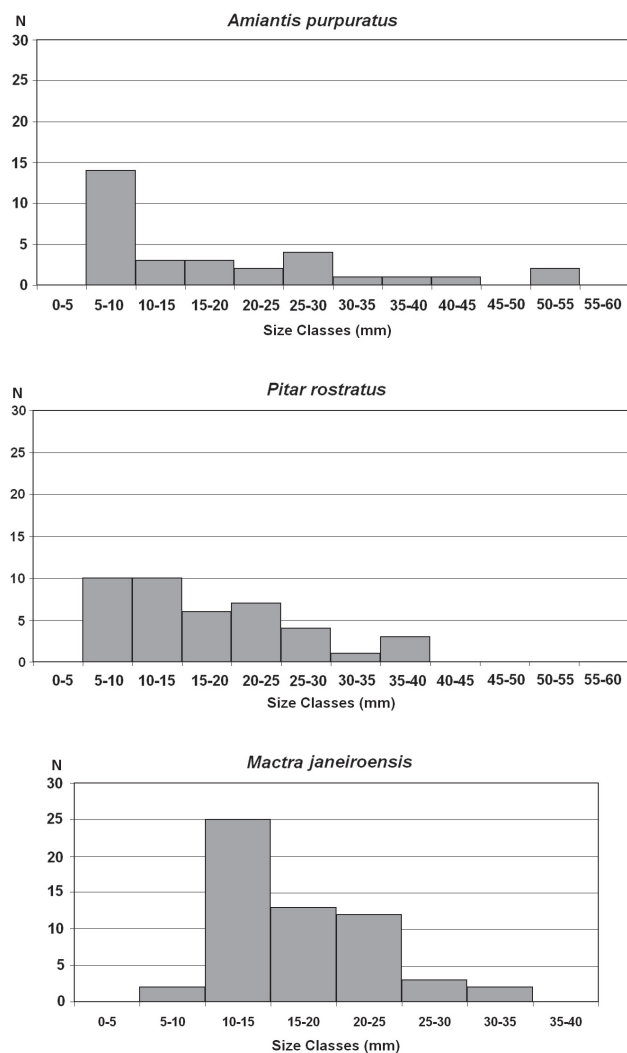


Figure 6. Size-frequency distribution of the length of complete, well-preserved specimens of the most abundant bivalve taxa found in Chuí Creek.

among the specimens. It seems, however, that the high degree of bioerosion seen in some specimens was to the direct cause of shell breakage (see Figure 5C).

Most of the dissolution that affects the shells occurs at the sediment-water interface and within the zone affected by bioturbation (Driscoll, 1970; Davies *et al.*, 1989a; Walker & Goldstein, 1999). Some processes related to storm events such as removal of organic matter, quick burial below the TAZ, and winnowing, which cause the shells to become densely packed, also protect shells against destruction by dissolution (Cherns *et al.*, 2008). Dissolution after burial was likely minimal, considering the presence of well-preserved foraminifer tests with the shells (Lopes & Bonetti, 2012) and ostracod carapaces. The concentrations are positioned at the phreatic level, permanently saturated in water with pH of 6.8-7.0 according to measurements taken in the outcrop M003. Even if few of the shell remains from Chuí Creek suffered partial dissolution, the release of calcium ions would result in low acidic to neutral pore water. Considering that water

moves very slowly in the phreatic level in comparison to the vadose zone above (Tucker, 1992), the low mobility of this low acidic-neutral water would prevent further dissolution of the shells. On the other hand, in outcrops of the marine facies of the Barrier III in the northern CPRS, preserved above the phreatic level, the shells were completely dissolved leaving only moulds (Tomazelli & Dillenburg, 2007), probably due to the free flow of pore water containing dissolved acids from the overlying soil.

One single storm event could not have produced the taphonomic signature (corrosion and abrasion) visible in the unidentifiable fragments (Davies *et al.*, 1989a). Rather, the poor preservation of these remains indicates that they were continuously reworked in shallower areas within the depths affected by waves prior to their final burial together with the well-preserved shells.

The shells from Chuí Creek resemble those found in Passo da Lagoa, with white to light grey color, while those from the Concheiros are dark grey to reddish (Lopes & Buchmann, 2008). The color variation seen among the shells from submarine deposits is probably caused by incorporation of iron, manganese and other components dissolved in the seawater. Coimbra *et al.* (2009) found oxidized glauconitic coatings on Neogene foraminifer tests from the southern Brazilian shelf, attributing it to a combination of glauconite incorporation under marine conditions and oxidization due to sea-level change.

The proportion of specimens affected by bioerosion is similar in the three assemblages (32% in Chuí Creek, 22% in Passo da Lagoa and 37% in the Concheiros). In soft bottom coasts such as in southern Brazil, any hard substrate, such as a shell or other skeletal element, has a high potential for colonization by epi- and endoskeletozoans. The longer these shells remain exposed at the water-sediment interface, the greater the degree of bioerosion that will be present. Remarkably, the most common ichnofossil observed among the shells from Chuí Creek is *Oichnus*, which is virtually absent from the other two concentrations (Lopes & Buchmann, 2008; Lopes, 2012). This ichnogenus, however, indicates predatory activity by gastropods, thus it is not produced on dead remains, although cases of erroneous attacks by predators on dead shells are possible (Kelley & Hansen, 2003; Simões *et al.*, 2007). The gastropods that exhibit bioerosion (*Zidona dufresnei*, *Adelomelon brasiliana* and *Olivancillaria urceus*) are epifaunal taxa that inhabit depths below the influence of normal waves (some 10-12 m) and are much larger than the bivalves, thus are likely to remain exposed for a long time period and be subject to the action of bioeroders after death. Bioerosion could have been also produced while the hosts were still alive, at least in the case of *Caulostrepsis*, which is produced by spionid polychaetes, as it was recorded in extant brachiopods (Rodrigues *et al.*, 2008). This trace was observed on the external surface of one *Mactra* (Figure 5b) ostreids (Figure 5F) and one gastropod (Figure 2J), thus it is possible that these individuals could have been infested while still alive, as is the case for fossil oysters (bioeroded mostly on the external surfaces of the valves) from the continental shelf

(Lopes, 2011b; 2012). The *Entobia* observed on the external surface of *Adelomelon* and *Zidona*, which are epifaunals, could also have been produced while these were still alive.

Paleoecology and paleobiogeography

The relative absence of articulated and/or specimens in life position, plus the mixing of unidentifiable fragments and complete specimens indicate that the concentrations are sedimentological in origin, rather than representing within habitat averaged shell beds preserved *in situ*. These concentrations can be considered parautochthonous (or mixed assemblages), formed by remains of shallow-living taxa reworked in their habitat (Kidwell *et al.*, 1986), concentrated together with allochthonous elements such as deep-living taxa (*Zidona dufresnei* and *Adelomelon brasiliana*), hard bottom dwellers (*Bostrycapulus odites*, *Diodora patagonica*) and inhabitants of brackish-water environments (*Erodona mactroides*).

Most of the taxa found in this assemblage live today in the southern Brazilian coast (Borzzone, 1988; Absalão, 1991; Gianuca, 1998; Capitoli, 1998; 2002), but some taxa (*e.g.* *Maetra guidoi*, *Maetra janeiroensis*) are not common among recent specimens found along the beach. Although living in most areas of the Brazilian coast, the bivalves *Anomalocardia brasiliana*, *Chione paphia*, *Chione cancellata*, *Anadara brasiliana* and *Arcinella brasiliana* are not found today in the coast of Rio Grande do Sul State; their southernmost distribution confirmed so far is the northern neighboring State of Santa Catarina (Figure 7; Veitenheimer-Mendes & Lopes-Pitoni, 1995; Klein *et al.*, 2001; Almeida *et al.*, 2004; Caregnato *et al.*, 2009; Rodrigues *et al.*, 2010). Although the current distribution of *Anomalocardia* has been described as reaching up to the Uruguayan coast (Rios, 1994; 2009), this taxon is not found living today in that area (Scarabino, 2003). Absalão (1986) mentioned one single specimen of *Anomalocardia* collected in the coast of Rio Grande do Sul, without specifying whether it was a living individual or just an isolated valve. Considering the presence of large concentrations of fossil and subfossil shells on the continental shelf (Figueiredo, 1975; Lopes & Buchmann, 2008), containing other taxa that do not inhabit the southern Brazilian shelf today (Simões *et al.*, 2011) it seems probable that the material mentioned by that author does not represent a recent individual.

Anomalocardia and other 'Brazilian' taxa (*e.g.* *Anadara brasiliana*, *Chione cancellata*, *Bulla striata*, among others) have been found in late Pleistocene and early-middle Holocene fossil deposits in the coastal areas of Uruguay and Argentina, at latitudes up to 38°S (Figure 10), and their presence so far to the south is considered as an indicator of conditions warmer than today around 6-4,5 kyr BP (Aguirre, 1993; Gordillo, 1998; Clavijo *et al.*, 2005; Martínez *et al.*, 2006; Aguirre *et al.*, 2011). The interval between ~10 and 5 kyr BP corresponds to the Holocene climatic optimum (Hypsithermal) marked by warmer temperatures in high latitudes (Emiliani, 1972; Rabassa, 1987; Ciais *et al.*, 1992). Aguirre & Farinatti (1999b) found a higher proportion

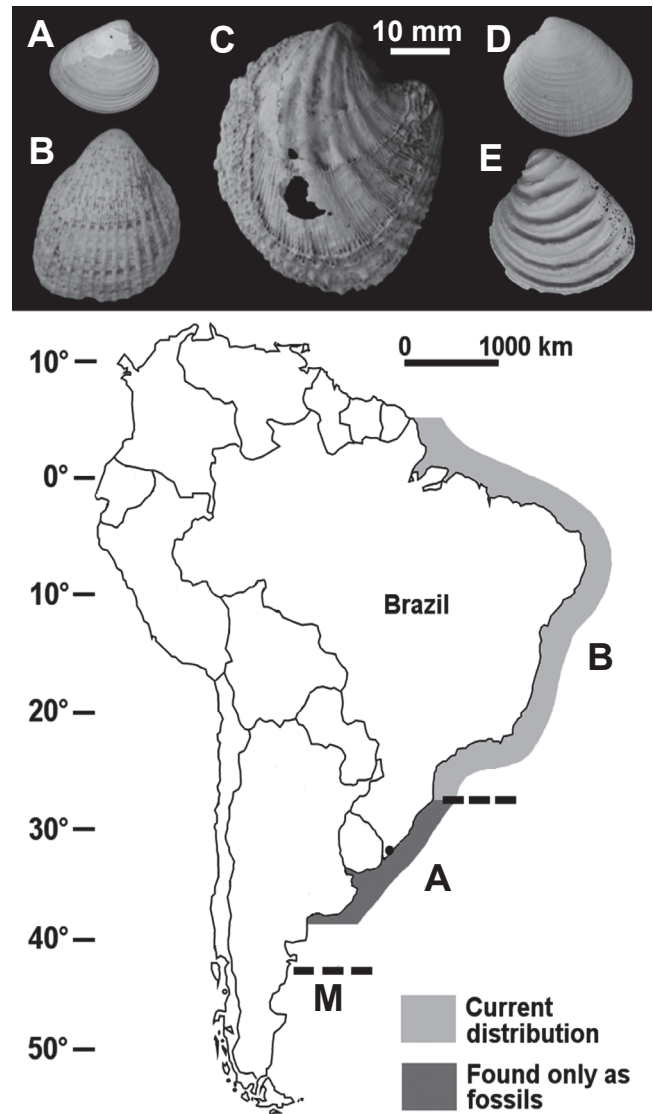


Figure 7. Bivalves that are not found living in the southern Brazilian coast today: *Anomalocardia brasiliana* (A), *Anadara brasiliana* (B), *Arcinella brasiliana* (C), *Chione cancellata* (D) and *C. paphia* (E). The map shows the current and middle Pleistocene-middle Holocene distribution of these taxa. Capital letters indicate the areas of the Caribbean/Brazilian (B), Argentinean (A) and Magellanic (M) malacological provinces; the black dot indicates the location of Chuí Creek.

(35%) of warm water mollusks (of the Caribbean/Brazilian malacological province) in middle Holocene fossil deposits of the Argentinean coast than in present-day assemblages (14%). Because the distribution of the Caribbean/Brazilian province is controlled by the warm Brazilian Current (Martínez & Del Río, 2002), a higher southern influence of this current during past interglacials has been considered the factor responsible for the southwards displacement of molluscan taxa that today reach only up to southern Brazil (Aguirre, 1993; Martínez & Del Río, 2005).

The oceanographic conditions in the area that encompasses southern Brazil, Uruguay and the Bonaerensian coast of Argentina (up to ~41°S) are controlled basically by the

interplay between the warm Brazilian Current (BC) and the cold Malvinas Current (MC), which is a branch of the Antarctic Circumpolar Current (ACC). The convergence between these two currents forms the Brazilian-Malvinas Confluence (BMC), which is subject to seasonal latitudinal shifts that characterize the Subtropical Front (STF). The southwards influence of the BC is stronger during austral summer, while during austral winter the pattern is reversed, when the ACC (and consequently the MC) are intensified; thus the intensity of the MC seems to exert control on the maximum southern reach of the BC (Matano *et al.*, 1993; Wainer *et al.*, 2000).

Several records have shown that during the Holocene hypsithermal, between ~10 and 5 kyr BP, the surface waters around Antarctica were warmer and ice-free, suggesting a polewards retreatment of the Subantarctic (SAF) and Polar (PF) fronts (Domack *et al.*, 2001; Hodell *et al.*, 2001; Lamy *et al.*, 2002). It seems likely that during past hypsithermals this retreatment resulted in a weakened ACC and a consequent reduction in the equatorwards influence of the MC, thus allowing the BC to reach farther south than during colder intervals. Additional evidence for this comes from paleotemperatures obtained from foraminiferal tests found in drilling cores, which indicate temperatures between 1 and 5°C warmer than today for the waters surrounding Antarctica during the early phases of the last five interglacials (Becquey & Gersonde, 2003). Thus it seems possible that these warmer conditions would have allowed a southwards expansion of tropical to subtropical taxa. The age of some 235-238 kyrs for these shells (Lopes *et al.*, in press) is correlated with an hypsithermal phase of the penultimate interglacial; the foraminiferal assemblage found associated with the shells also point to warmer conditions (Lopes & Bonetti, 2012).

The current southernmost distribution (28°S) of the 'Brazilian' taxa found here is coincident with mean sea surface temperature (SST) of 21°C, while in the latitude of Chuí Creek it is of 18°C (Garcia, 1998; Castro *et al.*, 2006). If temperature was the key environmental factor controlling the distribution of those taxa, then it is reasonable to assume that mean SSTs during past hypsithermals were at least 3°C warmer than today.

Anomalocardia was also recorded in fossil concentrations formed by the Holocene marine highstand around 6-5 kyr BP in the coast of Rio Grande do Sul (Closs & Forti, 1971; Buchmann *et al.*, 1998; Caron, 2007; Lima *et al.*, 2013), and Caron (2007) also reported the presence of *Chione paphia*. This suggests that during the Holocene Hypsithermal the marine conditions were also warmer than at present. The cooler conditions during the Neoglacial stage that followed the hypsithermal, would lead to the Present-day conditions of relatively increased influence of the Malvinas current, resulting in the northwards retreat of the fauna adapted to warmer waters. Although reliable data about molluscan faunas correlated to the ~123-kyr marine transgression (MIS 5) from Southern Brazil are not yet available, Aguirre *et al.* (2011) considered that the high molluscan diversity found in deposits of this age in the Argentinean coast is also related to

warmer conditions than at present. Thus, the data gathered so far points towards a cyclic pattern of southwards displacement of warmer marine conditions (and due southwards distribution of taxa adapted to warm waters) during the early phases of interglacial epochs. Conversely, the presence in the southern Brazilian continental shelf of late Pleistocene fossils of a brachiopod (*Magellania* cf. *M. venosa*) that today inhabits only the colder waters of Argentina, suggests that during glacial times the Magellanic fauna had its distribution extended northwards, following the displacement of the SAF and PF (Simões *et al.*, 2011). Becquey & Gersonde (2003) estimated that these fronts suffered a northwards shift of ~5° during glacial intervals.

Comparison with other fossil assemblages

In the southern sector of the CPRS, two other concentrations of fossil marine shells are found, one in the southwestern margin of Mangueira Lake, at the locality known as Passo da Lagoa, and the other, known as Concheiros, is found on the present shoreline, close to the Brazilian-Uruguayan border (Lopes & Buchmann, 2008). The fossils from Passo da Lagoa are found among sediments dredged from the bottom of the lake, thus their stratigraphic position is still unknown. The Concheiros are formed by fossils transported from the continental shelf to the beach by storm waves (Figueiredo, 1975; Buchmann, 2002; Lopes & Buchmann, 2008), therefore they actually represent several storm-generated concentrations (multiple event concentrations, *sensu* Kidwell, 1991). The fossiliferous deposits of the continental shelf, which constitute the source for the material accumulated on the beach, are likely to be lag deposits formed during past marine transgressions that are being reworked today by the erosive processes affecting the southern coast of Rio Grande do Sul (Dillenburg *et al.*, 2004).

The main taxonomic difference between the fossils from the Passo da Lagoa and Concheiros and those from Chuí Creek is the scarcity of the bivalve *Glycymeris longior* on the latter (only two specimens found), while it is common in Concheiros (72% of the specimens) and Passo da Lagoa (18%) (Lopes & Buchmann, 2008). The co-occurrence of both shallow living taxa such as *Amiantis purpuratus* and deeper dwellers such as *G. longior* indicates that the assemblages of Concheiros and Passo da Lagoa do not represent within habitat time averaged shell beds, but were formed by sedimentological processes related to sea-level oscillations. During a marine transgression, the rising sea-level would erode the shallow areas, removing finer sediments and leaving coarser ones (including fossils) concentrated on the ravinement surface, thus forming a transgressive lag deposit. The deeper-living taxa would also have their distribution expanded landwards following the rising sea-level, and would accumulate on top of the remains of shallow living taxa. Following the Holocene highstand, erosive processes such as seen today in most of the coast of Rio Grande do Sul for the last 7 ka (Dillenburg *et al.*, 2004; Lima *et al.*, 2013), these lag deposits would have been reworked and the fossil shells transported to the beach during storm surges, therefore mixing together remains of taxa

that inhabit different depths. A similar process seems to be responsible for the abundance on the present-day coastline of fossil remains of the echinoid *Encope emarginata* that inhabits the infralittoral (Lopes, 2011a).

Previous works regarding fossil marine mollusks found in the Chuí Creek were presented by Closs & Forti (1971) and Forti Esteves (1974). Although those authors have not described the precise stratigraphic position of the fossils, they considered that all samples were from the “Chuí Formation”, represented by the marine sediments exposed at the base of the banks of the creek.

Delaney (1965) attributed a Pleistocene age for the “Chuí Formation”, while Closs & Forti (1971) considered it Holocene, and correlated it to the “Querandinense” transgression and the Vizcaíno Formation of Uruguay, and to the “Belgranense” sediments of Argentina. Forti Esteves (1974) mentioned a ^{14}C age of 5,045 years for fossil shells collected 4 km to the south of the town of Chuí (outcrop E1/E2; Figure 1). Closs & Forti (1971) and Forti Esteves (1974) considered that all the five outcrops represented a single transgressive event, namely the Holocene transgression of some 6 kyr BP. Sprechmann (1978) also correlated marine deposits of the Vizcaíno Formation of Uruguay with those described from Santa Vitória do Palmar County, but concluded that the latter were also of late Pleistocene age.

Recent research on the outcrop from where samples E1/E2 were collected (Caron, 2007) revealed that this can be confidently considered a Holocene deposit, based on a ^{14}C age of $5,750 \pm 40$ years (cal. 6,260–6,080 yr BP) for an articulated bivalve (*Tagelus plebeius*). A ^{14}C age of $5,070 \pm 70$ years (cal. 5,073–5,541 yr BP) was found for a specimen of *Macra isabelleana* from the Uruguayan bank of Chuí Creek (Martinez *et al.*, 2006), which is part of the same deposit from where the samples E1/E2 were collected. This deposit represents a Holocene estuarine environment, as indicated by the muddy sediment and abundance of the mollusks *T. plebeius* (in life position), *Erodona mactroides* and *Heleobia australis*, and is positioned some 2 m above present sea-level (Caron, 2007). This deposit is part of the Barrier-Lagoon System IV and represents the last marine transgression (MIS 1), that reached an estimated amplitude of 4 ± 1 m above present sea-level in southern Brazil (Dillenburg & Hesp, 2009), thus it cannot be correlated to the fossil assemblage described here or to the samples E3, E4 and E5 of Closs & Forti (1971).

Although the fossils of the outcrop E3 of Closs & Forti (1971) are likely to be remains found scattered along the creek bed, removed from their original stratigraphic position by erosion, they probably came from the same stratigraphic level that contains the assemblage described here, because no shells were found so far in upper levels of the marine facies. The remains from E5, however, may represent fossils from different stratigraphic settings; these were collected among sediments extracted during the construction of a small dam in the late 1960s, according to verbal communication from local people. These shells are not exposed on the surface, so additional drillings are needed in order to identify their exact stratigraphic position.

The fossil assemblage described here is of Pleistocene age (see below), thus cannot be correlated to assemblages from outcrops E1 and E2 of Closs & Forti (1971).

Age and stratigraphic significance

Fifteen shells from the outcrops M001, 002 and 004 were dated using electron spin resonance (ESR), and provided a mean age close to ~235–238 kyr BP (Lopes *et al.*, in press). This result indicates a late middle Pleistocene age, and correlates this assemblage with the MIS 7, possibly representing the marine highstand during the substage 7.5. The ages are in agreement with the stratigraphic position of the shells, ESR ages of fossil mammals from the overlying sediments (Lopes *et al.*, 2010).

The presence of a ~2 m thick sand layer above the shells, containing ichnofossils *Ophiomorpha*, *Rosselia* and cross stratification indicates the persistence of shallow marine conditions after the deposition of the shell concentrations, until coastal progradation took place, as indicated by paleosoils, fluvial channels and vertebrate fossils found just above the marine facies. The absence of facies or environmental changes above the shell concentrations indicate that although sea-level continued to rise after the deposition of the shells, the total water depth did not change much. If depth was increasing, one would expect to find a greater proportion of mud, which accumulates in deeper areas (lower shoreface and offshore) below the influence of waves (Catuneanu, 2006; Holz, 2012). The sedimentary record, however, shows the persistence of shallow-marine conditions, seemingly under high rates of sedimentation, punctuated by storm events, as indicated by the shell concentrations and truncated ichnofossils *Rosselia* sp. Such a scenario of conditions of high sedimentation rates under a regime of sea-level rise is consistent with coastal aggradation followed by shoreline progradation, resulting in marine regression (Assine & Perinotto, 2001; Catuneanu, 2006; Holz, 2012).

Because of the low thickness and the same stratigraphic position of the shell concentrations along the banks of the creek, this assemblage can be used as a paleo sea-level indicator. Such indicators are scarce in the PCRS in comparison to other places of the Brazilian coast (*e.g.* Martin *et al.*, 2003; Angulo *et al.*, 2006). These concentrations are placed nearly 7.5 m above present sea-level (Lopes & Simone, 2012), but are overlain by ~2 m of marine sediments. Thus the total amplitude of this transgression was ~9.5 m above present sea-level, higher than the following transgression that formed Barrier III around ~123 kyr BP (Tomazelli & Dillenburg, 2007).

CONCLUSIONS

The fossils described by Lopes & Simone (2012) and here are the first records of body fossils from sediments of the Barrier System II. The characteristics of this assemblage suggest that its deposition was a short-termed process, possibly involving erosion of the lower shoreface and transportation of well-preserved shell remains to shallower zone by storm waves, followed by their final burial together with highly

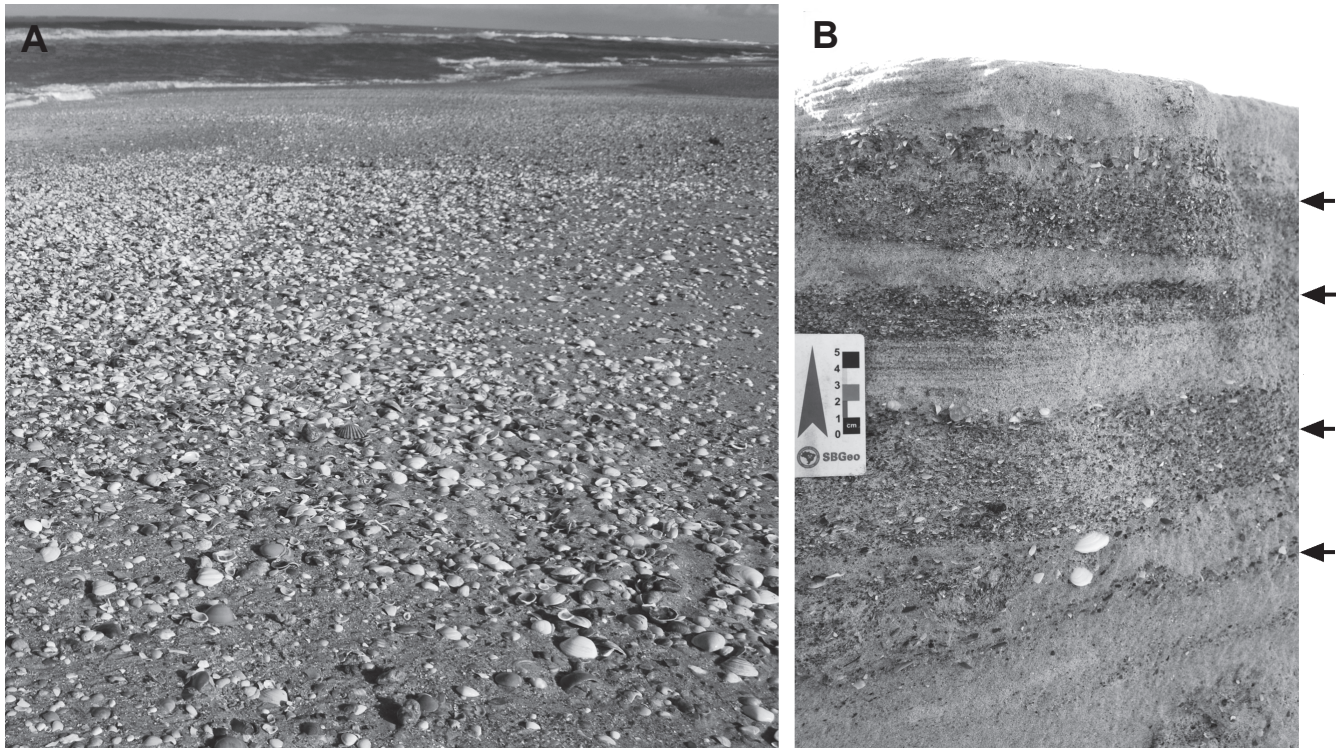


Figure 8. A, shell concentration formed by storm event in the foreshore at the Concheiros. B, vertical profile of the foreshore, showing alternate layers of shells (indicated by arrows) and sand (Scale bar = 5 cm).

reworked fragments at the DBF. This process would be similar to what is seen today in the Concheiros: during autumn and winter, storm waves deposit large amounts of fossil shells in the upper shoreface. These shells, transported from the lower shoreface, are then concentrated together with smaller shell fragments that are continuously reworked and abraded in the surf zone. During summer and spring, when storm surges are rare, these deposits remain above the range of waves and are covered by sand when the beach recovers the summer profile and also by sand blown from the foredunes (Lopes & Buchmann, 2008). The deposits formed in the shoreface exhibit densely packed layers of fossil shells, both well-preserved and fragmentary, with variable thickness and interspersed with sand layers (Figure 8).

From the taxonomic composition, taphonomy, ecological aspects and stratigraphy of this assemblage, several conclusions can be drawn: (i) most of the fossil mollusks found in Chuí Creek are shallow-living taxa that inhabit sandy bottoms, mixed together with gastropods from deeper areas and a few hard substrate dwellers. This, plus the mixture of shells exhibiting very distinct taphonomic features indicate that it is a parautochthonous assemblage, probably formed by storm events; (ii) most of the shell material from this assemblage is composed of unidentifiable, highly abraded shell fragments, but also includes well-preserved shells (lacking signs of abrasion, fragmentation and corrosion), including fragile juveniles. The good preservation indicates that these remains were quickly buried below the TAZ and were not subject to further reworking. The relative absence of corrosion, bioerosion or bioincrustation in most of the

complete shells indicates that these fossils remained exposed in the TAZ for a short period prior to their final burial, while those that are bioeroded and/or corroded were exposed for longer periods; (iii) the assemblage described here is probably the source of the fossil molluscan sample E3 described by Closs & Forti (1971) and Forti Esteves (1974) as collected near the bridge over Chuí Creek. The stratigraphic position of the assemblage and ESR datings, however, indicate that these fossils are Pleistocene and not Holocene in age, as stated by those authors; (iv) the presence of molluscan taxa that are not found living today in the coast of Rio Grande do Sul and whose current distribution seems related to warmer conditions (*Anomalocardia brasiliensis*, *Arcinella brasiliensis*, *Anadara brasiliensis*, *Chione cancellata* and *C. paphia*), also recorded in molluscan assemblages from Uruguay and Argentina, suggests lower influence of the Malvinas Current and stronger southwards influence of the Brazilian Current during this marine highstand and (v) the presence of taxa that indicate warmer conditions in the deposits of late middle Pleistocene of Chuí Creek and also in middle Holocene deposits of the CPRS, suggests a cyclic pattern of warmer oceanographic conditions during the hypsithermal phases of past interglacials, coincident with marine highstands.

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REFERENCES

- Absalão, R.S. 1986. *Discriminação ambiental entre associações de moluscos macro-bentônicos ao largo de Rio Grande, RS, Brasil. Situação inverno-primavera*. Programa de Pós-Graduação em Oceanografia Biológica, Universidade Federal do Rio Grande, M.Sc. Dissertation, 126p.
- Absalão, R.S. 1991. Environmental discrimination among soft-bottom mollusc associations of Lagoa dos Patos, southern Brazil. *Estuarine Coastal and Shelf Science*, **32**:71-85. doi:10.1016/0272-7714(91)90029-B
- Aguirre, M.L. 1993. Palaeobiogeography of the Holocene molluscan faunas from northeastern Buenos Aires province, Argentina: its relation to coastal evolution and sea level changes. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **102**:1-26. doi:10.1016/0031-0182(93)90002-Z
- Aguirre, M. & Farinatti, E.A. 1999a. Taphonomic processes affecting late Quaternary molluscs along the coastal area of Buenos Aires Province (Argentina, southwestern Atlantic). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **149**:283-304. doi:10.1016/S0031-0182(98)00207-7
- Aguirre, M. & Farinatti, E.A. 1999b. Paleobiogeografía de las faunas de moluscos marinos del Neógeno y Cuaternario del Atlántico Sudoccidental. *Revista de La Sociedad Geológica de España*, **12**:93-112.
- Aguirre, M.L.; Donato, M.; Richiano, S. & Farinatti, E.A. 2011. Pleistocene and Holocene molluscan assemblages from Patagonian and Bonaerensian littoral (Argentina, SW Atlantic): palaeobiodiversity and palaeobiogeography. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **308**:277-292. doi:10.1016/j.palaeo.2011.05.032
- Alexander, R.P. & Dietl, G.P. 2003. The fossil record of shell-breaking predation on marine bivalves and gastropods. In: P.H. Kelley; M. Kowalewski & T.A. Hansen (eds.) *Predator-Prey Interactions in the Fossil Record*, Springer, p. 141-176. doi:10.1007/978-1-4615-0161-9_7
- Almeida, T.C.M.; Rohr, T.E. & Schio, C. 2004. Associações de moluscos do infralitoral de Santa Catarina, SC - Brasil. *Notas Técnicas da FACIMAR*, **8**:119-126.
- Angulo, R.J.; Lessa, G.C. & Souza, M.C. 2006. A critical review of the mid- to late Holocene sea-level fluctuations on the eastern Brazilian coastline. *Quaternary Science Reviews*, **25**:486-506. doi:10.1016/j.quascirev.2005.03.008
- Assine, M.L. & Perinotto, J.A.J. 2001. Estratigrafia de sequências em sistemas deposicionais siliciclásticos costeiros e marinhos. In: H.J.P.S. Ribeiro (org.) *Estratigrafia de Sequências: Fundamentos e Aplicações*. São Leopoldo, Editora UNISINOS, p. 305-339.
- Becquey, S. & Gersonde, R. 2003. A 0.55-Ma paleotemperature record from the Subantarctic zone: implications for Antarctic Circumpolar Current development. *Palaeoceanography*, **18**:1014. doi:10.1029/2000PA000576
- Bianchi, L.A. 1969. Bancos de ostreídeos pleistocênicos da Planície Costeira do Rio Grande do Sul. *Iheringia, Série Geologia*, **2**:3-40.
- Borzzone, C.A. 1988. *Estudo da macrofauna bentônica infralitoral da região costeira adjacente à barra de Rio Grande, RS, Brasil*. Programa de Pós-Graduação em Oceanografia Biológica, Universidade Federal do Rio Grande, M.Sc. Dissertation, 112p.
- Brandt, D.S. 1989. Taphonomic grades as a classification for fossiliferous assemblages and implications for paleoecology. *Palaios*, **4**:303-309. doi:10.2307/3514554
- Buchmann, F.S.C. 2002. *Bioclastos de organismos terrestres e marinhos na praia e plataforma interna do Rio Grande do Sul: natureza, distribuição, origem e significado geológico*. Programa de Pós-Graduação em Geociências, Universidade Federal do Rio Grande do Sul, Ph.D. Thesis, 108p.
- Buchmann, F.S.C.; Barbosa, V.P. & Villwock, J.A. 1998. Sedimentologia e paleoecologia durante o máximo transgressivo holocênico na Lagoa Mirim, RS, Brasil. *Acta Geológica Leopoldensia*, **21**:21-26.
- Capitoli, R. 1998. Bentos da Plataforma Continental. In: U. Seeliger; C. Odebrecht & J.P. Castello (eds.) *Os Ecossistemas Costeiro e Marinho do Extremo Sul do Brasil*, Ecoscientia, p. 131-134.
- Capitoli, R.R. 2002. *Distribuição e abundância dos macroinvertebrados bentônicos da plataforma continental e talude superior no extremo sul do Brasil*. Programa de Pós-Graduação em Oceanografia Biológica, Universidade Federal do Rio Grande, Ph.D. Thesis, 173p.
- Caregnato, F.F.; Wiggers, F.; Tarasconi, J.C. & Veitenheimer-Mendes, I.L. 2009. Taxonomic composition of mollusks collected from the stomach content of *Astropecten brasiliensis* (Echinodermata: Asteroidea) in Santa Catarina, Brazil. *Revista Brasileira de Biociências*, **7**:252-259.
- Caron, F. 2007. *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*. Programa de Pós-Graduação em Geociências, Universidade Federal do Rio Grande do Sul, M.Sc. Dissertation, 81p.
- Carroll, M.; Kowalewski, M.; Simões, M.G. & Goodfriend, G.A. 2003. Quantitative estimates of time-averaging in terebratulid brachiopod shell accumulations from a modern tropical shelf. *Paleobiology*, **29**:381-402. doi:10.1666/00948373(2003)029<0381:QEOTIT>2.0.CO;2
- Castro, B.M.; Lorenzetti, J.A.; Silveira, I.C.A. & Miranda, L.B. 2006. Estrutura termohalina e circulação na região entre Cabo São Tomé (RJ) e Chuí (RS). In: C.L.D.B. Rossi-Wongtschowski & L.P. Madureira (eds.) *O Ambiente Oceanográfico da Plataforma Continental e do Talude na Região Sudeste-Sul do Brasil*, EDUSP, p. 11-120.
- Cate, A.S. & Evans, I. 1994. Taphonomic significance of the biomechanical fragmentation of live molluscan shell material by a bottom-feeding fish (*Pogonias cromis*) in Texas coastal bays. *Palaios*, **9**:254-274. doi:10.2307/3515201
- Catuneanu, O. 2006. *Principles of Sequence Stratigraphy*. Oxford, Elsevier, 375 p.
- Cherns, L.; Wheeley, J.R. & Wright, V.P. 2008. Taphonomic windows and molluscan preservation. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **270**:220-229. doi:10.1016/j.palaeo.2008.07.012
- Ciais, P.; Petit, J.R.; Jouzel, J.; Lorius, C.; Barkov, N.I.; Lipenkov, V. & Nicolaëv, V. 1992. Evidence for an early Holocene climatic optimum in the Antarctic deep ice-core record. *Climate Dynamics*, **6**:169-177.
- Clavijo, C.; Scarabino, F.; Rojas, A. & Martínez, S. 2005. Lista sistemática de los moluscos marinos y estuarinos del Cuaternario de Uruguay. *Comunicaciones de la Sociedad Malacológica del Uruguay*, **9**:381-411.
- Closs, D.L. 1970. Estratigrafia da Baía de Pelotas, Rio Grande do Sul. *Iheringia, Série Geologia*, **3**:3-75.

- Closs, D.L. & Forti, I.R.S. 1971. Quaternary mollusks from the Santa Vitória do Palmar County. *Iheringia, Série Geologia*, **4**:19-58.
- Coimbra, J.C.; Carreño, A.L. & Zeffass, G.S. 2009. Biostratigraphy and paleoceanographical significance of the Neogene planktonic foraminifera from the Pelotas Basin, southernmost Brazil. *Revue de Micropaléontologie*, **52**:1-14.
- Cummins, H.; Powell, E.N.; Stanton Jr., R.J. & Staff, G. 1986. The size-frequency distribution in paleoecology: effects of taphonomic processes during formation of molluscan death assemblages in Texas bays. *Paleontology*, **29**:495-518.
- Davies, D.J.; Powell, E.N. & Stanton Jr., R.J. 1989a. Taphonomic signature as a function of environmental process: shells and shell beds in a hurricane-influenced inlet on the Texas coast. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **72**:317-356. doi:10.1016/0031-0182(89)90150-8
- Davies, D.J.; Powell, E.N. & Stanton Jr., R.J. 1989b. Relative rates of shell dissolution and net sediment accumulation - a commentary: can shell beds form by the gradual accumulation of biogenic debris on the sea floor? *Lethaia*, **22**:207-212. doi:10.1111/j.1502-3931.1989.tb01683.x
- Delaney, P.J.V. 1965. *Fisiografia e Geologia de Superfície da Planície Costeira do Rio Grande do Sul*. Porto Alegre, Escola de Geologia da UFRGS, 105p. (Publicação Especial 6).
- Dillenburg, S.R. & Hesp, P.A. 2009. *Geology and Geomorphology of Holocene Coastal Barriers of Brazil*. Berlin, Springer-Verlag, 380 p. (Lecture Notes in Earth Sciences 107). doi:10.1007/978-3-540-44771-9
- Dillenburg, S.R.; Esteves, L.S. & Tomazelli, L.J. 2004. A critical evaluation of coastal erosion in Rio Grande do Sul, Southern Brazil. *Anais da Academia Brasileira de Ciências*, **76**:611-623.
- Domack, E.; Leventer, A.; Dunbar, R.; Taylor, F.; Brachfeld, S.; Sjunneskog, C. & ODP Leg 178 Scientific Party. 2001. Chronology of the Palmer Deep site, Antarctic Peninsula: a Holocene palaeoenvironmental reference for the circum-Antarctic. *The Holocene*, **11**:1-9. doi:10.1191/095968301673881493
- Driscoll, E.G. 1970. Selective bivalve shell destruction in marine environments; a field study. *Journal of Sedimentary Research*, **40**:898-905. doi:10.1306/74D720DB-2B21-11D7-8648000102C1865D
- Emiliani, C. 1972. Quaternary hypsithermals. *Quaternary Research*, **2**:270-273. doi:10.1016/0033-5894(72)90047-6
- Figueiredo, A.G. 1975. *Geologia dos depósitos calcários biodetríticos da Plataforma Continental do Rio Grande do Sul*. Programa de Pós-Graduação em Geociências, Universidade Federal do Rio Grande do Sul, M.Sc. Dissertation, 72p.
- Flessa, K.W. & Kowalewski, M. 1994. Shell survival and time-averaging in nearshore and shelf environment: estimates from the radiocarbon literature. *Lethaia*, **27**:153-165. doi:10.1111/j.1502-3931.1994.tb01570.x
- Forti Esteves, I.R. 1974. Bioestratigrafia e paleoecologia (Mollusca) do Quaternário da Planície Costeira do Rio Grande do Sul (Brasil). In: CONGRESSO BRASILEIRO DE GEOLOGIA, **28**, 1974. *Livro de Resumos*, Porto Alegre, p. 133-147.
- Frey, R.W.; Howard, J.D. & Pryor, W.A. 1978. *Ophiomorpha*: its morphologic, taxonomic and environmental significance. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **23**:199-229. doi:10.1016/0031-0182(78)90094-9
- Garcia, C.A.E. 1998. Oceanografia Física. In: U. Seeliger; C. Odebrecht & J.P. Castello (eds.) *Os Ecossistemas Costeiro e Marinho do Extremo Sul do Brasil*, Ecoscientia, p. 104-106.
- Gianuca, N.M. 1998. Invertebrados bentônicos da praia. In: U. Seeliger; C. Odebrecht & J.P. Castello (eds.) *Os Ecossistemas Costeiro e Marinho do Extremo Sul do Brasil*, Ecoscientia, p. 127-130.
- Godolphim, M.A.; Artusi, L.; Dehnhardt, B.A.; Villwock, J.A. & Esteves, I.R.F. 1989. Novas evidências da transgressão holocênica na porção média da Planície Costeira do Rio Grande do Sul. *Acta Geológica Leopoldensia*, **29**:23-36.
- Gordillo, S. 1998. Distribución biogeográfica de los moluscos holocenos del litoral argentino-uruguayo. *Ameghiniana*, **35**:163-180.
- Hodell, D.A.; Kanfoush, S.L.; Shemesh, A.; Crosta, X. & Charles, C.D. 2001. Abrupt cooling of Antarctic surface waters and sea ice expansion in the South Atlantic sector of the southern ocean at 5,000 cal yr BP. *Quaternary Research*, **56**:191-198. doi:10.1006/qres.2001.2252
- Holz, M. 2012. *Estratigrafia de sequências: histórico, princípios e aplicações*. Rio de Janeiro, Interciência, 258p.
- Imbrie, J.; Hays, J.; Martinson, D.; McIntyre, A.; Mix, A.; Morley, J.; Pisias, N.; Pell, W. & Shackleton, N. 1984. The Orbital Theory of Pleistocene climate: support from a revised chronology of the Marine ¹⁸O record. In: A. Berger; J. Imbrie; H. Hays; G. Kukla & B. Saltzman (eds.) *Milankovitch and Climate, Part I*, D. Reidel Publishing, p. 269-305.
- Kelley, P.H. & Hansen, T.A. 2003. The Fossil Record of Drilling Predation on Bivalves and Gastropods. In: P.H. Kelley; M. Kowalewski & T.A. Hansen, (eds.) *Predator-Prey Interactions in the Fossil Record*, Springer, p. 113-139. doi:10.1007/978-1-4615-0161-9_6
- Kidwell, S.M. 1989. Stratigraphic condensation of marine transgressive records: origin of major Shell deposits in the Miocene of Maryland. *The Journal of Geology*, **97**:1-24. doi:10.1086/629278
- Kidwell, S.M. 1991. The stratigraphy of shell concentrations. In: P.A. Allison & D.E.G. Briggs (eds.) *Taphonomy: releasing the data locked in the fossil record*, Plenum Press, p. 211-289.
- Kidwell, S.M. & Bosence, D.W. 1991. Taphonomy and time-averaging of marine shelly faunas. In: P.A. Allison & D.E.G. Briggs (eds.) *Taphonomy: releasing the data locked in the fossil record*, Plenum Press, p. 115-209.
- Kidwell, S.M.; Fürsich, F.T. & Aigner, T. 1986. Conceptual framework for the analysis and classification of fossil concentrations. *Palaios*, **1**:228-238. doi:10.2307/3514687
- Kidwell, S.M. & Holland, S.M. 1991. Field description of coarse bioclastic fabrics. *Palaios*, **6**:426-434. doi:10.2307/3514967
- Klein, J.A.; Borzone, C.A. & Pezzuto, P.R. 2001. A macro e megafauna bêmica associada aos bancos da vieira *Euvola ziczac* (Mollusca: Bivalvia) no litoral sul do Brasil. *Atlântica*, **23**:17-26.
- Krause; R.A.; Barbour, S.L.; Kowalewski, M.; Kaufman, D.S.; Romanek, C.S.; Simões, M.G. & Wehmiller, J.F. 2010. Quantitative comparisons and models of time-averaging in bivalve and brachiopod shell accumulations. *Paleobiology*, **36**:428-452. doi:10.1666/08072.1
- Lamy, F.; Rühlemann, C.; Hebbeln, D. & Wefer, G. 2002. High- and low-latitude climate control on the position of the southern Peru-Chile Current during the Holocene. *Paleoceanography*, **17**:1-10. doi:10.1029/2001pa000727
- Lazo, D.G. 2004. Bivalve taphonomy: testing the effect of live habits on the shell condition of the little clam *Protothaca (Protothaca) stamina* (Mollusca: Bivalvia). *Palaios*, **19**:451-459. doi:10.1669/0883-1351(2004)019<0451:BTTEO>2.0.CO;2
- Lima, L.G.; Dillenburg, S.R.; Medeanic, S.; Barboza, E.G.; Rosa, M.L.C.C.; Tomazelli, L.J.; Dehnhardt, B.A. & 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. doi:10.1016/j.jsames.2012.07.002
- Lopes, R.P. 2011a. Fossil sand dollars (Echinoidea: Clypeasteroidea) from the southern Brazilian coast. *Revista Brasileira de Paleontologia*, **14**:201-214. doi:10.4072/rbp.2011.3.01
- Lopes, R.P. 2011b. Ichnology of fossil oysters (Bivalvia, Ostreidae) from the southern Brazilian coast. *Gaea*, **7**:94-103. doi:10.4013/gaea.2011.72.02
- Lopes, R.P. 2012. Bioerosion and Bioincrustation in Body Fossils from the Coastal Plain of Rio Grande do Sul State, Southern Brazil. In: R.G. Netto, N. Carmona & F. Tognoli (eds.) *Ichnology of Latin America*, Porto Alegre, Sociedade Brasileira de Paleontologia, p. 179-194 (Monografias 2).
- Lopes, R.P. & Bonetti, C. 2012. Foraminíferos em sedimentos pleistocênicos no sul da Planície Costeira do Rio Grande do Sul. In: PALEO-RS 2012. *Livro de Resumos*, São João do Polêsine, p. 26.
- Lopes, R.P. & Buchmann, F.S.C. 2008. Comparação tafonômica entre duas concentrações fossilíferas (*shell beds*) da Planície Costeira do Rio Grande do Sul, Brasil. *Gaea*, **4**:65-77.
- Lopes, R.P.; Buchmann, F.S.C.; Caron, F. & Itusarry, M.E.G.S. 2001. Tafonomia dos fósseis de vertebrados (megafauna extinta) encontrados nas barrancas do Arroio Chuí e linha de costa, Rio Grande do Sul, Brasil. *Pesquisas em Geociências*, **28**:67-73.
- Lopes, R.P.; Buchmann, F.S.C.; Caron, F. & Itusarry, M.E.G. 2009. Barrancas fossilíferas do arroio Chuí, RS - importante megafauna pleistocênica no extremo sul do Brasil. In: M. Winge; C. Schobbenhaus; M. Berbert-Born; E.T. Queiroz; D.A. Campos; C.R.G. Souza, & A.C.S. Fernandes (eds.) *Sítios Geológicos e Paleontológicos do Brasil*, Serviço Geológico do Brasil/Comissão Brasileira de Sítios Geológicos e Paleobiológicos, p. 355-362.
- Lopes, R.P.; Dillenburg, S.R. & Schultz, C.L. 2011. Geological and environmental evolution of Lagoon System III in the southernmost coastal plain of Rio Grande do Sul state. In: CONGRESSO DA ASSOCIAÇÃO BRASILEIRA DE ESTUDOS DO QUATERNÁRIO, 13, 2011. *Resumos Expandidos*, Armação de Búzios, p. 6.
- Lopes, R.P.; Oliveira, L.C.; Figueiredo, A.M.G.; Kinoshita, A.; Baffa, O. & Buchmann, F.S.C. 2010. ESR dating of Pleistocene mammal teeth and its implications for the biostratigraphy and geological evolution of the coastal plain, Rio Grande do Sul, southern Brazil. *Quaternary International*, **212**:213-222. doi:10.1016/j.quaint.2009.09.018
- Lopes, R.P. & Simone, L.R.L. 2012. New fossil records of Pleistocene marine mollusks in southern Brazil. *Revista Brasileira de Paleontologia*, **15**:49-56. doi:10.4072/rbp.2012.1.04
- Lopes, R.P.; Kinoshita, A.; Baffa, O.; Figueiredo, A.M.G.; Dillenburg, S.R.; Schultz, C.L.; Pereira, J.C. In press. ESR dating of Pleistocene mammals and marine shells from the coastal plain of Rio Grande do Sul state, southern Brazil. *Quaternary International*.
- Martin, L.; Dominguez, J.M.L. & Bittencourt, A.C.S.P. 2003. Fluctuating sea levels in eastern and southeastern Brazil: evidence from multiple fossil and geometric indicators. *Journal of Coastal Research*, **19**:101-124.
- Martínez, S. & Del Río, C. 2002. Las provincias malacológicas miocenas y recientes del Atlántico Sudoccidental. *Anales de Biología*, **24**:121-130.
- Martínez, S. & Del Río, C. 2005. Las ingresiones marinas del Neógeno en el sur de Entre Ríos (Argentina) y litoral oeste de Uruguay y su contenido malacológico. *INSUGEO - Miscelánea*, **14**:13-26.
- Martínez, S.; Rojas, A.; Ubilla, M. Verde, M.; Perea, D. & Piñero, G. 2006. Molluscan assemblages from the marine Holocene of Uruguay: composition, geochronology and paleoenvironmental signals. *Ameghiniana*, **43**:385-397.
- Matano, R.P.; Schlax, M.G. & Chelton, D.B. 1993. Seasonal variability in the Southwestern Atlantic. *Journal of Geophysical Research*, **98**:18027-18035. doi: 10.1029/93jc01602
- Nara, M. 2002. Crowded *Rosselia socialis* in Pleistocene inner shelf deposits: benthic paleoecology during rapid sea-level rise. *Palaios*, **17**:268-276. doi: 10.1669/0883-1351(2002)017<0268:CRSIPI>2.0.CO;2
- Olszewski, T.D. 2004. Modeling the influence of taphonomic destruction, reworking, and burial on time-averaging in fossil accumulations. *Palaios*, **19**:39-50. doi: 10.1669/0883-1351(2004)019<0039:MTIOTD>2.0.CO;2
- Pimpão, D.M. 2004. *Moluscos bivalves da plataforma externa e talude superior ao largo de Rio Grande, Rio Grande do Sul, Brasil*. Programa de Pós-Graduação em Biologia Animal, Universidade Federal do Rio Grande do Sul, M.Sc. Dissertation, 190p.
- Pollard, J.E.; Goldring, R. & Buck, S.G. 1993. Ichnofabrics containing *Ophiomorpha*: significance in shallow-water facies interpretation. *Journal of the Geological Society*, **150**:149-164.
- Rabassa, J.O. 1987. The Holocene of Argentina: a review. *Quaternary of the South America and Antarctic Peninsula*, **5**:269-290.
- Rios, E.C. 1994. *Seashells of Brazil*. Rio Grande, Editora da Fundação Universidade Federal do Rio Grande, 368 p.
- Rios, E.C. 2009. *Compendium of Brazilian Sea Shells*. Rio Grande, Evangraf, 668 p.
- Rodrigues, A.M.L.; Borges-Azevedo, C.M. & Henry-Silva, G.G. 2010. Aspectos da biologia e ecologia do molusco bivalve *Anomalocardia brasiliana* (Gmelin, 1791) (Bivalvia, Veneridae). *Revista Brasileira de Biociências*, **8**:377-383.
- Rodrigues, S.C.; Simões, M.G.; Kowalewski, M.; Petti, M.A.V.; Nonato, E.F.; Martínez, S. & Del Río, C.J. 2008. Biotic interaction between spionid polychaetes and bouchardiid brachiopods: paleoecological, taphonomic and evolutionary implications. *Acta Palaeontologica Polonica*, **53**:657-668. doi:10.4202/app.2008.0410
- Rosa, M.L.C.C. 2012. *Geomorfologia, estratigrafia de seqüências e potencial de preservação dos sistemas Laguna Barreira do Quaternário Costeiro do Rio Grande do Sul*. Programa de Pós-Graduação em Geociências, Universidade Federal do Rio Grande do Sul, Ph.D. Thesis, 232 p.
- Scarabino, F. 2003. Lista sistemática de los bivalvia marinos y estuarinos vivientes de Uruguay. *Comunicaciones de la Sociedad Malacológica del Uruguay*, **8**:227-258.
- Schmitz, P.I.; Girelli, M. & Rosa, A.O. 1997. Pesquisas arqueológicas em Santa Vitória do Palmar, RS. In: P.I. Schmitz (ed.) *Arqueologia do Rio Grande do Sul*, Instituto Anchieta de Pesquisas/UNISINOS, 95 p. (Documentos 7).
- Simões, M.G.; Rodrigues, S.C. & Kowalewski, M. 2007. Comparative analysis of drilling frequencies in recent brachiopod-mollusk associations from the southern Brazilian shelf. *Palaios*, **22**:143-154. doi: 10.2110/palo.2006.p06-040r
- Simões, M.G.; Chiesi, C.M.; Kotzian, C.B. & Pätzold, J. 2011. Late Pleistocene (Ionian-Tarantian) brachiopods from the Rio Grande do Sul shelf, as recorders of cold climate conditions near the Brazil-Malvinas confluence zone. In: CONGRESSO DA ASSOCIAÇÃO BRASILEIRA DE ESTUDOS DO QUATERNÁRIO, 13, 2011. *Resumos Expandidos*, Armação de Búzios, p. 5.

- Soliani, E. 1973. *Geologia da Região de Santa Vitória do Palmar, RS, e a Posição Estratigráfica dos Fósseis de Mamíferos Pleistocênicos*. Programa de Pós-Graduação em Geociências, Universidade Federal do Rio Grande do Sul, M.Sc. Dissertation, 88p.
- Sprechmann, P. 1978. The paleoecology and paleogeography of the Uruguayan coastal area during the Neogene and Quaternary. *Zitteliana*, **4**:3-72.
- Tomazelli, L. J. & Dillenburger, S. R. 2007. Sedimentary facies and stratigraphy of a last interglacial coastal barrier in south Brazil. *Marine Geology*, **244**:33-45. doi: 10.1016/j.margeo.2007.06.002
- Tomazelli, L.J.; Dillenburger, S.R. & Villwock, J.A., 2000. Late Quaternary geological history of Rio Grande do Sul coastal plain, southern Brazil. *Revista Brasileira de Geociências*, **30**:474-476.
- Tucker, M.E. 1992. The Diagenesis of Fossils. In: S.K. Donovan (ed.) *The Processes of Fossilization*, CBS Publishers, p. 84-104.
- Veitenheimer-Mendes, I.L. & Lopes-Pitoni, V.L. 1995. Moluscos aquáticos atuais de ecossistemas costeiros em Imbituba, Imaruí e Laguna, Santa Catarina, Brasil: parâmetro de caracterização para paleoambientes. *Revista Brasileira de Zoologia*, **12**:429-434.
- Villwock, J. A. & Tomazelli, L. J. 1995. Geologia Costeira do Rio Grande do Sul. *Notas Técnicas*, **8**:1-45.
- Villwock, J.A.; Tomazelli, L.J.; Loss, E.L.; Dehnhardt, E.A.; Horn, N.O.; Bachi, F.A. & Dehnhardt, B.A. 1986. Geology of the Rio Grande do Sul Coastal Province. *Quaternary of the South America and Antarctic Peninsula*, **4**:79-97.
- Wainer, I.; Gent, P. & Goni, G. 2000. Annual cycle of the Brazil-Malvinas confluence region in the National Center for Atmospheric Research Climate System Model. *Journal of Geophysical Research*, **105**:26167-26177. doi: 10.1029/1999jc000134
- Walker, S.E. & Goldstein, S.T. 1999. Taphonomic tiering: experimental field taphonomy of molluscs and foraminifera above and below the sediment-water interface. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **149**:227-244. doi: 10.1016/S0031-0182(98)00203-x
- Weimer, R.J. & Hoyt, J.H. 1964. Burrows of *Callianassa major* Say, geologic indicators of littoral and shallow neritic environments. *Journal of Paleontology*, **38**:761-767.
- Wigger, F. & Veitenheimer-Mendes, I.L. 2003. Gastrópodes atuais da plataforma continental externa e talude continental ao largo de Rio Grande, Rio Grande do Sul, Brasil. *Revista Brasileira de Paleontologia*, **6**:55-60.
- Zuschin, M.; Stachowitsch, M. & Stanton Jr., R.J. 2003. Patterns and processes of shell fragmentation in modern and ancient marine environments. *Earth-Science Reviews*, **63**: 33-82. doi: 10.1016/S0012-8252(03)00014-x

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