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ARTICLE

High-Frequency Sequences in the Quaternary of Pelotas Basin (coastal plain): a record of degradational stacking as a function of longer-term base-level fall

Sequências deposicionais de alta frequência no Quaternário da Bacia de Pelotas (planície costeira): registro de empilhamento degradacional em função de queda do nível de base em longo período

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ABSTRACT: The aim of this work was to analyze the sedimentary record of the coastal plain of Pelotas Basin, placing it in the context of temporal and spatial scales, and proposing a stratigraphic hierarchical framework. The coastal plain, located in southern Brazil and in northern Uruguay, is mainly formed by four Quaternary barrier-lagoon systems. Three of these systems were studied through the integration of surface and subsurface data (geomorphological and topographical mapping, outcrops description, geoprocessing, dating and Ground Penetrating Radar — GPR — records) and interpreted as the preserved, onshore portion of depositional sequences mainly controlled by glacioeustatic cycles of about 100 kyr. The stacking pattern comprising these sequences is progradational with seaward downsteping (highest sea-levels measured: 9.5, 8 and 3 m, respectively), comprehending a degradational sequence set, or the regressive/falling stage systems tract of a higher order depositional sequence identified in seismic sections, with about 0.5 Ma. The youngest sequence has diachronous systems tracts — while some sectors have already transitioned from the transgressive to the highstand/falling stage systems tract, others are still under a transgressive context. It indicates that, in this time and scale, the sea level is not the main control of coastal evolution, and autogenic factors are fundamental in the run of geological record.

KEYWORDS: Barrier-Lagoon; Glacioeustasy; Diachronism of Systems Tracts; Ground Penetrating Radar; Rio Grande do Sul coastal evolution.

RESUMO: *O objetivo deste trabalho foi analisar o registro sedimentar da Bacia de Pelotas, contextualizando-o em escalas temporais e espaciais e propondo um arcabouço estratigráfico hierarquizado. A planície costeira, localizada no Sul do Brasil e Norte do Uruguai, é principalmente formada por quatro sistemas deposicionais do tipo laguna-barreira. Os três sistemas mais jovens foram estudados por meio da integração de dados de superfície e de subsuperfície (mapeamento geomorfológico e topográfico, descrição de afloramentos, geoprocessamento, datações e registros de georradar) e interpretados como a porção costeira, preservada, de sequências deposicionais controladas principalmente por ciclos glacioeustáticos da ordem de 100 ka. O padrão de empilhamento das três sequências, em conjunto, é progradacional com altitudes mais baixas no sentido do oceano (máximos níveis do mar medidos: 9,5, 8 e 3 m, respectivamente), correspondendo a um conjunto de sequências degradacionais, ou ao trato de sistemas regressivos/nível em queda de uma sequência de maior ordem, identificada em seções sísmicas, com aproximadamente 0,5 Ma. A sequência mais jovem possui tratos de sistemas diácronos — enquanto alguns setores já possuem o registro do trato de sistemas de nível alto/em queda, outros ainda se encontram em contexto transgressivo. Isso indica que nesse tempo e escala o nível do mar não representa o principal controle da evolução costeira, e fatores autogênicos são fundamentais no desenvolvimento do registro geológico.*

PALAVRAS-CHAVE: *Laguna-Barreira; glacioeustasia; diacronismo dos tratos de sistemas; georradar; evolução costeira do Rio Grande do Sul.*

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INTRODUCTION

Sequence stratigraphy is a method used to build stratigraphic frameworks and examine the geological record of sedimentary basins through the definition and mapping of coeval, genetically related packages of rock, emerging from the works of Blackwelder (1909), Grabau (1913), Sloss *et al.* (1949), Vail *et al.* (1977), Van Wagoner *et al.* (1988), among others. Sequence stratigraphy has evolved from seismic stratigraphy (Payton 1977) and established itself as a revolutionary paradigm for the understanding of stratigraphic record (Wilgus *et al.* 1988), mostly due to the demand and technological development of the oil industry and pioneer work of Sloss *et al.* (1949). Sequence stratigraphy can be used in the analysis of the record in different hierarchical ranks, from the great stages of sedimentary basin filling to the evolution of depositional environments (Posamentier *et al.* 1992; Schlager 2009; Catuneanu 2002; Neal & Abreu 2009).

The Pelotas Basin coastal plain, located in Rio Grande do Sul and Santa Catarina states, in southern Brazil and in northern Uruguay, has the most complete record of Quaternary events along the Brazilian coast (Fig. 1). This plain, with 770 km of extension and 15 to 100 km wide, is formed by alluvial fan systems and by the lateral juxtaposition of four barrier-lagoon depositional systems, firstly defined for Rio Grande do Sul by Villwock *et al.* (1986). Such systems have evolved during the Upper Quaternary, due to the combination of allochthonous and autochthonous processes, such as the eustasy (Delaney 1965; Villwock & Tomazelli 1995; Tomazelli & Villwock 1996), tectonics (Rosa *et al.* 2009), climate (Martinho *et al.* 2008, 2010; Lopes *et al.* 2013), coastal dynamics, and sedimentary budget (Toldo Jr. *et al.* 1999, 2004, 2005; Dillenburg *et al.* 2000, 2009; Gruber *et al.* 2003, 2006; Dillenburg & Barboza 2014). Thus, the understanding of the geological development of the coastal plain can be improved through the application of sequence stratigraphy.

Therefore, this work aimed at examining and organizing the fragmented sedimentary record of the coastal plain of Pelotas Basin, discussing scale issues, placing it in the context of the particular temporal and spatial scales, and proposing a stratigraphic framework to connect scales. Moreover, through the stratigraphic analysis we intended to show the diachronous nature of stratigraphic surfaces and systems tracts.

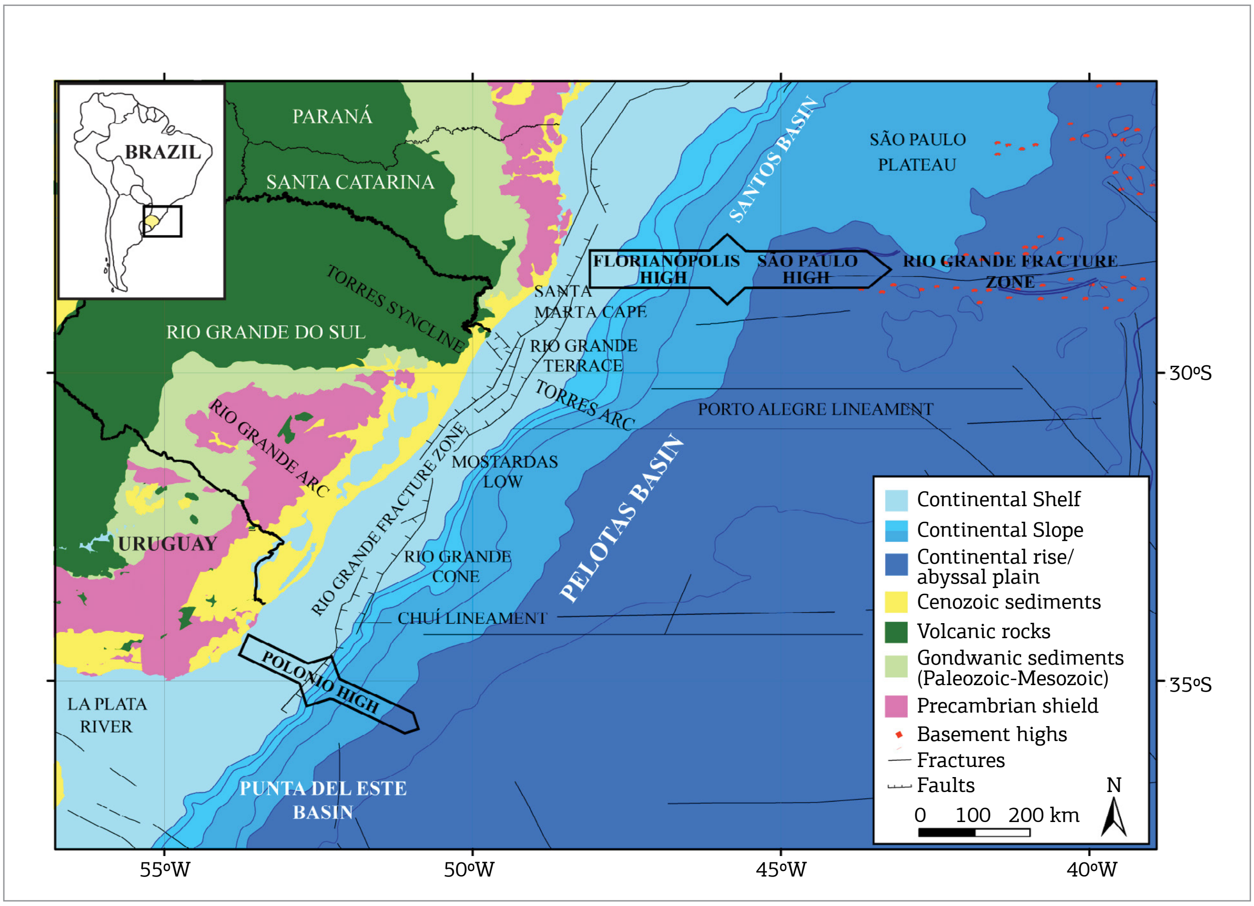


Figure 1. Location map of the Pelotas Basin depicting the main structural features (based on the works of Miranda 1970; Urien & Martins 1978; Alves 1977, 1981; Gamboa & Rabinowitz 1981; Dias *et al.* 1994; Fontana 1996; CPRM 2008).

GEOLOGICAL SETTING

In order to contextualize the coastal plain record and link large scale — regional and long-term trends — to short scale — high-frequency events affected by climate and local coastal processes — we started positioning the geological record through a hierarchical framework for the entire basin fill, from Cretaceous to Quaternary. This framework resulted from the analysis of the main studies related to the evolution of Pelotas Basin detailed ahead.

Pelotas Basin is located in the extreme south of the Brazilian Continental Margin (Fig. 1), and has an area of approximately 210,000 km^2. It borders Santos Basin to the north, through Florianópolis High (Gamboa & Rabinowitz 1981), and Punta Del Este Basin to the south, through Polonio High, in Uruguay (Urien & Martins 1978). The Pelotas Basin was formed due to tectonic movements associated with the opening of the South Atlantic Ocean (Asmus & Porto 1972). The basement is composed of Uruguayan-Sul-Rio-Grandense Shield, Santa Catarina Shield and Paraná Basin strata. Main stages of the basin filling are summarized in Figure 2, based on the works of Fontana (1996), Abreu (1998), Bueno *et al*. (2007), Neal and Abreu (2009), and Abreu *et al*. (2010).

Low-Frequency Sedimentary Record: Pelotas Basin

According to Fontana (1996), the Pelotas Basin can be divided into three major phases (Fig. 2). These phases would include the formation of a Rift Megasequence, developed in the early stages of opening, followed by a Transgressive Megasequence that started in the Aptian, and a Regressive Megasequence, which evolved since the Paleocene. These three megasequences were subdivided into 17 depositional sequences, five belonging to the transgressive phase and 12 to the regressive phase.

According to Bueno *et al*. (2007), main phases of basin filling are the Pre-rift, Rift, Post-rift and Drift Supersequences (Fig. 2). The Pre-rift Supersequence is related to magmatic processes that occurred prior to the initial stages of rifting, with the generation of thick volcanic flows (Serra Geral Formation). Continental magmatism was emplaced between 138 and 127 Ma, with peak at around 132 Ma (Stewart *et al*. 1996; Bueno *et al*. 2007).

The Rift Supersequence can be divided into two stages, Rift I, with a predominance of basalts (Imbituba Formation), and Rift II, with siliciclastic deposition (Cassino Formation). This phase consists of filling antithetical half grabens approximately 125 Ma. The Post-rift Supersequence is composed of the volcanic suite of the Curumim Formation (basalts, andesites, traquiandesites), alternated with lacustrine sediments grading to marine limestones and sandstones. Volcanic units comprising the oceanic crust are represented by seaward dipping reflections identified on seismic sections (Fontana 1996; Abreu 1998). According to Bueno *et al*. (2007), the continuation of the opening process led to the Drift Supersequence, which was divided into three phases: initial (shallow shelf), intermediate (transgressive) and final (regressive wedge). Bueno *et al*. (2007) interpreted 12 depositional sequences in the transgressive phase and four in the regressive phase, forming a siliciclastic wedge (Cidreira and Imbé formations) from the Miocene to the Holocene.

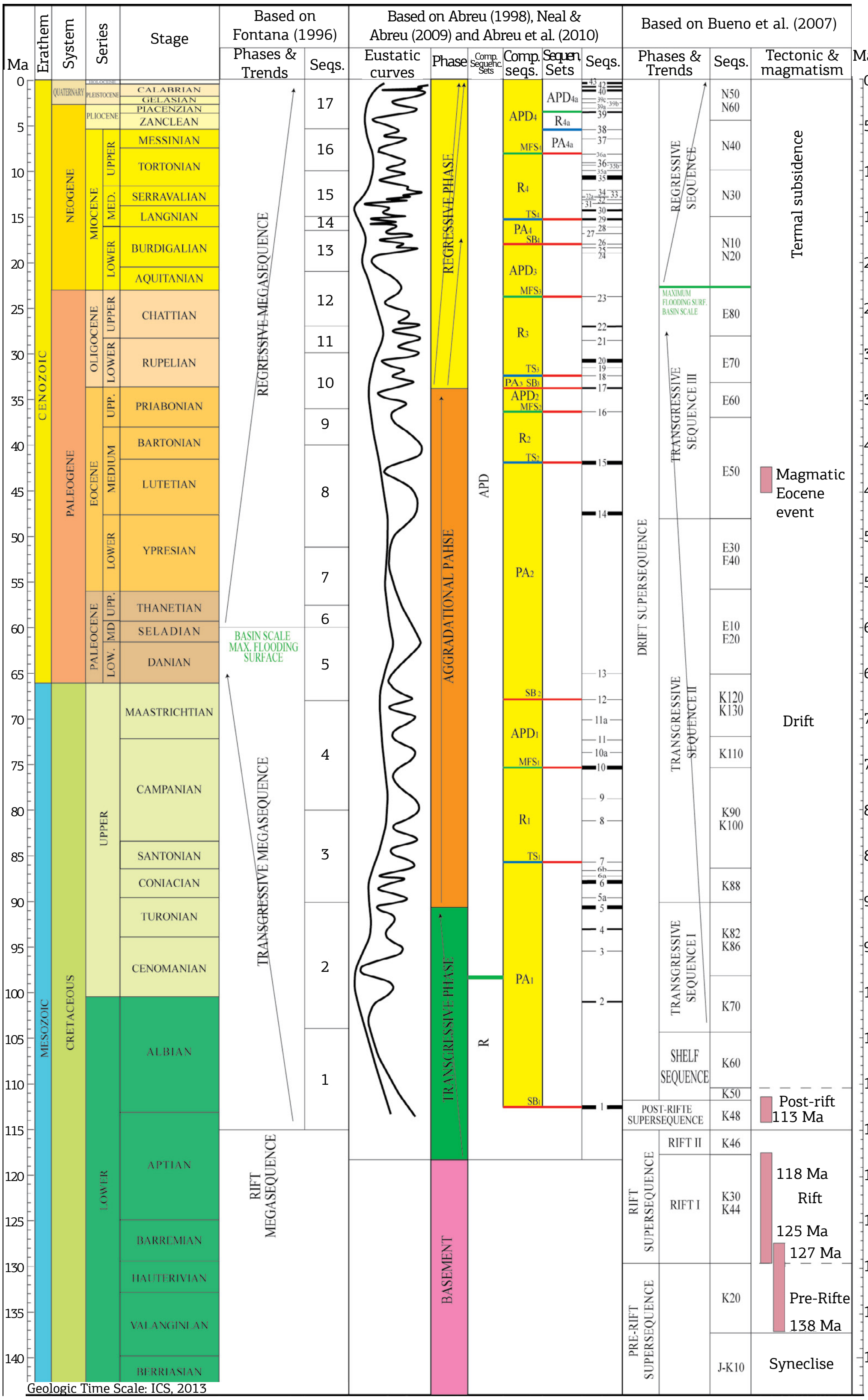
In Abreu (1998), 1,500 km of seismic sections were interpreted in Pelotas Basin and 3,000 km in the conjugate Walvis Basin in West Africa. These seismic lines have been integrated with core data in an attempt to correlate the existing record on both sides. In this work, Pelotas Basin has been divided into four units (Fig. 2): Basement, Transgressive phase (Aptian-Turonian), Aggradational phase (Coniacian-Eocene) and Regressive phase (Oligocene-Recent). The resulting stratigraphic framework is composed of 56 depositional sequences, in which 18 are Cretaceous and 38 are Cenozoic. The mean duration of sequences was determined based on biostratigraphy.

Low- and Medium-Frequency Sedimentary Record: Accommodation Succession

In Abreu *et al*. (2010), the stratigraphic framework established by Abreu (1998) for Pelotas Basin was used to apply the Accommodation Succession Method proposed by Neal and Abreu (2009). According to this method, sequence stratigraphic units and key-surfaces are defined regardless the time of duration, controlling mechanisms, or magnitude of the events. Thus, resulting sedimentary architecture identified to define sedimentary packages solely depends on two factors: on the rate of changes in accommodation and on sediment supply.

On the hierarchical framework of Abreu *et al*. (2010), four composite sequences were established for the Pelotas Basin (Fig. 3). Each composite sequence is formed by three sequence sets, defined according to their stacking pattern as Progradational-Aggradational (PA), Retrogradational (R) and Aggradational-Progradational-Degradational (APD). Thus, 12 sequence sets compose the basin filling (Fig. 3).

The last sequence set (APD4) comprises eight depositional sequences (Abreu 1998). Following the same reasoning of Neal and Abreu (2009) and Abreu *et al*. (2010), these sequences were grouped by Rosa (2012) according to the



R: retrogradational; PA: progradational-aggradational APD: aggradational-progradational-degradational; SB: sequence boundary; TS: transgressive surface; MFS: maximum flooding surface.

Figure 2. Diagram depicting the Pelotas Basin, with the summary of the stratigraphic framework (interpreted based on the works of Fontana 1996, Abreu 1998, Neal & Abreu 2009, Abreu *et al.* 2010, Bueno *et al.* 2007).

same patterns, resulting in $PA4_a$, $R4_a$ and $APD4_a$ (Figs. 2 and 3). Thus, the record that regards the upper portion of the basin has the APD pattern, and the last sequences jointly have a degradational architecture.

According to Abreu (1998), the last sequence boundary (no. 43) found in the seismic section is about 0.5 Ma. The age of this sequence corresponds to the existing Quaternary sedimentary record onshore, in which it is possible to interpret that this sequence is in fact composed of higher frequency sequences. As discussed ahead, these are partially represented in the onshore portion of the Pelotas Basin by the record of coastal plain depositional systems.

High-Frequency Sedimentary Record: Barrier-lagoon Systems

The coastal plain is a physiographic feature corresponding to the onshore portion of the Pelotas Basin (Villwock 1984). Younger deposits of the basin fill are exposed, consisting predominantly of alluvial fans near the basement, and of four barrier-lagoon depositional systems (Fig. 4). Pioneer studies of these depositional systems were developed in the coastal plain Rio Grande do Sul by Backeuser (1918), Lamengo (1940), Rambo (1942), Delaney (1965), Jost (1971) and Villwock (1972).

According to Villwock *et al.* (1986), these depositional systems were controlled by glacioeustasy with resulting transgressive-regressive cycles. Also, tectonics (Rosa *et al.* 2009), climate, coastal dynamic processes, and sedimentary budget (Toldo Jr. *et al.* 1999, 2004, 2005; Dillenburg *et al.* 2000, 2009; Gruber *et al.* 2003, 2006; Martinho *et al.* 2008, 2009, 2010; Lopes *et al.* 2013; Dillenburg & Barboza 2014) have controlled the creation and filling of accommodation. In this paper, we reviewed the age and sequence stratigraphic evolution of Systems II through IV. System I, which outcrops in the inner most position of the coastal plain and has almost 100 m of altitude, is not yet as well studied as the other systems and was not addressed in this paper.

The ages of the Barrier-lagoon Systems I through IV (400, 325, 125 and 7 ka to recent) have been first suggested by Villwock and Tomazelli (1995), based on oxygen isotope stages defined by Shackleton and Opdyke (1973) and Imbrie *et al.* (1984). These systems are interpreted to represent periods of high sea level, which Villwock and Tomazelli (1995) correlated to isotope stages 11, 9, 5 and 1, respectively. These correlations were confirmed for Systems III and IV by ^{14}C and thermoluminescence dating (Poupeau *et al.* 1988; Tomazelli *et al.* 1998; Buchmann & Tomazelli 2003; Dillenburg *et al.* 2006,ore recent work indicated that System II was developed in response to transgression related to the oxygen isotope stage 7, instead of stage 9, based on thermoluminescence ages in quartzose deposits and electron spin resonance ages in fossil teeth (Lopes *et al.* 2010, 2014). Then, according to these authors, System II was deposited around 200 ka, and Barrier I is likely to be correlated to stage 9 (Fig. 5).

The evolution of these systems was initially defined mainly based on geomorphological observations, as

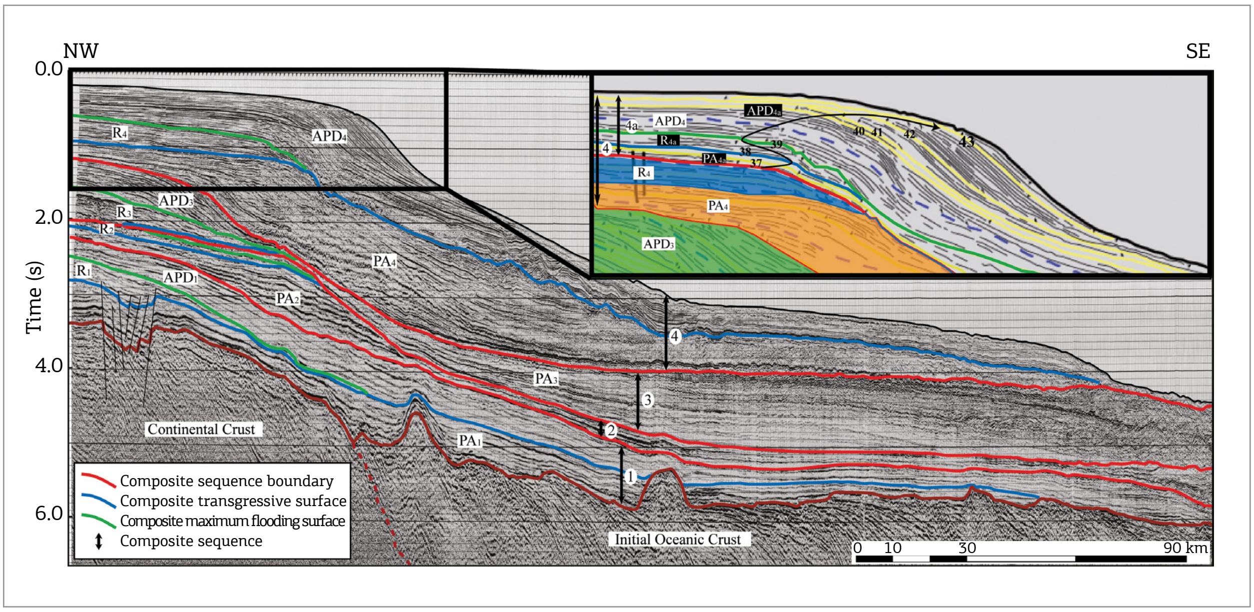


Figure 3. Seismic section of the Pelotas Basin with four composite sequences, each formed by three sequence sets (Abreu *et al.* 2010). Sequence stratigraphic hierarchy of the last sequence set (APD_4) of the Pelotas Basin shows the same patterns on a more detailed scale (interpreted based on the work of Abreu 1998, Neal & Abreu 2009, Abreu *et al.* 2010). The numbers indicated in the zoom in figure (yellow lines) correspond to the sequence boundaries interpreted by Abreu (1998).

well as on sedimentological data from outcrops and boreholes. More recently, high-resolution seismic and Ground Penetrating Radar (GPR) enabled a more continuous view of the depositional architecture and provided key-observations to further the understanding of the evolution of these systems (Weschenfelder *et al.* 2005, 2014; Barboza *et al.* 2009, 2011, 2013, 2014; Silva 2011, 2015; Silva *et al.* 2010, 2014; Fracalossi *et al.* 2010; Rosa 2012; Lima *et al.* 2013; Leal *et al.* 2016; Oliveira *et al.* 2016).

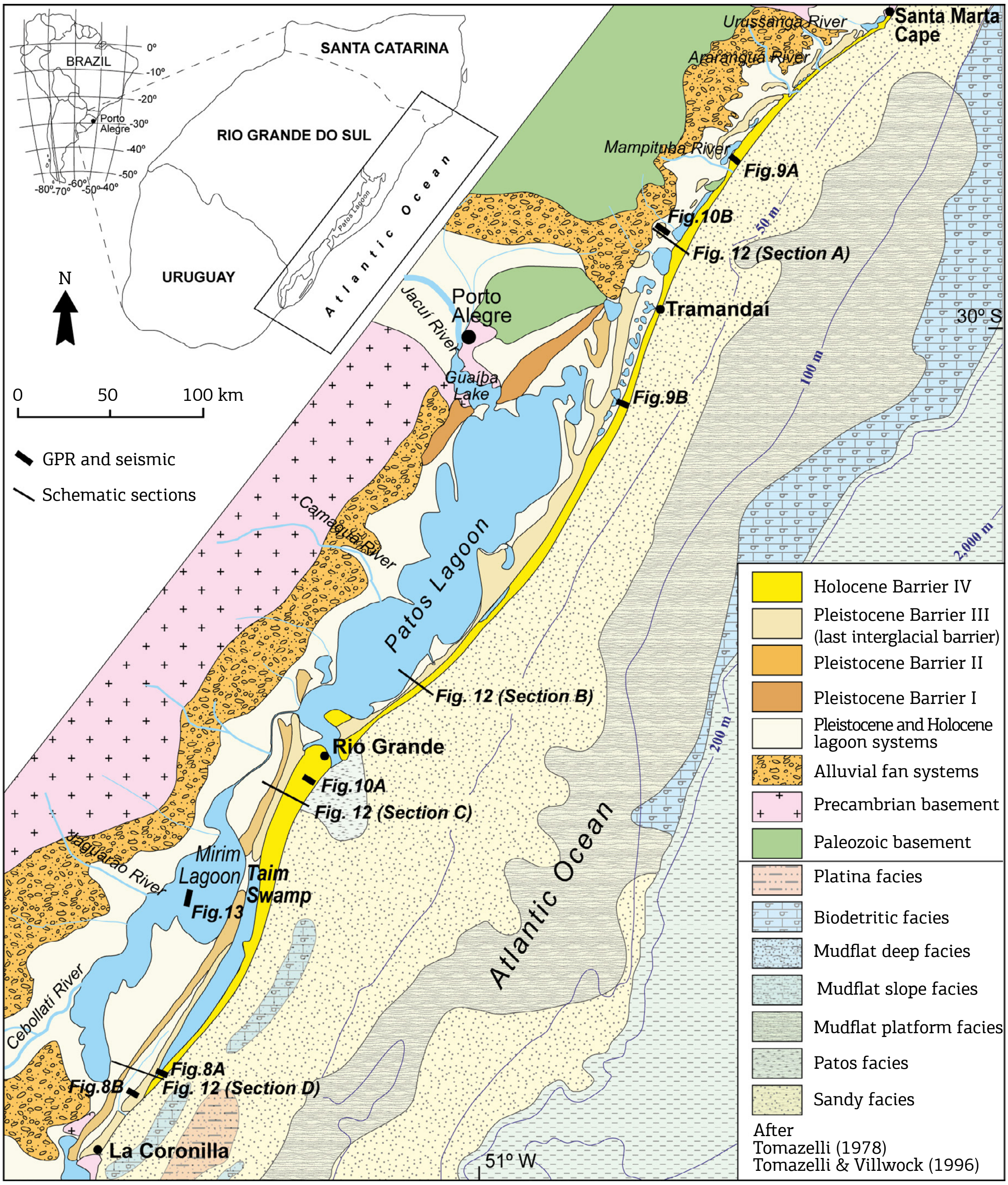
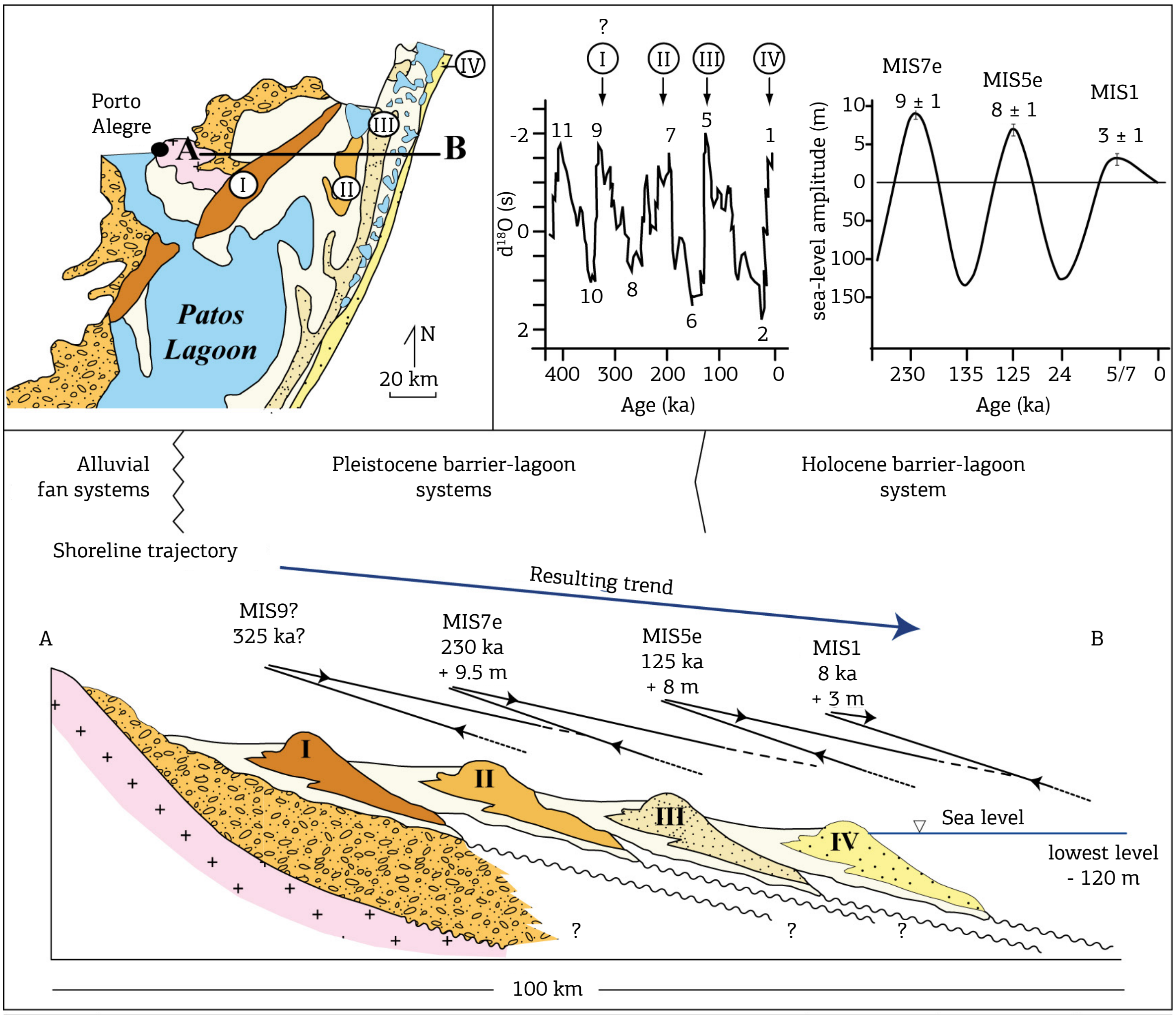


Figure 4. Simplified geological map of the coastal plain of Pelotas Basin, depicting the spatial distribution of the alluvial fans and barrier-lagoon systems in the emerged portion and facies of continental shelf and slope (modified after Dillenburg & Barboza, 2014). Location of Figures 8 to 10, 12, and 13 are outlined on the map.



System	Age dating and main references	Interpreted age	Minimum highest sea level	Isotope stage
IV	8.2 ka (Silva 2011), 7.8 to 2.9 ka (Dillenburg et al. 2013), 7.7 to 4.3 ka (Dillenburg et al. 2006, 2007, 2009), 6.6 ka (Travessas et al. 2005), 4.4 ka (Tomazelli et al. 1998), 3.2 ka (Dillenburg et al. 2004), 4.4 to 1.1 ka (Martinho et al. 2008)	8 to 0 ka	3 m	1
III	85 ka with a 30% precision (Poupeau et al. 1988), 109 ka (Buchmann and Tomazelli 2003)	125 ka	8 m	5e
II	226 ka (Lopes et al. 2010), 214 to 240 ka (Lopes et al. 2014)	230 ka	9.5 m	7e
I	–	325 ka	?	9

Figure 5. Schematic profile with the shoreline trajectory and ages of Systems I through IV, in which a general downward trend is observed (after Tomazelli & Villwock 2000). The onshore record of each system was associated by Villwock and Tomazelli (1995) to high sea levels, related to oxygen isotope stages from Imbrie *et al.* (1984). The altitudes of sea-level highs are defined through topographic measurements from this work, Tomazelli and Dillenburg (2007), and Lopes *et al.* (2014). The amplitudes of lowstands are from Rohling *et al.* (1998).

MATERIALS AND METHODS

The stratigraphic analysis performed is based on the integration of surface and subsurface data. Interpretations obtained from main studies summarizing the current understanding of the Pelotas Basin were integrated with new data, including geomorphological and topographical mapping, outcrops description, geoprocessing, and GPR records. Remote sensing and field data were organized and integrated into a Geographic Information System (GIS), using ArcGIS© platform. Optical images from Landsat 7 and 8, SPOT 5, QuickBird and RapidEye, as well as the topographic model of Shuttle Radar Topography Mission (SRTM) and ASTER Satellite, were the bases of the GIS project. The Global Navigation Satellite System (GNSS) was utilized to position field data, using the equipment Trimble® ProXRT (WGS84 datum), and the differential method.

Detailed topographic measurements were performed in order to establish the relative position of maximum sea level related to each system. Altitude measurements were based on paleo indicators, consisting of the combination of sedimentary structures generated on the beach face, the occurrence of *Ophiomorpha* ichnofossils, and the vertical facies succession. As discussed by many authors (Frey *et al.* 1978; Tomazelli *et al.* 1982; Pollard *et al.* 1993; Gibert *et al.* 2006), *Ophiomorpha nodosa* forms a complex 3D structure that can be extend in depth. Vertical shafts with thick-lined, narrower and not pelleted burrows correspond to the best indication of water-sediment interface (Gibert *et al.* 2006). As this feature was not easily identifiable at the measured outcrops, the combination of *Ophiomorpha* with sand deposits containing low-angle planar cross-stratification was related to foreshore. Considering the actual coast is microtidal, with semidiurnal mean range of only 0.5 m, the maximum altitudes of *Ophiomorpha* occurrence and the top of foreshore deposits were leveled, resulting in the minimum highest sea-level position for each evaluated system. The altitudes are considered the minimum in view of possible erosion.

The altitude of the paleo sea levels in each locality were referenced to the mean low tide determined by the tide gauge of Imbituba vertical datum, which is considered today's zero sea level along the Brazilian margin. Two methods were used to perform this reference: trigonometric leveling and satellite positioning. In System II, topography measurements were carried out in the southern region of the coastal plain, where it is well preserved (Fig. 6). Leveling was based on a reference given by the Brazilian Institute of Geography and Statistics (IBGE — RN1968U) at an altitude of 13.6217 m, and the stations were leveled with a Zeiss Elta 50 Total Station. Differential GNSS measurements were performed for the same type of features of Systems II and III. The model applied to convert ellipsoidal to geoidal altitude is MAPGEO2010, provided by the IBGE.

The GPR profiles were collected with a GSSI™ (Geophysical Survey Systems, Inc.) SIR-3000 with antennas of 200, 400 MHz (monostatic — GSSI™), 80 and 124 MHz (Subecho SE-70 and SE-150 bistatic — Radarteam Sweden AB). The GPR system was connected to the GNSS allowing the topographic positioning of the survey. The data were acquired in the common offset method, with 32 stacks for each trace to improve the signal-to-noise ratio, and varying the depth of investigation according to the penetration from about 300 to 1,000 ns of two-way travel time (TWTT). Considering the dielectric constant for sand (10), representing a velocity of 0.09 m/ns (Davis & Annan 1989), the depth of investigation ranged from about 15 to 45 m. This dielectric constant was validated using lithological data obtained from SPT drill holes (Dillenburg *et al.* 2011). Trace stacking, frequency and gain filters were applied during the collection to reduce noise and enable real time data viewing. The records were post-processed with the software packages Radan™, Reflex Win® and Prism 2®. Data processing comprised time-zero adjustment, background removal, band-pass frequency filters, gain equalization, time-to-depth conversion, and topographic corrections. A total of 220 km of GPR data were obtained in both dip and strike directions, along Systems II, III and IV.

The stratigraphic interpretation was based on the method of seismostratigraphy (Payton 1977). The method was based on termination (onlap, downlap, toplap and truncations), geometry and pattern of the reflections to interpret units and surfaces (Mitchum Jr. *et al.* 1977; Vail *et al.* 1977; Neal 2004; Catuneanu 2002; Catuneanu *et al.* 2009; Abreu *et al.* 2010; Barboza *et al.* 2009, 2011). GPR units are determined based on its internal configuration and geometry, allowing the definition of radarfacies and packages. The main radarfacies and its interpretation related to the depositional environment are well defined for the coastal plain of Pelotas Basin (Barboza *et al.* 2009, 2011).

The radiocarbon ages mentioned in this paper are related to the evolution of System IV, resulting from the works of Tomazelli *et al.* (1998, 2008), Dillenburg *et al.* (2004, 2006, 2007), Travessas *et al.* (2005), and Silva (2011). The samples were collected in standard penetrating test (SPT) cores and outcrops, and analyzed by Beta Analytic Inc., corresponding to six mollusk shell samples, one piece of wood, one sample of root and one sample of organic sediment (Table 1).

RESULTS

The applied methods resulted in the information that allowed characterizing the barrier-lagoon systems.

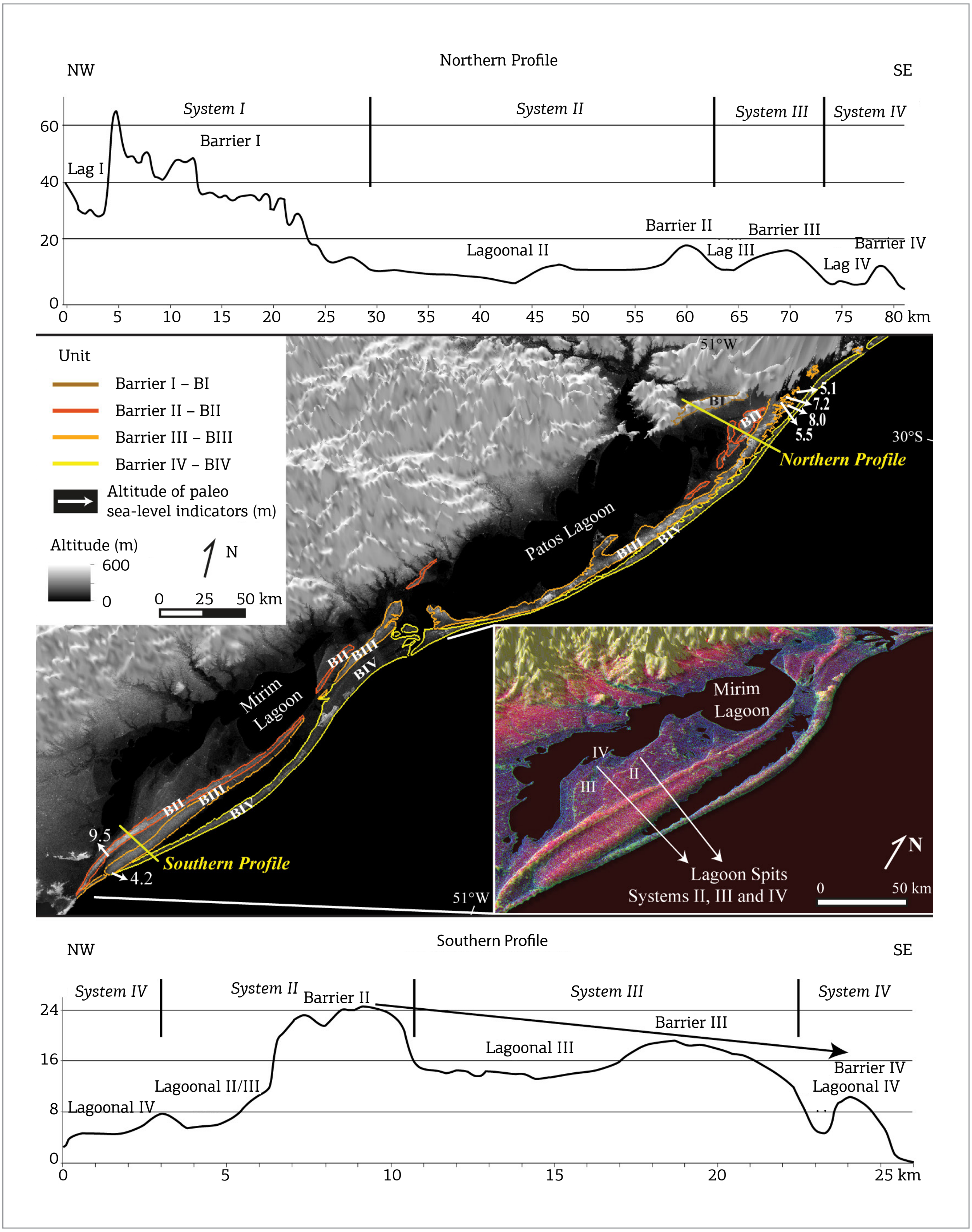


Figure 6. Digital surface model (version 4 of Shuttle Radar Topography Mission) with Barriers I to IV outlined. In detail the color composition of the southern region of the coastal plain, combining altitude, slope and aspect images (RGB). Barriers and lagoon spits morphologies of the southern coastal plain are highlighted in the zoom image. Topographic profiles were created based on the digital elevation model of Shuttle Radar Topography Mission (version 4). Steps in elevation differentiate Systems II (higher), III and IV (lower, still active). The altitude measurements of paleo sea-level indicators are outlined on the image.

The geomorphological analysis allows distinguishing the main units which compose the coastal plain: barriers and lagoons. Barriers can achieve altitudes of almost 30 m, with the exception of Barrier I, which is almost 100 m high in the north of the coastal plain in response of aeolian covering of the bedrock. Barriers have undulating surfaces related to aeolian activity in contrast with lagoonal features, which are plan or composed of distinguishing elongate curved spits (Fig. 6). As barriers are higher, dryer and mainly composed of sand, they tend to appear brighter in comparison with lagoonal deposits, and are easily to discriminate in remote sense images.

Topographic profiles from System I to IV show that together they are at progressively lower altitudes (Figs. 5 and 6). Outcrops measurements allowed defining the altitudes of paleo sea level along Barriers II and III, which have good exposures along the coastal plain. In the south of the coastal plain, the top of the beach and the base of the aeolian deposits of System II resulted in altitudes ranging from 8.1 to 9.5 m, with a maximum altitude of 8.3 m for *Ophiomorpha* occurrence (Fig. 7).

For System III, in the southern of the coastal plain, *Ophiomorpha* occurrence has a maximum altitude of 3.6 m and the top of foreshore is at 4.2 m. On the north coast, the measurements of these ichnofossils vary from 5 to 7 m of altitude, and the top of foreshore is at 7.2 m. In another outcrop on the north coast, also related to System III, Tomazelli and Dillenburg (2007) measured two different levels on the top of *Ophiomorpha* occurrence, one of 5.1 and other of 7.7 m, where the top of foreshore is at 8.0 m. As mentioned in the methods section, the combination of *Ophiomorpha* with sedimentary structures, and the vertical facies succession allowed for the interpretation of the closest position of paleo sea level. The measurements performed for this work

Table 1. Cited radiocarbon ages related to the evolution of System IV.

Sample	Laboratory Number	Material	$\delta^{13}C$ (‰)	^{14}C a BP	^{14}C cal yr BP 2σ calibration	After
T-14-06	Beta-56516	Organic sediment	–	5760 ± 120	6,843 – 6,303	Travessas *et al.* (2005)
PH-1	Beta-72865	Shell	-5.0	4330 ± 60	4,641 – 4,252	Tomazelli *et al.* (1998)
AM3B	Beta-119873	Shell	0.0	3390 ± 130	3,551 – 2,888	Dillenburg *et al.* (2004)
LS-2#16	Beta-285325	Wood	-28.4	7380 ± 40	8,320 – 8,070	Silva (2011)
FS-01-15	Beta-146847	Shell	0.0	6750 ± 250	7,685 – 6,685	Dillenburg *et al.* (2006)
FS-26-10	Beta-231433	Shell	-0.1	7220 ± 40	7,760 – 7,600	Dillenburg *et al.* (2007)
TA6A#15	Beta-247343	Shell	-0.8	7620 ± 40	8,160 – 7,990	Tomazelli *et al.* (2008)
TA7A#24	Beta-247347	Shell	+1.1	6270 ± 40	6,820 – 6,640	Tomazelli *et al.* (2008)
TA7A#27	Beta-247348	Roots	–	16290 ± 70	19,550 – 19,270	Tomazelli *et al.* (2008)

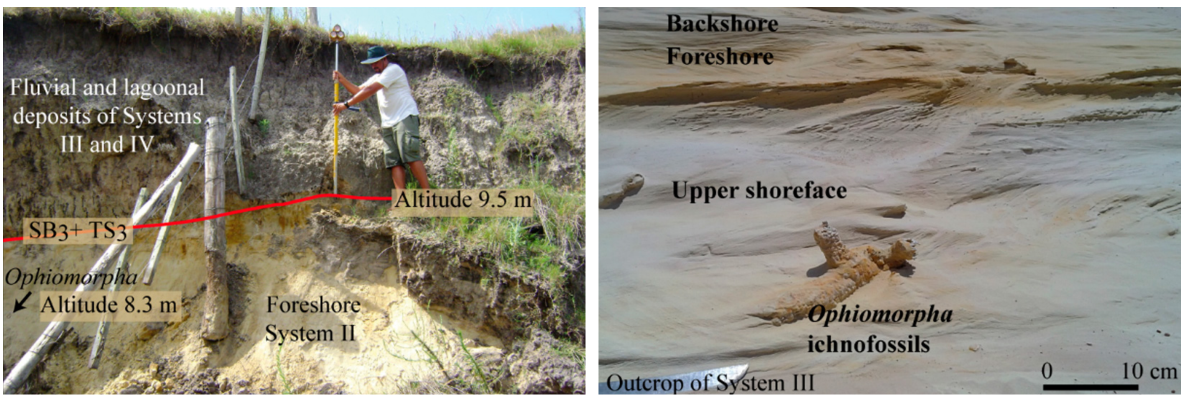


Figure 7. Example of sedimentary structures generated on the beachface (foreshore and upper shoreface) and the occurrence of *Ophiomorpha* ichnofossils. The combination of these indicators was measured to obtain minimum paleo "zero" sea-levels highs.

and those of Tomazelli and Dillenburg (2007) resulted in the minimum sea-level altitudes related to highstands of 9.5 ± 1 and 8 ± 1 m for Barrier II and III, respectively.

System IV indicators of paleo sea level are related to geomorphological features, as lagoonal terraces (Barboza & Tomazelli 2003), and the foreshore/shoreface position along strandplains, observed at outcrops, drill holes and GPR profiles (Barboza *et al.* 2009, 2011). As System IV has the most studied stratigraphic record of the coastal plain, and sea-level history during Holocene is quite well known we did not performed new measurements in this work. Barrier IV was studied in detail by Dillenburg *et al.* (2000, 2009), Dillenburg and Barboza (2014) and Hesp *et al.* (2005, 2007), which distinguished three main morphological barrier types: relict dunefields, active dunefields or a complex foredune ridges, and dunefields combination. The morphological types of Barrier IV are related to the stratigraphic stacking found in GPR data (Rosa 2012; Barboza & Rosa 2014).

GPR interpretation resulted in the definition of radarfacies correlated with depositional systems (Table 2 and Figs. 8 to 11). According to radarfacies relations, there are three main patterns defined: retrogradational, aggradational and progradational (Figs. 8 to 11). The retrogradational stacking is characterized by reflections dipping landwards (Barboza *et al.* 2011; Rosa 2012; Lima *et al.* 2013; Silva 2011, 2015; Dillenburg & Barboza 2014). Radarfacies are related to lagoonal deposits covered by aeolian, backshore, foreshore and shoreface deposits (Figs. 8 and 9). Usually, retrogradational pattern is associated with barrier morphology of dunefields. In some GPR sections, it is possible to recognize the maximum shoreline transgression (Barboza *et al.* 2011) where backshore and foreshore reflections reach its landward most position (Fig. 9).

Seaward, in some sectors of the coastal plain, progradational stacking is observed and characterized by continuous sets of beach and marine deposits (Figs. 9 and 10). In the GPR sections, progradational staking is composed by radarfacies related to aeolian, backshore, foreshore and shoreface deposits, forming a set of reflections dipping seaward (Silva *et al.* 2010; Barboza *et al.* 2011; Rosa 2012; Dillenburg & Barboza 2014). Barrier morphology is mostly represented by strandplains, with complex foredune ridges and dunefield combination (Dillenburg *et al.* 2000, 2009; Hesp *et al.* 2005, 2007; Martinho *et al.* 2008, 2010). The third pattern is defined as aggradational, with parallel to subparallel horizontal reflections related to aeolian deposits, where the barrier morphology is mainly of dunefields (Rosa 2012; Dillenburg & Barboza 2014).

The definition of stacking based on reflection configuration and radarfacies succession allowed identifying the main internal and bounding surfaces. Each barrier-lagoon system (II, III and IV) is separated by unconformities, representing a depositional sequence characterized by a conformable succession of strata. The architectural pattern of Systems II, III and IV is mostly the same. Thus, as the work done in System IV is so detailed and GPR data has a much better quality, and because System IV is less affected by digenesis, its understanding was used to guide the interpretation of Systems II and III.

The determination of retrogradational, aggradational, progradational and degradational stacking allowed defining the transgressive and the highstand/falling stage system tracts packages (Figs. 8 to 10). The lowstand system tract was only recognized into an incised-valley related to System IV, studied by Tomazelli *et al.* (2008), and the degradational stacking (also known as falling-stage, or forced regression) was not separated from the highstand system tract because of data resolution. Dillenburg *et al.* (2017) (in press), studying Barrier IV in the southern portion of the coastal plain, were able to separate highstand and falling-stage systems tracts.

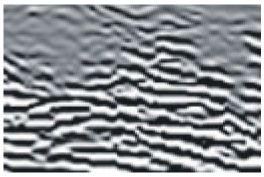
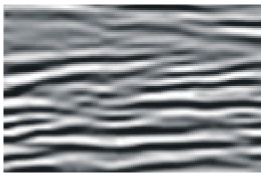
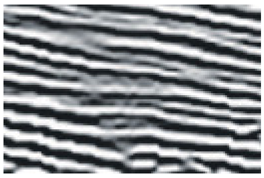
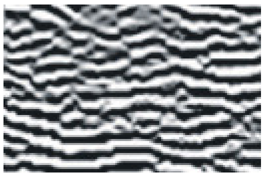
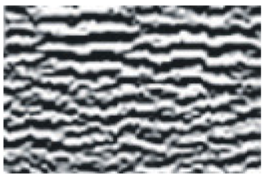
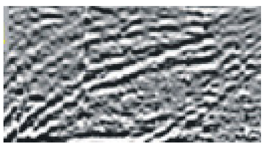
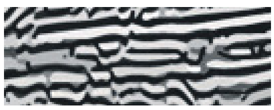
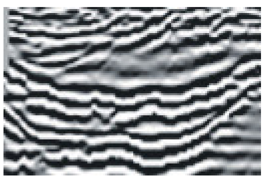
DISCUSSION

In order to contextualize the coastal plain record, we summarized current stratigraphic understanding of Pelotas Basin in a hierarchical scheme. Figure 11 and Table 3 show a summary of published data used to build the proposed hierarchy. Major phases of basin filling are defined as Rift, Post-rift and Drift (Fig. 2, Table 3 — Low), with the two later phases subdivided into transgressive, aggradational, and regressive intervals, which, according to Abreu *et al.* (2010), include four composite sequences (Fig. 3, Table 3 — Low and Medium). Each composite sequence is divided into three sequence sets, resulting in 12 sequence sets for the basin (Fig. 3). The last sequence set (APD_4) encloses eight depositional sequences (Fig. 3).

Starting from the interpretation of seismic sections of Pelotas Basin, it is possible to define that the geological record of the coastal plain is part of a depositional sequence defined by Abreu (1998) (number 43 of his work) with about 0.5 My. The integration of surface and subsurface data leave to interpret that this sequence is in fact composed of higher-frequency sequences, partially represented by each barrier-lagoon system (Table 3 — High I).

The onshore record of each system was associated by Villwock and Tomazelli (1995) to high sea levels, related to oxygen isotope stages from Imbrie *et al.* (1984). The age control demonstrates that, in general, this correlation is correct and each sequence was formed in response to glacioeustatic cycles of 100 kyr (Fig. 5), such as that represented in oxygen isotope records where there is a downward trend from

Table 2. Radarfacies description and interpretation based on reflection configuration (shape, dip, relationship between reflections and continuity). Sample images were acquired with a 200 MHz antenna and are W to E oriented.

Rf	Description	W	Sample image	E	Interpretation
1a	Shape: sinuous convex Dip: multidirectional, higher angles at the top Relationship: chaotic Continuity: discontinuous Amplitude: variable, higher in contact with Rf2 Dimension: sets with 5 m thick, 5 to 10 m length				Foredune
1b	Shape: planar Dip: horizontal or low angle to W Relationship: subparallel with oblique truncation between sets Continuity: relative continuous Amplitude: medium to high, variable Dimension: sets with 1 to 10 m thick, tens of meters in length				Transgressive Sand Sheets and Aggradational Aeolian Deposits
2	Shape: planar Dip: low angle unidirectional (5º) Relationship: parallel and oblique Continuity: continuous Amplitude: high Dimension: sets with about 5 m thick, 10s to 100s m in length				Backshore Foreshore
3a	Shape: sinuous Dip: multidirectional in detail, with resultant tendency to E Relationship: chaotic Continuity: discontinuous Amplitude: high Dimension: sets with about 5 m thick, metric to 10s m in length				Upper Shoreface
3b	Shape: gently sinuous to planar Dip: very low angle with resultant tendency to E Relationship: subparallel with oblique truncation between sets Continuity: relative continuous Amplitude: medium, variable Dimension: sets with about 5 m thick, metric to 10s m in length				Mid-Lower Shoreface
4a	Shape: sigmoidal Dip: unidirectional variable (low, high and low angle from topsets to bottomsets — 3 to 30º) Relationship: oblique tangential Continuity: continuous Amplitude: high to low, variable Dimension: sets with up to 5 m thick, 5 to 20 m in length				Lagoon Margin (beaches and deltas)
4b	Shape: planar to gently undulating Dip: horizontal to very low angle Relationship: single reflector or a parallel set Continuity: continuous Amplitude: high Dimension: 1 to 2 m thick, longer than 10s m in length				Lagoon Bottom
5	Shape: concave Dip: bidirectional on the edges and horizontal to oblique in the middle Relationship: parallel to oblique, variable filling Continuity: continuous edges, variable filling Amplitude: high in the bottom, variable filling Dimension: Swales — 1 to 4 m thick, 5 to 20 m in length Channels: can reach more than 30 m thick, can be longer than 10s or 100s m in length				Swales (between foredunes) or Fluvial Channels

about 400 ka (Chappell & Shackleton 1986, Martinson *et al.* 1987; Raymo *et al.* 1989; Gibbard & Cohen 2009).

The altitudes of relative sea-level highs defined through topographic measurements from this work are in accordance with those performed by Tomazelli and Dillenburg (2007), and Lopes *et al.* (2014). The minimum highest sea-level altitude estimated to System II is 9.5 ± 1 m, to System III is 7.7 ± 1 m, and to System IV is 3 ± 1 m. Rohling *et al.* (1998) and Rabineau *et al.* (2006) established magnitudes of lowstands to the past 500 kyr. Considering the correlation with oxygen isotope stages to determine the age of sequences lowstand, it is possible to determine that sea level was more than 100 m below its current position during each lowstand (Fig. 5).

Analyzing the magnitude of sea-level changes and the time of formation of each system, it is possible to interpret that expressive and regional unconformities were formed by exposition, erosion and non-deposition, bounding the related sequences. Considering the maximum measured paleo indicator of sea-level position as the minimum altitude of the zero shoreline at the time of deposition of each system, and the age control, Systems II to IV together are progradational and are at progressively lower altitudes, resulting in a degradational architecture.

Internally, each sequence at the onshore portion of the basin is formed by the record of depositional environments disposed in retrogradational, aggradational, progradational and degradational stacking (Figs. 8 to 12). The stacking defines system tracts and surfaces, prevailing the transgressive and highstand (Fig. 12).

Quaternary depositional sequences are worldwide identified, specially related to 41 and 100 kyr glacioeustatic cycles

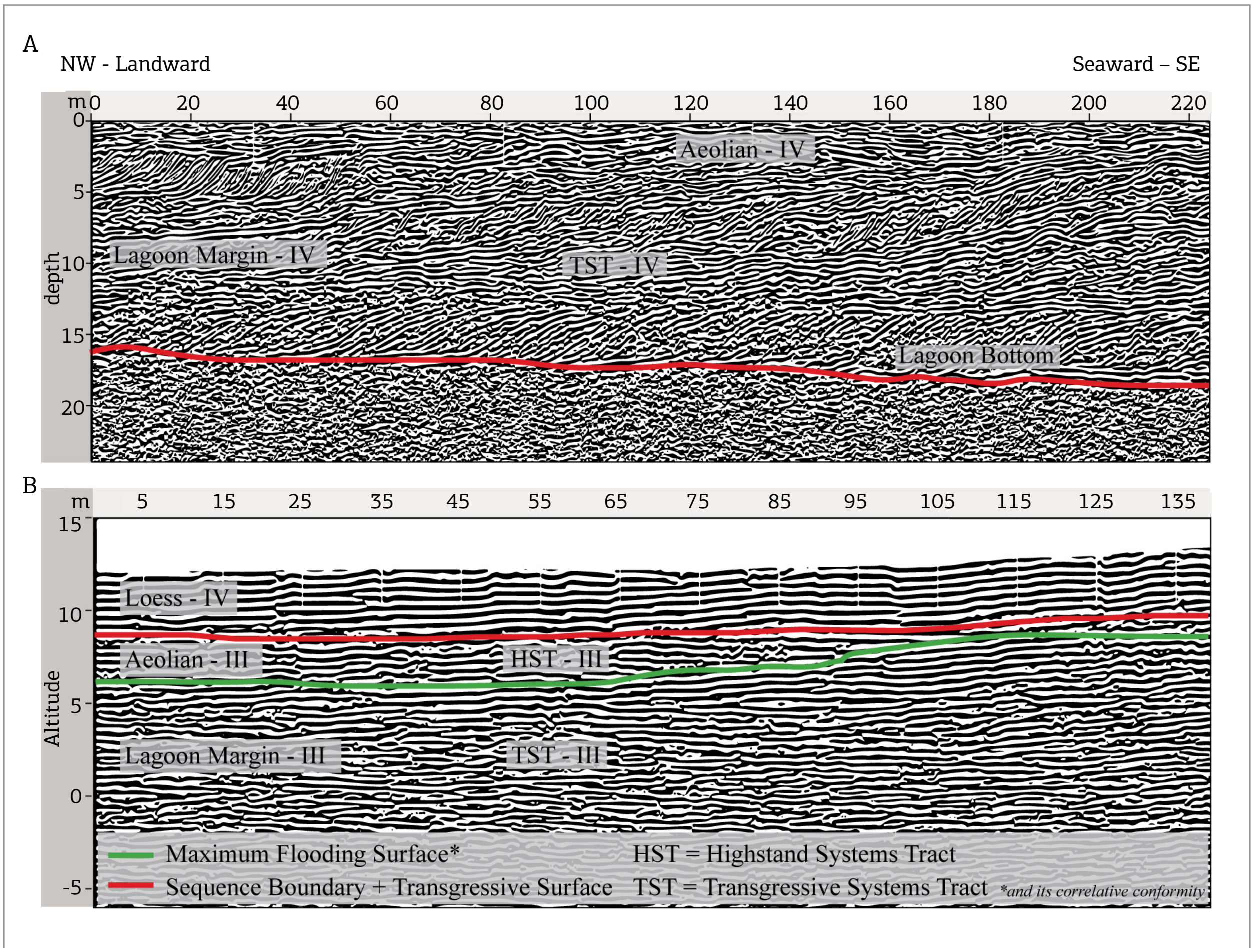


Figure 8. GPR sections obtained on the Barriers IV (A) and III (B). Locations are outlined on the map in Figure 4. Both sections are mainly composed by reflections dipping landwards associated to lagoonal (radarfacies 4a and 4b) and aeolian systems (radarfacies 1b) retrogradation, defining transgressive systems tracts related to two depositional sequences (IV – section A, and III – section B). The bottom of section A is interpreted as the limit with older deposits related to System III, representing both a sequence boundary and transgressive surface. In section B, lagoon margin is covered by two phases of aeolian deposits: one is related to the evolution of System III in a highstand systems tract context, while the other one is related to younger loess deposition related to System IV, described and dated (between 30 and 10 kyr) in the area by Lopes (2013) and Lopes *et al.* (2016).

(Boyd *et al.* 1989; Saul *et al.* 1999; Carter & Naish 1998; Yoo & Park 2000; Morton *et al.* 2000; Blum & Carter 2000; Blum *et al.* 2002; Abbott *et al.* 2005; Blum & Aslan 2006; Parham *et al.* 2007; Riboulot *et al.* 2012; Amorosi *et al.* 2016). However, the time of sequence formation and its record vary according to the factors controlling their evolution. Studies developed in New Zealand, where the record is strongly influenced by tectonics, identified the occurrence of sequences with frequencies of 41 and 100 kyr developed during the Pliocene and Quaternary (Naish & Kamp 1997; Carter & Naish 1998; Saul *et al.* 1999; Abbott *et al.* 2005). In the Golf Coast (USA), sea-level changes are responsible by the formation of Quaternary sequences related to upper Pleistocene and Holocene (Blum *et al.* 2002; Blum & Aslan 2006). Studying the coastal plain and incised-valleys, Blum *et al.* (2002) e Blum & Aslan (2006) defined depositional sequences related to the 100 kyr cycles, composed by lowstand, transgressive, highstand and regressive systems tracts. Sequences formed in response to 100 kyr are identified as well in Eastern Niger submarine delta (Riboulot *et al.* 2012),

In North Carolina, Parham *et al.* (2007) studied a drainage system and detected nine depositional sequences filling an incised-valley with ages younger than 140 ka, concluding that multiple sea-level oscillations occurred during this time or the area must be influenced by glacial isostatic uplift and subsidence.

The coastal plain of Pelotas Basin is located in the tectonic context of a passive margin, thus its evolution must be mostly influenced by sea-level changes. As its record is well correlated to oxygen isotope curves, and higher frequency sea-level oscillations are predicted in these curves, they could be recorded in the offshore portion of the basin, as well as a factor influencing onshore deposition. However, the data analyzed allow establishing only the influence of 100 kyr glacioeustatic cycles to form the studied depositional sequences.

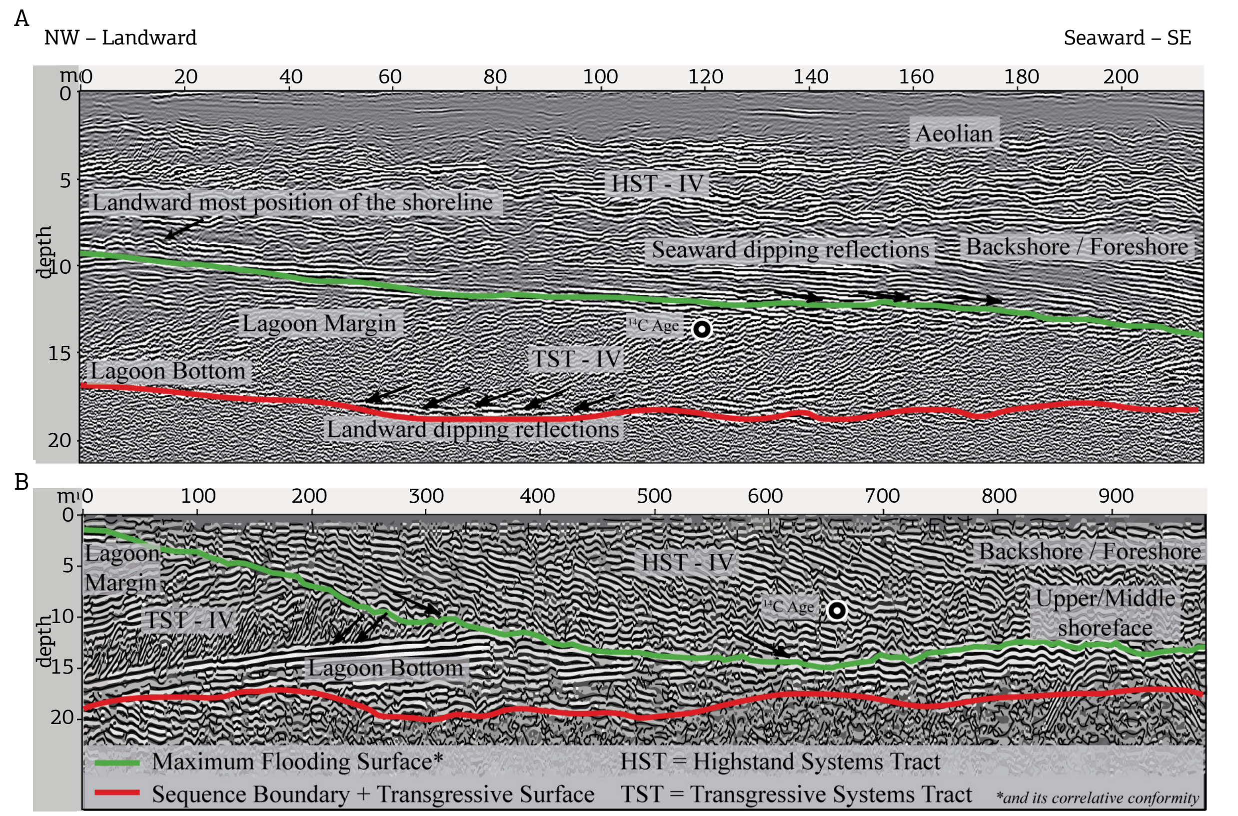


Figure 9. GPR sections obtained on the Barrier IV showing in the base the same type of record of Figures 8A and B, with landward dipping reflections representing lagoon margins (radarfacies 4a and 4b) moving to this direction. The shoreline landward most position related to its maximum transgression is located where reflections change and backshore, foreshore and upper shoreface (radarfacies 2 and 3) reflections configure barrier progradation. In section A, a ^{14}C analysis determined the age of 8,320–8,070 cal yrs BP (Silva 2011). In section B, a ^{14}C analysis determined the age of 7,760–7,600 cal yrs BP (Dillenburg *et al.* 2007). Sequence boundary is attested to sedimentary features interpreted as Barrier III deposits obtained in the drill holes (Silva, 2011 and Dillenburg *et al.* 2007). Sections locations are outlined on the map in Figure 4.

Tectonic influence in the relative sea level related to those sequences was not determined. Nevertheless, in Central Patagonia (Argentina), Pappalardo *et al.* (2015) measured similar coastal landforms (beach ridges, marine terraces and river mouth terraces) correlating its age to marine isotope stages 1, 5, 7, 9 and 11. The authors attributed the elevation of landforms to sea-level rises combined with tectonic uplifts, with rates varying from 0,016 to 0,067 m/kyr. Despite uplifts is not proved for the coastal plain of Pelotas Basin, a tectonic influence in its sedimentary record is not discarded, especially for the older deposits.

System IV

As previously discussed, Barrier III is interpreted as related to oxygen isotope stage 5 (125 ka) and has a sea-level position up to 7 m higher than current sea level based on the record of beach outcrops (Tomazelli & Dillenburg 2007; Rosa 2012). The oxygen isotope record shows a continuous trend of falling sea level starting in stage 5 until the Last Glacial Maximum (LGM) at about 20 ka. In the LGM, sea level is interpreted to have been situated at around 120 to 130 m below the current position (Fairbanks 1989; Corrêa 1995; Peltier & Fairbanks 2006). After the LGM, sea level rose at a fast rate. Along the Brazilian margin, sea level is interpreted to have exceeded the present level around 7.7 to 6.9 ka, reaching its maximum at approximately 5.6 ka (Martin *et al.* 1979; Angulo & Lessa 1997; Bezerra *et al.* 2003; Caldas *et al.* 2006; Angulo *et al.* 2006). In Rio Grande do Sul, sea level is estimated to have reached from 2 to 4 m above the current level (Barboza & Tomazelli 2003; Dillenburg *et al.* 2000, 2009). Since then, it would have started to fall again until it reaches the present level (Angulo & Lessa 1997; Angulo *et al.* 2006).

The formation of System IV is intrinsically related to sea-level changes already described (Table 3 — High II). Coeval fluvial and estuarine deposits are present in the coastal plain of Rio Grande do Sul (Tomazelli *et al.* 2008; Weschenfelder *et al.* 2005, 2014). Tomazelli *et al.* (2008) detailed the evolution of an incised valley in the area of Taim Swamp and Mirim Lagoon, located in the south region of the coastal plain (Fig. 4). Gravimetry and magnetometry (Rosa *et al.* 2009), seismic, GPR profiles, cores and sedimentological analysis were integrated to understand the geometry and the fill of the valley. GPR and seismic profiles (Fig. 13) show

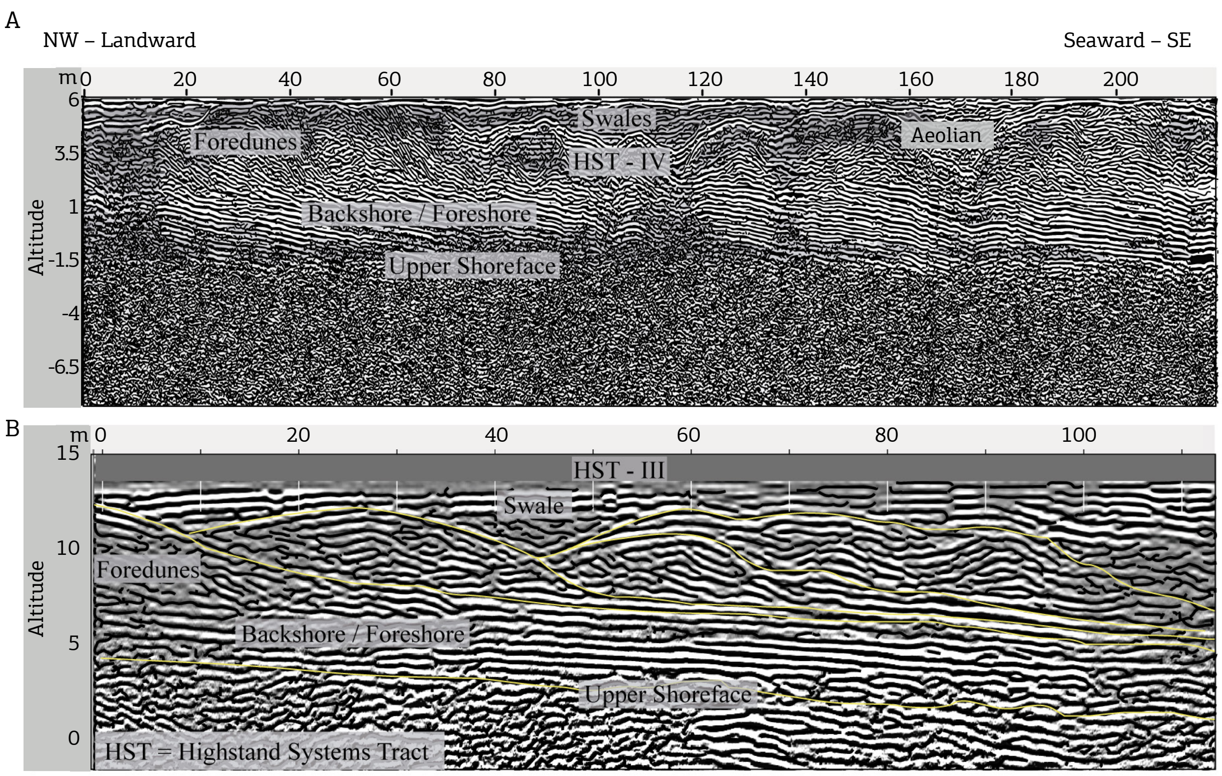


Figure 10. GPR sections obtained on the Barriers IV (A) and III (B). Locations are outlined on the map in Figure 4. Both sections are mainly composed by reflections dipping seawards associated to swales, backshore, foreshore and shoreface (radarfacies 1a, 5, 2 and 3) defining the progradational stacking of highstand systems tracts related to two depositional sequences (IV – section A, and III – section B).

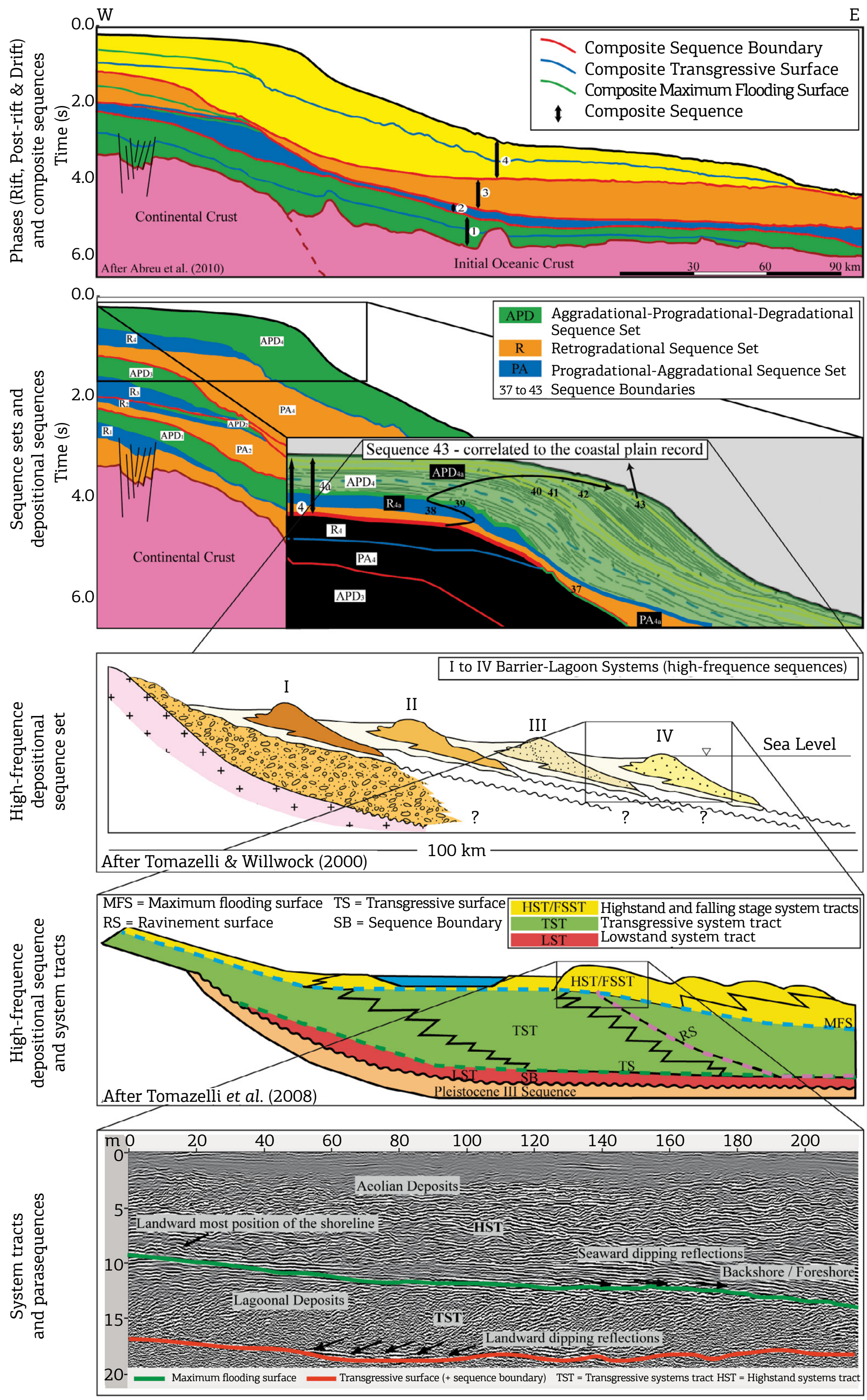


Figure 11. Hierarchization proposed for the Pelotas Basin, drawn from the various studies that have been previously reported.

the contact between the valley bottom and System III. [14]C age dating of shells obtained in SPT cores on the barrier indicates a Holocene age above this contact. The valley was completely filled during the Holocene, represented today by a swamp.

The base of this incised valley was defined as a sequence boundary by Tomazelli *et al.* (2008), separating System III from the valley deposits. This unconformity was interpreted by these authors as the sequence boundary formed as a consequence of the LGM. Roots from drill hole indicate [14]C ages of 19,550–19,270 cal yrs BP to the base of valley (Tomazelli *et al.* 2008). The lowstand system tract is interpreted to be related to the basal portion of the valley and to paleosoils and other continental correlated deposits beyond the coastal plain (Tomazelli *et al.* 2008; Rosa 2012). Atop the lowstand valley deposits, the transgressive surface is interpreted by the differentiation of filling architecture patterns in GPR and seismic profiles, associated to sedimentological changes (Fig. 13). Into the valley, the transgressive system tract is characterized by lateral accretion, related to the evolution of channel bars disposed in aggradational staking. Fluvial channel deposits are characterized by a high content of coarse sand. Mud lenses and biodetritical gravel are present too. To the top, estuarine and lagoon deposits were interpreted, and shells of reworked mollusks indicate [14]C ages between 8,160–7,990 and 6,820–6,640 cal yrs BP (Tomazelli *et al.* 2008).

The transgressive system tract is represented in GPR by landward dipping reflections of lagoonal deposits, when lagoonal margin migrates landwards (Fig. 8A). During transgression, beach face erosion caused sediment transport from the barrier to the lagoons, mostly through washover fans and wind. As they are below the wave level, these features have a higher preservation potential during barrier transgression. In this case, the transgressive surface and the sequence boundary are merged (Figs. 8A and 9).

The lagoonal radarfacies are, at some sectors of the coast, covered by the radarfacies of aeolian, backshore, foreshore and shoreface deposits, composing retrogradational parasequences. The landward most beach and marine deposits represent the maximum shoreline transgression or the maximum flooding surface (Fig. 9). In other sectors of the coastal plain, the shoreline transgression reached the western continental margin of the paleo lagoons, and wave action sculpted scarps in Barrier III. This induced a significant difference in the record of transgressive system tract along the coast, which is represented by thin marine deposits in these sectors.

The age of maximum flooding surface varies along the coastal plain, and occurred in some sectors even before sea level reached its maximum elevation at about 6 ka. Silva (2011) obtained a [14]C age of 8,320–8,070 cal yrs BP for a piece of wood from drill hole into the transgressive lagoonal margin deposits in the coastal plain of Santa Catarina (Fig. 9A). Dillenburg *et al.* (2006, 2007) dated preserved shells of marine mollusks in foreshore and shoreface deposits positioned at depths of 9 to 12 m. The oldest [14]C ages obtained in the barrier progradational phase was 7,760–7,600 cal yrs BP (Fig. 9B) and 7,685–6,685 cal yrs BP, interpreted as close to the beginning of the highstand.

Table 3. Summary of main works that depict the Pelotas Basin in different hierarchies.

Freq.	Beginning	Data type	Results	Main References Cited
Low	130 Ma	Seismic, drilling	Great phases of filling and basin evolution	Fontana (1996), Abreu (1998), Bueno *et al.* (2007)
Low and Medium	130 Ma	Seismic, drilling, dating	Four composite sequences, 12 sequence sets, 56 depositional sequences	Abreu (1998), Neal and Abreu (2009), Abreu *et al.* (2010)
High I	230 ka (325 ka?)	Geomorphology, remote sensing, outcrops, drilling, dating, GPR	Barrier-lagoon Systems I or II through IV (part of high frequency sequences, each sequence cyclicity is 100 ka)	Villwock, (1984), Villwock and Tomazelli (1995), Tomazelli and Villwock (2000), Lopes *et al.* (2010, 2013, 2014), Rosa (2012)
High II	20 ka	Geomorphology, remote sensing, outcrops, drilling, dating, seismic, GPR	System IV evolution (part of the younger high frequency sequence)	Tomazelli & Villwock (1989), Dillenburg *et al.* (2000, 2009), Tomazelli *et al.* (2008), Barboza *et al.* (2009, 2011), Rosa (2012), Dillenburg and Barboza (2014)
High III	500, 300, 60 and 22 yr	Geomorphology, remote sensing, including historical data, outcrops, drills, dating, beach profiles, monitoring of shoreline (DGPS), tide gauge, climatic, and meteorological data	Phases of dunes (~500 yr), Lagoon level rise (Lagoa dos Patos - 300 yr), increased vegetation in dune fields (60 yr), shoreline erosion (22 yr)	Toldo Jr. *et al.* (1999, 2004, 2005), Barboza *et al.* (2006), Martinho *et al.* (2008, 2009, 2010), Rosa (2012), Dillenburg *et al.* 2017 (in press)

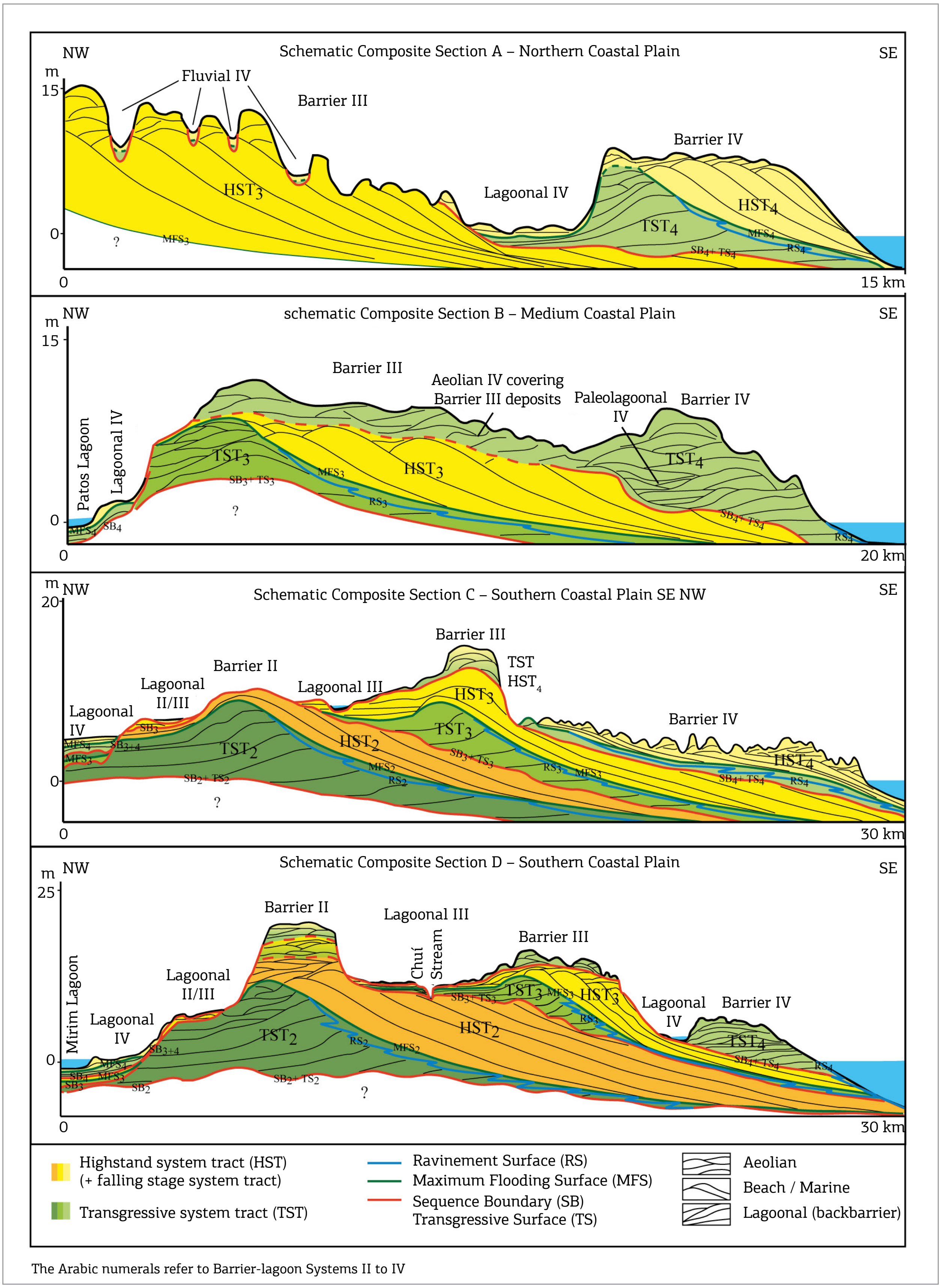


Figure 12. Schematic sections summarizing the stratigraphic framework of four sectors along the coastal plain (after Rosa 2012). The approximate location of the sections is outlined on the map in Figure 4.

Coastal embayments show a progradational stacking interpreted as the highstand systems tract, represented mostly by distinct strandplain morphology (Figs. 9, 10A and 14). Landward, the maximum flooding surface is positioned between the top of lagoonal and the base of beach deposits, while seaward it is in the shoreface deposits (Fig. 9). In most of the lagoons of the coastal plain, scarps were sculpted when the water level was higher in response to the high sea level. These scarps represent the continental record of the maximum flooding surface.

Some authors recognized progressive changes in the morphology and altitude of the strandplains, with foredune ridges narrower and downsteping, and interpreted the transition from normal to forced regression (Silva 2011, 2015; Dillenburg *et al.* 2006, 2009). According to models as the ones of Hunt and Tucker (1992), Helland-Hansen and Gjelberg (1994), and Plint and Nummedal (2000), this record could be related to the forced-regressive system tract. However, the basal surface of forced regression and the regressive surface of marine erosion are not recognized in most of GPR sections and cores. So the forced regression was only identified in some studies related to the evolution of Barrier IV (Dillenburg *et al.* 2006; Silva 2011, 2015; Dillenburg *et al.* 2017 in press).

As already observed by Tomazelli and Villwock (1989), Dillenburg *et al.* (2000, 2009), Barboza *et al.* (2011), Rosa *et al.* (2011), Rosa (2012), Dillenburg and Barboza (2014) and Barboza and Rosa (2014), the Pelotas Basin shoreline has sectors with different behaviors, with System IV presenting synchronous progradational, aggradational and retrogradational patterns along the coast.

System IV shows sectors along the coast with transgressive shoreline, where GPR record exhibits landward dipping reflections (Fig. 8A). These sectors are located where the shoreline is more projected seaward (Fig. 14). In these sectors, lagoonal mud and peat outcrop in the current beach face (Tomazelli *et al.* 1998; Dillenburg *et al.* 2004). ^{14}C dating of these deposits indicate ages of 6,843–6,303 cal yr BP (Travessas *et al.* 2005), 4,252–4,641 cal yr BP (Tomazelli *et al.* 1998) and 3,551–2,888 cal yr BP (Dillenburg *et al.* 2004), which imply that the barrier was positioned seaward of its present position.

Where the coastline form embayments, progradational stacking is observed in System IV (Fig. 14). In these sectors, GPR profiles show seaward dipping reflections (Fig. 10A). The strandplains of these areas can reach up to 15 km width (Dillenburg *et al.* 2009; Dillenburg & Barboza 2014). Aggradational behavior occurs in the transitions between the progradational and retrogradational sectors, mainly positioned where shoreline changes its orientation (Dillenburg & Barboza 2014).

The occurrence of different stacking patterns along the shoreline is interpreted to be controlled by the interaction of longshore currents and shoreline configuration, establishing local areas of erosion and deposition (Fig. 14). Main factors controlling the change in stacking would be wind and wave action, shoreline orientation and shelf slope and inner shelf bathymetry, as already discussed in previous studies (Toldo Jr. *et al.* 1999, 2004, 2005; Dillenburg *et al.* 2000, 2009; Martinho *et al.* 2009; Silva 2015; Barboza *et al.* 2006, 2011; Dillenburg & Barboza 2014). These factors influence and are recorded in even higher frequency scales, as lagoon level changes (Lagoa dos Patos — 300 yr), increased vegetation in dune fields (60 yr) and shoreline erosion (22 yr) (Table 3 – High III from the studies of Toldo Jr. *et al.* 1999, 2004,

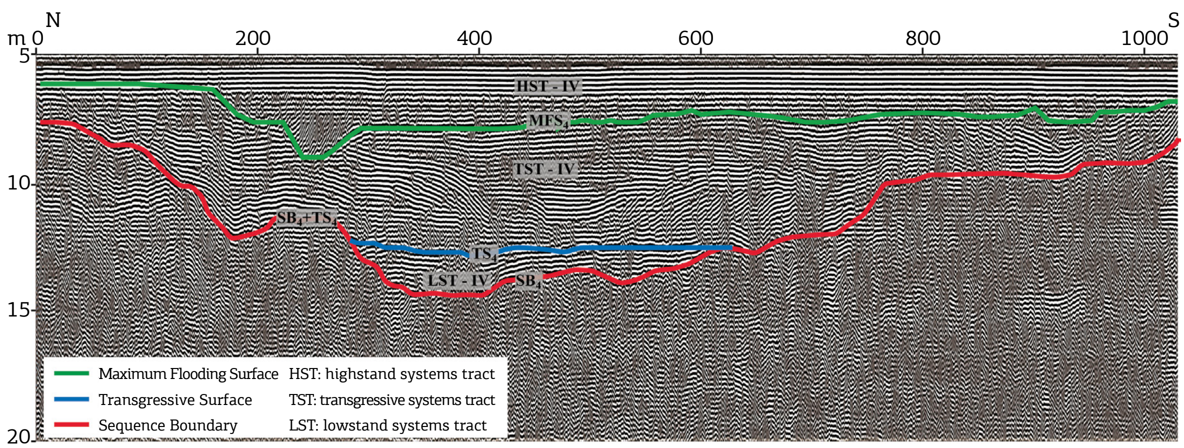


Figure 13. Strike seismic section of the incised valley where the sequence boundary is related to the unconformity between the depositional sequences of Systems III and IV. The valley fill refers to System IV, in which the main stratigraphic surfaces and system tracts were interpreted. The location of the section is outlined on the map in Figure 4.

2005; Barboza *et al.* 2006; Martinho *et al.* 2008, 2009, 2010; Dillenburg *et al.* 2017 in press). As already observed in experimental studies, the signal of autogenic processes may be preserved in the stratigraphic record (Paola *et al.* 2009; Jerolmack & Paola 2010; Straub & Esposito 2013; Kim *et al.* 2014). In the coastal plain of Pelotas Basin, the variability of the shoreline configuration, as well as the characteristics of depositional systems, is highly influenced by autogenic processes.

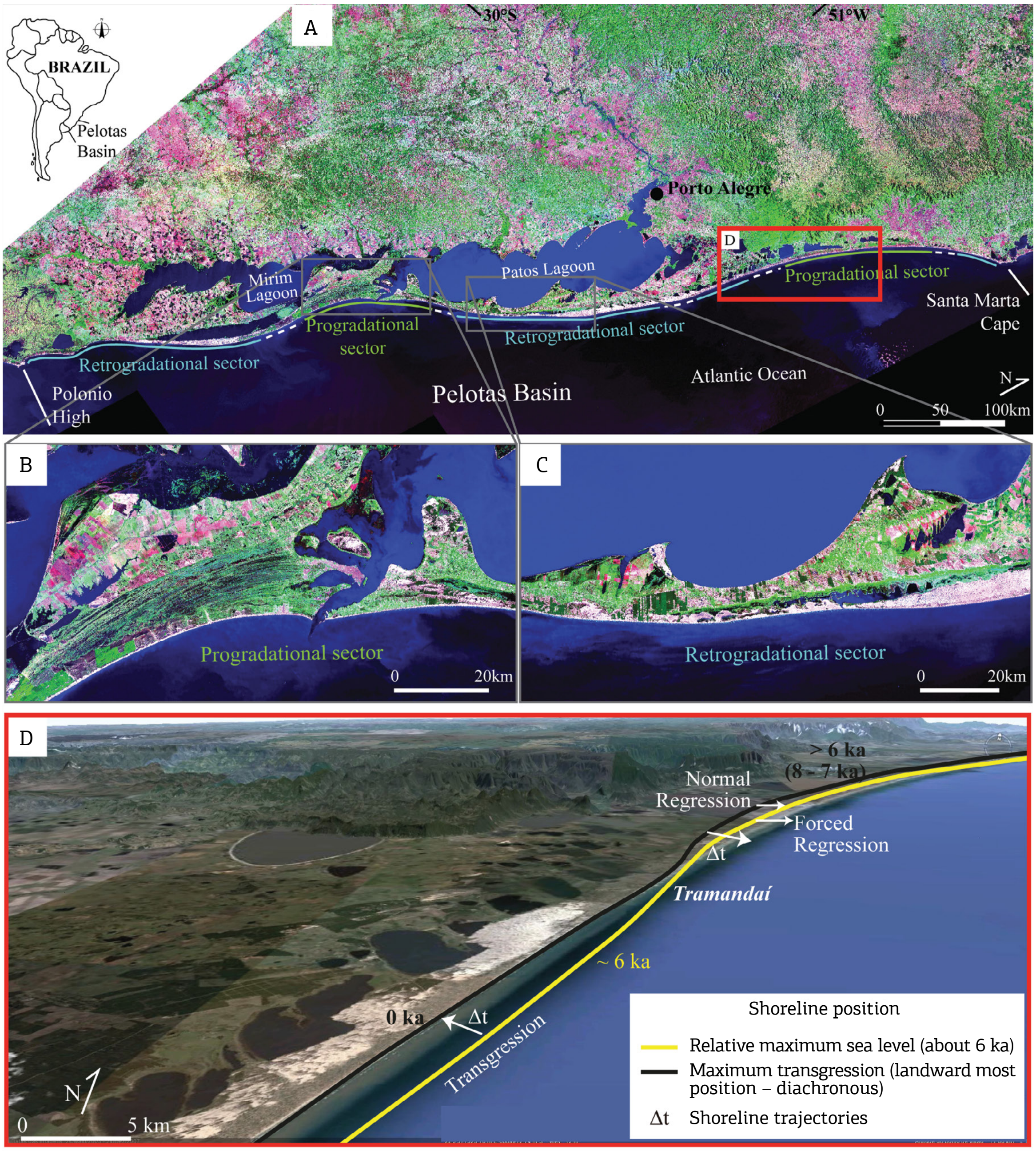


Figure 14. (A) Landsat 7 satellite image (ETM+ sensor, 7R4G2B composition) showing the shoreline morphology. Progradational sectors (B) are formed by strandplains and located in coastal embayment, while coastal projections are mainly retrogradational (C) and characterized by the presence of great dunefields. Sediment transport is largely controlled by the longshore drift, which resulting northeast, and by aeolian activity, with northeast predominant wind. (D) Oblique satellite image (source: Google Earth) of the northern coast of Rio Grande do Sul including the position of the shoreline related to the relative maximum sea level and maximum transgression, showing its diachronism (created, with no accuracy in the position, based on the works of Dillenburg *et al.* 2000, 2009, Travessas *et al.* 2005).

CONCLUSIONS

The performed analysis resulted in a Sequence Stratigraphic framework which allowed positioning the Quaternary record of the coastal plain of Pelotas Basin in relation to its evolution through a Sequence Stratigraphic view. Furthermore, the detailed analysis of System IV demonstrated the diachronous nature of stratigraphic surfaces and systems tracts, which is related to scale issues and the relation of autogenic and allogenic factors controlling the stratigraphic record.

The coastal plain is mainly formed by barrier-lagoon depositional systems, here interpreted to represent the preserved, onshore portion of depositional sequences (Systems II, III and IV). GPR and elevation data of the four systems indicate that they have a degradational stacking corresponding to a sequence set prograding and downsteping into the basin (Figs. 5 and 6), comprehending a degradational sequence set. Stacking and types of deposits are show in four schematic dip sections (Fig. 12).

These sequences are interpreted to be mainly controlled by glacioeustatic cycles of about 100 kyr duration represented in oxygen isotope records. Higher frequency sea-level oscillations were not detected in this studied, but could be recorded in the offshore portion of the basin as well as a factor influencing sedimentation. This record could be searched in future studies.

System IV shows the concomitant occurrence of progradational and retrogradational stacking along the coast. In some sectors, the maximum flooding surface reached its landward most position between 8 and 5 ka, with progradation occurring afterwards associated with the highstand system tract. In other sectors, the stacking pattern is still retrogradational and the shore is still under transgression (Fig. 14). It demonstrates the variability of factors controlling the sedimentary record. On this scale of analysis, coastal depositional systems behave differently at the same time along strike, demonstrating the importance of autogenic factors in its evolution.

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