

WAVE ENERGY, SEDIMENT SUPPLY, AND SEA-LEVEL FALL: LATE HOLOCENE BASIN INFILLING IN SOUTHERN BRAZIL

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Abstract: Coastal sedimentation is driven by a combination of wave and tidal energy, sediment supply, and relative sea-level change. During the Holocene, these factors have combined to fill coastal embayments along the headland-dominated coast of Santa Catarina, Brazil. Here, three partially filled basins exhibit marked variability in their sediment sources, wave exposure and resulting stratigraphy and beach morphology. Hydrodynamic modeling highlights the primary roles of sediment supply and wave energy in producing three vastly different basin-fill sequences. The lack of a river source to the Pinheira Strandplain results in a bay-fill sequence dominated by shelf-derived sand. Along the open coast of Navegantes, high wave energy removes fine sediments derived from the Itajaí-Açu rivers, producing a sand-dominated sequence. At Tijucas, fed by the much smaller Tijucas River, fronting headlands minimize wave energy, allowing for the accumulation of fluid mud in the shoreface. The result is a basin-fill sequence larger than that at Navegantes, but dominated entirely by mud.

Introduction

The long-term development of sedimentary systems is driven by changes in the relative rates of sediment delivery and the creation of accommodation (Posamentier et al. 1988). In coastal systems, these are, in turn, functions of relative sea-level (RSL) changes; antecedent topography; changes in the source, supply rate and type of sediment delivered to the coastal zone; and changes in storminess and the strength of waves and tides which rework those sediments (Wolinsky and Murray 2009; Moore et al. 2010; Hein et al. 2011). In southern Brazil, falling RSL following a 2–4 m highstand at 5 to 6 ka forced coastal progradation. This reworked abundant shelf and fluvial sediment, smoothing the irregular, headland-dominated coastline, filling coastal embayments, and developing 2–7-km wide strandplains (mainland-connected parallel / semi-parallel beach and/or dune ridges separated by shallow swales; Roy et al. 1994).

Here, we use sediment core data from three southern Brazilian strandplains (Navegantes, Tijucas, and Pinheira; Fig. 1) to compare their modern beach and late-Holocene bay-infill sequences in terms of their volumes, sedimentology, sediment sources, and morphology. Hydrodynamic modeling of wave processes at each site is then used to investigate the underlying bathymetric and oceanographic conditions responsible for the differences between these sites.

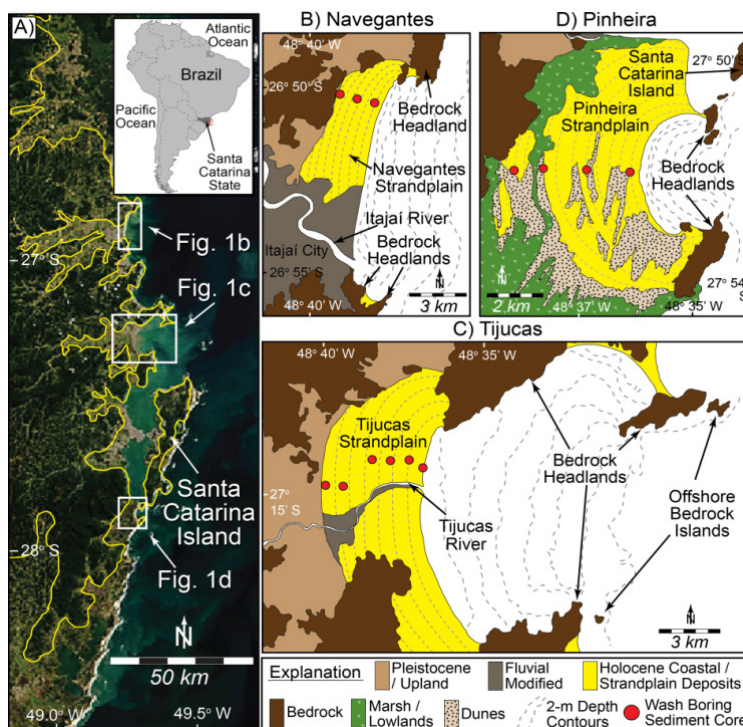


Fig. 1. A) Map of coast of Santa Catarina (mod. from McBride et al. 2013). Yellow line: landward boundary of Quaternary deposits (after Horn Filho and Diehl 1994). B) – D) Study sites and data collection schemes (mod. from Hein et al. 2013, in prep., and 2014, respectively).

Physical Setting of Central Santa Catarina, Southern Brazil

The central Santa Catarina (SC) coast of Brazil is characterized by low-relief bedrock promontories and small islands that have segmented the coastal plain. It is backed by the high relief Serra Geral and Serra do Mar Mountains, is tectonically inactive, and is fronted by the low gradient (0.01%; Angulo et al. 2009) Florianopolis shelf. Due to the proximity of the coastal mountain ranges, drainage is dominantly inland, into the Rio de la Plata basin. However, sediment sourced from the small, local rivers which feed the SC coast has been reworked

during the Quaternary by shoreline processes associated with large-scale RSL fluctuations to produce a series of transgressive barriers and regressive barrier-strandplain systems that have partly straightened the bedrock-dominated shoreline (FitzGerald et al. 2007). The presence of extensive Pleistocene and Holocene dune systems (10–50 m high; extending > 2 km inland) – such as those along the isolated Santa Catarina Island – and a number of strandplains not associated with local river systems (*e.g.*, Pinheira) suggest that both the Rio de la Plata (Paraná Basin), located 1000 km to the south, and other sand sources on the adjacent continental shelf, may have also contributed significant sediment volumes to plains of the southern SC coast (Dominguez et al. 1987).

Following the last glaciation, RSL in southern Brazil reached modern levels at 6.9–7.7 ka and continued to rise to a highstand elevation of 1–4 m above modern mean sea level (MSL) at 5.5–6.0 ka (Angulo et al. 2006). Although no reliable sea-level data have been reported for the Santa Catarina coast prior to ~6.5 ka, rheological models predict that RSL in this region reached modern elevations at *ca.* 7.6 ka, followed by a highstand lasting as long as 2000 years. RSL fall during the late Holocene was either smooth and gradual, or marked by centimeter- to decimeter- scale RSL oscillations (Angulo et al. 2006).

The modern SC coast experiences mixed tides, primarily semi-diurnal and microtidal with spring tidal ranges of 0.4–1.2 m (increasing to the north; Truccolo 1998). Deepwater waves are bimodal with heights ranging from 1.25 to 2.00 m (larger from the south) and periods of 8–12 sec (longer from the south) (Araújo et al. 2003; Klein 2004). However, shoreline wave energy varies greatly and is governed by shoreline orientation, exposure to open-ocean conditions, and inner shelf bathymetry. Due to the gentle, homogenous nature of the shorelines (< 0.2°; Fig. 1, Table 1) and headlands fronting the beaches at the three study sites, ocean swells are nearly fully refracted and diffracted, and waves breaking along the swash-aligned shorelines are commonly < 1 m. Longshore transport is generally to the north. However, rates and directions are highly variable and related to wind patterns and local wave refraction patterns. Moreover, it is unlikely that any longshore transport-derived sediment bypasses the largest headlands and is incorporated into strandplain systems in the most deeply embayed compartments (*e.g.*, Tijucas).

Study Sites: Contrasting Strandplains of Central Santa Catarina

This study focuses on three strandplain systems in central SC state: Navegantes, Tijucas, and Pinheira (Fig. 1; Table 1). All three are relatively flat with low, seaward-dipping gradients and local ridge-and-swale topography of generally < 1 m. They consist of dune/beach ridges and/or chenier systems, which have evolved through shoreface and foreshore accretion (FitzGerald et al. 2007).

Table 1. Comparison of three strandplain systems of central Santa Catarina discussed in this study.

Characteristic	Navegantes	Tijucas	Pinheira
Location (lat, long)	26° 50' S, 48° 38' W	27° 15' S, 48° 37' W	27° 52' S, 48° 36' W
Dimensions (alongshore x cross-shore)	10–12 km x 2–8 km	12 km x 6 km	8.5 km x 5 km
Associated river(s)** (catchment area; mean annual discharge)	Itajaí-Açu River (15.5 x 10 ³ km ² ; 6.9 km ³)	Tijucas River (2.42 x 10 ³ km ² ; 1.3 km ³)	Massaimbu River (0.07 x 10 ³ km ² ; 0.06 km ³); Madre River (0.33 x 10 ³ km ² ; 0.2 km ³)
Fluvial suspended sed. yield	0.76 Mt/yr	~0.1 Mt/yr (min.)	N/A
Dominant sediment source	fluvial	fluvial	shelf (Hein et al. 2013)
Slope of modern shoreface†	1.5–2.5°	5.0–6.0°	3.0–4.0°
Nearshore (0–20 m) slope	0.11°	0.06°	0.18°
Coastal compartment characteristics	largely exposed, small headlands	well protected: large headlands, offshore bedrock islands	well protected: large headlands, Santa Catarina Island
Wave climate (nearshore based on mean Fall offshore)	0.7–1.2 m	0.3–0.5 m	0.2–1.0 m
Modern beach sedimentology	Fine to medium-fine sand	Muddy intertidal, medium/coarse sand storm berm	Fine sand
Foredune sedimentology	Foredune with nebkas	No foredune	Well developed foredunes
Strandplain ridges†	Fine/medium-fine sand	Medium/coarse sand	Fine sand
Basal unit(s)	Bedrock; possible overlying fluvial deposits	Fluvial and/or Pleistocene (120ka) coastal deposits	Fluvial and/or Pleistocene (120ka) coastal deposits
Holocene sequence sedimentology	Fine / medium sand strandplain with thin basal muddy unit	Sand/mud strandplain overlying thick muddy basin-fill	Thick basin fill of nearly homogeneous fine to medium sand

* - area of Navegantes plain extrapolated in heavily anthropogenically modified areas proximal to Itajaí River; ** - data from ANA (2000), Milliman and Farnsworth (2011); † - data from FitzGerald et al. (2007)

The northern-most of the three sites, the Navegantes Strandplain, is fed by the Itajaí-Açu rivers, the largest river system draining to the SC coast. The

Navegantes shoreline is largely exposed to open-ocean waves, with only limited protection afforded to the northernmost region by a large bedrock promontory. The strandplain is dominantly composed of fine-grained sand and exhibits repetitive, shallowly seaward-dipping strata (1.5–2.5°) that are occasionally truncated by more steeply dipping clinoforms interpreted as high-energy event markers (Buynevich et al. 2011; FitzGerald et al. 2007). The modern Navegantes beach is fine-grained and dissipative, with a well-developed foredune 3–4 m in height (Fig. 2a).

The Tijucas Strandplain, located *ca.* 50 km south of Navegantes, is built into a ~100 km², semi-enclosed embayment fronted by bedrock headlands and a number of offshore bedrock islands. The strandplain gradually transitions from one dominated by sand proximal to the mid-Holocene highstand shoreline, into a mixed sand-and-mud system in the central plain, to widely spaced cheniers that extend 2.0 km inland from the modern beach. Tijucas is unique among these three sites in that much of the beach and intertidal zone is composed of fine silt and clay. Density profiles, surface sediment samples, and sediment cores collected at different times throughout the northern part of the bay have uncovered a 10–70-cm-thick fluid mud layer resting on top of the consolidated muddy bed (Schettini et al. 2010; FitzGerald et al. unpub.). South of the Tijucas River, the plain's dominant sediment source, the entire beach is mud-dominated; north of the river, it is commonly characterized by a reflective sandy upper berm fronted by intertidal mudflats / banks (Fig. 2b; Klein and Menezes 2001). The northernmost sections of the beach contain mud banks and mangroves.

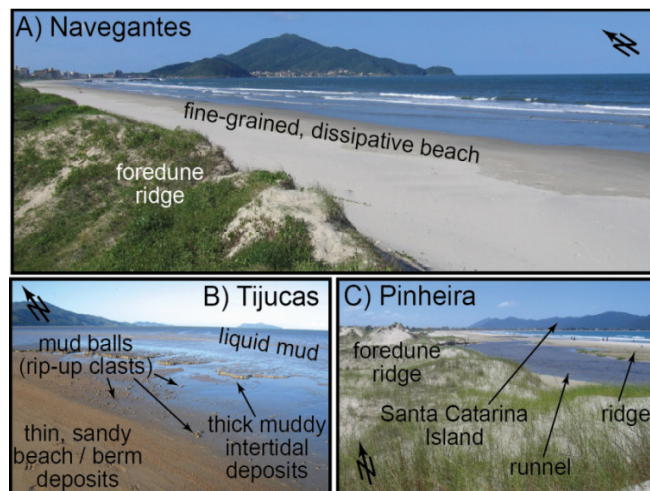


Fig. 2. Views of the beaches at the three study sites. All photos by C. Hein. All three beaches are dissipative, but those at Navegantes and Pinheira are composed of fine-grained sand, while Tijucas is characterized by a sandy berm fronted by a muddy intertidal zone and shoreface.

Pinheira, located ca. 65 km south of Tijucas, is a cusped-shaped strandplain highly protected by large abutting headlands. The plain is composed of well-sorted fine sand derived from the shallow shelf. Although two small rivers discharge along the coast immediately adjacent to the strandplain, there is little evidence that either has contributed much sediment to the development of the strandplain (Hein et al. 2013). This site is largely backed by low, river-modified coastal wetlands. This is the only site of the three with appreciable dunefield development (Hesp et al. 2009). Much of this plain formed from the same process of landward migration and welding of ridge-and-runnel systems that are today visible acting on the low-tide terrace of the fine-grained beach (Fig. 2c).

Methods

A series of 3–6 deep (8.5–24.0 m) sediment cores were collected across each of the strandplains. The cores were collected using a combination of alternating wash boring and percussion direct push that provided 45 cm of continuous recovery every meter. Sections of continuous core were described and photographed in the field. At least one sample was collected within each described sedimentologic unit (2–20 cm sampling intervals). Sediment samples were prepared and analyzed using combined wet / dry sieve (0.5 phi [ϕ] intervals) techniques to determine particle-size characteristics (Folk 1980).

Holocene strandplains were mapped in ArcGIS using digital topographic models (DTM) derived from data (SDS 2013), surficial geologic maps (Horn Filho and Ferreti 2010), and published (FitzGerald et al. 2007; Hein et al. 2013, 2014) and unpublished RTK-GPS and ground-penetrating radar data. Volumes of regressive sequences were calculated from core-log data assuming sediment core transects were representative of stratigraphy throughout strandplains. Sand volumes were calculated from core-log data and known spatial variability in sand contents (*e.g.*, absence of sand at Tijucas south of the Tijucas River).

Numerical hydrodynamic modeling at each site allows for characterization of relative wave energies and investigation of the governing processes driving the variability between them. A separate model domain was used for each region, with bathymetric data derived from SDS (2013) and with constant resolution in both easting and northing directions of approximately 100 m in Cartesian coordinates. Each model was forced at all marine open boundaries with wave observations and model reanalysis results from Araujo et al. (2003), and using seasonal mean and maximum wave climate from re-analysis conducted for Fall and Spring conditions, and was the same for each region. Offshore open boundaries are located in depths of 45–55 m to ensure insignificant bed interaction with the bed near the boundary. We used the JONSWAP distribution and selected frequencies spanning all observed conditions from observations,

mean wave direction, mean significant wave height and period, and utilized the standard deviation of the wave direction to define the directional spreading using analysis by Araujo et al. (2003).

Results and Discussion

Interpretation of the stratigraphic units at Tijucas (Fig. 4) is built upon a large database of sediment cores and radiocarbon dates (Hein et al. in prep). However, wide core spacing, insufficient depth penetration to basal (Pleistocene / bedrock) layers in most cores, and limited (Pinheira; Hein et al. 2013) or absent (Navegantes) chronological data at both Navegantes (Fig. 3) and Pinheira (Fig. 5) limit the interpretation of units with high confidence. Nonetheless, several significant trends across these sites can be discerned.

Stratigraphic Units and Interpretations

The base of the Holocene lithosome is variously shallow bedrock, earlier coastal deposits (*i.e.*, strandplain deposits likely dating to shoreline regression at 120 ka), or lowstand fluvial sediments. Across Tijucas and in the landward-most sediment core at Navegantes, core samples of these basal deposits are generally composed of poorly sorted, angular silty coarse sand and gravel. No such deposits were identified at Pinheira, however the deepest, seaward-most core bottomed on bedrock, suggesting possible absence of this unit.

Situated atop this basal unit at all sites are seaward-dipping silty or sandy clay deposits topped by medium to coarse sand that commonly contains shells. This unit is interpreted as transgressive deposits (backbarrier mud overlain by remnants of barrier sands / shoreline deposits). At Navegantes, these deposits are only recognized with certainty in the landward-most sediment core; elsewhere, they are tentatively interpreted as transgressive deposits, but may instead be a basal section of overlying basin-fill dating to the middle- to late-Holocene regression. At Tijucas and Pinheira, the transgressive unit thins in a seaward direction, and is entirely absent from the seaward-most sediment core at Tijucas. This likely reflects either complete shoreface erosion of these deposits during later stages of the transgression, or non-deposition due to early Holocene RSL at rates greater than those under which barrier systems could form.

Sediments driven onshore during the early to middle Holocene transgression were eventually reworked into barrier ridges (Type C highstand deposits) and barrier-island complexes (Type D highstand deposits) at Navegantes and Tijucas (Hein et al. 2014). No such highstand deposits have been identified at Pinheira, where the shoreline was characterized by bedrock headlands (Hein et al. 2013). At all three sites, these highstand shorelines are fronted by seaward-thickening

regressive shoreline and basin-fill deposits. These range from 45 to 90 km² in area and are up to ca. 20 m thick (Figs. 3–5).

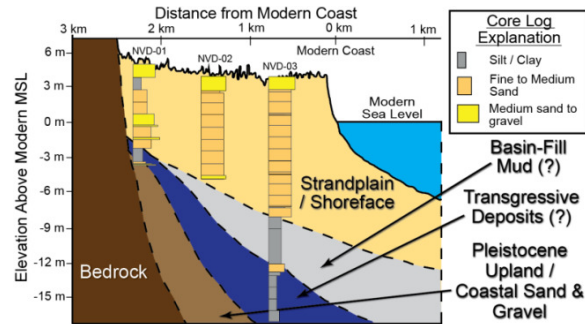


Fig. 3. Simplified shore-normal stratigraphic cross-section of Navegantes Strandplain. Note thin muddy basin-fill deposits underlying thick sand-dominated strandplain. See Fig. 1 for core locations.

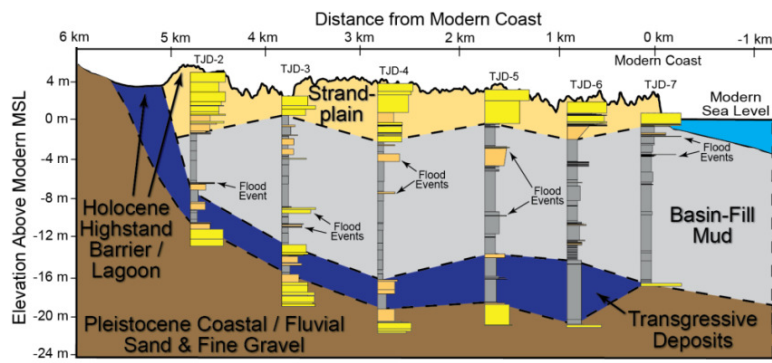


Fig. 4. Simplified cross-section of Tijucas Strandplain. Note thick muddy basin-fill deposits underlying mixed sand-and-mud strandplain. See Fig. 1 for core locations and Fig. 3 for core log explanation. Modified from Hein et al. (in prep).

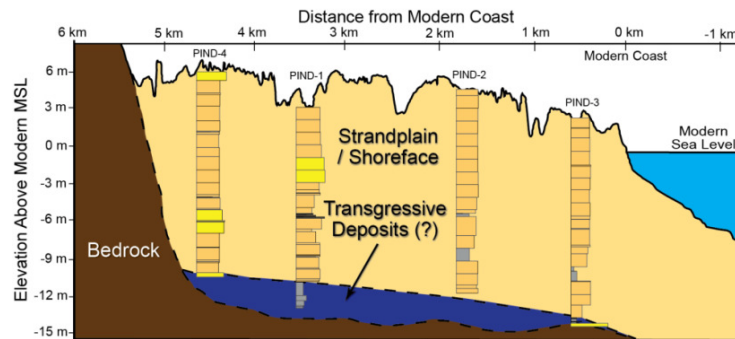


Fig. 5. Simplified cross-section of Pinheira Strandplain. Note thick sandy regressive sequence. See Fig. 1 for core locations and Fig. 3 for core log explanation. Modified from Hein et al. (2013).

The basin-fill sedimentary sequences at Navegantes and Pinheira are largely similar and composed of thick fine to medium sand deposits, which are sedimentologically indistinguishable from overlying shoreface and shoreline deposits (strandplain unit). The basal 5–10 m (below 9 m below MSL) of the regressive deposits at Navegantes contains abundant silt and clay, likely derived from the settling of fine sediments from the Itajaí River in the semi-protected Navegantes embayment during higher stages of RSL. Mud is rare in the Pinheira sequence, and is derived from the flooding of proximal rivers (Hein et al. 2013).

By contrast, sand comprises only ca. 6% of the regressive deposits at Tijucas. The 4–8-m-thick regressive Tijucas Strandplain is underlain by 5–16 m of fluviually derived mud (Fig. 4) deposited as basin-fill sequence at higher stages of RSL and during RSL fall. Thin (< 10 cm, though occasionally as thick as 1 m) sections of fine silty sand to coarse sand are interpreted as having been deposited by major floods of the Tijucas River, such as those observed to deliver moderate volumes of medium to coarse sand to the modern beach. Furthermore, the overlying strandplain unit itself contains abundant mud. The Tijucas strandplain contains extensive mud deposits in the form of cheniers, overbank deposits and mud tidal flats. South of the Tijucas River, the strandplain is entirely composed of mud, with little, if any, sand component. Moreover, north of the Tijucas River, the strandplain alternates between sandy and muddy segments, becoming more mud-dominated in a seaward direction (FitzGerald et al. 2007). By contrast, mud is much less abundant at Navegantes and Pinheira, and primarily forms a surficial cover (< 1.2 m thick) between some of the ridges.

Strandplain Volume Comparisons

The regressive sequences have estimated onshore volumes of 0.6 km³, 1.5 km³, and 0.9 km³, respectively at Navegantes, Tijucas, and Pinheira (Table 2). The volume of the Tijucas sequence is ~2.5 times that of Navegantes, despite Tijucas being fed by a river (Tijucas River) with a drainage area and discharge of only ca. 16% and 19%, respectively, of the drainage area and discharge of the river feeding the Navegantes strandplain (Itajaí-Açu rivers) (Tables 1, 2). Pinheira has a sand volume ~100 times larger than what is expected given the drainage area of the two most proximal rivers which may contribute sediment to this plain. This excess sediment reflects the dominance of a non-fluvial, shelf source for the development of the Pinheira plain, an observation confirmed by the sedimentology of Pinheira strandplain itself (Hein et al. 2013).

Despite its overall volume, the quantity of *sand* within the Tijucas strandplain / basin-fill sequence is only ~20% of the volume of sand within the Navegantes plain. In fact, when normalized by either the associated river's discharge or drainage area, the sand volumes of the two plains are very similar (Table 2).

Stated another way, the volume of *mud* within the Tijucas plain is nearly nine times greater than that within the Navegantes plain. It is this difference that is responsible for the substantially larger volume of the regressive sequence at Tijucas: without this mud, the Tijucas plain would be only ~20% as voluminous as Navegantes, *i.e.*, the approximate volume expected given the relative drainage of the Tijucas River as compared with the Itajaí-Açu rivers.

Table 2. Comparison of sediment volumes at the three studied strandplain systems.

	Navegantes	Tijucas	Pinheira
Surface area of Holocene coastal deposits	45 km ²	90 km ²	59 km ²
Ave. thickness regressive deposits	8–16 m	12–20 m	14–18 m
Ave. thickness regressive sand	9.5 m	3.0 m	15.5 m
Volume of onshore regressive sequence	5.8 x 10 ⁸ m ³	14.8 x 10 ⁸ m ³	9.1 x 10 ⁸ m ³
% Holocene sequence composed of sand (estimated)	~75% (4.3 x 10 ⁸ m ³)	~6% (0.9 x 10 ⁸ m ³)	~100% (9.1 x 10 ⁸ m ³)
Regressive sediment volume / river drainage area	0.4 x 10 ⁸ m ³ /km ²	6.1 x 10 ⁸ m ³ /km ²	22.6 x 10 ⁸ m ³ /km ²
Regressive sediment volume / river discharge	0.85 x 10 ⁸ m ³ /km ³	11.1 x 10 ⁸ m ³ /km ³	34.7 x 10 ⁸ m ³ /km ³
Regressive sand volume / river drainage area	0.28 x 10 ⁸ m ³ /km ²	0.36 x 10 ⁸ m ³ /km ²	22.6 x 10 ⁸ m ³ /km ²
Regressive sand volume / river discharge	0.62 x 10 ⁸ m ³ /km ³	0.67 x 10 ⁸ m ³ /km ³	34.7 x 10 ⁸ m ³ /km ³

Sediment Supply, Wave Energy and Depositional Trends

One mechanism possibly responsible for the disparity in sand/mud content between Tijucas and Navegantes is differences in the rate and/or nature of sediment delivered to the coast by these two systems. Unfortunately, no detailed hydrologic study has been completed on the Tijucas River. Moreover, suspended-sediment export rates are poorly constrained for the Tijucas River. Bedload transport rates are absent for both the Tijucas and Itajaí-Açu rivers. This lack of data constrains our ability to explore possible connections between fluvial sediment export processes and observed differences in the sediment content of each the Tijucas and Navegantes plains. However, to a first-order,

river sediment yields are directly correlated to discharge and drainage basin area (Milliman and Farnsworth 2011); minimum estimates – based on low-flow conditions – of suspended sediment yields from the Tijucas River (0.1 Mt/yr; Schettini et al. 1996) are ~13% of those from the Itajaí-Açu rivers, the same magnitude order as the relative basin area (16%) and discharge (19%) of the Tijucas River compared to the Itajaí-Açu rivers.

Inter-basin differences in sediment yields have also been demonstrated to be attributed to river basin lithology (*e.g.*, Hicks et al. 1996). However, the Tijucas and Itajaí-Açu rivers basins share largely similar lithologies as they both drain the Archaean- to Proterozoic-aged igneous (granities) and meta-sedimentary rocks (dominantly gneiss) of the Brusque fold belt (Jacques et al. 2014). Intense weathering of this crystalline bedrock has produced a saprolite that is tens of meters thick and supplies large quantities of fine-grained sediment as well as sand and fine gravel to both the Tijucas and Itajaí-Açu rivers. However, it is noted that the Itajaí-Açu River, with its much larger drainage basin, extends landward into the sedimentary Paleozoic Paraná Basin, and thus is likely to drain more sand-rich source regions. A more detailed characterization of the lithologies of these basins is beyond the scope of this study, but will serve as important future contribution to understanding the causes of variability observed within the SC strandplain systems.

Another likely reason for differences observed in the sand/mud content of these two plains is the contrasts in wave energy, resulting from the configurations of local bedrock headlands and bathymetry fronting the embayments. Hydrodynamic modeling (Fig. 6) shows that wave climate varies among the sites due to: 1) alignment of offshore isobaths; 2) presence of offshore islands; 3) shoreline orientation; and 4) slope of the shoreface. These factors contribute to differential wave transformation and wave energy dissipation. Waves 6–8 km offshore of Navegantes and Pinheira have similar characteristics and are larger than those offshore of Tijucas (Fig. 6a). For example, significant wave heights for Navegantes and Pinheira are in the range of 1.0–1.2 m, whereas at Tijucas they are from 0.7–0.9 m. Inside the 15 m isobath, waves at all three embayments experience significant shoaling and refraction, and wave transformation is chiefly governed by the shoreface slope (Fig. 6b). Tijucas is fronted by the shallowest slope and correspondingly has the lowest wave climate. Inshore of the 6-m isobaths, orbital velocities and significant wave heights are larger at Navegantes compared to Pinheira, even though the overall bathymetry is deeper offshore of Pinheira. The overall greater wave energy at Navegantes is explained by its open-coast condition versus the semi-protected nature of the Pinheira embayment, which results in wave crest spreading (refraction and diffraction).

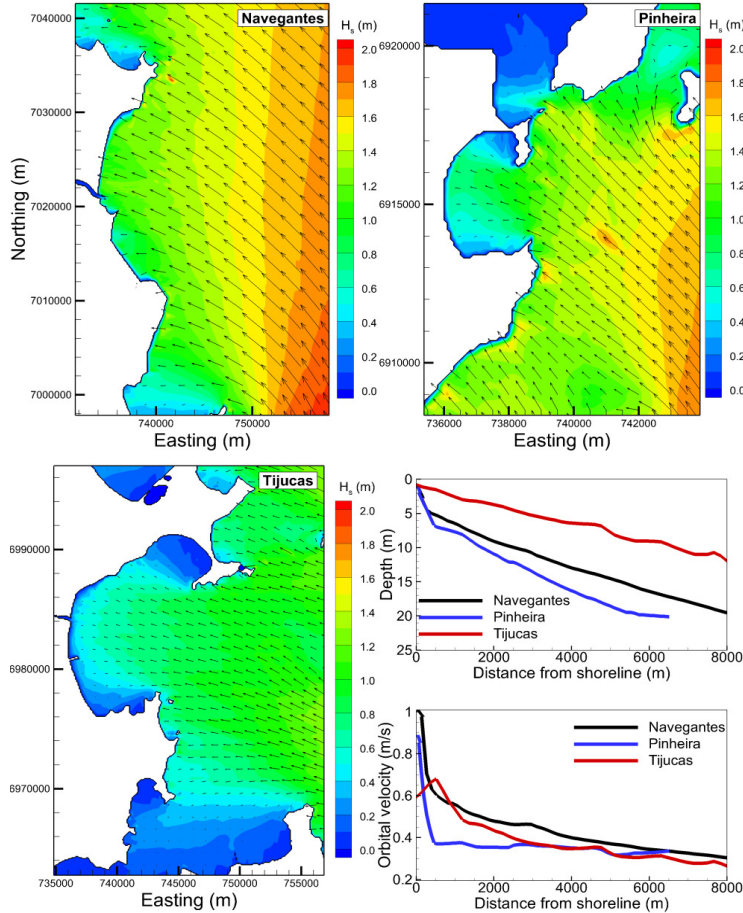


Fig. 7. Distribution of significant wave heights for Navegantes, Pinheira and Tijucas (color contours) during mean fall conditions (wave forcing from Araujo et al. 2003). Vectors are scaled and show the direction of wave-energy transport. The lower right panel shows profiles from nearshore to offshore of the bathymetry for each site (top), and the near-bed orbital velocity for this simulation (bottom).

Tijucas is tide-modified ($RTR \gg 3$; Klein and Menezes 2001), but in classical sense exhibits wave-dominated features. The bedrock morphology (headlands, etc.) and the presence of fluid mud at this site together reduce wave energy and contribute to increased mud deposition: all of the mud from Tijucas River gets trapped in Tijucas Bay by the headlands, contributing to the bay-fill / strandplain volume. At Navegantes, higher wave energy from exposure to shelf conditions leads to removal of mud onto the shelf. While some of this mud is likely deposited within the earliest, deepest sections of the strandplain, the fate of the rest of the mud is unknown; additional study is required to determine its

eventual fate. Assuming that the mud:sand ratio at Navegantes is the same as Tijucas, the higher wave energy, steeper slope and open conditions at Navegantes provide for higher near-bottom orbital velocities which likely rework the mud from the Itajaí-Açu rivers away from the shoreline and into deeper regions offshore.

The greater apparent dip of the Pinheira versus Navegantes plains may be due to the more protected nature and lower wave environment at Pinheira, as compared to the exposed Navegantes Plain. The fine sand at Pinheira compared to the fine to medium-fine sand at Navegantes explains further the present observed conditions. All else equal, a beach experiencing greater wave energy will be flatter, and beaches with greater wave energy tend to have coarser sand and steeper beach faces. Navegantes has both of these characteristics as compared to Pinheira (Table 1). These observations are further supported by GPR reflection angles (FitzGerald et al. 2007) and modern shoreface slopes (Table 1). Wave simulations confirm that it is the higher wave energy at Navegantes that is responsible for the flatter slopes found at that beach and in that plain, despite its somewhat coarser sediment population.

Conclusions

Relative SL along the southern Brazil coast reached a highstand elevation of 1–4 m above MSL at *ca.* 5.8 ka. Beach and shoreface sediments were driven onshore during this transgression, forming discontinuous barrier-lagoon systems, the remnants of which compose the deepest sections of basin-fill sequences. Following the highstand, basin infilling at the leading edge of a regression forced by RSL fall took the form of 9–16-m thick sandy shoreface deposits at the strandplains at Pinheira and Navegantes. In contrast, infilling at Tijucas was dominated by fine sediments, resulting in the deposition of a 20-m thick muddy sequence capped by a strandplain of mixed mud and sand. Hydrodynamic modeling demonstrates the dominant role of wave energy in producing these vastly different basin-fill sequences. The lack of a river source to Pinheira results in a relative dearth of fine sediments, and basin infilling is dominated by shelf-derived sand driven onshore by waves. Along the open coast of Navegantes, relatively high wave energy removes fine sediments derived from the Itajaí-Açu rivers, producing a sand-dominated basin-fill sequence. At Tijucas, bordering headlands greatly reduce wave energy and minimize shelf sediment input. This allows for the accumulation of liquid mud in the shoreface and initiates a feedback, which further reduces shoreline wave energy. The result has been the deposition of a basin-fill sequence that contains a volume of sediment comparable to that of Navegantes. However, the ratio of the volume of sand at Tijucas and Navegantes is of the same magnitude order as the relative sediment discharges of their source rivers.

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