Third IGCP 495 Meeting

Quaternary Land-Ocean Interaction: Natural and Human Forcings on Coastal Evolution

September, 2006

Santa Catarina and Paraná, Brazil

Field Trip Guidebook of Santa Catarina coast

Antonio Henrique da F. Klein
Duncan FitzGerald
William Cleary
José G.N de Abreu
Joao Thadeu de Menezes
Rafael Petermann
Christopher Hein
Ilya Buynevich

(Editors)

September 20th, 2006

Santa Catarina, Brazil

IGCP-495 Quaternary Land-Ocean Interactions:
Driving Mechanisms and Coastal Responses.
Project Leaders: Professor Antony J. Long
Dr. M. Shahidul Islam

SANTA CATARINA FIELD TRIP SCHEDULE

SEPTEMBER 20th

08:00 h. Departure **from Hotel Plaza Camboriú, Balneário Camboriú**

08:40-09:00 h. Stop 1A **Tijucas coast Pleistocene barrier**

09:25-09:40 h. **Stop 1B** Tijucas Cheniers

09:45-10:00 h. **Stop 1C** Tijucas muddy beach

10:40-10:55 h. **Stop 2** Taquaras beach

11:00-13:00 h. **Stop** 3 *Cablecar* and lunch. Balneário Camboriú Beach

13:30-13:45 h. **Stop 4** Itajaí hill

14:10-14:40 h. **Stop 5A** Piçarras beach

14:50-15:10 h. Stop 5B **Piçarras Pleistocene barrier**

INTRODUCTION

The IGCP fieldtrip to northern Santa Catarina (25°-26° S. Lat.) will cover a diverse section of coast varying from the strandplains of Tijucas and Navegantes and their associated estuaries of Tijucas and Itajai Rivers to the embayed beaches of Taquaras/Taquarinhas, Balneário Camboriú and Piçarras (Figure 1). The strandplains are a product of an abundant sediment supply and forced regression. Given the relatively small size of their catchments, the sediment output of the Tijucas and Itajai Rivers is quite large, which reflects the ruggedness of the topography and deeply weathered saprolite comprising much of the upper portion of the two basins. Differences in grain size, nearshore bathymetry, and wave exposure have led to development of vastly different beach morphologies along this coast ranging from highly dissipative shores to steep, reflective beaches. The trip is designed to introduce the participants to the geomorphology, sea-level history, geologic processes that have controlled the evolution of this region, and coastal engineering studies. An understanding of this coast has been achieved using a multi-disciplinary approach involving geomorphological, sedimentological, geophysical, and coastal engineering studies.

PHYSICAL SETTING

The central Santa Catarina coast of Brazil has a relatively narrow discontinuous coastal plain that is bordered by a variety of Archaean to Proterozoic-aged crystalline rocks. Exposed granitic plutons form numerous low relief headlands that dominate this section of coast. The large quartz grains and feldspar phenocrysts characterizing many of the granite outcrops demonstrate their great exhumation depths and their old age. The irregular coastline has been largely smoothed due to the deposition of extensive strandplains whose sediment is derived from small rivers and shelf sources (Dominguez *et al.*, 1987; Cleary *et al.*, 2004).

Wave energy varies greatly along the coast and is governed by shoreline orientation, exposure to open-ocean conditions, and inner shelf bathymetry. A wave gage located off Santa Catarina Island in 80 m of water (Jan 2002 to Jan 2003) recorded a bimodal sea-swell state with the following conditions: 1) well-defined 12s swell from the south with increasing significant heights from summer to winter, ranging from 1.25 to 2.0 m; and 2) a 8s sea with an average significant height of 1.25 m from the east. Although a general trend of northerly longshore sediment transport exists along this section of coast, rates and directions are highly variable and related to local refraction patterns. The Santa Catarina coast is microtidal with a mixed tide that is mainly semi-diurnal. Spring tidal ranges increase from approximately 0.5 m in the south to 1.2 m to the north.

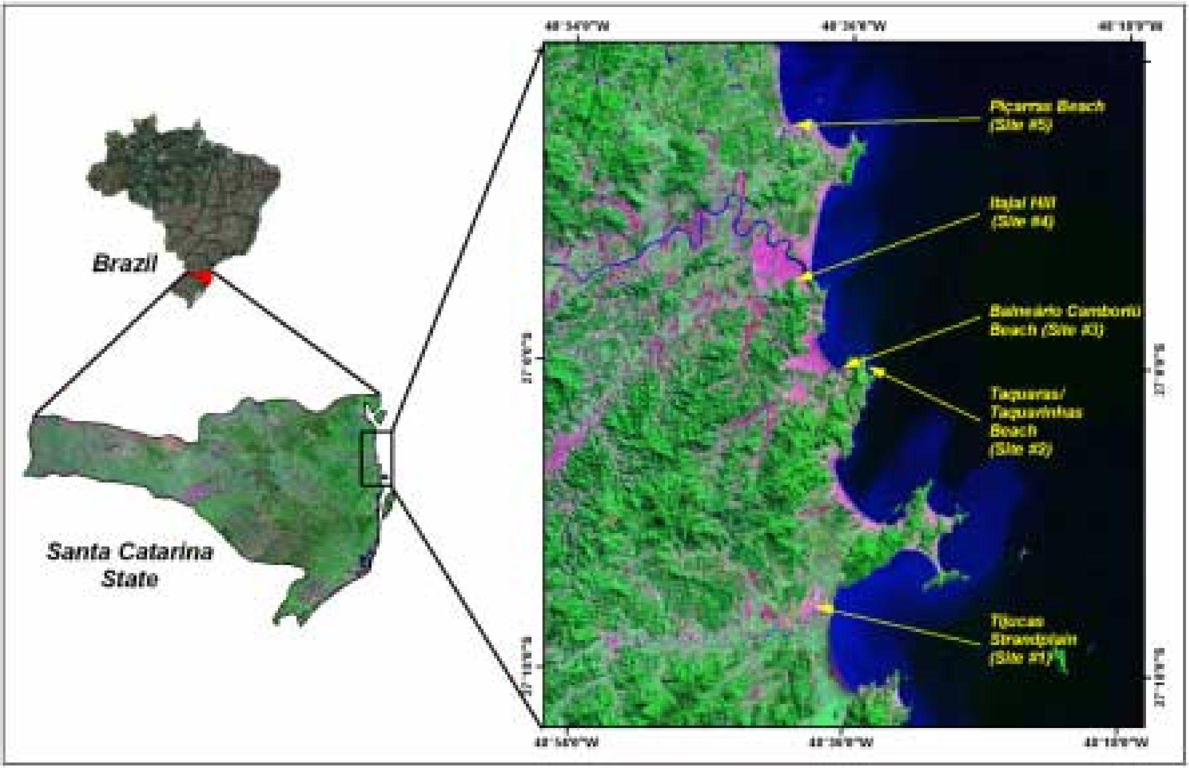


Figure 1. Location of sites visited during the field excursion. Image satellite source: NASA. S_22_25_2000 MrSid. 2000. https://zulu.ssc.nasa.gov/mrsid.

SOUTHERN BRAZIL SEA LEVEL HISTORY

The initiation of many strandplains, particularly those in the Northern Hemisphere, occurred during the Mid-Holocene, coinciding with a deceleration of sea-level rise when sediment supply out paced rising sea level. In the Southern Hemisphere strandplain development began 5 to 6.5 ka when sea level reached a high stand (e.g. Tuncurry, NSW Australia; Roy *et al.*, 1994) and in many regions sea level has fallen 2 to 4 m since that time (Angulo and Lessa, 1997; Angulo *et al.*, 2006). The fall in sea level in the southern oceans is a consequence of global isostasy. Mitrovica and Milne (2002) showed that collapsing forebulges in previously glaciated continental margins created accommodation space that siphoned water from far-field regions including the South Atlantic. Additional sea level lowering in the southern oceans is attributed to further accommodation space created by ocean loading in the near field. A recent test of this isostatic model for the east coast of South America showed a good correspondence between established sea level histories and predicted sea level curves (Milne *et al.*, 2005).

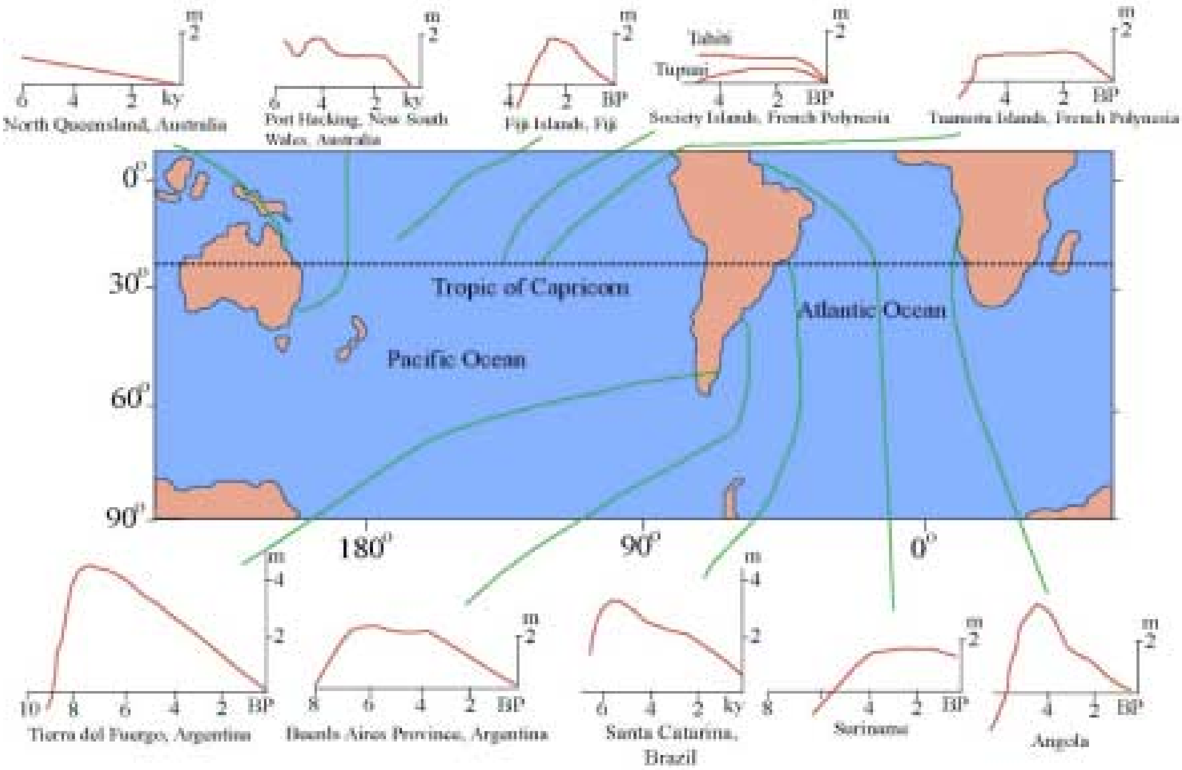


Figure 2. Sea level curves for Southern Hemisphere coasts. Note the fall in sea level during the past 5 to 6 ka (from Angulo and Lessa, 1997; Angulo *et al.*, 2006).

Along the southern Brazilian coast, an encrusting gastropod (vermitid: *Petaloconchus varians*) has been used a paleo-sea level indicator (Angulo and Lessa, 1997). The best estimates show that on the Santa Catarina coast sea level reached a highstand approximately 5.8 ka at an elevation of 2.5 m above present sea level (Angulo *et al.*, 2005). Along much of the southern coast of Brazil this forced regression coupled with an abundant supply of sediment has produced extensive strandplains that have smoothed the coast.

STOP #1 TIJUCAS STRANDPLAIN AND ESTUARY

We will visit three sites at the Tijucas strandplain that will help to explain its stratigraphy, sedimentological variability, and complex evolution. The overall construction of the plains and drastic change in sedimentary regime will evoke much discussion of the dominant forcings. Is it sea-level changes, climatic influences in precipitation and vegetation cover, natural basinal filling or other causes? We'll begin at a landward ridge that has been interpreted as the oxygen isotope 5e Pleistocene highstand shoreline and then proceed to the mid-Holocene highstand shoreline. Next, we'll look at cores and GPR records to explore the stratigraphy and type of ridge construction. The last stop for this part of the field trip will be at the beach and mouth of the estuary where we'll view the present wave regime and shoreline processes responsible for the present beach ridge-chenier system.

The Tijucas plain is approximately 5 km wide and extends 12 km along the coast. Up basin the drainage becomes segmented, narrower, and bounded by increasingly higher topography. The strand plain slopes very gently seaward and relief along the plain is generally less than a meter. There are several exceptions to this trend where the relief may reach 2 m, which is likely related to short term stillstands when the dune system was able to build vertically before being cutoff from its sand supply by a resumption of beach-ridge progradation.

The Tijucas strandplain has built into a semi-enclosed coastal basin protected to the north and south by low relief headlands and by a number of offshore islands. The mean tidal range is 0.8 m increasing to 1.2 m during spring tide conditions. The deepwater wave heights are between 1.0 and 1.5 m with a period ranging 8 to 10 sec. Due to the shore's protected nature ocean swell are almost totally refracted and the coast is largely swashed-aligned with low rates of longshore transport. The plain is fed with sediment from the Tijucas River, which flows through the middle of the plain. It has a relatively small drainage system with a catchment of 2420 km^2 and an average discharge of 40 m^3/sec (Figure 3). During periods of intense rainfall the high relief of the drainage basin produces flood discharges that can increase average flows by two orders of magnitude. Intense weathering of the Mesozoic-age bedrock within the drainage system has produced a saprolite that is tens of meters thick. During low flow conditions, the river delivers little sediment to the coast. However, during high precipitation events the saprolite supplies large quantities of fine-grained sediment as well as sand and fine gravel. During these periods the river turns chocolate brown and is thick with suspended sediment. Recent aggregate mining in the upstream river has decreased sand delivery to mouth and the contribution of coarse sediment to the nearshore.

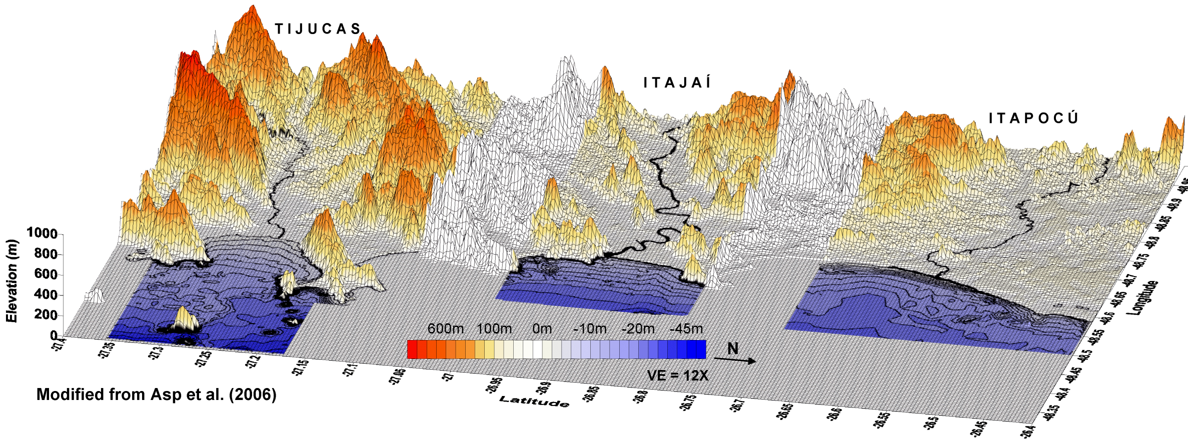


Figure 3. Tijucas, Itajaí River and Itapocú River catchments morphology.

To date, approximately 20 km of Ground Penetrating Radar (GPR) profiles and 24 sediment cores have been gathered at the study site. Although these are preliminary data, they do provide insight into the stratigraphic framework and constructional history of the plain. The strandplain is relatively flat and low gradient rising gently westward towards a high stand shoreline (elevation ~ 2.5 m), which is defined by a 1.0 to 1.5 m high dune ridge. Four hundred meters landward of this ridge the plain is punctuated by a 4 m-high scarp, which has tentatively been interpreted as the oxygen isotope 5e Pleistocene highstand shoreline. This interpretation is based on the dating of similar features reported at other Brazilian strandplains (Dominguez *et al.*, 1987). GPR reflector geometry and the facies association recorded in three sediment cores along a shore-normal transect suggest that the highstand ridge represents the leading edge of the Holocene transgression (Figure 4). Low angle, landward dipping reflectors produced by coarse sand layers (identified in hand augers and a core) front the ridge and prograde into muddy sediments. This sequence is believed to represent washover sands that were being transported into a muddy lagoon that existed between the Pleistocene scarp and the Holocene highstand transgressive barrier (Asp *et al.*, 2005; FitzGerald *et al.*, 2006).

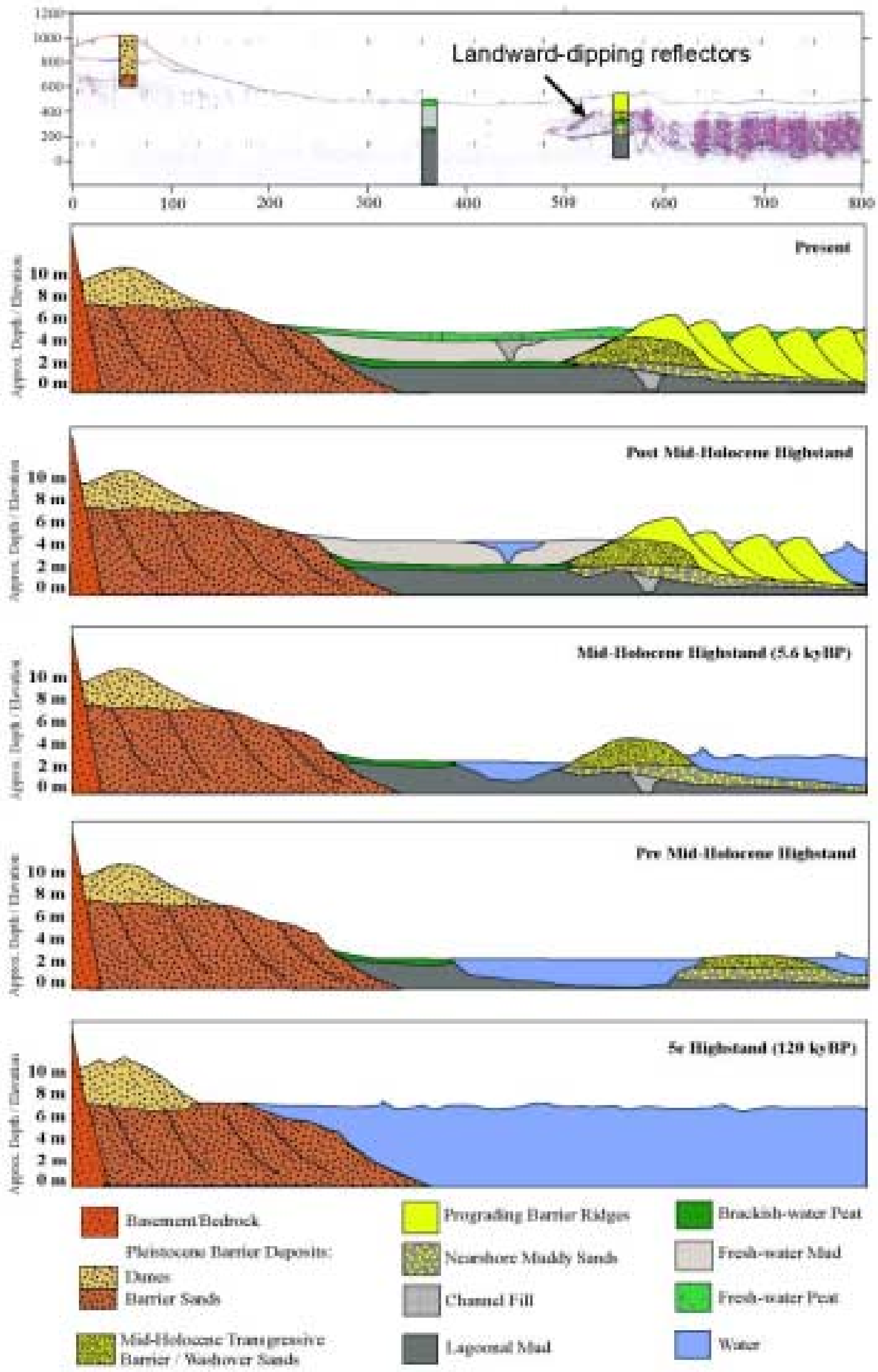


Figure 4. Conceptualized evolution of the highstand Holocene strandplain ridge system (Duncan FitzGerald, William Cleary and Nils Asp, personal communication).

Immediately east of the Holocene highstand, a GPR transect reveals repetitive seaward dipping reflectors that depict beach, shoreface, and foreshore accretion (Figure 5). Auger cores in this region indicate that the progradational sequence consists of medium to coarse-grained sand. The dip of the reflectors (5 to 12 degrees) and coarse nature of the sediment suggest that deposition took place in a moderately high-energy setting that is quite different from today's environment. When compared to geophysical records of the younger seaward plain, which is dominated by mud containing widely-spaced sandy ridges (Figure 6), it is apparent that temporal changes in wave energy, sedimentation patterns along the shore, and/or the sediment load of the Tijucas River have profoundly affected the depositional history of the strandplain.

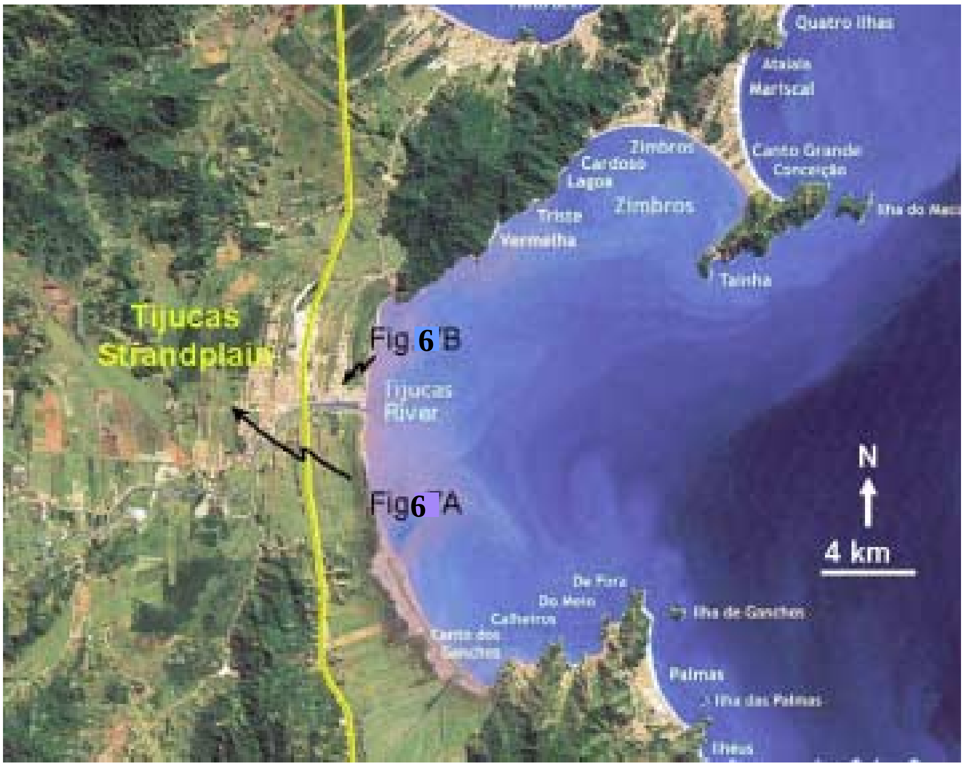


Figure 5. Vertical aerial view of the Tijucas strandplain. Note the Tijucas River and the protected nature of the Tijucas Embayment. Locations given for GPR profiles in Figure 6.

The initial geophysical survey also demonstrated that the thickness of the clinoforms decreases in a down dip direction, reflecting a reduction in accommodation space for sand deposition. This trend can be explained by either a rapid rate of sea-level fall, or more likely, by decreasing accommodation space due to shoaling offshore caused by fine-grained sedimentation from the suspension load of the river. In the latter scenario the thickness of the Holocene regressive package remains fairly constant, but the ratio between the steeply dipping sandy beach nearshore units and the lower muddy flat-lying offshore deposits decrease seaward. A series of deep cores through the entire plain sequence is needed to confirm this.

The present coast is dominated by mud, producing a widely spaced chenier system that extends 2.0 km inland. The inland portion of the strandplain is characterized by tightly-spaced beach ridges, although occasional chenier systems do exist. Recent radiocarbon dating of shells underlying one of the most landward chenier ridges, indicates that the transition from sand to mud-dominated deposition took place sometime prior 1 ka (Buynevich *et al.*, 2005). The reason for this alteration in the sedimentation regime within Tijucas Bay may be related to decreasing wave energy due to bay infilling. Alternately, it may be the result of changes in the fluvial bedload/suspended load ratio caused by climate change, which in turn produced modifications in vegetation patterns, bedrock weathering and soil formation processes, and ultimately sediment contribution in the drainage basin-dominated sequence.

Reinforcing the relevance of recent fine-grained sedimentation in the area mud flat and mud bank formation at beachface can be referred (Klein and Menezes, 2001) (Figure 7 and 8).

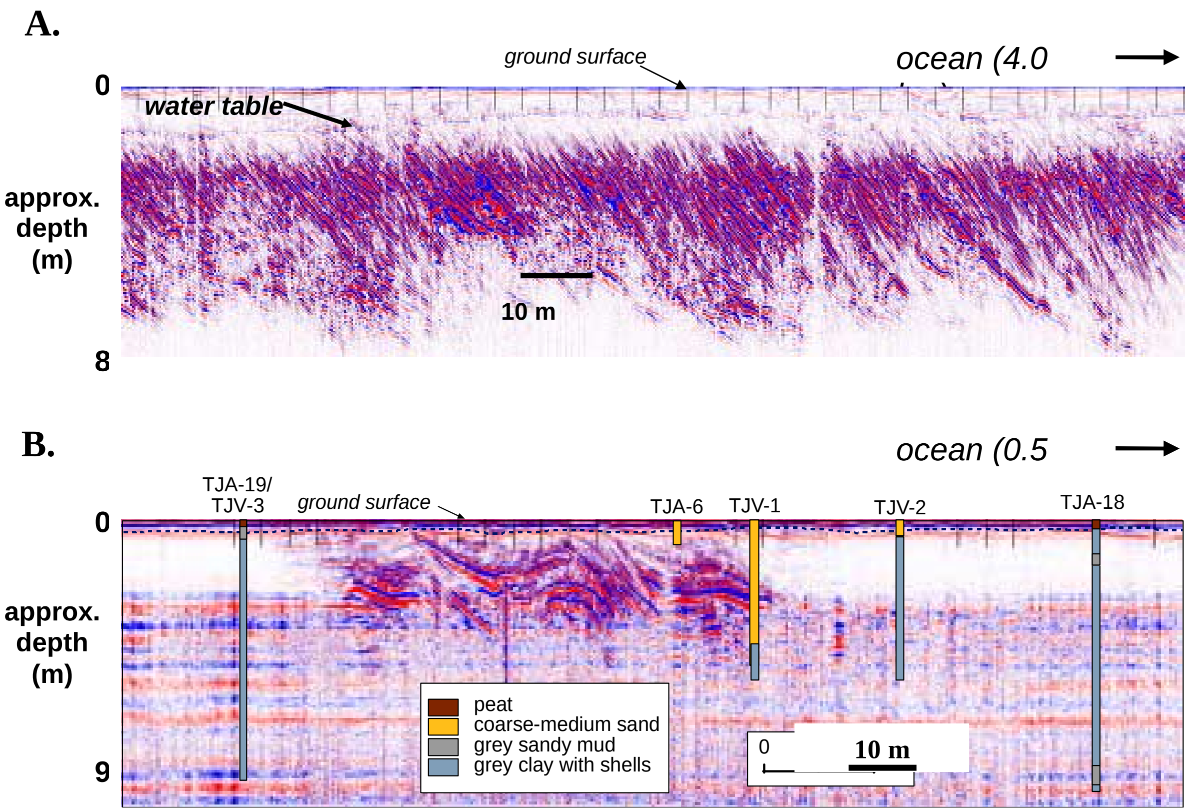


Figure 6. Shore normal GPR transects taken along dirt roadways north of the Tijucas River. A. Sandrich section of the plain. The landward most profile images steeply dipping reflectors formed by shoreface and foreshore progradation. B. Mud-rich section of the plain. Subsurface image from the younger part of the plain reveals a different, mud-dominatedregime, with sand deposited in narrow, low ridges (TJA – Eijkelkamp auger core; TJV – vibracore) (Buynevich *et al.*, 2005).

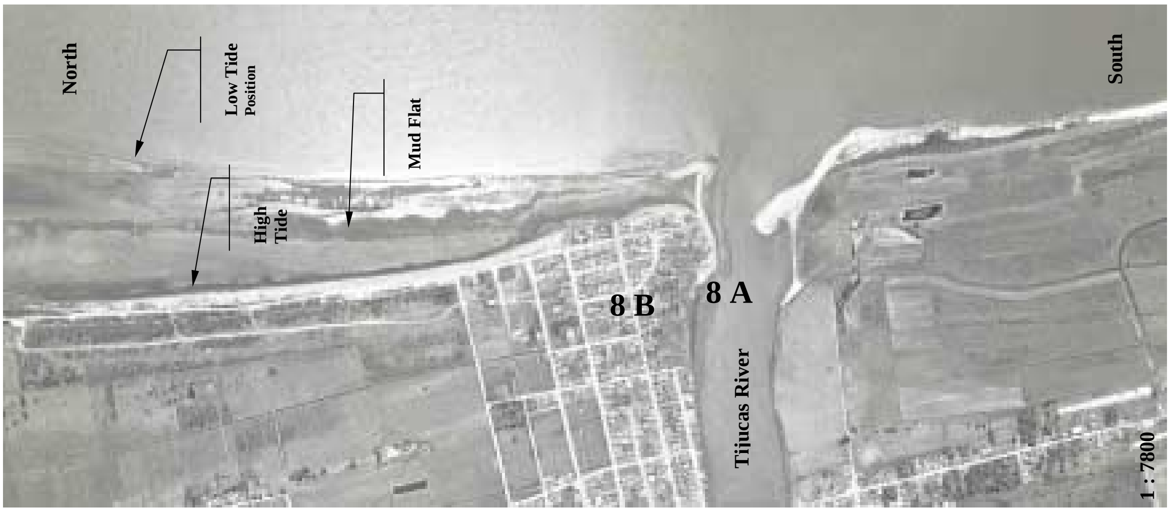


Figure 7. The reflective tidal modified beach with tidal flat and mud ridge at the river mouth in Tijucas bay (Klein and Menezes*, 2001*). Locations given for photos in Figure 8.

Figure 8. Ground photos of the Tijucas River. A. View of the river mouth looking southward. The upper beach (out of the picture) is composed of moderately-sorted, medium to coarse sand. The intertidal zone consists of compact muddy sand with numerous clay intraclasts. The armored clay balls range from pebble to cobble size. Note that breaking waves are being modified by the high concentration of suspended sediment. B. North of the river mouth the lower beach is composed of a 2- m thick soupy mud (Photos Author: Duncan FitzGerald).

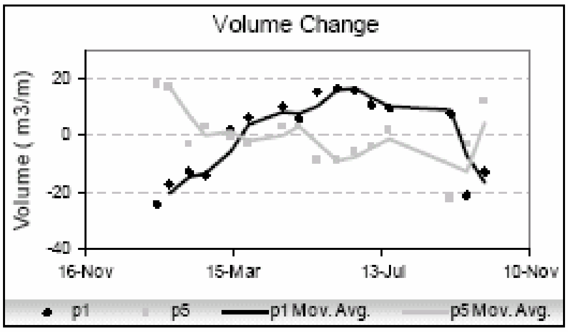
STOP #2 TAQUARAS/TAQUARINHAS REFLECTIVE BEACH

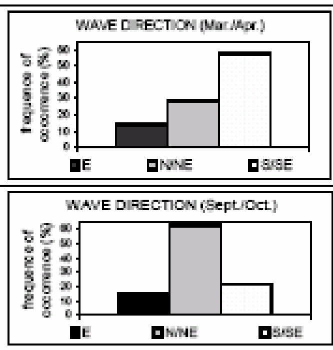
We will visit two sites at the Taquaras/Taquarinhas beach that will help to explain its morphodynamic. We'll begin at the beach that has been interpreted as reflective beach. Next, we'll have an over view of mainland beach and the wave regime and shoreline processes responsible to form beach cusps.

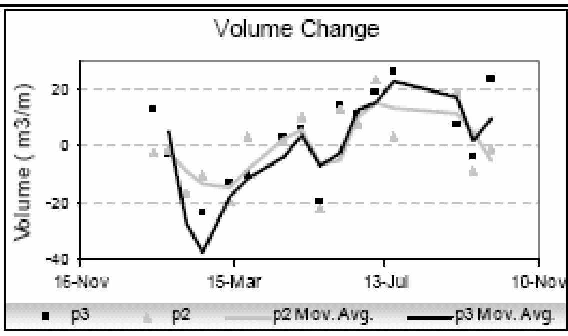
Taquaras/Taquarinhas Beach is divided by a rocky outcrop that extends about 10 m offshore, located in the northern sector of the beach arc (Figure 9). These beaches are considered to be part of the same beach system, as they belong to the same beach arc and the outcrop does not interrupt the continuity of the shoreline. They have also similar sedimentary characteristics and sediment exchanges (Klein 2005). This beach system has a parabolic planform, with a curved zone, a transitional zone, and a straight end. The shoreline is 1570 m long, with an average dry beach width of 27 m. This reflective beach is composed by coarse sand (0.90 mm), has a N-S orientation, and is exposed to the waves from the SE quadrant. Morphologic characteristics include beach cusps wave length between 30 to 35 m, and there are no submerged bars (Klein and Menezes, 2001). After storm surge event a 3 meters scarp could be viewed.

Figure 9. Vertical aerial view of the Taquaras/Taquarinhas mainland beach (Image source Google Earth).

Beach volume variation in different sections of the beach is presented in Figure 10. This figure shows, starting from the top left, beach volume variations in Profiles 1 and 5 during the period shown. Note the opposite trends between these two profiles, while Profile 1 is eroding Profile 5 is accreting, and vice versa. Profile 1 is located at the northern end of the beach, while Profile 5 is located at the southern end of the beach (see Figure 10). The opposite behavior between these two profiles results from changes in wave direction, as illustrated in the top right diagram. Simple linear correlation between volume variations in different profiles are shown in the table (right bottom); similar variations of Profiles 2 and 3 in the central north section of the beach is shown in the left bottom diagram.







	P2	P3	P4	P5	P6
Profile 1	0.39	0.26	0.25	*- 0.63*	*-0.43*
Profile 2	-	*0.69*	0.28	- 0.22	0.02
Profile 3	-	-	0.28	0.13	0.29
Profile 4	-	-	-	0.21	-0.25
Profile 5	-	-	-	-	0.31

Italic gray numbers p<0.05.

Figure 10. Inverse beach volume changes between Profiles 1 and 6, similar volume variation between Profiles 2 and 3, and correlation coefficients between all profiles at Taquaras/Taquarinhas Beach. Predominant wave directions are shown for the months March and April, and September and October (Klein *et al.*, 2002).

The out of phase variations between opposite ends observed at Taquaras/Taquarinhas Beach suggests an apparent rotation of the beach planform, and this rotation might be a response of changes in predominant wave direction. According to field data, Taquaras/Taquarinhas Beach exhibited a behavior similar to the one described by the theoretical model presented in Figure 11. In this beach, erosive events in one extremity imply in sediment being transported and redistributed to another sector of the beach. It shall return to its original location when predominant wave direction changes.

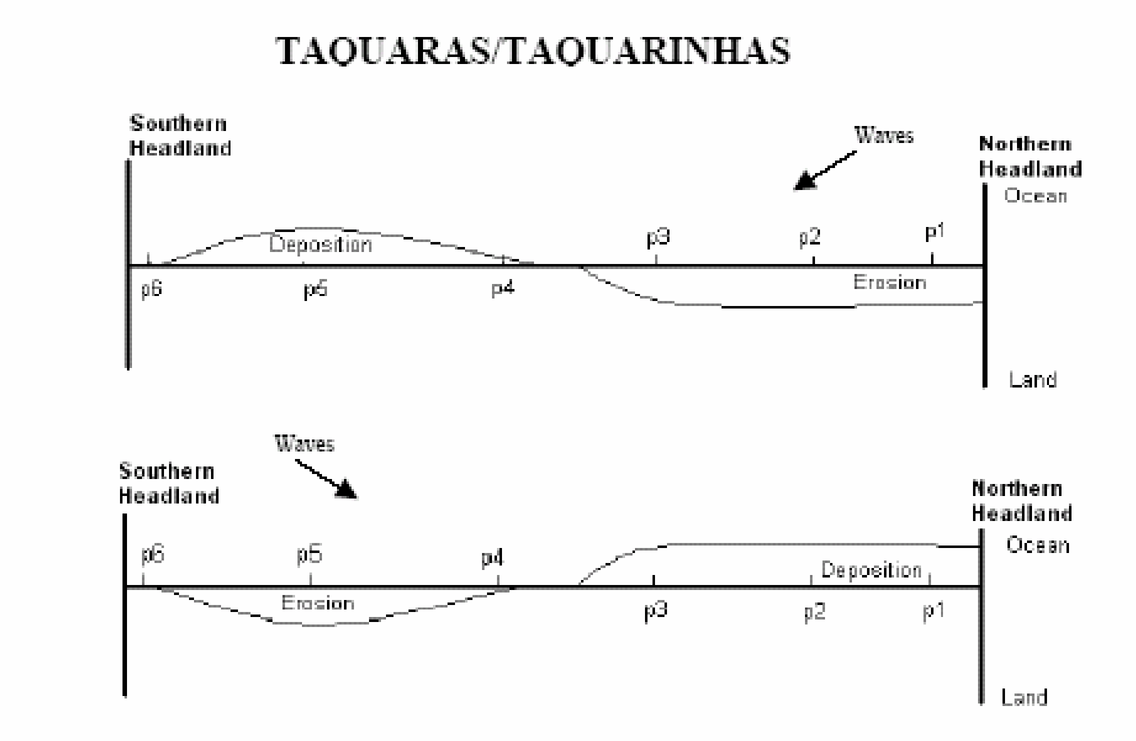


Figure 11.Schematic diagram representing the general trend of sediment removal at Taquaras/Taquarinhas Beach (Klein *et al*., 2002)

Klein and Menezes (2001) reported that the beach type can be directly be associated with geological inheritance through its influence on sediment source and type. In norther sector of Santa Catarina coast reflective beaches have coarse sediments (ex. Taquaras/Taquarinhas beach) resulting from reworking of older deposits (Fan deltas or older barrier islands systems) (Figure 12 and 13a). Dissipative beaches are associated with beach ridges or foredune ridges with fine sediment input (sand) throught a river influx (Figure 13c) and intermediate beaches are placed where medium sand reworked from old barrier island (Pleistocene deposits 5e) and river sediment input occurs (Figure 13b). There is also a relationship between nearshore slope and the type of exposed beach. Reflective beaches normally present steeper nearshore slope (1:40) than that intermediate and dissipative (between 1:100 and 1:300).

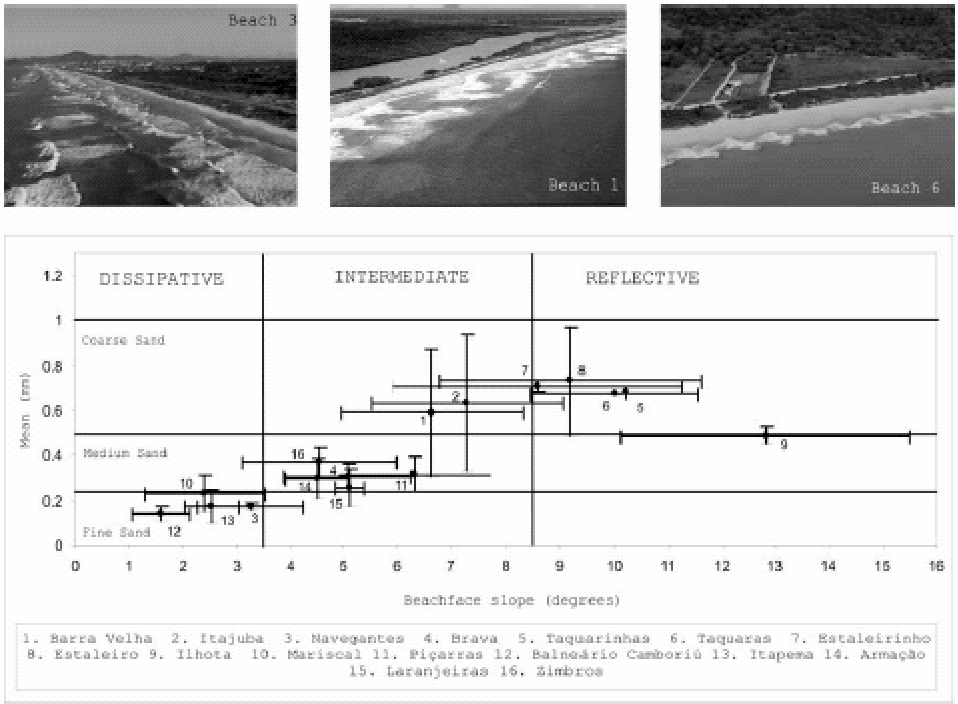


Figure 12. Relationship between sedimentary grain size and slope of the beachface indicates the importance of morphodynamic stages and energy level (Klein and Menezes, 2001).

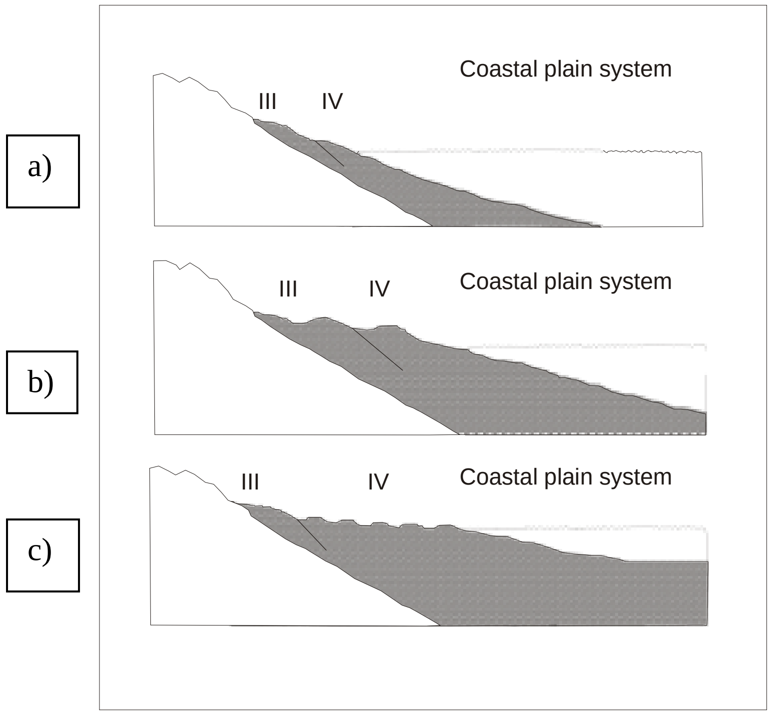


Figure 13. Relation between type of beach and coastal plain system for exposed beaches (a) Reflective beaches; (b) intermediate beaches; and (c) dissipative beaches. (not to scale). Pleistocene sediments (5e) (III); Holocene sediments (IV) (Klein and Menezes, 2001).

Geophysical profiles collected from mainland beaches of Camboriu Peninsula (Estalerinho, Estaleiro, Taquaras) indicate relatively complex reflection patterns within barrier lithosomes, with traces of paleo-lagoon in the landward segment and bedrock ledges in the deeper sections of Estalerinho Beach. In contrast to relatively regular strandplain architecture, the embayed beaches exhibit sedimentary patterns that reflect interaction of adjacent bedrock promontories and islands, refracting waves, and cross-shore sediment fluxes. High vegetated dune ridges are common at a number of mainland beaches, providing additional sediment sink for the coastal sands. Small inlets adjacent to headlands aid in upland drainage following large rainstorms and may be ephemeral in nature. At Estalerinho Beach, both berm and dune scarps attest to the high-energy wave climate of these largely reflective beaches. A relict storm scarp imaged beneath Estaleiro Beach coincides with accumulation of heavy minerals in the sediment core (see figure), attesting to past storm impact.

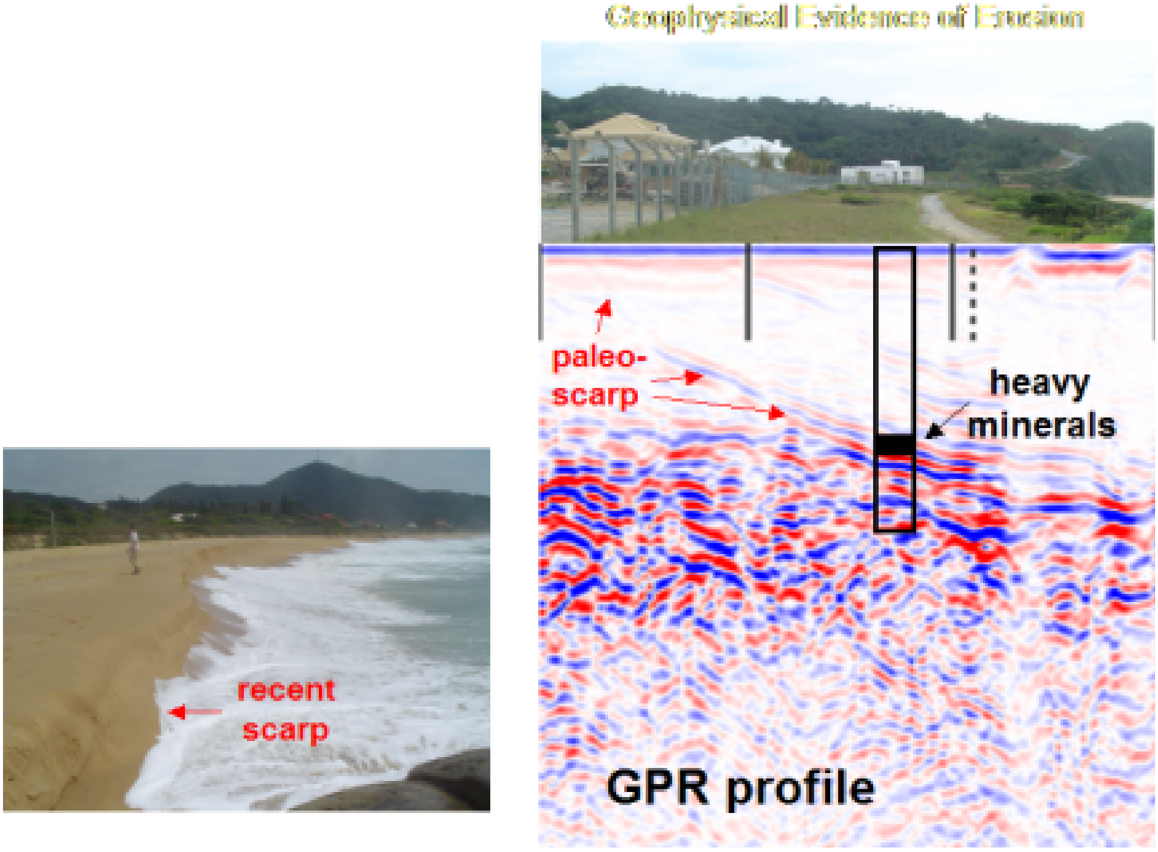


Figure 14. GPR profiles show a relict storm scarp imaged beneath Estaleiro Beach (near Taquaras/Taquarinhas Beach) coincides with accumulation of heavy minerals in the sediment core (see figure), attesting to past storm impact (Buynevich *et al*., 2006).

STOP # 3 BALNEÁRIO CAMBORIÚ BEACH NOURISHMENT AND INNER SHELF

We will visit one site at Balneário Camboriú Beach that will help to explain its morphodynamic and beach nourishment project. We´ll cross over the mountain between Lajanjeiras beach (pocket beach) and Balneário Camboriú Beach, using the cable car, with a short stop at cable car station. We'll have an over view of the beach using a platform in the cable car station. It will be also possible to have a idea of "Mata Atantica" rain forest in the cable car station, during the lunch time.

Balneário Camboriú is one of the main tourist resorts in Southern Brazil. Most of the year the local population is around 80,000 inhabitants but increases to more than 1 million during the summer. Since the 1960' the city has experienced an intensive but not planned growth, resulting in many environmental problems (Temme et al., 1997). The urbanization of the coastal plain was not conducted on a safe distance from the beach, the sand dunes been replaced by a protection wall, a road and tens of tall buildings along the over than 5.8 km long shoreline. This process changed the dynamic equilibrium of the beach and therefore, Balneário Camboriú has exhibited strong erosional events during storms and a significant reduction of the beach-width with time (Temme et al., 1997), mainly in the south part of beach (Figure 15).

In order to minimize the losses on the most affected areas, between June and August 2002 the municipality suddenly decided to nourish the southern sector of the beach using sediments, which were been dredged from the Camboriú River mouth in order to deepen its navigation channel. Nearly 50,000 cubic meters of sediments were hydraulically dredged and deposited along 800 m of the beach using a mobile pipeline (Figure 16). While authorized by the environmental agency of the Santa Catarina State (FATMA), the project was not preceded by any specific study to assess its technical viability and its environmental impacts on the beach and nearshore zones (Pezzuto et al. 2006).

Analysis showed: a) ecotoxicological effects of the sediment elutriate in the dredging zone as well as in the water deposited with the sediment at the nourished site, suggesting a poor chemical quality of the material used in the nourishment project; b) massive quantitative of shell hash, vegetal debris and death macro fauna deposited by the pipeline on the nourished area, totalising at least 2.3 t of material exposed along 350 m of restored beach in a single day; c) a very different composition between the original beach sediments and the sediments dredged from the Camboriú River estuary, the latter exhibiting a higher gravel and mud contents than the former; d) significant changes in the characteristics of the beach sediments after the replenishment, which became coarser and more gravelly than the original sediments and e) profound changes in the surface sediments of the Balneário Camboriú Bay, with a very strong increase in their silt and clay contents, suggesting a progressive transport of fine particles from the nourished area towards the northern and deeper zones of the bay.

Figure 15. Study area showing the sites of dredging and nourishment on the southern sector of the beach. (Image source Google Earth).

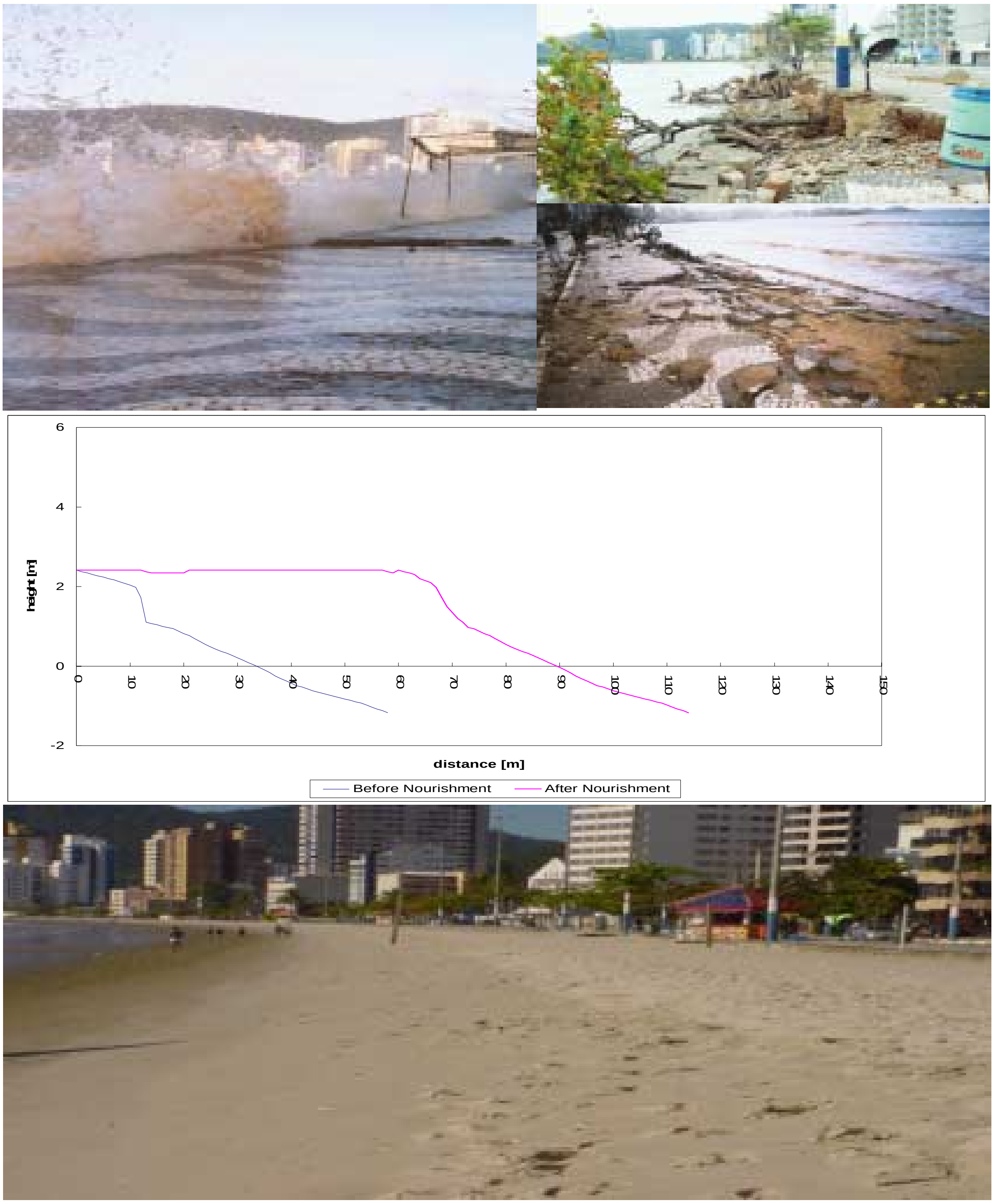


Figure 16. Beach nourishment project at southern sector of Balneário Camboriú beach using sediments, which were been dredged from the Camboriú River mouth in order to deepen its navigation channel. Nearly 50,000 cubic meters of sediments were hydraulically dredged and deposited along 800 m of the beach using a mobile pipeline. A. Photo and beach profile at the begging of project and B today (João Thadeu de Menezes, personal communication).

Balneário Camboriú and Taquaras/Taquarinhas Inner Shelf

The seismic profiles confirmed that the geomorfologic and sedimentary evolution of the continental shelf is very related to the fluctuations of the sea level during the Quaternary Period. The paleochannels recorded in the seismic profiles represent structures of deposition and the erosive processes developed in sedimentary environments during events of the sea level lowest than the actual, probably in the pre-holocenic period (Figure 17). The channel filled observed probably is associated to ancient drainage of the Camboriú river that was drawn and fill during transgression occurred after last maximum glacial (Abreu *et al.*, 2006).

The inner shelf in front of Camboriu Peninsula may be have good sand for future beach nourishment project.

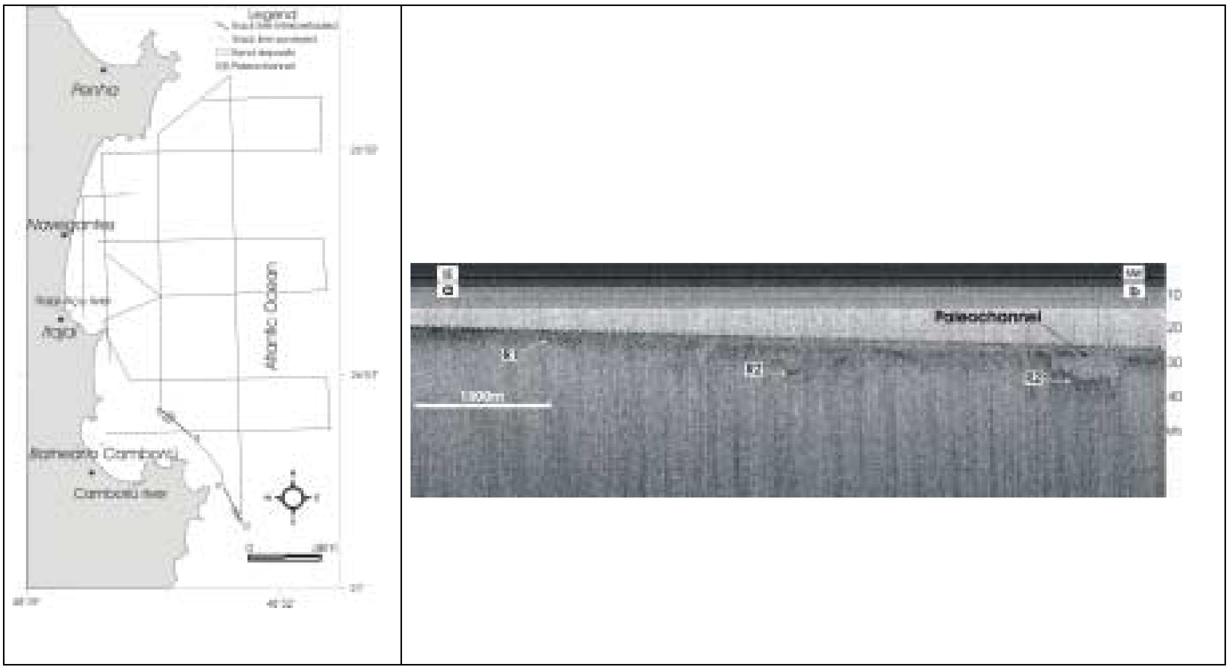


Figure 17. Seismic profile showing the reflectors more detached in the study area. The reflector R1 is the contact between muddy sediments that cover the inner continental shelf and R2 its associate to the very erosive paleosurface. Is possible to see a drowned channel recorded close to actual Camboriú river mouth (Abreu *et al.,* 2006 in press).

STOP #4 NAVEGANTES STRANDPLAIN

We will visit one site at Cruz Hill, Itajaí City, to have an overview of Itajaí River and Navegantes Strandplain. We'll look at cores and GPR records to explore the stratigraphy and type of ridge construction.

The Navegantes Strandplain is cut by the Itajai River and extends 2 to 8 km inland. It is fronted by a 10-km-long, fine-grained, dissipative beach, which experiences moderate wave energy with a mean breaker height of 0.8m. The plain is fed with reworked sediment sourced from the Itajai River, having a drainage area of 15,500 km^2 and an average discharge of 230 m^3/sec, which is approximately six times the annual discharge of the Tijucas River (see Figure 3). Similar to the Tijucas system, the drainage becomes segmented, narrower, and bounded by increasingly higher topography upstream (Figure 18). The plain is composed chiefly of fine-grained sandy beach/dune ridges with occasional intervening muddy swales. The beach is directly exposed to open-ocean waves, excepting the northernmost region where it is protected by a large bedrock promontory (Figure 18).

GPR records, sediment cores, magnetic susceptibility measurements, and radiometric and optically stimulated luminescence (OSL) dates have provided means for interpreting the evolution of the Navegantes region. GPR profiles across the plain exhibit mostly monotonous, shallow seaward-dipping reflectors representing continuous shoreface accretion. The slope of both paleo-beach and current beachface are very shallow (gradient $<3^o$) (Figure 19). Well-developed dunes are present within 0.5 km of the coast and are likely the result of the recent stable sea level and reduction in the rate of beach progradation. Inland, the sandy ridges are occasionally interrupted by muddy swales, 10 to 30 m in width. The landward portion of these ridges is composed of shallow, landward dipping strata that grade seaward into flat-lying then seaward dipping layers (Figure 20). The seaward dipping layers that comprise most of the plain are occasionally truncated by more steeply dipping surfaces seen in GPR records as sharp reflectors formed due the concentration of heavy minerals during storms. Preliminary radiocarbon dating of basal wetland organics suggest coastal progradation on the order of 1 m/year during the past 1,300 – 1,500 years.

Figure 18. Vertical aerial view of the Navegantes strandplain. Note the meandering nature of the bordering headlands to the north and south. Thick red line indicates GPR section shown in Figure 17.

Figure 19. View of the beach in Navegantes. Note both the very gentle slope and abundance of heavy mineral deposits, seen in the photo as dark striped lines.

(Photo Author: Duncan FitzGerald)

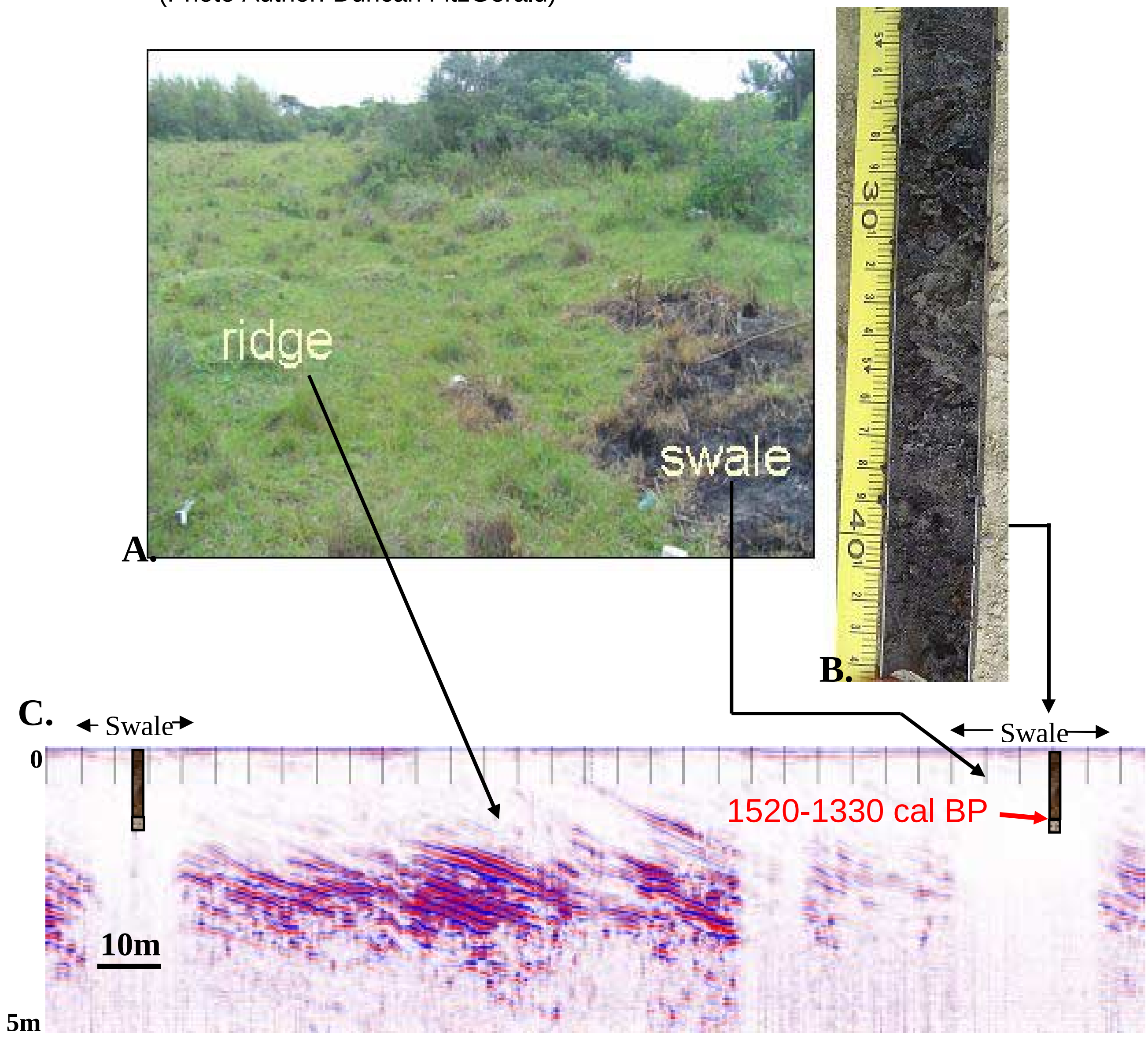


Figure 20. A. View of ridge and adjacent swale topography along dirt road next to vibracore site. B. Vibracore section taken though a swale, which is dominated by dark peat. C. Shore normal GPR transect taken along a dirt roadway north of the Itajai River. Note the prominent shallow dipping reflectors along the sandy ridges as compared to the transparent reflectors associated with muddy swale areas (FitzGerald *et al.*, 2006).

Comparison of Tijucas & Navegantes Strandplains

Although the Itajai River has a larger drainage basin and greater sediment discharge compared to the Tijucas River, the beach of Navegantes is finer grained than the beach adjacent to the Tijucas River. Both rivers export large quantities of suspended and bed loads relative to their size due to the Paleozoic age of the granitic plutons and the 10's of meters thick saprolite. The bedload contribution of Navegantes is medium to fine-grained whereas Tijucas is medium to coarse-grained. One hypothesis explaining the difference in grain size between the two rivers is that the coarse sediment in the Navegantes River is deposited within the river mouth, and thus it is not reworked onto the adjacent beaches. The Tijucas River is much smaller and therefore even during periods of high discharge little of the coarse-grained bedload becomes buried or is lost from the nearshore system. This is one of the scientific questions to be explored in future work. The difference in sand size exported by the two rivers is manifested in the gradient of shoreface and nearshore. Coarser-grained Tijucas Beach produces a steeper beachface than the finer-grained Navegantes Beach. Historically, grain size does not appear to have affected aeolian processes as both regions exhibit very subdued dune ridge development and low relief of paleo-beach ridges. It should be noted that present day beach system north of the Navegantes River has a well-developed foredune ridges (> 3m in height). In some regions secondary dune development landward of the shore contains vegetated dunes 2 to 3 m high. As stated previously, foredune development and the presence of rear dunes are believed to be a product of stable sea level and an abundant sand supply. In most areas at Tijucas the foredune is low and poorly developed. Progradation of the strandplains appears to be the result primarily of beachface and shoreface accretion.

The accretionary surfaces represented by the GPR reflectors of the two plains exhibit dissimilar geometries. Reflectors in the Tijucas strandplain have an apparent dip of between 9 and 10^{o} and those in Navegantes dip at only 1.5-2.0^{o} (Figure 21). Modern gradients along the Tijucas beach are 5-6^{o} and those in Navegantes are 2.5-3.5^{o}. At Navegantes reflectors are low angle and become tangential with the flat nearshore. Reflectors observed in the Tijucas GPR records are steeper dipping than Navegantes and in many regions have a sharp contact with the flat offshore reflectors. In other sections, the seaward portion of the reflectors becomes tangential to the flat offshore. The difference in geometry between the two plains may be partly a function of the greater wave energy in Navegantes, but primarily a function of the finer-grained sediment. It is acknowledged, however, that grain size and wave energy are not isolated parameters.

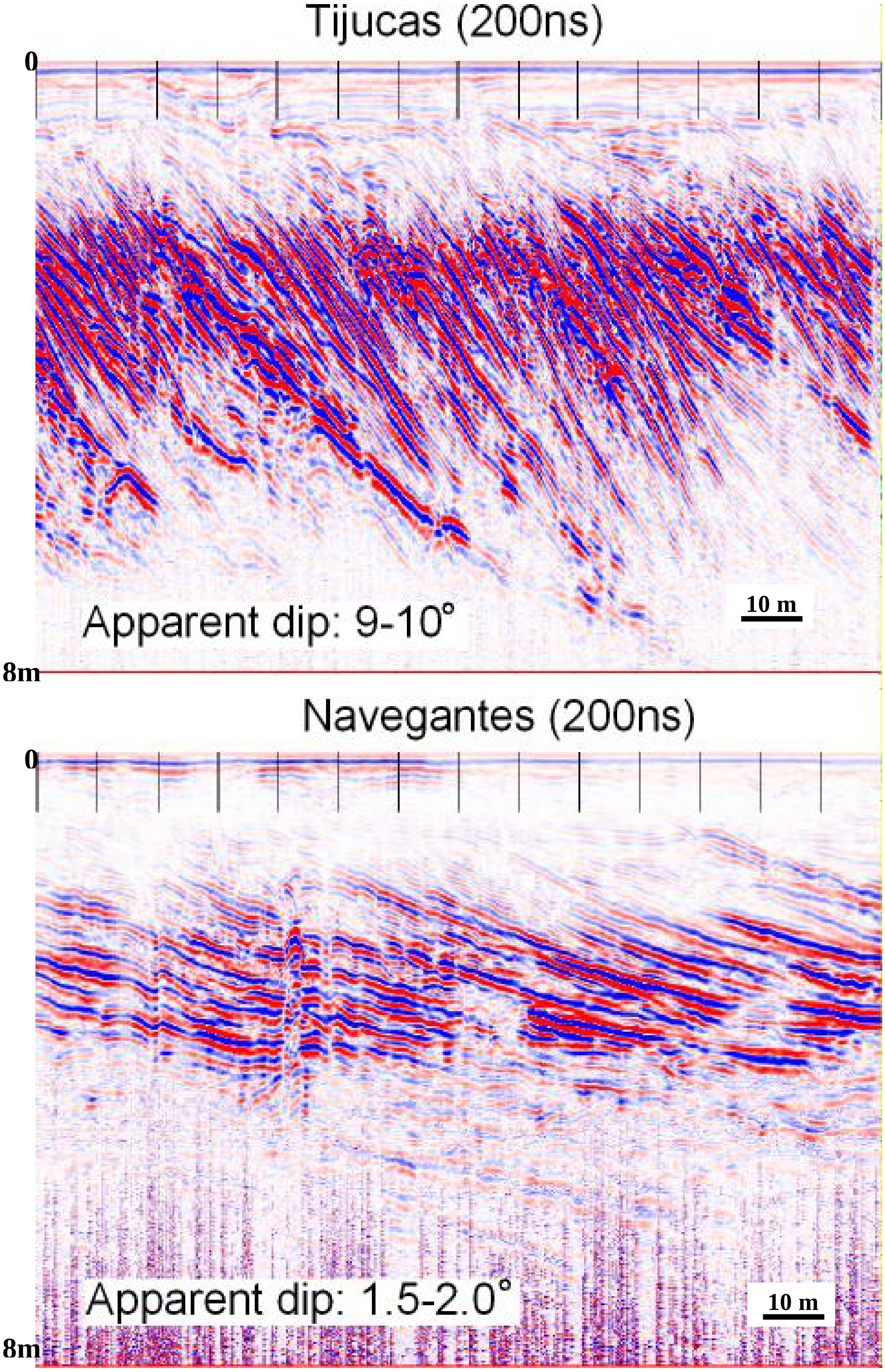


Figure 21. Beach ridges seen in GPR sections along both the Tijucas and Navegantes strandplains. Both records are at the same scale (Fitzgerald *et al*., 2006).

STOP #5 PIÇARRAS BEACH NOURISHMENT PROJECT AND 5E PLEISTOCENE BARRIER

We will visit two sites at Piçarras Beach that will help to explain its morphodynamic and beach nourishment project and to see the 5e Pleistocene barrier system at the coast, as a 6-8 meter scarp, in contrast to Tijucas and Navegantes inland 5e Pleistocene barrier system.

Piçarras beach is situated in the north coast of Santa Catarina, Brazil (Figure 22). The city has been building on the 5e Barrier system, Pleistocene sediments. Piçarras means red sand with mud. The red color is a result of iron impregnations of sediments. The Pleistocene scarp is a result of sea leve rise 120 thousand year BP. It is 6 to 7 meter high (Figure 23).

Piçarras beach is a sand beach in an arch form (headland bay-beach) with 8.5 Km length. In 1980 the beach was about 60 m wide. From 1983 the beach started to erode during storm events. In 1985, storms destroyed the seawall, the public pathway and parts of the road (figure 21 b). In 1989 five groins were constructed in order to try to protect the beach (Reid *et al.*, 2005).

Due to the inefficiency of the groins, and the increased erosive effects of storm events, in 1998 the City Council decided to nourish the beach to minimize the problems. The work lasted for three months (Nov98-Jan99) with a total sand volume of 888.000 m^3 being added along the 2200 m of beach. The borrow area was located 4 km offshore (Figure 24 c) (Reid *et al.*, 2005)

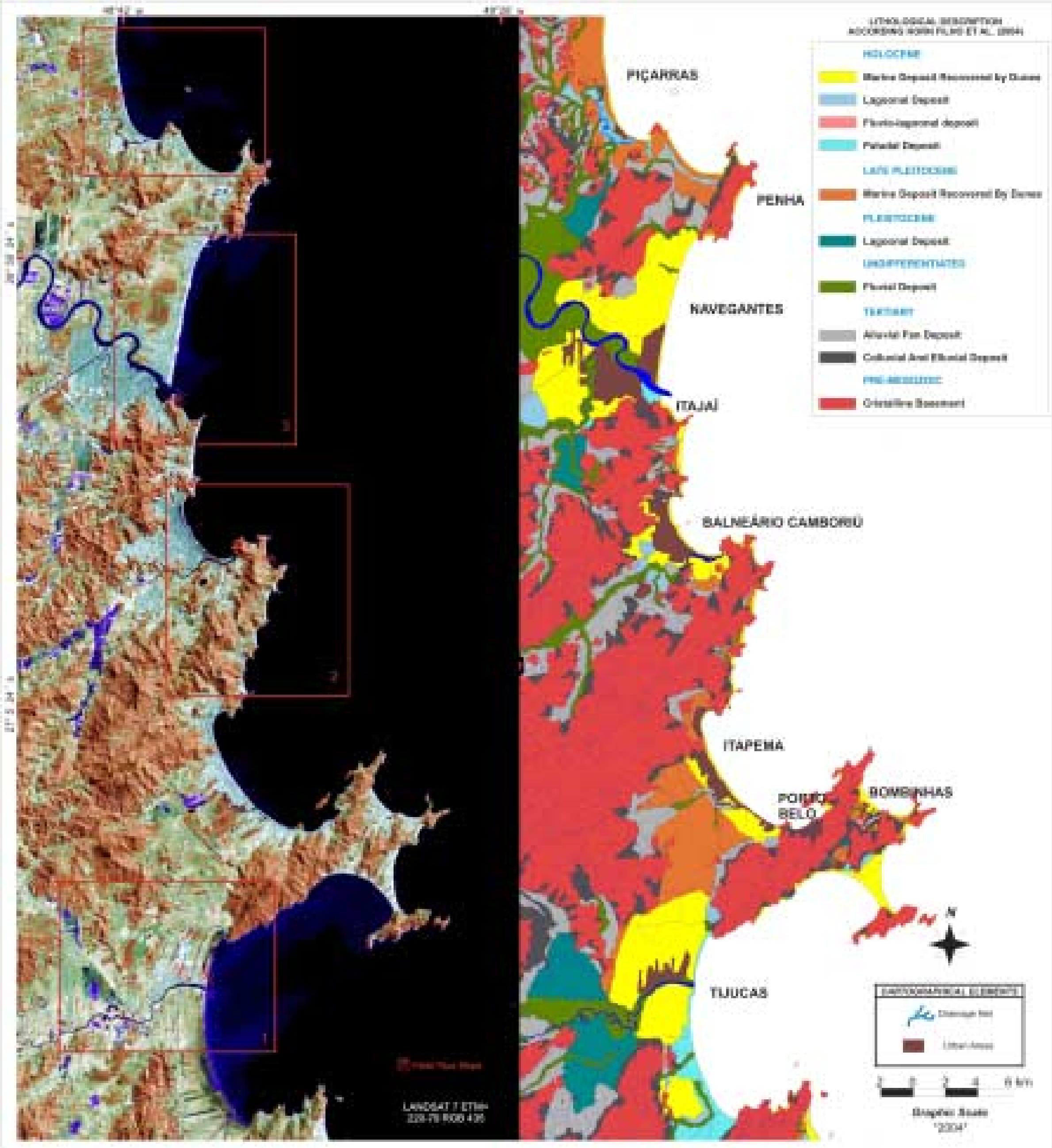


Figure 22. Map of Quaternary deposits according to Horn Filho *et al.* (2006). The rectangles are the field trip stops. Image satellite source: Inpe. Tiff. 99 mb. Landsat 7 etm+: wrs 219_079. 07/05/04. São José dos Campos, 2005.

Figure 23. 5e Pleistocene Scarp at Piçarras and Barra Velha Beaches. (Photo Author: Rafael Petermann)

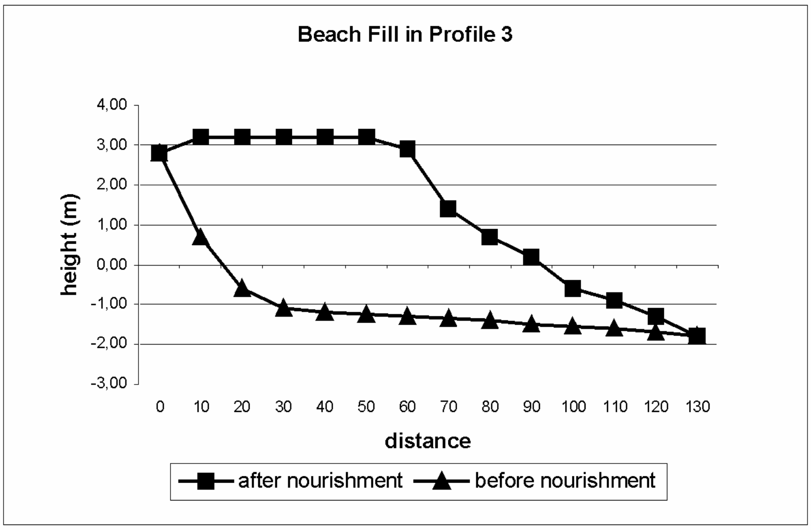


Figure 24. Beach profile shape before and after beach nourishment.   Photo of Piçarras beach before and in February 1999, right after nourishment project (Reid *et al.*, 2005).

Literature Cited

Abreu, J.G.N.; Mahiques, M.M. de; Schettini, C.A.F.; Klein, A.H.F. and Grabowski Neto, D. 2006 (in press) . High-resolution seismic survey in the inner continental shelf adjoinning the center-north coast at Santa Catarina State, South Brazil.Journal of Coastal Research, SI 39 (Proccendigs of the 8th International Coastal Symposium), Itajaí, SC – Brazil.

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

Angulo, R.J., de Souza, Maria C., Reimer, Paula J., Sasaoka, Sueli K., 2005. Reservoir effect of the southern and southeastern Brazilian coast. Radiocarbon, 47 (1), p. 67-73.

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

Asp, N. E., Buynevich, I. V., Siegle, E., FitzGerald, D., Klein, A. H. F., Cleary, W., Angulo, R. J. 2005. Coastal Geomorphology of theTijucas Plain – Brazil: A Preliminary Evolutionary Model. Anais do 10o Congresso da ABEQUA, Guarapari/ES – Brasil. Paper 89, 6 p.

Asp, N.E, Siegle, E., Schettini, C.A.F., Losso, A.P. and Klein, A.H.F. 2006 (submetido). Geomorfologia comparada de bacias de drenagem do centro-norte catarinense e implicações para a zona costeira.

Buynevich, I.V., Asp, N.E., FitzGerald, D.M., Cleary, W.C., Klein, A.H.F., Siegle, E., and Angulo, R., 2005. Mud in the surf: Nature at work in a Brazilian bay. Eos Transactions, AGU, v. 86, p. 301, 304.

Buynevich, Ilya V.,; Cleary, William, J.; FitzGerald, Duncan M.; Klein, Antonio H.F.; Asp, Nils E.; Hein, Christopher; Veiga, Fernando, A.; Petermann, Rafael M. 2006 (in this meeting). Modern and ancient erosion indicators on a high-energy coast: Camboriú Peninsula and Navegantes Plain, SC, Brazil. IGCP 495 Meeting, 17 to 23 September, Balneário Camboriú, Brazil.

Cleary, W. J., Smith, M.S., FitzGerald, D. M., Doughty, S. D., Silva, G. M. da, and Klein, A. H. da F., 2005, Provenance of beach sands along southern Brazilian strandplains: Santa Catarina, Brazil, GSA Abstracts with Programs Vol. 37, No. 2.

Dominguez, J.M., Martin, L. and Bittencourt, A.C.S.P., 1987. Sea-level history and Quaternary evolution of river mouth-associated beach-ridge plains along the East-Southeast Brazilian coast; a summary. In: Nummedal, D., Pilkey, O.H., Howard, J. D. (eds.), *Sea-level fluctuation and coastal evolution, Society for Sedimentary Geology Special Publication* No.41, 115-127.

FitzGerald, Duncan M.; Cleary, William, J.; Buynevich, Ilya V. ;Hein, Christopher; Klein, Antonio H.F.; Asp, Nils E.; Angulo, Rodolfo J.; Veiga, Fernando, A. 2006. Variability of Strandplain Development in Santa Catarina, Brazil. IGCP 495 Meeting, 17 to 23 September, Balneário Camboriú, Brazil.

Horn Filho, N.O., Diehl, F.L., Amim Júnior, A.H., Meireles, R.P., Abreu, J.G. N., 2006 (in press). Coastal Geology of the Central-North Littoral of the Santa Catarina State, Brazil. Journal of Coastal Research, SI 39 (Proccendigs of the 8th International Coastal Symposium), Itajaí, SC – Brazil.

Klein, A.H.F, 2004. Morphodynamics of headland-bay beaches: examples from the coast of Santa Catarina state, Brazil. PhD dissertation, University of Algarve, Portugal, 218pp.

Klein, A.H.F. and Menezes, J.T., 2001. Beach morphodynamics and profile sequence for a headland bay coast. Journal of Coastal Research, 17 (4), 812-835.

Klein, A.H.F., Benedet, L., and Schumacher, D.H., 2002. Short-term beach rotation processes in distinct headland bay beach systems. Journal of Coastal Research, 18(3), 442-458.

Milne, G.A., Long, A.J., Bassett, S.E., 2005. Modeling Holocene relative sea-level observations from the Caribbean and South America, *Quaternary Science Reviews*, 24, p. 1183-1202.

Mitrovica, J.X., Milne, G.A., 2002. On the origin of late Holocene sea-level highstands within equatorial ocean basins, *Quaternary Science Reviews*, 21 (20-22), p. 2179-2190.

Pezzuto, P. R.; Resgalla JR., C.; Abreu, G. N. and Menezes, J. T., 2006 (in press). Environmental Impacts of the Nourishment of Balneário Camboriú Beach, SC, Brazil. Journal of Coastal Research, SI 39 (Proceedings of the 8th International Coastal Symposium), Itajaí, SC – Brazil, ISSN 0749-0208

Reid, J.; Santana, G.G.; Klein, A.H.F.; Diehl, F.L. 2005. Perceived and realized social and economic impacts of sand nourishment at Piçarras beach, Santa Catarina, Brazil. Shore & Beach, Vol. 73, No. 4, Fall 2005, pp 14-18.

Roy, P.S., Cowell, P.J., Ferland, M.A., Thom, B.G., 1994. Wave-dominated coasts. In: Coastal evolution; late Quaternary shoreline morphodynamics, (R.W.G. Carter and C.D. Woodroffe, eds), p. 121-186.

Temme, B, Klein, AHF, Carvalho, J.L.B and Diehl, F.L. 1997 Morphologic behaviour of the beach of Balneario Camboriu: preliminar results. Notas Técnicas da FACIMAR, 1,49-65.

ANNOTATION

ANNOTATION

ANNOTATION

ANNOTATION

ANNOTATION

ANNOTATION

Supporting