COASTAL GEOMORPHOLOGY OF THE TIJUCAS PLAIN – BRAZIL:
A PRELIMINARY EVOLUTIONARY MODEL

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Abstract. Geological and geophysical data, satellite imagery, field observations and numerical
modeling, were used to reconstruct the Holocene evolution of the coastal area of Tijucas Plain,
Santa Catarina, Brazil. This area is associated with the Tijucas River, which has a mean discharge
of 40 m³/s and complex transport patterns of fine- and coarse-grained sediments. The plain was
formed mainly over the past 6 to 5 ka due to abundant sediment supply and gentle sea-level fall.
Using ground-penetrating radar (GPR), coring, and elevation measurements, the morphology and
stratigraphy of the progradational sequences were investigated. It was possible to identify two
main regions: a landward lagoonal/estuarine portion and a seaward strandplain. These are
separated by a transgressive barrier associated with the mid-Holocene sea-level maximum.
Seaward of this Holocene barrier, the strandplain exhibits a complex pattern of progradation. The
extensive information acquired was then used to develop the first evolutionary model of the
Tijucas region.

Keywords: Holocene, strandplain, GPR

1. Introduction

The Tijucas coastal plain (fig 1) located
along the Santa Catarina State coastline in
southern Brazil has experienced extensive
sedimentation, especially since mid-
Holocene. The coastal plains in this part of
South America represent periods of
abundant sediment supply combined with a
slow sea-level fall of about 2.5 m from
around 5,700 cal. yr BP (mid-Holocene
highstand) to the present (Angulo et al.
2005).

Recently, intensive fieldwork has been
carried out to study the progradational
sequences at Tijucas. Based on previous
studies of coastal plains around the world
(Roy 1984, Domínguez et al. 1987,
Flemming and Davis 1994, Asp 2004) a
preliminary Holocene evolutionary model
for the Tijucas area is presented here. The
model consists of an initial phase of
drowning of the Tijucas river valley by the
rising sea level during early Holocene,
subsequent formation and partial isolation of
a large estuary by the stabilization of the
Holocene transgressive barrier at the time of
mid-Holocene maximum, and finally the
relatively rapid infilling of the estuary driven
by both falling sea level and fluvial/marine
sediment supply. The last phase, which
might have begun simultaneously with the
estuary-infilling phase, would explain the
formation and rapid progradation of the
strandplain.

1.1. Study area

The Tijucas river basin is relative small,
comprising about 2,400 km² with an average
discharge of 40 m³/s. However, the river
presents usually suspended sediment
concentrations three orders of magnitude greater than those with similar sized drainage systems in the Santa Catarina region. Average concentrations have been measured to be 70 mg/l (Schettini et al. 1996). Furthermore, the progradational holocenic ridge sequences in the area also indicate abundant sand-gravel supply.

The Tijucas River empties into a bedrock-framed embayment system, leading to a high protection level of the area with respect to wave energy. Tides are semi-diurnal with a mean tidal range of 0.8 m and maximum of 1.2 m. These characteristics result in a complex balance between wave and tide domination in the hydrodynamic regime at the area.

2. Applied methods

The landward limit of the marine incursion during Holocene was determined based on elevation measurements and satellite imagery interpretation, which was combined with field observations to as a first step in identifying former depositional environments.

More than 20 km of ground-penetrating radar (GPR) profiles were used to image the stratigraphy of the Tijucas Plain. The digital GSSI SIR-2000 GPR system was used to image the subsurface geology of the plain. A monostatic 200 MHz antenna provided the optimal range of subsurface penetration and resolution. The vertical resolution of the GPR signal of 0.1-0.3 m and penetration of 5-12 m allowed imaging of major lithological units and their bounding surfaces. In addition, the attenuation of electromagnetic signal was used to identify and map mud-rich facies.

Several vibracores and pulse auger cores were also obtained, providing valuable information for facies interpretation, validation and calibration of GPR data and material for AMS radiocarbon dating, which is underway at the Woods Hole Oceanographic Institution (WHOI).

The DGPS (positioning and elevation) survey was carried out using a DGPS-system Novatel™, with two satellite signal receptors and radio intercommunication with Pacific Crest™. Acquiring and controlling was done with a PC 9800 data logger.

Some additional work comprises numerical modeling to simulate wave refraction at former evolution stages of the area, which are proposed based on the available information (geological maps, images, core descriptions, soundings, etc) for the area and new field data. The nearshore spectral wave module of the MIKE21 modeling system (developed by DHI Water & Environment) has been applied. The model describes the propagation, growth, and decay of short-period waves in nearshore areas and includes the effects of refraction and shoaling due to varying depth, energy dissipation due to bottom friction and wave breaking. The Tijucas Holocene wave model domain includes an area of 70 x 40 km, with grid resolution of 40 m in x and y directions. Several runs were carried out using as offshore boundary condition those wave characteristics that represent the dominant regional wave climate.

3. Results

Preliminary field observations, supported by geomorphological mapping, enabled the division of the coastal area of Tijucas in two main portions: 1) the estuarine/lagoonal domain and 2) the strandplain domain. Regarding geophysical imaging and coring, fieldwork was focused on the coastal plain and reveals a complex stratigraphy. Different types of ridges could be visualized in a variety of orientations and internal geometries. In general, results show a distinct increase in the mud sedimentation in the younger (seaward) portions of the
plain. While extensive beach-ridge sequences were found throughout most of the plain, cheniers characterize the younger portions. Despite differences between ridges, four similar sequences were identified across the plain. Cheniers (i.e. mud sedimentation) seem to prevail only at the fourth (younger) sequence. The relevance of recent fine-grained sedimentation in the area is exemplified by extensive mudflat formation in the nearshore.

Regarding Holocene evolution, important results include the detection of the Holocene transgressive barrier, with associated lagoonal deposits. An older (Pleistocene?) barrier partially limited the landward extension of the lagoonal deposits there (fig. 3). Furthermore, the results enabled us to distinguish the two proposed domains (estuarine and coastal plain), which are separated by the Holocene transgressive barrier.

The extension of the transgressive barrier and of the estuarine domain was supported by satellite imagery and aerial photograph interpretation, as well as by near-surface sediment samples from mining sites along the river valley and elevation data.

Preliminary numerical modeling simulations of wave propagation over the developed morphology corresponding to mid-Holocene highstand indicate wave energy concentration at the area where the Holocene transgressive barrier was detected (fig. 2). Furthermore, results show distinct wave height reduction landward of that area. Simulations that included the morphology of the transgressive barrier have demonstrated conservation of relatively high wave energy at the barrier front and effective sheltering of the estuarine area by the barrier.

4. Discussion

The drainage basin of the Tijucas River is composed mainly by friable Pre-Cambrian meta-sedimentary rocks (Brusque Group), which are very efficient in producing fine-grained sediments. On the other hand, the drainage system seems also to be quite effective in producing coarse-grained sediments, originated from the meta-sedimentary rocks, the volcanic and meta-volcanic rocks that border the river basin and especially from associated alluvial fans.

In this context, it can be affirmed that during the whole Holocene the system was effective in producing abundant coarse- and fine-grained sediments.

The distinct (relative?) increase of mud deposition at the younger portions of the coastal plain would result mainly from the trapping of silt and clay by the estuarine domain. The preliminary analysis of coring and GPR data support these considerations.

Furthermore, aspects involving extensive mining activities at the river basin and gradual reduction of accommodation space since mid-Holocene and their influence in the increase of mud deposition in the late Holocene are being considered by Buynevich et al. (submitted.). The authors conclude that mining activities might have caused an increase in the mud sedimentation, but this effect would be important only in the last 100 years, whereas preliminary stratigraphic and chronological data shows ages around 1,000 years for the early stages of development of this younger, muddy progradational sequence.

In addition, the sedimentation at the nearshore zone and the fall of sea level led to a reduction in accommodation space, which might have contributed to the increase in mud sedimentation. However, the mud supply to the shoreface was certainly increased distinctly after the infilling of the paleo-estuary and this process is believed to be the most important in the change of sand-to mud-dominated sedimentation mode.

The wave refraction data from numerical modeling are very helpful in showing wave energy concentration in the
area of the transgressive Holocene barrier. Furthermore, simulations results show very low wave energy at the southern portion of the plain, associated to the Inferninho River (fig. 1). There, the GPR data have shown predominantly muddy sediments. It can be stated that even when the paleo-estuary of Tijucas was effective in exporting muds to the nearshore, these were probably trapped by the paleo-Inferninho estuary.

5. Conclusions

A new set of stratigraphic data has demonstrated the existence of a paleo-estuary and a strandplain associated with the Tijucas River, and revealed the existence of a Holocene transgressive barrier, which separates them. The geomorphological evolution of the area from mid- to late-Holocene was mainly controlled by sediment supply and falling sea-level, resulting in estuarine infilling and strandplain progradation.

A second-order paleo-estuary was also identified, associated to the Inferninho River. However, preliminary results do not show any evidence of a Holocene barrier there.

Results of wave refraction simulations explain this by wave energy concentration at the area of barrier formation in the northern portion of the area, associated to the Tijucas river, while the southern portion (Inferninho River) was sheltered from the main wave attack.

The data showed also a distinct increase in the mud sedimentation at the younger portions of the ridge plain. The fine-grained sediments would have been captured by the paleo-estuary of the Tijucas River. After its infilling somewhere in the late Holocene, more mud was delivered to the nearshore and shoreface. Suspended load eventually exported by the Tijucas paleo-estuary might have been captured by the Inferninho paleo-estuary, which presents massive mud deposits. The infilling of that estuary in the late Holocene has certainly contributed to the recent increase in mud sedimentation at the northern portion of the Tijucas plain.

These preliminary findings on the Holocene evolution of the Tijucas coastal area are summarized in a conceptual model, which is presented here in Figure 4. The Holocene evolution is represented in terms of the stabilization of the transgressive barrier, with the formation and initial infilling of estuary (1), the estuarine-infilling phase and strandplain progradation (2 and 3) and the present situation (4).

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7. References


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Figure 1: Location of the Tijucas coastal plain. The red line indicates the approximate limit of the marine incursion during mid-Holocene. Black lines indicate main GPR-DGPS profile sites.

Figure 2: A – Paleogeography of the Tijucas basin for the mid-Holocene (highstand) and B - numerical modeling of wave refraction ($H_{sig}$: 1.5 m; $T$: 12 s; dir: SE).
Figure 3: Top- Shore-normal topographic profile and GPR image. Bottom - Interpretation of a profile based on GPR, topographic and core data at a section in Tijucas strandplain (see fig. 4 for location), showing the transgressive Holocene barrier (TB) with associated lagoonal/estuarine deposits (M1, M2 and P) and washover deposits (W). A sequence of regressive Holocene beach ridges (HBr) begins seaward of the highstand barrier, with the older (Pleistocene) barrier (PB) with associated reworked sediments (PHr) imaged in a landwardmost part of the section.

Figure 4: The developed evolution model for the area of Tijucas, comprising the period of the mid-Holocene highstand to the present.