Journal of Coastal Research	SI 56	579 - 583	ICS2009 (Proceedings)	Portugal	ISSN 0749-0258

Ground-penetrating radar profiles of two Holocene regressive barriers in southern Brazil

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ABSTRACT

BARBOZA, E.G., DILLENBURG, S.R., ROSA, M.L.C.C., TOMAZELLI, L.J. AND HESP, P.A., 2009. Ground-penetrating radar profiles of two Holocene regressive barriers in southern Brazil. Journal of Coastal Research, SI 56 (Proceedings of the 10th International Coastal Symposium), 579 – 583. Lisbon, Portugal, ISBN

The Ground-penetrating radar (GPR) allowed the collection of high quality records of subsurface deposits of coastal environments. GPR records substantially increase the capacity of analysis and definition of depositional geometries of coastal strataforms, and the establishment of their evolutionary models. This abstract summarizes the results of a comparison between the morphology and stratigraphy of two regressive barriers of southern Brazil. GPR records (70 and 200 MHz), along shoreline transverse profiles were obtained for the subsurface of both barriers. Curumim barrier has an internal reflection configuration of the type parallel oblique progradational clinoforms, and Pinheira barrier has a complex sigmoid-oblique progradational pattern. While Pinheira has a classic morphology of a foredune ridge plain, Curumim had its foredune ridge plain recovered by transgressive dunefields, which have defined the formation of precipitation ridges. These distinct morphologies are a product of local factor differences such as, coastline geometry, climate and oceanic.

ADDITIONAL INDEX WORDS: *GPR, Stratigraphy, Barrier Evolution*

INTRODUCTION

The relatively recent application of the Ground Penetrating Radar (GPR) on studies of coastal environments has allowed the collection of high quality records of sedimentary deposits. The GPR permits the visualization of the depositional geometry and stratigraphy of coastal systems, and consequently is being of great importance on the refining of preexistent coastal models.

Recent GPR data were obtained in aeolian and beach systems (BOTHA *et al.*, 2003; HAVHOLM *et al.*, 2003; MOLLER *et al.*, 2003; BRISTOW *et al.*, 2007; JOHNSTON, *et al.*, 2007; BARBOZA *et al.*, 2008), and in alluvial and fluvial systems (HEINZ AND AIGNER, 2003; ROBERTS *et al.*, 2003; MUMPY *et al.*, 2007; HICKIN *et al.*, 2007; TOMAZELLI *et al.*, 2008). This paper presents some comparative results of GPR records of two different models of Holocene regressive barriers in southern Brazil.

Regressive barriers here occur in wave-dominated coastal reentrances. Their main geomorphologic features are beach and dune ridges orientated parallel to the coastline (LESSA *et al.*, 2000). They are formed under stable or quasi-stable sea-level (normal regression) or during a sea-level fall (forced regression) (POSAMENTIER *et al.*, 1992).

REGIONAL SETTING

The study area comprises two coastal sectors: one in the northern littoral of Rio Grande do Sul (RS) state, and other one in the southern-central littoral of Santa Catarina (SC) state (Fig. 1). At RS the regressive Holocene barrier was studied at Curumim. The barrier here was named a prograded transgressive dunefield barrier by HESP *et al.* (2005). It is essentially a regressive barrier, that during progradation was covered by aeolian deposits in the form of transgressive dunefields. These dunefields display high to low precipitation ridges along the landward margins of each dunefield phase (DILLENBURG *et al.*, 2005, 2006 and 2009; HESP *et al.*, 2005 and 2007; MARTINHO *et al.*, 2008). At Curumim, the Holocene barrier prograded 4.7 km during middle and late Holocene. In SC the regressive barrier of Pinheira prograded 5.0 km, approximately in the same time period, but differently the barrier at Pinheira shows a surface morphology dominated by foredune ridges (HESP *et al.*, 2009). At the general coastal region where both sectors occur, the maximum sea level of the Postglacial Marine Transgression (PMT) was around + 2 meters, at 5-6 cal ka (ANGULO *et al.*, 1999 and 2006; BARBOZA AND TOMAZELLI, 2003).

METHODS

The GPR records were acquired over roads along cross shore profiles (Fig. 1). A SIR-3000 data acquisition system of GSSI™ (Geophysical Survey Systems, Inc.) in 70 MHz for Curumim profile (recording up to 20 m depth), and 200 MHz for Pinheira profile (recording up to 12 m depth). The GPR system was connected to a DGPS, allowing a real time topographic survey. At the time of data acquisition noise and gain filters were applied. A dielectric constant for dried sand (6) was used, representing a velocity of 0.15 m/ns (DAVIS AND ANNAN, 1989). This constant was validated by lithologic data obtained from drillings performed at both coastal sectors. The Common Off-set array was used. The

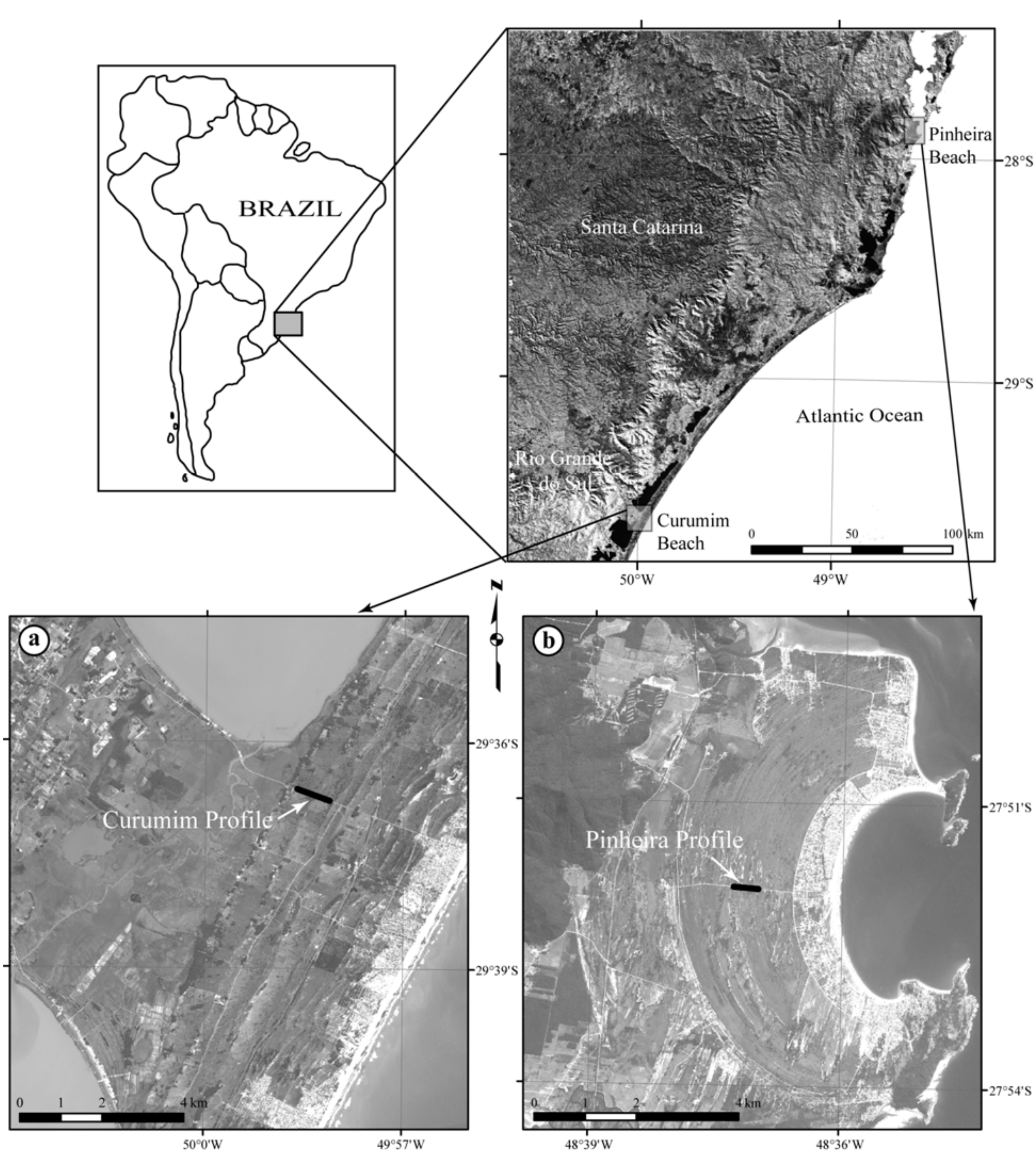

Figure 1. Satellite images of the study areas, showing location of GPR profiles at Curumim (a) and Pinheira (b).

field records of GPR were processed and interpreted by the software RADAN® 6.6.

RESULTS

Interpretation of GPR data followed the sismostratigraphy method based on reflectors termination (onlap, downlap, toplap and truncations), geometry and pattern of reflectors (MITCHUM JR. *et al.*, 1977; VAIL, 1987).

Curumim GPR profile (70 MHz) (Fig. 2a) shows four units. Unit A has irregular, non-continuous and sub-parallel reflectors, in a general segmented undulated pattern. Unit B shows a downlap termination over unit A surface, and a toplap termination with unit C. The downlap and toplap terminations of unit B characterize a pattern of parallel oblique progradational clinoforms, which indicate high sediment supply, slow or no subsidence and a

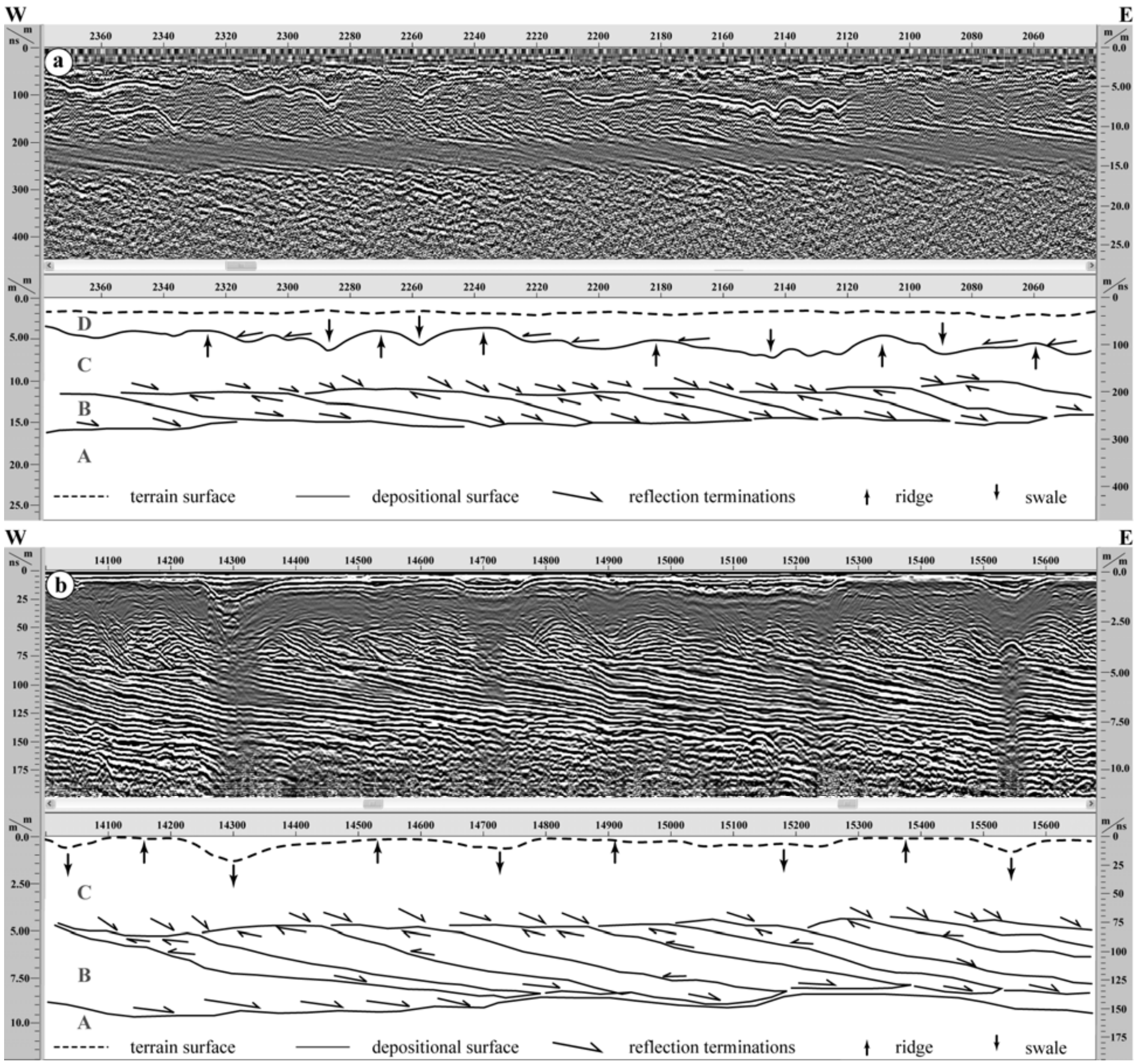

Figure 2. a) Curumim profile acquired with a frequency of 70 MHz. b) Pinheira profile acquired with a frequency of 200 MHz. Both profiles show similarities regarding their depositional systems, but they are distinct by the presence of unit D (transgressive dunefields) in Curumim, and on the geometry and pattern of internal configuration of the clinoforms reflectors (unit B) of Curumim and Pinheira.

stillstand sea-level to allow sedimentary bypass or scour of the upper depositional surface. A relative high-energy depositional condition in shallow waters (foreshore-upper shoreface deposits). Unit C: the internal configuration of this unit is of a contortea pattern, and it is associated to backshore deposits. At 10 m depth this unit shows reflectors in downlap termination over the clinoforms of unit B. In some places these reflectors seem to have continuity with the clinoforms, probably marking the transition between backshore and foreshore deposits. The upper limit of unit C is marked by a continuous and undulated reflector that occurs at an average depth of 6 m. This reflector represents crests and swales of the palaeotopography of a foredune ridge plain. Unit D shows reflectors with a low-angle downlap termination. Differently than units B and C these reflectors are migrating to the west. They are associated with phases of dunefields transgression, well characterized in Curumim by HESP *et al.*, 2005. Finally, the last upper 2 m of the GPR record corresponds to pavement and sub-grade layers of road construction.

Pinheira GPR profile (200 MHz) (Fig. 2b) is in general similar to Curumim. As in Curumim the basal record corresponds to a irregular, non-continuous and sub-parallel reflectors, in a general segmented undulated pattern (Unit A). Unit B shows downlap, onlap and toplap terminations, characterizing a complex sigmoid-oblique progradational reflection configuration, formed under a high-energy depositional condition, in shallow waters. The topset of the unit is characterized by a complex alternation of horizontal sigmoid topset reflections and segments of oblique configuration with toplap terminations. This variability implies an alternating up-building and depositional bypass. At 9 m depth, the base of unit B shows a downlap termination. Unit C is the same contortea pattern internal configuration of reflectors as in Curumim. It corresponds to backshore deposits, and their transition to foreshore deposits is much clearer in Pinheira. The upper surface of unit C shows the same topography of a foredune plain as interpreted for Curumim. The foredune crests at Pinheira were flattened by road construction.

The GPR record of both barriers shows a classic progradational pattern, previously interpreted by DILLENBURG *et al.* (2006) and HESP *et al.* (2009). However the GPR allowed the observation of an important difference at Curumim that is the recover of a foredune plain by deposits of transgressive dunefields. This difference produced a distinct surface morphology for Curumim, which is characterized by precipitation ridges formed by phases of dunefields transgression, with ridges on average spaced from 80 to 600 m apart. Pinheira shows a typical foredune ridge plain, with ridges spaced at around 20-30 m.

The pattern of progradation of the two barriers indicates a higher input of sediments during progradation at Curumim and Pinheira. During the same time (Middle and Late Holocene) both barriers have evolved under distinct depositional processes, as a consequence of local and distinct coastline geometry, climatic and oceanic factors. All factors affecting sediment budget and processes of sediment distribution and by this producing distinct morphology for Curumim and Pinheira regressive barriers.

The topographic survey of the two profiles (Curumim and Pinheira) suggests that progradation has started as a normal regression, followed later by a stage of forced regression, as pointed out by HESP *et al.* (2007).

The investigation of two coastal sites (Curumim and Pinheira) points out to the great improvement of models interpretation that is allowed by the fast acquisition and high quality data of a GPR system. Particularly at Curumim the GPR records has revealed that at least along some sectors of barrier progradation foredune ridges were preserved buried by aeolian deposits of transgressive dunefields.

CONCLUSIONS

In general, Curumim and Pinheira show similar GPR records. However, when analyzed in detail some important differences appear. Unit B in Curumim has an internal reflection configuration pattern of the type parallel oblique progradational clinoforms, and Pinheira has a complex sigmoid-oblique progradational pattern. While Pinheira has a classic morphology of a foredune ridge plain, Curumim had its foredune ridge plain recovered by transgressive dunefields, which have defined the formation of precipitation ridges. These distinct morphologies are a product of differences on local factors as coastline geometry, climatic and oceanic factors

ACKNOLEDGEMENT

This research was funded by a grant from CNPq (472484/06-0) and (454804/2008-3) and by the Project 2736-7 — FAURGS. The authors Barboza, Dillenburg and Tomazelli thank CNPq for their research grants and Rosa thank to ANP for her scholarship.

LITERATURE CITED

ANGULO, R.J.; GIANNINI, P.C.F.; SUGUIO, K. AND PESSENDA, L.C.R., 1999. Relative sea-level changes in the last 5500 years in southern Brazil (Laguna-Imbituba region, Santa Catarina State) based on vermetid ^{14}C ages. *Marine Geology* 159:323-339.

ANGULO, R.J.; LESSA, G.C. AND SOUZA, M.C., 2006. A critical review of Mid- to Late-Holocene sea-level fluctuations on the eastern Brazilian coastline. *Quaternary Science Reviews*, 25:486-506.

BARBOZA, E.G. AND TOMAZELLI, L.J., 2003. Erosional features of the eastern margin of the Patos Lagoon, southern Brazil: significance for Holocene history. *Journal of Coastal Research*, SI 35, p. 260-264.

BARBOZA, E.G.; ROSA, M.L.C.C.; TOMAZELLI, L.J. AND DILLENBURG, S.R., 2008. Análise estratigráfica da barreira pleistocênica III através da técnica de georadar na região de Osório - RS. In: 44º Congresso Brasileiro de Geologia, 2008, Curitiba - PR. *Anais*..., p. 1003-1003.

BOTHA, G.A.; BRISTOW, C.S.; PORAT, N.; DULLER, G.; ARMITAGE, S.J.; ROBERTS, H.M.; CLARKE, B.M.; KOTA, M.W. AND SCHOEMAN, P., 2003. Evidence for dune reactivation from GPR profiles on the Maputaland coastal plain, South Africa. *In:* BRISTOW, C.S. AND JOL, H.M. (eds.). *Ground Penetrating Radar in Sediments*. The Geological Society, London, Special Publication, 211: pp. 29-46.

BRISTOW, C.S.; JONES, B.G.; NANSON, G.C.; HOLLANDS, C.; COLEMAN, M. AND PRICE, D.M., 2007. GPR surveys of vegetated linear dune stratigraphy in central Australia: Evidence for linear dune extension with vertical and lateral accretion. *In:* BAKER, G.S. AND JOL, H.M. (eds.). *Stratigraphic Analyses Using GPR*. The Geological Society of America, Colorado, Special Publication, 432: pp. 19-34.

DAVIS, J.L. AND ANNAN, A.P., 1989. Ground-penetrating radar for high-resolution mapping of soil and rock stratigraphy. *Geophysical Prospecting*, v.37, p. 531-551.

DILLENBURG, S.R.; TOMAZELLI, L.J.; MARTINS, L.R. AND BARBOZA, E.G., 2005. Modificações de Longo Período da Linha de Costa das Barreiras Costeiras do Rio Grande do Sul. *Gravel* (Porto Alegre), Porto Alegre-RS, v. 3, p. 4-9.

DILLENBURG, S.R.; TOMAZELLI, L.J.; BARBOZA, E.G.; CLEROT, L.C.P.; SILVA, D.B. AND HESP, P.A., 2006. Stratigraphy and evolution of a prograded transgressive dunefield barrier in southern Brazil. *Journal of Coastal Research*, SI 39, v. 1, p. 131-134.

DILLENBURG, S.R.; BARBOZA, E.G.; TOMAZELLI, L.J.; HESP, P.A.; CLEROT, L.C.P. AND AYUP-ZOUAIN, R.N., 2009. The Holocene Coastal Barriers of Rio Grande do Sul. *In:* DILLENBURG, S.R. AND HESP, P.A. (eds.). *Geology and Geomorphology of Holocene Coastal Barriers of Brazil*. Berlin Heidelberg: Springer-Verlag, v. 107: pp. 53-91.

HAVHOLM, K.G.; BERGSTROM, N.D.; JOL, H.M. AND RUNNING, G.L., IV., 2003. GPR survey of a Holocene aeolian/fluvial/lacustrine succession, Lauder Sandhills, Manitoba, Canada. *In:* BRISTOW, C.S. AND JOL, H.M. (eds.). *Ground Penetrating Radar in Sediments*. The Geological Society, London, Special Publication, 211: pp. 47-54.

HEINZ, J. AND AIGNER, T., 2003. Three-dimensional GPR analysis of various Quaternary gravel-bed braided river deposits (southwest Germany). *In:* BRISTOW, C.S. AND JOL, H.M. (eds.). *Ground Penetrating Radar in Sediments*. The Geological Society, London, Special Publication, 211: pp. 99-110.

HESP, P.A.; DILLENBURG, S.R.; BARBOZA, E.G.; TOMAZELLI, L.J.; AYUP-ZOUAIN, R.N.; ESTEVES, L.S.; GRUBER, N.L.S.; TOLDO JR., E.E.; TABAJARA, L.L.C.A. AND CLEROT, L.C.P., 2005. Beach Ridges, Foredunes or Transgressive Dunefields? Definitions and an Examination of the Torres to Tramandaí Barrier System, Southern Brazil. *Anais da Academia Brasileira de Ciências*, Rio de Janeiro - RJ, v. 77, n. 3, p. 493-508.

HESP, P.A.; DILLENBURG, S.R.; BARBOZA, E.G.; CLEROT, L.C.P.; TOMAZELLI, L.J. AND AYUP-ZOUAIN, R.N., 2007. Morphology of the Itapeva to Tramandaí transgressive dunefield barrier system and mid- to late Holocene sea level change. *Earth Surface Processes and Landforms*, v. 32, p. 407-414.

HESP, P.A.; GIANNINI, P.C.F.; MARTINHO, C.T.; SILVA G.M. AND ASP NETO, N.E., 2009. The Holocene Barrier Systems of the Santa Catarina Coast, Southern Brazil. *In:* DILLENBURG, S.R. AND HESP, P.A. (eds.). *Geology and Geomorphology of Holocene Coastal Barriers of Brazil*. Berlin Heidelberg: Springer-Verlag, v. 107: pp. 53-91.

HICKIN, A.S.; BOBROWSKY, R.C.; PAULEN, R.C. AND BEST, M., 2007. Imaging fluvial architecture within a palaeovalley fill using ground penetrating radar, Maple Creek, Guyana. *In:* BAKER, G.S. AND JOL, H.M. (eds.). *Stratigraphic Analyses Using GPR*. The Geological Society of America, Colorado, Special Publication, 432: pp. 133-154.

JOHNSTON, J.W.; THOMPSON, T.A. AND BAEDKE, S.J., 2007. Systematic pattern of beach-ridge development and preservation: Conceptual model and evidence from ground penetrating radar. *In:* BAKER, G.S. AND JOL, H.M. (eds.). *Stratigraphic Analyses Using GPR*. The Geological Society of America, Colorado, Special Publication, 432: pp. 47-58.

LESSA, G.C.; ANGULO, R.J.; GIANNINI, P.C. AND ARAÚJO, A.D., 2000. Stratigraphy and Holocene evolution of a regressive barrier in south Brazil. *Marine Geology*, 165:87-108.

MARTINHO, C.T.; DILLENBURG, S.R. AND HESP, P.A., 2008. Mid to late Holocene evolution of transgressive dunefields from Rio Grande do Sul coast, southern Brazil. *Marine Geology*, 256: 49-64.

MITCHUM JR., R.M.; VAIL, P.R. AND SANGREE, J.B., 1977. Seismic Stratigraphy and Global Changes of Sea Level, Part 6: Stratigraphy interpretation of seismic reflection patterns in depositional sequences. *In:* PAYTON, C.E. (ed.). *Seismic Stratigraphy — Applications to Hydrocarbon Exploration*. Tulsa, AAPG, 117-133 (Memoir # 26).

MOLLER, I. AND ANTHONY, D., 2003. GPR study of sedimentary structures within a transgressive coastal barrier along the Danish North Sea coast. *In:* BRISTOW, C.S. AND JOL, H.M. (eds.). *Ground Penetrating Radar in Sediments*. The Geological Society, London, Special Publication, 211, 55-66.

MUMPY, A.J.; JOL, H.M.; KEAN, W.F. AND ISBELL, J.L., 2007. Architecture and sedimentology of an active braided bar in the Wisconsin river based on 3-D ground penetrating radar. *In:* BAKER, G.S. AND JOL, H.M. (eds.). *Stratigraphic Analyses Using GPR*. The Geological Society of America, Colorado, Special Publication, 432, 111-132.

POSAMENTIER, H.W.; ALLEN, G.P. AND JAMES, D.P., 1992. High resolution sequence stratigraphy: the East Coulee delta, Alberta. *Journal of Sedimentary Petrology*, v. 62 (2), p. 310-317.

ROBERTS, M.C.; NILLER, H.P. AND HELMSTETTER, N., 2003. Sedimentary architecture and radar facies of a fan delta, Cypress Creek, West Vancouver, British Columbia. *In:* BRISTOW, C.S. AND JOL, H.M. (eds.). *Ground Penetrating Radar in Sediments*. The Geological Society, London, Special Publication, 211, 111-126.

TOMAZELLI, L.J.; BARBOZA, E.G.; DILLENBURG, S.R.; ROSA, M.L.C.C.; CARON, F. AND LIMA, L.G., 2008. *Implantação, preenchimento e desenvolvimento de vales incisos na porção sul da Planície Costeira do Rio Grande do Sul*. Projeto PETROBRAS. Relatório Interno, 102p.

VAIL, P.R., 1987. Seismic Stratigraphy Interpretation Using Sequence Stratigraphy. Part 1: Seismic Stratigraphy Interpretation Procedure. *In:* BALLY, A.W. (ed.). *Atlas of Seismic Stratigraphy*. Tulsa, AAPG, v. 1, p. 1-9, (AAPG Studies in Geology # 27).