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High-resolution stratigraphy of Holocene lagoon terraces of Southern Brazil

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ABSTRACT

The northern portion of the coastal plain of the Rio Grande do Sul State (southernmost Brazil) comprises an outer sandy barrier that protects a complex lagoon system formed during the Holocene. The terraces of three different lagoons (Gentil, Malvas and Pinguela) formed along their margins record the depositional processes and the relative base level changes over the past 5000 yr. Therefore, our main objective was to characterize and quantify base level fluctuations from the study of these terraces, to correlate them to sea-level changes and to describe the depositional architecture related to the distinct sea-level stages (high-resolution sequence stratigraphy). Satellite images, topographic and GPR profiles, auger holes and radiometric dating were used. The main results indicate a close relationship between relative base level and relative sea-level changes, a stillstand period just after the last transgressive maximum (4840–4650 cal yr BP) and a subsequent overall relative sea-level fall of about 3 m. Both a normal (highstand systems tract) and a forced regression (falling-stage systems tract) controlled the geological record preserved in the terraces. The highstand (older terrace) is characterized by agradational bedding, whereas the falling stage comprises three progradational sets (terraces) bounded by erosive surfaces related to smaller-scale sea-level drops.

Introduction

The coastal plain of the Rio Grande do Sul State (CPRGS) encompasses about 33,000 km^2 of lowlands that includes continental, transitional and marine deposits that are linked to Tertiary alluvial fans and four successive barrier-lagoon systems related to transgressive–regressive Quaternary cycles (Villwock, 1984; Villwock et al., 1986). The last (the Holocene) consist on a well-preserved barrier and lagoon system. One key aspect related to this system in the Rio Grande do Sul (Figure 1) is the alternation between convex (erosional) and concave (depositional) areas in the coastline, which indicate that tectonics has also played its role on Holocene relative sea-level changes.

There are many cordiform lagoons throughout the CPRGS. Initial studies on them were conducted by Delaney (1960), who linked their shape to the northeasterly winds. From then, several studies have been conducted in those coastal lagoons and throughout the CPRGS (Barboza, 1999; Caron, 2007; Delaney, 1965; Hermany, 2009; Lima, 2008; Lima et al., 2013; Manzolli, 2011; Silva, 2011; Tomazelli, 1990; Tomazelli and Villwock, 1991; Tomazelli et al., 2000; Travessas et al., 2005; Villwock, 1972, 1984; Villwock and Tomazelli, 1995; Villwock et al., 1986; Weschenfelder et al., 2005).

Distinct terraces may be identified in the lagoon system. They record different stages of the lagoon's evolution that are related to relative base-level fall through the Holocene. On the other hand, the existence of high-frequency sea-level changes during the Holocene has been the subject of several studies in the Brazilian coast (Angulo and Lessa, 1997; Angulo et al., 2006; Côrrea, 1995; Martin and Suguio, 1992; Martin et al., 1998, 2003; Suguio et al., 1985), and the use of marine terraces to infer relative sea-level changes has been a common practice (Mason, 1993; Oliveira et al., 2012; Otvos, 2000; Tamura, 2012; Tamura et al., 2008, 2010; Tanner, 1995; Taylor e Stone, 1996). However, a few studies (e.g. Barboza, 1999; Manzolli, 2011) have used lagoon terraces to infer relative sea-level changes. As shown in this paper, besides being better preserved than their marine counterparts, these features seem to be fair relative sea-level indicators.

In this context, this study describes and interprets the evolution of three Holocene lagoons in the CPRGS (Figure 2) based on geomorphology and high-resolution subsurface stratigraphy to evaluate relative base level changes in the lagoons related to relative sea-level fluctuations.

Study area

The CPRGS is a micro-tidal lowland with a maximum annual variation of 30 cm (Motta, 1969) that is shaped by waves and longshore currents (Villwock and Tomazelli, 1995). The climate is mild mesothermal (Nimer, 1977) and prevailing winds are northeast, mainly during the spring and summer. Sudden falls in temperature and winds from the

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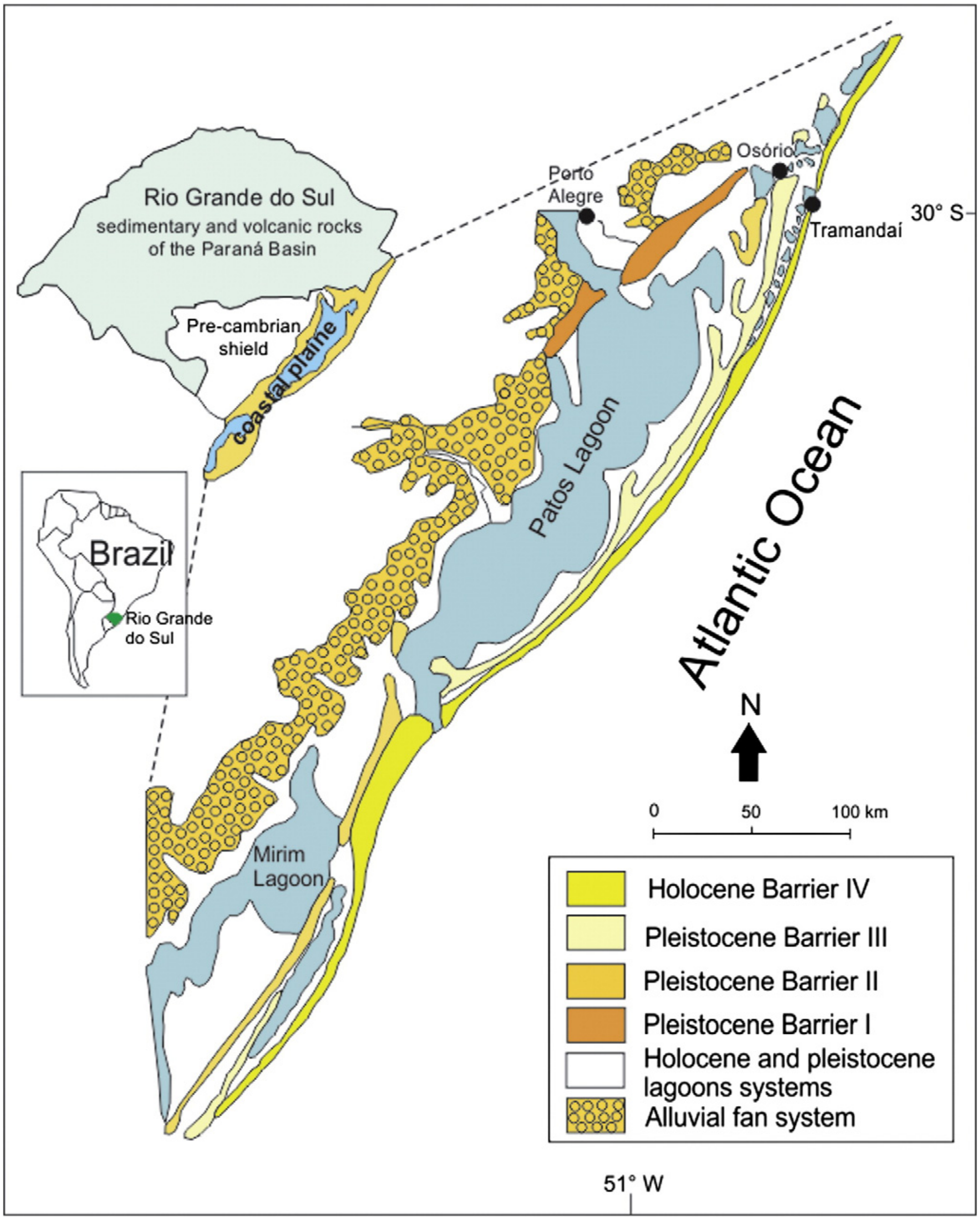

Figure 1. Schematic depositional systems of the Coastal Plain of Rio Grande do Sul. Correlation between the barriers and the last peaks of the oxygen isotope curve profile (Tomazelli & Villwock, 2000).

south and southwest occur during fall and winter due to the Mobile Polar Anticyclone circulation system (Krusche et al., 2002; Tomazelli, 1993).

The Quaternary barrier-lagoon depositional systems that form the CPRGS are the result of four transgressive–regressive, glacio-eustatic cycles (Figure 1). These four cycles have been adjusted to the oxygen isotope curve and ascribed to 400, 325, 125 and 7 ka, respectively (Villwock and Tomazelli, 1995). Some radiometric data confirm part of these ages. Barrier III was dated by thermoluminescence at 109 ka (Buchmann and Tomazelli, 2003), whereas Barrier IV was dated by ^{14}C dating at 6 ka (Angulo and Lessa, 1997). During the deposition of Barrier III, sea level reached about 7 m above its present-day position (Tomazelli and Dillenburg, 2007). This barrier system is preserved throughout the CPRGS and delineates a very irregular western limit of the barrier-lagoon system IV (Dillenburg, 1994; Tomazelli and Vilwock, 2005).

During the last glacial maximum (LGM), at 17 ka, the sea level is estimated between 114 and 135 m below its present-day position (Clark and Mix, 2002; Côrrea, 1990; Peltier, 2002). This sea-level fall caused localized erosion of the Barrier III deposits due to the drainage network incision (Dillenburg, 1994). Next, during sea-level rise, this drainage network was flooded and partially constrained the development of the lagoon system IV (Dillenburg, 1994, 1996).

From the LGM to about 6 ka, the sea-level rose to its higher position (2 to 5 m above the present-day) and a transgression then took place along the Brazilian coast (Angulo and Lessa, 1997; Angulo et al., 2006; Dillenburg et al., 2000, 2005; Martin et al., 2003; Suguio et al., 1985; Tomazelli and Vilwock, 2005). However, the sea-level rise was not steady but stepwise as attested by some breaks below the present-day sea level reported by Côrrea (1995). There is a large debate on high-frequency sea level changes over the past 6000 years, but a general fall from then to the present-day is also clear. Some authors have indicated the existence of high frequency sea-level cycles within this interval (Barboza, 1999; Côrrea, 1995; Dillenburg, 1994; Martin et al., 1998, 2003; Suguio et al., 1985). However, Angulo and Lessa (1997) and Angulo et al. (2006) challenged this assumption by suggesting that the methods used to infer these high-frequency sea-level changes are unreliable. They produced a sea-level curve based on vermetid dating,