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Late Quaternary stratigraphic evolution of the inner continental shelf in response to sea-level change, Santa Catarina, Brazil

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ABSTRACT

The inner continental shelf (0–50 m water depth) off Santa Catarina, southern Brazil was investigated using seismic stratigraphic methods to identify and interpret the major seismic stratigraphic units and to reconstruct the late Quaternary evolution of the inner shelf and coast. The stratigraphy comprises a bedrock basement overlain by a thick (> 30 m) unit that comprises, in the distal portion, laminated muds and sands, and in the coast-proximal zone, offlapping deltaic deposits, whose upper surface has been reworked to form alongshore-prograding barrier spits. Deposition of this unit is tentatively attributed to sea levels (− 20 m MSL) during the late Pleistocene (MIS 5a, or 5c). A normal fault in the muddy units with a vertical offset of 3.5 m indicates episodic tectonic activity. Cut into this unit is a profusion of incised valleys, associated with sea level fall ultimately to − 120 m at the last glacial maximum (LGM). The associated subaerial unconformity is only preserved close to shore, where it has escaped subsequent wave ravinement. This, coupled with the well-preserved incised valleys implies the underlying substrate to be weakly cohesive material (mud).

The incised valleys display a variety of infilling sediments interpreted variously as basal fluvial sediments, estuarine basin infill muds and marginal bar or barrier-associated sands deposited during the postglacial marine transgression. During a sea level stillstand at ca. -50 m, a 3.5 km-wide planar surface was cut into the unconsolidated coastal plain sediments forming a terrace on which a thick sequence of sands accumulated. This unit is regionally developed and the acoustic signature implies it to comprise littoral sand including a large aeolianite component. The accumulation of sand on this mainland beach/dune system is attributed to establishment of a mature littoral system with strong longshore drift. The fact that it rests on an erosional surface that truncates incised valleys, suggests the unit to be Holocene in age. It is interpreted to have been deposited during a still stand in the Holocene and to have undergone aggradation and cementation until it was overstepped by sea-level rise. Its surface and the coastal plain to landward were then subject to wave ravinement and a thin (ca. 5–6 m) layer of modern marine sands was deposited on the eroded surface.

Sea-level rise continued to the regional glacio-isostatic highstand of ca. 5.5 m, after which regressive strandplains developed in response to a renewed mature longshore drift system similar to that prevailing during the − 50 m stillstand of sea level. In the intervening period, rapid shoreline translation over the low gradient surface inhibited the development of the longshore transport system.

The three shoreline systems identified show marked differences that relate to sea level change and the influence of the underlying topography. Shoreline 1 (Pleistocene highstand) developed by localised wave-reworking of delta deposits and involved a series of alongshore-prograding barrier spits on a shoreline of alternating high-relief bedrock and littoral sands in coastal re-entrants. Shoreline 2 (− 50 m) was a major accumulation of beach and dune sand deposited as a mainland-attached beach dune system on a low-lying coastal plain environment. Shoreline 3 (the modern coast) comprises a series of headland-embayment beaches, strandplains and transgressive dunes with a strong bedrock control and a well-developed longshore drift system delivering sediment northward.

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1. Introduction

The inner shelf contains records of past environments that have the potential to inform our understanding of the relationships between underlying topography, littoral dynamics, sea-level change and overall shoreline morphology and dynamics (Roy et al., 1994; Peterson et al., 2016, Lee et al., 2017). The nature of the record itself, and the preservation of former shoreline features is also subject to control by the same factors. The inner shelf records geomorphic and sedimentological change under a variety of sea-level changes and offers potential insights into the influence of sea-level change on nearshore environments in various settings (e.g. Barnhardt et al., 1997; Green et al., 2015; Plets et al., 2015).

In this paper we investigate the inner shelf stratigraphy (to a depth of ca −50 m) off a portion of the Santa Catarina Coast of southern Brazil. The modern coastline has been well studied and comprises a series of beaches backed by transgressive dunes, strandplains and prograding spits, developed since the late Holocene sea level highstand under regressive conditions and high sediment supply via longshore sediment transport (Siegle and Asp, 2007; Klein et al., 2016; da Silva et al., 2016a). The surrounding and underlying high-relief bedrock topography exerts a strong control (Hein et al., 2013, 2016; Klein et al., 2016) on these environments, creating high promontories that separate the many headland-embayment beaches (Klein et al., 2016).

Studies of coastal change during the Holocene in the region have focussed largely on the onshore record preserved in beachridge plains (e.g. FitzGerald et al., 2007; Hein et al., 2013, 2016) and barrier lagoon systems (e.g. Amaral et al., 2012) deposited in the past 5500 years. The late Holocene was a period of sediment abundance during which extensive littoral deposits have accumulated. The role of the continental shelf as a source area for sediments and as a record of coastal evolution during the last glacial cycle remains largely unknown apart from a study offshore of Tijucas Bay (Cooper et al., 2016), north of Florianopolis Island. Tijucas Bay is unusual in terms of the regional geology, being a mud-dominated embayment in an overwhelmingly sandy littoral zone. Its stratigraphy is unlikely to be representative of the region as a whole.

The aim of this paper is to describe the regional nearshore stratigraphy along a 60 km-long coastal stretch covering the entire length of Santa Catarina Island and the adjacent mainland shore. To do this, we identify and interpret the major seismic stratigraphic packages recorded in a regional-scale investigation. On the basis of these interpretations, we reconstruct the late Quaternary evolution of the inner shelf and coast in the context of Quaternary sea-level change, influence of antecedent topography and sediment supply.

2. Study area

The Santa Catarina coast of southern Brazil (Fig. 1) is bounded by high granitic promontories (Dominguez, 2009) that form headlands between which sandy beaches and aeolian dune systems have developed (Klein et al., 2010, 2016). The shelf is 100–160 km wide and the shelf break varies between 140 and 180 m depth (Mahiques et al., 2010). Tidal range averages 0.7 m and surges of up to 1 m occur (Truccolo et al., 2006). Ocean waves are bimodal (Araujo et al., 2003; Pianca et al., 2010) with wind waves from the east (Ts = 8 s; Hs = 1.25 m) and swell from the south (T = 12 s; Hs (summer) = 1.25 m; Hs (winter) = 2 m). Southerly waves prevail in winter and autumn and waves from the NE dominate in summer and spring. Net longshore drift is to the north (Klein et al., 2010). The outer shelf is swept by the Brazil Current, while the inner shelf is wave-dominated (Mahiques et al., 2010). Santa Catarina Island encloses a single water body (divided by a bedrock constriction at the city of Florianopolis into the interconnected North and South Bays, Fig.1). The constricted channels between the ends of the island and the mainland create strong tidal flows with which are associated tidal deltas akin to tidal inlet environments. Fluvial systems are short and steep as a result of the proximity to the coast of the Serra do Mar range. Contemporary fluvial sediment supply in the study area is largely manifest as bayhead delta deposits in large coastal lagoons and embayments.

Sea level in southern Brazil (Fig. 2) is poorly constrained before the Mid Holocene. Available data suggest that it rose from a minimum of −120 m at the last glacial maximum (Corrêa, 1996), to a mid-Holocene highstand of approximately +3 m ca. 5000 cal yr BP after which it fell to the present level (Angulo and Lessa, 1997). On the basis of erosional terraces and lag shell deposits Corrêa (1996) identified several potential periods of slow and rapid sea-level rise during the postglacial marine transgression on the Brazilian shelf that were tentatively correlated with meltwater pulses and intervening stillstands (e.g. Liu and Milliman, 2004) by Cooper et al. (2016). A comparative sea-level record from the neighbouring Argentina shelf (Guilderson et al., 2000) shows a broadly similar curve.

The coastline in the study area is regarded as tectonically inactive (Giannini, 1993), although Cooper et al. (2016) reported seismically-deformed shallow marine sediments off Tijucas Bay and linked them to occasional seismic activity on the east Brazil margin (Assumpcão et al., 2011). Sandy sediment is abundant on the contemporary coast. Discrete Holocene beachridge plains are preserved at several locations on the Santa Catarina Coast. Pinheira Bay (Fig.3) (Hein et al., 2013;) and Tijucas Bay (Hein et al., 2016) respectively, south and north of Santa Catarina Island, contain strandplains that formed during sea-level fall after the mid-Holocene highstand ca 5.5 ka cal BP. Large transgressive dunefields also indicate sediment abundance during the mid-Late Holocene (Bigarella 1975, Hesp et al., 2009).

3. Methods

Over 400 line kilometres of seismic data were collected from the continental shelf of Santa Catarina between depths of ~3 and ~60 m (Fig. 1) using an Edgetech (0.5–12 kHz) SB512 CHIRP system (resolution ca. 0.1 m) and a boomer system (C-Boom; 0.5–2 kHz; resolution ca. 0.2 m) between 17th and 23rd February 2016. Conditions were calm (maximum wave height 0.5 m). Navigation was acquired using a differential GPS with real-time correction. Boomer data were collected using Hypack. Boomer data were processed in MDPS Meridata. A detailed survey in Pinheira Bay (Fig. 3) was augmented by regional cross-shore profiles offshore Barra da Lagoa and Santinho (Fig. 1), at the midpoint and north end of Santa Catarina Island, respectively.

Two-way travel time was converted to depth assuming the speed of sound in the water column as 1550 m/s and a speed of sound of 1650 m/s for the underlying stratigraphy. Sound velocity profiles were measured at the start and end of each day's survey. All isopach calculations and interpolations were derived from the digitising of key bounding reflectors in SonarWiz and converted to thicknesses in metres.

4. Results

4.1. Seabed topography

The generally smooth seabed (Fig. 4) slopes gently offshore to −35 m at 0.14°. There is a marked break in slope between −35 m and −50 m where the gradient increases to 0.64°.and the seabed assumes a convex profile. Seaward of this, the gradient returns to 0.14. Close to shore, a few bedrock pinnacles break the surface, giving a locally rugged topography.

4.2. Seismic stratigraphy

Five major seismic units (Units 1–5) with distinctive acoustic properties and bounding surfaces (S1–5) were identified in Boomer records (Fig. 4). The successive units and bounding surfaces are described below.