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Understanding Late Quaternary change at the land–ocean interface: a synthesis of the evolution of the Wilderness coastline, South Africa

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ABSTRACT

Coastal barrier systems have been widely used to understand the responses of coastal margins to fluctuating Pleistocene sea levels. What has become apparent, particularly with the development of robust chronological frameworks, is that gaps in terrestrial barrier sedimentary records are not uncommon and that they most likely reflect phases of barrier construction on the now submerged continental shelf. Thus, understanding the land–ocean interface through time is critical to fully appreciate the Quaternary archives contained within the barriers and their associated back-barrier deposits. This study uses offshore and lakefloor (back-barrier) seismic profiling from the South African south coast at Wilderness to link the sub-aerially exposed barrier stratigraphy to the currently submerged geological and sedimentological record. A total of eight separate submerged aeolian units are identified at water depths of up to 130 m below mean sea level. Their approximate ages are constrained with reference to the eustatic sea-level record and the deepest units are consistent with the estimated magnitude of sea-level lowering during the Last Glacial Maximum (LGM) on the South African coastline. As previously assumed, aeolian sedimentation tracked the shoreline onto the continental shelf during the Late Pleistocene. During sea-level regressions, both the incision of fluvial channels and the deposition of back-barrier systems occurred across the continental shelf. During late low stand/early transgression periods, landward shoreface migration occurred, pre-existing channel incisions were infilled and pre-existing barriers were truncated. Rapid transgression, however, allowed the preservation of some back-barrier deposits, possibly aided by protection from antecedent topography. As sea level neared the present-day elevation, erosion of the mid-shelf sediments resulted in the development of a Holocene sediment wedge, which was augmented by Holocene fluvial sediment supply. The Holocene sand wedge is preserved in the back-barrier lakes and was deposited during the Holocene highstand inundation. Overlying middle to late Holocene terrestrial muds reflect the deposition of river-borne mud onto the shelf. These results clearly demonstrate that within transgressive–regressive sea-level cycles, accommodation space for barriers is controlled by antecedent drainage systems and gradients on the adjacent inner continental shelf.

1. Introduction

The South African Wilderness Embayment is characterised by large-scale shore-parallel barriers or dune cordons which reach a maximum elevation of 200 m above Mean Sea Level (AMSL). These are separated by a series of interconnected back-barrier/interdune lakes (Bateman et al., 2011). Globally, the significance of coastal barrier systems is recognised in terms of their roles as terrestrial palaeoenvironmental archives (e.g. Billeaud et al., 2009), recorders of the geomorphic evolution of coastal margins (e.g. Cowell and Thom, 1994; Tomazelli and Dillenburg, 2000, 2007; Brooke, 2001) and their significance for our understanding of coastal geomorphological responses to Pleistocene sea-level change (e.g. Murray-Wallace et al., 1999; Dillenburg et al., 2000; Frechen et al., 2002;

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Sloss et al., 2006; Hearty and O'Leary, 2008; Andreucci et al., 2009; Bateman et al., 2011). In the South African context they are also the key to understanding many significant Middle and Late Stone Age archaeological sites and the associated palaeoenvironments our ancestors occupied (e.g. Jacobs et al., 2003; Marean et al., 2007; Roberts et al., 2008).

Barrier systems are characteristic of wave dominated coastlines and typically comprise several depositional facies, the extent and arrangement of which, at any one time, are controlled by sediment supply, geological setting (hard rock geological and continental shelf configuration) and wave energy (Colman and Mixon, 1988; Dominguez et al., 1992; Riggs and Cleary, 1995). The links between the evolution of dune barriers (largely aeolian facies) and back-barrier development has been considered using chronologies of aeolian facies and marginal marine deposition (Murray-Wallace et al., 2001; Bateman et al., 2004; Carr et al., 2007; Murray-Wallace et al., 2010; Bateman et al., 2011). In some instances this has led to large chronological datasets from which phases of coastal dune accumulation and marine inundation have been identified. What has become apparent from such work is that in the absence of tectonic uplift gaps in the terrestrial barrier dune record probably reflect phases of barrier dune construction on currently submerged parts of the coastal plain (Bateman et al., 2011). It has also been shown that the morphology of the continental shelf as well as the route of rivers across this surface (both currently exposed and submerged) has a significant control on the timing, position and style of barrier construction (Dingle and Rogers, 1972; Bateman et al., 2004, 2011). Understanding the land–ocean interface is thus critical to appreciate fully the Quaternary sedimentary archives contained within the barriers and their associated back-barrier deposits. In this study, for the first time in a southern African context, the integrated links between accommodation space, sediment supply and coastal plain/barrier evolution are described. Deposits of the Wilderness Embayment (both terrestrial and currently submerged), offer an excellent opportunity to consider in detail the land–ocean interface, its response to Quaternary sea-level forcing and the role of cumulative evolution or landscape inheritance in shaping the contemporary coastlines (e.g. Cowell and Thom, 1994). A fuller understanding of sedimentation history within the lakes/back-barrier lagoons is also relevant to ongoing work seeking to use these archives of palaeoenvironmental and palaeoecological change (Reinwarth et al., 2013).

2. Regional setting

The southern coastal plain of South Africa extends from the Bot River (34º14′S; 19º20′E) to Port Elizabeth (33°58′S; 23°83′E) (Fig. 1). We define the coastal plain as the emerged low-gradient zone flanking the shoreline. The adjacent submerged component currently constitutes the continental shelf, defined to shelf/slope break. Southern South Africa is located on an intra-plate continental margin which rifted during the Cretaceous (Watkeys, 2006) but is considered passive and tectonically stable within the Quaternary. Planation events enlarged this coastal plain during the Cenozoic (Partridge, 1998; Marker and Holmes, 2005; Erlanger et al., 2012), creating prominent erosional surfaces. The continuity of the southern Cape coast from Port Elizabeth in the east to Cape Agulhas in the west is broken by a series of zeta (half-moon) bays (Fig. 1). These are linked to deformation associated with Gondwana break-up (Toerien, 1979; Hälbich, 1983; Malan and Viljoen, 1993; Watkeys, 2006) and the formation of several half-grabens (e.g. Algoa Bay). The bedrock lithology of pre-Cenozoic strata along the south coast is highly variable, creating variation in geomorphic expression (Roberts et al., 2013). The south coast broadly comprises Neogene and Quaternary marine, aeolian and lacustrine deposits (Dingle et al., 1983; Partridge and Maud, 1987) with the former related to sea-level fluctuations within these time periods (Dingle et al., 1983; Malan, 1990). The origins and age of geologically recent coastal sediment accumulations, including episodes of coastal dune building, the accumulation of sand sheets and their association with sea-level fluctuations have been investigated in some detail during the last decade (Illenberger, 1996; Bateman et al., 2004; Marker and Holmes, 2005; Carr et al., 2007; Holmes et al., 2007; Bateman et al., 2008; Roberts et al., 2008; Carr et al., 2010; Marker and Holmes, 2010; Bateman et al., 2011).

The south coast is a wave-dominated coastline and the tidal range around much of the coastline is generally low and is classed as micro-tidal (<2 m spring tidal range) to meso-tidal (Davies, 1980). The major wave direction on the southern African coastline is from the southwest (Davies, 1980; Heydorn and Tinley, 1980) and the associated long fetch means that the coastline is dominated by swell waves (Whitfield, 1983). The Wilderness Embayment (Fig. 1) is a prominent physiographic feature within the coastal plain of the southern Cape, South Africa. It, along with Nature's Valley to the east, are unusual embayments in that the cliff lines are eroded in less resistant strata, rather than half-grabens. Eastward, longshore drift on the south coast provides a major source of sediment, ultimately derived from river discharge, and this has promoted the construction of a nearshore sediment wedge (Birch, 1980). Studies within the Wilderness Embayment have largely focussed on the system of shore-parallel barriers (dunes) which record long-term coastal aeolian activity, largely driven by glacial–interglacial sea-level change (e.g. Bateman et al., 2011). Within the Wilderness Embayment, Bateman et al. (2011) further proposed that localised variability in continental shelf bathymetry has resulted in complexity within the onshore sedimentary aeolian record.

3. Previous studies

3.1. The Wilderness Embayment

The large, approximately shore-parallel ridges of the Wilderness Embayment are also referred to as cordon dunes (sensu Illenberger, 1996). These aeolian deposits comprise unconsolidated sand to heavily lithified aeolianite and they are separated by several back barrier lakes. While lithification of the aeolian sediments has rendered them relatively resistant to erosion, the barriers have been breached in places by rivers (e.g. the middle barrier by the Swartvlei River). Four shore-parallel barriers were originally identified by Martin (1962), termed (from landward to seaward) I, II, III and IV. Illenberger (1996) condensed these to three units by combining the most seaward barriers (III and IV) and referring to them as the seaward, middle and landward barriers, which is followed here (Fig. 1). The seaward and middle barriers are the most prominent features. The landward barrier often lacks clear geomorphic expression and its distribution is seemingly constrained by hard rock geology in some locations (Fig. 1). The modern seaward barrier is being eroded by the sea, forming seacliffs in excess of 180 m. Palaeo-seacliffs and wave cut platforms are observed on the seaward side of the middle barrier (Illenberger, 1996). The present chronological framework suggests that the each of the Wilderness barriers have been constructed over at least two glacial–interglacial cycles and possible as far back as Marine Isotope Stage (MIS) 11 (Illenberger, 1996; Bateman et al., 2011). Notable phases of construction have been constrained to between 241 and 221 ka, 159–143 ka, 130–120 ka, 92–87 ka and post 6 ka. These appear to be associated with regressive phases subsequent to sea-level highstands (Bateman et al., 2011). Tectonic stability within the embayment has meant that glacio-eustatically formed