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Chronology of Quaternary coastal aeolianite deposition and the drowned shorelines of southwestern Western Australia – a reappraisal

B.P. Brooke [a,*], J.M. Olley [b], T. Pietsch [b], P.E. Playford [c], P.W. Haines [c], C.V. Murray-Wallace [d], C.D. Woodroffe [d]

[a] Coastal Marine and Climate Hazards Group, Geoscience Australia, Canberra, ACT 2601, Australia
[b] Australian Rivers Institute, Griffith University, Nathan, QLD 4111, Australia
[c] Geological Survey of Western Australia, East Perth, WA 6004, Australia
[d] School of Earth & Environmental Sciences, University of Wollongong, NSW 2522, Australia

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ABSTRACT

Aeolianite successions of low-gradient continental margins commonly show complex records of coastal dune deposition linked to a wide range of sea-level positions and climatic periods of the middle and late Pleistocene, recording both regional and broader-scale drivers of sediment production, coastal dune development and landform preservation. To better characterise the general pattern of sedimentation that occurs over Quaternary glacial–interglacial cycles on low-gradient, temperate carbonate continental shelves we examine the morphology, stratigraphy and age of aeolianite deposits in the Perth region, Western Australia. This includes an analysis of well-defined drowned coastal landforms preserved on the adjacent shelf. New and previously published optical ages provide a preliminary timeframe for the deposition of aeolianite in the Perth region and on Rottnest Island, 17 km offshore. An extensive aeolianite ridge near Perth, representing a former barrier, has Optically Stimulated Luminesence (OSL) ages that range from 120 ± 12 to 103 ± 10 ka (MIS 5e–5a in the context of associated age uncertainties). OSL ages for an exposure in the same ridge 2.5 km inland, record the onlap of much older aeolianite, OSL age 415 ± 70 ka, by shell-rich estuarine beds, OSL age 290 ± 30 ka. A further 5.5 km inland from the coast, two thick aeolianite units, separated by a well-developed palaeosol, have stratigraphically consistent OSL ages of 310 ± 30 and 155 ± 20 ka. In contrast, aeolianite units that form the northern coast of Rottnest Island have OSL ages of 77 ± 12 ka and 27 ± 5 ka. The new OSL ages and previously reported TL and U/Th ages indicate that the bulk of the island comprises dunes deposited around the end of the Last Interglacial *sensu lato* (MIS 5a–4) and during the Last Glacial (MIS 4–2), accumulating over a Last Interglacial coral reef and basal calcarenite. Drowned barrier and dune landforms preserved on the adjacent continental shelf reveal that barriers were formed during periods of intermediate sea level (e.g. MIS 3) and significant dune mobility occurred when the shelf was subaerially exposed. The pattern of shelf sedimentation discernible in the Perth region – large-scale coastal carbonate dune deposition during periods of high and intermediate sea level and reactivation during glacial lowstands – is largely consistent with published stratigraphic and age data for large-scale aeolianite deposits on other low-gradient carbonate shelves. Based on these data, a general model is proposed for the cycle of Quaternary sedimentation and landform evolution that occurs on these shelves, which are dynamic sedimentary environments with coastal landforms and sedimentary successions that are very sensitive to erosion and sediment reworking.

1. Introduction

Aeolianite coasts have provided many fundamental insights into coastal sedimentation and landform development during Quaternary glacial cycles. Classic sites such as the aeolianite islands of

* Corresponding author. Tel.: +61 2 62499434; fax: +61 2 62499920.
E-mail address: Brendan.Brooke@ga.gov.au (B.P. Brooke).

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Bermuda and the Bahamas have well-preserved relict coastal dune landforms that have recorded the mode and rate of Quaternary coastal landform evolution and marine biogenic carbonate sediment production during the past few glacial–interglacial cycles, when sea level was high enough to flood the surrounding shallow shelves (Vacher et al., 1995; Carew and Mylroie, 1997; Kindler and Hearty, 1997; Vacher and Rowe, 1997). The gently uplifting Coorong Coastal Plain of South Australia preserves an even more extensive series of relict coastal barriers that formed marginal to a broad continental shelf (Murray-Wallace, 2002). These barriers developed with the input of fluvial and marine carbonate sediment to the coast during successive interglacial and glacial periods over at least the past 1 million years (Murray-Wallace et al., 2001).

Studies of several continental aeolianite coasts commonly show a more complex record of coastal dune deposition linked to a wide range of sea-level positions and climatic periods of the middle and late Pleistocene (Brooke, 2001), including the South African eastern (Porat and Botha, 2008) and southern coasts (Bateman et al., 2004, 2011; Carr et al., 2007), Carmel coast of Israel (Frechen et al., 2004; Sivan and Porat, 2004), Victorian coast of Australia (Gardner et al., 2006) and Mallorca (Fornos et al., 2009). In addition to dune emplacement during the last couple of interglacials, these deposits include units emplaced through the aeolian reworking of coastal and shelf sediment during periods of low sea level (e.g. Sivan and Porat, 2004; Porat and Botha, 2008) and under a more arid and windy climate than present (Porat and Botha, 2008; Fornos et al., 2009; Playford et al., 2013), or with fluctuations in sea level during interstadials (Bateman et al., 2004, 2011; Gardner et al., 2006). Aeolianite on these coasts appears to record both regional and broader-scale drivers of coastal dune mobility and accumulation. To better understand these Quaternary shelf sediment systems, information is required on the stratigraphy and age of coastal deposits and landforms that formed on the adjacent continental shelves during periods when sea level was lower than present (e.g., Brooke et al., 2010; Bateman et al., 2011; Cawthra et al., 2012). In particular, preserved morphological information on drowned shelf deposits can provide new insight into the glacial–interglacial cycle of carbonate shelf sedimentation, during which coastal deposits may accumulate with the direct input to the coast of carbonate produced offshore; or with the reworking of subaerially exposed shelf sediment during periods of low sea level.

This study examines a range of new and previously published age data for the aeolianite deposits around Perth, Western Australia. The data are set within a regional morphostratigraphic context provided by a high-resolution digital elevation model of the coastal plain and adjacent continental shelf, which reveals a number of relict shorelines. We examine the timing of deposition of the aeolianite in relation to the glacio-eustatic sea-level record and the morphology and elevation of relict shorelines. A conceptual model of Quaternary carbonate production and aeolianite formation over a full glacial–interglacial cycle is proposed that may also be applicable to other carbonate continental shelves.

2. Regional setting

Aeolianite along the coast of southwestern Australia is known as the Tamala Limestone, a Pleistocene lithostratigraphic unit of the Perth and Carnarvon Basins (Playford et al., 1976, 2013), and represents a vast accumulation of Pleistocene marine carbonate sediment (Fig. 1; Mayer, 2008). The great extent, composition and general stratigraphy of these deposits, including exposures in what is now the Perth region, were first described in 1801 by geologists on the French scientific expedition of the coast of western and southern Australia, led by Nicholas Baudin (Mayer, 2008). Since then several exposures of the Tamala Limestone have been examined in which dune, palaeosol and subordinate shallow-marine units record cycles of coastal sedimentation (Fairbridge and Teichert, 1953; Playford et al., 1976; Murray-Wallace and Kimber, 1989; Kendrick et al., 1991, 1997; Price et al., 2001; Hearty, 2003; Gozzard, 2007; Hearty and O'Leary, 2008; Playford et al., 2013).

Perth has a Mediterranean climate, with hot dry summers (average max. 31 °C, min. 19 °C; average monthly rainfall 12 mm) and cool relatively wet winters (average max. 19 °C, min. 8 °C; average monthly rainfall 132 mm) (Bureau of Meteorology, 2012). There is an energetic wind regime on the coast (average monthly 3 pm wind speed, 12.5–19.5 km/h), dominated by onshore wind from the SW–W (Bureau of Meteorology, 2012). The orientation of large-scale dune foreset beds measured at the aeolianite exposures described below record deposition under wind from similar onshore directions. The Perth coast forms the margin of the broad (up to 50 km wide) Rottnest Shelf, which receives very little terrestrial sediment and is dominated by marine biogenic carbonate sediment (Collins, 1988). The shelf experiences a high-energy south to southwesterly swell, with a mean deep-water wave height of 2–3 m and period of 10–14 s. Shelfal waters are subtropical (16–20 °C) and influenced by the warm, low-nutrient waters of the southerly flowing Leeuwin Current (Collins, 1988), with a micro-tidal regime (<2 m range).

The Perth coast, part of the Swan Coastal Plain, comprises three major aeolianite ridges, with 20–40 m of relief, that run semi-parallel to the shoreline and rise in elevation with distance from the coast (Fig. 2; Playford et al., 1976; Playford, 1988, 1997; Gozzard, 2007; Brooke et al., 2010). A chain of aeolianite islands and reefs extend out from the Perth coast (Fig. 2). These features include a series of submerged ridges that are the remnants of a recurved aeolianite coastline that existed when sea level was more than 20 m lower than present (Fig. 2; Playford, 1988, 1997). Further offshore, a less well defined linear structure extends along most of the outer Rottnest Shelf and probably represents the erosional remnant of a drowned shoreline barrier (James et al., 1999; Brooke et al., 2010). This feature rises 5–15 m above the adjacent seabed, is approximately 2–4 km wide and sits 60–50 m below sea level (Fig. 2B). It merges with the western margin of Rottnest Island, while south of the island the features becomes less distinct (Brooke et al., 2010).

Several sections of middle and late Pleistocene dune units have been studied in the Tamala Limestone near Perth and on the nearby islands (Price et al., 2001; Hearty, 2003; Hearty and O'Leary, 2008), with occasional outcrops of Last Interglacial coral reef (Szabo, 1979; Kendrick et al., 1991; Stirling et al., 1998) and middle Pleistocene and Last Interglacial mollusc-rich estuarine beds (Hewgill et al., 1983; Murray-Wallace and Kimber, 1989; Kendrick et al., 1991). The elevation of reliably dated estuarine and reef deposits, in particular the robustly dated Last Interglacial (MIS 5e) coral reef at Fairbridge Bluff on Rottnest Island (Szabo, 1979; Stirling et al., 1995, 1998) suggest that the area has been tectonically stable since at least the later part of the middle Pleistocene (Kendrick et al., 1991). However, examples of neotectonism in the region have been noted by Playford et al. (2013), who record faulting that post-dates deposition of part of the Tamala Limestone near Jurien, 220 km north of Perth, raising the possibility of faulting in the late Pleistocene or early Holocene.

The chronology of the ubiquitous aeolianite of the Tamala Limestone is relatively poorly resolved (Kelletat, 1991; Price et al., 2001; Hearty, 2003; Hearty and O'Leary, 2008). Whole-rock amino acid racemisation (AAR) age estimates of aeolianite near Perth are middle Pleistocene and Last Interglacial, whereas age estimates for aeolianite on Rottnest Island predominantly lie within the period from marine oxygen isotope substages (MIS) 5c to 5a (Hearty, 2003). In contrast, thermoluminescence (TL) ages of the