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Rates of Shoreline Progradation during the Last 1700 Years at Beachmere, Southeastern Queensland, Australia, Based on Optically Stimulated Luminescence Dating of Beach Ridges

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ABSTRACT

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The optically stimulated luminescence (OSL) dating method was used to determine the geochronology of seven relict beach ridges that sit immediately behind the modern beach at Beachmere, a low-energy sandy coast within Moreton Bay, Queensland. Between 2600 ± 400 and 1700 ± 130 years ago, the shoreline eroded and foreshore sediment was deposited over the older beach deposit. Subsequently, there was a 1500-year period of shoreline progradation: the shoreline advanced 0.16 m/y between 1700 ± 130 and 1140 ± 80 years ago; and 0.41 m/y between 1140 ± 80 and around 200 years ago. Shortly after 690 ± 60 years ago, a series of well-developed regularly spaced beach ridges gave way to an intertidal flat and then deposition of a set of lower amplitude, closely spaced beach ridges. The younger ridges were deposited between 230 ± 40 and 140 ± 50 years ago, at a rate of around 1.06 m/y. During the last several decades, much of the Beachmere shoreline has eroded into these younger relict ridges. Drivers of these changes in shoreline sedimentary regime are yet to be accurately determined; however, it seems likely they are related to switches that occur in the nearshore sand transport pathway. Our results demonstrate the utility of the OSL method for providing insights into coastal change that occurred in the historical and recent geological period. Better understanding the tempo of shoreline change in the recent past is particularly relevant for assessments of vulnerability to erosion of rapidly developing, low-lying sandy coasts such as northern Moreton Bay.

ADDITIONAL INDEX WORDS: *Beach sediments, shoreline erosion, coastal evolution.*

INTRODUCTION

Beach ridges form on accreting coasts where waves and onshore winds emplace sediment, ranging from sand to gravel, in foreshore and backshore settings. They are generally regularly spaced, low amplitude (a few metres thick) shore-parallel ridges that mark the former position of the shoreline. The ridges may be of beach or foredune origin; they are often a combination of both types of deposits (Otvos, 2000); and they occur in tropical to polar settings (*e.g.,* Anthony, 1995; Arthurton *et al.,* 1999; Carter, 1986; Mason and Jordan, 1993; Murray-Wallace *et al.,* 2002). Beach ridges develop during periods of storm waves and elevated sea level or during quiescent periods with constructive waves, currents and winds, or with a combination of these modes of accretion (Orford, Murdy, and Wintle, 2003; Otvos, 2000; Sanderson, Eliot, and Fuller, 1998; Woodroffe, 2002). Beach-ridge successions, therefore, can provide useful records of the character and rate of shoreline sediment accumulation and progradation. Beach ridges may also provide records of past relative sea level where an intertidal facies can be identified within the ridge sequence (Orford, Murdy, and Wintle, 2003; Otvos, 2000).

Numerous studies of beach-ridge successions have been able to reconstruct shoreline depositional regimes that operated during the Last Interglacial and Holocene using radiometric (*e.g.,* radiocarbon; uranium-thorium) and luminescence dating methods (*e.g.,* Brückner and Schellmann, 2003; Goy, Zazo, and Dabrio, 2003; Mason and Jordan, 1993; Murray-Wallace *et al.,* 2002; Orford, Murdy, and Wintle, 2003; Shepard, 1991). The rate at which beach ridges and beach-ridge successions develop has also been measured using aerial photographs and survey markers (*e.g.,* Carter, 1986; Sanderson, Eliot, and Fuller, 1998).

There are difficulties, however, in obtaining chronologies for beach ridges that are older than the historical period but too young to be accurately dated by the radiocarbon method, the most commonly used dating tool. For example, in southeastern Australia the advent of systematic aerial photography of the coast was approximately 60 years ago, while the effective limit of the radiocarbon method for this region is approximately 500 years due to the marine reservoir effect

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(−450 ± 35 y, Gillespie and Polach, 1979). New optical dating methods using the optically stimulated luminescence (OSL) signal are now providing the opportunity to accurately date relict sandy beach deposits in this age range that otherwise cannot be numerically dated and thereby provide important insights into past rates of coastal sedimentation (*e.g.,* Ballarini *et al.,* 2003; Goodwin, Stables, and Olley, 2006; Murray-Wallace *et al.,* 2002).

In this paper we examine a series of beach ridges at Beachmere, a rapidly developing low-lying coastal plain of Moreton Bay, southeastern Queensland, Australia. We present OSL ages that in combination with geomorphological and sedimentological data show that the beach ridges preserve a relatively detailed record of shoreline progradation, changes in shoreline morphology, and erosion for the last 2600 years.

Study Area

Beachmere is located approximately 40 km north of Brisbane on the west coast of Deception Bay, an embayment on the northwestern margin of Moreton Bay (Figure 1). There has been a continual supply of marine sand to Moreton Bay during the Holocene highstand via the regional longshore sediment transport systems that operate along the southeastern coast of Queensland (Jones, 1992; Stevens, 1992). Moreton Bay sits in a tectonically quiescent midplate setting far from the influence of glacial isostasy (Lambeck and Nakada, 1990). Any changes in sea level in this region during the late Holocene, therefore, will be related to hydroisostatic or eustatic adjustments. For example, the modelled hydroisostatic movement of the tectonically stable continental shelf of central Queensland, 470 km north of Moreton Bay, indicates relative sea level on this coast would have been 2–3 m higher than the present at around 6000–7000 years ago, then gradually fell to its present level (Yokoyama *et al.,* 2006).

The Beachmere coastal plain comprises Triassic-Jurassic Landsborough sandstone bedrock overlain by late Quaternary coastal, estuarine, and fluvial sediments that are capped by a series of sandy beach ridges (Cranfield *et al.,* 1983; Lee, Cox, and Brooke, 2002; O'Flynn, 1980). The ridges extend 10 km along the coast from the Caboolture River to Godwin Beach and up to 3.0 km inland (Figure 1B). They rise no more than 3 m above the surrounding plain and rarely exceed 5 m above mean sea level (MSL; Flood, 1980; Lang *et al.,* 1998; Lee, Cox, and Brooke, 2002). Two morphologically different sets of beach ridges have been identified, (i) the inner ridges of middle Holocene age that appear to cap Pleistocene coastal deposits and (ii) the set of narrow younger ridges immediately behind the shoreline. A coastal lowland approximately 700 m wide separates the two sets of ridges (Flood, 1980; Lang *et al.,* 1998).

The series of seven ridges examined in this study extend approximately 600 m inland from the modern shoreline at Beachmere (Figures 1B, 2). The older beach ridges extend a further 2 km inland, are more widely spaced, and are broader than the younger ridges. Shells collected from these older deposits have returned marine-reservoir corrected radiocarbon ages of approximately 5000–6000 years BP (Flood, 1981). In contrast, the corrected radiocarbon age of a shell collected from within one of the younger (low) ridges at the southern end of the Beachmere coast is 545 ± 45 years BP (Flood, 1981). In contrast to the records of accretion preserved in the ridges, aerial photographs of Beachmere indicate that since at least 1960 (Flood, 1980) the beach has eroded and sand has been transported alongshore to the south and deposited in the spit at the mouth of the Caboolture River.

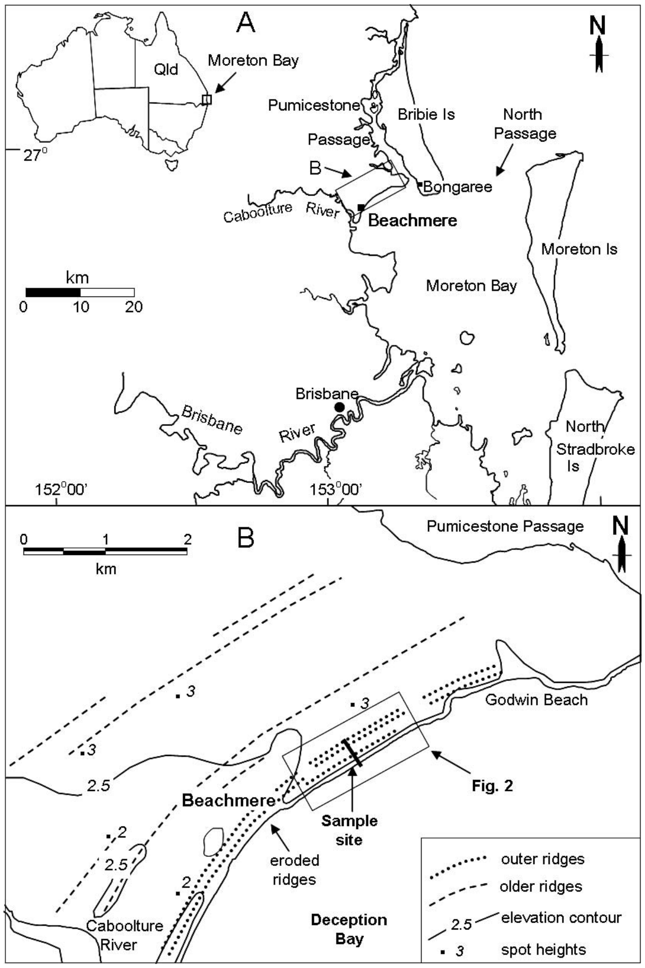

Figure 1. (A) Location of Beachmere, at the northwestern margin of Moreton Bay, southeastern Queensland. Sites discussed in the text are shown. (B) Beachmere and Deception Bay, showing the approximate location of the two series of Holocene beach ridges on the low-lying strandplain.

Moreton Bay is protected from most Pacific Ocean swell by the very large sand islands and shallow bars that act as barriers around its seaward margin (Figure 1). Because of this arrangement, sediment transportation in the bay is controlled by the action of tidal currents and local waves (mean wave height ~40 cm, Queensland EPA, 2005). The bay is mesotidal, and at the closest tidal gauge to the study site, Bongaree (Figure 1), mean sea level (MSL) is 1.08 m above lowest astronomical tide (LAT); mean high water spring is

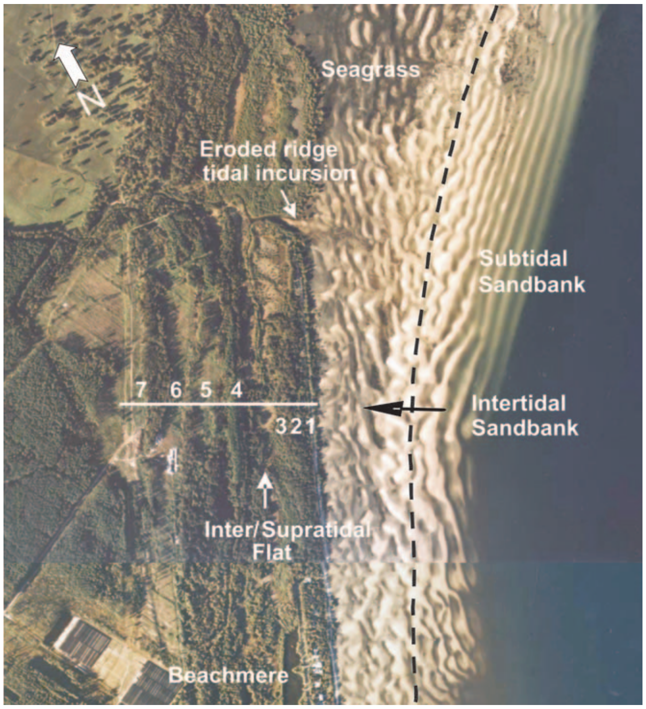

Figure 2. An aerial photograph of Beachmere showing the location of the beach-ridge transect. The approximate positions of ridges 1–7 are indicated. The dashed line marks the boundary between intertidal and subtidal sand deposits (Beach Protection Authority, 1994).

1.86 m; and maximum tidal range is 2.33 m (Martin and Broadbent, 2004). The dominant wind and longest fetch in the bay is from the southeast, to which the beach and beach ridges at Beachmere are aligned (Figure 1).

Siliciclastic sand accumulates at Beachmere in beach deposits, shore-parallel intertidal sand banks, and in spits at the mouth of the Caboolture River (Figures 1, 2; Flood, 1980). Marine sand is delivered to Beachmere from the Northern Passage as indicated by the distribution of marine sand in the bay and the seasonal pattern of currents in northern Moreton Bay (Dennison and Abal, 1999; Stevens, 1992; Figure 1A). Additionally, sand and mud are delivered to this coast via the Caboolture River, which discharges into Deception Bay immediately south of Beachmere township (Flood, 1980).

Subtidal deposits of sand are evident in aerial photographs of Beachmere, and to the north at Goodwin Beach the sand banks are covered by extensive seagrass meadows that merge into the muddy shoreline of Pumicestone Passage (Figure 2). The combination of southeasterly shoreline orientation that exposes the coast to the prevailing onshore wind and relatively high wave energy regime and the supply of marine sand from the bay and terrigenous sediment from the Caboolture River has produced this section of sandy coast in a tide-dominated, predominantly muddy embayment (Abal, Dennison, and O'Donohue, 1998).

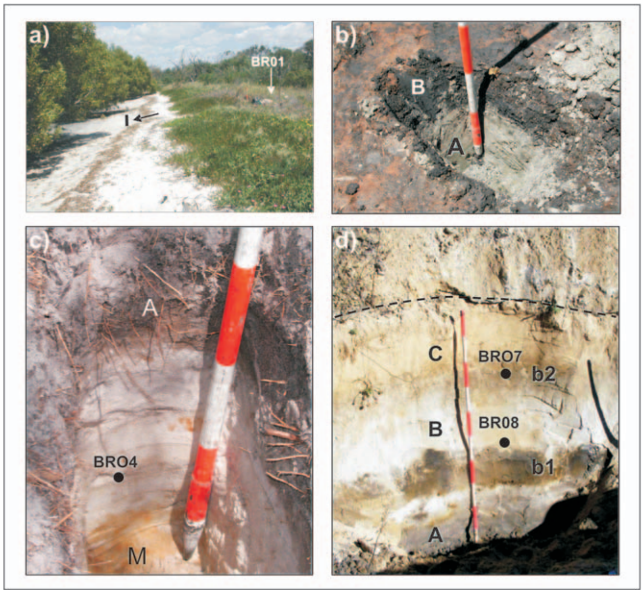

Figure 3. Photographs of the beach-ridge sample sites. (a) The modern beach and foredune, ridge 1. The OSL sample site is indicated (BR01). The black scale (arrow) is 0.5 m long and sits on the high tide strandline behind the "stranded" mangroves. (b) A trench in the intertidal flat between ridges 4 and 3 reveals fine–medium sand (A) overlain by organic-rich sandy mud (B). (c) The trench in ridge 4. An organic-rich A horizon overlies leached sand that sits on a weakly developed B horizon of reddish brown mottles (M). The location of OSL sample BR04 is indicated. (d) The pit in ridge 7. This exposure comprises muddy sand (A), and two units of fine–medium sand with pebbles (B and C) capped by 30–40 cm of fine–medium dune sand. The palaeo B horizon (b1) and modern soil B horizon (b2) are evident in units B and C. The dotted line indicates the land surface. The positions of the OSL samples are indicated (BR07, BR08).

METHODS

Beach-Ridge Transect

The modern beach and seven beach ridges were examined along a 600-m transect perpendicular to the shoreline (Figure 2). The transect location was selected because all ridges are well defined on this section of coast, based on an examination of aerial photographs and field observations. The prominent two most western ridges (ridges 6 and 7) and the set of younger, low eastern ridges (1–3) were surveyed to a Queensland Government survey mark south of the study area (Permanent Mark 126953; UTM coordinates E 508345.9, N 7002970; Queensland Department of Lands, 1995) using a dumpy level (Figure 2). The two middle ridges (4–5) were not surveyed but levelled using poles and tape due to the dense forest and vine thicket that covers these ridges. A standard global positioning system and aerial photographs were used to record the location of the sediment sample sites on each ridge (Table 1).

A trench was dug in the crest of each ridge to a depth of approximately 1.3 m. Soil and other sedimentary features evident in the wall of the trenches were recorded and sediment samples were collected for description and OSL dating (Table 1). Prior to the collection of the samples for dating, the

Table 1. *Beach-ridge field data and sample descriptions.*

Sample No.	Ridge No.	Sample Depth (m)	Location (UTM)[1]	Sediment Description
BR01	1	1.1	509382 7002936	Fine–medium quartz sand, light grey 2.5Y 7/2 (Munsell colour).
BR02	2	1.1	509370 7002944	Fine–medium quartz sand, 2.5Y 7/2 with darker A horizon.
BR03	3	1.2	509345 7002969	Fine–medium quartz sand, light grey 2.5Y 7/2, with darker A horizon and tree roots.
BR04	4	0.8	509220 7003122	Fine–medium quartz sand, light grey 2.5Y 7/2, with reddish orange 7.5YR 6/6 mottles at 0.7 m. Minor shell fragments.
BR05	5	0.7	509152 7003186	Fine–medium quartz sand, very pale brown 2.5Y 7/3. Minor shell fragments; clayey sand at 0.7 m.
BR06	6	0.8	509095 7003263	Fine–medium quartz sand, very pale brown 2.5Y 7/2.
BR07	7	0.7	509049 7003333	0–80 cm: Fine–medium sand (0–40 cm), very pale brown 2.5Y 7/2, over fine–medium sand with poorly sorted quartz and feldspar pebbles (~3% by weight of sample). Soil B horizon at 40 cm.
BR08	7	1.2	509049 7003333	80–220 cm: Fine–medium sand with poorly sorted quartz and feldspar pebbles (~3% of sample). Palaeosol with reddish brown mottles at 1.4 m. Grey muddy sand at 200 cm.

[1] 1 : 25,000 Topographic Sheet, Toorbul 9543-44 (Queensland Department of Lands, 1995).

trenches were covered with a light-proof black plastic sheet. The samples were then collected by hammering a 75-mm diameter 400-mm long aluminium tube into the freshly exposed face of the trench at a depth of 0.7–1.2 m, well below any recent disturbance evident in the soil profile (Figure 3). The sample tubes were extracted, capped, and sealed before being exposed to light.

OSL Dating

OSL dating has been successfully used to date eolian, freshwater and marine sediments (*e.g.,* AITKEN, 1998; BAILEY *et al.,* 2001; MURRAY and OLLEY, 2002; OLLEY, CAITCHEON, and ROBERTS, 1999; OLLEY, PIETSCH, and ROBERTS, 2004; RADTKE *et al.,* 2001). A subsample from each of the eight samples was taken for water content determination and for measurement of the lithogenic radionuclide concentrations. The dating was undertaken on quartz grains (180–212 μm in diameter) that were extracted from each sample by wet sieving. The grains were then etched in 40% hydrofluoric acid for 50 minutes to remove the outer (alpha irradiated) 10-μm rinds (AITKEN, 1985), and to completely remove any feldspars. The absence of feldspars was checked using infrared stimulated luminescence, and where necessary samples were re-etched in silica saturated fluorosilicic acid to remove any residual feldspar. Acid-soluble fluorides were removed in 15% hydrochloric acid.

The burial dose was determined by measurement of the OSL from 1-mm aliquots of quartz. All measurements were made on one of three Riso automated thermoluminescence (TL)/OSL readers, each fitted with an EMI 9635QA photomultiplier tube and three U-340 transmission filters. The aliquots were analysed using the single aliquot regenerative dose (SAR) protocol (MURRAY and WINTLE, 2000). The samples were illuminated for 100 seconds at 125°C. In each case the OSL signal was integrated over the first 2 seconds of illumination. A per second background value was calculated by integrating over the last 20 seconds of illumination and subtracted from the OSL signal. A preheat temperature of 200°C for 10 seconds was used for the natural and regenerative dose measurements, and a cut heat to 160°C was given after each test dose. Test doses of 1 to 5 Gy were used, depending on the brightness of the sample. Six regenerative dose cycles were used, one of which was a repeat of a near natural dose.

The dose rates were determined from the radionuclide concentrations in the sediment subsamples by high-resolution gamma spectrometry (MURRAY *et al.,* 1987). Dose rates were calculated using the conversion factors of STOKES, BRAY, and BLUM (2001) and were corrected for water content (AITKEN, 1985). The cosmic-ray dose rates were calculated from PRESCOTT and STEPHAN (1982) and PRESCOTT and HUTTON (1988). Beta-attenuation factors were taken from MEJDAHL (1979), and the effective alpha dose rate contribution has been estimated using an alpha-efficiency "a" value for quartz of 0.04 ± 0.02.

RESULTS

Ridge Morphology and Sediments

The better developed landward ridges (7–4, Figure 2) extend along the entire length of the Beachmere strandplain, while the lower younger ridges (3–1) have been eroded near Beachmere township (Figure 1B). The most landward ridge, ridge 7, has a consistent elevation along the strandplain of between 2.5 and 3 m above MSL (Figures 1B, 4). The most prominent and persistent ridge in the younger set, ridge 2, has an elevation of approximately 2–2.5 m above MSL.

The landward ridges (ridges 7–4) have a wavelength (crest to crest) of around 100 m and amplitude (elevation above the swale) of 0.5–1.2 m (Figure 4). In contrast, the younger set of ridges immediately behind the modern beach (ridges 3–1) have a wavelength of approximately 15–30 m and amplitude of 0.2–0.7 m. We infer these differences to formation of the three younger ridges during a much shorter phase of accretion, when small foredunes were emplaced over a beach foreshore deposit (*e.g.,* OTVOS, 2000; Figure 4).

Sediment samples from the beach ridges and modern beach are generally very similar, comprising fine to medium quartz sand (Table 1; Figure 5). A minor gravel component (~3%, small-medium pebbles) was evident in samples from ridge 7, while the sample from ridge 4 has a larger proportion of fine sand compared with the other samples (Figure 5). There is an increase in the degree of soil profile development inland from the shoreline as observed in the trenches: organic enrichment in the A horizon is the only discernible feature in the first three ridges; orange mottles of incipient B horizons are evident in ridges 4–6; and in the deeper pit in ridge 7

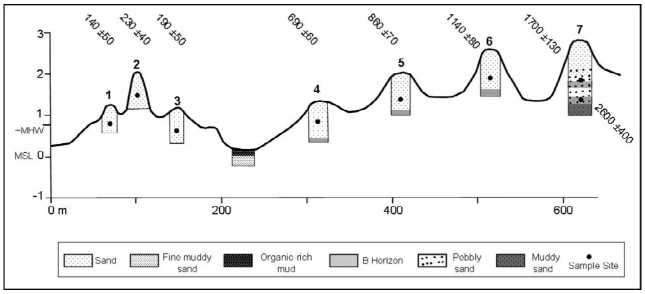

Figure 4. East-west cross-section of the outer coastal plain at Beachmere, showing the succession of seven outer beach ridges, their stratigraphy, and OSL ages. Note the large vertical exaggeration (VE = 55).

there are two moderately cemented B horizons that record two phases of soil development (Table 1; Figure 3).

Ridge 7 comprises three sedimentary facies (Figure 3d; Table 1): (i) fine to medium sand in the top 30–40 cm with no discernible bedding that is likely to be a foredune deposit; (ii) from 40 to 160 cm fine to medium sand with stringers of small quartz and feldspar pebbles. The pebbles define bedding planes that dip at low angles (~5°) seaward and the unit is likely of beach foreshore origin; and (iii) grey muddy sand below 160 cm that reflects a shoreface to foreshore depositional environment (Figure 3d; Table 1).

OSL Ages

The sample lithogenic radionuclide concentrations are summarized in Table 2, and water contents, calculated dose rates, burial doses, and OSL ages are reported in Table 3. The OSL ages increase sequentially in a landward direction from ridge 1 (BR01, 140 ± 50 y, Table 3) to ridge 7 (BR07, 1700 ± 130). Although there is an apparent age reversal between ridges 2 (BR02, 230 ± 40 y, Table 3) and 3 (BR03, 190 ± 40 y), these ages overlap within their 1 σ uncertainty and probably indicate a period of rapid shoreline progradation (discussed below). The age of ridge 4, 690 ± 60 years (Figure 4), is similar to the marine-reservoir corrected radiocarbon age of shell collected south of Beachmere township in what appears to be the same ridge, 545 ± 45 years BP (FLOOD, 1981). The two OSL ages for the beach deposit in ridge 7 (BR07 and BR08) indicate two phases of deposition, the first at approximately 2600 ± 400 years ago (BR08, Table 3), the second at 1700 ± 130 years ago (BR07; Figures 3, 4).

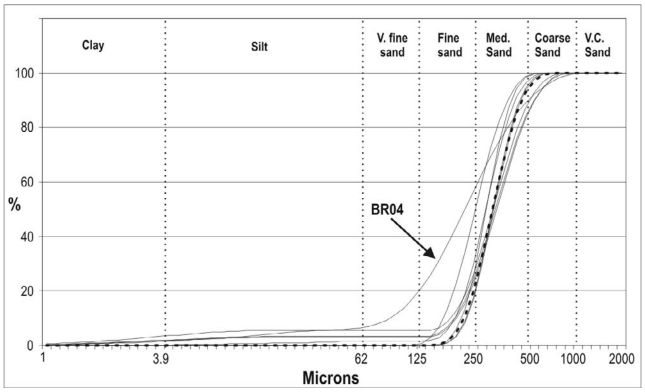

Figure 5. Cumulative grain-size distribution curves for the beach and beach-ridge samples measured by laser grain-size analyser. All samples have a similar grain-size population (samples BR07 and BR08 also contain a small gravel fraction; see Table 1). The sample from the modern beach (−0.5 m MSL) is indicated by the dashed line. There is a slightly larger proportion of very fine and fine sand in BR04.

DISCUSSION

Depositional Environments

The series of seven beach ridges examined at Beachmere form the eastern margin of the Holocene strandplain. Compared with beach-ridge successions reported on many sandy coasts (*e.g.,* ANTHONY, 1995; HESP, 1984; MURRAY-WALLACE *et al.,* 2002; OTVOS, 2000), these ridges are relatively subtle topographic features that reflect rapid deposition (SHEPARD, 1990) and a relatively low-energy shoreline regime (MELDAHL, 1995).

The most landward ridge examined, ridge 7, is the only ridge that could be clearly identified as comprising sand beds that were emplaced in a foreshore environment rather than a foredune setting (Figure 3). Sedimentological features evident in trenches in the other ridges and grain-size data are not clearly diagnostic of either a beach or foredune origin (Figure 5). The subdued morphology of the ridges, however, is indicative of deposition in a foreshore setting with a subsequent capping of eolian sand (OTVOS, 2000).

Ridge 7 is a composite structure that includes two beach units (Table 1, Figure 3d). The lower beach unit includes pebbly sand and muddy sand that was deposited approximately 2600 years ago in a subtidal to lower intertidal setting (Figures 3, 4). Feldspar pebbles indicate that this sediment is at

Table 2. *Sample lithogenic radionuclide activity concentrations in Bq kg^{-1}.*

Sample	^{238}U	^{226}Ra	^{210}Pb	^{228}Ra	^{228}Th	^{40}K
BR01	3.6 ± 4.7	1.5 ± 0.3	3.1 ± 1.8	1.5 ± 0.5	1.8 ± 0.1	1.4 ± 2.5
BR02	3.6 ± 1.7	1.8 ± 0.1	2.1 ± 0.9	1.8 ± 0.2	2.0 ± 0.0	13.2 ± 1.1
BR03	4.1 ± 1.8	2.0 ± 0.1	2.3 ± 0.9	2.2 ± 0.2	2.8 ± 0.1	15.4 ± 1.1
BR04	12.4 ± 3.0	3.0 ± 0.2	6.1 ± 1.8	4.3 ± 0.4	4.5 ± 0.2	60.7 ± 3.1
BR05	6.5 ± 3.2	3.3 ± 0.2	0.5 ± 1.6	4.4 ± 0.4	4.8 ± 0.2	64.1 ± 3.1
BR06	0.9 ± 1.9	2.1 ± 0.1	1.9 ± 1.0	2.2 ± 0.2	2.7 ± 0.1	11.6 ± 1.1
BR07	11.4 ± 2.9	2.6 ± 0.2	5.5 ± 1.7	2.9 ± 0.4	2.8 ± 0.2	10.8 ± 2.3
BR08	4.7 ± 1.9	2.1 ± 0.2	0.2 ± 1.5	2.5 ± 0.3	3.2 ± 0.3	14.0 ± 2.2

Table 3. *Sample burial dose, measured water contents, dose rates, and OSL ages.*

Sample	Burial Dose (Gy)	As Measured Water Content (%)	Dose Rate (Gy ka^{-1})	Age (y)
BR01	0.037 ± 0.013	3.8	0.26 ± 0.03	140 ± 50
BR02	0.07 ± 0.01	1.1	0.30 ± 0.02	230 ± 40
BR03	0.065 ± 0.012	2.9	0.34 ± 0.015	190 ± 40
BR04	0.37 ± 0.020	11.7	0.54 ± 0.03	690 ± 60
BR05	0.44 ± 0.014	4.7	0.51 ± 0.04	860 ± 70
BR06	0.35 ± 0.016	1.5	0.31 ± 0.01	1140 ± 80
BR07	0.63 ± 0.021	3.6	0.37 ± 0.02	1700 ± 130
BR08	0.83 ± 0.10	3.1	0.32 ± 0.02	2600 ± 400

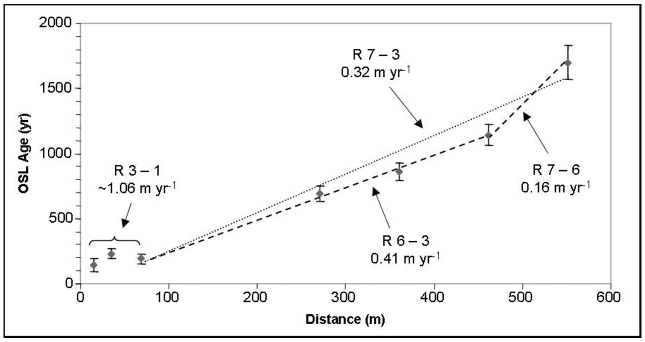

Figure 6. A plot of the beach-ridge OSL ages and distance inland from the modern beach. The dashed lines indicate rates of shoreline progradation between ridges 7 and 6 (0.16 m/y), and ridges 6 and 3 (0.41 m/y). The overall rate at which the strandplain developed is shown by the dotted line (0.32 m/y), while the younger set of ridges (3–1) record progradation of around 1.06 m/y.

least partially derived from the Caboolture River (FLOOD, 1980), which currently discharges into Deception Bay 7 km south of the sample site (no pebbles were evident on the modern beach). A preserved podzolic B horizon formed near the top of this deposit during up to 1000 years of subaerial exposure. This deposit was subsequently partially eroded, and a second beach unit, which includes a similar small coarse fraction, was emplaced over the older deposit approximately 1700 years ago (Figure 3b).

Pebbles within the beach units in ridge 7 define low-angle seaward dipping beds that reflect a foreshore depositional setting. When compared with the modern beach environment, the beach unit emplaced ~1700 years ago sits approximately 1 m higher than the upper limit of modern foreshore deposits (Figure 4). The elevation of these deposits, therefore, may provide an indicator of relative sea level at this time or reflect emplacement during storms, when high waves and storm surge deposited sand and pebbles in this elevated position. An elevated relative sea level at this time could be related to hydroisostatic effects. On the central Queensland coast, water loading and tilting of the shelf appears to have resulted in relative sea level around 2 m higher than present 7000–6000 years ago (YOKOYAMA *et al.,* 2006). Alternatively, an oscillating regressing Holocene sea level has been proposed by BAKER, HAWORTH, and FLOOD (2001), with a relatively abrupt fall of around 1 m shortly after 2000 years ago. More extensive mapping and sedimentological analysis of the beach unit in ridge 7 is required to better determine its significance as a marker of late Holocene sea level.

Shoreline Progradation

Our chronostratigraphic data for Beachmere indicate a rate of shoreline progradation of approximately 0.32 m/y since the upper unit in ridge 7 was deposited 1700 ± 130 years ago (BR07; Figure 6). However, the data also suggest an increase in the rate of progradation after ridge 6 was deposited 1140 ± 80 years ago (BR06). The rate of shoreline movement for the period represented by ridges 7 and 6 was approximately 0.16 m/y, which increased to 0.41 m/y as ridges 5–3 were emplaced. Ridges 3–1 show that at around 190 years ago the shoreline prograded at least 1.06 m/y, based on a depositional period of 50 years, which is the uncertainty of the three statistically indistinguishable OSL ages for these ridges (Table 3, Figure 6).

There has been a clear change in the mode of shoreline accretion since the end of the period of more pronounced ridge formation around 690 years ago (BR04, Table 3; Figure 4), with the formation of a tidal flat east of ridge 4 (Figure 4). This area comprises a thin bed of brown organic-rich mud, deposited in the current mangrove environment, over light grey muddy sand (Figures 3b, 4). Seaward of this low-lying deposit, three closely spaced ridges were rapidly emplaced around 200 years ago (BR01–3, Table 3). Sand is supplied to the beach system from both offshore (Figure 2; marine sand from the Northern Passage) and the Caboolture River (FLOOD, 1980). The recent phase of rapid ridge formation may, therefore, reflect a change in the sand transport pathway in Deception Bay and a subsequent increase in the flux of sand onshore. Another possible driver of this rapid ridge formation may have been an increase in the load of sediment supplied to the coast by the Caboolture River associated with European settlement of the region during the last two centuries (*e.g.,* CAITCHEON *et al.,* 2001; HANCOCK, 2001; NEIL, 1998).

Modern Shoreline Change and OSL Chronologies

The OSL age of ridge 1 (140 ± 50 y; BR01) reveals that the foredune behind the modern beach comprises sediments deposited at least a century ago. Aerial photographs show that the beach north of the Caboolture River, between Beachmere and Goodwin Beach, has been eroding since at least 1960 (FLOOD, 1980; Figure 1B). The eroded sand has moved southward to a spit at the mouth of the Caboolture River, while erosion of the beach has left mangroves "stranded" in the relatively high-energy environment at the front of the beach (Figure 3a). The current phase of erosion began after ridge 1 was deposited (140 ± 50 y ago) and prior to 1960, the year of the earliest available aerial photograph (FLOOD, 1980). Possibly, there was a switch to the dominantly southerly longshore movement of sand at Beachmere following the deposition of ridge 1.

There are historical records of long-term erosion of sandy shorelines at other sites in northern Moreton Bay, such as the east coast of Bribie Island (LESTER, BROOKE, and COX, 2002) and on the shores of the tidal inlet between Moreton Island and North Stradbroke Island (COVACEVICH, DURBIDGE, and MCINNES, 1984; Figure 1). Changes in storm frequency and associated shoreline erosion are a possible contributing factor; however, storm frequency in this region has not changed significantly over the last 60 years (LESTER, BROOKE, and COX, 2002). FLOOD (1980) suggested that there has been a slight rise (several centimetres) in relative sea level in Moreton Bay during the last century that has contributed to shoreline erosion at Beachmere. STEVENS (1992) suggested that shoreline erosion in the tidal entrances to Moreton Bay could be explained by switches in the location of sites of erosion and accretion due to tidal channel migration. In turn, these spatial changes in sand transport pathways may reflect switches in the regional wind regime. Support for this is provided by GOODWIN, STABLES, and OLLEY (2006), who found that on the open coast of eastern Australia regional-scale shifts in climate patterns have been a major driver of changes in shoreline configuration. To test this as a driver of change at Beachmere and more broadly in Moreton Bay, a systematic assessment of sand transport pathways, paleoshoreline configuration, and depositional history within the region is required.

The stratigraphically consistent OSL ages reported in this study (2600 ± 400 to 120 ± 50 y, Table 3) demonstrate the utility of this geochronological method for providing insights into past coastal change. Deriving records of shoreline movement for the historical and recent geological period is problematic in locations such as Beachmere because of the marine reservoir effect on radiocarbon ages. Also, in this region historical records of any sort extend back less than 200 years, to the time of the early European explorers (NEIL, 1998). Better understanding the tempo of shoreline change in the recent past is particularly relevant for assessments of vulnerability to erosion in rapidly developing, low-lying sandy coastal regions such as northern Moreton Bay. Our data show that there was an episode of significant shoreline erosion between 2600–1700 years ago when ridge 7 was partially eroded and then capped by a much younger (1700 y) beach deposit. During the last four decades, the Beachmere shoreline has retreated into the beach ridges that were emplaced at least a century ago, which indicates the vulnerability of the coast to further erosion induced by storms or rising sea level.

CONCLUSIONS

The chronostratigraphy of the seven beach ridges that sit immediately behind the modern beach at Beachmere demonstrates the utility of applying the OSL dating method to geologically young beach deposits. Between 2600 and 1700 years ago, the shoreline here eroded and beach sediment was deposited over the remnant of a relict beach. Following this event there was a 1500-year period of shoreline progradation, during which there were changes in the rate and mode of shoreline growth: the shoreline advanced 0.16 m/y between 1700–1140 years ago, and 0.41 m/y between 1140 and around 200 years ago. Shortly after 690 years ago, a series of well-developed regularly spaced beach ridges gave way to a wide intertidal flat and then deposition of a set of lower amplitude, closely spaced ridges. The younger set of ridges was rapidly deposited between 200 and 100 years ago (~1.06 m/y). During the last several decades, much of the Beachmere shoreline has eroded into these younger relict ridges. Drivers of these changes in shoreline sedimentary regime are yet to be accurately determined. However, since there are nearby sources of marine and terrestrial sand, it seems likely these changes are related to switches that occur in the nearshore sand transport pathway.

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