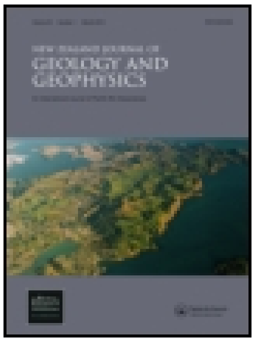

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Wayne Stephenson & James Shulmeister

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A Holocene progradation record from Okains Bay, Banks Peninsula, Canterbury, New Zealand

WAYNE STEPHENSON
Department of Geography
University of Canterbury
Private Bag 4800
Christchurch, New Zealand

JAMES SHULMEISTER
Research School of Earth Sciences
Victoria University of Wellington
P.O. Box 600
Wellington, New Zealand

Abstract Fifty-eight distinct ridges are preserved on the Holocene progradation plain in Okains Bay, Banks Peninsula, Canterbury. Of these, 48 represent beach berm and foredune complexes and the remaining 10 are transverse dune ridges. Periods of rapid coastal progradation are marked by multiple beach berm preservation, whereas intervening periods of lower sediment accumulation result in a stable coastline and transverse dune formation.

Infilling of the bay began following sea-level stabilisation in the mid Holocene. The fill is dominantly fine sand, which is derived from sediment carried around Banks Peninsula in the Southland Current and washed into Okains Bay by wave action. Variations in the progradation rate are therefore proxy indicators of coastal erosion in the Canterbury Bight. We demonstrate that there is little progradational fill preserved between c. 6500 and 2000 yr BP. This implies significant changes in sediment delivery to the Southland Current within the last 2000 yr, which we attribute to increased coastal erosion in South Canterbury. We speculate that this increasing erosion resulted from increased wave energy regimes, which in turn may relate to increasing Southern Hemisphere seasonality following the precessional cycle.

Keywords Okains Bay; banner bank; Canterbury; continental shelf; coastal erosion; precessional cycle; Holocene; climate change

INTRODUCTION

Okains Bay (Fig. 1) is a small embayment located on the northeastern side of Banks Peninsula on the east coast of South Island, New Zealand (43°42′S, 173°04′E). Within Okains Bay a sequence of dune and beach ridges that extend inland for 3.0 km was described initially by Dingwall (1966, 1974) and noted by later workers (Martin 1969; Stephenson 1992). Stephenson (1992) proposed that this dune and beach ridge sequence began prograding after the termination of the postglacial transgression, which occurred in the Canterbury region at c. 6500 yr BP (Suggate 1968; Brown & Weeber 1992). Dingwall (1966) noted that the sediment in the progradation ridges is fine sand, derived not from the local valley, but worked onshore by wave action from Pegasus Bay. This raised the intriguing possibility that the progradation plain contains a proxy record of the wave climate in Pegasus Bay and/or sediment flux into the bay. This paper presents the results of a pilot investigation of the progradation plain, and attempts to decipher whether such a signal is discernible.

STUDY AREA

Banks Peninsula consists of the remnants of two primary shield volcanoes of Miocene–Pliocene age (Sewell et al. 1988). Based on the existence of inactive and land-locked shore platforms at elevations of +6 and +8 m above mean sea level (a.m.s.l.), Lawrie (1993) concluded that there has been no subsidence of the peninsula during the Quaternary. Individual lava flows have created a series of steep-sided spurs, with deep valleys in the interflow areas. The numerous bays of Banks Peninsula have formed as a result of flooding of these valleys by rising seas at the termination of the Pleistocene. Most of these embayments have sediment fills composed of fine silts and clays, which are of originally aeolian or marine provenance (e.g., Soons et al. 1997). In a limited number, including Okains Bay (see Fig. 1), fine marine sands dominate (Dingwall 1966, 1974). The beach at Okains Bay is 0.9 km long and confined by steep basaltic side walls. Behind the beach, complexes of low dunes extend upvalley. A small river, the Opara Stream, enters the bay at its northern end and has formed a small estuary. The bay entrance is orientated northeast and is 1.3 km wide. Inside the entrance, the bay widens to 2 km. From the beach to the drainage divide at the top of the valley (elevation 573 m a.m.s.l.) is a distance of 8 km.

Dingwall (1966, 1974) noted that the ridges in Okains Bay display relative regularity in their spacing and height. He reported that most ridges are between 0.15 and 1.2 m high, although two are 1.5 m high and a third rises to 3.0 m. Spacing of dune ridges varies from 10 to 65 m. Based on mineralogical evidence, Dingwall (1966) demonstrated that the sediment supplied to Okains Bay is derived from the adjacent Canterbury continental shelf rather than the local catchment. The beach in Okains Bay is composed of quartz sands, probably originally derived from greywacke, whereas the hinterland of the bay is basaltic (Sewell et al. 1988), and free quartz is rare.

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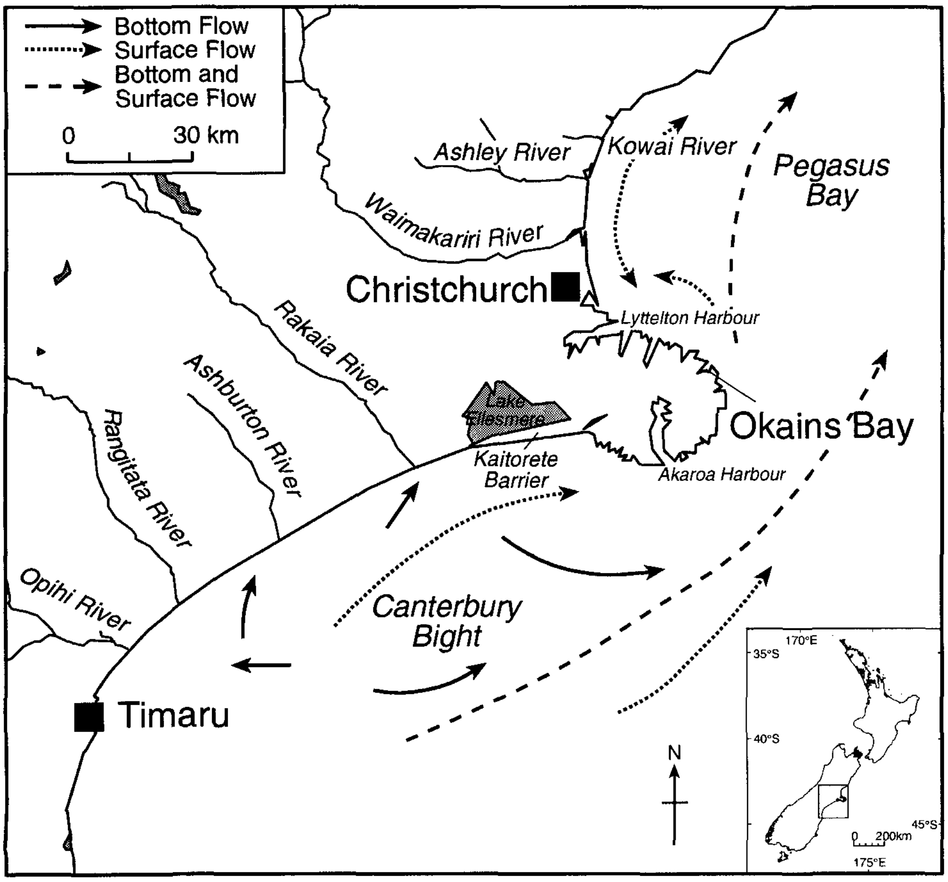

Fig. 1 Okains Bay in relation to Banks Peninsula, the Canterbury coast, and the Southland Current (current positions adapted from Carter & Herzer 1979).

Wave climate and hydrography of the Canterbury coast

The dominant direction from which waves arrive on the Canterbury coast is from the east and southeast (Brown 1976; Hastie 1983). This is true both south of Banks Peninsula along the Canterbury Bight and to the north in Pegasus Bay. The other significant wave direction is from the northeast. Northeasterly waves are generated by local sea breezes, or under lee trough conditions, or are associated with subtropical depressions tracking south into Pegasus Bay. Brown (1976) described Pegasus Bay as having a medium to high energy wave climate, with 95% of wave heights <2.4 m. The tidal range in Pegasus Bay is c. 2 m. In Okains Bay, the wave environment is one where low energy waves, commonly 0.3 m or less and of 5–6 s period, dominate. However, ocean swells do reach the beach; waves higher than 1.0 m with 14 s periods have been observed at Okains Bay (Stephenson 1992). Since the entrance to Okains Bay is orientated to the northeast, only waves generated by northeasterly winds can shoal directly into the bay.

Pegasus Bay banner bank and sediment transport to Okains Bay

The most significant regional current is the Southland Current, a shore-parallel current that sweeps the Canterbury shelf flowing from south to north (Carter & Herzer 1979). This current is fast enough to carry sand and is well supplied from the large braided rivers that debouch into the Canterbury Bight (e.g., the Rakaia and the Ashburton), as well as from coastal erosion. The Southland Current is deflected eastward by the obstruction caused by Banks Peninsula. Constriction around Banks Peninsula causes the current to accelerate, but where the coast north of Banks Peninsula swings away to the west the constriction is reduced and the current slows, depositing the fine sand. As a result of this deposition, a banner bank (Fig. 2) has formed across the entrance to Pegasus Bay (Herzer 1977).

This banner bank is an area of higher relief on the seafloor. It is most evident between the −18 m and −40 m isobaths. The bank is 20 km long and 7 km wide at its widest point. Dingwall (1966, 1974) and Stephenson (1992) considered this bank to be the immediate source of sediment for the northeastern bays of Banks Peninsula and particularly Okains Bay. Herzer (1977) showed how the bank was composed of fine quartz sand similar to that identified by Dingwall (1966) in Okains Bay. The principal means by which sediment is transported into the bay is thought to be by shoaling of waves across this banner bank. Added to shoaling are wind-generated currents and tidal currents that ebb and flow in and out of the bay. The net effect is a strong flux of sediment from the banner bank to Okains Bay.

Dingwall (1966) calculated that sediment from the continental shelf has caused the mean high water mark to migrate seaward 230 m in the 100 years to 1966. Martin (1969) concluded from maps dating from 1872 that the mean high water mark at Okains Bay had been migrating seaward at a rate of between 2.4 and 3.6 m/yr for the last 100 years. Stephenson (1992), using repeated surveys of beach profiles, calculated a progradation rate of 3.9 m/yr. Historically, Okains Bay has been characterised by rapid coastal progradation.

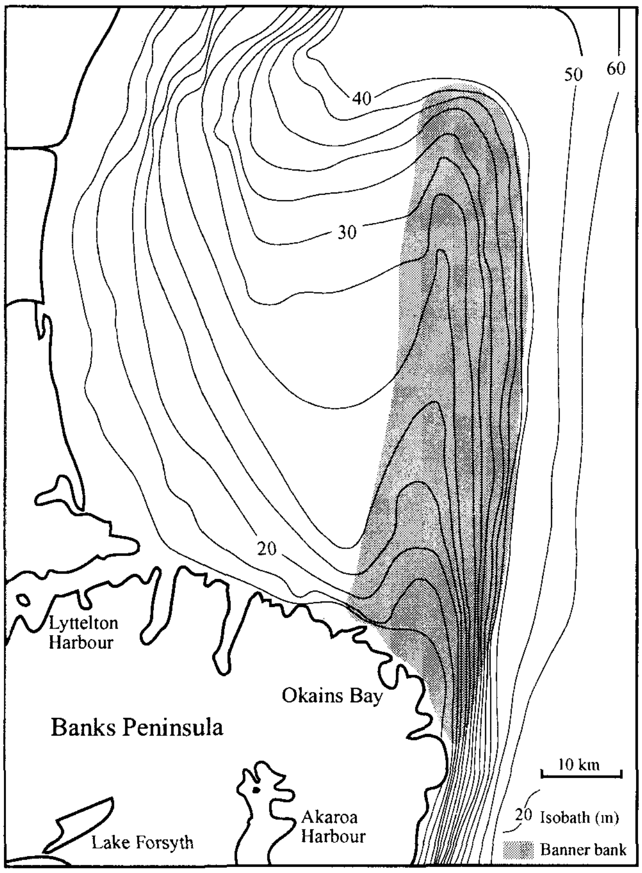

Fig. 2 Bathymetric chart showing the banner bank across the entrance to Pegasus Bay (adapted from Herzer & Carter 1983).

METHODS

From aerial photographs, a geomorphological map was constructed and ground truthed during fieldwork. Using historical data in Dingwall (1966) and aerial photographs, we identified shorelines from 1860, 1920, 1941, 1966, 1984 and 1993 to recalculate the historical progradation rates. A transect was surveyed from the modern beach inland for 2.4 km using a Sokia Set 4B total station theodolite. There are no benchmarks in Okains Bay, so elevations are reported relative to mean sea level as determined from profile surveys of the modern beach between January and April 1992 (Stephenson 1992). Each survey was conducted at low tide so that the high and low tide mark could be identified. Mean sea level was taken as the mean average difference in elevation between the two.

Both radiocarbon and thermoluminescence dating were utilised. Radiocarbon dating was limited by the comparative rarity of carbonates. Two shell samples were submitted for AMS radiocarbon dating to the Institute of Geological & Nuclear Sciences in Lower Hutt. Two sand samples were submitted to the Thermoluminescence Dating Laboratory at the University of Wollongong, Australia.

RESULTS

Based on aerial photograph interpretation, field mapping using the pace and compass technique, and levelling, a geomorphological map has been constructed (Fig. 3). A transect through the progradation sequence is presented in Fig. 4. Buildings prevented a continuous line of sight, so the transect is offset and ends c. 500 m from the beginning of the sequence (Fig. 3). A total of 58 ridges are identified. Based solely on morphology, two types of ridges can be identified. Ten are erect transverse dune ridges, including the foredune behind the modern beach. The remaining 48 are low-amplitude beach ridges.

Shoreline positions in 1860, 1920, 1941, 1966, and 1984 were mapped on to an aerial photograph from 1993. Table 1 shows progradation rates between these periods and for the entire length of the record. Rates varied between 1.63 m/yr (1966–84) and 4.66 m/yr (1920–41). The total distance advanced by mean high water from 1860 to 1993 was 313.4 m at a rate of 2.35 m/yr.

The results of radiocarbon dating are given in Table 2, and the locations from where samples were taken are indicated on Fig. 3. At location OK4BR30, shell samples of *Xenostrobus pulex* (little black mussel) and *Perna canaliculas* (green shell mussel) were retrieved from a beach ridge and yielded a radiocarbon age of 672 ± 63 yr BP (NZA3750). These species of mussel can be found today growing in the intertidal and subtidal zones along the rocky shoreline of the bay. The second radiocarbon sample from location OK2/1 was extracted from the base of a dune and identified as mainly *Paphies subtriangulata* (the pipi) but included one specimen of *Xenostrobus pulex* and one specimen of either *Mytilus* sp. (blue mussel) or a juvenile *Perna* sp. This sample yielded a radiocarbon age of 1674 ± 76 yr BP (NZA6074).

Table 3 shows the results of thermoluminescence dating. At location OK3/1 (Fig. 3) a sand sample was removed from the base of a dune 1.5 m below the surface. This was determined to have an age of 13.5 ± 1.6 ka (W1612). The second sand sample from OK1 (Fig. 3) was also extracted from the base of a transverse dune. It returned a TL age of 7.5 ±1.2 ka (W1613).

DISCUSSION

Dating control

We have presented four dates from two techniques. These dates confirm that the progradation sequence is of mid–late Holocene origin, but there are specific issues involved in the interpretation of both the radiocarbon and luminescence results.

Radiocarbon

$\Delta^{13}C$ values for the shell samples are consistent with ocean water, and the standard New Zealand marine calibration has been applied to the dates, so it is unlikely that old carbon effects are significant. Nevertheless, these radiocarbon ages should be regarded as maxima. The residence time of the molluscs in sediments offshore, before they were incorporated into the beach ridges, is unknown. In extreme circumstances, shells may stay in storage offshore for thousands of years before they are incorporated into a deposit (e.g., Lees 1992). However, given the high rates of coastal progradation in Okains Bay, this should be a minor problem, as it is likely that material on the bay floor will be rapidly incorporated into the beach.

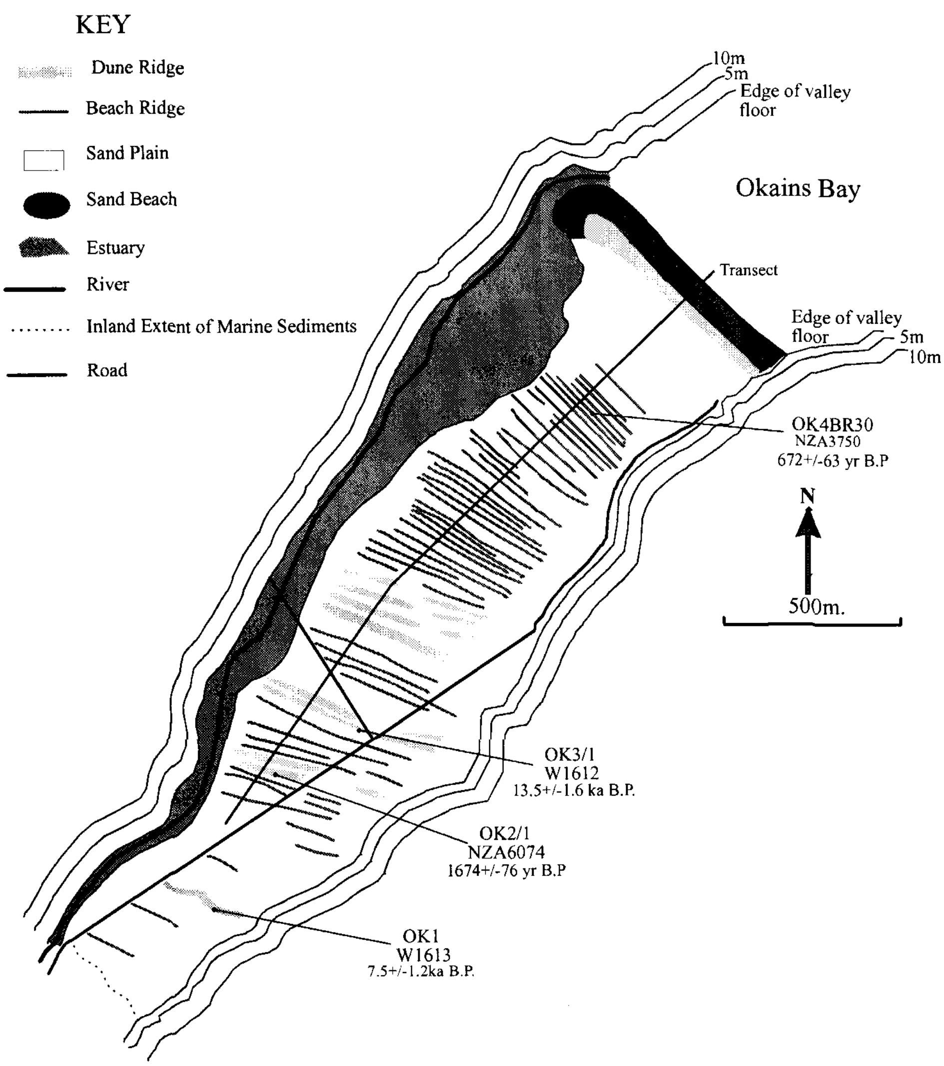

Fig. 3 Geomorphological map of Okains Bay progradation plain. There are 48 beach berm and foredune ridges and 10 transverse dune ridges. The locations of dating samples and survey transects are shown.

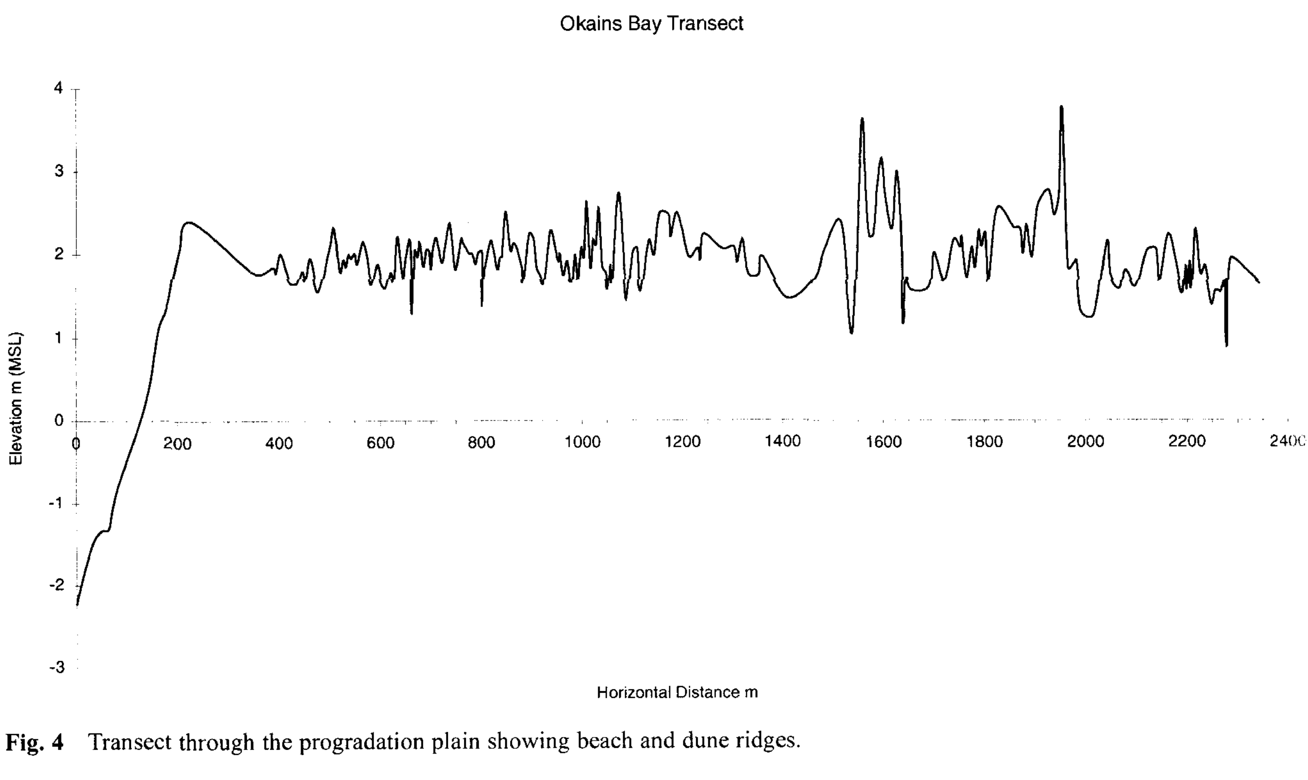

Fig. 4 Transect through the progradation plain showing beach and dune ridges.

Luminescence dating

The use of luminescence dating for establishing coastal dune chronologies is now well established and it has been applied successfully to dune sequences on the Canterbury coast (Shulmeister & Kirk 1996). Light and heat zero the luminescence signal in a sediment and "set" the luminescence clock. Thus, luminescence dating determines the age of last exposure of a sediment to light or heat (e.g., Berger 1988). Aeolian sands are a preferred target for luminescence dating because they are likely to be well exposed to sunlight before deposition. Nevertheless, one of the most common problems with luminescence dating of dune sands is incomplete zeroing of the material before burial. In this instance, the sand delivered to the bay is at the end of a long marine transport system and is unlikely to be zeroed when deposited on the foreshore in Okains Bay. The anomalously old age of 13.5 ± 1.6 ka derived for sample W1612 may result from very rapid working of sand from the foreshore into the dune, perhaps during a storm event when sediment flux was high and the material was incompletely exposed. The result of 7.5 ± 1.2 ka from W1613 near the limit of maximum marine transgression is consistent with the age of that transgression elsewhere in Canterbury (Gibb 1986).

Implications of the different ridge types

The relative regularity of height and spacing of the ridges in Okains Bay suggested to Dingwall (1966) that progradation occurred at a steady rate. An important feature of ridges in Okains Bay is that, although ridge heights are fairly constant, they are not spaced at regular intervals, and they comprise two different styles (Fig. 4). We interpret the alternation between beach ridges and dune ridges to represent two distinctly different coastal environments. When the rate of supply of sediment was high the shoreline moved seaward too quickly to allow the formation of dunes; instead, numerous beach ridges representing short-lived coastal positions were preserved. When the rate of sediment supply decreased, the seaward movement of the shoreline slowed or even ceased. Under these circumstances, sand brought onto the beach is likely to be gradually fed into a foredune behind the beach. The longer the stabilisation at a specific coastline, the greater the number and/or size of the dune ridges created behind the beach. The ridges can be grouped into five distinct geomorphic units. Each consists of a sequence of beach ridges and dune or dunes. Assuming the whole sequence has been preserved, there have been five periods of rapid sedimentation interceded by five periods of slower sedimentation. Thus, there are five dune complexes in Okains Bay. The differences in spacing and height of dune and beach ridges in each unit and between the five units indicate that rates of rapid sedimentation varied as did rates of slower sedimentation.

Table 1 Progradation rates from Okains Bay between 1860 and 1993.

Time period	Total distance (m)	Years	Progradation rate (m/yr)
1860–1920	121.3	60	2.02
1920–41	97.8	21	4.66
1941–66	41.2	25	1.65
1966–84	29.3	18	1.63
1984–93	23.8	9	2.65
1860–1993	313.4	133	2.35

Sedimentation and coastal progradation in Okains Bay

All of the previous studies in Okains Bay have demonstrated fairly rapid coastal progradation of between 2 and 4 m/yr in historical times. From our calculations based on re-surveys, the coastline, taken as the mean high water mark, prograded at a rate of 2.35 m/yr between 1860 and 1993. Since the total length of sequence from the inner relict beach ridge to the modern beach is 2.55 km, based on modern progradation rates, the entire infill sequence could be accumulated in about 1000 years. This observation is not consistent with the expectation that progradation would initiate soon after the Holocene transgression ceased at roughly 6500 yr BP, and the luminescence age of 7.5 ± 1.2 ka from the oldest beach ridge supports a mid-Holocene infill initiation. Although the oldest part of the fill appears to be mid Holocene in age, within a few hundred metres of the limit of the marine

Table 2 Results of radiocarbon dating.

Sample number and location NZMS 260, N36	$\delta^{13}C$ (‰)	Age uncalibrated (yr BP)	Material dated	Notes	Identification
NZA3750 173°03′30″E 43°41′55″S	1.59	672 ± 63	Shell	AMS	OK4BR30
NZA6074 173°02′40″E 43°42′32″S	0.8	1674 ± 76	Shell	AMS	OK2/1

Table 3 Results of thermoluminescence dating.

Sample no. & location NZMS 260, N36	Plateau region (°C)	Analysis temp. (°C)	Moisture content (% wt)	Specific activity (Bq/kg)	Rb content (ppm assumed)	K content (% by AES)	Cosmic contr. (μGy/yr)	Annual dose (μGy/yr)	Paleodose (Gy)	TL age	Notes
W1612 173°02′30″E 43°42′45″S	300–375	325	6.3 ± 3	46.9 ± 4	100 ± 25	1.5 ± 0.005	150 ± 50	2558 ± 72	34.5 ± 4.0	13.5 ± 1.6 ka	OK3/1
W1613 173°02′55″E 43°42′25″S	300–500	325	7.7 ± .	46.8 ± 4	100 ± 25	1.5 ± 0.005	150 ± 50	2532 ± 71	19.0 ± 1.9	7.5 ± 1.2 ka	OK1

transgression, the age drops to 1600 yr BP, which is more consistent with the rapid modern sedimentation rate.

There are two possible causes: (1) part of the record is missing because there has been a major erosional event/s in the bay which has/have excavated most of the older fill; or (2) initial progradation into the bay was very slow because sediment supply rates were low, but at c. 2000 yr BP the rate of sedimentation accelerated, causing rapid progradation. We will present both hypotheses, but there are strong logical arguments to support the latter.

1. An erosional history of storm events

A single severe storm might be strong enough to evacuate the entire embayment of its fill. Because the bay is sheltered from southerly swell, a Southern Ocean storm will not impact Okains Bay. The storm track must be from the northeast. Ex-tropical cyclone systems do track down the east coast of the North Island and affect the northern South Island. Two severe ex-tropical cyclones have reached the South Island this century. In February 1936 a cyclone caused widespread damage over the North Island and north of the South Island (Brenstrum 1997). In 1968 Cyclone Gisele tracked as far south as Wellington and was strongly felt in Marlborough. This particular storm is famous for sinking the Cook Strait ferry *Wahine*. As a result, Cyclone Gisele is more commonly known as the Wahine Storm. The most likely wave trains associated with the approaching ex-tropical storms would come from the north to northeast. These outbursts of ex-tropical storms are associated with weak La Niña conditions, so each erosional event may represent a period of El Niño-Southern Oscillation activity.

Alternatively, it is possible that an erosional event could be caused by a number of smaller storm events in quick succession. Kirk (1979) demonstrated the occurrence of "storms in series" in Pegasus Bay between 1900 and 1979. He identified 16 episodes of intense coastal erosion and damage to infrastructure in Pegasus Bay. One-half resulted from southerly storms and one-half from northeasterly storms. Forty-three lesser storms were identified that caused coastal erosion. Of these, 60% were of a northeasterly to easterly origin. Each episode was the result of a number of severe storms following relatively close together, some only months apart, others over several years. A feature of a storm-in-series event is that there is not enough time between storms for the beach to recover from erosion. The most recent event was in 1977 and 1978 when winter storms caused severe erosion that threatened housing on the Christchurch foreshore. The main storm in 1978 originated from the northeast.

There are significant problems in attempting to identify erosional events in sedimentary records. In particular, the evidence for such events tends to be negative and, as such, inconclusive. The types of features that might be observed include truncation surfaces, lag deposits, and, possibly, large foredune ridges built immediately after the event as sand migrates back onshore. We observed none of these features. In the absence of direct evidence it is difficult to sustain an erosional hypothesis.

There is one possible piece of indirect evidence which might support an erosional hypothesis: Shulmeister & Kirk (1997) have demonstrated that gravel beach ridges on the Pegasus Bay coast north of Christchurch are generated episodically in storms. Sand, from formerly sandy beaches with occasional gravels, is excavated from the shoreface during storm events and the residual gravels are concentrated into a new gravel berm. The youngest large beach ridge, termed Ashworths Beach Ridge, has been dated to 1958 ± 70 yr BP (NZ7953), suggesting a major storm/s at that time. This age is consistent with the observation that the fill in Okains Bay is mainly <2000 yr old, but it hardly constitutes reliable evidence.

In addition to the lack of evidence, a major limitation on the storm erosion model is the morphology of Okains Bay itself. It is unlikely that any storm, irrespective of size or track, could severely impact Okains Bay. The bay is narrow mouthed (1.3 km) and quite shallow (depth at bay entrance is 10 m), with a distance of 2.4 km between the bay entrance and the beach. Shoaling across this shallow, sloping bay floor means that only small waves reach the shoreface before breaking. Larger waves will break farther from the beach and shoal across a wide dissipative surf zone. In summary, we find no convincing evidence for an erosional origin, and we are dubious that the material could be excavated from the bay under any wave conditions.

2. A sediment supply control model

We have already summarised the evidence for rapid beach progradation in the last 2000 yr BP. Total beach progradation in Okains Bay before 2000 yr BP was only 500 m over 4000+ yr (c. 0.8 m/yr), and there was insufficient sediment to allow the development of a large transverse dune sequence. Thus, we have clear difference in sedimentation between the mid and late Holocene.

The model needs a substantial increase in sand supply from the banner bank to Okains Bay in the last 2000 years. There are two possible models for this: (1) late formation of the banner bank; (2) increased sand supply from the Southland Current to the banner bank.

(1) Formation of the banner bank: It is possible the sediment delivery into Okains Bay was initially slow because it took some time for the banner bank to develop. A period of time was required to build the bank and raise the elevation of the ocean floor to a level where currents generated by northeasterly wave trains could transport sediment into the bay. We have no way of telling how long the lag between the beginning of the development of the bank and large-scale sediment delivery to the bay was. Although the maximum transgression occurred at 6500 yr BP, Banks Peninsula acted as an obstruction to northward current well before this date. Armon (1973) placed the coast along the southwest flank of Banks Peninsula, in the vicinity of Kaitorete Barrier, in roughly its modern location at 8000 yr BP, and there is a large topographic depression along the southwest flank of the peninsula which constrains the coastline under interglacial and interstadial sea levels. It is improbable (but not impossible) that it took 4000 years for the bank to aggrade to a depth shallow enough to allow waves to transport material into Okains Bay. Nevertheless, it is probable that a lag occurred between the maximum transgression and the onset of large-scale sediment transport into Okains Bay.

(2) Change in sediment delivery to the banner bank: Recent work by Soons et al. (1997) on the development of the Kaitorete Barrier/Lake Ellesmere system on the southwestern flank of Banks Peninsula (i.e., upstream of Okains Bay with respect to the Southland Current) has also highlighted a discrepancy between the behaviour of the coastal system in the mid Holocene and over the last 2000 yr BP. The Kaitorete Barrier was substantially in place by 8000 yr BP, well before maximum transgression occurred, and a barrier-blocked lake was established behind a continuous barrier by c. 6000 yr BP. There are no gravel deposits along the flanks of Banks Peninsula related to longshore transport of gravel along the mid-Holocene barrier that record this event. Some time after 6000 yr BP the barrier decayed and on several occasions estuarine conditions were re-established in Lake Ellesmere. The most recent closure of the barrier occurred in the last few hundred to a thousand years. Since this closure, there has been massive transport of gravel along the barrier onto the Banks Peninsula coastline beyond, filling several valleys. Short-term rates of up to 13 m/yr progradation have been recorded in historical times (Soons et al. 1997).

If the barrier were open for long periods in the early and mid Holocene, the longshore movement of sand along the Canterbury Bight coast might be disrupted either by diversion of sand into the Ellesmere Embayment/Lagoon or by offshore flow from the lagoon interfering with longshore transport. In either case, enhanced longshore sand transport would occur after the barrier closed.

Coastal erosion in South Canterbury

There is a clear implication that the sediment delivery regime along the South Canterbury coast has altered significantly with comparatively low rates in the early and mid Holocene and greatly increased sedimentation in the latter part. Soons et al. (1997) attributed the opening and closure of the Kaitorete Barrier to diversion of the Waimakariri River to and from the Ellesmere Basin. Their model does not explain the apparently dramatic increase in longshore transport in the latest stages of barrier development. Okains Bay displays a compatible signal; it is downstream of the Kaitorete Barrier and sources its fill from the same parent material, if not the same size fraction. We believe that Okains Bay provides strong circumstantial evidence of a significant alteration of sedimentation dynamics along the Canterbury coast. This shift almost certainly predates human activity in this region.

Reduced sediment supply would result in starvation of the Kaitorete Barrier and prevent large-scale gravel accumulation at the downdrift end. This explains the propensity of the barrier to revert to marine conditions during the mid and early late Holocene. Reduced sediment supply to the Canterbury Bight would also reduce sediment flux in the Southland Current and consequently reduce sediment delivery to Okains Bay. Thus, the observation that Okains Bay contains little mid-Holocene fill is consistent with the observation of low rates of barrier formation south of the peninsula. The converse is also true. Increased sediment supply in the Canterbury Bight will nourish the Kaitorete Barrier and feed increased sediment to the Southland Current causing progradation in Okains Bay. These are precisely the changes we observe both at Kaitorete Barrier and in Okains Bay.

This pattern of change does not recur in Pegasus Bay north of Banks Peninsula. Here, episodic coastal progradation and dune formation continued throughout the Holocene after maximum transgression was achieved (Shulmeister & Kirk 1993, 1996, 1997). Shulmeister & Kirk (1997) have demonstrated that the coastal system in North Canterbury is nourished by sediment delivery from the local rivers, not downdrift transport from the Southland Current, which bypasses the bay (Herzer 1977). They have also demonstrated that while storms cause short-term erosion along this coast, the sediment is merely transferred to temporary storage offshore, and the coastline is progradational on longer time scales. Thus, there is no expectation that this coast should respond in the same way as Okains Bay and the Canterbury Bight.

Wave climate and climate change

Sediment supply in the Canterbury Bight is controlled primarily by coastal erosion rather than fluvial input (Kirk 1983). The Rakaia River, a major braided river south of Banks Peninsula, provides only 11.7% of the annual sediment budget for the coastline along its mouth (Kirk 1983). Longshore drift and long-term rates of cliff erosion are consequently controlled by the wave climate in the Canterbury Bight. Individual cliff erosion events, however, are a product of large (usually southerly) storms. Flatman (1997) demonstrated statistically that storm frequency has a significant control on temporal variations in cliff erosion between the Rangitata and Ashburton River mouths.

A number of authors (e.g., McGlone et al. 1992, 1994) have highlighted the gradual increase in westerly circulation in southern New Zealand as the Holocene has progressed. Shulmeister (1995, in press) has attributed this to the gradual increase in Southern Hemisphere seasonality tied to the precessional cycle where Southern Hemisphere precessional minimum occurred at c. 9000 yr BP. One of the primary effects of increased seasonality is an increase in the seasonal temperature contrast between the poles and the Equator. This contrast is the first order control on atmospheric circulation (and hence surface ocean circulation) and drives the strong westerly circulation in the Southern Ocean. Reduced seasonal contrasts in the early part of the Holocene would be expected to reduce the circulation and might be expected to reduce the energy of the wave climate in the Southern Ocean. We speculate that what we observe on the Canterbury coast may be the effect of coastal response to increased seasonal wave energy in the late Holocene.

High precision record for the last c. 2000 years

Irrespective of the mechanism of infilling, our data clearly show that most of the current fill of Okains Bay including about 50 beach ridges and transverse sand dunes dates to the last c. 2000 years. These comprise four periods of rapid sedimentation and three phases of coastal dune building. The highly coherent pattern of beach ridges alternating with dune complexes suggests that these represent systematic environmental changes. A number of authors have recognised periods of enhanced erosion in the late Holocene (Grant 1989; McFadgen 1985, 1989). Although we have no suggestion of the eight phases of enhanced erosion in the last 1800 years recognised in fluvial systems in the North Island by Grant (1989), our data may be more compatible with the coastal chronostratigraphy proposed by McFadgen. He recognised three phases of dune building in coastal areas between Auckland and Dunedin since the Taupo eruption 1800 yr BP. These are the Tamatean (1800–450 yr BP), the Ohuan (450–150 yr BP), and the Hoatan (150 yr BP to the present). The Hoatan is clearly a response to post-European changes to regional sediment budgets. In Okains Bay the post-European phase is marked by the most rapid phase of beach progradation. This differs from McFadgen's general findings which suggest that the Hoatan is the least severe of the events New Zealand wide. We have inadequate dating control to confidently correlate our other units to McFadgen's scheme, though the numbers of units and the remaining radiocarbon age of 673 ± 63 yr BP are consistent.

CONCLUSIONS

The progradation sequence in Okains Bay is remarkable because it is composed dominantly of material reworked from the continental shelf rather than directly from terrigenous sources. As a consequence, deposition in Okains Bay is sensitive to three things: (1) the growth and development of the banner bank near its mouth; (2) the availability of sediment eroded from the South Canterbury coast and catchment; and (3) the wave climate that drives the process regime on the continental shelf. We conclude that the primary signal comes from variation in sediment supply and thus the record in the bay is a proxy for coastal erosion in South Canterbury.

We have demonstrated that sedimentation in the bay increased dramatically after c. 2000 yr BP. This suggests a period of enhanced coastal erosion along the Canterbury Bight, and this is compatible with the record from the Kaitorete Barrier on the southern flank of Banks Peninsula. The increase in coastal erosion must relate to wave energies along the coast. We postulate that this is driven by regional to hemispheric climate change. We provisionally attribute these changes to precessionally driven changes in seasonality, which control the strength of circulation in the Southern Ocean.

This pilot study highlights, but does not fully realise, the potential of downdrift sediment accumulations as repositories for environmental change data. Further work is required to confirm the patterns suggested by this study and to refine a potentially important climate change indicator.

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