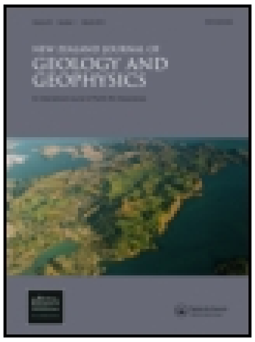

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Holocene history and a thermoluminescence based chronology of coastal dune ridges near Leithfield, North Canterbury, New Zealand

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Abstract Dunes of the Pegasus Bay progradation sequence, North Canterbury, New Zealand, have been assigned previously to three soil-based systems, with age estimates based on inferred rates of coastal progradation and soil development. The present study of the coastal reach between the Kowai and Ashley Rivers, Pegasus Bay, identifies five transverse dune systems. The dune ridge systems trend subparallel to the coast and each system relates to a specific, relict or active, sand and/or mixed sand and gravel beach. A morphogenetic classification based on the relationship of the dunes to the prior strandlines is proposed. This is supported by an absolute (coarse fraction thermoluminescence) chronology of the dune systems. Dune-forming events occurred at c. 6500, <6000, <2600, 1000, and 500 years ago.

The transverse dune ridges relate to onshore northeasterly winds. The effective inland penetration of these winds with respect to sand transport is limited to a few hundred metres. Transverse dunes inland of the modern coast are being slowly degraded by the development of low-amplitude parabolic dunes aligned with the northwest föhn wind. These winds are blowing sand back towards the beach.

Keywords Canterbury; Pegasus Bay; dune ridges; Holocene; thermoluminescence dating; C–14 dating; föhn wind

INTRODUCTION

The Canterbury Plains is a gravelly alluvial plain stretching from the Southern Alps in the west of the South Island, New Zealand, to Banks Peninsula in the east. The plain is derived from the erosion of the Southern Alps. The coastal section of this plain is bisected by the Banks Peninsula volcanic complex. South of Banks Peninsula the coast is rapidly eroding, but north of the peninsula an extensive Holocene progradation sequence exists in Pegasus Bay (Blake 1964). This progradation sequence is composed of sand and mixed sand and gravel beaches, lagoon and swamp deposits, and locally extensive sand dunes (Blake 1964; Brown & Wilson 1988) forming the Holocene Springston Formation of Suggate (1958) (Brown & Wilson 1988).

Detailed investigations of the Pegasus Bay Holocene wedge between the Ashley and Kowai Rivers (Shulmeister & Kirk 1993, in press) have deciphered the modes of transgression and regression and provided a long-term (c. 8 ka) sea-level history. In the course of these investigations, a complex suite of transverse dune ridge systems was observed. This paper presents a geomorphological description and chronology of the dune systems between the Kowai and Ashley Rivers (Fig. 1) and discusses the relationship of the dunes to the local climate and geomorphic setting.

Wind regime

Three major wind fields affect Canterbury. These are northwesterly föhn winds, southerly/southwesterly frontal winds, and easterly/northeasterly winds associated with sea breezes and, more especially, the lee trough effect of the Southern Alps (e.g., Sturman & Tyson 1981; McKendry 1983; McKendry et al. 1987). McKendry (1983) noted that the sheltering effect of Banks Peninsula from southwesterlies creates the conditions for enhanced (easterly/northeasterly) sea breezes north of the peninsula. This, combined with the diminishing effect of the föhn (northwest) wind away from the Alps (McKendry 1983) and the lee trough effect in Pegasus Bay, creates the conditions for the dominance of northeast winds along this coast.

Previous work

Coastal dune systems in New Zealand have received considerable attention (e.g., Cowie 1963; Pullar et al. 1967; Pullar & Selby 1971; Pain 1976; Shepherd 1985; Enright & Anderson 1988) with a variety of pedological and stratigraphical approaches undertaken to reconstruct the history and chronology of the dunefields. The existence of dunes in the Pegasus Bay progradation sequence is well known but very little work has been carried out on the dune systems. The dunes were classified by Blake (1964) as part of a study of progradation in Pegasus Bay, and this remains the primary source of data on the dunefield.

Blake (1964) identified three series of dunes and their associated soils (Fig. 2A) on the Pegasus Bay progradation plain:

(1) dunes associated with the present beach (modern and active);

(2) the Kairaki Dune Complex. Inland of the coastal dune series and well developed between Waimakariri River and Ashley River is a series of low dunes with few steep

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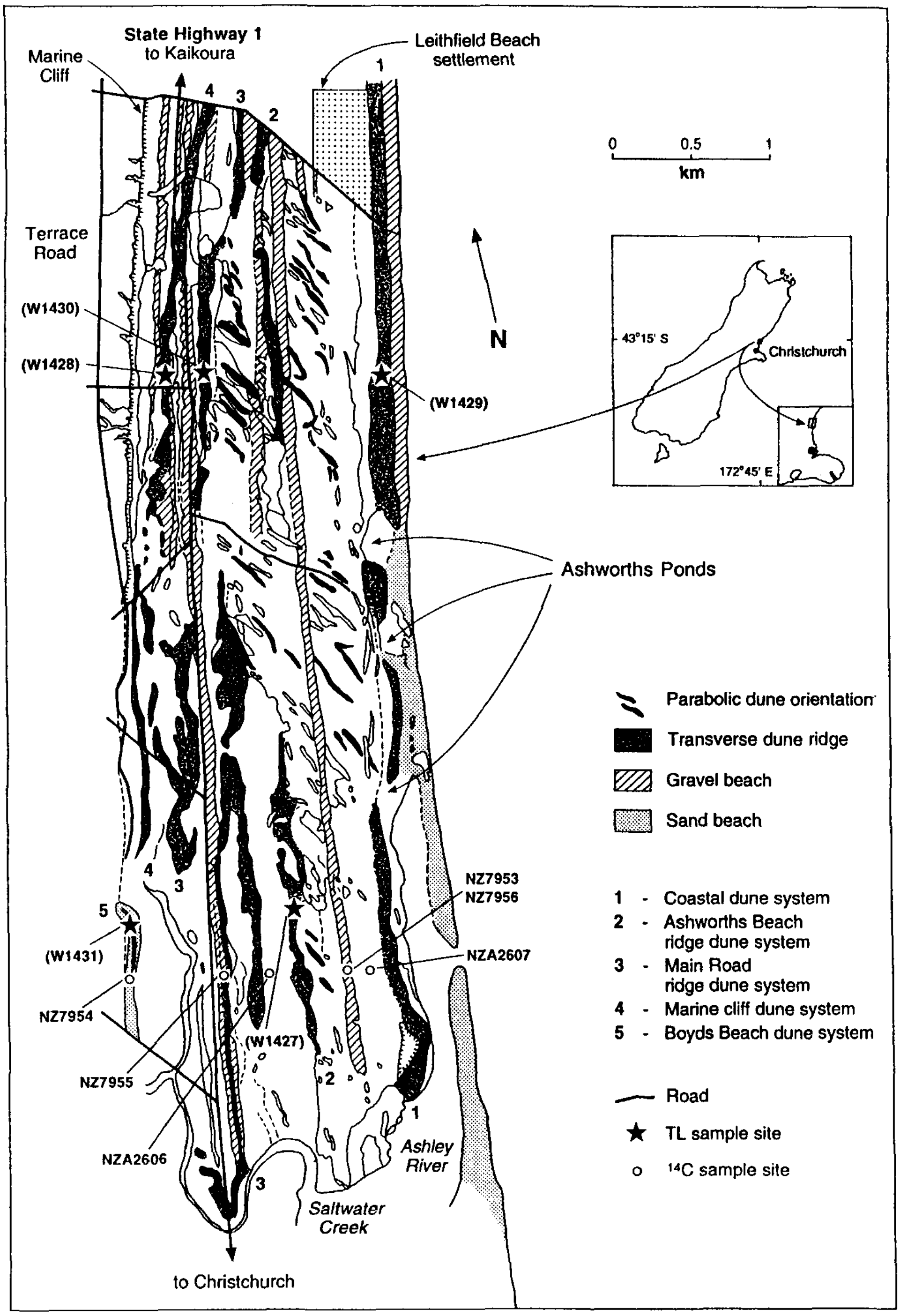

Fig. 1 Location and geomorphological map of the study area showing beach ridges, transverse dune ridges, and TL sample sites (modified from Shulmeister & Kirk 1993).

slopes (no measurements are provided). This dune series has a soil cover composed of 12–15 cm of "dark grey structureless sand grading into a light brown-grey loose sand". Topsoils (presumably equivalent to humus-rich horizons) range from 5 cm on ridges to 30 cm in closed depressions. From Waimakariri River south, the dunes of this series coalesce.

(3) the Waikuku Dune Complex. Dunes of the Waikuku Complex form a discontinuous belt on the inland fringe of the progradation plain from Christchurch north to Ashworths. The largest dunes of this series occur near Ashworths where they reach 8–9.5 m in height. A soil profile from a site 1.6 km north of Kaiapoi had a 17.5 cm layer of dark brown-grey loamy sand over a 25 cm thick unit of light brown loamy sand grading downward to a light brown sand. Some podzolisation was apparent beneath sites with pine cover.

Blake (1964) attempted to date the dunes by two methods. Firstly, he directly compared the Pegasus Bay dune units to dated dune phases identified by Cowie (1963) in Manawatu. Secondly, he estimated the ages of the Pegasus Bay dune units on the basis of a steady Holocene progradation of the Pegasus Bay foreshore since 6500 yr B.P. (based on data in Suggate 1958). The dates derived from

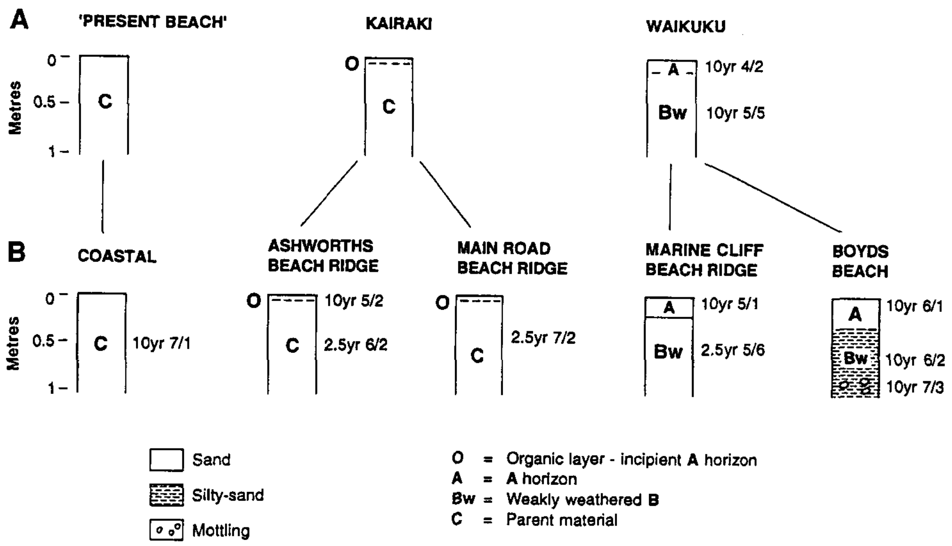

Fig. 2 Comparative soil profiles between Blake's (1964) work (A) and this study (B). The official Kairaki and Waikuku sand profiles of Raeside & Rennie (1974) are used as a proxy for Blake's (1964) soils of those names.

the two techniques did not tally and Blake rejected the comparison to Manawatu in favour of a progradation-based age sequence. He hypothesised ages of:

(1) 0–700 yr B.P. for the coastal dunes;

(2) c. 2000 yr B.P. for the Kairaki Dune Complex; and

(3) 5000–6000 yr B.P. for the Waikuku Dune Complex.

These predicted ages and the dune systems themselves have not been seriously evaluated since Blake's work. From aerial photographs of the reach between the Ashley and Kowai Rivers, there appear to be at least five distinct sets of ridges. Fieldwork was undertaken to investigate whether the five ridges fitted into Blake's classification.

TECHNIQUES

Dune ridges were mapped from aerial photographs and confirmed by detailed field mapping. Soil pits were examined on each of the ridges, and representative sites were chosen for thermoluminescence (TL) dating. All soil (Fig. 2B) and TL samples (Table 1) were recovered from dune crest positions.

Thermoluminescence dating

Samples of sand from the ridges were dated using the coarse fraction (quartz inclusion) TL technique at the TL laboratory of the University of Wollongong, Australia. (See Berger (1988) and Forman (1989) for reviews of the technique and geological uses of TL.) The TL methodology of the Wollongong laboratory is described in detail in Nanson et al. (1991). The samples, except for W1429, were analysed using the combined regenerative/additive (total bleach) method on the 90–125 μm quartz grain fraction. Sample W1429 exhibited an apparent TL sensitivity change, possibly attributable to the UV lamp used to bleach the sample, and was analysed using the additive method only. All other sample results showed good correspondence between the two methods.

Two ages have been calculated for most samples. TL_{uv} dates are derived by bleaching samples of their natural TL under UV light in the laboratory. In practice, this tends to over-bleach the sample and the ages derived are maximum ages. TL_S dates derive their zeroed signal from the measurement of the residual TL in grains of sand exposed at the surface of the sample deposit. In theory, these samples should provide the correct residual TL level. In practice, many surface samples are under-bleached, and only those samples where the bleaching characteristics are satisfactory are used for TL_S dates. In this study, both TL_S and TL_{uv} ages have been determined for three of the five samples (on Boyds Beach Dune Ridge, Ashworths Beach Dune Ridge, and the Coastal Dune System). In these samples, the TL_S age is the preferred result.

Morphology, stratigraphy, and TL chronology

Morphological changes in the transverse ridges require bisecting the area along an east–west line running through the northern limit of Ashworths Ponds (see Fig. 1). South of this line, the transverse dune ridges run roughly parallel to the modern coast. Convergence and divergence of the ridges occur where short sections (200–300 m) of transverse ridges depart from the main ridge lines at 30–60°. All such convergences/divergences occur within 2 km of the Ashworths Ponds line. Up to eight transverse ridges can be recognised (including the modern spit dunes); however, when conjoining ridges are excluded, five transverse ridge systems are identified.

Dune ridges north of Ashworths Ponds are more constrained. They run subparallel to each other with the older ridges being slightly oblique (5–10°) to the coast. Four distinct transverse ridge systems are present. There is no apparent equivalent dune ridge for the most inland ridge present in the southern half of the study area.

The five transverse systems were named by their proximity to geomorphic features, to which, as will be shown, they are related.

The systems may be summarised as follows.

1. The Coastal Dune System: This comprises two transverse dune ridge groups. Firstly, an inland series lies on the west bank of the Ashley River. These are the remnants of a prior coastal dune ridge system that is being partially destroyed by the northward migration of Ashley River since 1979

Table 1 TL and radiometric results from the University of Wollongong Laboratory.

Sample	Plateau region (°C)	Analysis temp. (°C)	Moisture content by weight %	Specific activity (Bq/kg)	Rb content (ppm assumed)	K-40 % by AES	Cosmic contribution (mGy/yr)	Annual dose (mGy/yr)	Paleodose (Gy)	TL age (ka)	Notes
W1427	300–500	375	1.2 ± 3	38.6 ± 1.2	100 ± 25	0.85 ± 0.005	150 ± 50	1849 ± 53	1.8 ± 1.0s	1.0 ± 0.6s	Ashworths Beach Dune Ridge
									5.5 ± 1.0uv	3.0 ± 0.6uv	
W1428	275–425	375	1.7 ± 3	41.7 ± 1.3	100 ± 25	0.8 ± 0.005	150 ± 50	1849 ± 53	11.4 ± 1.4uv	6.0 ± 0.5uv	Marine Cliff Dune Ridge
W1429	300–400	375	2.5 ± 3	29.7 ± 0.9	100 ± 25	0.9 ± 0.005	150 ± 50	1698 ± 51	0.8 ± 0.1s	0.5 ± 0.0s	Coastal Dune Ridge
									12.1 ± 1.6uv	5.3 ± 0.6uv	
W1430	300–425	375	2.5 ± 3	29.7 ± 0.9	100 ± 25	1.0 ± 0.005	150 ± 50	1804 ± 51	4.7 ± 0.7uv	2.6 ± 0.4uv	Main Road Beach Dune Ridge
W1431	300–425	375	9.0 ± 3	37.1 ± 1.2	100 ± 25	0.22 ± 0.005	150 ± 50	1055 ± 48	7.7 ± 1.5s	7.3 ± 1.6s	Boyds Beach Dune Ridge
									9.7 ± 1.6uv	9.2 ± 1.6uv	

uv = Measurements based on reference samples bleached under UV light.
s = Samples where a surface residual has been applied.
The specific activity of these specimens was measured with a thick source alpha counter over a 42 mm scintillation screen.
Uncertainty levels represent one standard deviation. All samples except W1429 measured using combined additive/regenerative method, W1429 uses additive method only.

(Little 1991). The single dune complex behind the mixed sand and gravel beach is part of this system. Dunes of the this system are up to 200 m wide and 4–6 m high.

The dunes are composed of a light grey (10YR 7/1) fine sand. There is no evidence of soil horizon formation. Roots penetrated to 0.7 m (Fig. 2B).

The second series is the modern berm and foredune system on Ashworths Spit. These dunes are less well developed but have not been disrupted. There are no soil horizons visible in these dunes.

TL sample W1429 was recovered from 0.4 m depth on the most landward dune of the inland series (see Fig. 1). It yielded a TL_{uv} age of 5.3 ± 0.6 ka, which reduced to 0.5 ± 0.1 ka (TL_s), when a surface correction was applied (Table 1).

2. Ashworths Beach (AB) Dune System: This is a single line or small complex of dunes forming a transverse feature, 0–300 m west of Ashworths Beach Ridge (Blake 1964; Shulmeister & Kirk 1993). Dune preservation is variable but the dune line is clearly visible from air photographs. These dunes are laterally constrained (<100 m wide) and <2 m high on average, though dunes up to 7 m high occur.

Soil horizons are weakly developed. A 0.04 m root mat caps a shallow (0.04 m) organic-rich layer composed of a greyish yellow brown (10YR 5/2) fine sand with root and humic material. From 0.08 m to the base of section at 0.9 m is a greyish yellow (2.5Y 6/2) fine sand (Fig. 2B).

A TL sample (W1427) was recovered from this unit at a depth of 0.60 m. It yielded a TL_{uv} age of 3.0 ± 0.6 ka and a TL_s age of 1.0 ± 0.6 ka (Table 1).

3.The Main Road Beach (MRB) Dune System: A complex series of transverse ridges extends east and west of the Main Road Ridge, which is a sand and gravel beach ridge (Blake 1964; Shulmeister & Kirk 1993). These dunes are severely degraded in places due to human activity. Where undisturbed, the dunes are up to 6 m high, and dune ridge width varies from single dunes <50 m wide to dune complexes 300 m wide.

Soil and TL sampling was carried out on a northern dune. No soil horizons are present. A 0.05 m litter of pine needles overlies a massive greyish yellow fine sand (2.5Y 7/2) (Fig. 2B). A TL sample (W1430) was recovered from 0.75 m. This sample yielded an age of 2.6 ± 0.4 (TL_{uv}) (Table 1). The TL signal from the surface residual sample of this material exceeded the TL signal of the buried deposit and was clearly not an appropriate surface sample.

4. The Marine Cliff Dune System: This is the closest dune system to the cliff that marks the limit of the Holocene marine transgression. This is a single dune ridge in the northern half of the study area, bifurcating south of Ashworths Ponds. It is the best defined transverse dune system with stabilised dunes c. 100 m wide and up to 10 m high. Steep headwalls (c. 30°) are locally preserved.

This is the first dune system to show marked soil horizon development (Fig. 2B). It comprises a 0.22 m cap of brownish grey (10YR 5/1) fine sand with extensive root penetration. This grades into a yellowish brown (2.5Y 5/6) fine sand to at least 0.77 m. A TL sample (W1428) was taken from 0.60 m. It yielded a TL_{uv} age of 6.0 ± 0.5 ka (Table 1). As per the Main Road Beach Dune Ridge sample, the surface sample collected to provide a surface residual had an anomalously high value of residual TL and appeared to be unbleached.

5. *Boyds Beach (BB) Dune Ridge*: Near Ashley River, the inland boundary of the Holocene marine wedge is marked by a low sandy ridge which has been identified (Shulmeister & Kirk 1993) as a beach. A single, low dune ridge (average width 20 m, height 2–3 m) abuts the western side of the beach. This marks the inland extent of dune ridges on this stretch of coast.

The dune surface has been recently disturbed by ploughing. From 0 to 0.25 m depth is a fine sand. A very fine brownish grey (10YR 6/1) sand extends from 0.25 to 0.35 m fining to a greyish yellow brown (10YR 6/2) silty sand between 0.35 and 0.50 m. A greyish yellow brown (10YR 6/2) sandy silt with dull yellow orange (10YR 7/3) mottling extends to 0.65 m (Fig. 2B).

TL sample (W1431) was recovered from 0.40 m depth. It yielded a TL_{uv} age of 9.2 ± 1.6 ka and a TL_s age of 7.3 ± 1.6 ka (Table 1).

DISCUSSION

Applicability of the TL dates

There are no reversals in the TL dates and the ages are consistent with expected ages from the progradation plain. Two primary assumptions must be met for TL dating to be reliable:

(1) the sediments must have been effectively "zeroed" before burial. Zeroing is the removal of any pre-existing TL signal from the sample, by heating or light exposure, prior to burial;

(2) the sediments must be collected from a homogeneous sedimentary unit, more than 0.30 m from a stratigraphic or sedimentary boundary, to avoid TL contamination from surrounding material and/or a variable internal dose rate.

The latter point can be dealt with by careful sampling procedures in the field, and none of the samples recovered in this study contravene this requirement. Although zeroing of sediment before burial is hard to prove, reliable results have been achieved from aeolian dune sands where corroborative dating was available (e.g., Shepherd & Price 1990; Nanson et al. 1991; Shulmeister et al. 1993).

Indirect corroborative dating is available for this study. Shulmeister & Kirk (1993, in press) have established a ^{14}C chronology for the marine sequence between the Kowai and Ashley Rivers (Table 2, Fig. 1). Dates from the beaches provide benchmarks for the TL results and are generally consistent with them (see below).

Chronology of the dune ridge systems

The five dune ridge systems reflect five separate chronological events. The most inland of the Coastal Dune System dunes yielded a preferred TL_s age of 0.5 ± 0.1 ka (W1429). This is a satisfactory date for the longest stabilised dune in a partially active system. It suggests that the modern coast is <600 years old.

The AB Dune Ridge preferred TL_s age of 1.0 ± 0.6 ka (W1427) is compatible with the age of Ashworths Beach Ridge (c. 2000 yr B.P.; Shulmeister & Kirk in press). The large margin of error on younger TL dates has already been noted by Shepherd & Price (1990) but the date is nevertheless a valuable corroboration of the ^{14}C chronology. On the basis of the relationship of the dunes to the beach ridges, we suggest that the dune system is likely to be closer to 2 ka in age.

The MRB Dune Ridge also yielded an unsatisfactory TL_s date, and the TL_{uv} date of 2.6 ± 0.4 ka (W1430) must be regarded as a maximum age for the sample. The TL technique dates the last exposure of the sand to light, and since the Main Road Beach Ridge dates to c. 4100 yr B.P., the sand sampled may have been reworked during a younger reactivation of the dune ridge. Using the proxy support of the ^{14}C date, we suggest that a cautious interpretation of the ridge as <4000 yr B.P. is appropriate.

The Marine Cliff Dune System was derived from a regressive beach east of the cliff marking the maximum Holocene transgression (Shulmeister & Kirk 1993). Since no TL_s date is available from this system, it can only be directly determined to be <6.0 ± 0.5 ka (W1428). This dune system is inland of the Main Road Beach Ridge, which has been radiocarbon dated to c. 4100 yr B.P. (Shulmeister & Kirk 1993) and relates to an earlier beach. Thus, the original formation of the system is unlikely to have occurred later than 4100 yr B.P or before 6000 yr B.P.

The most inland of these, the BB Dune System, is parallel with the inferred maximum Holocene transgression, and the date of 7.3 ± 1.6 ka (W1431) is wholly compatible with the maximum Holocene transgression shoreline in North Canterbury at c. 6500 yr B.P. (Suggate 1958; Brown & Wilson 1988). Given the secure stratigraphic position, this date suggests that a ^{14}C date of 4154 ± 74 yr B.P. (NZ7954; Shulmeister & Kirk in press), derived from wood in a swamp deposit below the beach, is anomalously young.

Table 2 ^{14}C dating of mixed sand and gravel beach ridges between the Kowai and Ashley Rivers, north Canterbury. (Modified from Shulmeister & Kirk 1993, in press).

Sample no.	Uncalibrated age (yr B.P.)	Relationship to geological features
NZ7953	1958 ± 70	On Beach berm of Ashworths Beach Ridge
NZ7954	4154 ± 74	In Boyds Beach
NZ7955	4138 ± 71	Under Main Road Beach Ridge
NZ7956	2895 ± 88	Under Ashworths Beach
NZA2606	3810 ± 94	In progradational marine gravels between Ashworths and Main Road Beach Ridges
NZA2607	2090 ± 80	In progradational marine sands between Ashworths Beach Ridge and the modern coast

Use of Blake's classification to categorise samples from this study

A reasonable correspondence exists between the dune series identified in this study and the classification suggested by Blake (1964) with the Coastal Series equating to present dunes, Ashworths Beach Ridge Dunes to Kairaki Dunes, and the Marine Cliff Dunes to Waikuku Dunes. The Main Road Beach Dune Ridge is classified as Kairaki by default, and Boyds Beach Dune Ridge is tentatively assigned to the Waikuku Series. These dune soils all classify as either Raw Soils (present beach and Kairaki Series and equivalents) or Recent Soils (Waikuku and correlates) under the New Zealand Soil Classification (Hewitt 1992). There is no evidence of the development of an E (elluvial) horizon characteristic of older dune sands.

Despite the comparatively good correspondence between the classifications in this study and Blake's, two lines of evidence suggest the soil-based system is inappropriate for the classification of the dunes:

1. There is a genetic relationship between individual (and/or pairs of) transverse dune ridges and relict beaches. Since these beaches represent distinct geomorphic events, the dunes more accurately reflect the geomorphic evolution of the coastal plain than the development of a pedological sequence. This point is central to understanding the morphology, chronology, and significance of the dune ridges. Failure to relate the dunes to the events that formed them seriously erodes the information that can be derived from them.
2. The TL dates from this study and ^{14}C dates available in Shulmeister & Kirk (1993, in press) indicate that the five ridges represent five chronological events and not the two or three suggested by the soil sequence.

Relationship between dune ridges and beaches (relict and modern)

Field evidence shows that the transverse dune ridges behind the modern beach are foredunes related to the onshore accumulation of sand driven up the beach face. The proximity of transverse dune ridges and relict beaches is regarded as evidence that the modern arrangement of beach and dune ridge system has recurred in the past and that the dune systems are directly related to specific beaches. Points which require further clarification are discussed below.

Coastal dunes and the modern mixed sand and gravel beach

Although sand dunes have been described landward of gravel beaches (e.g., Bluck 1967), the preservation of substantial sand dunes is more normally associated with sand than mixed sand and gravel beaches. The mixed sand and gravel beaches north of the Leithfield Beach settlement (Fig. 1) are, as expected, marked by a low berm rather than a foredune behind the beach. At Leithfield Beach, however, the largest and best preserved sand dunes in the study area lie directly behind the mixed sand and gravel beach, while farther south, this line of coastal dunes becomes discontinuous almost exactly at the point where the beach switches from gravel to sand.

This implies that the formation of the dunes is related to the formation of the mixed sand and gravel beach, but this is misleading. Shulmeister & Kirk (in press) have demonstrated that the sand and mixed sand and gravel beach contact migrates along the beach. From air photographs it has been shown that a sandy beach extended as far north as the Leithfield Beach settlement as recently as 1956. The formation of transverse beach ridges in the northern half of the field area appears to occur when a sandy foreshore extends to near the mouth of Kowai River. This explains the presence of dune ridges behind mixed sand and gravel beaches.

The development of a sandy foreshore at Leithfield Beach is dependent on the position of the mouth of Ashley River. Sand from Ashley River only nourishes the foreshore in the northern half of the study area when the mouth has migrated to a northerly position, at or near Ashworths Ponds (Fig. 1). When the mouth is in a southerly location (Waikuku), beaches in the northern half of the study area are starved of sand, and a mixed sand and gravel beach re-establishes itself. A deflation surface is often visible at the contact betwen the sand and mixed sand and gravel beach.

The formation of dune ridges in the northern half of the field area occurred when a sandy beach extended to Leithfield Beach. By implication, each of these ridges must relate to a period when Ashley River discharged by a northerly outlet. Since there are only four suites of transverse dune ridges in the northern half of the area, it appears that either Ashley River has maintained a northern outlet only four times (including its present course) in the last 6000 years or that dune-preserving conditions do not recur with each beach formation. We are inclined towards the latter view, based on the historical behaviour of the river charted by Little (1991) showing two such migrations in the last 60 years.

A consequence of the relationship of dune ridge building to complex coastal-fluvial interactions is that direct paleoclimatic interpretations cannot be made from the periodicity of dune ridge formation. Dune ridge formation is dependent on beach ridge formation, and this is a function of sediment supply and nearshore aggradation rather than a direct response to climate change. Thus, the fine scale inferences on late Holocene climate change derived by McFadgen (1985, 1989) from coastal sites are not appropriate to this dataset.

Variation in dune ridge morphology between the northern and southern parts of the study area

The migration of Ashley River also explains the difference in preservation and number/complexity of dune ridges between the northern and southern half of the study area. Examination of the modern coastal sequence is the key to understanding the relict pattern. On the modern coast, a single dune ridge exists behind the mixed sand and gravel beach north of Ashworths Ponds. South of Ashworths Ponds, a semicontinuous dune ridge associated with a spit extending north from the Ashley River mouth, fringes the coast. Inland of the spit, on the true right bank of Ashley River, patchy remnants of the coastal dune sequence that backed the beach before the Ashley River mouth started moving north are preserved. The pattern of dune preservation on the modern beach fits the distribution of dune ridges and dune ridge remnants on the progradation plain.

Orientation of the dune ridges

The primary control on dune ridge orientation is the direction of the dominant wind, which in this part of Pegasus Bay is considered to be the northeasterly. Although it has been

Fig. 3 Aerial photograph (4126/12: 1967) of the Leithfield area. Kowai River is at top right (A) and the dunefield (B) is visible in the lower right-hand section of the photograph. Note the northwest–southeast alignment of the low-amplitude parabolic dunes. These are orientated towards the beach and appear to be controlled by northwest föhn winds. Leithfield settlement is marked C. This photograph is copyright and courtesy of the New Zealand Department of Survey and Land Information.

observed by McKendry (1985) that the northeasterly sea breeze is enhanced in the northern part of Pegasus Bay under southwesterly flows, the dominant lee trough northeasterlies appear to be less effective. This is probably a function of increased frequency of northwest (föhn) winds due to the proximity of the mountains. An absence of weather stations in this area prevents the direct observation of this effect, but there is geomorphological evidence to support this hypothesis.

Initial construction of the coastal foredune system is strongly dependent on onshore easterly and northeasterly winds. This is evident from the shore-normal development of the coastal foredune system. All the transverse dunes are located within a few hundred metres of a relict or modern coastline (Fig. 1), and it has already been argued that they are sourced from these coasts. Thus, it appears that no transverse system has migrated inland more than 500 m from its source and most are less than 100 m. By contrast, the sand plains between the dunes, especially between Ashworths Beach Ridge and the modern coast, have a veneer of very low amplitude parabolic dunes. From aerial photographs (Fig. 3), these dunes are aligned on a northwest southeast axis and are migrating towards the coast under the influence of the northwest (föhn) wind. It is notable that the sand plains occur between the transverse ridges but not landward of the oldest (BB Dune System) ridge. Since the plains are dominated by gravels under a thin surface sediment veneer (Shulmeister & Kirk 1993), the sand in the plains is most likely to be derived from the transverse ridges.

Postdepositional disruption of the transverse dune ridges is supported by the difficulty of recovering good TL_S samples from these dunes. Deflation of the surface cover would have caused exposure of buried sediment and/or incorporation of older material into the profile, and would have resulted in the anomalously high surface TL signals that were observed in three of the five TL samples.

The crosscutting of the relict beaches by the dune ridges in the northern half of the area may reflect the preferential migration of the northern end of the ridges towards the beach. Why this effect concentrates along the northern end of the ridges is uncertain. The most likely possibility is the funnelling of northwesterly winds down the entrenched Kowai valley, concentrating a dominantly west–northwest airflow at the juncture between the Kowai valley and the progradation plain.

CONCLUSIONS

Dune behaviour is complex in the study area but the transverse dune ridges are genetically associated with relict or active beaches. The pedologically based chronosequence proposed by Blake (1964) for the dunes of the Pegasus Bay progradation plain is, therefore, not a satisfactory classification scheme. We propose a geomorphologically based classification for the dunes between the Ashley and Kowai Rivers. Five distinct dune ridge systems have been identified and a TL chronology provided. The overall chronology is consistent with, and supported by, ^{14}C ages on the gravel beaches and under the progradation plain. In the one instance where the TL result disagrees with the radiocarbon age (Boyds Beach Ridge), the TL chronology agrees better with the regional transgression history.

The general absence of parabolic dunes west of the transverse dune ridges and the relictual nature of the inland ridges indicate that northeasterly winds do not dominate more than a few hundred metres inland from the coast. The presence of extensive low-amplitude parabolic dunes orientated towards the southeast over most of the study area, away from the immediate coastal zone, supports a hypothesis that the northwesterly föhn wind is the most effective sand-moving wind.

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