New Zealand Journal of Geology and Geophysics

ISSN: 0028-8306 (Print) 1175-8791 (Online) Journal homepage: http://www.tandfonline.com/loi/tnzg20

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New Zealand Journal of Geology & Geophysics, 2005, Vol. 48: 517–522
0028–8306/05/4803–0517

Short communication

The source, age, and stabilisation of the Koputaroa dunes, Otaki-Te Horo, New Zealand

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Abstract From Te Horo on the Kapiti Coast, north to Manawatu, a typical sequence of landforms has been described and characterised. However, there are significant differences in specific landform suites. In the Manawatu–Horowhenua area, previous research has postulated the origin of the Koputaroa dunes and argued they were active until c. 24 000 yr BP. Luminescence dating of the Koputaroa dunes at Otaki-Te Horo suggests that they stabilised only 11 000 yr ago. The effects of the Otaki River and Holocene dunes cause this difference in age of stabilisation. At Otaki-Te Horo, a lack of sand has prevented more recent dunes from migrating and covering the Koputaroa dunes. Therefore, the last phase of activity has been preserved. This is not the case in the Manawatu–Horowhenua area. Dune formation, or remobilisation, around 11 000 yr BP is synchronous with a recognised dune building period in Australia, and paleoenvironmental evidence from New Zealand of cold and dry conditions.

Keywords sand dunes; Pleistocene; luminescence dating

INTRODUCTION

New dating techniques are being used to improve our understanding of landforms, landscape processes, and geomorphic evolution. Previous research has led to a general understanding of the relationships between climatic oscillations, vegetation cover, and sea-level change; and between climatic fluctuations, terrace formation, and associated loess deposition. Within the Manawatu–Horowhenua area, North Island, New Zealand, a broad chronological sequence of landscape evolution has been postulated. This sequence explains the relative stratigraphy, the Holocene dune phases, the fluvial terraces and loess deposits, and the present interglacial highstand seacliff (Cowie 1963; Palmer et al. 1988; Muckersie & Shepherd 1995).

Many of these same landscape elements (including the Koputaroa dunes), although significantly smaller, are also present farther south at Otaki-Te Horo (Fig. 1). In this area, the Koputaroa dunes have particular significance because they lie on the last glacial aggradation surface ($\delta^{18}O$ stage 2), c. 500 m inland from the present interglacial highstand seacliff (itself 3 km from the present shoreline). The date at which this aggradation surface ceased to form provides a maximum age estimate for these dunes of 10 000 yr (Palmer et al. 1988). The truncation of the aggradation surface, resulting in the seacliff, provides a minimum age estimate for these dunes of 6500 yr (Gibb 1986). In the Horowhenua–Manawatu area, the Koputaroa dunes are no closer than 5 km from the coast and extend up to 25 km inland. Using radiocarbon, thermoluminescence (TL), and infrared stimulated luminescence dating, and sedimentological analysis, their relative stratigraphic position, origin, and age have been postulated (Cowie 1963; Shepherd 1985; Shepherd & Price 1990; Duller 1996). Pollen analysis of these dunes shows they formed during cool climatic conditions, most likely during a late stage of $\delta^{18}O$ stage 2 (McIntyre 1963). The degree of soil development led Cowie (1963) to conclude that they were between 10 000 and 20 000 yr old.

Shepherd & Price (1990) obtained a TL date of 24 000 ± 3700 yr for a sample of Koputaroa dune sand taken from Paiaka Road, Horowhenua (Fig. 2). This reinforced the previously hypothesised age of the dunes that was based on the presence of Kawakawa Tephra, from the Oruanui eruption. Radiocarbon dating of the Oruanui eruption suggested a mean conventional age of 22 590 ± 230 yr BP for this tephra (Wilson et al. 1988). Subsequent infrared stimulated luminescence dating of this site resulted in mean age estimates of 19 200 and 21 200 yr (Duller 1996). These ages are considerably younger than the 35 000 ± 1700 yr BP obtained from radiocarbon dating of silty peat in the same area (Fleming 1972). However, Duller (1996), on the basis of nine samples from the area, obtained age estimates ranging from 46 000 to 9900 yr. He concluded that the Koputaroa dunes were probably formed during an interstadial of the early part of the last glacial cycle when the coastline was relatively close to the present location of the dunes. These dunes were subsequently remobilised about the time of the Kawakawa Tephra deposition.

Cowie (1963) and Fleming (1972) argued that the Koputaroa dune sand was of fluvial origin. However, Shepherd (1985) concluded that some, if not all, of the sand in these dunes in Manawatu–Horowhenua was of coastal origin. This was because of its heavy mineral content and the degree of particle rounding. He further suggested that the most likely origin of this dune sand was the mobilisation of transgressive and/or regressive sands deposited on the inner continental shelf during relatively higher sea levels during $\delta^{18}O$ stage 3. The Koputaroa dune sand is almost identical to the Holocene dune sand, but it is distinctly different to that derived from local rivers. In terms of landscape evolution, this suggests that the present prevailing northwesterly winds were also characteristic of the last glacial.

G04025; Online publication date 22 August 2005
Received 22 June 2004; accepted 30 March 2005

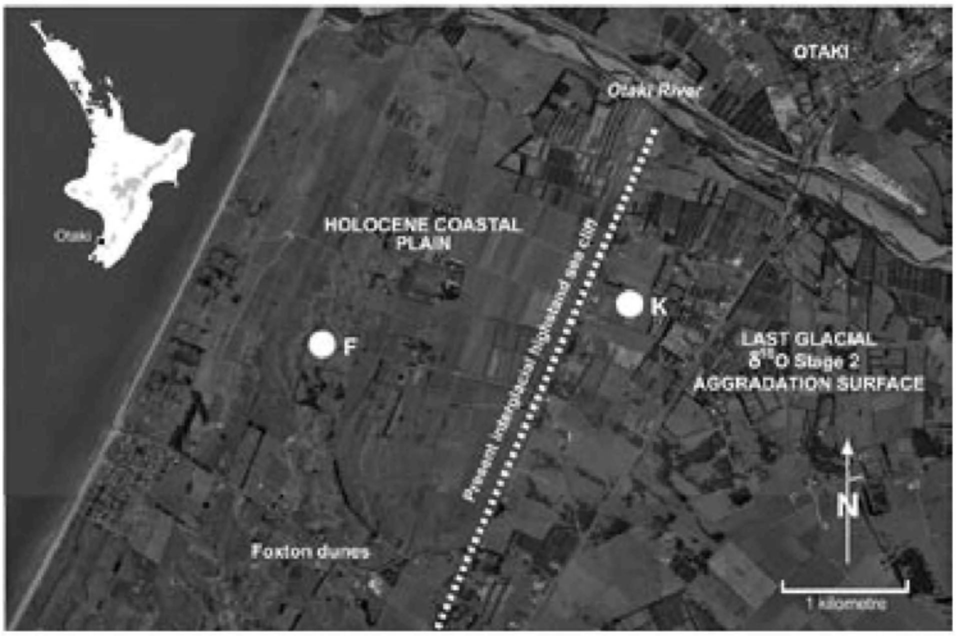


Fig. 1 In the Otaki-Te Horo area the Koputaroa dunes (K) are only found on the last glacial ($\delta^{18}O$ stage 2) aggradation surface, inland of the present interglacial highstand seacliff, and c. 1 km south of the Otaki River. Elsewhere Holocene dunes (F) have migrated over the seacliff, masking the Koputaroa dunes (Aerial photographs: R251507,1607,1508,1608; S250107,0108 © Greater Wellington Regional Council).

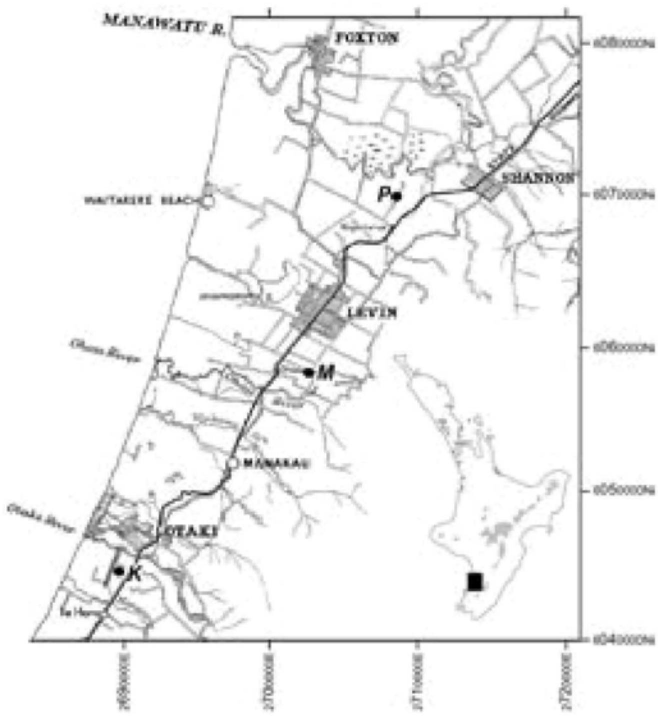


Fig. 2 North Island, New Zealand (inset), showing the location of the sample locations within the Manawatu–Horowhenua area. Grid references for the sites are: K (Otaki-Te Horo Koputaroa Dunes) NZMS 260 S25/896456 and S25/897455; M (McLeavy Rd Koputaroa Dunes) NZMS 260 S25/027578; P (Pakaia Rd Koputaroa Dunes) NZMS 260 S25/078683.

Palmer & Wilde (1990) mapped some soils in the Otaki-Te Horo area as Koputaroa soils. While this mapping was largely based on their geographic and topographic position, the soil properties were consistent with the Koputaroa soils to the north (Cowie 1968). The small area of remnant Koputaroa dunes in the Otaki-Te Horo area is c. 8 km due south of the dunes analysed by Shepherd (1985). Since the Koputaroa dunes are argued to be early $\delta^{18}O$ stage 2 in age, sea levels would have been considerably lower than at present (Gibb 1986). Cowie (1963) and Fleming (1972) concluded that it was most likely that these dunes were related to the braided courses of rivers draining periglacial areas. The objectives of this paper are therefore to use sedimentological evidence to confirm the source of the sand in the Koputaroa dunes in the Otaki-Te Horo area; to use luminescence dating to establish their age; and to comment on the significance of these remnant landforms in terms of paleoenvironmental conditions and landform preservation.

STUDY AREA

Otaki-Te Horo is at the southern end of the Manawatu coast (Fig. 1, 2). Westerly swell and locally generated waves transport large quantities of sand-sized sediment along this coast. The prevailing NNW wind promotes a net longshore drift of sediment to the south and this has been confirmed by mineralogical data (Gibb 1977, 1978). Coarse cobble and gravel-sized material brought down the Otaki River results in steep, moderate energy beaches in the vicinity of the river mouth. This disrupts the general pattern of coastal landforms that have developed in response to an abundant sand supply.

Since present sea level was attained 6500 yr ago, the coast has prograded c. 3 km (Fig. 1) (Hesp & Shepherd 1978; Gibb 1986). The present interglacial highstand seacliff (c. 6500 yr BP), eroded into the last glacial aggradation surface ($\delta^{18}O$ stage 2) formed by the Otaki River and others in the area, is well preserved for c. 2 km south of the Otaki River. In this area, Holocene dune sands have not buried the seacliff. A suite of small Koputaroa dunes overlies the aggradation surface just landward of the seacliff (Fig. 1). The relative position of these dunes suggests they are not as old as those to the north (Shepherd & Price 1990); hence, the present investigation and application of luminescence dating.

ANALYSIS

Sedimentology

Samples were collected from two apparently undisturbed Koputaroa dunes, c. 500 m inland from the seacliff, at 70 cm depth, for sedimentological analysis and luminescence dating (Fig. 1, location K). These samples were taken from within 100 m of the dunes analysed by Palmer & Wilde (1990) when mapping the soils of Otaki District. The soil profile at the sample site was similar to that used to characterise the Koputaroa fine sandy loam (Palmer & Wilde 1990), and the Koputaroa dunes to the north (Cowie 1968).

There is no published summary of the sedimentological characteristics of sand from the Koputaroa dunes farther to the north. Hence, samples were collected from Paiaka Rd and McLeavy Rd (Fig. 2) for sedimentological analysis. The particle size characteristics of the Koputaroa dunes at all three locations are similar. These particle size characteristics are also similar to the Holocene dunes, but significantly different to the sand of the contemporary Otaki River (Fig. 3; Table 1). As expected all the dunes are composed of well-sorted, positive-skewed fine sand; however, the Koputaroa dunes have a lower percentage of magnetic minerals. This lower percentage of magnetic minerals suggests either a reduced input of volcanic material from the north, or an increased percentage of non-magnetic minerals. The presence of magnetic minerals, which are not available locally, suggests the sand is of coastal origin. This finding supports the conclusion of Shepherd (1985). Hence, the sedimentological results reported here are consistent with those of previous work on the Koputaroa dunes to the north.

Despite this evidence (Fig 3; Table 1) there is still some uncertainty as to the source of the sand comprising the Koputaroa dunes. Dunes are the result of a complex interaction of sediment supply, sediment availability, and the transport capacity of the wind. Therefore, while the particle size distribution of sediment sources may be different, the resultant dunes may have the same particle size distribution. Although specific magnetic minerals are not available locally, the analytical technique included composite grains, which may contain magnetic minerals from sedimentary sources (Gibb 1977). Therefore, it is possible that Otaki River sand includes some "magnetic minerals". Hence, some of the Koputaroa dune sand may be of fluvial origin and a definitive answer as to the source of sand is not possible without more detailed mineralogical analysis.

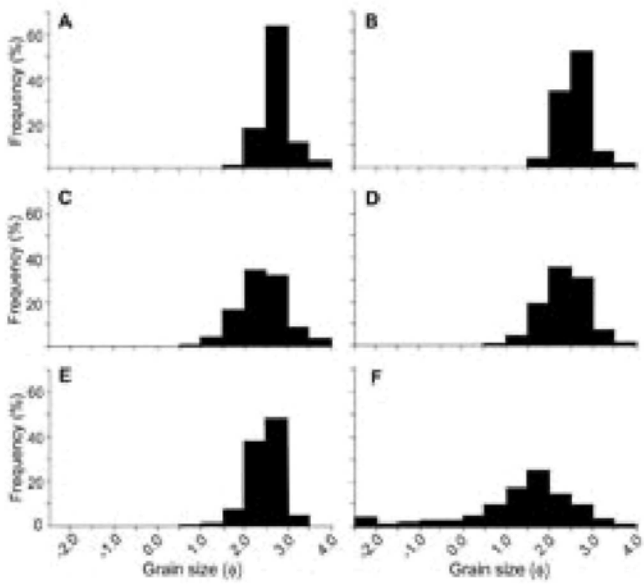


Fig. 3 Grain-size distributions: **A**, McLeavy Road; **B**, Paiaka Road (Koputaroa dunes from the Manawatu–Horowhenua area); **C, D**, Koputaroa dunes from Otaki-Te Horo; **E**, Holocene (Foxton) dunes from Otaki-Te Horo; **F**, contemporary Otaki River.

Luminescence dating

Luminescence dating determines the paleodose of a sample (i.e., the radiation accumulated since its last exposure to light). Therefore, the age obtained using this technique is the minimum time since the dunes were last active. The paleodose of two samples was determined using the single aliquot regenerative protocol (SAR) applied to the 90–125 μm quartz grains. All measurements were carried out on a Riso TL-DA15 at Victoria University of Wellington; equipped with an $^{90}Sr/^{90}Y$ beta source for irradiation, and an IR diode

Table 1 Sediment characteristics for various landforms in the Otaki-Te Horo area[1].

Property	Koputaroa[2]	Waitarere[3,4]	Motuiti[3,4]	Foxton[3,4,5]	Otaki River[6]	Koputaroa[7]
Grain size[4] φ	2.35 (0.01)	2.87 (0.46)	2.87 (0.60)	2.90 (0.13)	0.84 (0.85)	2.67 (0.11)
Sorting	0.63 (0.16)	0.34 (0.09)	0.35 (0.08)	0.34 (0.06)	1.19 (0.65)	0.35 (0.00)
Skewness	0.03 (0.10)	0.14 (0.05)	0.10 (0.11)	0.09 (0.11)	–0.13 (0.24)	0.09 (0.06)
% Magnetics[8]	26	39.2 (8.2)	37.8 (7.3)	39.8 (2.3)		32.2 (9.1)

[1]Mean (1 SD) grain size, sorting, and skewness were computed using graphical measures from sieve analysis (–2 to 4 φ, Folk & Ward 1957).

[2]Samples from NZMS 260 S25/896456 and S25/897455.

[3]These Holocene dunes are seaward of the present interglacial highstand seacliff. They are significantly larger than the Koputaroa dunes and have distinct soil profile and particle size characteristics.

[4]Twenty-one samples each.

[5]Shepherd (1985) used the same dune phase as a reference point.

[6]Seven samples collected between the State Highway bridge and the river mouth (3 km downstream).

[7]Mean of samples collected from Pakaia Road (NZMS 260 S25/078683) and McLeavy Road (NZMS 260 S25/027578).

[8]Computed using a Franz Magnetic Separator; the percent magnetics refers to the percentage of particles with a magnetic susceptibility >1.2 Å (Gibb 1977).

array for stimulation. Radionuclide concentrations of ^{40}K, ^{208}Tl, ^{212}Pb, ^{228}Ac, ^{210}Pb, ^{214}Bi, ^{214}Pb, ^{226}Ra, and ^{234}Th were measured by gamma spectrometry at the National Radiation Laboratory, Christchurch, New Zealand. In addition, the feldspars (4–11 µm) from sample WLL135 (subsample b) were analysed by measuring the blue luminescence output during infrared optical stimulation. The paleodose was estimated using the multiple aliquot additive-dose method (with late-light subtraction). The analyses show that both samples were last exposed to light (i.e., part of active dunes) at approximately the same time: WLL135, 10 800 ± 2800 (quartz) and 9900 ± 900 (feldspars); and WLL136, 11 300 ± 1400 (quartz) yr ago. The dates obtained from the two dunes, using two different size fractions and two different techniques, are consistent (Table 2).

DISCUSSION

The three new luminescence dates show a high degree of consistency; both within a single dune using different techniques and between dunes. While the dates do not indicate when the dune-building phase was initiated, they suggest that the Koputaroa dunes were active as recently as c. 10 000 yr ago. The activity of the Koputaroa dunes in Otaki-Te Horo is therefore substantially younger (13 000 yr) than for similar dunes to the north. The combination of: the definitive nature of the published dates (Shepherd & Price 1990); the successful use of luminescence dating in developing chronologies of coastal landform evolution (e.g., Duller 1996; Clemmensen et al. 2001); the similarity of these new dates with those of Duller (1994); and the consistency between dunes and techniques presented here, suggest that these new dates are accurate. The age difference between the Koputaroa dunes from these northern and southern study areas therefore requires explanation.

One possibility is that the samples are from two distinct dune phases, not the same phase in two different locations. Sedimentological analysis does not distinguish between the dune phases because all the dunes have been formed under similar conditions and from material of similar origin (Table 1; Fig. 3). However, the presence of two dune phases as opposed to one is unlikely since no additional phase has been recognised anywhere along this section of coast. It is therefore suggested that the "young" Koputaroa dunes in the north have either been buried by the Holocene dunes, or their sand was remobilised and incorporated into these more recent dunes. This argument is supported by the significantly greater amount of sediment in the north, and the larger distances over which the Holocene dunes have migrated. In the north, around Pakaia Rd and McLeavy Rd, the Koputaroa dunes are tens of metres in elevation and hundreds of hectares in extent. In the Otaki-Te Horo area they are restricted to only a couple of hectares in extent and are <2 m high (Fig. 1).

Dune formation in a coastal environment is controlled by wind velocity, the supply and size of sediment, and the availability of accumulation sites. The Otaki River is very different to the major rivers to the north. While the northern rivers currently flow across wide, flat, sandy and silty floodplains, the Otaki is a steep, high-energy river that transports gravel and cobble-sized material all the way to the coast. This creates a distinctly different beach in the vicinity of the Otaki River mouth. The steep, narrow, moderate energy gravel beach severely restricts the availability of sand for dune building. This is particularly the case along the 3 km section of the coast south of the river. The position of the Otaki River, and its influence on sediment transport processes, has therefore been responsible for both the preservation, and development, of landforms in the area.

The Koputaroa dunes lie on the Ohakean aggradation surface ($\delta^{18}O$ stage 2). This surface is <2 km from the present position of the Otaki River, and it is not covered by any loess, or the Kawakawa Tephra. This surface must therefore be younger than 22 590 yr BP. Thus, during $\delta^{18}O$ stage 2, the wide braided and mobile nature of the Otaki River would have prevented dunes from forming (Fig. 1).

All dune phases in the Otaki-Te Horo area are different from the comparable dunes in Manawatu. They are substantially smaller (in height, volume, and extent) and do not extend as far inland. Their smaller size is a function of reduced sediment supply. The discharge of gravel from the Otaki River, and its effect on beach form and process, restricts the availability of sand for dune development. Also, south of the river mouth, drainage from the hills is impeded and peat swamps have developed. This restricts dune migration, particularly given the reduced sediment availability (Shepherd & Hesp 2003). To the north of the river, and more than 3 km south of it, the Holocene dunes have migrated over the interglacial highstand seacliff. Therefore, if Koputaroa dunes were present in these areas they have since been buried and are no longer visible as distinct landforms (Fig. 1).

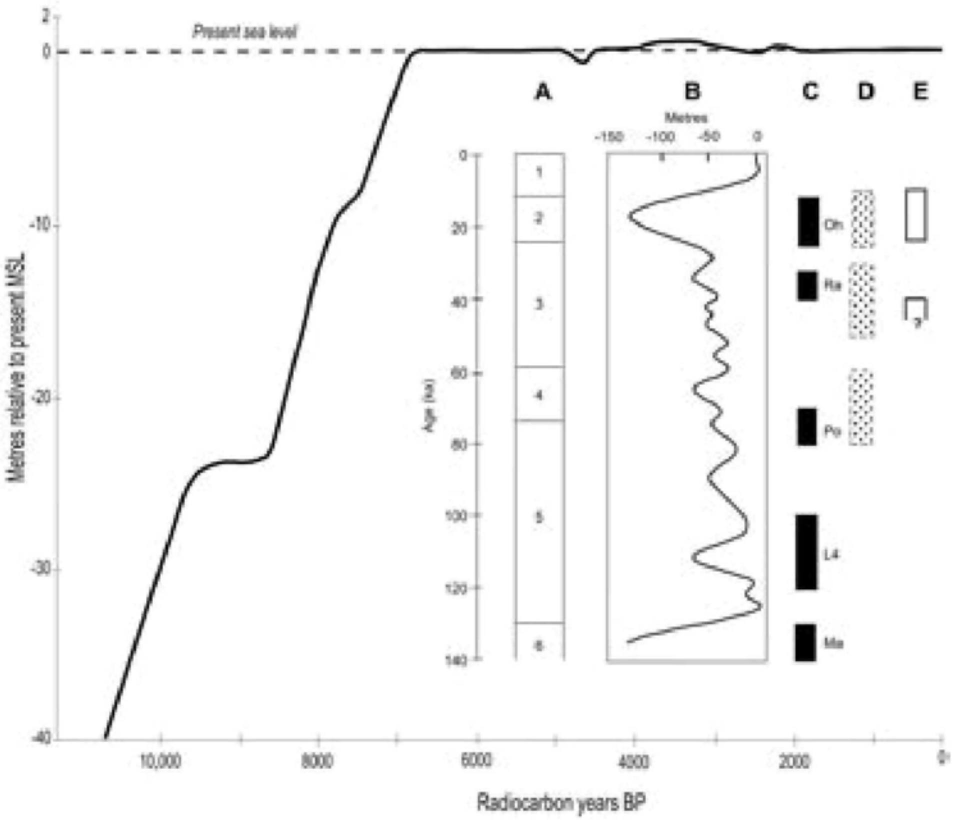
The $\delta^{18}O$ stage 2 in this area has been characterised as one of rapid environmental change. A range of paleoenvironmental indicators suggests that the region was cool and dry with strengthening westerly winds. These conditions would have been ideal to remobilise, or initiate, dune formation (Pillans et al. 1993). This period of dune activity has also been recognised along the east Australian coast (Thom et al. 1994). Therefore, in the Otaki-Te Horo area, the Koputaroa dunes formed during $\delta^{18}O$ stage 2 and stabilised c. 10 000 yr ago. This does not preclude the possibility that these dunes were active for a considerable period before stabilisation. When the Kawakawa Tephra was being deposited, eustatic sea level

Table 2 Luminescence dating results.

Sample location	Sample number	U (µg/g) from ^{234}Th*	U (µg/g) from ^{226}Ra, ^{214}Pb, ^{214}Bi*	U (µg/g) from ^{210}Pb	Equivalent dose (Grays)*	Age (yr)*
Koputaroa dune 1	WLL135a	0.91 ± 0.31	1.06 ± 0.06	<1.70	21.1 ± 5.4	10 800 ± 2800 (quartz)
	WLL135b				23.2 ± 1.9	9900 ± 900 (feldspars)
Koputaroa dune 2	WLL136	1.56 ± 034	1.20 ± 0.06	1.56 ± 0.38	25.9 ± 3.1	11 300 ± 1400 (quartz)

*Mean ± 1 SD.

Fig. 4 Holocene sea level variations for New Zealand (Gibb 1986). A, Oxygen isotope stages. B, Eustatic sea level variations over the last 140 000 yr from the Huon Peninsula (Chappell & Shackleton 1986). C, Loess stratigraphy: Oh = Ohakean loess, Ra = Rata loess, Po = Porewa loess, Ma = Marton loess (Pillans 1988). D, Loess stratigraphy (Palmer et al. 1988). E, Koputaroa dune phase activity (Duller 1996).



was between 100 and 130 m lower than today (Chappell & Shackleton 1986), which would have resulted in a coastline c. 30 km to the west of the current shoreline (Fig. 4). This led to the suggestion that the Koputaroa dune sand may have originated from the beds of braided rivers. In the Otaki-Te Horo area, the source would have been the Otaki River (Cowie 1963; Fleming 1972). Sedimentological evidence now suggests that this is unlikely (Table 1). Also, the active fluvial processes would have restricted stable sites for dune formation. Although the dunes may have been reactivated and migrated over time, no buried paleosols have been observed in this area. Paleosols, however, have been noted within several of the significantly younger Holocene dune phases.

The lack of sand immediately south of the Otaki River mouth during the Holocene therefore preserved the youngest of the Koputaroa dunes in the study area. Such conditions do not exist to the north where the youngest Koputaroa dunes have been buried by, or incorporated into, the more extensive and larger Holocene dunes. This argument is supported by the fact that at Otaki-Te Horo, the Koputaroa dunes are only 3 km from the coast. North of the Otaki River they are no closer than 5 km from the coast and extend up to 25 km inland.

A definitive statement as to the origin of the Koputaroa dune sand still requires future research. Even detailed analysis of mineralogy and grain roundness (Shepherd 1985) has been inconclusive because of the complicated interacting controls on dune formation. While luminescence ages provide the date of stabilisation, the period of activity is unknown. Multiple phases of sediment reworking are possible, and the final dune deposit is the result of the complex interaction of sediment supply, availability, and transport capacity.

Paleoenvironmental evidence from New Zealand and Australia is consistent with a phase of dune building during $\delta^{18}O$ stage 2. It is unknown exactly when the Koputaroa dunes started forming and were active at Otaki-Te Horo. However, the dates presented here indicate that these dunes stabilised much more recently than previous evidence suggests for their counterparts in the Horowhenua–Manawatu area.

ACKNOWLEDGMENTS

We thank Uwe Rieser of the Luminescence Dating Laboratory, SES, Victoria University of Wellington, for determining the luminescence dates. This research was funded by a URF Grant from Victoria University of Wellington. Anonymous journal reviewers provided comments and suggestions that improved the final paper.

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