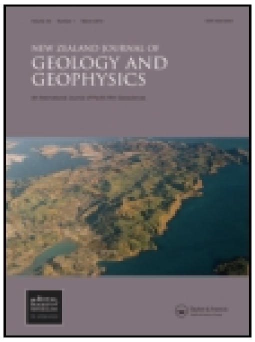

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Holocene alluviation and transgressive dune activity in the lower Manawatu Valley, New Zealand

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with an Appendix

Pollen analysis of two Holocene sites in Manawatu

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Abstract Location of an estuarine bed near Opiki enabled the approximate mid Holocene limit of the Manawatu River estuary to be determined. Since about 6000 years B.P., flood-plain accretion in that area has averaged 1.5 mm/year, although accretion rates may have diminished with time. Two riverbank sections near Rangiotu provide evidence for the initial encroachment of Foxton Phase dunes. Thin sand horizons overlying the former flood-plain surface are identified as eolian veneer deposits, preserved at the rear of former migrating dunes, which constructed sand plains. Radiocarbon dates obtained from interbedded organic material reveal that dunes first entered the area c. 2300 years B.P. with further episodic encroachment until c. 1600 years B.P. As the Foxton Phase dunes had migrated c. 16 km inland there is no absolute date for the commencement of the phase but study of contemporary rates of dune advance suggests that the Foxton Phase may have been initiated at the coast about 5500–6000 calendar years ago.

Attempted correlation of the Foxton dune phase with Australian and New Zealand phases is considered premature owing to insufficient radiocarbon dates and the difficulties imposed by the time-transgressive nature of major dune events.

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Keywords Manawatu; estuaries; Holocene; shells; alluvial plains; accretion rates; sea level; dunes; Foxton Phase; eolian; radiocarbon dating; sand plains; palynology; grain-size analysis

INTRODUCTION

During the Holocene epoch, the lower Manawatu Valley was shaped by a sequence of contrasting geomorphological processes. A period of estuarine deposition initiated by the Postglacial Transgression was succeeded by a phase of fluvial deposition which dominated the subsequent development of the valley. However, to the west, fluvial processes were supplanted by eolian processes as sand dunes migrated inland from the coast. This paper provides new information about the nature and age of each depositional phase, and the origin of eolian beds in two riverbank exposures is examined in detail.

THE ESTUARINE PHASE

Rich's (1959) proposal that an estuary was present in the lower Manawatu Valley during the Postglacial Transgression was confirmed when Hesp & Shepherd (1978) identified estuarine beds of mid Holocene age beneath the flood plain near Shannon.

In 1980, information obtained from a well (grid ref. NZMS 260 S24/147802) drilled in the presence of the writer by H. B. Smith on the farm of G. K. Murray (now owned by R. Funnell) 4 km southwest of Opiki has enabled the approximate northern limit of the mid Holocene estuary to be identified. The borehole, sited on a broad levee of the Manawatu River (Fig. 1), 8 m above mean sea level, penetrated 9 m of fine alluvium before passing through at least 11 m of thinly interbedded silty sand and clay of probable estuarine origin. A shelly facies containing only one species, the mollusc *Austrovenus stutchburyi* (Gray), was present 5.5–8.5 m below mean sea level. The fragile shells showed no evidence of abrasion caused by transportation, and they were considered by A. G. Beu (pers. comm. 1980) to have "lived in the extreme marginal low salinity for the species, in other words near the upper end of an estuary.". Shells from c. 5.6 m

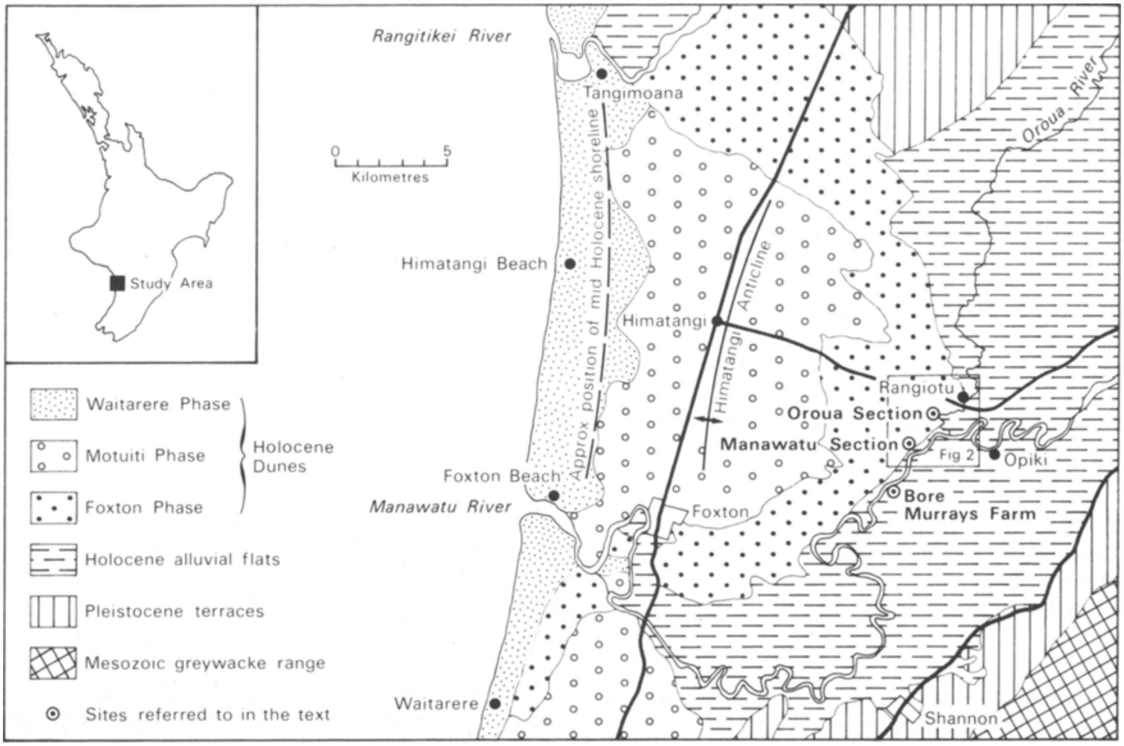

Fig. 1 Geomorphology of the lower Manawatu Valley, showing the location of sites mentioned in the text. Sources: Cowie 1963; Kingma 1962, 1967; Rich 1959.

Table 1 Details of radiocarbon dates obtained by the author (except where otherwise stated) and referred to in this paper (NZA = old half-life; NZB = new half-life; NZC = new half-life corrected for secular effects). All radiocarbon dates supplied by New Zealand Radiocarbon Dating Laboratory.

		Age in years B.P.			
Locality	^{14}C numbers	NZA	NZB	NZC	Material
Shannon*	NZ3085	6150 ± 60	6330 ± 70	-	Shell
Rangitikei River†	NZ3186	4170 ± 60	4290 ± 60	4850 ± 120	Wood
Rangitikei River†	NZ3187	3470 ± 60	3570 ± 60	3840 ± 70	Wood
Murray's Farm	NZ5128	6280 ± 220	6460 ± 230	7110 ± 230	Shell
Manawatu River section	NZ5219	3410 ± 80	3510 ± 80	3730 ± 100	Wood
Manawatu River section	NZ5220	2270 ± 60	2340 ± 60	2380 ± 110	Wood
Manawatu River section	NZ5221	1875 ± 65	1930 ± 65	1860 ± 65	Wood
Oroua River section	NZ4820	1800 ± 65	1855 ± 70	1785 ± 70	Wood
Oroua River section	NZ5215	1595 ± 65	1645 ± 70	-	Peat
Oroua River section	NZ5216	1950 ± 65	2010 ± 70	1945 ± 85	Peat
Oroua River section	NZ5217	1775 ± 65	1825 ± 65	1765 ± 65	Peat

*Collected by P. A. Hesp; †Collected by J. D. G. Milne.

below mean sea level were radiocarbon dated at 6280 ± 220 years B.P. (NZ5218A). (For full details of the ^{14}C dates refer to Table 1.) As the species normally lives beneath lower tidal flats, and as the New Zealand sea level curve was at approximately the present level at that time, Gibb (1983) suggested that this date indicates tectonic downwarping of the area. However, such a proposition should be treated with caution because of uncertainty regarding the reservoir effect and because compac-

Fig. 2 Vertical aerial photograph showing Foxton Phase dunes and sand plains to the west of the Manawatu and Oroua Rivers, with alluvial plain to the east. Location of riverbank sections are indicated. Published with permission of Department of Lands and Survey.

tion in underlying muddy and peaty beds may have lowered the level of the shells since deposition. Near Shannon, 10 km to the south, estuarine beds underlie a thin cover of Manawatu River flood-plain alluvium and extend from at least 3 m below to 1.1 m above mean sea level. Shells *in situ* at the top of the estuarine facies were dated at 6150 $\pm$ 60 years B.P. (NZ3085A, Hesp & Shepherd 1978). Evidence presented above indicates that the estuary extended north to within a few kilometres of Opiki immediately after the Postglacial Transgression. By about 6000 years B.P., the uppermost reaches had probably been infilled whereas further seaward, at sites such as that near Shannon, tidal flats were developing at the margins of the estuary.

THE FLUVIAL PHASE

The phase of estuarine deposition was succeeded by a phase of fluvial deposition. The boundary between the Holocene estuarine facies and the overlying fluvial facies is time transgressive owing to progressive infilling of the estuary. However, the transition to the fluvial phase is now almost complete because the present estuary near Foxton is limited in extent. In the Opiki–Rangiotu area, the head of the former estuary had probably been infilled by about 6000 years B.P. Subsequently an alluvial plain with broad natural levees and backswamps developed.

The borehole at Murray's Farm revealed that 9 m of fine alluvium accumulated in approximately 6000 years: an average vertical accretion rate of 1.5 mm/year. Further evidence for rates of flood-plain accretion is provided at the Manawatu River site (Fig. 2) which is described in detail in the next section. At that location, 1.2 km north of Murray's Farm, a former levee surface about 7.5 m above mean sea level was covered by migrating sand dunes about 2200 years ago. The rate of accretion indicated for the period between 6000 years B.P., when it is assumed that the plain was at mean sea level, and 2200 years B.P. is 2 mm/year. A ^{14}C date of 3410 $\pm$ 80 years B.P. (NZ5219A) was obtained from a small stem of *Podocarpus taxifolia*, probably river driftwood, within the alluvium at a height of 5.5 m above mean sea level. If the wood was not derived from an older deposit, average accretion rates of 2.1 mm/year and 1.6 mm/year can be calculated for the periods 6000–3410 years B.P. and 3410–2200 years B.P., respectively. If similar

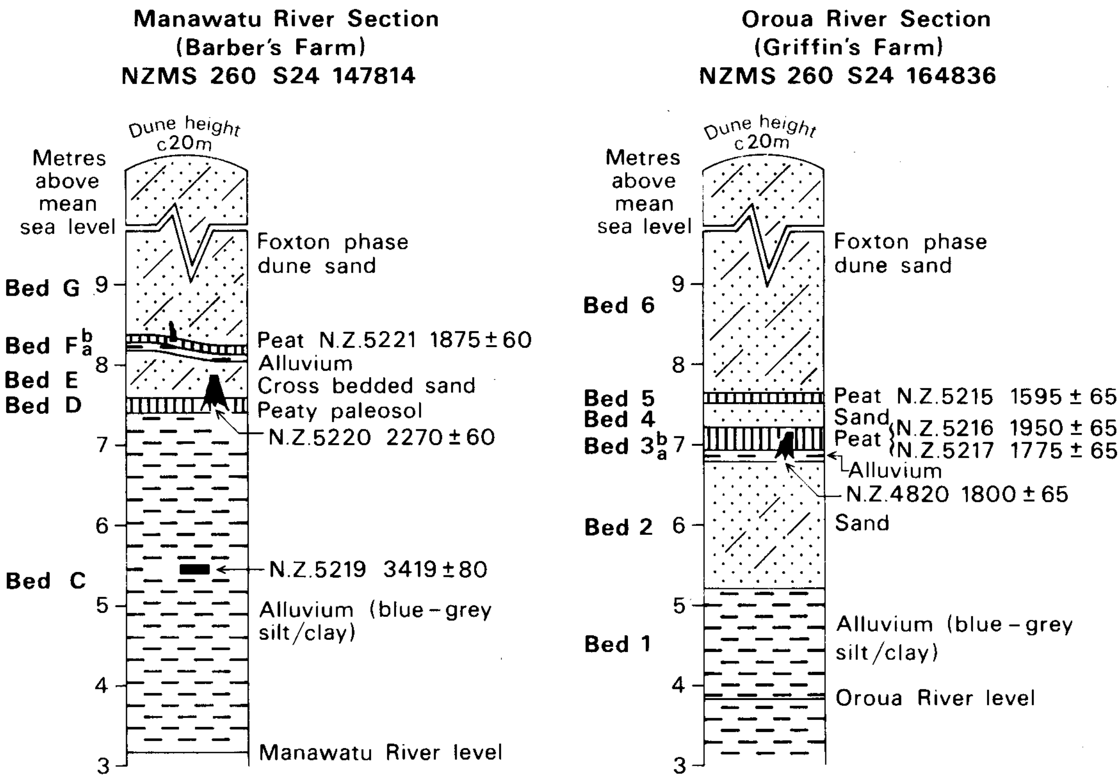

Fig. 3 Stratigraphy of the Manawatu and Oroua River sections. See Fig. 1 and 2 for location.

accretion rates occurred at Murray's Farm during the period 6000–2200 years B.P., a lower accretion rate of only 0.7 mm/year is indicated for the past 2200 years. These figures suggest that in more recent times the broad levees may have increased their elevation above the level of the river channel to such an extent that the frequency of inundation by flood waters, and therefore accretion rates, diminished. This proposition is supported by the fact that the borehole site at Murray's Farm was not inundated by the largest measured flood of the Manawatu River, which occurred in 1952. However, the thin alluvial horizons at 8.2 m and 6.9 m above mean sea level at the Manawatu and Oroua River sections, respectively (Fig. 2), are overbank deposits, indicating that maximum flood levels 1800–1900 years ago were similar to those of today.

Further south, near Shannon, only 1–2 m of alluvium overlies the estuarine beds dated at 6150 years B.P., indicating lower accretion rates of 0.25–0.40 mm/year. This may be related to uplift at the margin of the plain but it is also likely that the diminishing estuary, together with the thickly vegetated pre-European flood plain and swamps, was effective in trapping much of the suspended sediment before it reached the lower southern portion of the flood plain. In much of the lower Manawatu Valley, fluvial processes continued uninterrupted until the period of European settlement when forest clearance, together with swamp drainage and flood control schemes, substantially modified the natural landscape. However, in the western part of the valley, the fluvial landscape was greatly altered by sand dunes encroaching from the west.

THE EOLIAN PHASE

Cowie (1963) identified and described three distinct surges of dune activity which occurred in the Manawatu region during the Holocene. The first advance, termed the Foxton Phase, was the most active with dunes migrating up to 16 km inland from the former coastline. In no other part of New Zealand was Holocene dune activity so extensive.

Two stratigraphic sections at the innermost margin of the Foxton Phase dunes, approximately 19 km from the present coastline, have been exposed at eroding outer bends of meanders of the Manawatu and Oroua Rivers. The first, termed the Manawatu River section, is located 4.5 km southwest of Rangiotu, and the second, the Oroua River section, lies 1 km southwest of Rangiotu (Fig. 1–3).

The Manawatu River section (Fig. 3, 4)

Blue-grey flood-plain alluvium (bed C) extends to about 4 m above the mean level of the Manawatu River. The surface of the former flood plain is covered by a peaty paleosol with remnants of small to medium sized trees in growing position. The outermost rings of a *Dacrycarpus dacrydioides* (kahikatea) tree were dated at 2270±60 years B.P. (NZ5220A). Pollen analysis by C. M. Lees (Appendix 1) indicates that the flood-plain surface was initially vegetated by kahikatea forest, probably similar to the semiswamp forest which covered alluvial flats in the area 100 years ago (Esler 1978). The appearance of pollen of *Myoporum laetum*, a species which commonly grows in dune areas, near the top of bed D may signify the proximity of coastal dunes encroaching from the WNW. It is possible that disruption to flood-plain drainage by migrating dunes caused the waterlogging of the site indicated by the pollen diagrams for the upper part of bed D.

A 40–60 cm bed of well-sorted fine sand (bed E), which is steeply crossbedded in places, separates the flood-plain surface from bed Fa, a 10 cm band of horizontally laminated fine alluvium which is overlain by 10–13 cm of sandy peat (bed Fb). Macrovegetation remains associated with bed F include a small fallen trunk of *Dacrydium cupressinum* and a small *Podocarpus taxifolia* tree in growing position, the outer trunk of which was dated at 1875±65 years B.P. (NZ5221A). Pollen analysis of horizon Fb indicates recolonisation by kahikatea forest.

The uppermost bed (G) consists of c. 12 m of well-sorted, crossbedded, fine dune sand which records the final encroachment of parabolic dunes into this area. The dunes are mapped by Cowie et al. (1967) as Foxton Phase dunes.

The Oroua River section (Fig. 3)

This section is similar in many respects to the Manawatu River section which is 3.5 km to the southwest.

The base of the section consists of blue-grey gleyed alluvium (bed 1) with only a minor organic layer at the former flood-plain surface. No macrovegetation remains were observed but pollen indicative of a swamp environment was present within the organic layer. The alluvium is succeeded by c. 1.5 m of well-sorted fine sand (bed 2) which

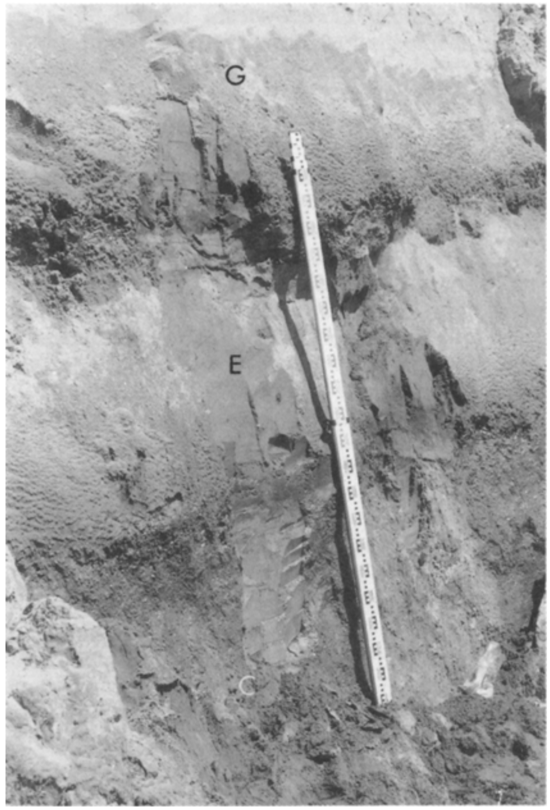

Fig. 4 Manawatu River section. See Fig. 3 for key to beds. Length of staff 2 m.

is crossbedded in places. Bed 3a consists of 15 cm of alluvium which grades upwards into 20–30 cm of peat (bed 3b). Remains of small *Podocarpus totara* and *Leptospermum scoparium* trees, in growing position, together with *Phormium tenax*, are associated with bed 3. A sample of *Leptospermum scoparium* was dated at 1800±65 years B.P. (NZ4820A). Dates of 1950±65 years B.P. (NZ5216A) and 1775±65 years B.P. (NZ5217A) were obtained from the upper and lower peat layers respectively. Although for reasons unknown the two peat dates are not in sequence, the three dates for bed 3 are similar. Pollen analysis indicates that the peat accumulated at a poorly drained, open site with scrub and a few forest elements.

A 0.3 m layer of fine sand (bed 4) separates the peat in horizon 3 from a thinner peat layer (bed 5) which was dated at 1595±65 years B.P. (NZ5215A). No macroplant remains were associated with the peat, and the abundant tree pollen, particularly that of rimu, within the peat may have been background pollen.

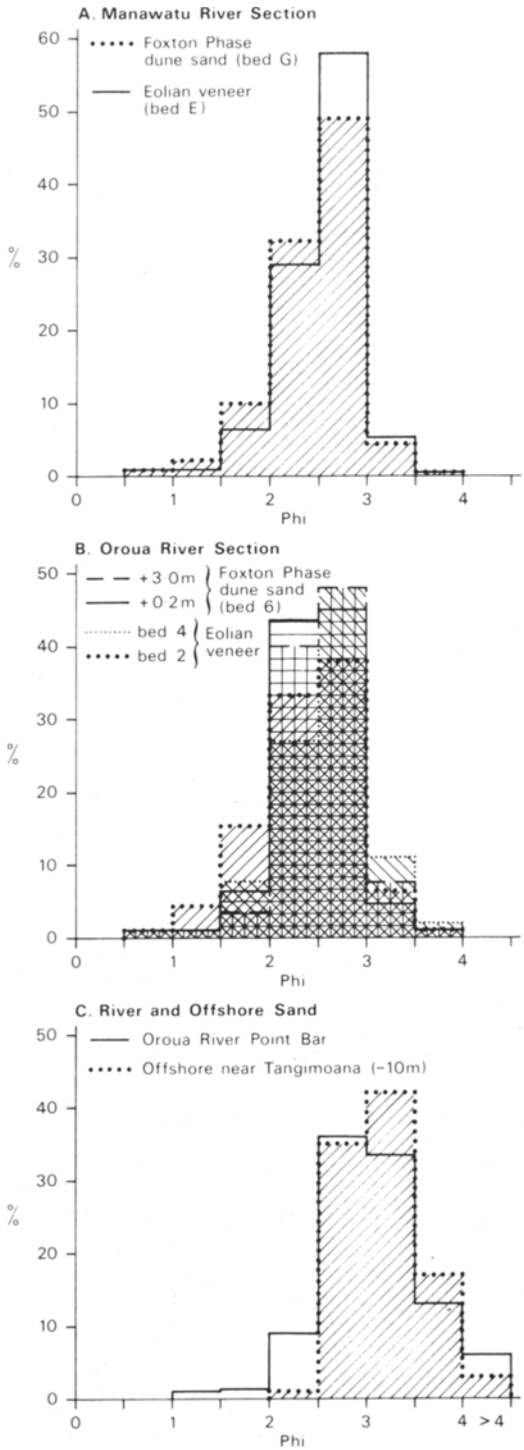

Fig. 5 Similar size distribution of eolian veneer deposits and the uppermost Foxton dune sand (A, B) and of river sand and offshore sand (C).

The uppermost bed consists of well-sorted Foxton Phase dune sand with high-angle crossbedding. The dunes are morphologically similar at both the Oroua River and Manawatu River sites and have been mapped by Cowie et al. (1967) as Foxton Phase dunes with Foxton black sand soils.

Eolian veneer deposits

Whereas the lowermost beds at both sections clearly consist of vertical accretion deposits associated with flood-plain alluviation, and the uppermost beds consist of the eolian sand responsible for the present dune topography, the origin of the thin intermediate sand horizons (beds E, 2, and 4 in Fig. 3) was not immediately apparent. The grain-size distribution, roundness, and heavy mineral content of sand samples from both sites were analysed in order to identify the depositional environment and source of the sand forming those horizons. The results are shown in Table 2.

In most respects sand forming the intermediate horizons is very similar to the uppermost Foxton dune sand. However, it differs markedly from fluvial sand owing to its greater roundness, negligible silt/clay content, and markedly higher heavy mineral content, together with its negative skewness and better sorting. Rounding and heavy mineral content are properties which have been used previously in this area to distinguish dune sand from fluvial sand (Shepherd 1985).

The almost identical size distribution of Foxton dune sand and the intermediate horizons at each site is shown in Fig. 5A, B. The histograms also demonstrate the paucity of very fine sand in the 3–4ϕ range, a fraction which is poorly represented in beach, dune, and surf zone environments in Manawatu. The 3–4ϕ fraction, however, is well represented in river sediment and also offshore at depths in excess of about 15 m where the 3.0–3.5ϕ fraction is often dominant (Fig. 5C). It seems likely that the finest sand particles delivered to the coast by rivers are selectively removed from the beach and surf zones by wave-induced currents and deposited in deeper water further offshore where energy levels are lower. As the Holocene dune sand was derived from the beach, it appears that the 3–4ϕ fraction was deficient at that source.

The presence of high-angle cross-stratification and frosted grains within the intermediate horizons at both sites is also consistent with an eolian origin for those beds.

The process likely to be responsible for the deposition of such thin eolian beds can be recognised by reference to a large mobile transverse dune near Himatangi which the writer has monitored for a number of years. The dune is migrating inland across a sand plain, leaving in its wake a planar deposit of sand, about 0.7 m in thickness, which has resisted deflation owing to its close proximity to the water table. The bare surface of this thin veneer is rapidly colonised by pioneering native grasses which often trap additional sand blown back from the dune to form low ridges. The larger contemporary Manawatu sand dunes would be capable of migrating more than 10 km inland before the deposition of such veneers at their trailing edges would exhaust the sand reservoir. At least some of the extensive sand plains of coastal Manawatu appear to have been built up by the repetition of this constructional process, because beds similar to the eolian veneers described above have been observed to underlie the surface of the plains in several other locations.

For multiple beds of eolian veneer deposits to be preserved, a rising water table would seem to be necessary: this would enable deflation-plain surfaces to develop at successively higher levels.

The Manawatu sand plains, which greatly exceed the area occupied by dune hillocks, have slopes determined by regional water tables. Cotton (1942) and Fleming (1953, p. 43) attributed the even surfaces of such sand plains to erosion, by deflation, to levels near the water table, a process Fleming termed ventiplanation. The mechanism of sand plain formation is erosional, however, only in the sense that material in transportation during dune migration is both deposited and eroded as part of the transportation process. Sand is left behind as a veneer because, during this process, less is "eroded" than deposited.

At the sites of the two sections, there is little doubt that the surfaces of the eolian veneer deposits (beds E, 2 and 4) originated close to former water tables, for they extend no more than 1.5 m above impermeable horizons of alluvium and are overlain by peat.

The grain-size distribution of the eolian veneer deposits is indicative of a depositional environment where a slight excess of coarser grains may accumulate. In Manawatu, negatively skewed sand has been sampled at the leading edge of advancing dunes in locations where coarser grains have preferentially rolled to the foot of the slip faces. With further dune advance such sand becomes incorporated within the basal layers of the dunes and may later emerge from the trailing edge to form the eolian veneers.

CHRONOLOGY OF DUNE ENCROACHMENT

Stratigraphic, sedimentological, and chronological information obtained from the two sections described above has enabled the history of dune encroachment to be determined. By about 2300 years B.P. Foxton Phase dunes, having advanced across the Himatangi Anticline from the west (Fig. 1), had reached the extensive forested flood plain near the junction of the Manawatu and Oroua Rivers. The leading dunes migrated beyond the present position of the rivers but were entirely removed by fluvial erosion at some later stage: in

Table 2 Characteristics of sediment from the Manawatu River and Oroua River sections and from the Manawatu and Oroua Rivers.

Location	Size parameters*				Powers's roundness†	Silt/clay (%)	Heavy minerals‡ (%)
	Mz	σ_I	Sk_I	K_I			
Manawatu River site							
Horizon G, dune sand	2.56	0.38	−0.28	0.96	0.36	trace	2.2
Horizon E	2.49	0.43	−0.27	0.95	0.41	trace	2.3
Manawatu River sand, —various locations	—	generally 0.5–1.0	positive	—	0.28 (av.)	6.2 (av.)	0.7 (av.)
Oroua River site							
Horizon 6 (+11.5 m), dune sand	2.54	0.37	−0.01	0.86	0.34	0.1	n.d.
Horizon 6 (+8.6 m), dune sand	2.49	0.37	−0.08	0.85	0.35	trace	3.1
Horizon 4	2.56	0.48	−0.16	1.16	0.33	0.1	4.9
Horizon 2	2.38	0.53	−0.14	1.00	0.33	0.1	4.3
Oroua River, point-bar near site	3.07	0.57	0.08	1.11	0.28	9.8	0.1

*Samples sieved for 10 min. through sieves stacked at ½ phi intervals. Folk & Ward (1957) parameters.
†Powers's (1953) visual method.
‡Separation using tetrabromoethane (S.G. 2.96).
n.d. = not determined.

their wake, thin eolian veneers were left mantling the flood-plain surface. At least one major flood inundated the low sandy plain, depositing a thin layer of alluvium which impeded drainage. Swamps and forest became established on the plain, enabling a layer of peat to accumulate.

By c. 1800–1900 years B.P. a second series of Foxton Phase dunes had advanced into the area. At the Manawatu River site, this was the final advance, for the dunes became stabilised to form the present topography. However, at the Oroua River site, the dunes passed over and beyond the area for a second time, leaving a second eolian veneer deposit to record their passage. The new sand-plain surface at that site received no further alluvial deposits, either because no major floods occurred or because dunes to the east, which were subsequently removed by fluvial erosion, prevented the incursion of flood water. After a brief period of peat accumulation, this somewhat drier sand plain was finally covered a little over 1600 years ago by the third and final series of dunes to reach the site. Since that time the landscape of Foxton Phase dunes has been stable, apart from fluvial erosion and deposition at the eastern margin, and the later encroachment of Motuiti and Waiterere Phase dunes to the west.

AGE AND INITIATION OF FOXTON PHASE DUNES

No absolute dates have previously been published for Foxton Phase dunes in the Manawatu area but Cowie (1963) estimated the dunes to be 2000–4000 years in age. A minimum age of about 1800 years B.P. was inferred from the stratigraphic position of Foxton Phase dunes beneath Taupo Pumice Alluvium in the lower Rangitikei Valley and from the location of dunes with similar pedogenic development to Foxton Phase dunes landward of the Taupo Pumice dunes in Horowhenua (Cowie 1963). However, Horowhenua dunes are not strictly comparable with most Manawatu dunes because the former seldom migrated far from the coastlines where they originated.

The ^{14}C dates included in this paper indicate that Foxton Phase dunes reached the Rangiotu area about 2250 years ago and continued to encroach for a period spanning more than 600 years until final stabilisation less than 1600 years ago. The occurrence of a number of separate waves of migrating dunes during the Foxton Phase is suggested not only by the stratigraphy discussed in this paper but also by the composite and/or nested nature of many of the Foxton dunes in the Manawatu region. It is unknown whether dune activity during the Foxton Phase was episodic or occurred more or less continuously within the general area. However, the ^{14}C dates do not preclude the possibility that the first two dune advances at the two sites, together with the intervening stable period of peat accumulation, were contemporaneous. Dunes mapped by Cowie et al. (1967) as Foxton Phase dunes occur to the west of the dated dunes, so it is likely that some migration continued after 1595 years B.P. when activity at the Oroua site finally ceased.

Although Foxton Phase dunes appear to have been mobile more recently than hitherto suspected, there are major difficulties in determining the date of initiation of the phase. As the Rangiotu district is located where the dunes reached their maximum inland extent, only the final stages of the Foxton Phase are likely to be recorded by dates from that area. Holocene dunes first encroached into the Rangiotu region about 2250 years ago but, if generated at the coast, must have migrated 16 km inland before reaching that area. It would be possible to determine an approximate age for the initiation of the phase only if the rate of dune migration and continuity of movement were known. Migration rates would have been influenced not only by former windiness but also by the nature of the vegetation covering the surfaces over which the dunes advanced, which would have affected the size and shape of the dunes. The Foxton Phase dunes of the Rangiotu area probably migrated over forest as broad parabolic or transverse dunes (the precipitation ridges of Cooper 1958); in places, narrower parabolic lobes appear to have extended downwind during only the final stages of advance after the dunes had become partially stabilised, in the manner suggested by Pain (1976) for dunes of similar age near Kawhia.

The Manawatu coast provides an environment particularly conducive to dune activity, including an abundant sand supply and a very windy climate. According to records from Ohakea Aerodrome near Bulls, winds capable of initiating sand transport (>16 kph) blow for approximately 33% of the time. The wind resultant vector calculated for sand-moving winds, using the method of Landsberg (1956), is strongly WNW: all dunes in the area are closely aligned to that direction. The beach and dune sands have a mean grain size only slightly larger than that most easily set in motion by wind. These conditions are unlikely to have changed significantly since mid Holocene times.

Holland's (1983) study of coastal blowout dunes between Himatangi Beach and Foxton Beach indicates contemporary migration rates varying between 1 and 200 m/year. The higher rates were recorded when very low dunes migrated across short pasture during a period of exceptionally persistent westerly winds. Perhaps a better guide to the rate at which

Foxton Phase dunes may have advanced is provided by a transverse dune located 3 km inland from the coastline near Himatangi Beach; the dune is migrating across pasture which contains a block of mature pine forest. For the past 22 years, the dune, with a slip face about 6 m in height, has advanced across pasture and low scrub at an average rate of 17 m/year. Where impeded by the forest, the dune has piled up to a height of 15 m and has advanced at only 1.5 m/year. However, much sand is able to bypass the forest which is of limited lateral extent. Consequently, migration rates across a continuous forest are likely to be greater than 1.5 m/year.

Many Foxton Phase dunes attained a height of about 20 m which was probably sufficient to enable advance across native forest. If the advance of 17 m/year for a 6 m dune provides an approximation of mass transport rates in the area, a 20 m dune would advance at $6/20 \times 17 = 5.1$ m/year. This can be compared with an average migration rate of 8 m/year for a dune sheet migrating over low coastal forest near Sydney (Pickard 1972) and rates of 1.5–3.0 m/year for dune advance over forest in Oregon (Cooper 1958). Pickard cited examples of coastal dune migration in Europe ranging from 1 to 24 m/year.

It is clear that average rates of dune migration vary greatly, but the estimated rate of 5 m/year for the advance of dunes over forest in the Manawatu area falls within the range of migration rates encountered elsewhere. If continuous dune encroachment was 5 m/year, Foxton Phase dunes would have required 3200 years to have travelled to the Rangiotu area from the former coastline c. 16 km to the WNW. As the initial encroachment of Foxton dunes into the Rangiotu area occurred about 2380 years ago (NZ5220C), the Foxton Phase would have commenced at the coastline approximately 5580 calendar years ago. In the absence of any precise dating, this figure can only be regarded as a rough estimate.

Some of the uncertainty is reduced if reference is made to a second site, 20 km NNW of Rangiotu, adjacent to the Rangitikei River (NZMS 1 N148/830468). Wood from a tree buried by the first encroachment of Foxton Phase dunes 5 km inland from the former coastline was dated (Milne pers. comm.) at 4170 ± 60 years B.P. (NZ3186A). Using the secular corrected age of 4850 ± 120 years B.P. and a migration rate of 5 m/year we can calculate that the dunes were initiated c. 5850 calendar years ago. This figure is a little older than that calculated for the Rangiotu dunes but, if a slower encroachment rate of 4.5 m/year is assumed for both areas, the dunes at both sites would have been initiated c. 5950 calendar years ago.

Although such a date is older than Cowie's (1963) estimate for the maximum age of the Foxton Phase dunes, it is consistent with dates of 4730 and 5290 conventional ^{14}C years B.P. reported by Fleming (1972) for the oldest Foxton dunes near Waikanae, 60 km to the south, where dune migration was minimal.

A second date from the Rangitikei River site of 3470 ± 60 years B.P. (NZ3187A) (Milne pers. comm.) indicates that the Foxton Phase dunes continued to migrate across the site for c. 700 years. The duration of the mobile phase was remarkably similar to that at the Oroua River site where encroachment continued for 650 years before final stabilisation.

The chronological reconstruction attempted above clearly demonstrates the time-transgressive nature of a major dune phase. It seems highly likely that the stabilisation and pedogenic development of the easternmost Foxton Phase dunes and sand plains may have commenced 3000 years after the dunes first began to migrate inland. It follows that Foxton dunes which did not migrate inland or which advanced only a short distance, such as those which occur near Foxton and Tangimoana and more generally in the Horowhenua region to the south, are likely to be much older than those which encroached far inland.

Correlation of the Foxton Phase dunes

Nearly 200 km to the north, the Paparoa dunes near Kawhia were active well before the Taupo Pumice eruption of c. 1800 years B.P. but were not stabilised until after that eruption (Pain 1976). The dunes developed a soil cover prior to Maori occupation about 800 years ago. Dates for the Foxton Phase dunes cited in this paper support Pain's suggestion that the Paparoa dunes and Foxton Phase dunes may be equivalent in age.

Limited dating in eastern Australia has indicated that dune surges may have occurred at c. 4000 ± 500 years B.P., c. 2000 ± 500 years B.P., and <700–800 years B.P. (Thom et al. 1981). The authors suggested possible climatic causes for episodic dune development. This paper has demonstrated that in locations where dunes have trangressed far inland a period spanning several thousand years may have elapsed between the initiation of a dune phase and its final stabilisation. Although the dated Foxton Phase dunes near Rangiotu fall within the period of the second dune surge suggested by Thom et al., it is more likely that they were initiated about 5500–6000 years ago, with the initiation of Motuiti and Waitarere Phases of Cowie (1963) possibly correlating with the second and third periods, respectively. In the Manawatu area, it is even possible that the easternmost Foxton Phase dunes were still active at a time when the succeeding Motuiti Phase dunes were being initiated at the coast, possibly as a result of the Taupo Pumice eruption c. 1800 years ago.

This clearly demonstrates the difficulty of correlating time-transgressive events. In areas where depositional units (eolian veneers) and dune-plain surfaces are time-transgressive, the identification and correlation of chronozones (McFadgen 1985) may not be possible: episodes of dune activity may continue long after the climatic, or other, events which initiated them, and stable periods of soil formation will commence on the sand plains behind the migrating dunes much earlier near the coast than further inland. Although there is some suggestion that Holocene dune phases may have occurred contemporaneously along the west coast of the North Island and possibly also in Eastern Australia, far more ^{14}C dating is required before correlation can be attempted with any confidence, and even then little precision may be possible. At present it cannot be ascertained whether major dune surges were initiated by purely local factors or whether more general fluctuations in climate or sea level were involved. However, if the major Foxton Phase commenced about 6000 calendar years ago, as suggested in this paper, it seems likely that rapid onshore transport of sediment following the Postglacial Transgression was at least a contributary factor.

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APPENDIX 1

Pollen analysis of two Holocene sites in Manawatu

C. M. LEES

Manawatu River section (Fig. 6 *over page*)

This site contained two organic deposits which were sampled at 10 mm intervals; not all samples were counted. Samples were processed by the standard methods of Faegri & Iversen (1975). The minimum count was 300 grains. The pollen spectra indicate that a forest dominated by *Dacrycarpus dacrydioides* grew on the site. Poor drainage, suggested by the high proportion of Cyperaceae, may have caused the elimination of this forest during the period of deposition of bed D. The coastal species *Myoporum laetum* (Ngaio) is represented by a single grain at the top of bed D. A *D. dacrydioides* forest probably associated with *Beilschmiedia tawa* became established on the site in the period covered by bed F. (The pollen of the latter species is not preserved.)

Oroua River section (Fig. 7 *over page*)

This site contained three organic deposits which were sampled and processed as above. A minimum count of 200 grains was attempted but the pollen was not as well preserved as at the Manawatu site. The pollen spectrum of the basal organic layer (single sample) is impoverished but is dominated by Cyperaceae. A poorly drained open site dominated by Cyperaceae and *Leptospermum* scrub is indicated by the pollen spectrum of bed 3b; some forest elements were probably present. The pollen of this forest element increased during deposition of bed 5 with *Dacrydium cupressinum* and possibly *B. tawa* becoming dominant. The two life-form diagrams presented at the right hand side of the pollen diagrams indicate similar patterns of succession from open swamp scrubland vegetation, which provided suitable conditions for peat accumulation, to a drier more woody vegetation. Mosimann's method of statistical analysis (Mosimann 1965) was used in a computer program to establish the significance of the changes in the pollen spectra. These are indicated on the pollen diagrams.

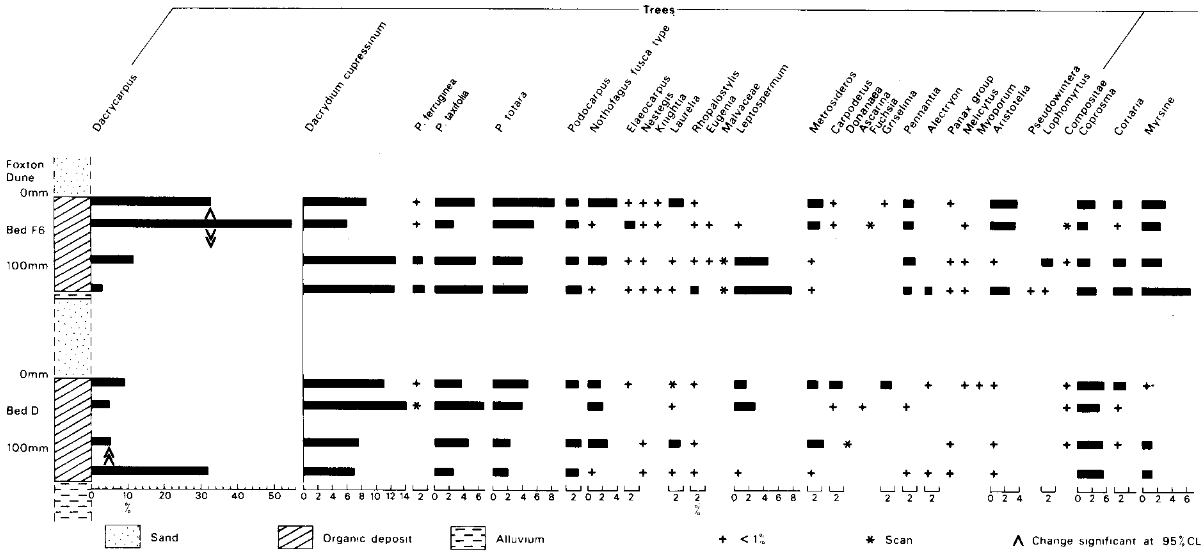

Fig. 6 Pollen diagram from the Manawatu River section (Barber's Farm), NZMS 260 S24/147814.

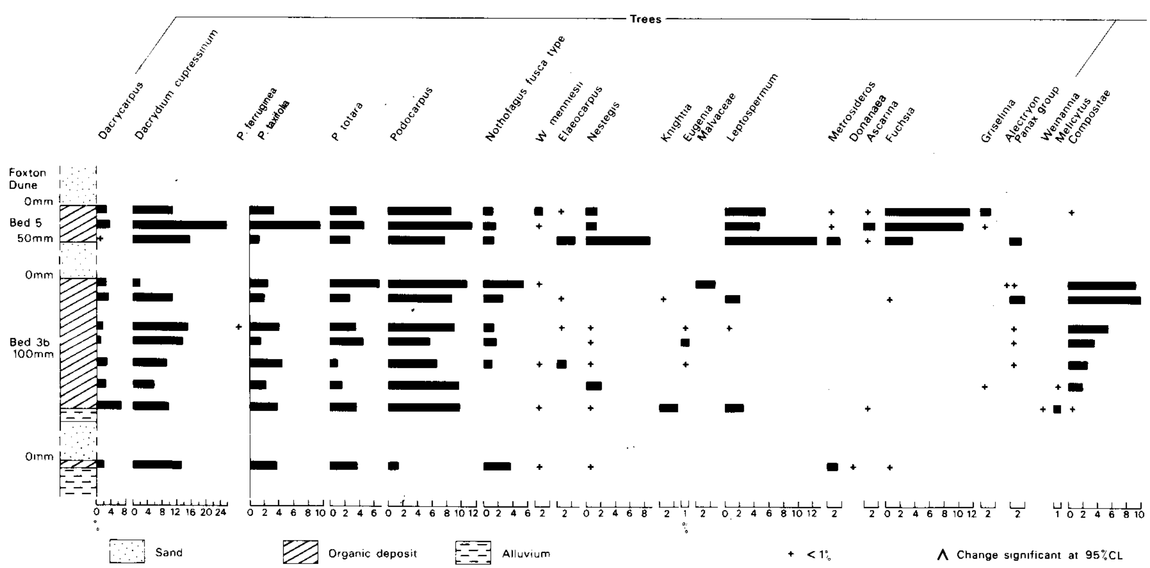

Fig. 7 Pollen diagram from the Oroua River section (Griffin's Farm), NZMS 260 S24/164836.

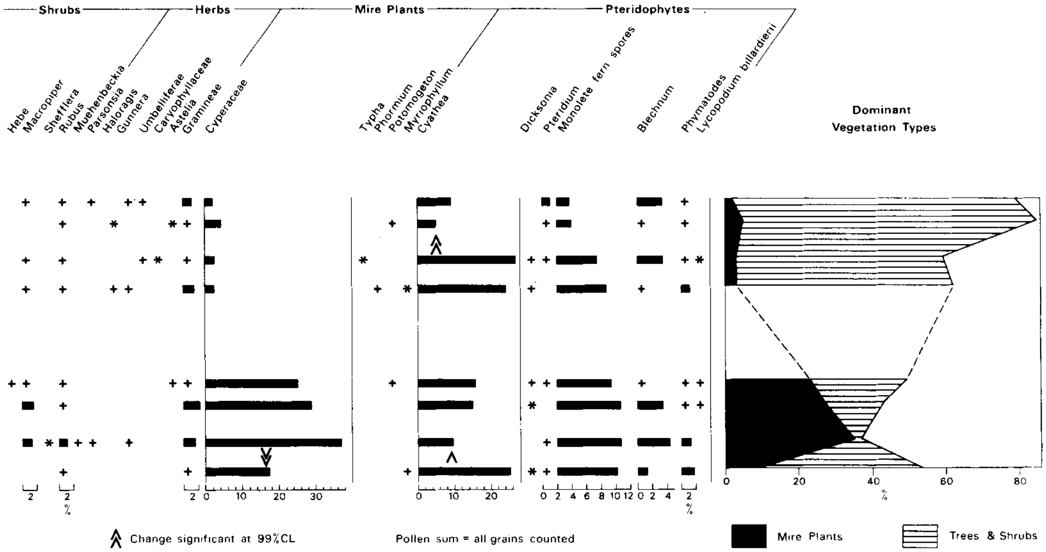

Fig. 6 *(continued).*

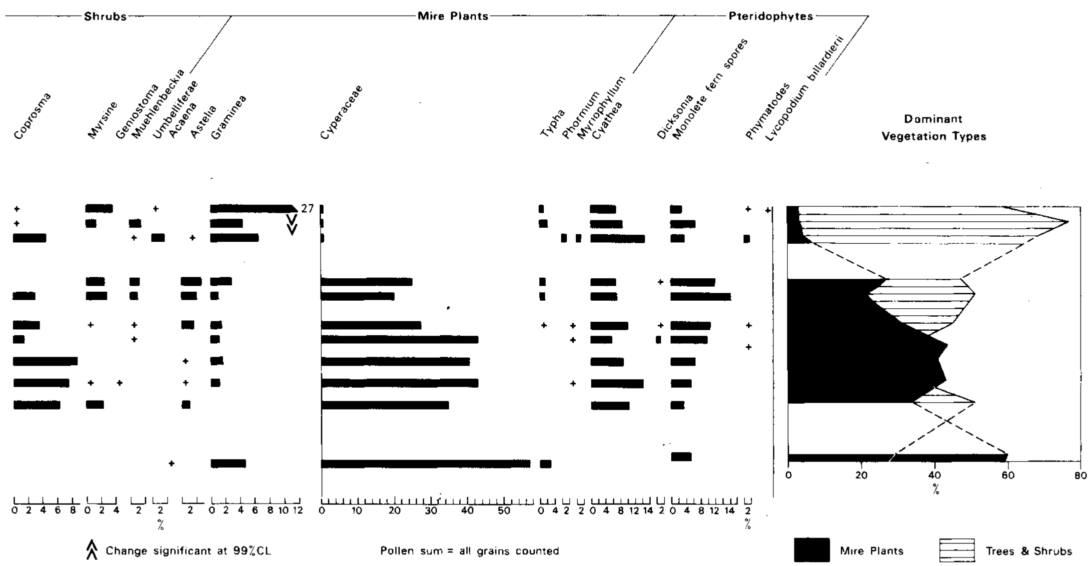

Fig. 7 *(continued).*