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Late Holocene stratigraphy of coastal deposits between Auckland and Dunedin, New Zealand

B. G. McFadgen*

Three chronostratigraphic units based on accumulative deposits and their respective soils are proposed for late Holocene coastal deposits between Auckland and Dunedin, New Zealand: Tamatean Chronozone (*c.* 1,800 to 450 years BP), Ohuan Chronozone (*c.* 450 to 150 years BP), and Hoatan Chronozone (*c.* 150 years to present day). The chronozones represent depositional episodes each consisting of two phases: a high rate of deposition (unstable phase), followed by a low rate of deposition and soil formation (stable phase). Vegetation on soils formed during the stable phases is inferred principally from landsnails recovered from archaeological sites. Forest on Tamatean soil (600 to 450 years BP) advanced almost to the coast in the Manawatu, the southeast Wairarapa, and on the East Coast. Sediment thicknesses measured at sections along the eastern North Island coast show that rates of deposition during unstable phases have decreased during the last 650 years. The depositional episodes appear to be unrelated to sea level changes, tectonic activity, volcanic eruptions or cultural influence. Unstable phases appear to correlate with times of high temperatures, and stable phases with times of low temperatures; it is suggested that the episodes may be related to changes in the frequency of tropical and extratropical cyclones. Inferred climate during unstable phases is windy and dry, and during stable phases, less windy and moist.

Keywords: Sand dunes, soils, alluvium, Holocene stratigraphy, Loisels pumice, Taupo pumice, archaeology, prehistoric vegetation, climate change.

INTRODUCTION

In several parts of New Zealand, late Holocene formations in river alluvium and dune sand have been recognised and named by pedologists. In the North Island the boundaries of the formations have been volcanic deposits (airfall tephra) and soils (*e.g.*, Pullar and Penhale, 1970); and in the South Island, soils only (*e.g.*, Cox and Mead, 1963). At some places the formations can be traced to the coast where there are layers of identifiable sea-rafted pumices (Wellman, 1962b). The pumices, which occur extensively in the North Island, are valuable for correlation, particularly along the North Island east coast. The soils are the most widely distributed features for correlation, and are of two kinds: buried soils and ground soils. They are found in both the North and the South Islands, and are considered to mark rhythmic climatic changes.

The soils and pumices are best exposed in *sections* cut by marine and river erosion. In its simplest form a section is a near-vertical exposure a few metres high, often along a coastline or river bank. Its meaning is extended here to include a generalised section determined from several exposures, including dug holes. Most sections are through coastal deposits younger than 6,000 years (*i.e.*, deposited since the end of the post-glacial eustatic sea level rise), and places where the record for the last 2,000 years is between 2 m and 5 m thick give the best sections. Ideal sections contain alternating fluvial, aeolian and marine deposits, sea-rafted pumice of known age, buried soils, and remains of human occupation.

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Occupation remains of stratigraphic importance are shell middens, occupation layers and artifacts. The *middens* vary from scattered shells to extensive layers of food refuse, which include shells and animal bones, generally with charcoal and oven stones. *Occupation layers* are Maori occupation remains not sufficient to be called middens and are generally traces of charcoal, rarely with associated oven stones, but more extensive than middens. The most important *artifacts* are European, since their known date of introduction and rapid spread throughout New Zealand make them useful for correlation.

Two kinds of soils are recognised. Their difference depends on relative rates of soil development and sediment accumulation: they are *ground soils* (Ruhe, 1969) when they are part of the present land surface; and *buried soils* when part of a past land surface. The simplest case of a soil stratigraphy for accumulating layers is shown by Fig. 1. Deposition rates range from high to zero, but with negligible erosion. A soil forms when sediment accumulation is slower than soil formation, and is buried when sediment accumulation is faster than soil formation.

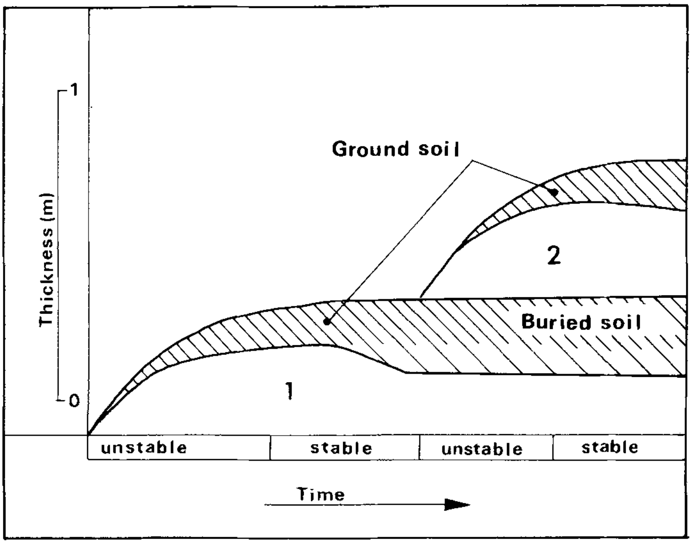


Fig. 1—A time-thickness diagram for sand dunes and fans showing two depositional episodes. In each episode, deposition was at first rapid and then slowed to zero. Soil development began when the first period of deposition slowed down, and ended when the second period of deposition began. A soil is first a "ground" soil, and may become a "buried" soil. Periods of rapid accumulation and little soil formation are termed "unstable" phases; periods of slow accumulation and appreciable soil formation are termed "stable" phases. The thickness represented is generally more than one metre.

A time of high sediment accumulation is called here an *unstable phase*, and a time of soil formation, a *stable phase*. The relative length of an unstable phase to a stable phase is highly variable. Continued deposition need not occur throughout an unstable phase. For some sand dune areas and fans, it is the continual reworking of deposits that prevents soil formation.

Deposits are layers, and in vertical section they commonly exhibit sedimentary character and, by reason of their bedding (size, shape and orientation of their components), are often contrasted with soils. Soils exhibit *layering*, but their sedimentary character is often obscured by past or present biological activity and pedogenic processes. These layers, called *soil horizons*, have formed *in situ* and are therefore not deposits, and I have not considered them here as layers. A soil is recognised by its organic content, structure and, usually, its dark colour (Appendix 1).

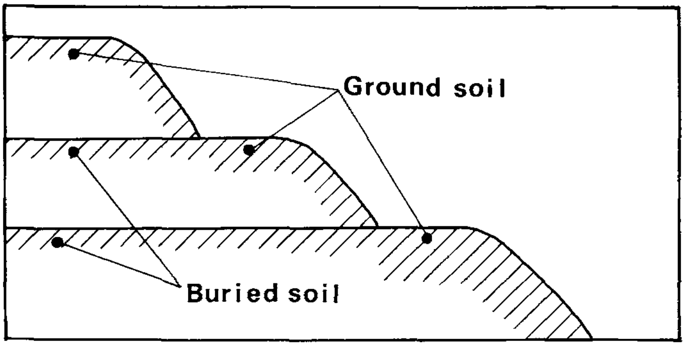


Fig. 2—Idealised cross-section of three partly overlapping layers each with its own ground soil. The boundary between layers is shown by buried soils. Ground soil development is greatest on the oldest layer. The degree of soil profile development is shown by depth of cross-hatching.

A soil horizon is a zone approximately parallel to the land surface on which it formed. Soils that have been forming for a short time show little soil development, but soils that have been forming for a long time may show several soil horizons: a top horizon (topsoil); a middle horizon (subsoil); and a lowermost horizon. The topsoil and subsoil must have properties induced by soil processes, but the lowermost horizon may not. The degree of soil profile development indicates the approximate age of the underlying deposit if it is a depositional landform (Fig. 2): younger soils have only a topsoil, whereas older soils also have a recognisable subsoil. A contrasting situation is a sequence of river terraces cut into old gravels so that soils are younger on lower terraces. Here, degree of soil development dates terrace surfaces, but not underlying deposits, because they are erosional landforms.

All soils in this account have a topsoil, and define the ground surfaces on which the prehistoric Maori lived. Where occupation has been intensive, topsoil development may be obscured by occupation remains, *e.g.*, by shells, charcoal or ovenstones, but in such cases the topsoil can usually be recognised by following the occupation layer laterally until the shells *etc.* are no longer abundant.

The time represented by a section is partly that of sediment deposition, and partly that of soil formation. For sediments the passage of time is represented by layers: the top is younger than the bottom. For soils, passage of time is represented by degree of soil formation: soil horizons develop within the sedimentary layers, and the top is not necessarily younger than the bottom.

The important sea-rafted pumices are Taupo pumice (1,800 years old; Healy *et al.*, 1964), and Loisels pumice (*c.* 650 years old; McFadgen, 1982). They are found in sections both as primary and secondary (reworked) deposits. Primary deposits are the lowest in a section, are the thickest layers, and include the biggest lumps.

Taupo pumice was erupted from near Lake Taupo and is part of the Taupo Pumice Formation (Healey *et al.*, 1964). It occurs on all North Island coasts except North Auckland, and in the northern South Island. It is found in sand dunes as lapilli-like granules, and in beach deposits as exceptionally large pieces up to 0.5 m. It is recognised by its light yellowish-brown colour and coarse irregular gas cavities, is easily broken, and can often be crushed in the hand. Primary deposits are well below the earliest evidence of human occupation.

Loisels pumice, first recognised by Wellman (1962b), occurs only along the eastern North Island coast and at the extreme north of the western North Island coast (Fig. 3). It is most abundant at the extreme north. In addition to the localities given by Wellman (1962b), I have found the pumice along the southeast Wairarapa coast between Flat Point

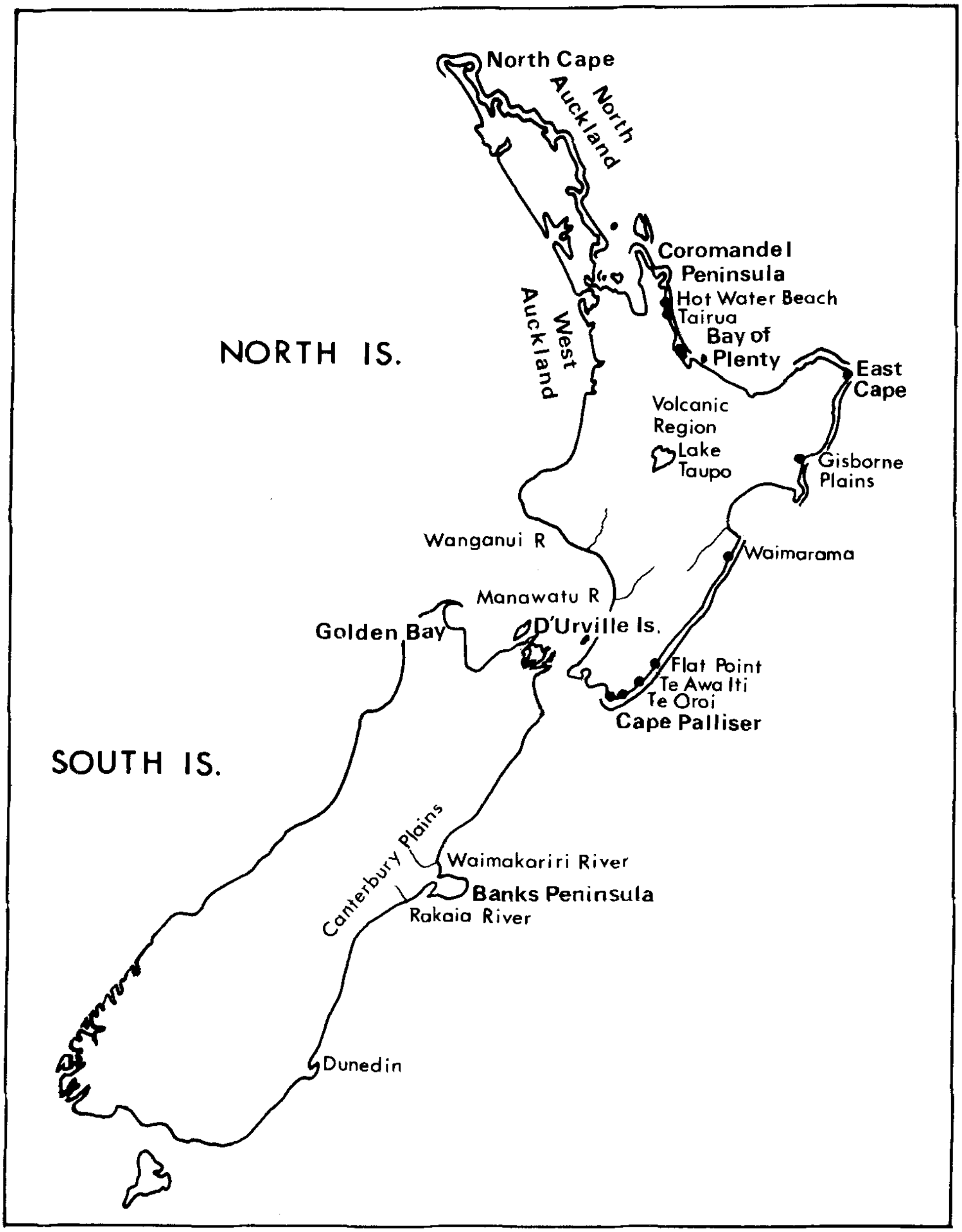


Fig. 3—Map of New Zealand showing distribution of Loisels pumice (heavy line) and localities of particular interest to late Holocene stratigraphy.

and Cape Palliser, and just west of Cape Palliser at the base of Wellman's (1962b) Kupe's Sail section. Its distribution suggests an origin outside New Zealand, possibly in Melanesia. It is entirely different from the Taupo pumice, and is recognised by its grey colour with black bands and fine gas cavities. It is strong, and difficult to crush in the hand. Primary deposits are usually just above the earliest evidence of human occupation.

LATE HOLOCENE CHRONO-STRATIGRAPHIC UNITS

The two pumices are overlain in many sections by three soils, two buried and one at the ground surface. The buried soils appear to be unrelated to any special events recorded in the sections themselves, such as tectonic uplift, volcanic eruptions, or vegetation clearance by man, and are thought to have been caused by changes in climate. The occurrence of sea-rafted pumice, tephra layers, radiocarbon dates, and European artifacts, make it likely that the two buried soils are nearly synchronous over the greater part of coastal New Zealand.

For the last 1,800 years, there are three deposits each overlain by one of the three soils. Each deposit with its soil is considered to be a chrono-stratigraphic unit (Hedberg, 1976), each unit representing a phase of deposition (unstable phase) followed by a phase of soil formation (stable phase). The units are named from old to young: the Tamatean*, Ohuan and Hoatan* Chronozones.

Chronozone names are applied to the soils and to the deposits in which the soils have formed. A buried soil and its groundsoil counterpart thus have the same name, qualified by the adjectives "buried" or "ground" as appropriate. Although this nomenclature is stratigraphically convenient, it should be noted that whereas the name of a deposit refers to the age of the deposit, the name of a soil refers to when the soil began forming.

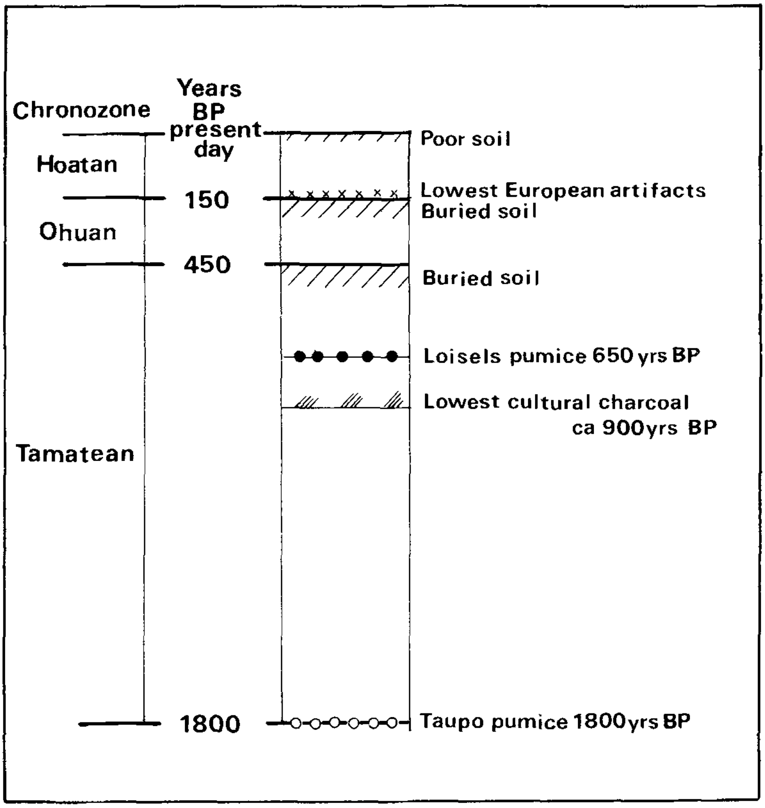


Fig. 4 — Idealised section showing late Holocene soils and the Loisels and Taupo pumices. Inferred ages in calendar years ago.

* Tamatean replaces Tirean, and Hoatan replaces Hunan (McFadgen, 1981) in order to avoid confusion with like-sounding names already in use. The names, adopted from Maori lore, are nights of the moon's age (Williams, 1975).

Ages and criteria used to define the chronozones are shown as an idealised section by Fig. 4. Stratigraphic boundaries are the tops of the two buried soils. Approximate dates for the start of the Ohuan and Hoatan Chronozones are inferred from historic dates, the occurrence of European artifacts, and corrected radiocarbon dates: the Ohuan began about 450 years ago; the Hoatan about 150 years ago.

I have recognised these chronozones in late Holocene deposits in the area between Dunedin in the South Island and Auckland in the North Island (Fig. 3), but do not know if they occur throughout New Zealand. The type locality is here defined at Flat Point, Wairarapa.

RADIOCARBON DATES

Radiocarbon dates are extremely important for dating the chronozones, but not all dates are equally good. The best dates for a deposition or soil formation would be those made directly on samples killed by those events (*i.e.* "close" dates; McFadgen, 1982). Soil formation, however, does not cause death, and samples killed by deposition are rarely found; the chronozones are therefore indirectly dated by using "maximum" and "minimum" dates (McFadgen, 1982) from samples below and above the deposits and soils, that is, by "bracketing" (McFadgen, 1982).

A sample stratigraphically younger than a layer gives only a minimum date for the layer if its "inbuilt age" (McFadgen, 1982) is small. Inbuilt age is the time lapse between the date a sample died and the date it was deposited where it was found. Midden shells which have not been reworked have a negligible inbuilt age and provide good minimum dates. Wood and charcoal, however, can have an inbuilt age of several hundred years if the centre of a long-lived tree is dated, and unless the wood or charcoal is identified as having come from twigs, small branches, outside rings, or a short-lived tree, its inbuilt age is unknown and possibly large. Because the phases of deposition and soil formation described here are short compared with the possible inbuilt ages of many New Zealand trees, dates on unidentified wood or charcoal from stratigraphically above a layer are not used as minimum dates.

An exception may be made if the wood or charcoal used to date a soil comes from a tree which grew in that soil. Regardless of whether or not its inbuilt age is known, the sample gives a minimum date for the start of soil formation (McFadgen, 1982).

Unidentified wood and charcoal give maximum dates when they come from stratigraphically below the layer being dated, providing they are not from the roots of trees which grew on a later ground surface.

The buried soils were ground surfaces on which the prehistoric Maori lived, and more than three quarters of the dates used in this paper are from archaeological samples: midden shells, moa bones, charcoal and wood. More dates than listed here were generally available from any one site, but for dating the chronozones the critical dates are the youngest maximum dates and the oldest minimum dates, and only those dates within a bracket width of 700 years are used. Dates are averaged if they are on the same kind of material with a negligible inbuilt age, date the same archaeological event, and are not statistically different. The formula used is that given by Ward and Wilson (1978) for Case II samples.

Dates reported by the radiocarbon laboratories are converted to calendar years following the procedures described in McFadgen (1982), and are expressed as a 95% confidence interval in years BP (1950). Dates suffixed "A" are uncorrected; dates suffixed "B" are on marine mammal bone and are corrected for half-life by multiplying by 1.03; dates suffixed "C" are on wood, charcoal or moa bone and are corrected for secular variation in atmospheric radiocarbon and for half-life using Clark's (1975) curve; dates suffixed "D" are on shell and are corrected for half-life by multiplying by 1.03, and for change in the marine shell standard by subtracting 55 years (McFadgen, 1978).

TYPE LOCALITY, FLAT POINT, WAIRARAPA

At Flat Point, aeolian sands form a belt about 1 km wide across the Holocene bench

(Fig. 5), and extend for more than 6 km to the south. Ground soils show three different stages of profile development, and it is inferred that sand accumulated in three distinct phases, at different times, each followed by a phase of soil formation. The youngest sand is overlain in places by water-deposited silt. The three different sand accumulations, their associated soils and the silt, are the type deposits of the Tamatean, Ohuan and Hoatan Chronozones.

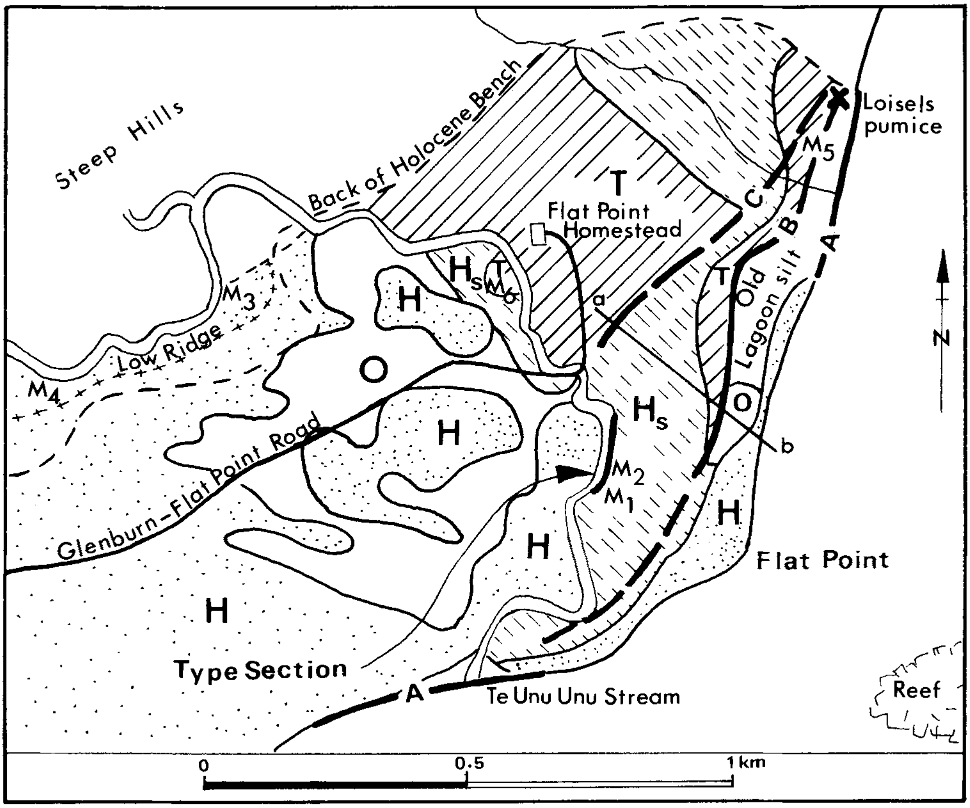


Fig. 5—Sketch map of Flat Point area drawn from air photographs. "A", "B" and "C" are the youngest of 5 beach ridges; "A" is the growing beach ridge. Aeolian sands belong to three depositional episodes: H = Hoatan; O = Ohuan; T = Tamatean. H_s = Hoatan silt. Six middens are mapped as M1 to M6. Line "a-b" is cross-section (Fig. 6).

North of the Te Unu Unu Stream (Fig. 5), raised beach ridges indicate that Flat Point is being uplifted. Beach ridges immediately south of the stream are obscured by sand dunes. The growing beach ridge and the two youngest uplifted beach ridges (A, B and C; Wellman, 1971) are shown in Fig. 5. Loisels pumice lies along the outer edge of Beach Ridge B just below the crest, and Taupo pumice lies behind Beach Ridge C south of Flat Point (Wellman, 1971).

Beach Ridge B was thus uplifted after the Loisels pumice was deposited, and Beach Ridge C after the Taupo pumice was deposited.

A cross-section exposed in the left bank of the Te Unu Unu Stream between beach ridges B and C (Section 1) is 2 m thick and 200 m long. A description of each unit exposed in the section follows.

*SECTION 1: On left bank Te Unu Unu Stream, Flat Point, the type locality for the three late Holocene chronozones (T27/581919)**.

	metres
Hoatan Chronozone	
Dull yellow silt loam soil	0.25
Yellow silt with thin bands of blown sand	0.45
Grey slightly silty sand	0.10
Ohuan Chronozone	
Brownish-black sand (topsoil) with charcoal and occasional shells. Pieces of iron, chinaware and red brick on the upper surface	0.15
Grey sand	0.26
Tamatean Chronozone	
Brownish-black sand (topsoil) with occasional charcoal, shell and bone	0.15
Brown sand	0.65
A lens of charcoal-blackened sand and oven stones in Tamatean sand about 20 cm below the Tamatean topsoil immediately behind Beach Ridge B	0.25
Brown sand same layer as above	0.45
Stream gravels	0.50

A soil description of the section is given in Appendix I.

The oldest cultural remains are below the Tamatean soil in the stream section. There are shell middens among the sand dunes, on the Tamatean and Ohuan soils. A generalised cross-section at right-angles to the coast is shown in Fig. 6.

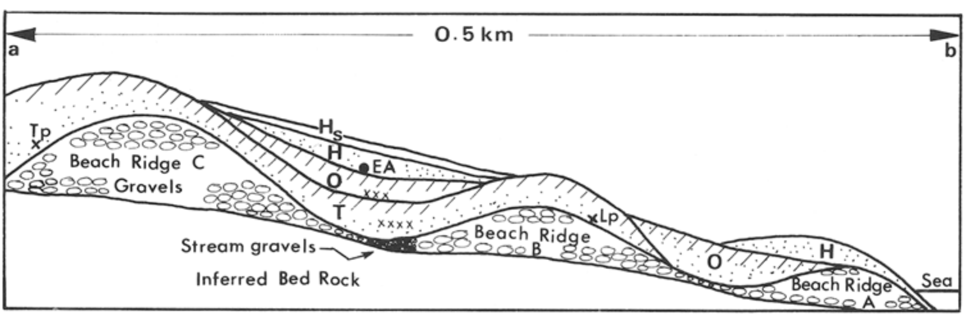


Fig. 6—Generalised cross-section along line "a-b" in Fig. 5. Symbols as in Fig. 5. "xxx" = midden layers; Tp = Taupo pumice; Lp = Loisels pumice; EA = European artifacts. Soils shown cross-hatched.

Tamatean sand overlies beach ridges B and C. It contains primary sea-rafted Taupo pumice, and thus began accumulating before the Taupo Pumice eruption. Dunes are subdued and rounded. Tamatean ground soil has a well-defined topsoil and a poorly-defined subsoil. A representative profile is:

Topsoil:	0.12 m	black to brownish-black (10YR2/1-2/2) sand; weakly developed coarse and medium blocky structure; few roots; diffuse boundary.
Subsoil:	0.30 m	brown (10YR4/4) sand; single grain with few very weak aggregates; loose; diffuse boundary.
	on:	dull yellowish-brown (10YR4/3) sand; loose.

* Grid reference is based on the metric grid of the 1:50,000 topographical map series NZMS260.

Tamatean soil is younger than the uplift of Beach Ridge B and is thus younger than the Loisels pumice.

Ohuan sand is behind Beach Ridge A (Fig. 6). Further inland it overlies Tamatean soil. Dunes are more hummocky and less subdued than Tamatean dunes. Ohuan ground soil has a reasonably well-defined topsoil, but no subsoil, and is a brownish-black sand 10 cm thick over loose dark grey-yellow sand. European artifacts are found on the surface of the buried Ohuan soil.

Hoatan sand extends inland from the foreshore and is interbedded with silt. It overlies Ohuan and Tamatean soils and European artifacts. Hoatan dunes are both mobile and fixed. Elongated isolated dunes, aligned southeast-northwest, are separated from the sea by a near continuous foredune. They include sand from the coast and from eroded Ohuan and Tamatean dunes. Hoatan ground soil on sand is a thin layer of plant litter. On silt it is a dull yellow silt loam without appreciable darkening.

The following table summarises the relationship between the chronozones and dated events at the type locality:

Chronozones	*Event*
Hoatan unstable phase	—
Ohuan stable phase	Oldest European artifacts (150 years BP)
Ohuan unstable phase	—
Tamatean stable phase	—
Tamatean unstable phase	Loisels pumice (650 years BP) Taupo pumice (1,800 years BP)

RECOGNITION OF CHRONOZONES ELSEWHERE IN NEW ZEALAND

The following account includes the North Island south of Auckland, the northern South Island and the South Island east coast as far south as Dunedin. Sites are described in clockwise order from Flat Point, as follows: the southeast Wairarapa coast, the South Island east coast, Golden Bay, D'Urville Island, the southwest North Island coast, west Auckland, the Coromandel Peninsula, the Bay of Plenty, and the East Coast.

Southeast Wairarapa Coast

At Te Awa Iti, on the coast 33 km southwest of Flat Point, I examined two good sections (2 and 3). Here there is exposed:

SECTION 2: On right bank of small stream 4 km north of Oterei River, Te Awa Iti (S28/284688).

Hoatan Chronozone	metres
Dull yellow-brown silt loam soil	0.15
Dull yellow-brown stream alluvium	1.00
Ohuan Chronozone	
Brownish-black gravelly silt loam (topsoil) with charcoal, shells and heat fractured stones. European artifact on upper surface	0.10
Dull yellow-brown stream alluvium	1.40
Tamatean Chronozone	
Greyish-yellow-brown gravelly silt loam (topsoil) with charcoal, shells (radiocarbon dated), fishbones and heat fractured stones	0.25
Dull yellow-brown stream alluvium	0.30+

A stream at Te Awa Iti has built a fan across the Holocene bench (Fig. 7), and has cut down exposing Section 2 deposits in its right bank. The fan is composed mostly of fluvial deposits which, at the coast, are interbedded with beach deposits. The lowest fluvial deposits, exposed by digging, are more than a metre below high water mark and are overlain by a metre thickness of lagoon muds. The lagoon muds contain primary Loisels pumice and secondary Taupo pumice at their base (Section 3), and are overlain directly by Ohuan sediments. There is no primary Taupo pumice.

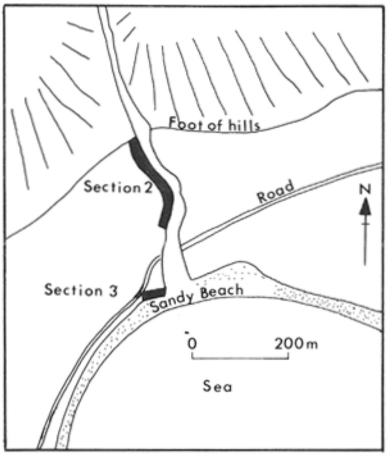


Fig. 7 — Location of sections 2 and 3 at Te Awa Iti.

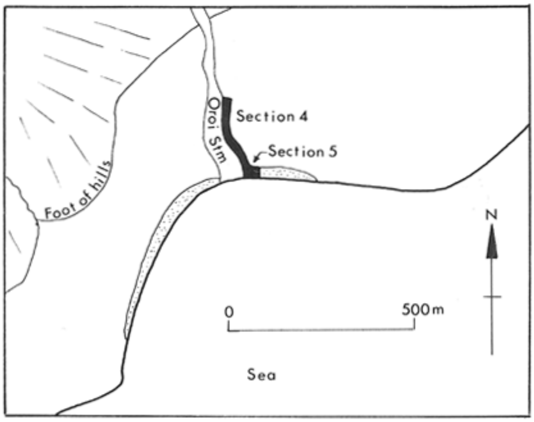


Fig. 8 — Location of sections 4 and 5 at Te Oroi.

SECTION 3: At coast, south side of mouth of small stream 4 km north of Oterei River, Te Awa Iti (S28/284686).

	metres
Hoatan Chronozone	
Silty sand with poor soil	0.20
Fine and medium beach gravel	0.10
Ohuan Chronozone	
Buried soil	0.15
Fine and medium stream gravels	0.20
Fine stream gravels and coarse sand	0.15
Fine silty sand	0.15
Fine gravels and silt	0.20
Tamatean Chronozone	
Blue-grey mud with charcoal	1.00
Blue-grey mud with Loisels pumice, Taupo pumice and charcoal	0.10
Sand	0.05
Stream gravel	0.20+

The Tamatean and Ohuan soils at Te Awa Iti are reasonably well defined in Section 2, but the Ohuan soil only is present in Section 3. Both buried soils contain shell midden near where the stream flows from hills behind the Holocene bench, and a piece of iron was found on top of the Ohuan buried soil in the left bank of the stream. A radiocarbon date for rocky shore shells from the midden on the Tamatean soil (Section 1) is 485 to 245 years BP (NZ 1874D, Table 1).

At Te Oroi (Fig. 3), on the coast 18 km southwest of Te Awa Iti, Section 4 is exposed in the left bank of the Oroi Stream (Fig. 8).

SECTION 4: Left bank Oroi Stream, Te Oroi (S28/149589).

Hoatan Chronozone	metres
Stream gravels and silt with poorly developed soil	0.80
Ohuan Chronozone	
Dark brown silt loam (buried topsoil) with charcoal and shell, changing downstream to a thin silt band	0.50
Brown sandy silt with occasional shells and charcoal	0.25
Tamatean Chronozone	
Dark brown gravelly silt loam (buried topsoil) with charcoal and shells, merging downstream with silty gravel overlying silt	0.10
Stream gravels and silt with occasional charcoal, shells and bone	0.60+

Te Oroi Section 4 extends continuously for 100 m back from the coast and is mostly fluvial deposits which interfinger with beach deposits near the coast. Section 5 was uncovered by digging at the coast near the stream mouth.

SECTION 5: North side of mouth of Oroi Stream (dug out) (S28/150588).

Hoatan Chronozone	metres
Windblown sand, iron at base	0.50
Ohuan Chronozone	
Shell midden in top of gravelly topsoil	0.03
Gravelly topsoil	0.25
Silt	0.25
Tamatean Chronozone	
Sandy soil with charcoal, Loisels pumice at base	0.30
Brown sandy lagoon mud	0.50+

East Coast South Island

On the coast between the Kowhai River and Banks Peninsula in the South Island, 290-320 km southwest of Te Oroi, is a wide belt of unstable and fixed dunes (Figs. 9 and 10). Unstable dunes are nearest the sea and are more widespread north of the Waimakariri River mouth than south.

According to Kear *et al.* (1967) and Raeside and Rennie (1974), there are two degrees of soil profile development on the fixed dunes: Waikuku soils (more developed), and Kairaki soils (less developed). Waikuku soils are further inland than Kairaki soils. I have not examined the dune belt, but I infer three ages of dunes named Waikuku and Kairaki (from the soils developed on each), and Modern dunes, which are unstable.

At Hohoupounamu, 12 km south of the Kowhai River (Fig. 9), there is an archaeological site (S76/7)* with three occupation layers (M.M. Trotter, *pers. comm.* 1984) situated on Waikuku dunes. The earliest occupation layer was deposited on a loamy soil formed on sand containing a burnt totara tree root, and was buried by a metre-thick layer of sand containing the two later occupation layers. Shells from the earliest occupation layer have a radiocarbon age of 570 to 370 years BP (NZ 1375D, Table 1), and shells from the second occupation layer, an age of 340 to 200 years BP (mean of NZ 1158 and NZ 1159, Table 1).

The hills of Banks Peninsula, formed of volcanic rock, are flanked by a discontinuous narrow belt of dunes (Fig. 10). At Redcliffs, immediately south of the Avon-Heathcote estuary (Fig. 10), the dunes are Waikuku. Haast in 1874 found a layer of blown sand on Redcliffs Flat and in Moa-Bone Point Cave separating his Moahunter from his

* NZ Archaeological Association Site number.

Table 1 – Radiocarbon and other dates used to define ages of chronozones. Stratigraphic positions of samples given by authors listed. Previously unpublished dates are shown by an asterisk. In this table dates suffixed A are uncorrected; dates suffixed D are corrected marine shell dates; dates suffixed C are corrected charcoal or moa bone dates. Method of correction set out in McFadgen (1982). Maximum dates for the beginning of events indicated >; minimum dates <; and close dates =. "Unusable" dates (McFadgen, 1982) not listed. T_u = Tamatean unstable phase, T_s = Tamatean stable phase, &c.

NZ Number	Date Years BP (1950)	Significance	Locality	Author	Sampled Layer and Sample
Radiocarbon dates					
86 A	940 ± 70	$>T_s$	Waimakariri River	Cox and Mead (1963)	Wood in Waimakariri alluvium (T_u).
C	1,080 – 710				
293 A	855 ± 50	$>T_s$	Manawatu sand plain	Cowie (1963)	Wood 90 rings in from outside of a tree rooted in Foxton soil and overlain by Motuiti sand. Tree thought to have been killed by advancing Motuiti sand.
C	960 – 650				
312 A	735 ± 55	$>T_s$	Waimakariri River	Cox and Mead (1963)	Wood in estuarine silt below Waimakariri alluvium.
C	850 – 570				
432 A	< 200	$>O_s$	Waimakariri River	Cox and Mead (1963)	Wood (kanuka) in Selwyn alluvium.
C	< 300 – 440				
481 A*	680 ± 67	$>O_u$	D'Urville Is., Greville sand bar, section D	Wellman (1962a)	Charcoal from outside of a prostrate charred log in lower occupation layer on top of lower buried soil. Associated with charred tree roots.
C	780 – 535	$<T_s$			
482 A*	570 ± 90	$>O_u$	D'Urville Is., Greville sand bar, section B	Wellman (1962a)	Shells from lower occupation layer, part of lower buried soil.
D	715 – 355				
483 A*	< 200	$>H_u$	As for NZ 482	Wellman (1962a)	Shells from upper occupation layer.
	< 200 – 300				
595 A	443 ± 40	$>O_u$	Tairua, Coromandel Pen.	Smart and Green (1962)	Charcoal from oven in lower occupation layer (Layer 2) in buried soil (Site N44/2).
C	570 – 370				
631 A*	519 ± 41	$>O_u$	Cook's Cove East Coast	Wellman (1962b)	Charcoal from lower occupation layer
C	610 – 460				
682 A	728 ± 42	$<T_s$	Manawatu sand plain	McFadgen (1972)	Charcoal from an oven on a buried soil on Motuiti sand. Probably from vegetation growing nearby (Site N148/1).
C	820 – 570				
851 A	340 ± 47	$<O_s$	Murdering Beach	Lockerbie (*pers. comm.* 1981)	Outer rings of post butt in top of Ohuan sand (Site S164/16).
C	520 – 300				

852	A C	333 ± 47 520 – 295	< O_s	Murdering Beach	Lockerbie (*pers. comm.* 1981)	As for NZ 851.
853	A C	310 ± 47 510 – 280	< O_s	Murdering Beach	Lockerbie (*pers. comm.* 1981)	As for NZ 851.
1,158	A* D	294 ± 40 350 – 150	< O_u	Hohoupounamu, North Canterbury	M. M. Trotter (*pers. comm.* 1984)	Shells (*Chione stutchburyi*) from middle occupation layer in sand above buried soil (Site S76/7).
1,159	A* D	335 ± 40 390 – 190	< O_u	Hohoupounamu, North Canterbury	M. M. Trotter (*pers. comm.* 1984)	Shells (*Paphies* sp.) from middle occupation layer in sand above buried soil (Site S76/7).
1,162	A C	615 ± 40 700 – 520	< T_s	Redcliffs, Banks Pen.	Trotter (1975)	Moa bone collagen from occupation layer on Waikuku sandy loam (on old "stained" ground surface in sewer trench).
1,296	A D	453 ± 40 510 – 310	> O_u	Hot Water Beach, Coromandel Pen.	Leahy (1974)	Shells from above Loisels pumice (Site N44/69).
1,297	A D	524 ± 40 585 – 385	> O_u	Hot Water Beach, Coromandel Pen.	Leahy (1974)	Shells from above Loisels pumice (Site N44/69).
1,375	A* D	509 ± 40 570 – 370	< T_s > O_u	Hohoupounamu, North Canterbury	M. M. Trotter (*pers. comm.* 1984)	Shells (*Chione stutchburyi*) from lowest occupation layer on buried soil (Site S76/7).
1,376	A D	581 ± 40 660 – 505	< T_s	Redcliffs, Banks Pen.	Trotter (1975)	As for NZ 1162.
1,480	A* D	587 ± 55 660 – 440	< T_s	Manawatu sand plain	This paper	Shells from midden on buried soil on Motuiti sand (Site N148/1).
1,874	A* D	410 ± 60 485 – 245	> O_u	Te Awa Iti	This paper	Shells (*Haliotis iris*, *Lunella smaragda*, *Cellana* sp., *Malagraphia aethiops*) from midden in lower buried soil (Site N166/67).
1,875	A D	570 ± 60 645 – 405	> O_u	Tairua, Coromandel Pen.	Smart and Green (1962)	Shells from lower occupation layer (Layer 2) in buried soil (Site N44/2).
1,876	A D	250 ± 70 340 – 60	> H_u < O_s	Tairua, Coromandel Pen.	Smart and Green (1962)	Shells from upper occupation layer (Layer 6) on buried soil (Site N44/2).
4,505	A D	510 ± 40 570 – 370	< O_s	Parapara Spit, Golden Bay	McFadgen and Challis (1979)	Shells from midden in ground soil on Stratigraphic Division 2 sand.
4,506	A D	480 ± 50 540 – 340	< O_s > H_u	Parapara Spit, Golden Bay	McFadgen and Challis (1979)	Shells from midden in buried soil on Stratigraphic Division 2 sand.
4,701	A C	712 ± 57 810 – 555	> O_u	Long Beach	Leach and Hamel (1981)	Charcoal from shortlived species from Layer 4c on old beach ridge.
4,704	A C	476 ± 57 590 – 410	> O_u	Long Beach	Leach and Hamel (1981)	Charcoal from shortlived species from Layer 4a on old beach ridge.

Table 1 –

NZ Number	Date Years BP (1950)	Significance	Locality	Author	Sampled Layer and Sample
4,705 A C	868 ± 80 1,010 – 620	$>O_u$	Long Beach	Leach and Hamel (1981)	Charcoal from longlived species from Layer 4b on old beach ridge.
5,279 A* D	477 ± 34 520 – 320	$<O_u$	Manawatu sand plain (nr Hima-tangi)	D. Butts (*pers. comm.* 1983)	Shells from coastal midden on Waitarere sand.
5,280 A* D	504 ± 34 550 – 350	$<O_u$	Manawatu sand plain (nr Hima-tangi)	D. Butts (*pers. comm.* 1983)	Shells from coastal midden on Waitarere sand.
5,462 A B *wrt seal protein standard	1,035 ± 65* 1,195 – 935	$>T_s$	Long Beach	This paper	Seal bones in Tamatean sand.
5,462 A B *wrt NZ surface ocean flesh	1,200 ± 60* 1,330 – 1,070				
WK 31 A C	660 ± 120 900 – 480	$>O_u$	Near Aotea Harbour	Pain (1976, 1979)	Charcoal from midden in top of recently exposed Parangi soil.
WK 32 A C	350 ± 120 580 – 130	$>O_u$	Taharoa	Pain (1976, 1979)	Charcoal in top of recently buried Parangi soil.
Historical Records					
	130	$=H_u$	Gisborne	Pullar and Pen-hale (1970)	Beginning of deposition of Late Matawhero alluvium.
	133	$<O_s$	Murdering Beach	Lockerbie (1959)	Established village on Ohuan sand.

"Shellfish-eater" occupation layers. According to Trotter (1975) some Moahunter remains rest on a stained sand which I consider, after discussion with Mr Trotter, could be a buried soil. Trotter (1975) gives radiocarbon dates for Moahunter remains on the Flat and in the cave of between about 800 and 500 years BP.

For the sand underlying the earliest occupation layer at Hohoupounamu, and underlying the Moahunter remains at Redcliffs, I suggest direct correlation with Waikuku sand. For the overlying sand at each place I suggest direct correlation with Kairaki sand.

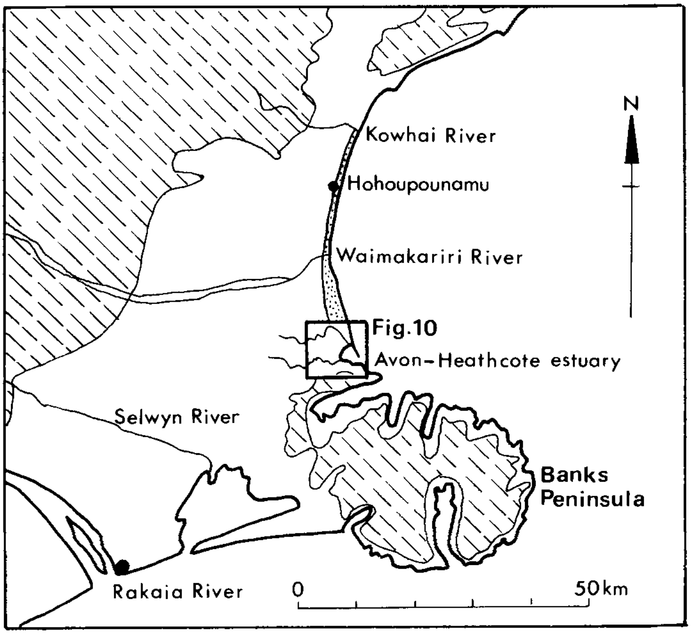


Fig. 9—Sketch map of Central Canterbury Plains. Land above 450 m shown with broken cross-hatching. Dune belt north of Banks Peninsula shown stippled. Moahunter site at Rakaia River mouth shown by a heavy dot.

Thus, overall correlation of Waikuku dunes with the Tamatean, Kairaki dunes with the Ohuan, and the Modern dunes with the Hoatan, is suggested by the radiocarbon dates.

In the lower reaches of the Waimakariri River, more than 10 km inland from the coast, there is a series of fluvial deposits and soils dated by radiocarbon, but not examined by me. Deposition was followed by down-cutting, giving four age-groups of sediments and soils (Cox and Mead, 1963); but only the two youngest, Waimakariri followed by Selwyn, are within the time range of the chronozones discussed here. According to the radiocarbon dates, Waimakariri sediments (2,400 to 700 years BP) are Tamatean in age; and Selwyn sediments (less than 300 years BP) are Ohuan in age. Hoatan sediments and soils appear to be absent, possibly because stopbanks were built about 1870 (Cox and Mead, 1963). Two age groups of Waimakariri sediments are recognised (Cox and Mead, 1963), indicating the possibility of a period of soil formation within the Tamatean unstable phase, but corresponding soils have not yet been recognised in coastal deposits elsewhere.

At the mouth of the Rakaia River, 50 km southwest of Banks Peninsula, there are three down-cut terraces, progressively younger from highest to lowest. Ward *et al.* (1964) named the soil on the lowest terrace, Selwyn soil, and the soils on the two higher terraces, Waimakariri soils. Moa bone collagen from an archaeological site on the highest terrace has a radiocarbon age of 710-400 years BP (corrected mean of NZ 930A and 932A) (Trotter, 1972), a date that agrees with the date of Waimakariri soils according to Cox

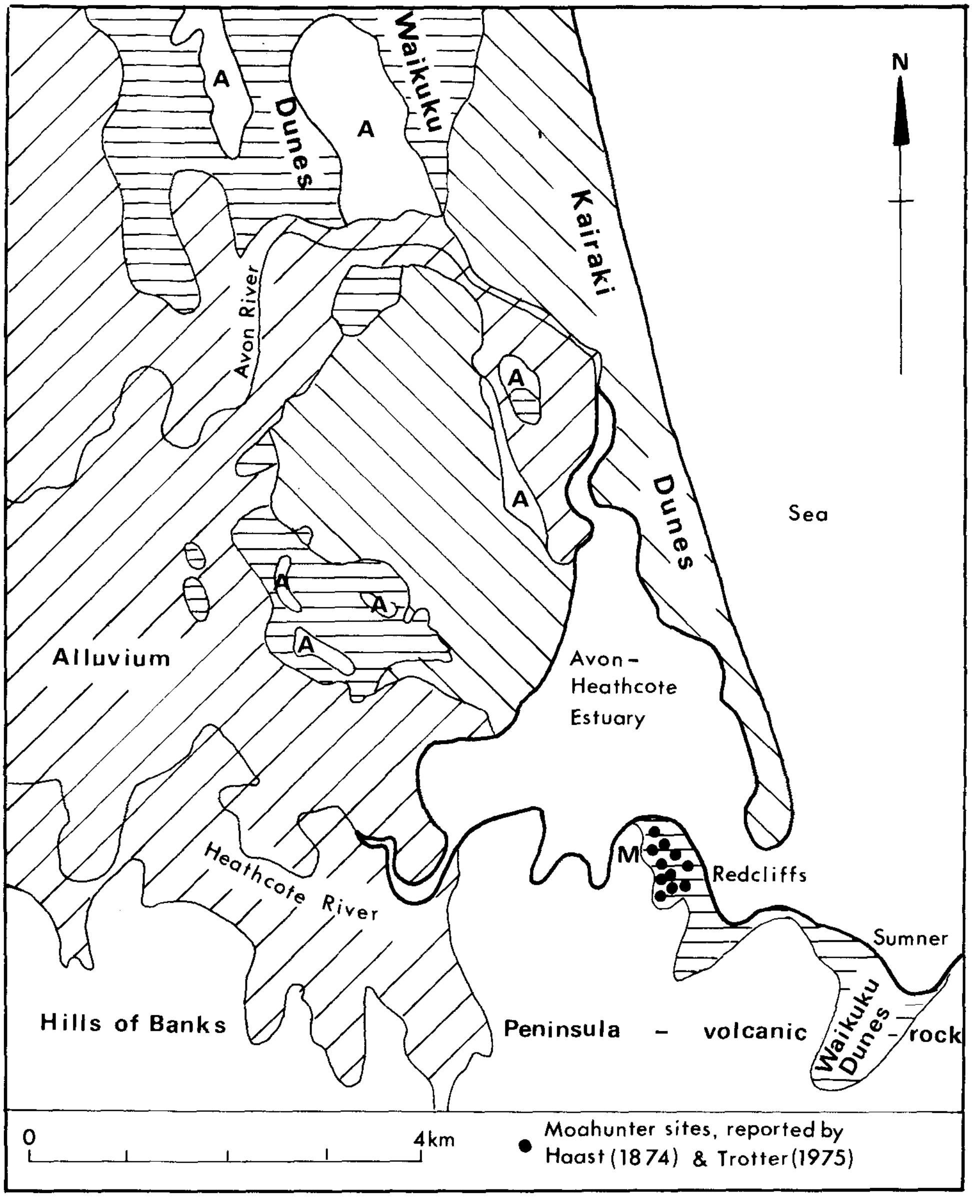


Fig. 10—Sketch map of Avon-Heathcote estuary and coast north of Banks Peninsula showing dune belts inferred from soil data in New Zealand Soil Survey Report No. 16 (Raeside and Rennie, 1974): Waikuku dunes (older) defined by Waikuku sandy loam and soils of Aranui complex (A); Kairaki dunes (younger) defined by Kairaki sand. M = Moa-Bone Point Cave.

and Mead (1963). The soils on the two higher terraces are therefore considered to be Tamatean in age; and that on the lowest terrace is considered to be Ohuan in age.

At Long Beach and Murdering Beach near Dunedin, 300 km southwest of Banks Peninsula, dune sand infills two embayments surrounded by steep hills (Fig. 11). There is no Taupo or Loisels pumice and deposits are correlated with the chronozones using soil profile development, radiocarbon dates and historic records.

Tamatean sand forms a belt up to 200 m wide around the back of the embayments (Fig. 11). It comprises a dune, which rises to nearly 4 m above present high water mark, and a deposit of very shelly sand beneath the dune and along its seaward edge (Fig. 12). Comparison of the particle size distribution of the Tamatean shelly sand with sand on the present foreshore suggests that, when the Tamatean sand accumulated, the shoreline was along the seaward edge of the Tamatean sand belt. The Tamatean shelly sand below high water level (Fig. 13, sample c) has a particle-size distribution similar to that of sand below high water mark on the present beach (Fig. 13, sample a), and the Tamatean shelly sand above high water level (Fig. 13, sample d) has a particle-size distribution similar to sand above highwater mark on the present beach (Fig. 13, sample b).

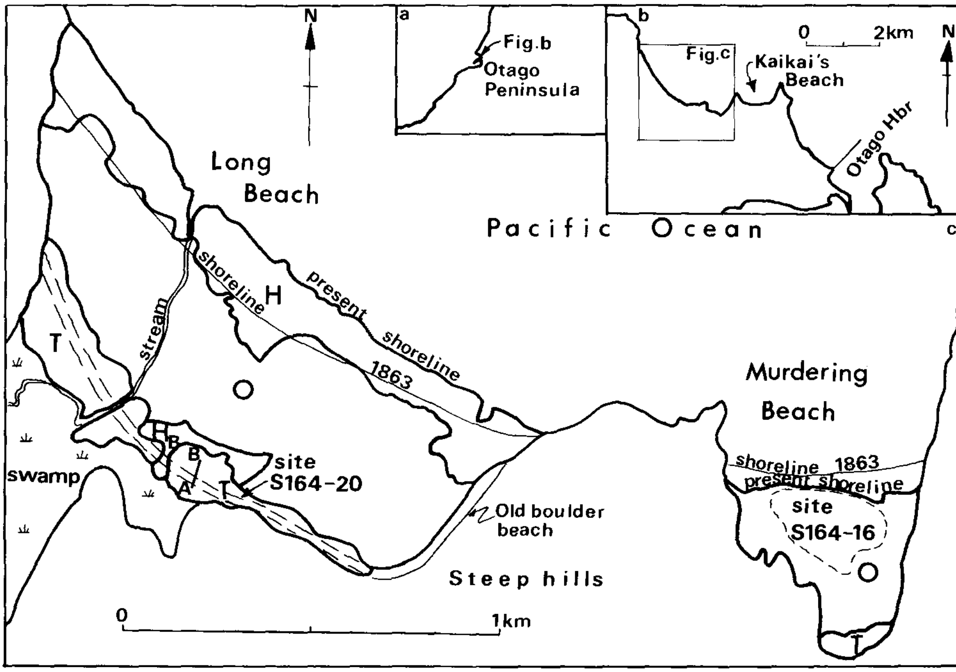


Fig. 11 — Sketch map of sand dunes at Long Beach and Murdering Beach, Dunedin (Insets = locality maps). H = Hoatan; O = Ohuan; T = Tamatean; H_B = bulldozed sand. Cross-section A-B shown in Fig. 12. Broken lines = inferred position of old boulder beach under Tamatean sand, based on archaeological excavations (Leach and Hamel, 1981) and reports of stones found by local residents in their gardens. Note absence of Hoatan sand at Murdering Beach. 1863 shoreline from cadastral maps S.O.1270 and S.O.1271 held by Dept of Lands and Survey, Dunedin.

Although the ground soil on Tamatean sand has been disturbed in many places by fossicking, bulldozing and residential development, two different stages of soil development are recognised. The inland side of the dune at Long Beach (Fig. 11) has a well-defined topsoil and a subsoil defined by both colour and structure. A representative profile is:

Topsoil:	0.30 m	brownish-black (10YR2/3) friable sand; single grain and weakly developed fine nut and granular structure; many roots; diffuse boundary.
Subsoil:	0.30 m	brown (10YR4/6) very friable sand; single grain and very weakly developed fine nut structure; few roots; diffuse boundary.
	on:	dull yellowish-brown (10YR5/4) loose sand.

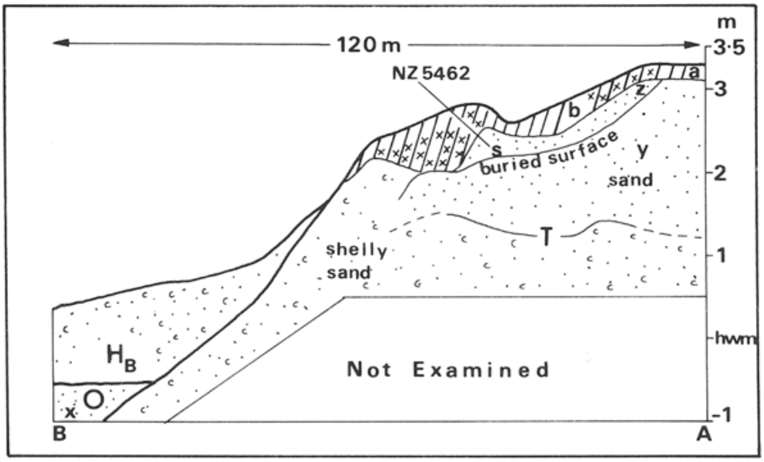


Fig. 12—Cross-section along line A-B in Fig. 11. ccc = shelly sand; xxx = shell midden deposits; soils shown cross-hatched. Note bulldozed sand (= H_B), and seal (= S) on buried surface. a = well-developed topsoil on Tamatean dune; b = less well-developed topsoil; x,y,z = sand samples (Table 2). Other symbols as used in Fig. 11. Note absence of buried soil on Ohuan sand.

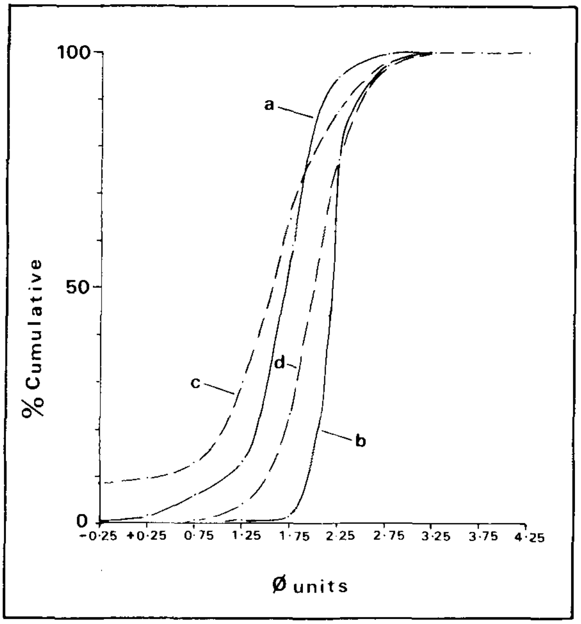


Fig. 13—Cumulative particle size frequency distributions of Long Beach sands.
a = sand just below high water mark on present beach.
b = sand just above high water mark on present beach.
c = Tamatean shelly sand just below high water level.
d = Tamatean shelly sand 1 m above high water level.

Along the seaward side of the Long Beach dune, however, the ground soil is less well developed. It has a well-defined topsoil, but no subsoil, and is a brownish-black sand 10 cm thick over loose greyish-yellow brown sand. Since the seaward edge of the dune appears to have been an old foreshore, the ground soil on the seaward side of the dune is unlikely to have begun forming until after the sea had retreated.

About half a metre below the ground surface on the seaward side of the dune is a light-coloured weakly-coherent layer (Fig. 12) which appears once to have been an old dune surface, for resting on it were found the bones of a seal (*Arctocephalus forsteri*). The seal bones give a radiocarbon date of 1195 to 935 years BP (NZ 5462B, Table 1), a time when the Tamatean sand was still accumulating.

Tamatean sand partly buries an old beach ridge composed of basalt stones and boulders around the back of Long Beach (Fig. 11). There is no sign of the beach ridge at Murdering Beach, although there is a beach ridge around the back of Kaikai's Beach (Fig. 11) and the beach ridge at Murdering Beach is probably entirely buried. The height of the beach ridge crest, found by spirit levelling, is about a metre above present high water mark. Maori occupation remains on the beach ridge are important for dating the beginning of Ohuan sand accumulation.

Table 2 — Sand Mineralogy at Long Beach

Chronozone	*Provenance*	*Quartz* %	*Rock Fragments and Heavy Minerals* %
Hoatan	Present beach (Below HWM)	95	5
Hoatan	Present beach (Just above HWM)	96	4
Ohuan	Sand dune	95	5
Ohuan	Sand plain (X, Fig. 12)	100	—
Tamatean	Sand dune (Y, Fig. 12)	70	30
Tamatean	Sand dune (Z, Fig. 12)	74	26

Ohuan sand forms a belt, up to 450 m wide, seawards of Tamatean sand (Fig. 11) which it overlaps (Fig. 12). It comprises dunes, which rise less than 4 m above present high water level, and sand plains which are close to present high water level. The mineral component of the sand differs from Tamatean sand. It is more that 95% quartz and less than 5% heavy minerals and basalt fragments compared with Tamatean sand, which is about 70% and 30% respectively (Table 2). Ohuan ground soil is a well-defined brownish-grey topsoil 12 cm thick over loose sand. A late Maori village on Ohuan sand at Murdering Beach (Site S164/16, Fig. 11) was occupied in 1817 AD (Lockerbie, 1959), and samples from the site have given radiocarbon dates of 485 to 325 years BP (corrected mean of NZ 851, 852 and 853, Table 1).

A maximum date for the accumulation of Ohuan sand is provided by radiocarbon dates for Maori occupation remains on the beach ridge at Long Beach (Site S164/20, Fig. 11). The lowest of three occupation layers (Layer 4) contained a shell midden that appeared to have been washed over by wave action (Leach and Hamel, 1981) and was presumably deposited before the Ohuan sand. Radiocarbon dates indicate that the age of the midden is between 800 and 400 years BP (NZ 4701C, 4704C, Table 1).

Hoatan sand is absent from Murdering Beach, but forms a foredune belt up to 150 m wide seawards of Ohuan sand at Long Beach (Fig. 11). It comprises dunes, which rise to 4 m above present high water level. Like Ohuan sand, its mineral component is more that 95% quartz and less that 5% heavy minerals and basalt fragments (Table 2). Hoatan ground soil is little more than thin bands of plant litter on loose light grey sand.

Northern South Island

At Parapara Spit in **Golden Bay**, at the north of the South Island, there are three belts of dune sand, each with a different degree of soil profile development (McFadgen and Challis, 1979). The oldest (Stratigraphic Divison 1) has a ground soil profile similar to Tamatean ground soil at Flat Point. The next oldest (Stratigraphic Divison 2) has a ground soil profile similar to Ohuan ground soil at Flat Point. Midden shells in Division 2 buried soil and in Division 2 ground soil have radiocarbon dates of about 350 to 550 years BP (NZ 4505 and NZ 4506, Table 1). The youngest belt (Stratigraphic Division 3) is dated as less than 150 years, based on historical records and an assumption of a constant rate of sand accumulation. Correlation of Stratigraphic Divison 1 with the Tamatean Chronozone, Stratigraphic Division 2 with the Ohuan Chronozone and Stratigraphic Division 3 with the Hoatan Chronozone is based on ground soil development, radiocarbon dates, and historical records.

At **D'Urville Island**, at the north of the South Island (Fig. 3), there are two occupation layers (Wellman, 1962a). The layers are unusually well defined, especially those in dune sand. There is Taupo pumice but no Loisels pumice. Buried soils exist immediately below the occupation layers in some places. Dates for occupation layers were estimated (Wellman, 1962a) by assuming uniform accumulation rates. Wellman collected radiocarbon samples but published his estimated ages before the samples were dated. The dates (Table 1) were some hundreds of years younger than his estimates. Satisfactory correlation of Wellman's (1962a) lower occupation layer with the Tamatean buried soil, and upper occupation layer with the Ohuan buried soil, is based on the Taupo pumice, the radiocarbon dates, and soil formation.

Southwest North Island Coast

The southwest coast of the North Island is about 120 km northeast of D'Urville Island, and 90 km northwest from the type locality at Flat Point. From the Manawatu River in the south to the Wanganui River in the north, belts of Holocene dune sand parallel the coast (Cowie, 1963; Campbell, 1974). Three distinct periods of sand accumulation, called by Cowie (1963) "Dune-building Phases", are inferred from sharp differences in the degree of ground soil development on the sand belts. In general, the oldest sands are the furthest inland (Fig. 14). According to Cowie (1963) the sequence of Dune-building Phases younger than 2,000 years is Motuiti followed by Waitarere. Motuiti dunes contain Taupo pumice (Cowie, 1963).

The soils on Motuiti sand are dated in the Manawatu district. There, Motuiti sands have advanced inland over a tree radiocarbon dated 960 to 650 years BP (NZ 293C, Table 1). The Motuiti ground soil has a profile development similar to that of the Tamatean ground soil at Flat Point.

Two kilometres north of the Manawatu River, and 2.5 km from the sea, is a Moahunter site (N148/1) investigated by McFadgen (1972). The site is on the eastern side of a lake (Fig. 14), locally called the Pothole, and rests on a thin soil formed in Motuiti sand. The site has a radiocarbon date of 820 to 570 years BP (NZ 682C, Table 1) determined on charcoal from a tree that is thought to have grown on the thin soil. The date is thus considered to be a minimum date for the start of soil formation.

Waitarere dunes have patchy, poorly developed soils, and have not previously been dated. They comprise a coastal belt of unstable sand dunes up to 3 km wide and an inland belt of stable sand plains up to 4 km wide (Fig. 14) (Cowie *et al.*, 1967) which I recognise as two dune-building episodes within the Waitarere Dune-building Phase.

The stable sand plains of the early dune-building episode extend inland to a line of lakes. At the Pothole, 2.5 km inland, Waitarere sand overlies Motuiti sand and forms the western shore of the lake. The lake is 3.3 m above sea level, and used to seep to the sea. It now has an artificial outlet which has lowered its level by 1.4 m. An old lake shore 1.4 m above the present level, cut into Waitarere sand, agrees well with the position of the lakeshore mapped by surveyors in 1889 (S.O. 12963^{L}) (McFadgen, 1972). Sand of the early dune-building episode had thus already advanced inland and become stable by 1889.

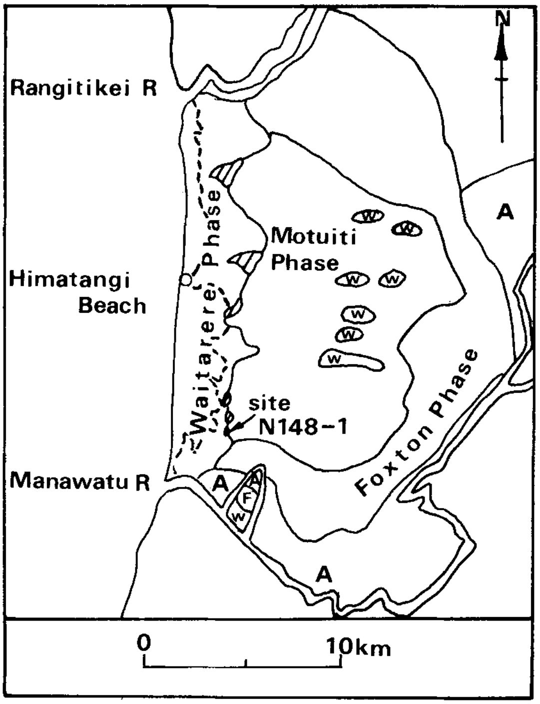


Fig. 14—Sketch map of Manawatu sand country showing Dune-building Phases (Cowie, 1963) and archaeological site N148/1. Note lagoons (shown cross-hatched) along inland boundary of Waitarere Phase dunes. Boundary between older and younger Waitarere dune-building episodes shown as a pecked line, the younger episode being nearer the coast.
W = Waitarere Phase dunes, which occur where blowouts began in Motuiti Dune-building Phase.
F = Foxton Dune-building Phase.
A = Holocene river alluvium.

An age for the beginning of the early dune building episode of 550 to 350 years BP (NZ 5280D, Table 1) is indicated by radiocarbon dates for shell middens on Waitarere sand 300 m from the present coast, at Himatangi Beach (Fig. 14) (D. Butts, *pers. comm.*, 1983).

The younger dune-building episode is younger than European settlement. According to Cowie (1963), Waitarere dunes cover European artifacts and the remains of introduced plants. The dunes began to advance inland in the 1880s and continued to drift and erode until the early 1900s, when they were brought under control following the planting of marram grass. Cowie (1963) attributes their advance partly to reactivation of formerly stable dunes and partly to an increased sediment supply to the coast.

Correlation of the Motuiti Dune-building Phase with the Tamatean Chronozone, the early Waitarere dune-building episode with the Ohuan Chronozone, and the later Waitarere dune-building episode with the Hoatan Chronozone, is based on radiocarbon dates, ground soil development, and historical records.

West Auckland

Along the west Auckland coast, 300 km north of the southwest North Island coast, there are coastal sections not seen by me but described by Wellman (1962b). As at Moa-

Bone Point Cave at Redcliffs in the South Island, there are two occupation layers, but both are poorly defined. The sections are mostly sand; Taupo pumice is present, but not Loisels pumice. One reasonably well-defined buried soil exists below the lower occupation layer and above the Taupo pumice. Four sections (44, 47, 48 and 49, Wellman, 1962b) are correlated with the proposed chronozones in Fig. 15 according to soils described by Wellman (1962b). Deposits between the Taupo pumice and the top of the buried soil are Tamatean in age; and above the buried soil, Ohuan-Hoatan in age.

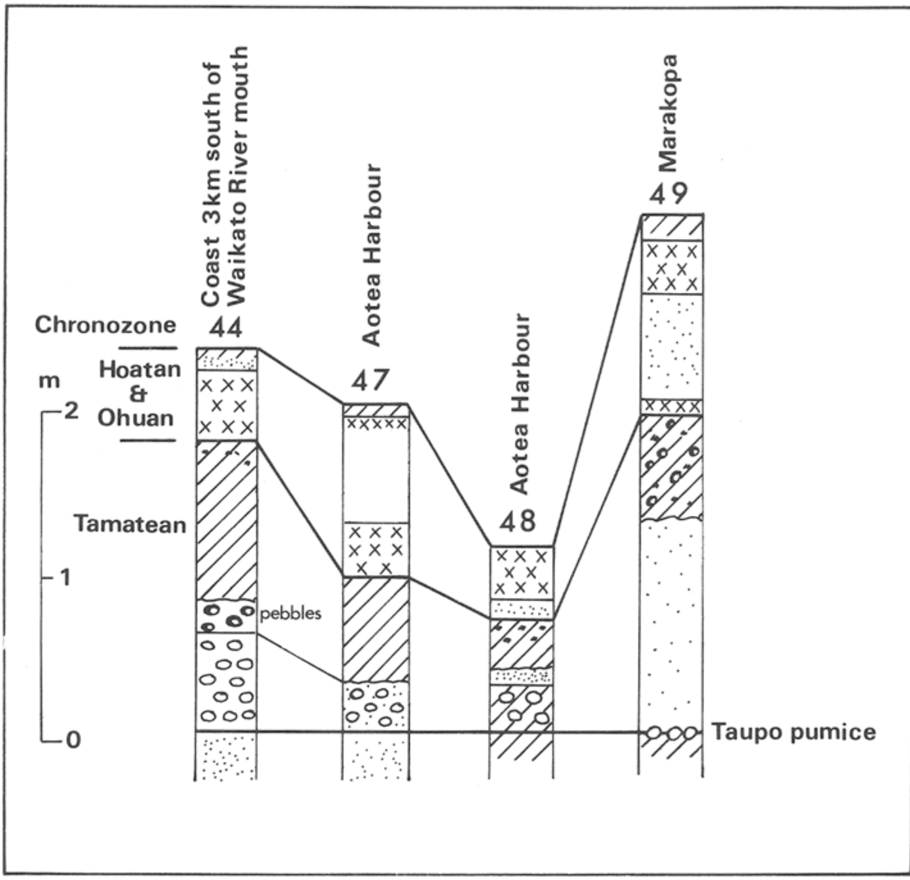


Fig. 15—Application of my proposed chronozones to Wellman's (1962b) west Auckland coastal Holocene sections most important to late Holocene stratigraphy. Section numbers from Wellman (1962b). Symbols as for Fig. 16. Note absence of Loisels pumice and Ohuan soil.

Near Aotea and Kawhia Harbours are two sets of dunes less than about 2,000 years old (Pain, 1976). The dunes, which are part of the Mitiwai Formation (Kear, 1965), include the Paparoa Sands Member and the Nukumiti Sands Member (Pain, 1976).

The topsoil on Paparoa dunes contains lumps of Taupo pumice and the pumice is also found in peat which was forming at the same time as the dunes were accumulating. Maori middens overlie the topsoil formed on the dunes, and in places are buried by the younger Nukumiti dunes, which are still forming. Radiocarbon dates from samples collected by Pain (1979) suggest that Nukumiti dunes started to form about 300 to 400 years ago (Pain, 1979). The topsoil on Nukumiti dunes is patchy and poorly developed, and it is not known when it began to form. Correlation of Paparoa dunes with the

Tamatean and Nukumiti dunes with Ohuan and Hoatan is based on the Taupo pumice and the radiocarbon dates.

Coromandel Peninsula

Along the Coromandel Peninsula, 150 km northeast of the west Auckland coast, coastal sections are described by Wellman (1962b). There is one well-defined occupation layer, which is exposed in sections composed principally of sand. Taupo pumice is absent, Loisels pumice is present. Buried soils are not evident from Wellman's (1962b) descriptions, but are described by Smart and Green (1962) at Tairua, and are assumed to be present in the sections described by Wellman (1962b).

At Hot Water Beach, an archaeological site (N44/69) in dune sand contains six layers numbered from top to bottom, Layer 1 to Layer 6 (Leahy, 1974). From my examination of the site I consider layers 2 and 4 to be buried soils. Maori occupation remains are in the lower part of Layer 3 and in layers 4, 5 and 6. Taupo pumice is absent, Loisels pumice is in Layer 5. European artefacts are in Layer 2 (Leahy, *pers. comm.*, 1973). A radiocarbon date for midden shells in Layer 4 is 520 to 380 years BP (corrected mean of NZ 1296D and 1297D, Table 1). Correlation of Layer 4 with the Tamatean buried soil, and Layer 2 with the Ohuan buried soil, is based on Loisels pumice, the radiocarbon dates and European artefacts.

Tairua, an archaeological site (N44/2) in dune sand, contains two occupation layers separated by dune sand (Smart and Green, 1962). Each is part of a poorly developed buried soil. Taupo pumice, Loisels pumice and European artefacts are absent. The lower occupation layer (Layer 2) has a radiocarbon date for shell midden of 645 to 405 years BP (NZ 1875D, Table 1); and two radiocarbon dates, 570 to 370 years BP (NZ 595C, Table 1) and 980 to 680 years BP (NZ 594C), on unidentified charcoal from an oven. The upper occupation layer (Layer 6) has a radiocarbon date for shell midden of 340 to 60 years BP (NZ 1876D, Table 1). Correlation of the lower buried soil with the Tamatean stable phase, and the upper buried soil with the Ohuan stable phase, is based on the radiocarbon dates.

Bay of Plenty — East Coast

Along the eastern Bay of Plenty and East Coast, 300 km southeast of the Coromandel Peninsula, are coastal sections described by Wellman (1962b). As at Moa-Bone Point Cave, there are two well-defined occupation layers. Wellman (1962b), assuming a uniform rate of sediment accumulation, considered the dark discoloration and extent of the layers to be determined by population density. Taupo pumice and Loisels pumice are both present. I consider the occupation layers to be times of non-deposition and soil formation, and the layers are correlated with the Tamatean and Ohuan soils.

Of the 21 East Coast and Bay of Plenty sections described by Wellman (1962b), the most important for late Holocene stratigraphy are reproduced and correlated with my chronozones in Fig. 16. In all sections there are two buried soils above the Loisels pumice. For sections 5, 7, 19, 21 (numbers according to Wellman (1962b)), which I did not see, the buried soils are based on Wellman's (1962b) descriptions; and for sections 8, 9, 13, 14, 15 and 18, on my observations.

The Ohuan soil contains European artefacts at three places. At Maraetaha Diggings (Section 8), a fortified pa on the banks of the Maraetaha River, Wellman's (1962b) upper occupation layer is a cultivated soil containing clay pipe (E. Shaw, *pers. comm.*, 1973). At Cook's Cove (Section 15) the upper occupation layer is a ground soil containing iron and earthenware. At Anauru Bay (Section 18) there is iron in the top of the upper occupation layer.

In the Gisborne Plains Basin, on the East Coast, there are five alluvial formations and their associated coastal sands. The alluvial formations are named by Pullar and Penhale (1970), in order of decreasing age; Kaiti, Waihirere, Early Matawhero, Late Matawhero, and Post-Matawhero. The last four named formations are separated by buried soils; the first two, by Taupo Pumice. Pullar (1959) describes Loisels pumice in Waihirere

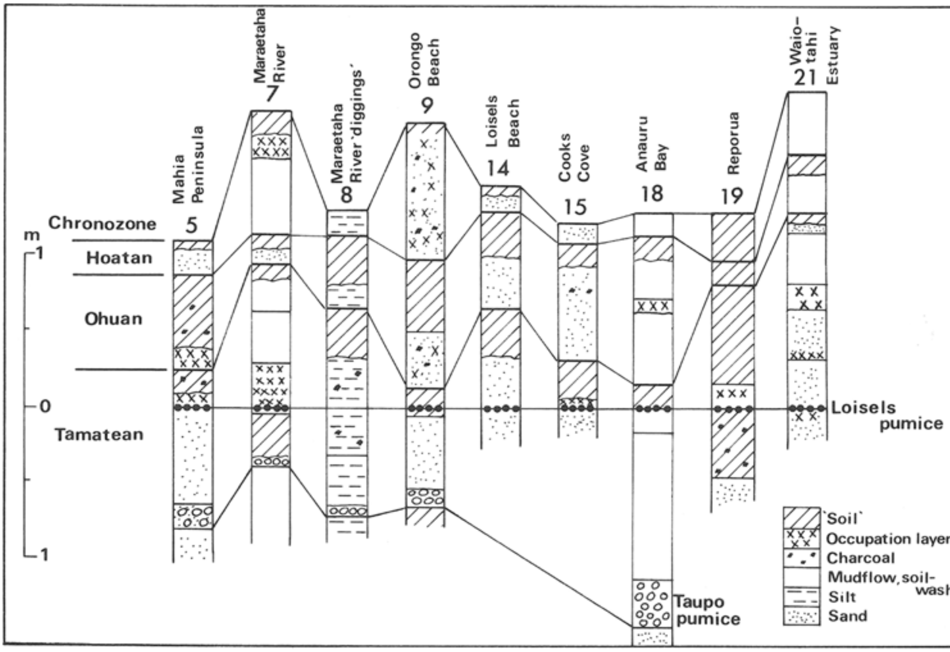


Fig. 16 – Application of my proposed chronozones to Wellman's (1962b) East Coast and Bay of Plenty coastal Holocene sections most important to late Holocene Stratigraphy. Section numbers from Wellman (1962b).

soil at the Maraetaha River mouth. Basal layers of early Matawhero alluvium are olive-yellow in colour and contrast strongly with the black Waihirere buried soil which they cover, indicating that alluvium was deposited rapidly after a long period with no flooding. Basal layers of Late Matawhero alluvium are olive in colour and contrast with the very dark greyish-brown early Matawhero buried soils which they cover, indicating that alluvium was deposited rapidly after another period with no flooding. Late Matawhero alluvium began accumulating about 1820 AD. Coastal sands that accumulated when Waihirere and early Matawhero alluvium was deposited have Opoutama loamy sand and Opoutama sand soils formed on them respectively (Pullar, 1962; Pullar and Penhale, 1970). Younger sand accumulation is minor and is not separately mapped (Pullar and Penhale, 1970). I correlate the Waihirere soil and Opoutama loamy sand with the Tamatean soil, and the early Matawhero soil and Opoutama sand with the Ohuan soil, from the presence of the Taupo and Loisels pumices.

From the Gisborne Plains Basin it is 360 km southwest to Flat Point, the type section first described.

ADOPTED AGES FOR LATE HOLOCENE DEPOSITS

My interpreted ages for the late Holocene deposits of the North Island and northern and eastern parts of the South Island are given in Figs. 17 and 18. Tamatean, Ohuan and Hoatan deposits are present in both the North and South Islands. The Tamatean soil is present on deposits at all places. The Ohuan soil is present in the northern and eastern South Island and on the eastern and southwestern North Island, but has not been recognised on the west Auckland coast of the North Island. Although Hoatan deposits are present in eastern South Island sand dune systems, they have not been recognised separately along the Waimakariri or Rakaia Rivers.

DATING THE CHRONOZONES

The age range for the start of each phase is determined by bracketing (McFadgen, 1982). Dates used are listed in Table 1 and are classified as maximum, minimum or close dates depending on their inbuilt age and stratigraphic relationship to the event dated (McFadgen, 1982). Dates on unidentified charcoal samples which are stratigraphically younger than the event dated are disregarded, because of unknown and possibly large inbuilt ages of the samples. Data for determining the age range for the start of each phase are set out in Fig. 18. The age ranges are controlled by their stratigraphic order, and where appropriate are reduced.

Adopted ages in calendar years for stratigraphic events are as follows:

Stratigraphic Event	*Years* BP	*Years* AD
Ohuan soil buried	150	1800
Ohuan soil begins to form	400	1550
Tamatean soil buried	450	1500
Tamatean soil begins to form	600	1350
Loisels pumice deposited	650	1300

The earliest three events could be up to 100 years in error, the last two events, somewhat less.

VEGETATION ON TAMATEAN AND OHUAN SOILS

On D'Urville Island, charred logs 15 cm in diameter are embedded in the top of the lower buried soil at Greville Harbour, and charred roots extend down into the soil below (Wellman, 1962a). There is less evidence of what vegetation grew on the lower buried soil elsewhere, however, so it has to be inferred from other kinds of remains, of which the most important are landsnails.

Landsnails are particularly abundant in some shell middens. They indicate whether there was forest near the middens when the middens were laid down; hence if the middens are dated, so is the forest. *Stable* species of landsnails require forest conditions and live either in damp forest litter or in rotting logs, or are arboreal and live in leaf axils or in suspended litter. Some *tolerant* species normally live in damp forest litter but can tolerate dry open conditions; others live in litter in dry open conditions, but can tolerate damp forest litter.

In the Manawatu, at the Foxton site (N148/1), a shell midden with landsnails appears to have accumulated near forest (McFadgen, 1972). Motuiti soil, the same age as the midden, is developed upon the Motuiti Dune-building Phase. The soil began forming about 600 years ago and contains charcoals from kahikatea and totara (Appendix 2). Humic acid analyses of the soil confirm podocarp-dominated vegetation (Appendices 2 and 3). At the time of European settlement the forest had been replaced by bracken fern and scrub.

On the southeast Wairarapa coast forest vegetation on Tamatean soil is indicated by landsnails from shell middens at Flat Point (Figs. 19 and 20), at Te Awa Iti (Fig. 21), and at Te Oroi (Fig. 22). A paucity of landsnails in shell middens on the Ohuan soil at Flat Point and Te Awa Iti indicates that the forest edge was well inland of the middens. According to Colenso, in the 1840s and 1850s the the coast was barren and treeless (Bagnall and Petersen, 1948). It is noteworthy that at the Oroi Stream, where Colenso does mention one of the few stands of bush on the coast, a midden on the Ohuan soil does contain landsnails (Fig. 22).

At Cook's Cove, forest vegetation on Tamatean soil is indicated by landsnails from a shell midden (Fig. 23). Landsnails were not found in shell middens on the Ohuan soil.

The above results show that during formation of the Tamatean soil in the Manawatu, along the southeast Wairarapa coast, and on the East Coast, the forest advanced almost to the coast. Each of these areas, however, was forest-free at the time of European settlement. In the Manawatu district, and at Flat Point on the southeast Wairarapa coast, the coastal region was forest-free at the time of Maori settlement.

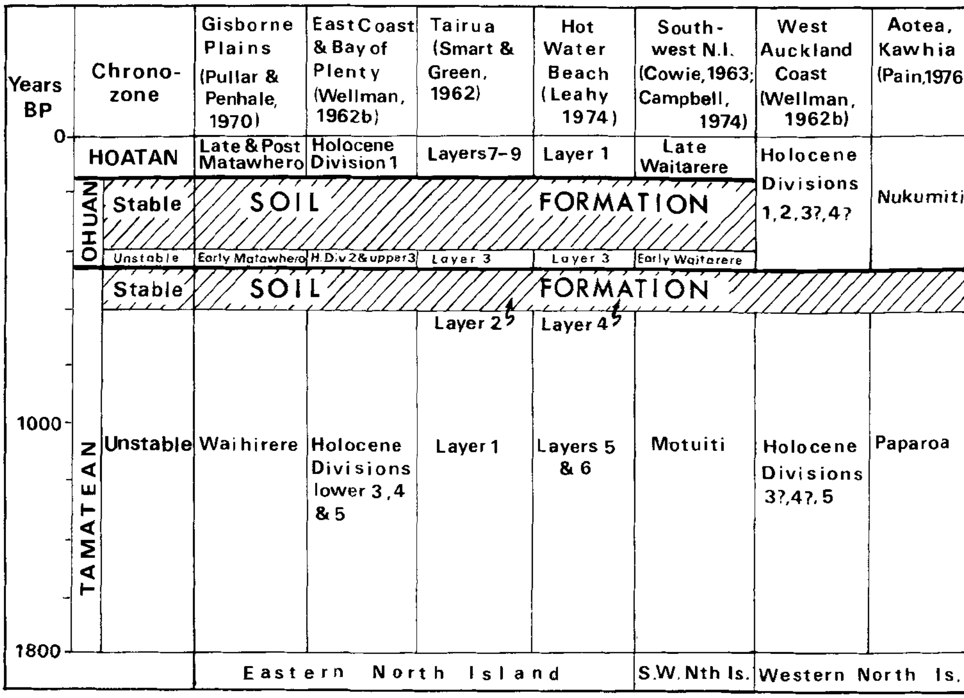


Fig. 17—Columns showing adopted ages for late Holocene deposits of the North Island and north and eastern South Island. Sites first described by the authorities listed at the heads of columns. Their formation names are given in the columns, except for Banks Peninsula where the dune phases were not named, and D'Urville Island where deposits were not named. H = Hoatan; O = Ohuan; T = Tamatean. For D'Urville Island, deposits above upper occupation layer = H,

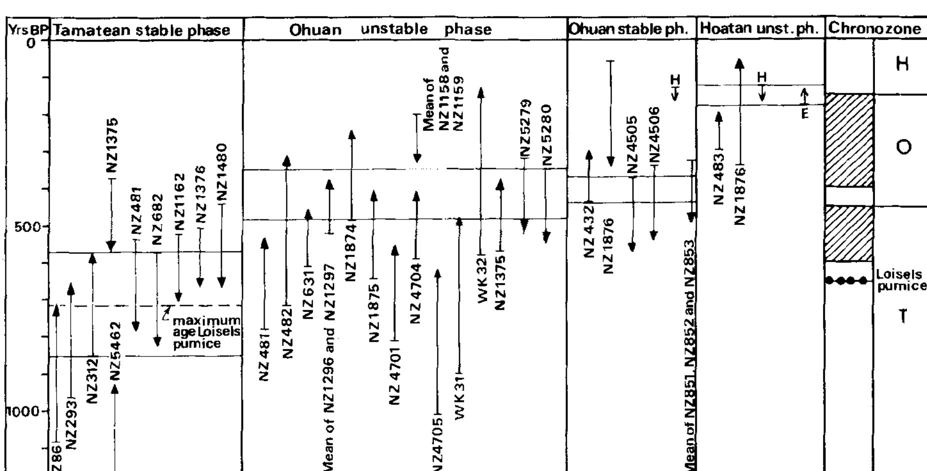
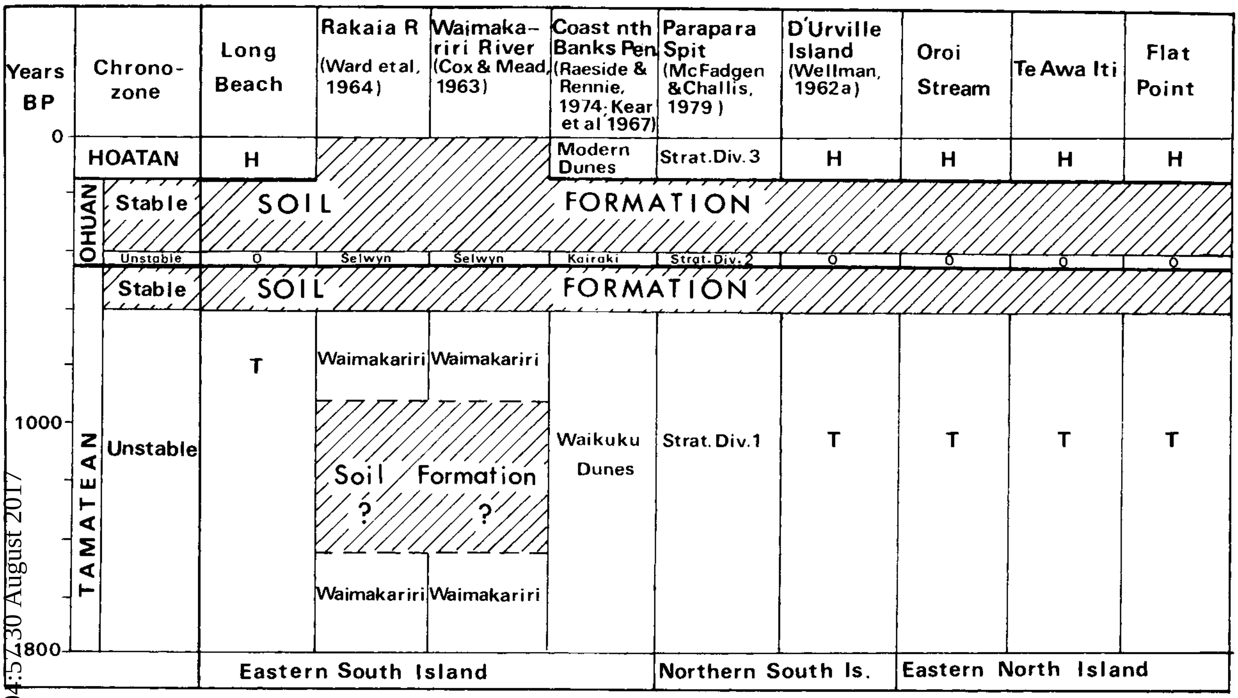


Fig. 18—Diagram showing calendar age ranges for key stratigraphic events: beginning of Tamatean stable phase, Ohuan unstable phase, etc. Included are all known historic dates (H), and all corrected radiocarbon dates within a bracket width of 700 years. Arrow heads indicate two kinds of dates: upward- pointing = maximum dates; downward-pointing = minimum dates. Arrow length equals four standard errors. Two dates (N.Z. 432 and 483) reported as being younger than "X" years are assumed to have a standard error of ± 50 years. European artifacts (E) used to indicate a maximum age of 180 years.



from top of lower occupation layer to top of upper occupation layer = O, and from Taupo pumice to top of lower occupation layer = T. Adopted ages for Holocene Divisions 3 and 4 on the west Auckland coast vary from section to section. Adopted ages for Holocene Divisions on the East Coast and Bay of Plenty generally as shown.

DEPOSITIONAL EPISODES

I conclude that for the last 2,000 years, there were three well defined episodes, each apparently synchronous over much of New Zealand, and each with two phases: a phase with a high rate of deposition (unstable phase), followed by a phase with a low rate of deposition and soil formation (stable phase). The pattern is similar in different parts of New Zealand except that the soil between the two younger episodes has not been recognised on the west Auckland coast of the North Island (Fig. 24).

In the North Island there is no obvious correlation of depositional episodes with tectonics. Tamatean sand at Flat Point mantles Beach Ridges B and C and contains primary sea-rafted Taupo pumice, also found behind Beach Ridge C. Accumulation of Tamatean sand thus spans two tectonic uplifts. Ohuan and Hoatan sands, however, are both younger than the most recent uplift.

The depositional episodes are unrelated to volcanic eruptions. Tamatean sand at Flat Point began acccumulating before the Taupo pumice eruption. Pumice (Taupo and Loisels) occurs as well-defined deposits in the Tamatean sand, but its volume is unimportant relative to the sand, and pumice has not been found in the Ohuan or Hoatan sands. The South Island deposits are too far removed from the North Island volcanic centres to have been influenced by volcanic eruptions.

I have correlated unstable phases in coastal dune systems with river aggradation and fan building (Fig. 17). Sand along the southwest North Island coast is shown by its mineral content to have come from the larger North Island rivers (Oliver, 1948; Cowie and Smith, 1948), and quartz sand along the Dunedin coast appears to have come from the Clutha River (Marshall, 1905). The depositional episodes are therefore attributed by me to changes in erosion rates in river systems: unstable phases occurring when rates were high; stable phases when rates were low.

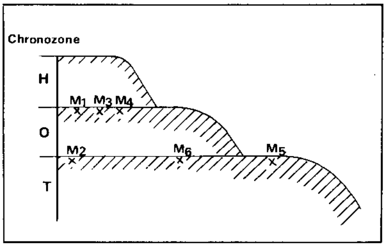


Fig. 19—Diagram showing chronozones, soils and middens at Flat Point. Soils cross-hatched. Middens lettered M1 to M6. Snails from middens show evidence of forest on Tamatean soil and no evidence of forest on Ohuan soil (snails listed in Fig. 20).

CLASS	HABITAT	SPECIES	Midden M2	Midden M5	Midden M6
STABLE	Forest litter, logs	Charopa coma punctid lateumbilicata 'Geminoropa' microrhina		23	
TOLERANT	Forest litter	Fectola trilamellata Fectola buccinella Mocella eta Cavellia brouni charopid prestoni		51	
	Plant litter, dry, open	charopid n.sp.'nthern maculata' Mocella cf. rakiura Paralaoma caputspinulae Therasia zelandia	present	26	100
		Nº in sample	5	364	150
		SCALE		10%	20%

Fig. 20—Percentage abundance of different species of landsnails from samples of shell middens in Tamatean soil at Flat Point. Species divided into three habitats and two classes. Percentage abundance shown by boxes on right hand side. Midden numbers as in Fig. 19. No landsnails were found in middens on Ohuan soil.

CLASS	HABITAT	SPECIES	
STABLE	Aboreal	Huonodon hectori	2
	Forest litter, logs	Charopa coma Phenacharopa novoseelandica charopid pilsburyi charopid prestoni 'Geminoropa' microrhina	29
TOLERANT	Forest litter	Cavellia buccinella Cavellia colensoi Mocella eta	39
	Plant litter, dry, open	charopid n.sp.'nthern maculata' Cavellia serpentinula Therasia zelandia	30
		Nº in sample	72
		SCALE	10%

Fig. 21—Percentage abundance of different species of landsnails from a sample of shell midden (site N166/67) in Tamatean soil in Section 2 at Te Awa Iti. Species divided into four habitats and two classes. Percentage abundance shown by boxes on right hand side.

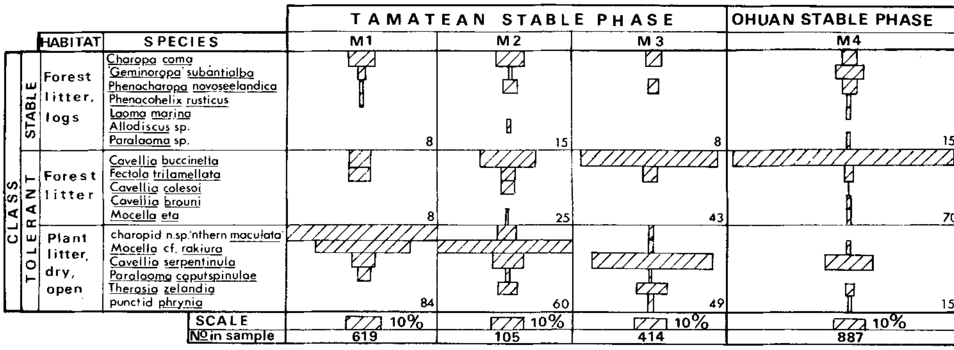


Fig. 22 — Percentage abundance of different species of landsnails from samples of shell middens (M1 to M4) in Tamatean and Ohuan soils in the left bank of the Oroi Stream. Species divided into three habitats and two classes. Percentage abundance shown by boxes on right hand side. M1 = site N168/131 (45 m from stream mouth); M2 and M4 = site N168/134 (100 m from stream mouth); M3 = site N168/133 (75 m from stream mouth).

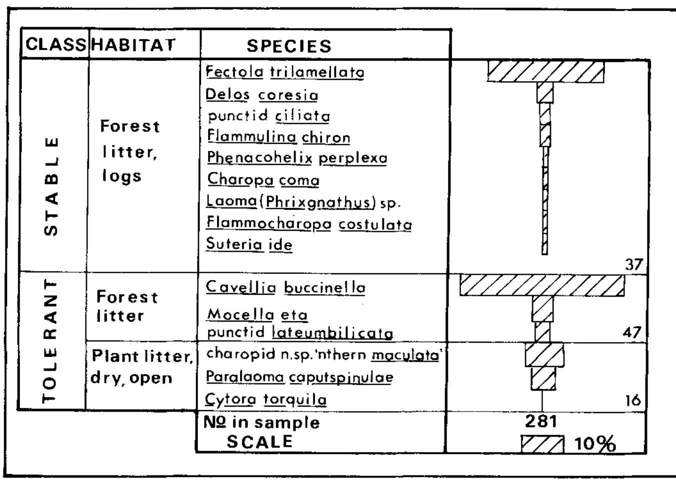


Fig. 23 — Percentage abundance of different species of landsnails from a sample of shell midden in Tamatean soil at Cooks Cove. Species divided into three habitats and two classes. Percentage abundance shown by boxes on right hand side.

Erosion is generally considered to follow forest clearance. All areas except the Central Otago basins and alpine areas were probably in forest before Maori settlement (McGlone, 1983). Man arrived during the Tamatean unstable phase, which had begun more than 800 years earlier, and the lowest charcoals in coastal sections mark the beginning of forest fires shortly before the Loisels pumice. The Maori burnt about half the forest (Wendleken, 1976), presumably whenever he could. The formation of Tamatean soils after some 300 to 400 years of burning is surprising.

Europeans cleared a further quarter of the forest. I recognise sediments deposited during the Hoatan unstable phase in the North Island and in the northern and eastern South Island, but not on the Canterbury Plains. Deposition by the lower Rakaia and Selwyn Rivers (Ward *et al.*, 1964), indicated by the distribution of Selwyn soils, has been relatively minor compared with deposition during earlier unstable phases. "Severe" erosion in the

South Island since European settlement (Gibbs *et al.*, 1945) does not appear to be reflected in the river deposits.

Forest clearance may possibly have accelerated erosion during unstable phases, and would appear to account for examples of severe erosion in the North Island since European settlement, but how much erosion since European settlement is due to forest clearance, and how much is due to the present unstable phase, is uncertain.

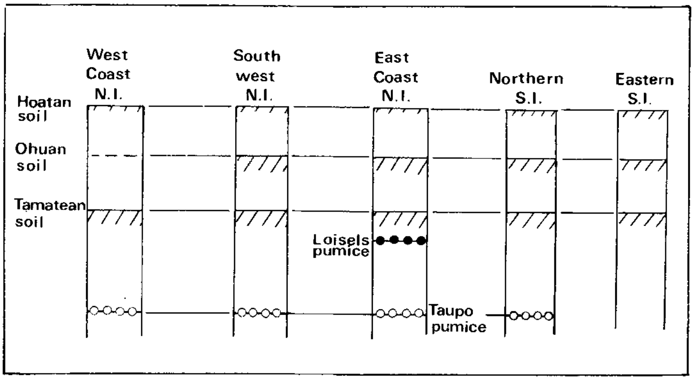


Fig. 24—Five columns to show correlation of the Hoatan, Ohuan and Tamatean soils present on the east and west coasts of the North Island, and the northern and eastern coasts of the South Island.

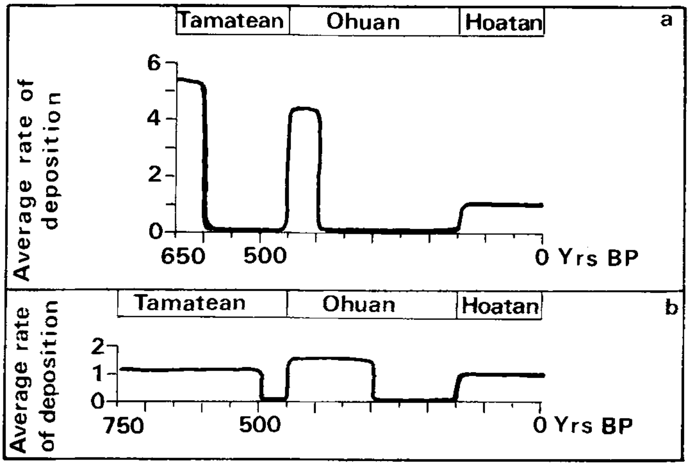


Fig. 25—Average deposition rates for deposits younger than the Loisels pumice along the North Island east coast. Rates expressed as a proportion of the rate for the last 150 years (=1).
a = rates for deposition using the adopted ages for the Taupo pumice (1800 years BP), Loisels pumice (650 years BP), the end of the Tamatean unstable phase (600 years BP), the beginning of the Ohuan unstable phase (450 years BP), and the end of the Ohuan unstable phase (400 years BP).
b = rates of deposition assuming a maximum error of +100 years for the adopted age of the Loisels pumice and −100 years for the adopted age of the end of the Tamatean unstable phase and the Ohuan unstable phase.

Average deposition rates for deposits younger than the Loisels pumice are given in Fig. 25. The rates are determined in Appendix 4 from sediment thicknesses at 16 selected sections along the east North Island coast between the Coromandel Peninsula and Cape Palliser. They are expressed as a proportion of the rate for the last 150 years, which is given the value of one unit. For this calculation it is assumed that all deposition occurred during unstable phases. Two sets of rates are shown. The set shown by Fig. 25a uses the adopted ages for stratigraphic events given above. The set shown by Fig. 25b assumes a maximum error of 100 years for the adopted ages of the Loisels pumice and the formation of the Tamatean and Ohuan soils. There is every indication that the rate of deposition has decreased with time or remained steady, and I therefore consider that the depositional episodes were independent of vegetation clearance and hence of cultural influence.

The phases are interpreted by me to be climatically controlled. Slips are the most important kind of erosion in much of New Zealand (Gibbs *et al.*, 1945; Grange and Gibbs, 1947) and are caused by occasional very heavy and long-continued rain. Thunderstorms generally appear to be unimportant, because they rarely last long enough, but the effect of tropical and extra-tropical cyclonic storms on erosion, even under forest, is well-

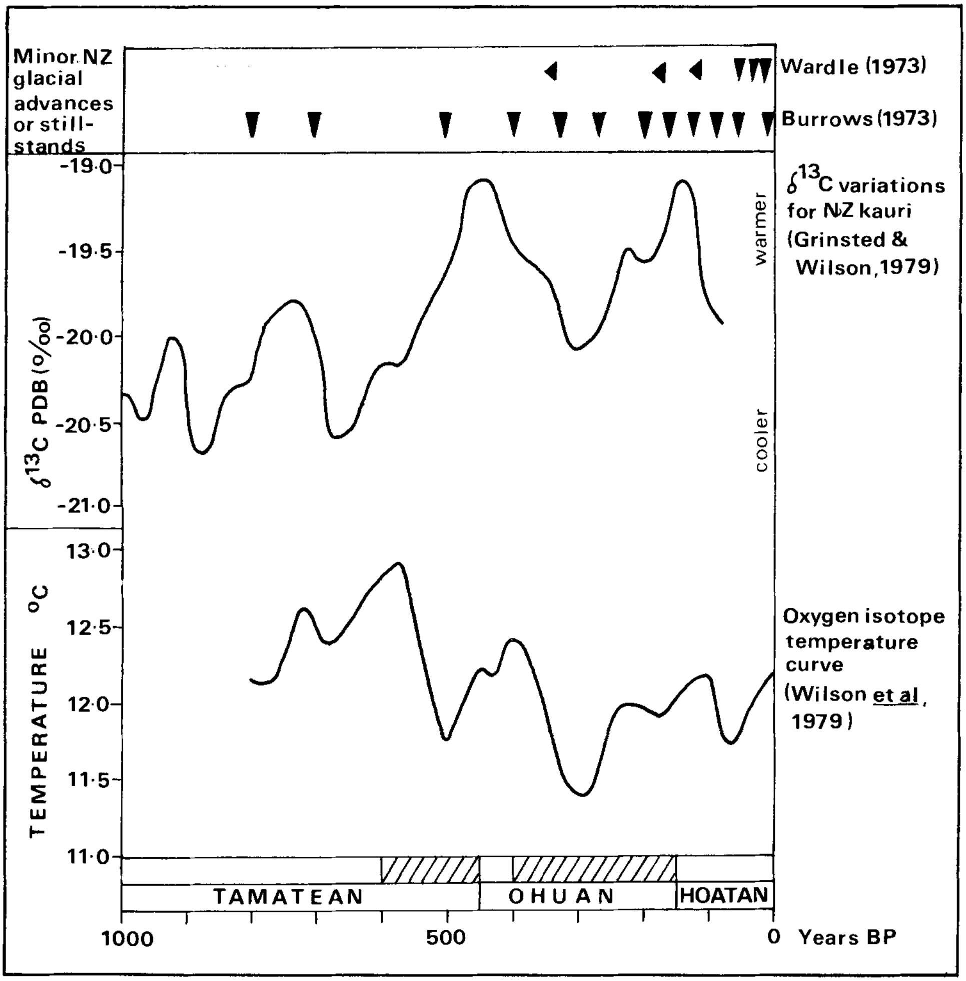


Fig. 26—Depositional episodes compared with existing climatic records. Cross-hatching = stable phases, no hatching = unstable phases. Downwards-pointing arrowheads = times of minor glacial advances or still-stands; sidewards-pointing arrowheads = minimum dates of glacial advances or still-stands.

established (Selby, 1967; Pain, 1969; Grant, 1983; Grant *et al.*, 1978). The worst of the storms cause widespread flooding, severe forest damage, bring down many slips, and greatly increase the transport of sediment in river channels (Kidson, 1930; Thomson, 1936; Gabites, 1968; Tomlinson, 1975; Barnett, 1938; Grant, 1983; Grant *et al.*, 1978).

I have shown above that during the Tamatean stable phase forest vegetation established on formerly unstable sand in the Manawatu and at Flat Point. Favourable climatic conditions for erosion and subsequent deposition would be frequent tropical and extra-tropical storms and drying windy conditions, which discourage the establishment of vegetation on dunes and on coasts. Favourable climatic conditions for soil formation would be fewer tropical and extra-tropical storms, and more uniformly moist conditions with less violent winds, encouraging the establishment of vegetation on dunes and on coasts.

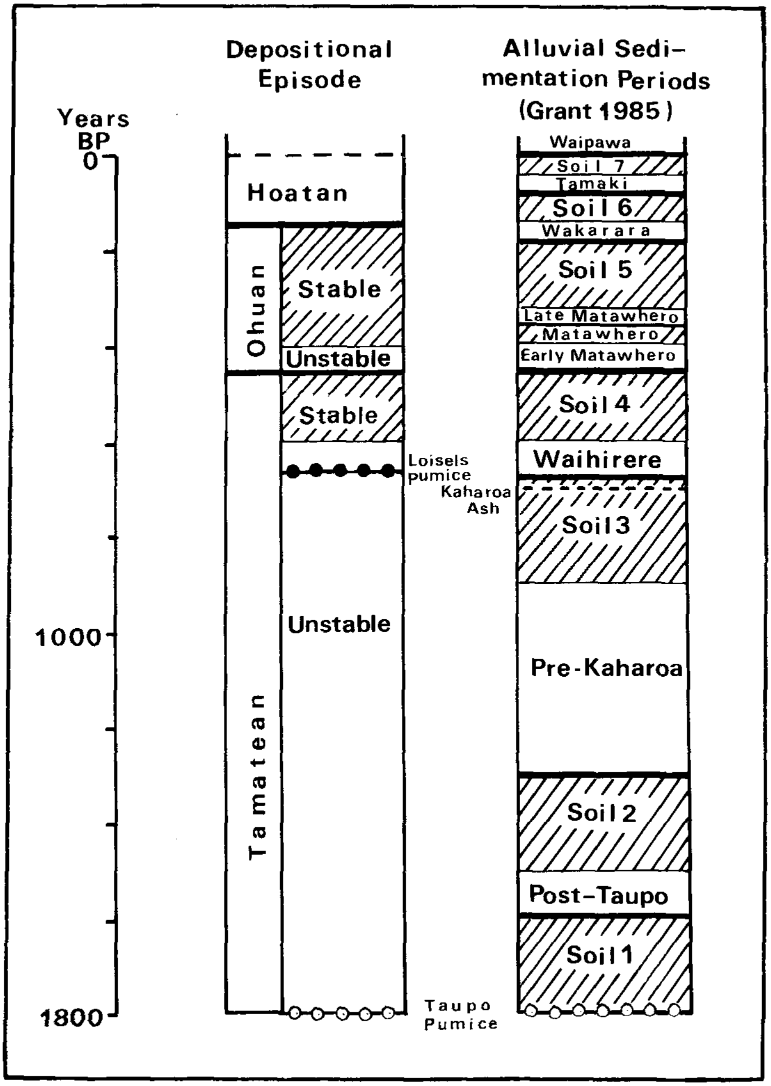


Fig. 27—Correlation of Depositional Episodes with Alluvial Sedimentation Periods of Grant (1985). Stable phases and tranquil intervals shown cross-hatched.

Depositional episodes and existing climatic records are compared in Fig. 26. Studies of some South Island glaciers appear to indicate minor advances or still-stands superposed on a gradual retreat that began at an uncertain date. The advances or still-stands began on the west coast *c.* 400 years ago (Wardle, 1973), and on the east coast *c.* 800 years ago (Burrows, 1973), but they do not correlate with either stable or unstable phases. There is somewhat better correlation between depositional episodes and temperatures inferred from oxygen isotope measurements on the northwest Nelson stalagmites reported by Wilson *et al.* (1979), and temperature variations inferred from short term $\delta^{13}C$ variations in New Zealand kauri trees (Grinsted and Wilson, 1979). As illustrated in Fig. 26, unstable phases appear to correlate with times of high temperatures; stable phases with times of low temperatures.

It is possible that tropical storms may occur more frequently during warm periods than during cold periods (Lamb, 1972: 132). Grant (1981) has shown a significant increase in the frequency of tropical cyclones in the southwest Pacific since about 1954, which is correlated with an increase in summer-autumn temperatures (Grant, 1983). He suggests that there was probably an increase in the frequency of extra-tropical cyclones at about the same time (Grant, 1983). If tropical and extra-tropical storms are responsible for depositional episodes, then obviously they are very important, but further details of the topic are outside the scope of this paper and cannot be discussed further.

CORRELATION OF DEPOSITIONAL EPISODES WITH PERIODS OF EROSION AND ALLUVIAL SEDIMENTATION IN NEW ZEALAND

Eight periods of erosion and alluvial sedimentation in New Zealand since the Taupo Pumice are described by Grant (1985), each followed by a tranquil interval when erosion rates were low and soils formed on the fresh alluvium (Fig. 27). Adopted dates for the periods are based on radiocarbon, tree rings and historic records (Grant, 1985). Stratigraphic marker beds are Taupo Pumice and Kaharoa Ash (Healy *et al.*, 1964).

Grant adopts a date of 690 years BP for Kaharoa Ash, which is close to the date of 650 years BP adopted by McFadgen (1982) for Loisels pumice. Kaharoa Ash appears to have been erupted just before the onset of Grant's (1985) Waihirere alluvial sedimentation period; Loisels pumice, which is described by Pullar (1959) in Waihirere soil at the Maraetaha River mouth, would have been deposited during the same period. Correlation of my proposed depositional episodes with Grant's (1985) periods of erosion and alluvial sedimentation (Fig. 27) is based on the Taupo Pumice, Loisels pumice, and the adopted dates for the periods.

There is good agreement between my stable phases and the tranquil intervals represented by Grant's (1985) soils 4 and 5, but overall there are fewer stable phases in the coastal deposits than tranquil intervals in the alluvial sequence, indicating the possibility of periods of soil formation as yet unrecognised within the Tamatean and Hoatan unstable phases. Coastal dune systems, however, are very fragile and susceptible to wind erosion, and the soils may not have survived. Alternatively, climatic conditions favouring low rates of erosion and soil formation on alluvium may not always favour soil formation on coastal dunes.

CONCLUSIONS

Late Holocene dune sand and coastal alluvium accumulated during three major depositional episodes. The first episode appears to have begun more than 1,800 years ago; its unstable phase (accumulation), which may have been interrupted by periods of soil formation, continued until after the first (Polynesian) human settlement. The second episode began about 450 years ago; its unstable phase appears to have been short, lasting only about 50 years. The third episode began about 150 years ago, shortly after European contact, and its unstable phase still continues.

The depositional episodes do not appear to be directly related to forest clearance by man, to earthquakes, volcanic eruptions, or sea level changes, but they do appear to be related to climate. Inferred climate during unstable phases was windy and dry, and during stable phases (soil formation), less windy and moist.

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Cadastral Maps

S.O. 12963L. Held by the Department of Lands and Survey Wellington District Office.
S.O. 1270 and S.O. 1271. Held by the Department of Lands and Survey Dunedin District Office.

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APPENDIX 1

SOIL DESCRIPTION OF SECTION ON LEFT BANK OF TE UNU UNU STREAM, FLAT POINT (T27/581919)*

Depth (cm)	*Layer*	*Horizon Designation***	*Soil Organic Matter**** (%)	*Description*
Hoatan Chronozone				
0-20	1	A	2.0	Dull yellow orange (10YR6/3)+ silty sand, very friable, moderately developed very fine to fine nut structure, few fine roots, indistinct boundary.
20-63	2	C	0.9	Dull yellow brown (10YR4/3) sand, very friable, single grain with some weakly developed fine nut and fine granular structure, few fine roots, indistinct irregular boundary.
Ohuan Chronozone				
63-75	3	luA.1	2.2	Brownish black (10YR2/3) sand with many fine distinct dull yellow brown (10YR4/3) mottles, very friable, weakly developed fine and medium granular and very fine nut structure with some single grain, very few fine roots, indistinct boundary.
75-90	4	luA.2	1.8	Brownish black (10YR2/2) sand, very friable, weakly developed fine and medium granular structure with some single grain, very few fine roots, indistinct boundary.
90-107	5	C	0.6	Dark brown (10YR3/3) sand, loose, single grain, very few fine roots, indistinct boundary.
Tamatean Chronozone				
107-123	6	2uA	1.2	Brownish black (10YR2/2) sand, very friable, weakly developed fine to very fine nut structure with some single grain, very few fine roots, very rare fragments of charcoal and shell, indistinct boundary.
123-160+	7	C	0.5	Dark brown (10YR3/3) sand, loose, single grain, no roots.

* This soil description was recorded after the generalised section given in the text had been cut back 1 m to 2 m by stream erosion.

** According to Taylor and Pohlen (1970).

*** Determined according to Kosaka *et al.*, (1963). Small shell fragments (< 0.5 mm) were seen in layers 3 to 7. Only layer 7 (basal) reacted to dilute acid. Carbonate determinations showed only 0.1% for layer 7. It is considered that carbonate levels are lower in layers 1-6. Carbon determinations are consistent with the colour (value) of the buried soils.

\+ Soil colours according to Oyama and Takehara (1967).

APPENDIX 2

DATA FOR DETERMINING THE VEGETATION THAT GREW ON A FOXTON PALEOSOL: ACID HYDROLYSIS OF SODIUM HYDROXIDE EXTRACTED HUMIC ACIDS.

K. R. Tate, N.Z. Soil Bureau, DSIR, Lower Hutt.

Humic acids were extracted from two paleosol samples, one at archaeological site N148/1 and one from a Motuiti dune 600 m south of the site, using Goh's (1970) modification of the method of Gascho and Stevenson (1968). Both paleosols were formed in sand of the Motuiti Dune-building Phase.

After prolonged hydrolysis of the humic acids with 6M HCl the products were separated from the humic acid residue, and analysed by gas liquid chromatography (glc). Large amounts of vanillic acid (4-hydroxy-3-methoxybenzoic acid) were detected in the hydrolysis products, while 4-hydroxy benzoic acid and syringic acid (4-hydroxy-3, 5-dimethoxy benzoic acid) were either absent or present in very small amounts.

The results of the investigation are summarised in the following Table. The glc data indicate that the vanillic acid/4-hydroxy benzoic acid ratio was high in both samples, as compared with ratios obtained for soil humic acids extracted from soils under hardwoods (*ca.* 2-3) or grasses (*ca.* <0.5).

Source of Humic Acid	*Depth (cm)*	*Soil Carbon (%)*	*C/N*	*Ratio of vanillic acid: 4-hydroxy benzoic acid in humic acid hydrolysate.*
Paleosol, archaeological site	20-25	1.2	15	>10
Paleosol, Motuiti dune	74-84	1.3	13	>10

The agreement between the data is consistent with the hypothesis that the archaeological site and Motuiti dune samples are from the same paleosol.

The acid hydrolysis experiment indicates that the vegetation present at the archaeological site prior to Maori occupation contained lignin with predominantly vanillyl units—this is typical of gymnosperm lignin.

I have previously examined a humic acid extracted from a topsoil beneath white pine (*Podocarpus dacrydioides*), which I commented on at the 1971 Radiocarbon Users Conference. In that case, a high vanillic acid/4-hydroxy benzoic acid ratio was obtained.

However, the present techniques do not allow me to be more specific than to say that a softwood, rather than a hardwood or grassland vegetation, probably covered the site prior to Maori occupation.

APPENDIX 3

DATA FOR DETERMINING THE VEGETATION THAT GREW ON A FOXTON PALEOSOL: IDENTIFIED CHARCOALS

B. P. J. Molloy, Botany Division, D.S.I.R., Christchurch.

Sample	*Genus/species*
Paleosol, archaeological site	*Podocarpus dacrydiodes* *Podocarpus totara* *Leptospermum* sp. (probably *ericoides*) *Coprosma* sp. *Pseudopanax* sp. (*colensoi-arboreum* type)
Paleosol, Motuiti dune	*Podocarpus dacrydiodes* *Leptospermum ericoides*

In both samples the podocarp (softwood) elements tended to dominate. The species quite likely grew *in situ* or at least nearby.

APPENDIX 4

RATES OF SEDIMENT DEPOSITION ALONG THE EASTERN NORTH ISLAND COAST SINCE THE TAUPO PUMICE

Average rates of sediment deposition along the eastern North Island coast (Fig. 25 and Table 3), are based on thicknesses at 16 selected sections given by Wellman (1962b: Sections 5, 7-9, 14-15, 18-19, and 21), Smart and Green (1962: Tairua), Leahy (1974: Hot Water Beach), and in this paper (Sections 1-5). Correlation of the coastal sections with the chronozones is given in Fig. 17.

All deposition is assumed to occur during unstable phases. Rates are calculated from thicknesses between marker beds: the Taupo pumice, Loisels pumice, the Tamatean buried soil, and the Ohuan buried soil. Thicknesses are measured to the bottoms of the pumice deposits and to the tops of the buried soils, and are normalised by expressing them as a proportion of the thickness between the top of the Tamatean soil and the ground surface, which is the largest stratigraphic interval present in all sections. For ease of comparison, rates are expressed as a proportion of the rate for the last 150 years.

The Taupo pumice occurs in 4 sections, the Loisels pumice in 11 sections and the buried soils in all 16 sections. The numbers of sections (n) on which the rates are based are: from the Taupo pumice to the Loisels pumice, 4; from the Loisels pumice to the Tamatean soil, 11; from the Tamatean soil to the Ohuan soil, 16; and from the Ohuan soil to the ground surface, 16. Errors shown with the rates are standard errors of the mean of n sections (Snedecor and Cochran, 1967).

Two sets of rates are shown in Table 3 for deposits younger than the Loisels pumice. The first set, labelled (a), uses the adopted ages for stratigraphic events. The second set, labelled (b), assumes a maximum error of 100 years for the adopted ages of the Loisels pumice, and the formation of the Tamatean and Ohuan soils. These errors do not significantly affect the rate of deposition between the Taupo pumice and Loisels pumice.

The rates of deposition between the Taupo pumice and the Loisels pumice, as determined from only 4 sections, is low. Rates of infilling of the Gisborne Plains Basin, using volumes determined by Pullar and Penhale (1970) for the period between the Taupo pumice and Tamatean soil formation, are also low. The Pullar and Penhale (1970) data support the rates determined using the coastal data.

From the coastal data it would appear that there is every indication that deposition since the Loisels pumice has decreased with time or has remained steady.

Table 3—Rates of deposition in eastern North Island coastal sections

Taupo pumice to Loisels pumice	Loisels pumice to top of Tamatean buried soil	Top of Tamatean buried soil to top of Ohuan buried soil	Top of Ohuan buried soil to ground surface
t = 1,150 years t′ = 1,050 years n = 4	t = 50 years t′ = 250 years n = 11	t = 50 years t′ = 150 years n = 16	150 years n = 16
a = 0.2 ± 0.1 b = 0.3 ± 0.1	a = 5.4 ± 0.4 b = 1.1 ± 0.4	a = 4.4 ± 0.1 b = 1.5 ± 0.1	1.0 ± 0.1

t = time intervals for unstable phases between marker horizons listed at heads of columns. Intervals calculated using adopted ages for the Taupo and Loisels pumices, the end of the Tamatean unstable phase, and the beginning and end of the Ohuan stable and unstable phases.
t′ = time intervals assuming maximum errors of 100 years for the adopted ages of the Loisels pumice and end of the Tamatean and Ohuan unstable phases.
a = rates of deposition for each time interval t expressed as a proportion of the rate for the last 150 years.
b = rates of deposition for each time interval t′ expressed as a proportion of the rate for the last 150 years.
n = number of sections used to measure rates.