Journal of the Royal Society of New Zealand

ISSN: 0303-6758 (Print) 1175-8899 (Online) Journal homepage: https://www.tandfonline.com/loi/tnzr20

Palynology, sedimentology and environmental significance of Holocene swamps at northern Kaitoke, Great Barrier Island, New Zealand.

M. Horrocks , J. Ogden , S. L. Nichol , B. V. Alloway & D. G. Sutton

To cite this article: M. Horrocks , J. Ogden , S. L. Nichol , B. V. Alloway & D. G. Sutton (2000) Palynology, sedimentology and environmental significance of Holocene swamps at northern Kaitoke, Great Barrier Island, New Zealand., Journal of the Royal Society of New Zealand, 30:1, 27-47, DOI: 10.1080/03014223.2000.9517608

To link to this article: https://doi.org/10.1080/03014223.2000.9517608

Published online: 30 Mar 2010.

© Journal of The Royal Society of New Zealand,
Volume 30, Number 1, March 2000, pp 27–47

Palynology, sedimentology and environmental significance of Holocene swamps at northern Kaitoke, Great Barrier Island, New Zealand.

M. Horrocks[1], J. Ogden[2], S. L. Nichol[3], B. V. Alloway[4], D. G. Sutton[1]

Pollen and sediment analyses of two cores from coastal freshwater swamps at northern Kaitoke (Kaitoke Swamp and Police Station Swamp), Great Barrier Island, show that c. 7300 calibrated yr B.P. Kaitoke Swamp was an estuary with tidal flats. *Avicennia*, now absent from the swamp area, was present in the estuary. By c. 4500 yr B.P. fresh water conditions had developed at the Kaitoke Swamp site as marine influences decreased. Around the same time, fresh water swamp conditions commenced at the Police Station Swamp site on the surface of a low lying area of a Late Pleistocene dune. A sandy layer at Kaitoke may represent rapid infilling followed by a dry soil surface until c. 1000 yr B.P. Conifer-hardwood forest on the hills surrounding the sites c. 7300–c. 1800 yr B.P. was dominated by *Dacrydium* and *Metrosideros*. During this period, environmental conditions were relatively stable, with little change in forest composition. Between 1800 yr and 800 yr B.P. Kaitoke Swamp was reflooded, and the Police Station Swamp extended as a shallow lake over the nearby dune flat. These new shallow swamps were invaded by swamp forest (mainly *Dacrycarpus* with some *Laurelia*). The presence of charcoal and *Pteridium* spores above the Kaharoa Tephra suggests that major Polynesian deforestation at northern Kaitoke began c. 600 calibrated yr B.P.

Keywords palynology, sedimentology, Holocene, coastal geomorphology, disturbance, Kaharoa Tephra, Rotoehu Tephra, Great Barrier Island

INTRODUCTION

A few Late Quaternary pollen studies from the Auckland region have provided information relating to vegetation and environmental change. From a pre-human pollen sequence from Lake Waiatarua on the Auckland isthmus, Newnham & Lowe (1991) described a Late Glacial to Mid Holocene (12 000–4000 yr B.P.) record in which local and regional vegetation changes point to a mild, moist and weakly seasonal early Holocene climate, which subsequently became drier with greater seasonal temperature extremes. Records from the Auckland region covering the Late Holocene and showing human influences have been provided by Hume & McGlone (1986) and Elliot & Neall (1995), who found evidence that Polynesian deforestation began around the Waitemata Harbour at 700 ± 100 conventional yr B.P. and on Motutapu Island at 980 calibrated yr B.P.

[1] Centre for Archaeological Research, University of Auckland, Private Bag 92–019, Auckland, New Zealand
[2] School of Environmental & Marine Sciences, University of Auckland, Private Bag 92–019, Auckland, New Zealand
[3] Department of Geography, University of Auckland, Private Bag 92–019, Auckland, New Zealand
[4] Institute of Geological & Nuclear Sciences, P.O. Box 30–368, Lower Hutt, New Zealand

Great Barrier is the largest island in the Hauraki Gulf and forms the far eastern boundary of the Auckland region. Pollen preserved in swamps that have developed behind Holocene coastal dunes on the island record the island's ecological history. Results of pollen and sediment analyses of two sediment cores from northern Kaitoke on Great Barrier Island are presented here. The cores provide a c. 7300 year record of the transition from estuary to fresh water swamp.

THE STUDY AREA

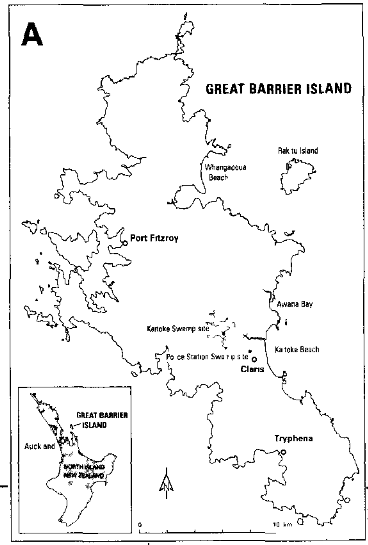
Great Barrier Island, located in the outer Hauraki Gulf, Auckland, is the largest off-shore island in New Zealand, comprising an area of approximately 28 500 ha. The island interior is steeply dissected, with several craggy peaks of volcanic origin up to 620 m altitude. The base rock is predominently Jurassic-Permian greywackes and shales (Marjoribanks 1976). On the exposed eastern side of the island, a series of swamp systems, impounded by sand dunes, are oriented either parallel to the shoreline or extend inland into valleys formerly occupied by estuaries.

The Kaitoke swamp system is located on the southern central east coast of Great Barrier (36°14′S, 175° 28′E) (Fig. 1). It is 6.5 km long in the northwest-southeast direction and highly segmented as a result of dune formation and extensive European drainage. The immediate study area is the northern half of this system (i.e., northern Kaitoke, that part of the swamp system north of Claris). Northern Kaitoke comprises an area of mainly fixed dunes (with a few small swampy areas) immediately north of Claris, and the Kaitoke Swamp proper, a large wetland 320 ha in area, lying northeast of these dunes and extending up to 4.5 km inland. The swamp is partially bisected in the west-east direction by a "tongue" of higher, drier land extending seawards. Most of the tongue comprises old dunes, with crenate ridges extending across it clearly visible from the air. Parts of the seaward side of Kaitoke Swamp have been drained in the past, but the area is still predominantly swamp.

The nearest weather station to northern Kaitoke is 10 km north-west at Port Fitzroy. Mean annual rainfall is 1839 mm (1961–97: NIWA 1997). Rainfall is distributed throughout the year with maximum falls in March, June and August, and minimum falls in October and December. Mean daily maximum air temperature is 19.4 °C, and the minimum 11.8 °C.

Existing vegetation cover on Great Barrier Island reflects a history of intense and widespread modification by people. The predominant current vegetation type is *Kunzea ericoides* and/or *Leptospermum scoparium* regenerating forest, with *Cyathea dealbata* frequently forming a major part of the sub-canopy (New Zealand Map Series 336–02, 1996). Areas of podocarp-hardwood forest are found in the far south, and especially the far north, of the island. Predominant canopy species in this forest are *Beilschmiedia taraire*, *B. tawa* and *Dysoxylum spectabile* with occasional *Metrosideros robusta*, *Knightia excelsa*, *Vitex lucens* and *Dacrydium cupressinum*. Some regenerating *Agathis australis* forest, with occasional very large emergent trees, survives in the central part of the island. *Dacrydium cupressinum*, *Phyllocladus trichomanoides* and hardwood species also form part of the canopy of this forest type. The few small patches of coastal forest remaining on Great Barrier are dominated at canopy level by *Metrosideros excelsa*, *Beilschmiedia taraire*, *B. tawa* and *Dysoxylum spectabile*, with less common *Knightia excelsa*, *Vitex lucens*, *Corynocarpus laevigatus*, *Nestegis apetala* and *Planchonella novo-zelandica*. Mobile fore-dunes on the east coast are stabilised by sand-binding *Desmoschoenus spiralis* and *Spinifex hirsutus*. The vegetated dunes further inland are covered by mats of *Muehlenbeckia complexa*, *Pomaderris phylicifolia* and *Cassinia vauversilliae* bushes, with some exotic *Lupinus arboreus*.

Freshwater swamp associations on Great Barrier include *Typha orientalis*, *Cyperus ustulatus*, *Leptospermum scoparium*, *Baumea* spp. and *Gleichenia dicarpa* (New Zealand



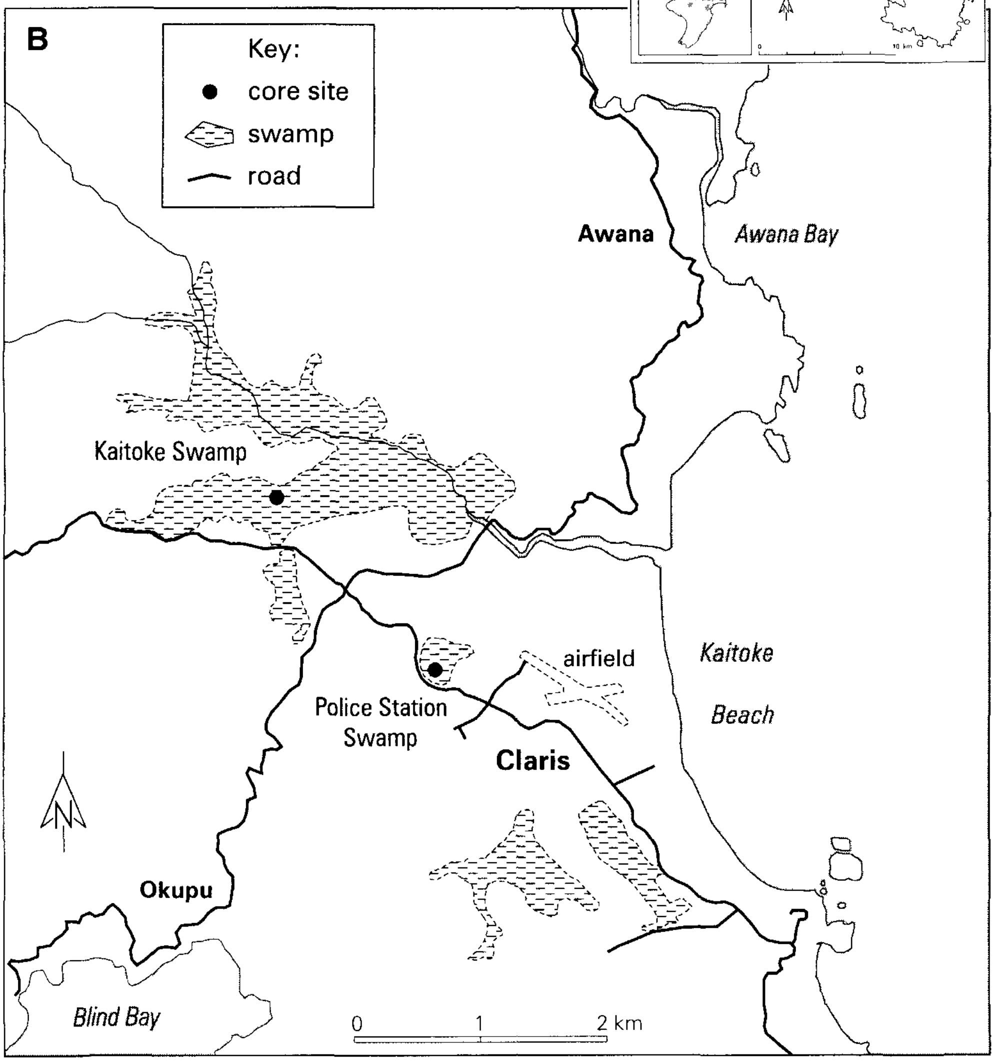


Fig. 1 (A). Great Barrier Island. (B). Central eastern Great Barrier Island showing location of Kaitoke Swamp, Police Station Swamp and core sites.

Map Series 336–02, 1996; Rutherford 1998). Estuarine wetland associations are dominated by *Avicennia marina* with *Zostera muelleri*, *Juncus maritimus*, *Leptocarpus similis* and *Plagianthus divaricatus*. Saltmarsh is dominated by *Salicornia australis*, *Baumea juncea* and *Leptocarpus similis*. The Kaitoke Swamp vegetation has been mapped by Rutherford (1998).

METHODS

Two sites at northern Kaitoke were examined for stratigraphy and pollen profiles: Kaitoke Swamp (New Zealand Map Series 336 02 301495) and Police Station Swamp (*ibid.*, 314481). (As the latter site is unnamed, we informally name it after its proximity to the local police station.) Site locations are shown in Fig. 1.

Continuous sediment cores were collected in aluminium tubes using a vibracoring system, with sediment compaction measured before core retrieval. The elevation of each core site was levelled relative to mean sea level, using high tide line on Kaitoke Beach as a local datum and tidal predictions for the secondary port of Tryphena. This provided levelling accuracy to within approximately 0.3 m.

In the laboratory, cores were split lengthwise, described and sediments were sub-sampled for grain size analysis. Tephric beds were also sub-sampled for geochemical characterisation and correlation studies. The Kaitoke Swamp core was sub-sampled at 32 locations for detailed grain size analysis. Because the Police Station Swamp core recovered mostly peat, we did no detailed grain size analysis on this core. Grain size was measured using a laser particle sizer (Galai™) that determines particle size based on the time of transition principle, whereby the larger the particle diameter the longer the time of transition across the path of the laser beam. Approximately 1 g of sample was introduced to a solution of filtered water and 10% calgon to assist particle dispersion, with data collection set to the 99% confidence level. Results reported here are for grain size classes expressed as percent of total particle volume, which is essentially equivalent to a mass based measurement of grain size distribution.

Samples were prepared for pollen analysis by the standard acetylation and hydrofluoric acid method (Faegri & Iversen 1989), and bleached. The pollen sum was at least 250 grains, excluding swamp plants and ferns (except *Pteridium*, spores of which are widely dispersed: McGlone 1982). *Leptospermum* and *Myrsine* were also excluded from the pollen sum, since in this case they probably grew primarily on or directly adjacent to the swamp. The software packages TILIA and TILIAGRAPH were used to construct pollen diagrams (E. Grimm, Illinois State Museum, Springfield, Illinois). In the "dinoflagellate" category in the diagrams, only marine dinoflagellate cysts are included since they are easy to identify compared with brackish or freshwater cysts, which generally appear as featureless "bags" (Traverse 1988). Pollen diagram zonation was facilitated by a stratigraphically constrained classification of pollen spectra using CONISS, which is included in the TILIA software package.

Cores were also sampled for conventional radiocarbon age determinations. Six radiocarbon dates were carried out by the University of Waikato (Wk). Calibrated dates, given in Table 1, are used in the text (B.P. refers to Before Present, where, by convention, A.D. 1950 is "Present"). For ease of comparison with other published dates, conventional (Libby) dates are also given in Table 1.

TEPHROSTRATIGRAPHY

Distal tephras, used as stratigraphic marker horizons, provide the key to understanding the relationships of aeolian and organic sequences at sites where stratigraphies and ages are not well known. In this study, two distal silicic tephras are recognised at northern Kaitoke and are enclosed within organic and aeolian deposits.

Table 1 Radiocarbon dates from sites at northern Kaitoke Notes (1) Libby date based on 5568 year half-life of ^{14}C (2) Range within which dates calibrated by reference to tree-ring curve lie (Stuiver & Reimer 1993, Stuiver et al 1998), allowing also 40 year offset for the Southern Hemisphere 0* represents a "negative" age B P

Site	Laboratory sample no	Sample type	Depth (cm)	Conventional yr B P (1)	Calibrated range based on one std deviation (2)
Kaitoke Swamp	Wk–5558	peat	105–106	Modern (<200)	NA
	Wk–5947	peat	108–110	300 ± 120	470–0*
	Wk–5948	sandy silt	255–260	4180 ± 100	4830–4460
	Wk–5557	mollusc shell	685–690	6800 ± 70	7370–7220
Police Station Swamp	Wk–6800	peat	71–73	1870 ± 170	1990–1560
	Wk–6398	peat	198–200	4470 ± 70	5290–4860

Table 2 Glass shard major element composition of Kaharoa and Rotoehu Tephras

			SiO_2	TiO_2	Al_2O_3	FeO	MgO	CaO	Na_2O	K_2O	Cl	H_2O	n
Kh	AT–172	Police Station Swamp (29–32 cm)	77 80	0 13	12 67	0 88	0 07	0 54	3 79	3 94	0 19	2 23	12
			(0 23)	(0 05)	(0 15)	(0 13)	(0 03)	(0 07)	(0 13)	(0 10)	(0 05)	(0 81)	
Kh	AT–178	Kaitoke Swamp (104–107 cm)	77 89	0 13	12 48	0 80	0 07	0 53	3 82	4 02	0 25	2 62	11
			(0 23)	(0 05)	(0 16)	(0 09)	(0 04)	(0 04)	(0 09)	(0 09)	(0 09)	(1 42)	
Kh	AT–179	(114–116 cm)	77 46	0 12	12 72	0 85	0 08	0 53	3 96	4 08	0 20	2 94	9
			(0 25)	(0 03)	(0 14)	(0 06)	(0 04)	(0 05)	(0 14)	(0 09)	(0 04)	(0 61)	
Kh	50009‡	Gavin Road Type Section near Mt Tarawera	78 21	0 06	12 53	0 75	0 07	0 50	3 81	4 02	—	2 63	9
			(0 16)	(0 02)	(0 11)	(0 05)	(0 03)	(0 03)	(0 10)	(0 10)		(1 10)	
	50010‡	(V16/174198)	78 47	0 08	12 47	0 63	0 08	0 47	3 73	4 03	—	2 57	11
			(0 30)	(0 04)	(0 19)	(0 09)	(0 03)	(0 04)	(0 26)	(0 12)		(0 97)	
	50011‡		78 37	0 08	12 63	0 58	0 06	0 45	3 79	4 03	—	2 04	10
			(0 22)	(0 03)	(0 14)	(0 12)	(0 02)	(0 10)	(0 11)	(0 11)		(0 75)	
Re	AT–176	Police Station Swamp (244 –255 cm)	78 03	0 19	12 49	0 90	0 21	0 87	3 96	3 10	0 24	4 34	10
			(0 30)	(0 09)	(0 20)	(0 09)	(0 08)	(0 05)	(0 16)	(0 13)	(0 08)	(1 05)	
Re	AT–101	Curreens' Drain Great Barrier Island	78 31	0 09	12 26	0 94	0 13	0 87	4 09	3 16	0 15	4 47	12
			(0 44)	(0 05)	(0 11)	(0 06)	(0 02)	(0 04)	(0 42)	(0 10)	(0 02)	(0 88)	
Re	AT–30	Papatoetoe Auckland Isthmus (R11/776683)	78 10	0 15	12 26	0 93	0 13	0 88	4 24	3 14	0 15	4 02	12
			(0 18)	(0 05)	(0 10)	(0 04)	(0 02)	(0 04)	(0 12)	(0 10)	(0 02)	(1 04)	
Re	AT–108″ (DJL–2B)	Mimiha Stream Bay of Plenty (V15/352638)	78 26	0 12	12 19	0 92	0 13	0 86	4 09	3 32	0 12	3 05	12
			(0 19)	(0 06)	(0 14)	(0 04)	(0 02)	(0 05)	(0 11)	(0 15)	(0 03)	(1 75)	

Notes Analyses made using a JEOL JXA–733 electron microprobe housed at Victoria University of Wellington A beam current of 80nA and a 20 µm beam diameter were used for all analyses All elements calculated on a water-free basis, with H_2O by difference from 100% All Fe expressed as FeO Mean and ± 1 SD (in parentheses) based on n analyses Analyst — B V Alloway ‡ Analyses courtesy of P C Froggatt (unpubl data), ″ Sample courtesy of D J Lowe, Waikato University Kh – Kaharoa Tephra, Re – Rotoehu Tephra

Kaharoa Tephra

Kaharoa Tephra, erupted from Mt Tarawera (within the Okataina Volcanic Centre) c. 600 calibrated yr B.P. (665 ± 15 conventional yr B.P.) (Lowe et al. 1998), is the product of the only rhyolitic (SiO2 > approx. 75% wt %) eruption documented in New Zealand in the past 1000 years (Froggatt & Lowe 1990). The on-land area covered by the 3 cm isopach is 30 000 km^2, which represents approximately one quarter of the North Island (Lowe et al. 1998; Newnham et al. 1998).

Distal deposits of Kaharoa Tephra on Great Barrier Island are expressed either as an approximately 2 cm thick tephra air-fall, or as concentrations of pumiceous ash dispersed in sand and organic mud sediments. Mineralogically, these tephric deposits are typically composed of vesicular and chunky glass shards (70–90%) with subordinate plagioclase and quartz (<10–15%). Deposits are also characterised by the presence of biotite phenocrysts with minor hypersthene, hornblende and rare Fe-Ti oxides.

The major element composition of glass shards was determined by electron microprobe (EMP) analysis (Table 2). On the basis of major element composition, Kaharoa Tephra correlatives from Kaitoke Swamp (AT–178 and –179) and Police Station Swamp (AT–172) are indistinguishable from Kaharoa Tephra samples analysed from its Gavin Road Type Section. Kaharoa Tephra has a distinctive glass major element composition (Table 2). Kaharoa Tephra and its correlatives can be unequivocally distinguished from other distal tephras derived from the Okataina Volcanic Centre (AT–30, –187 and –188) and from the widespread Kawakawa Tephra (AT–218) derived from the Taupo Volcanic Centre (Fig. 2).

Rotoehu Tephra

Rotoehu Tephra is a widespread pyroclastic unit from the Okataina Volcanic Centre and is known to cover a large area of the North Island from south of Lake Taupo (i.e., Howarth & Topping 1979) to Northland (Pullar et al. 1977; Newnham et al. in press) and from Taharoa on the west coast (Pain 1975) to East Cape (Vucetich & Pullar 1969; Berryman 1992). At present, the precise age of the Rotoehu Tephra is not known, but appears, from several radiocarbon dates (e.g., NZ–877A and NZ–1126A) of wood, charcoal and peat, to be at about the limit of radiocarbon dating. Berryman (1992) presented a stratigraphic age of 52 ± 7 ka for Rotoehu Tephra and Wilson et al. (1992) presented a K-Ar age of 64 ± 4 ka.

At northern Kaitoke, correlatives of Rotoehu Tephra occur as concentrations of glass shards within aeolian sands underlying, and protruding through, coastal freshwater swamp deposits. So far, no primary fall beds have been identified. Major element composition of glass shards (AT–176) from Police Station Swamp (2.45–2.70 m depth) and exposed in a deep drain on Curreens' property at Awana (AT–101) supports an Okataina Volcanic Centre origin (Table 2) and are indistinguishable from Rotoehu Tephra analysed from the Auckland isthmus (AT–30) and the Bay of Plenty (AT–108). Mineralogical examination of the Rotoehu Tephra correlatives (AT–176 and –101) did not reveal cummingtonite that is a characterisitic component of Rotoehu Tephra at its type area and in the Auckland isthmus area, where the primary fall bed is approximately 14 cm thick (B. Alloway unpubl. data). The apparent absence of these minerals reflects redeposition in the coastal environment and an initial small abundance of heavy mineral grains (calculated as 1.7% ± 1.5% in several Okataina-derived tephras by Lowe 1988).

Rotoehu Tephra (AT–30 and –108) and its Great Barrier correlatives (AT–176 and –101) can easily be distinguished from other distal tephras similarly derived from the Okataina Volcanic Centre (Fig. 2).

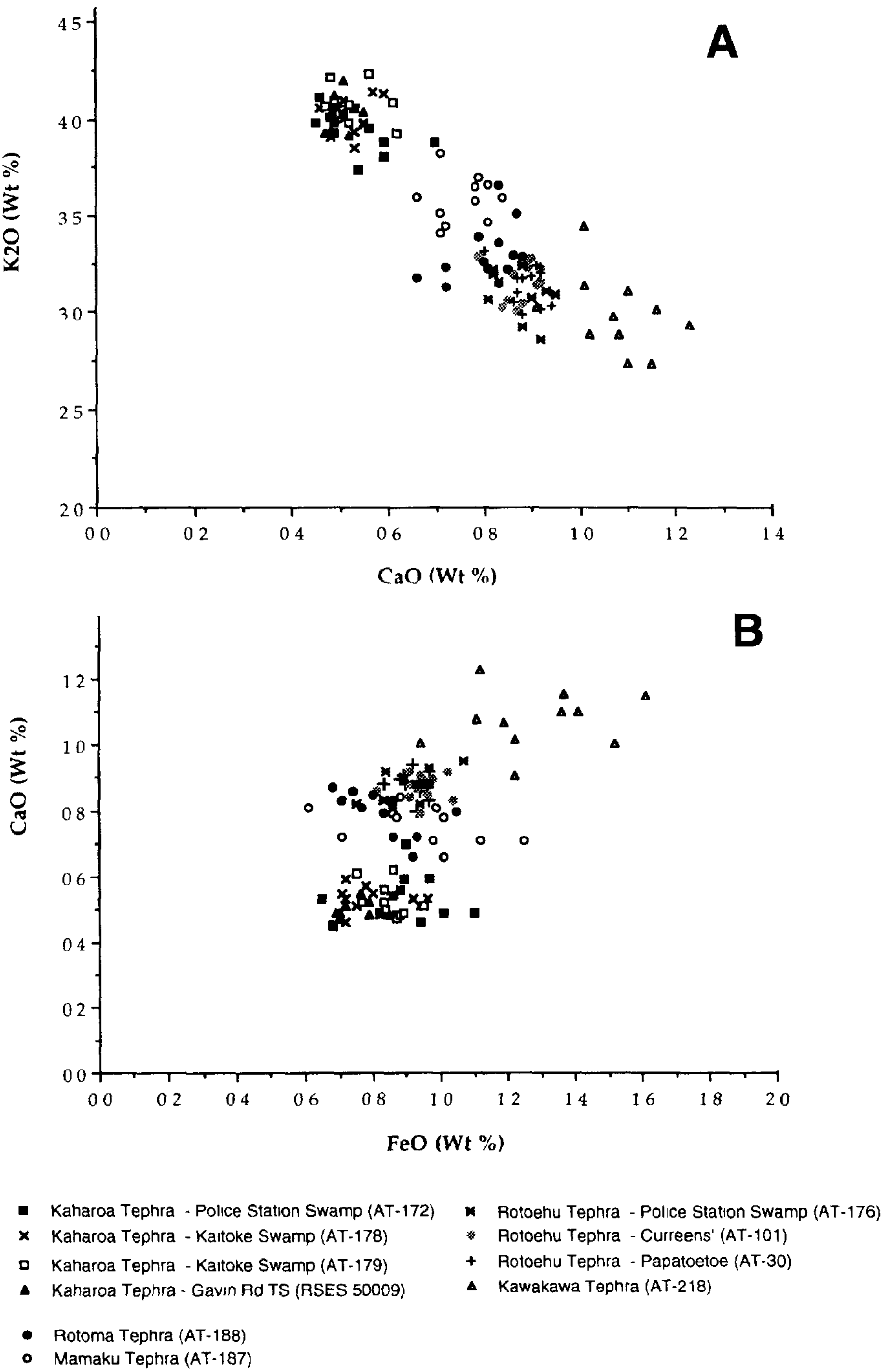


Fig. 2 (A). CaO verses K2O and (B). CaO versus FeO for glass shards (determined by EMP) of Kaharoa and Rotoehu Tephras and their distal correlatives, older distal tephras similarly derived from the Okataina Volcanic Centre (AT–30, –187 and –188) and the widespread Kawakawa Tephra (AT–218) derived from the Taupo Volcanic Centre.

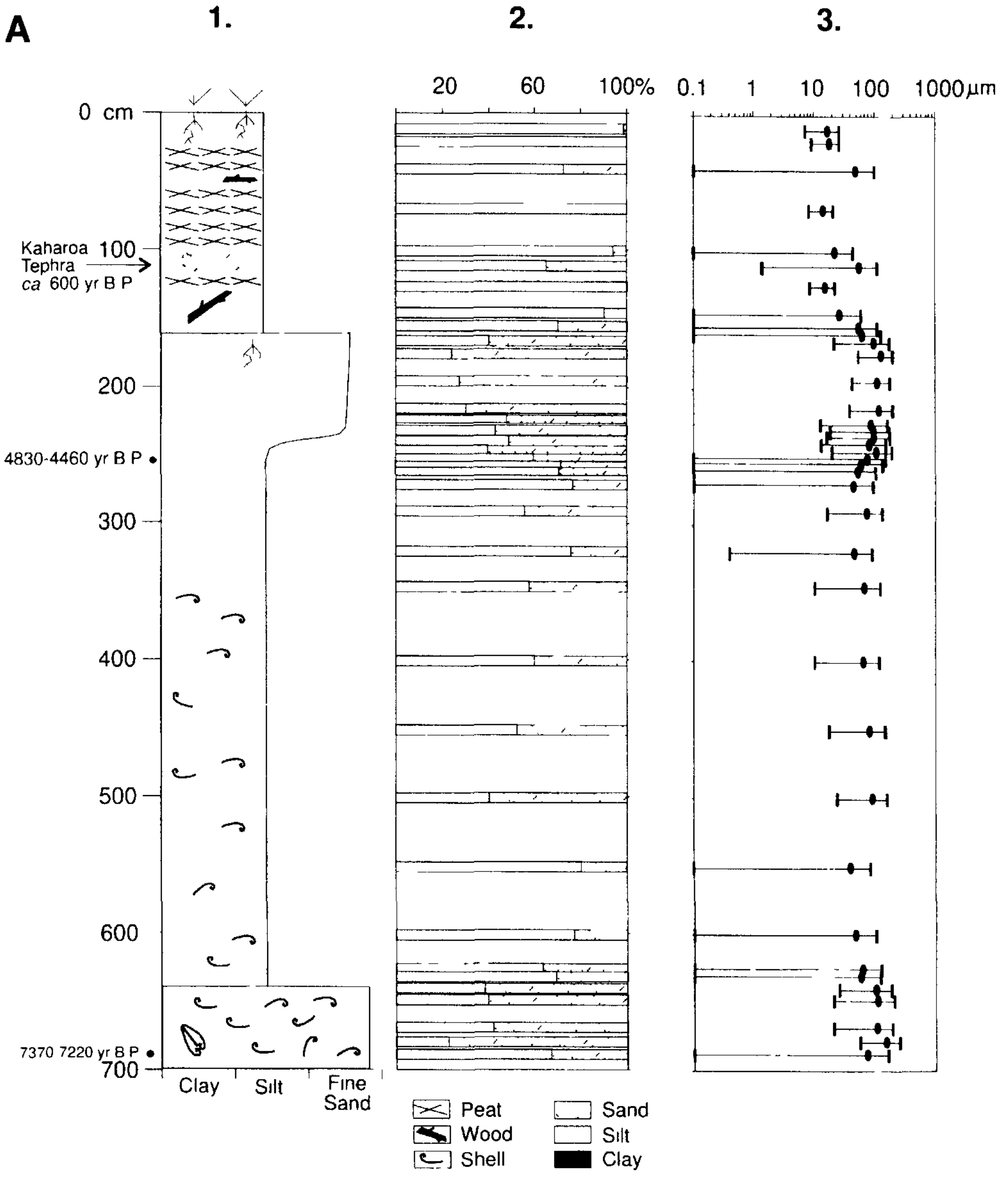
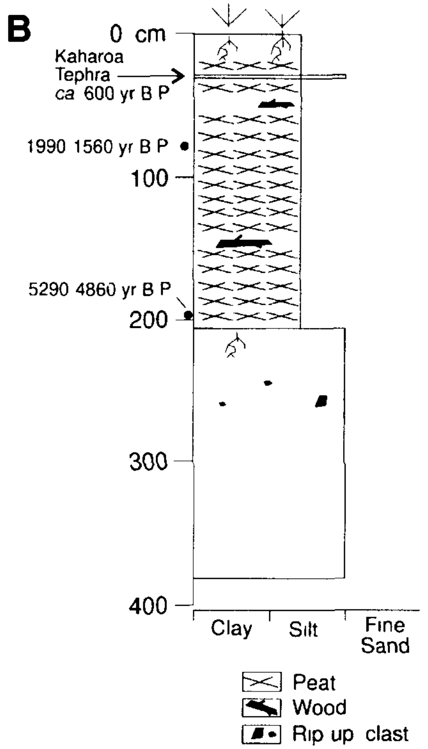


Fig. 3 Sediment analyses of northern Kaitoke cores (A. Kaitoke Swamp, B (next page). Police Station Swamp). 1. Graphic log of core, 2. Sand:silt:clay percentages of clastic sediment fraction, 3. mean grain size of clastic sediment fraction, plus/minus one standard deviation.

CORE ANALYSES

Kaitoke Swamp

Kaitoke Swamp is enclosed by hills with clay slopes on all sides except for the southeastern margin, which is bordered by fixed dunes. The core site is south of the "tongue" and is now 3.5 km from the sea (Fig. 1). Plant species predominating in the immediate vicinity of the site are: *Gleichenia dicarpa*, *Baumea juncea*, *B. articulata*, *B. teretifolia*, *Leptospermum scoparium*,



Typha orientalis and *Blechnum minus* (or *capense*) Also present in the vicinity but not within probably 10 m of the core site are *Baumea rubiginosa* and *Tetraria capillaris*

Sedimentology (Fig 3A)

This core reached a depth of 7 m at a site elevated 0 8 m above mean sea level The basal 60 cm of the core comprises fine-grained sand (mean size 74–154 µm) that is moderately sorted and mixed with numerous fragments of marine mollusc shells (Fig 3A) An articulated specimen of a large (7 cm long axis) *Mactra ovata* recovered from 7 m yielded a radiocarbon age of 7370–7220 calibrated yr B P (Wk-5557) At a depth of 6 4 m the basal sand grades upwards over 4 cm to a 3 6 m thick bed of coarse silt and very fine sand (mean size 40–90 µm) that is massive in structure and contains isolated shell fragments, organic flecks and rare sand-filled burrows Mollusc shells and shell fragments are found in this bed upwards to a depth of 3 4 m *Austrovenus stutchbury*, *Nucula hartvigiana* and *Macomona liliana* are present throughout, indicating a sandy mudflat exposed at low tide (Morton & Millar 1973) Other molluscs identified were *Atrina zealandica* (6 8 m), *Diloma substrata* (5 91 m and 4 45 m) and *Amphibola crenata* (5 27 m) The latter species characterises the upper (landward) edge of *Avicennia* flats in the Auckland region, so it suggests a shallowing of the water (less frequent inundation) with sediment accretion Fragments of *Pomatocerus caeruleus* and Echinoidea were also recorded at 6 5 m and 6 46 m, respectively Between 2 8 and 2 3 m depth, a subtle coarsening-upward transition occurs from very fine water borne sand towards a 0 7 m thick bed of fine water borne sand (mean size 87–128 µm) The upper 1 6 m of the core comprises silt (mean size 14–56 µm) with upward-increasing concentrations of organic material that becomes a dark peat toward the surface Microscopic analysis of samples from this upper peaty silt revealed low concentrations of Kaharoa Tephra dispersed between 1 04 m and 1 16 m

The basal deposit of shelly sand is interpreted as part of a shallow water estuarine deposit that formed under relatively high energy depositional conditions, as evidenced by the fragmented condition of all but the most robust shells The size and articulated condition of the fossil *Mactra* indicates that this particular specimen was not transported far from source and can be used as a good indicator of the age of enclosing sediments The radiocarbon age of this shell is consistent with the latter stages of sea-level rise across the New Zealand coast, according to the Holocene sea-level curve of Gibb (1986) Based on the elevation of this core site and the width of Kaitoke Swamp, the 3 6 m thick silt deposit probably accumulated in an estuarine basin that was initially ~5 m deep The basal shelly sand can be interpreted as a transgressive estuarine deposit

With continued sea-level rise until c 6000 yr B P , water depth at the core site would have increased, leading to the onset of relatively low energy depositional conditions that we interpret to be recorded by the 3 6 m thick deposit of silt The shift from *Mactra* to *Macomona* and *Austrovenus* supports this interpretation. The mollusc species present in this deposit indicate that the site was on the lower inter-tidal level of an estuarine flat (Morton & Millar 1973). Around 5000 yr B.P. marine dinoflagellates were absent from the sediments, and soon after this *Avicennia* pollen also disappeared, indicating a shift from estuarine to freshwater conditions. The sandy bed between 2.5 cm and 1.6 m depth probably represents transport of sand-sized sediment to the site from the landward end of the estuary. The nearby sand dunes of the "tongue" would have been a ready source of such coarser sediments, and they have clearly been eroded along their steep southern edge. The upper part of this deposit lacked pollen.

Above 1.6 m, the peaty silts with wood fragments represent freshwater swamp development followed by human impacts after the deposition of the Kaharoa Tephra. Thus the site was transformed from an estuarine flat to a freshwater swamp between c. 4600 and 1000–800 yr B.P. This considerable time interval is represented only by relatively coarse (freshwater?) sands, without pollen in the upper part. Moreover, this upper part has a very sharp boundary with the overlying sediments. Elsewhere this boundary is very firm when probed. This suggests that marine infilling of the Kaitoke estuary was followed by the deposition of riverine sands (derived from nearby dunes). If this sand infilling phase was followed by a reduction in water level at the site (due to stream downcutting elsewhere) then the dry sandy surface would be colonised by plants (e.g., *Leptospermum*), pollen would be lost due to aeration, and palaeosol development would commence. A subsequent rise in water level (c. 1000–800 yr B.P.) would have flooded the scrubland on the site and led to the development of the peaty silts characteristic of the upper part of the core. The non-polleniferous sand thus represents either a period of very rapid sand accumulation, or a period of soil formation. Whichever is the case, the pollen diagram is likely to have a substantial hiatus between c. 4500 yr and 1000 yr B.P.

Palynology (Fig. 4A)

The pollen profile of Kaitoke Swamp is divided into three zones, as follows:

Zone 1: 690–210 cm, c. 7300–c. 4200 yr B.P. The pollen sum throughout the zone is dominated by tall tree taxa, mainly *Dacrydium* (28–57%) and *Metrosideros* (up to 19%). Except for *Ascarina*, *Leptospermum* type and *Cyathea dealbata* type, all shrub, small tree, herb, swamp plant and fern taxa record very low values (generally <5%). *Avicennia*, extremely under-represented in pollen spectra (M. Horrocks unpubl. data), is recorded in a few samples, indicating that *Avicennia* plants were almost certainly present in the estuary, possibly close to the site. Marine dinoflagellates were present in progressively diminishing numbers from the bottom of the zone to 300 cm.

Absence of shells, marine dinoflagellates and *Avicennia* pollen in the upper part of the zone indicate diminishing marine influence at the site from c. 4500 yr B.P. The continued absence of significant swamp taxa pollen suggests that the site remained unvegetated, possibly as a fresh water lagoon or a deltaic deposit. The small but possibly significant amount of Malvaceae pollen in one of the upper zone samples suggests that *Plagianthus divaricatus* grew close by.

Lack of significant changes in pollen composition within the relatively long time span covered by this zone indicates stable environmental conditions in the catchment. Dryland vegetation surrounding this part of the harbour c. 7300–c. 4200 yr B.P. would have been podocarp-hardwood forest dominated by *Dacrydium* and *Metrosideros* with some *Phyllocladus*, *Libocedrus* (Cupressaceae), *Prumnopitys* and *Agathis*. *Dacrycarpus* appears to have been present but not abundant. *Cyathea*, *Ascarina* and *Rhopalostylis* were probably common in the sub-canopy, and *Leptospermum*/*Kunzea* would have been present on the margins *Nothofagus fusca* type (distant dispersers) appears to have been of minor importance during this period (and subsequently) Its persistent presence in low amounts throughout the core may indicate wind transport predominantly from the southwest, as this is the direction in which extensive stands of *Nothofagus* are to be found today (the Coromandel Peninsula and Hunua Ranges)

Sandier non-polleniferous sediments occur between Zones 1 and 2 (210–150 cm) The percent sand, which was probably water borne, increases from 270–210 cm suggesting increased sand transport to the site, followed by a rapid accretion of 60 cm of sand An extensive aerial surface with *Leptospermum* and *Gleichenia* probably developed on the sand surface As discussed earlier, soil development or loss of sediments, creating a time hiatus, probably occurred at this Zone boundary The area was reflooded subsequently, probably c 1000–800 yr B P Dates above and below the sand layer suggest absence of sediments representing some or all of the period c 4200–c 1000 yr B P

Zone 2 150–120 cm c 1000–c 600 yr B P Tall tree taxa continue to dominate the pollen sum throughout this zone *Dacrydium* (approx 30%) and *Dacrycarpus* (progressively increasing from 6% to 37%) are the main contributors *Agathis* records a high value (18%) in the lowest sample while *Myrsine* increases slightly *Gleichenia* appears significantly for the first time, recording high values then progressively declining

The sudden appearance of abundant *Gleichenia* spores (coupled with a high *Leptospermum* type value) marks the definite end of estuarine influence and the commencement of freshwater peat formation A mainly *Gleichenia-Leptospermum* association, with some Cyperaceae, appears to have colonised this new swamp surface

The water table of the swamp appears to have dropped further during the upper part of this zone, allowing *Dacrycarpus* to invade the site and form a swamp forest, progressively replacing the *Gleichenia-Leptospermum* vegetation *Myrsine* may have been part of the sub-canopy of the swamp forest Although *Agathis* may initially have been abundant on dry land near the site, surrounding dryland forest probably remained generally similar in composition to that of the previous zone, i e , *Dacrydium/Metrosideros*-dominated conifer-hardwood forest

Zone 3 110–0 cm c 600 yr B P–present This zone is characterised by a sharp and permanent decline in pollen of several forest taxa (*Dacrycarpus*, *Dacrydium* and *Metrosideros*), coinciding with the dramatic appearance of *Pteridium* spores and an increase in Poaceae pollen, both dryland taxa of open conditions Values for some swamp and fern taxa (Cyperaceae, *Gleichenia*, *Typha*, *Blechnum* and monoletes) also increase dramatically during this zone These changes indicate widespread forest decline, both of local swamp forest and surrounding dryland forest The appearance of microscopic charcoal at the same time clearly indicates fire (by Polynesians) as the cause of vegetation change Although radiocarbon dates from 105–106 cm (Wk 5558) and 108–110 cm (Wk–5947) are "modern" and 470 0 yr B P , respectively (Table 1), the presence of the 600 yr B P Kaharoa Tephra (determined microscopically as a very diffuse layer, indicating some reworking) at 104–116 cm dates the start of the deforestation This suggests contamination of the radiocarbon samples with younger carbon, presumably due to down-profile transport of carbon in plant roots or as carbon particles (c f McGlone & Wilmshurst 1999) However, if the tephra is reworked, the radiocarbon dates may possibly be correct

The appearance of *Typha* in the swamp immediately after burning of the swamp forest indicates some eutrophication and a higher water table, most likely due to increased runoff from adjacent deforested hills and reduced transpiration from the swamp surface The sequence deposited at the site recorded the initial burning of the swamp and then the successional changes that followed *Typha* dominated first, largely replaced by Cyperaceae,

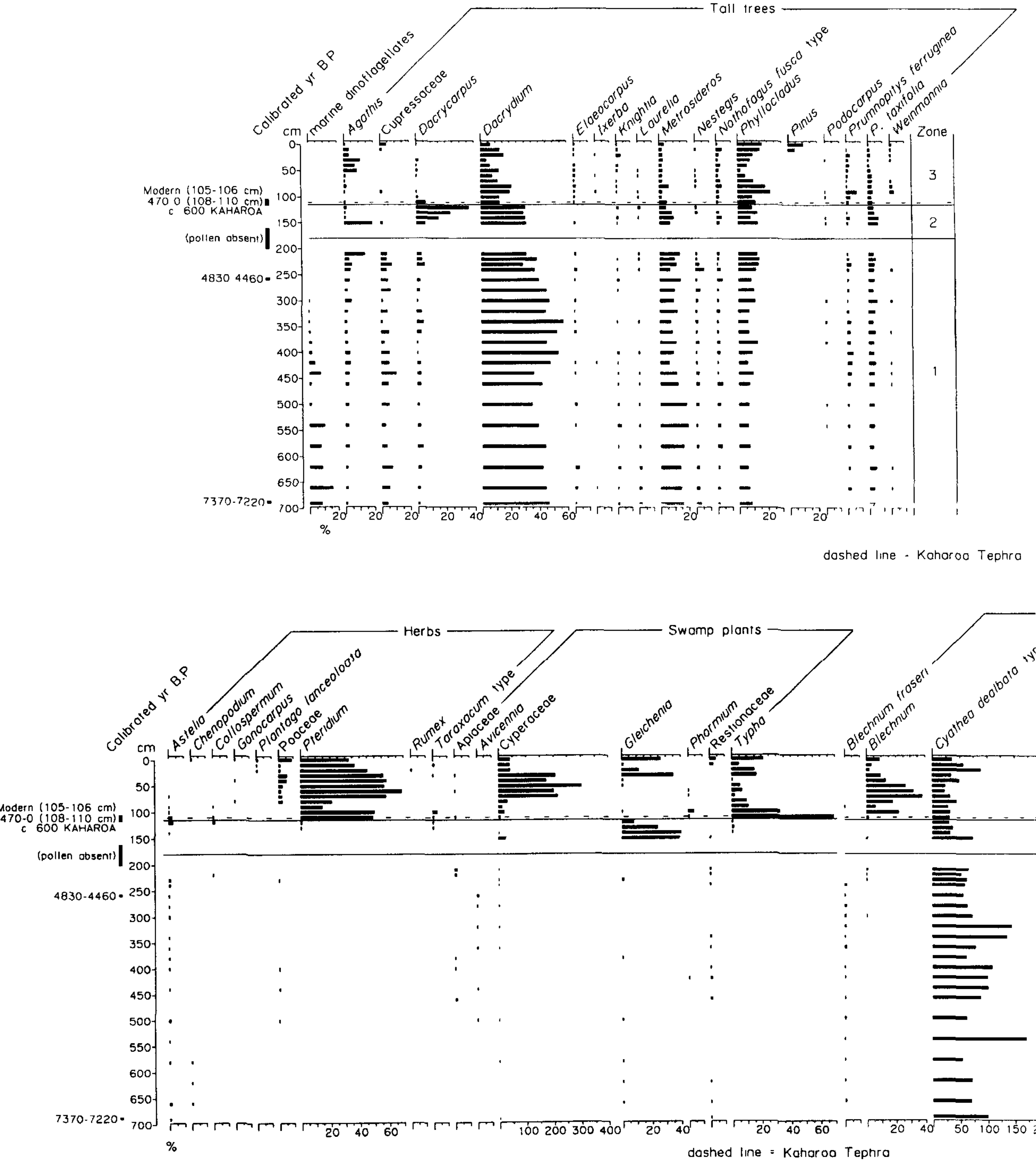
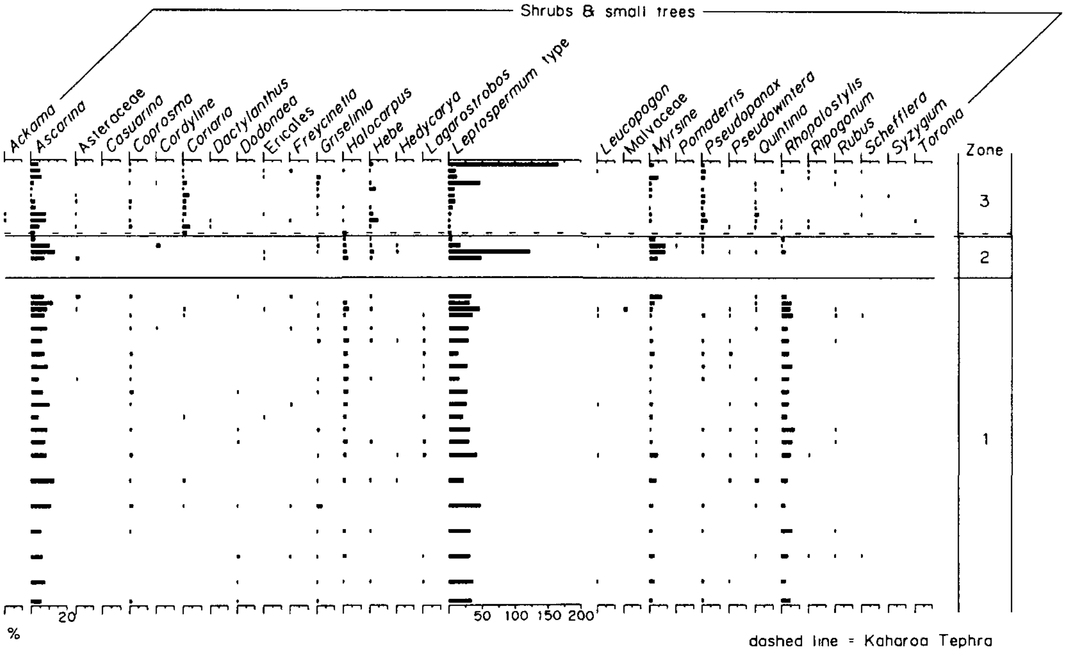
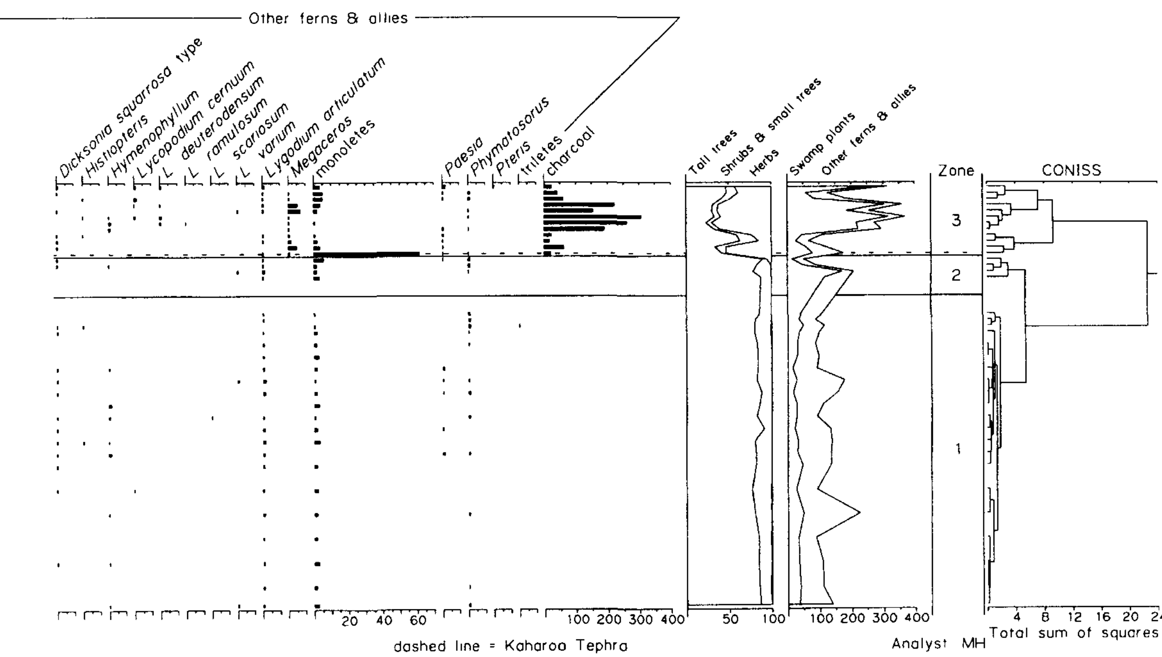


Fig. 4A Pollen diagrams from northern Kaitoke: Kaitoke Swamp.


Shrubs & small trees
Ackama
Ascarina
Asteraceae
Casuarina
Coprosma
Cordyline
Coriaria
Dactylanthus
Dodonaea
Ericales
Freycinetia
Griselinia
Halocarpus
Hebe
Hedycarya
Lagarostrobos
Leptospermum type
Leucopogon
Malvaceae
Myrsine
Pomaderris
Pseudopanax
Pseudowintera
Quintinia
Rhopalostylis
Ripogonum
Rubus
Schefflera
Syzygium
Toronia
Zone
3
2
1
20
%
50 100 150 200
dashed line = Kaharoa Tephra


Other ferns & allies
Dicksonia squarrosa type
Histiopteris
Hymenophyllum
Lycopodium cernuum
L. deuterodensum
L. ramulosum
L. scariosum
L. varium
Lygodium articulatum
Megaceros
monoletes
Paesia
Phymatosorus
Pteris
triletes
charcoal
Tall trees
Shrubs & small trees
Herbs
Swamp plants
Other ferns & allies
Zone
3
2
1
CONISS
20 40 60
100 200 300 400
50 100
100 200 300 400
4 8 12 16 20 24
Total sum of squares
dashed line = Kaharoa Tephra
Analyst MH

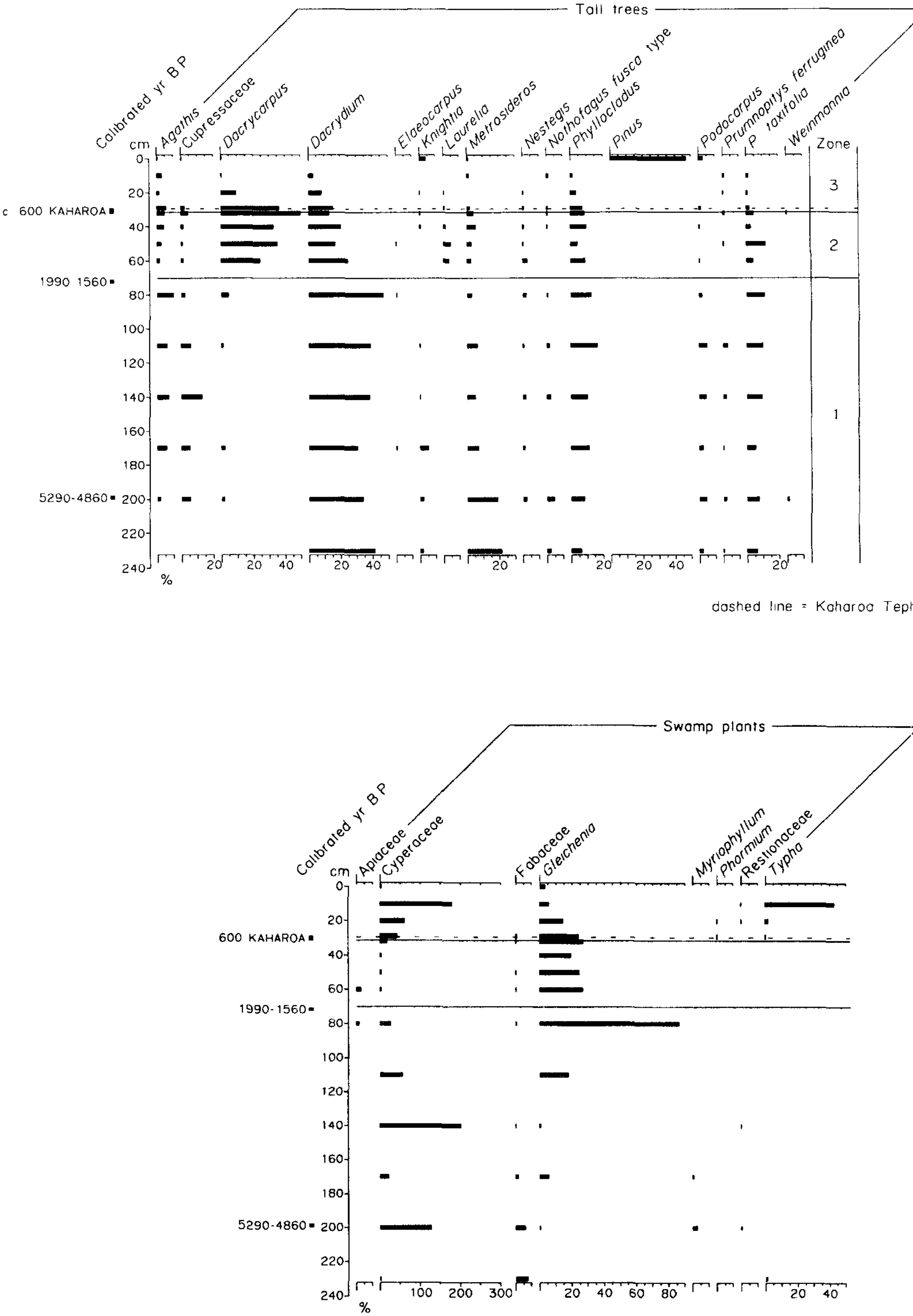
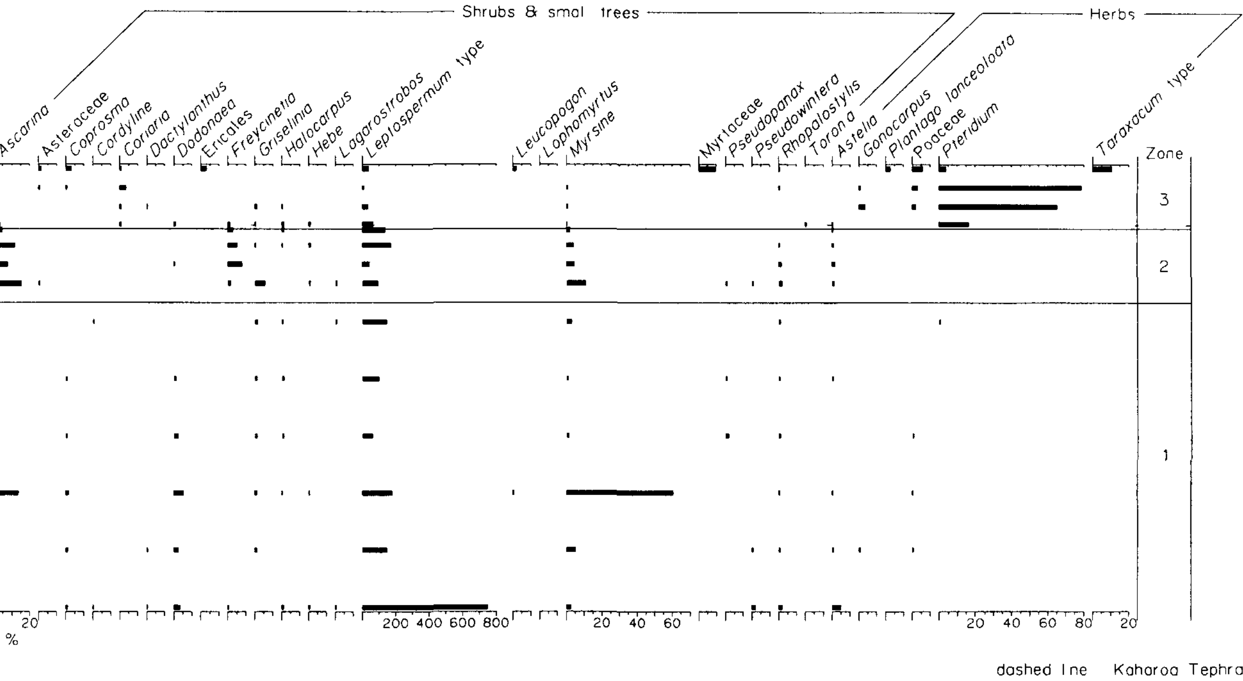
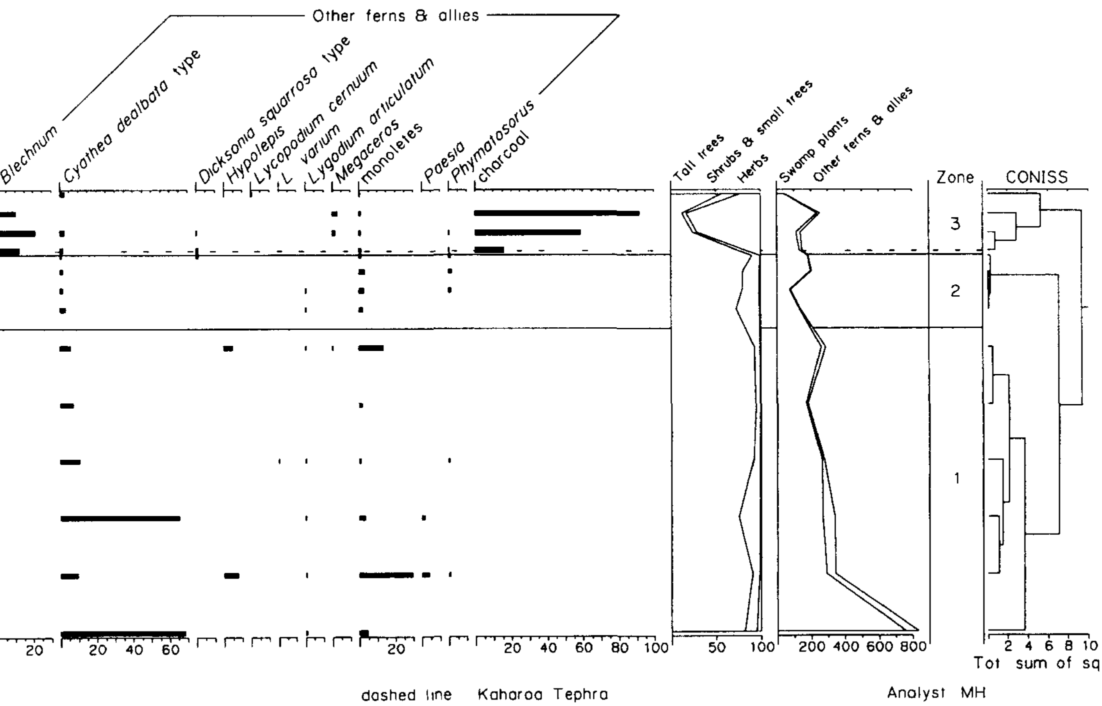


Fig. 4B Pollen diagrams from northern Kaitoke: Police Station Swamp.


Shrubs & small trees
Herbs
Ascarina
Asteraceae
Coprosma
Cordyline
Coriaria
Dactylanthus
Dodonaea
Ericales
Freycinetia
Griselinia
Halocarpus
Hebe
Lagarostrobos
Leptospermum type
Leucopogon
Lophomyrtus
Myrsine
Myrtaceae
Pseudopanax
Pseudowintera
Rhopalostylis
Toronia
Astelia
Gonocarpus
Plantago lanceolata
Poaceae
Pteridium
Taraxacum type
Zone
3
2
1
20
%
200 400 600 800
20 40 60
20 40 60 80
20
dashed line Kaharoa Tephra


Other ferns & allies
Blechnum
Cyathea dealbata type
Dicksonia squarrosa type
Hypolepis
Lycopodium cernuum
L varium
Lygodium articulatum
Megaceros
monoletes
Paesia
Phymatosorus
charcoal
Tall trees
Shrubs & small trees
Herbs
Swamp plants
Other ferns & allies
Zone
CONISS
3
2
1
20
20 40 60
20
20 40 60 80 100
50 100
200 400 600 800
2 4 6 8 10
Tot sum of sq
dashed line Kaharoa Tephra
Analyst MH

which in turn was replaced by *Gleichenia* and *Typha*. Mixed communities of the latter two taxa now cover large areas of Kaitoke Swamp, where the water table is generally 7–21 cm depth. The two upper samples contain exotic *Pinus* pollen, representing the arrival of European influences last century.

Police Station Swamp

Police Station Swamp is located in the area of fixed dunes immediately to the north of Claris. It is much smaller in area (10 ha) than Kaitoke Swamp and is 1.75 km southwest of the Kaitoke Swamp core site. It is bordered by fixed dunes on the seaward side and by the main east coast road built on older dune sands on the inland side (Fig. 1). Much of the swamp is better described as a shallow lake, with the summer water depth averaging 50 cm. The core site is on the western side of the swamp in a slightly drier area, and is currently 1.75 km from the sea. Vegetation in the immediate vicinity of the site is dominated by *Baumea teretifolia*. Also present in the immediate vicinity are *Gleichenia dicarpa, Baumea articulata, Leptospermum scoparium* and *Tetraria capillaris*. *Typha orientalis* and *Eleocharis sphacelata* are nearby, but probably not within 20 m of the site. *Baumea juncea* is also present on the swamp but not close to the core site.

Sedimentology (Fig. 3B)

Core recovery at the Police Station swamp was 3.8 m, at a site located 4.8 m above mean sea level. Probing elsewhere in the swamp indicated the presence of a steep sided channel (>6 m deep) running through the basal dune sands on which the swamp lies. But these deeper sediments were not sampled. Below a depth of 2 m the core recovered a bed of moderately well sorted silty fine-grained sand that is preserved to an unknown depth (Fig. 3B). Pollen is absent below 2.3 m. This bed is massive in structure and orange-brown in colour, indicating post-depositional weathering. The deposit contains flecks of organic material, and local rip-up clasts of very fine sand (the c. 55 ka B.P. Rotoehu Tephra) between 2.45 m and 2.7 m. A gradational contact at 2–2.05 m marks the upwards transition to a 2 m thick deposit of dark brown silty peat that contains fragments of wood. The only interruption to the peat deposit is a sharply defined 1 cm thick *in situ* bed of Kaharoa Tephra at a depth of 0.3 m.

This core may be interpreted to represent two quite distinct depositional environments. First, the basal deposit of fine-grained weathered sand provides a record of aeolian deposition, most likely in the form of a coastal dune in Late Pleistocene time. The weathered state of the sand indicates a period of sub-aerial exposure during lower sea levels of the Last Glacial. The presence of rip-up clasts of Rotoehu Tephra within this bed is interpreted as evidence for local down slope reworking of primary tephra deposits into the site.

The second depositional environment represented in this core is the Holocene freshwater swamp that has accumulated 2 m of peat since its impoundment c. 5200 yr B.P. Given the elevation of the Police Station Swamp site of approximately 5 m above sea level, it is unlikely that the site was inundated with sea water during the Holocene, although this cannot be ruled out for the deeper (uncored) channel. Rather, the present freshwater swamp at the site most likely formed in a low lying area of a deflated dune surface, and has since remained sheltered from marine/estuarine waters by the surrounding dunes. The palynology and depth probes across the swamp (J. Ogden unpubl. data) suggest that the freshwater deposits represent two distinct environments.

Palynology (Fig. 4B)

Three pollen zones are recognised in the Police Station Swamp core, the first commencing at 230 cm where pollen was first recorded.

Zone 1 230–80 cm c 5200–c 1800 yr B P Tall tree taxa (*Dacrydium* and initially *Metrosideros*) dominate the pollen sum during this zone *Ascarina* values are generally lower than those of Zone 1 at Kaitoke Swamp The very high *Leptospermum* type pollen value in the lower sample may indicate a high abundance of *Leptospermum* growing on or near the site during initial freshwater swamp impoundment, although erratic pollen abundance or "over-representation" is not uncommon for insect-pollinated plants (i e , local pollen dispersers) The presence of the aquatic *Myriophyllum* indicates that the swamp surface was frequently inundated *Leptospermum* formed associations at the site firstly with Cyperaceae then, towards the upper zone boundary, with *Gleichenia* *Myrsine* records one very high value during this zone but again, as this taxon is insect-pollinated, this may be an over-representation

Zone 2 60–32 cm c 1800–c 600 yr B P This zone appears to correspond approximately with Zone 2 of Kaitoke Swamp, where reflooding of the sandier palaeosol resulted in the invasion of parts of the swamp surface by *Dacrycarpus*, forming a swamp forest Probing across the swamp (J Ogden unpub data) suggests expansion of the swamp (as a shallow lake) about this time As at Kaitoke Swamp, *Myrsine* was apparently a significant understorey component of the swamp forest *Laurelia* and *Freycinetia* may have been more abundant in swamp forest at this site than at Kaitoke *Ascarina* pollen increased at Police Station Swamp during this zone to values similar to those at Kaitoke Swamp, suggesting an increased local abundance of this taxon in swamp forest *Gleichenia-Leptospermum* vegetation remained dominant on unforested parts of the swamp near the site

Zone 3 29–0 cm, c 600 yr B P -present Zone 3 of Police Station Swamp corresponds to Zone 3 of Kaitoke Swamp Above the 600 yr B P Kaharoa Tephra, a decline in several forest taxa (e g , *Dacrycarpus* and *Dacrydium*), coinciding with the dramatic appearance of charcoal and *Pteridium*, mark the commencement of large scale Polynesian burning resulting in deforestation *Typha* pollen is abundant in the upper zone, indicating a return to wetter swamp conditions after burning, but is absent from the surface sample, reflecting its current absence in the immediate vicinity of the site Exotic *Pinus* pollen in the surface sample indicates European effects

DISCUSSION AND CONCLUSIONS

The pre-Kaharoa environment

The pollen and sediment records of the two northern Kaitoke sites contain a history of the local coastal and regional environment since c 7300 yr B P An older sequence of aeolian sands underlies, and protrudes through, coastal freshwater swamp as evidenced by the presence of c 55 ka yr B P Rotoehu Tephra glass shards within the sands These older sand deposits may have been exhumed during periods of low sea level that post-dated the deposition of the Rotoehu Tephra but pre-date the formation of the Holocene coastal freshwater swamp

At c 7300 yr (calibrated) B P , the seaward end of Kaitoke Swamp was an estuary with tidal flats and *Avicennia* By c 4500 yr B P , however, marine influences were reduced, possibly a result of sea level recession (Naish et al 1992), and fresh water was depositing sand at the Kaitoke Swamp site Shortly before this, fresh water swamp conditions were initiated at Police Station Swamp *Leptospermum* and Cyperaceae dominated swamp vegetation at the core sites during much of the period c 4500–1800 yr B P , with *Gleichenia* replacing Cyperaceae to a large extent in the later part of this period

Conifer-hardwood forest surrounding the sites c 7300–c 1800 yr B P was dominated by *Dacrydium cupressinum* and *Metrosideros* Other canopy taxa were *Phyllocladus*, *Prumnopitys*, *Libocedrus* (Cupressaceae) and *Agathis*

As the pollen taxa representing regional conifer-hardwood forest changed little c 7300–c 2000 yr B P , this period appears generally to have been characterised by a relatively stable environment The changes in local vegetation, possibly commencing c 2000 yr B P , but more likely closer to yr 1000 B P , could indicate a disturbance event at that time The initial invasion of both sites by *Dacrycarpus* (and *Laurelia* and probably *Ascarina* at Police Station) forest suggests a shallow swamp, perhaps as a consequence of sand deposition in both systems Although not present in the northern Kaitoke cores, aeolian sand lenses dated to c 2500 yr B P appear in pollen cores from sites elsewhere on the east coast of Great Barrier (M Horrocks unpub data) Furthermore, *Dacrycarpus* and *Laurelia* forest apparently established in previously open (wetter) swamps at some of these sites after c 2500 yr B P

At Waihi Beach, Bay of Plenty, Newnham et al (1995) found that the open coastal marsh was invaded by the same tree taxa (*Dacrycarpus* and *Laurelia*) c 2500 conventional yr B P They suggested that a fall in relative sea level and/or a prograding coast was responsible As well as a sea level fall, sediment accretion could explain a drier Kaitoke swamp system There is certainly evidence for a prograding Holocene coast at northern Kaitoke the dunes on the southeastern edge of Kaitoke Swamp now extend seawards for 3 km

A body of evidence indicates that a long-term Holocene trend towards a drier climate in the North Island intensified c 3000–2000 yr B P (conventional dates) In the Kaimanawa Range, Rogers & McGlone (1989) found evidence of fires destroying forest c 3000 yr B P Green & Lowe (1985) studied the sedimentary stratigraphy of Lake Maratoto, near Hamilton, and concluded that precipitation had decreased sometime before 2000 yr B P De Lange (1989) came to the same conclusion in his study of Kopouatai Bog, Hauraki Lowlands In the Waikato Lowlands, Newnham et al (1989) found evidence for a substantial *Agathis australis* expansion c 3000 yr B P , pointing to increasing dryness In the Far North, Enright et al (1988) described fires between 2620 yr B P and 2150 yr B P indicating a change to a drier climate with more frequent droughts Also in this region, Dodson et al (1988) suggested that the contraction in *Agathis*, recorded around this same time by Kershaw & Strickland (1988) at Whangarei and at one of their own sites, might be related to increased burning as a result of precipitation decrease In the central Bay of Islands, Elliot et al (1998) suggested that climate became drier c 4000 yr B P

McGlone et al (1992) concluded that greater climatic *variability* associated with increased amplitude of the El Nino/Southern Oscillation (ENSO) commenced between 5000 yr B P and 3000 yr B P The results presented here suggest a change in climate on Great Barrier Island after c 2000 yr B P , probably involving increased frequency of droughts, leading to the invasion by forest of swamps that had become drier

The effect of increased dryness or more extreme climates on the dune system of northern Kaitoke would probably have been increased dune instability This would result not only in aeolian sand lenses in swamps, but also in more erosion of the dune system and more frequent blockage of drainage channels Drainage blocking by dune movement and/or spit formation on the nearby coast could have caused the reflooding of Kaitoke Swamp and the extension of Police Station Swamp, both at probably c 1000 yr B P The new shallow swamps were rapidly invaded by *Dacrycarpus*, forming swamp forest

An alternative explanation for the period of disturbance at Police Station Swamp commencing c 1800 yr B P and probably a little later at Kaitoke Swamp is early Polynesian impact (c f Holdaway 1996), perhaps coinciding with the suggested climatic change However, the complete absence of charcoal, and pollen associated with forest clearance and open conditions (e g , *Pteridium* and Poaceae) in the Police Station Swamp core during this period does not support this contention (sediments covering this period are probably missing from the Kaitoke Swamp core due to the possible hiatus)

The post-Kaharoa environment

The northern Kaitoke pollen record indicates that a period of extreme forest disturbance, both of the local swamp forest and of the surrounding dryland forest, commenced in the area after the Kaharoa eruption This disturbance appears to coincide with the Kaharoa Tephra, suggesting extensive canopy damage as a result of this event However, pollen values immediately above the tephra in profiles from elsewhere on the east coast of Great Barrier (M Horrocks, Y Deng unpub data) are similar to values immediately below the tephra, suggesting that the eruption had little immediate adverse effect on Great Barrier forest We suggest that the sudden appearance of abundant microscopic charcoal, a corresponding and dramatic increase in *Pteridium* spores and declining values for several forest taxa clearly indicate that fires (by Polynesians) were the cause of vegetation change (McGlone 1983, 1989)

The presence on Great Barrier of the Kaharoa Tephra, which has a reliable age estimate from multiple radiocarbon determinations, allows the commencement of major Polynesian deforestation at northern Kaitoke to be reliably dated to c 600 calibrated yr B P Compared with pollen studies elsewhere in the Auckland region covering the Late Holocene, this is within the range of Hume & McGlone's (1986) inferred date of 800–600 conventional yr B P for the deforestation of the region, but much later than Elliot & Neall's (1995) estimation of at least 1200 conventional (980 calibrated) yr B P for deforestation on Motutapu Island in the inner Hauraki Gulf However, McGlone & Wilmshurst (1999) suggests that Elliot & Neall's (1995) estimation is anomalously old, the dates having probably suffered contamination from inwash (McFadgen 1996) Newnham et al 's (1998) analysis of 11 other pollen records (from the Hauraki Lowlands south east to Poverty Bay) known to contain the Kaharoa Tephra found that Polynesian deforestation also commenced at these sites around the time of deposition of the tephra or later

AKNOWLEDGMENTS

We thank Charlie Carter (University of Akron, Ohio) for fieldwork assistance and Paul Froggatt (Victoria University of Wellington) for glass shard major element analyses We also thank Bob Creese (University of Auckland) for marine invertebrate identification MH was supported by a University of Auckland post-doctoral fellowship for the duration of this project We also acknowledge financial assistance from the University of Auckland Research Grants Committee, the New Zealand Lotteries Commission, the National Geographic Society and the Marsden Fund administered by the Royal Society of New Zealand – Contract UOA609 (for BVA)

REFERENCES

Berryman, K R 1992 A stratigraphic age of the Rotoehu Ash and Late Pleistocene climate interpretation based on marine terrace chronology, Mahia Peninsula, North Island, New Zealand *New Zealand Journal of Geology and Geophysics 35* 1–7

de Lange, P J 1989 Late Quaternary development of the Kopouatai Peat Bog, Hauraki Lowlands, and some palaeoenvironmental inferences Unpublished MSc thesis, University of Waikato, Hamilton, New Zealand

Dodson, J R , Enright, N J , McLean, R F 1988 A late Quaternary vegetation history for far northern New Zealand *Journal of Biogeography 15* 649–56

Elliot, M B , Flenley, J R , Sutton, D G 1998 A late Holocene pollen record of deforestation and environmental change from the Lake Tauanui catchment, Northland, New Zealand *Journal of Paleolimnology 19* 23–32

Elliot, M , Neall, V 1995 A twelve hundred year history of deforestation and a new age for the Rangitoto Ash from Motutapu Island, Hauraki Gulf, New Zealand *Geological Society of New Zealand Miscellaneous Publication 81A* 106

Enright, N J , McLean, R F , Dodson, J R 1988 Late Holocene development of two wetlands in the Te Paki region, far northern New Zealand *Journal of the Royal Society of New Zealand 18* 369–382

Faegri, K , Iversen, J 1989 Textbook of pollen analysis 4th ed Chichester, John Wiley & Sons

Froggatt, P F , Lowe, D L 1990 A review of late Quaternary and some other tephra formations from New Zealand their stratigraphy, nomenclature, distribution, volume and age *New Zealand Journal of Geology and Geophysics 33* 89–109

Gibb, J G 1986 A New Zealand regional Holocene eustatic sea-level curve and its application to determination of vertical tectonic movements *The Royal Society of New Zealand Bulletin 24* 377–395

Green, J D , Lowe, D J 1985 Stratigraphy and development of c 17 000 year old Lake Maratoto, North Island, New Zealand, with some inferences about postglacial climatic change *New Zealand Journal of Geology and Geophysics 28* 675–99.

Holdaway, R N 1996 The arrival of rats in New Zealand Scientific correspondence *Nature 384 (No 6606)* 225–226

Howorth, R , Topping, W W 1979 Rhyolitic late Pleistocene tephras to the south and west of Lake Taupo, New Zealand *New Zealand Journal of Geology and Geophysics 22* 759–762

Hume, T M , McGlone, M S 1986 Sedimentation patterns and catchment use change recorded in the sediments of a shallow tidal creek, Lucas Creek, Upper Waitemata Harbour, New Zealand *New Zealand Journal of Marine and Freshwater Research 20* 677–687

Kershaw, A P , Strickland, K M 1988 A Holocene pollen diagram from Northland, New Zealand *New Zealand Journal of Botany 26* 145–52

Lowe, D J 1988 Stratigraphy, age, composition and correlation of Late Quaternary tephras interbedded with organic sediments in Waikato lakes, North Island, New Zealand *New Zealand Journal of Geology and Geophysics 31* 125–165

Lowe, D J , McFadgen, B G , Higham, T F G , Hogg, A G , Froggatt, P C , Nairn, I A 1998 Radiocarbon age of the late Holocene rhyolitic Kaharoa tephra, a key marker bed in New Zealand's pre-history *The Holocene 8* 487–495

Marjoribanks, E C 1976 Motairehe, Great Barrier Island an assessment of the Motairehe 1 incorporation resettlement proposals Auckland, Department of Lands and Survey

McFadgen, B 1996 Re dating the Rangitoto Ash and its implications *Geological Society of New Zealand Newsletter No 109* 4 5

McGlone, M S 1982 Modern pollen rain, Egmont National Park, New Zealand *New Zealand Journal of Botany 20* 253–262

McGlone, M S 1983 Polynesian deforestation of New Zealand a preliminary synthesis *Archaeology in Oceania 18* 1–10

McGlone, M S 1989 The Polynesian settlement of New Zealand in relation to environmental and biotic changes *New Zealand Journal of Ecology (supplement) 12* 115–129

McGlone, M S , Kershaw, A P , Markgraf, V 1992 El Nino/Southern Oscillation climatic variability in Australian and South American paleoenvironmental records *In* Diaz, H F , Markgraf, V *ed* El Nino historical and paleoenvironmnetal aspects of the Southern Oscillation Cambridge, University Press Pp 435–462

McGlone, M S , Moar, N T 1977 The *Ascarina* decline and post-glacial climatic change in New Zealand *New Zealand Journal of Botany 15* 485–489

McGlone, M S , Wilmshirst, J M (in press) Dating initial Maori environmental impact in New Zealand *Quaternary International*

Morton, J E , Millar, M C 1973 The New Zealand sea shore 2nd ed London, Collins

Naish, T R , Nelson, C S , Hodder, A P W 1992 Evolution of Holocene sedimentary bentonite in a shallow-marine embayment, Firth of Thames, New Zealand *Marine Geology 109* 267–278

Newnham, R M , Lowe, D J 1991 Holocene vegetation and volcanic activity, Auckland Isthmus, New Zealand *New Zealand Journal of Quaternary Science 6* 177 193

Newnham, R M Lowe, D J , Alloway, B V (in press) Volcanic hazards in Auckland, New Zealand a preliminary assessment of the threat posed by central North Island silicic volcanism on the basis of the Quaternary tephrostratigraphical record *In* Firth, C R *ed* Volcanoes in the Quaternary London, Geological Society Special Publication

Newnham, R M , Lowe, D J , Green, J D 1989 Palynology, vegetation and climate of the Waikato lowlands, North Island, New Zealand since c 18 000 years ago *Journal of the Royal Society of New Zealand 19* 127 150

Newnham, R M , Lowe, D J , McGlone, M S , Wilmshurst, J M, Higham, T F G 1998 The Kaharoa Tephra as a critical datum for earliest human impact in northern New Zealand *Journal of Archaeological Science 25* 533–544

Newnham, R M , Lowe, D J , Wigley, G N A 1995 Late Holocene palynology and palaeovegetation of tephra-bearing mires at Papamoa and Waihi Beach, western Bay of Plenty, North Island, New Zealand *Journal of the Royal Society of New Zealand 25* 283–300

New Zealand Map Series 336–02 1996 Great Barrier Island Wellington, Department of Survey and Land Information

NIWA 1997 Port Fitzroy Climatological Summaries Wellington, National Institute of Water and Atmospheric Research Ltd

Pain C F 1975 Some tephra deposits in the south-west Waikato area, North Island, New Zealand *New Zealand Journal of Geology and Geophysics 18* 541–550

Pullar, W A , Kohn, B P , Cox, J E 1977 Airfall Kaharoa Ash and Taupo Pumice, and sea rafted Loisels Pumice, Taupo Pumice and Leigh Pumice in northern and eastern New Zealand *New Zealand Journal of Geology and Geophysics 20* 697 717

Rogers, G M , McGlone, M S 1989 A post-glacial vegetation history of the southern-central uplands of North Island, New Zealand *Journal of the Royal Society of New Zealand 19* 229–248

Rutherford, G N 1998 The current vegetation of Kaitoke Swamp, Great Barrier Island (Aotea) Unpublished MSc thesis, University of Auckland, Auckland, New Zealand

Stuiver M , Reimer, P J 1993 University of Washington Quaternary Isotope Lab radiocarbon calibration program REV 3 0 3A Mactest version #6 *Radiocarbon 35* 215–230

Stuiver, M , Reimer, P J , Bard, E , Beck, J W , Burr, G S , Hughen, K A , Kromer, B , McCormac, G , van der Plicht, J , Spurk, M 1998 INTCAL98 radiocarbon age calibration, 24,000–0 cal BP *Radiocarbon 40* 1041–1052

Traverse, A 1988 Paleopalynology Boston, Unwin Hyman

Vucetich, C G , Pullar, W A 1969 Stratigraphy and chronology of late Pleistocene volcanic ash beds in central North Island, New Zealand *New Zealand Journal of Geology and Geophysics 12* 784–797

Wilson, C J N , Houghton, B F , Lanphere, M A , Weaver, S D 1992 A new radiometric age for the Rotoehu Ash from Mayor Island Volcano, New Zealand *New Zealand Journal of Geology and Geophysics 35* 371–374

R9906 Received 3 March 1999 accepted 4 August 1999