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Late Holocene palynology and palaeovegetation of tephra-bearing mires at Papamoa and Waihi Beach, western Bay of Plenty, North Island, New Zealand

R. M. Newnham,* D. J. Lowe†, G. N. A. Wigley†‡

The vegetation history of two mires associated with Holocene dunes near the western Bay of Plenty coast, North Island, New Zealand, is deduced from pollen analysis of two cores. Correlation of airfall tephra layers in the peats, and radiocarbon dates, indicate that the mires at Papamoa and Waihi Beach are c. 4600 and c. 2900 conventional radiocarbon years old, respectively. Tephras used to constrain the chronology of the pollen record include Rotomahana (1886 AD), Kaharoa (700 yr B.P.), Taupo (Unit Y; 1850 yr B.P.), Whakaipo (Unit V; 2700 yr B.P.), Stent (Unit Q; 4000 yr B.P.), Hinemaiaia (Unit K; 4600 yr B.P.), and reworked Whakatane (c. 4800 yr B.P.) at Papamoa, and Kaharoa and Taupo at Waihi Beach. Peat accumulation rates at Papamoa from 4600 – 1850 yr B.P. range from 0.94 to 2.64 mm/yr (mean 1.37 mm/yr). At Waihi Beach, from 2900 yr B.P. – present day, they range from 0.11 to 0.21 mm/yr (mean 0.20 mm/yr). Peat accumulation at both sites was slowest from 1850 to 700 yr B.P., suggesting a drier overall climate during this interval.

At both sites, the earliest organic sediments, which are underlain by marine or estuarine sands, yield pollen spectra indicating salt marsh or estuarine environments. Coastal vegetation communities declined at both sites, as sea level gradually fell or the coast prograded, and were eventually superseded by a low moor bog at Papamoa, and a mesotrophic swamp forest at Waihi Beach. These differences, and the marked variation in peat accumulation rates, probably reflect local hydrology and are unlikely to have been climatically controlled. The main regional vegetation during this period was mixed northern conifer-angiosperm forest. Kauri (*Agathis australis*) formed a minor component of these forests, but populations of this tree have apparently not expanded during the late Holocene at these sites, which are near its present southern limit. Occasional shortlived forest disturbances are detectable in these records, in particular immediately following the deposition of Taupo Tephra. However, evidence for forest clearance during the human era is blurred by the downward dislocation of modern adventive pollen at these sites, preventing the clear differentiation of the Polynesian and European eras.

Keywords: palynology, late Holocene, vegetation history, climate change, tephrochronology, peat, Papamoa Bog, Waihi Beach Swamp

INTRODUCTION

A belt of coastal sand dunes, aligned parallel to the coast, stretches from Waihi Beach in the northwest to eastern Bay of Plenty (Fig. 1). Inland from this narrow coastal strip are low-lying (2–6 m a.s.l.) drained swamplands, peatlands, tidal flats, river terraces, and floodplains, all formed since Holocene sea level reached approximately its present position c. 6500 years

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ago (Wigley 1990). At numerous sites along this coastline, a number of thin tephra layers are found within peat in bogs or in swales between dunes, while the organic sediments preserve records of the past vegetation and environmental history of the area. A chronology of development of the dunes at Papamoa Beach, western Bay of Plenty (Fig. 1), has been established (Lowe et al. 1992), similar to that described for the Rangitaiki Plains, eastern Bay of Plenty, by Pullar & Selby (1971).

Campbell et al. (1973) described the vegetation history at three peat sites along the coastal Bay of Plenty strip, based on plant macrofossils and pollen. The peat is mainly a low-moor, sedge peat formed from *Baumea* (Cyperaceae). They concluded that in wetter periods Restionaceae (mostly *Empodisma minus*) became established, and in drier periods, *Leptospermum* and *Gleichenia*.

In this study, we present palynological evidence for the development of coastal mire vegetation communities at Papamoa Bog and Waihi Beach, from tephra-bearing organic sediments overlying sands at both sites. An understanding of the origins and evolution of these features of the western Bay of Plenty coastline is important because the sites are likely to become less accessible, or to be destroyed, by expanding urban development. The dryland pollen assemblages also provide evidence for the regional vegetation history of western Bay of Plenty since c. 4600 years ago, with chronologies at both sites determined from tephrochronology and radiocarbon dating.

The physical setting, modern vegetation, and location of coring sites

Papamoa Bog

Papamoa Bog (also known as Kaituna swamp) is a mesotrophic mire, 35.4 km² in area and with a maximum elevation of 7.5 m a.s.l. (Davoren 1978), near Papamoa (Fig. 1). Currently up to 4.5 m deep, the bog is bounded largely by Holocene coastal dunes and low-lying fluvial terraces (Wigley 1990). Extensive drainage, particularly since implementation of the Kaituna River Catchment Scheme in the 1950s, has caused shrinkage of the bog's surface by up to 2 m in places (Pullar 1970); the surface gently undulates because of subsidence and exhumation of old stumps (probably *Laurelia novae-zelandiae*, *Dacrycarpus dacrydioides*, or *Prumnopitys taxifolia*; Pullar & Patel 1972; Davoren 1978). The bog has been developed for agriculture and is today mostly covered in pasture grasses with patches of rushes (*Juncus* spp.) and occasional blackberry (*Rubus fruticosus* agg.), cabbage tree (*Cordyline australis*), and willow (*Salix cinerea*) (Davoren 1978).

Mean annual rainfall at nearby Te Puke is 1680 mm; mean daily temperature is 13.9° C (Quayle 1984).

The core (code Kt16-b) was taken from around the deepest part of the bog on 2 July, 1991, using a D-section 'Russian' corer at site Kt16 (Fig. 1B). This site is c. 10 m or so from a site cored previously by Wigley (1990) (code Kt16-a).

Waihi Beach Swamp

Waihi Beach Swamp occupies a depression adjacent to low-lying fluvial terraces on the inland margins of Holocene coastal dunes at Waihi Beach (Fig. 1). The swamp has an area of c. 0.5 km² and lies at c. 5–10 m elevation a.s.l.; a small, sluggish stream partly drains it (Fig. 1A). The peaty sediments in the swamp are everywhere likely to be <1 m deep.

The modern vegetation comprises three main assemblages (P.J. de Lange pers. comm. 1994): (1) grey or pussy willow car (*Salix cinerea*) with manuka (*Leptospermum scoparium*); (2) rushland dominated by *Juncus gregiflorus* with *J. effusus*, *J. australis*, and *J. articulatus*, and occasional *Carex virgata* and *C. secta*; and (3) marginal rough pasture likely to be dominated by creeping bent (*Agrostis stolonifera*), yorkshire fog (*Holcus lanatus*), and floating sweet grass (*Glyceria fluitans*) with articulated rush (*Juncus articulatus*). Such assemblages are typical of mesotrophic mires (bordering on eutrophic).

Mean annual rainfall at Waihi Beach is 1620 mm; the mean daily temperature at nearby Waihi is c. 13.7° C (Quayle 1984).

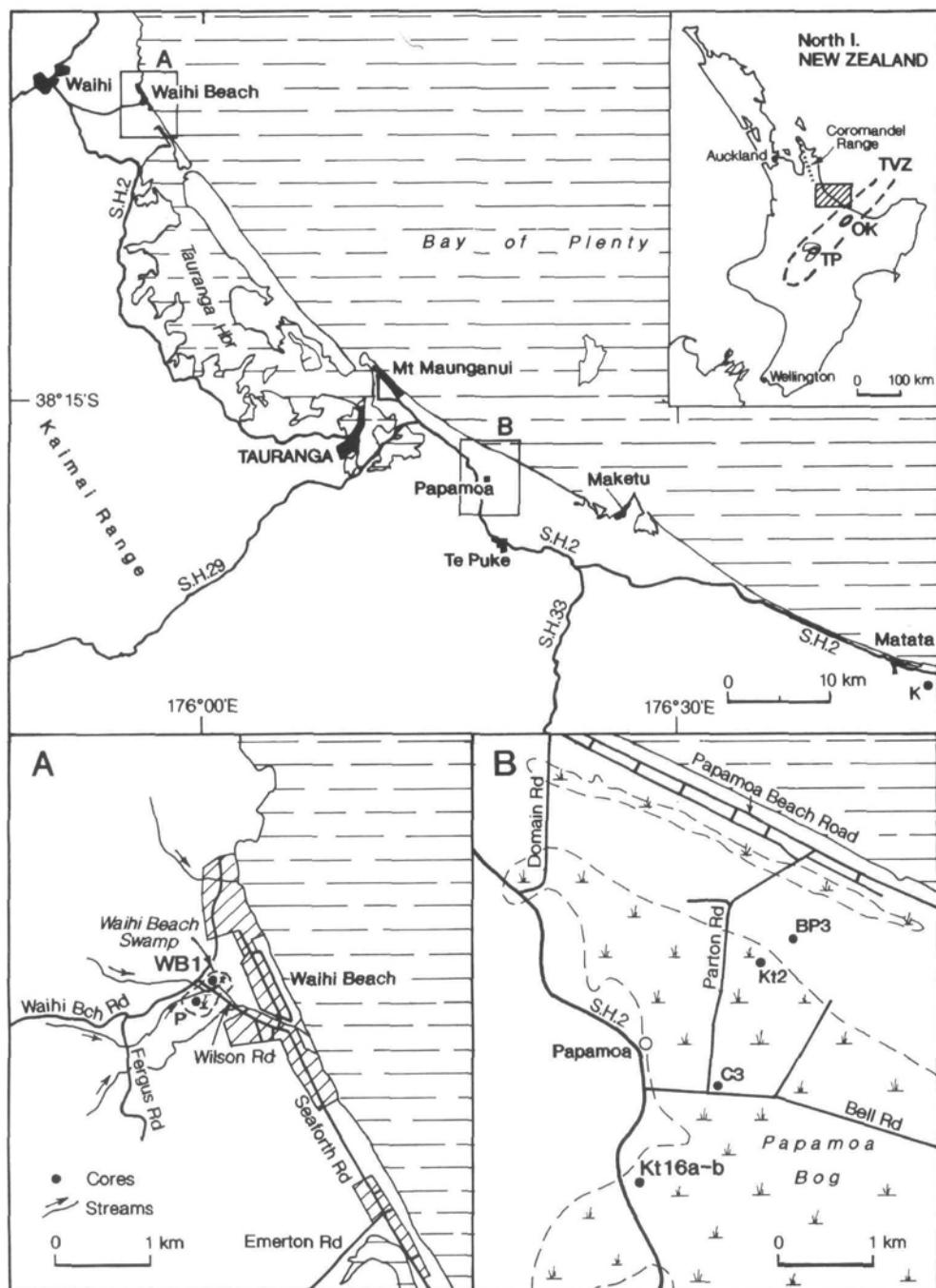


Fig. 1 – The western Bay of Plenty region showing locations of the Waihi Beach (WB1) and Papamoa (Kt16a-b) coring sites. Other core sites mentioned in the text are shown also: K, (Kohika swamp, McGlone 1981); P, Pullar et al. (1977); C3, Campbell et al. (1973); BP3, Alloway et al. (1994); Kt2, Wigley (1990). Inset shows locations of the Okataina (OK) and Taupo (TP) volcanic centres (Froggatt & Lowe 1990).

The core (code WB1) was taken from a patch of willow car with a D-section 'Russian' corer on 3 July, 1991 (Fig. 1A).

STRATIGRAPHY AND CHRONOLOGY OF THE CORES

Papamoa Bog

The stratigraphy of the core used for pollen analysis, Kt16-b, is virtually identical to that of core Kt16-a (Fig. 2A). Both cores are underlain by fine sands or silts, with occasional cockle shells (*Chione stutchburyi*), of estuarine origin. Elsewhere in Papamoa Bog (core Kt-2, Fig. 1B) such shells have been dated at (Wk-1440) 5888 ± 160 yr B.P.* (corrected for the marine reservoir effect). Overlying these basal sediments are peat deposits, up to 4.4 m thick, interspersed with tephra layers. The peat colour ranges from black to brown and, apart from the upper metre or so which is fibrous, is strongly decomposed. Woody fragments occur throughout the cores (Fig. 2A).

Tephrochronology

Most of the tephra deposits form macroscopic layers 1 to 5 cm thick that range from fine ash to lapilli in grade. One layer (Stent), found as a gritty, disseminated deposit in core Kt16-b, is well represented as a macroscopic layer in the equivalent stratigraphic position in core Kt16-a (Fig. 2A). Six tephra layers are identified in the peat columns, as shown in Fig. 2A. All are derived from either Okataina or Taupo volcanic centres (Fig. 1, inset). Correlations with named deposits elsewhere are based on a combination of stratigraphic position, field properties, radiocarbon age, ferromagnesian mineralogical assemblage, and major element composition of glass (e.g., see Lowe 1988a, b).

Rotomahana Mud (a member of Tarawera Tephra; Froggatt & Lowe 1990) forms a discontinuous brownish-grey medium ash layer up to 2 cm in thickness, and was erupted in 1886 AD from Tarawera volcano in the Okataina Volcanic Centre (OVC).

Kaharoa Tephra is a 5 cm-thick layer comprising greyish-brown fine pumiceous ash over brownish-grey coarse pumiceous ash with a few fine lapilli, and is dominated by biotite, a diagnostic mineral for this tephra (Table 1; Froggatt & Lowe 1990). Erupted from Tarawera volcano in the OVC, it has an error-weighted mean age (EMA; using the formula of Gupta & Polach 1985) of 770 ± 20 yr B.P. ($n = 15$, Froggatt & Lowe 1990). However, Lowe & Hogg (1992) suggested that Kaharoa Tephra may have erupted around, or soon after, c. 700 yr B.P., based on new dates with an EMA of 665 ± 17 yr B.P. ($n = 4$). Consequently, we have adopted an age of 700 yr B.P. for Kaharoa Tephra here.

Taupo Tephra is a cream-coloured, 4 cm-thick layer of pumiceous coarse ash and lapilli, the latter readily crushed between fingernails. It is derived from Taupo Volcanic Centre (TVC) and is dominated by hypersthene, typical of Holocene tephra layers from this source (Table 1; Froggatt & Lowe 1990). Taupo Tephra corresponds to Unit Y in the nomenclature of Wilson (1993). It has an EMA of 1850 ± 10 yr B.P. ($n = 41$, Froggatt & Lowe 1990), which we have adopted here.

Whakaipo Tephra forms a 1 cm-thick layer of brownish-stained fine ash. It is dominated by hypersthene (Table 1). Correlation was aided by major element analysis of glass from the equivalent tephra in another core from Papamoa Bog (BP3, Fig. 1B): glass from this layer (sample WG21, Table 2) closely matches analyses of Whakaipo Tephra from other environments, including lakes in the Waikato region (Table 2). The composition of glass from Whakaipo Tephra differs from that of other Holocene eruptives from TVC in having lower CaO and FeO concentrations (Lowe 1988b; Stokes et al. 1992). The two radiocarbon

*All ages reported and discussed in the text are conventional radiocarbon ages based on the Libby (old) half-life of 5568 years. Wk- numbers are University of Waikato Radiocarbon Dating Laboratory numbers (Hogg et al. 1987).

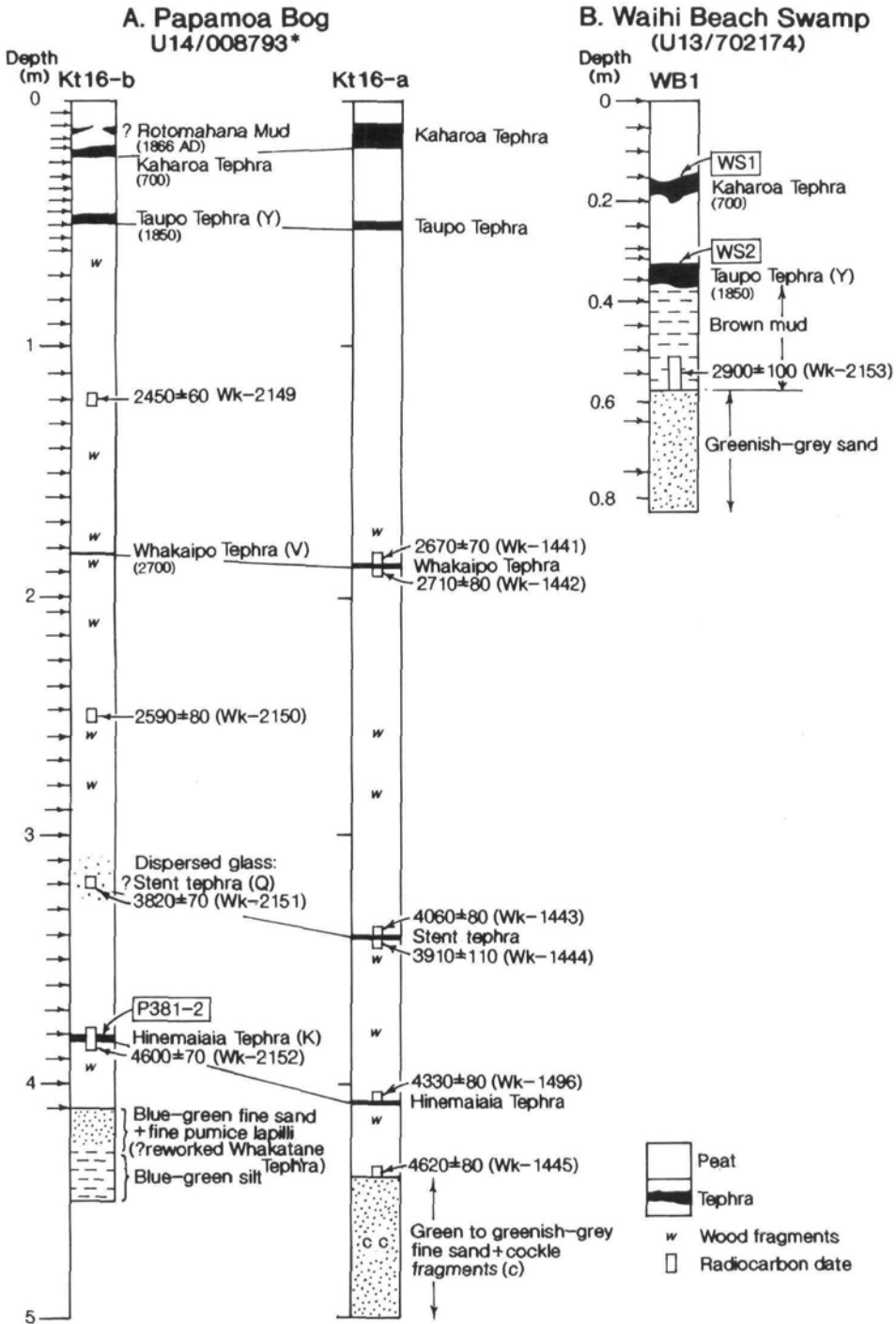


Fig. 2 – Stratigraphy and chronology of cores from (A) Papamoa and (B) Waihi Beach. Tephra names follow the nomenclature of Froggatt & Lowe (1990); the letters in parentheses are likely correlatives of Taupo eruptives using Wilson's (1993) terminology. Ages are discussed in the text. Arrows mark pollen sampling positions (see text). * Grid references are based on the metric 1:50 000 topographical map series NZMS 260.

Table 1 – Ferromagnesian mineralogy of tephra layers identified in peats at Papamoa, based on point counts using optical microscopy (Wigley 1990).

Tephra	n	Hyp	Aug	Hble	Bio
Trm	1	36	7	10	47
Ka	2	24–29	1–2	14–16	53–61
Tp	6	73–84	5–21	2–11	0
Mp*	3	85–89	2–9	1–7	0–6
Wo	4	88–96	3–10	1–2	0–1
St [#]	n.d.				
Hm	1	81	15	4	0

n.d. = not determined; n = no. of samples

Hyp = hypersthene; Aug = augite; Hble = calcic hornblende; Bio = biotite

* Mapara Tephra (c. 2160 ± 25 yr B.P., Unit X of Wilson 1993) was not observed in the core analysed for pollen, but was identified at other Papamoa sites (Wigley 1990; Lowe et al. 1992).

[#] Dominant mineral is hypersthene (Alloway et al. 1994).

Trm = Tarawera Tephra (Rotomahana Mud); Ka = Kaharoa Tephra; Tp = Taupo Tephra (Unit Y); Wo = Whakaipo Tephra (Unit V); St = Stent tephra (Unit Q); Hm = Hinemaiaia Tephra (Unit K).

dates obtained from core Kt16-a (Wk-1441, Wk-1442) have an EMA of 2690 ± 55 yr B.P., identical to the EMA of 2685 ± 20 (n = 13) reported by Froggatt & Lowe (1990) for this tephra, so we adopted the age of 2700 yr B.P. Whakaipo Tephra corresponds to Unit V, aged 2700 yr B.P. (Wilson 1993).

Stent tephra (informally named by Alloway et al. 1994) is found as a 2 cm-thick layer of whitish-grey medium ash in core Kt16-a and as sparse, disseminated glass in Kt16-b (Fig. 2A). Five radiocarbon dates were obtained on Stent tephra at Papamoa Bog (three from cores Kt16a-b; two from core BP3: Alloway et al. 1994), and the EMA of these is 3990 ± 40 yr B.P. An age of 4000 yr B.P. is therefore adopted here. Alloway et al. (1994) tentatively correlated the Stent tephra, derived from TVC, with Unit Q of Wilson (1993), which has an estimated age of 4050 yr B.P.

Hinemaiaia Tephra is found near the base of the peat as a 2.5 cm-thick, whitish-grey medium ash layer (Fig. 3A). Derived from TVC, it has a mineralogy dominated by hypersthene (Table 1). Analysis of glass from Kt16-b (sample P381-2) supports a Taupo origin and matches analyses from Hinemaiaia Tephra identified in Waikato lakes (Table 2). The two radiocarbon dates obtained from core Kt16a-b (Wk-1496, Wk-2152) differ from each other by several hundred years (Fig. 2A). They have an EMA of 4485 ± 55 yr B.P. (if the underlying sample Wk-1445 is included, the EMA is 4525 ± 45 yr B.P.), close to the EMA of 4510 ± 20 yr B.P. (n = 12) reported by Froggatt & Lowe (1990) for Hinemaiaia Tephra. It is likely that the tephra we refer to as Hinemaiaia at Papamoa Bog is a correlative of Wilson's (1993) Unit K, the most widely dispersed of the Taupo-derived tephtras erupted in the period from c. 4000 to 5000 yr B.P. Unit K has an estimated age of 4600 yr B.P. (Wilson 1993). We thus adopted this age (identical to Wk-2152 from Kt16-b, anyway) for Hinemaiaia Tephra in our study.

Microscopic analysis of the ferromagnesian mineralogy of the fine sand and pumice lapilli underlying the peat (at 4.2–4.3 m depth) in core Kt16-b showed an assemblage dominated by cummingtonite with biotite, hypersthene, augite, calcic hornblende, opaque minerals, and very rare aegirine. Such an assemblage, apart from the aegirine, is characteristic of OVC eruptives, with the abundant cummingtonite indicating a source specifically from Haroharo volcano (Froggatt & Lowe 1990). It is very likely therefore that the fine pumice lapilli represent Whakatane Tephra, a cummingtonite-rich tephra with an EMA of 4830 ± 20 yr B.P.

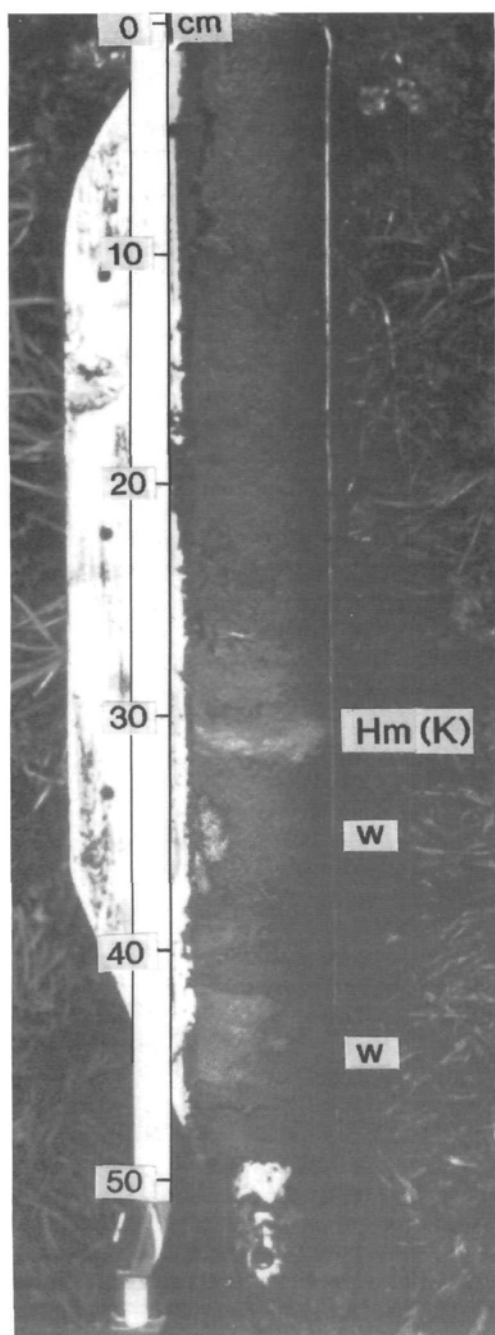


Fig. 3(A) – Part of core Kt16-b showing Hinemaiaia Tephra (Hm; Unit K of Wilson 1993), and wood fragments (w).

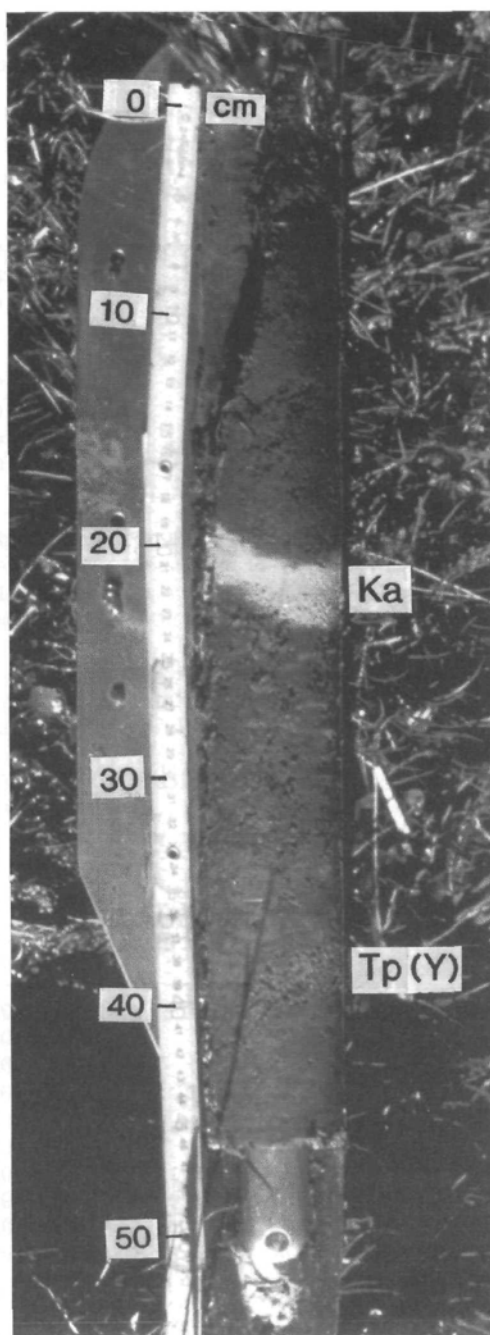


Fig. 3(B) – Part of core WB1 showing Kaharoa Tephra (Ka) and Taupo Tephra (Tp; Unit Y of Wilson 1993). Photos: D.J. Lowe.

Table 2 – Glass compositions* of Kaharoa, Taupo, Whakaipo, and Hinemaiaia tephra from Papamoa and Waihi Beach, and comparative analyses from elsewhere.

	Kaharoa		Taupo (Unit Y)	
	WS1 ^d	Mt Tarawera ^c	WS2 ^d	Waikato ^f
SiO ₂	78.46 (0.40)	78.34 (0.21)	76.58 (1.10)	76.43 (0.64)
Al ₂ O ₃	12.31 (0.11)	12.50 (0.12)	12.90 (0.46)	13.05 (0.23)
TiO ₂ ^a	0.14 (0.06)	0.11 (0.02)	0.22 (0.05)	0.23 (0.05)
FeO ^b	0.88 (0.14)	0.80 (0.08)	1.75 (0.32)	1.81 (0.19)
MgO ^a	0.10 (0.05)	0.10 (0.01)	0.22 (0.07)	0.22 (0.05)
CaO	0.72 (0.17)	0.61 (0.05)	1.41 (0.27)	1.31 (0.16)
Na ₂ O	3.53 (0.16)	3.22 (0.15)	3.77 (0.35)	3.97 (0.31)
K ₂ O	3.78 (0.15)	4.21 (0.14)	2.99 (0.39)	2.84 (0.17)
Cl ^a	0.15 (0.03)	0.16 (0.02)	0.16 (0.03)	0.14 (0.03)
Water ^c	2.18 (1.67)	3.05 (0.93)	1.71 (1.70)	3.21 (1.83)
n	9	11	10	10

*Means and standard deviations (in parentheses) as determined by JEOL-JXA-733 electron microprobe at Victoria University of Wellington, using 8 nA beam current at 15 kV and defocussed to 10 micrometres (Froggatt 1983); normalised to 100% loss-free

^a Analyses were below detection in some shards; these values omitted from the means

^b Total Fe as FeO

^c Difference between analytical total and 100

^d Sample from Waihi Beach Swamp (Fig. 2A) (this study; analyst P.C. Froggatt)

^e Sample from Mt Tarawera Rift (from Hodder et al. 1991)

^f Sample from Lake Rotomanuka, Waikato region (from Lowe 1988a)

^g Sample from Papamoa Bog (Core BP3, Fig. 1B) (Alloway et al. 1994)

^h Sample from Papamoa Bog (core Kt16-b, Fig. 1B) (Alloway et al. 1994)

n Number of analyses (individual shards) in mean

Table 2 Continued

	Whakaipo (Unit V)		Hinemaiaia (Unit K)	
	WG21 ^g	Waikato ^f	P381–382 ^h	Waikato ^f
SiO ₂	77.76 (0.22)	77.91 (0.26)	76.84 (0.23)	77.01 (0.67)
Al ₂ O ₃	12.43 (0.20)	12.48 (0.07)	12.86 (0.10)	12.88 (0.33)
TiO ₂ ^a	0.17 (0.04)	0.16 (0.05)	0.21 (0.03)	0.17 (0.03)
FeO ^b	1.58 (0.08)	1.52 (0.08)	1.75 (0.05)	1.68 (0.14)
MgO ^a	0.11 (0.02)	0.13 (0.01)	0.17 (0.02)	0.16 (0.05)
CaO	1.06 (0.05)	0.98 (0.03)	1.26 (0.30)	1.30 (0.16)
Na ₂ O	3.60 (0.25)	3.62 (0.11)	3.72 (0.12)	3.71 (0.17)
K ₂ O	3.15 (0.10)	3.09 (0.10)	3.06 (0.06)	3.00 (0.25)
Cl ^a	0.14 (0.03)	0.12 (0.02)	0.14 (0.03)	0.11 (0.03)
Water ^c	3.40 (1.75)	1.55 (0.79)	1.57 (1.76)	1.70 (1.97)
n	11	11	10	20

(n = 21, Froggatt & Lowe 1990). Aegirine is unique to Tuhua Tephra, which has an EMA of 6130 ± 30 (n = 10) (Lowe 1988a, b; Froggatt & Lowe 1990). The mixture of cummingtonite and aegirine thus indicates that the basal sediments comprise mainly reworked Whakatane Tephra plus a trace of Tuhua Tephra, a notion consistent with the estuarine environment in which the sediments were deposited, and with the age on the cockles (reported above), i.e., the basal sands must date from c. 4800 yr B.P. (Airfall Whakatane Tephra was identified in dune systems in the Rangitaiki Plains in eastern bay of Plenty; Pullar & Selby 1971.)

Two further radiocarbon dates, in addition to those obtained in association with the tephra layers, were assayed from core Kt16-b: Wk-2149 and Wk-2150 (Fig. 2A). Wk-2149 is consistent with the tephrochronology we have established, but Wk-2150 is not, being apparently younger than Whakaipo Tephra 0.65 m above it in the core (Fig. 4A). We have therefore omitted it from our pollen diagram chronology.

Waihi Beach Swamp

Core WB1 (Fig. 2B) comprises basal sands of likely estuarine origin overlain by sticky, brown, organic-rich muds, and blackish peat, intercalated with two macroscopic tephra layers (Fig. 3B). A radiocarbon date of 2900 ± 100 yr B.P. (Wk-2153) at the base of the brown muds indicates that infilling of the estuarine embayment began around that time.

Tephrochronology

The upper tephra layer, identified as Kaharoa Tephra, is 4 cm thick and comprises white, fine pumiceous ash over coarse ash with sparse fine, hard lapilli towards the base. Abundant biotite is evident in hand specimen, and the major element chemistry of glass at Waihi Beach (sample WS1, Fig. 2B) closely matches that of Kaharoa Tephra at source (Table 2). As at Papamoa, we adopt an age of 700 yr B.P. for the tephra here.

The lower tephra layer is identified as Taupo Tephra, a brownish-stained coarse ash and fine lapilli deposit 4 cm thick. Correlation is based on its field properties and stratigraphic position between Wk-2153 and Kaharoa Tephra, and corroborated by the similarity of the major element chemistry of its glass (sample WS2, Fig. 2B) to Taupo Tephra from other environments, including Wakato lakes (Table 2). We adopt an age of 1850 yr B.P. for Taupo Tephra (Unit Y of Wilson 1993) at Waihi Beach, as discussed above for Papamoa.

Both tephtras were recorded by Pullar et al. (1977) in a core taken from another part of Waihi Beach Swamp (core P, Fig. 1A).

PEAT ACCUMULATION RATES

Papamoa

Rates of peat accumulation for core Kt16-b are plotted in Fig. 4A. From 4600 to 2700 yr B.P., peat accumulated between 0.94 and 1.06 mm/yr, increasing markedly to 2.64 mm/yr from 2700 to 2450 yr B.P., and returning to 1.15 mm/yr from 2450 to 1850 yr B.P. The mean rate for this period is 1.37 mm/yr. The rate of accumulation since Taupo Tephra is likely to be severely underestimated because there has been considerable shrinkage of the bog's surface layers in historical times.

The rates are comparable with those reported for the large ombrogenous bogs in the Hauraki Lowlands (mean 0.86 ± 0.67 mm/yr for central and southern, and 1.68 ± 0.87 mm/yr for northern, parts of Kopouatai Bog; Newnham et al. 1995), but around ten times faster than those of some other Holocene bogs in central North Island (e.g., 0.19 mm/yr for both Holden's Bay, Rotorua, and Kaipo Lagoon, Urewera National Park; McGlone 1983; Lowe & Hogg 1986), and at Waihi Beach Swamp (see below). The rates of accumulation may vary for many reasons including climatic variation, influxes of nutrients, changes in sea level or ground level (tectonism), or geomorphic events causing changes in drainage patterns. At Papamoa, the initiation and rapid growth of the bog from just before c. 4600 yr B.P. was probably due in part to a net rise in water table, either by local tectonic subsidence, as suggested by Wigley (1990) for the Te Puke area (and for the Rangitaiki Plains by Nairn & Beanland 1989), or by a small rise (≈ 1 m) in sea level c. 4600 yr B.P., as suggested by Hull (1985) and Gibb (1986). At Kopouatai Bog, Hauraki Lowlands, changes in trophic status and peat accumulation rates were influenced by mid-Holocene sea level changes (Newnham et al. 1995). Sea levels have apparently oscillated by only a few tens of centimetres since then (e.g., see Woodroffe et al. 1983; Gibb 1986; Naish 1990). The initial bog development at Papamoa may also have been aided by a substrate of nutrient-rich estuarine sediments, and

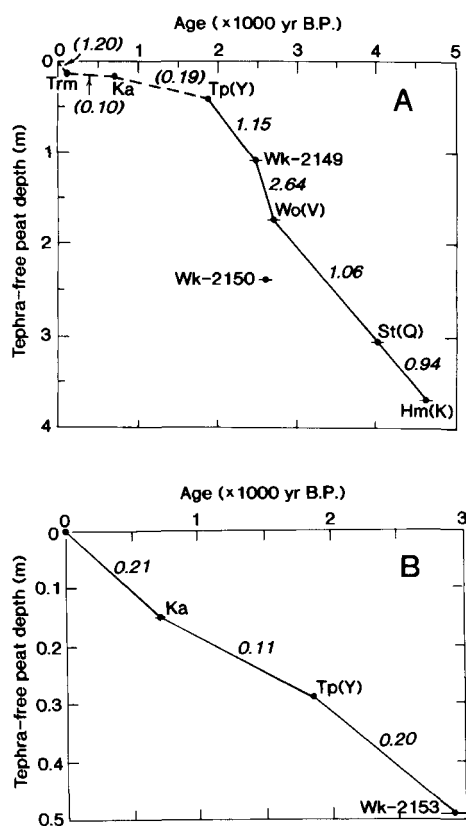


Fig. 4 – Peat depth-age curves for cores (A) Kt16-b at Papamoa, and (B) WB1 at Waihi Beach. Tephra abbreviations are as in Table 1. Sedimentation rates between dated points are shown in italics. At Papamoa, the rate of accumulation since Taupo Tephra (Tp) was deposited is probably grossly underestimated (see text).

enhanced by occasional influxes of nutrient-bearing flood waters. Variations in local drainage conditions are also likely to have influenced development.

Waihi Beach

The rates of peat accumulation since 2900 yr B.P. are plotted in Fig. 4B. From 2900 to 1850 yr B.P., the rate is 0.20 mm/yr; from 1850 to 700 yr B.P. it slows to 0.11 mm/yr; and from 700 yr B.P. to the surface (assumed to represent present day), it is 0.21 mm/yr. The extent to which partial drainage has affected peat thickness is unknown, but the depths are comparable with those recorded by Pullar et al. (1977), suggesting that there has been rather little shrinkage over the past c. 20 years. The mean rate of accumulation for the entire period from 2900 yr B.P. to the present day is 0.20 mm/year, considerably slower than that at Papamoa prior to deposition of Taupo Tephra (Fig. 4A).

PALYNOLOGY

Methods and results

Pollen samples were analysed from the base of the Papamoa Bog core at 410 cm, at 20 cm intervals from 400 cm to 60 cm, and at 5 cm intervals from 50 cm to 10 cm (Fig. 2A). The closer sampling interval reflects our particular interest in the last 2000 years. Samples at 400 and 380 cm yielded very little or no pollen and are not included in the pollen diagrams. All other samples yielded sufficient numbers to achieve a minimum sum of 250 dryland pollen.

Pollen samples were taken at 10 cm intervals from the base of the Waihi Beach core (75 cm) to 55 cm, and thereafter at 5 cm intervals except where tephra layers intervened (Fig. 2B). Pollen recovery was generally good, except in the uppermost two samples, where levels of indigenous dryland pollen taxa were comparatively low. Microscope slides were prepared following standard procedures (Faegri & Iversen 1989) including hydrofluoric acid treatment. Tablets of exotic *Lycopodium* spores were added to each sample to permit the determination of pollen concentrations and accumulation rates. Charcoal concentrations were estimated using the point count method described by Clark (1982) for the Papamoa Bog samples, and using the nitric acid digestion method described by Winkler (1985) for the Waihi Beach samples. Besides mire taxa, ferns and allies taxa, and exotic taxa, *Leptospermum* was omitted from the pollen sum at both sites, because high numbers of this taxon suggested the local presence of *Leptospermum scoparium* or *Kunzea ericoides*. Several grains of walnut (*Juglans*) pollen were recorded in the Papamoa samples between 430 and 100 cm depth. As this tree has only recently been introduced into New Zealand, this record is assumed to have resulted from contamination of the samples after the core was extracted.

The pollen profiles at both sites are divided into three time intervals, as follows:

Papamoa Bog (Fig. 5)

Time Zone 1: c. 4600 – 1850 yr B.P.

The lowermost spectra are characterised by high levels of *Leptocarpus*, Cyperaceae and *Coprosma* pollen. *Leptocarpus* and Cyperaceae pollen levels then decline, and *Leptocarpus* disappears from the record after c. 4600 yr B.P. Meanwhile, *Empodisma* pollen and *Gleichenia* spores increase to high levels. These changes are associated with a sediment transition from black peat to sludgy brown peat. Cyperaceae pollen remains important, although at lower levels than in the lowermost spectra, and possibly other sedge species are now present. Other important mire taxa in this zone are *Leptospermum*, *Typha*, especially in the upper part of the zone, and *Phormium*, especially in the lower to middle part of the zone. *Pteridium* spores are common in several spectra, as are charcoal fragments, particularly at 240 cm.

Dryland pollen spectra are dominated by *Dacrydium*, with other prominent Podocarpaceae taxa including *Dacrycarpus*, *Phyllocladus*, *Podocarpus*, and *Prumnopitys*. *Agathis australis* pollen is consistently present in this zone but never exceeds 2%. *Metrosideros* species are the dominant angiosperm pollen taxa, and numerous other angiosperm trees and shrubs are present, including *Nothofagus fusca* type. *Cyathea dealbata* type spores are also prominent.

Time Zone 2: c. 1850 – 700 yr B.P.

The lower part of this zone is characterised by strong increases in *Pteridium* spores and Poaceae pollen at, and shortly after, the time of the Taupo eruption of 1850 yr BP. This evidence suggests that vegetation disturbances caused by the eruption extended to a considerable distance from its source, although the local mire vegetation and regional conifer-angiosperm forests remained largely unaffected. *Pteridium* and Poaceae levels return to zero 15 cm above the tephra, suggesting that the disturbance interval was short. Fire, apparently, was not involved.

Time Zone 3: c. 700 yr B.P. to near-present

Charcoal concentrations rise immediately below Kaharoa Tephra and remain comparatively high to the top of the sequence. Exotic pollen, particularly *Pinus* and *Salix* are first recorded immediately above the Kaharoa Tephra. *Taraxacum* type pollen is also common in this zone, and may also be from adventive taxa. Poaceae pollen and *Pteridium* spores are also at their highest levels. Tree pollen percentages are lower overall than in the previous zone, with a notable decline in *Prumnopitys* spp.

Discussion

The lowermost pollen spectra at Papamoa Bog, from sediments overlying sand, indicate a coastal or estuarine *Leptocarpus similis*/Cyperaceae marsh. After around 4600 yr B.P., the pollen record indicates a decline of these coastal/estuarine communities and a transition to an early oligotrophic or low moor bog, with *Empodisma minus* and *Gleichenia dicarpa* prominent. Fire was associated with the bog environment. Pollen of raupo (*Typha orientalis*) and flax (*Phormium tenax*) probably originated from lagg vegetation at the margins of the bog. An increase in *Phormium* pollen (an under-represented pollen taxon) at 200 cm, followed by an increase in *Typha* pollen at 160 cm, and the simultaneous decline in *Empodisma* pollen and *Gleichenia* spore levels, suggests that more parts of the bog were subject to eutrophic conditions at this time than at any other time during its history. This period, spanning the 1000 or so years before the deposition of the Taupo Tephra at 1850 yr B.P., encompasses the period of most rapid peat accumulation at Papamoa Bog (Fig. 4A) The bog has persisted to the present day, judging by the *Empodisma* pollen curve, although the bog vegetation has been greatly reduced during the European era.

The regional dryland vegetation consisted primarily of diverse conifer-angiosperm forest, which persists to the European era. At least some *Coprosma* pollen may have originated from mire communities, particularly in the lowermost spectrum, where *Coprosma* reaches almost

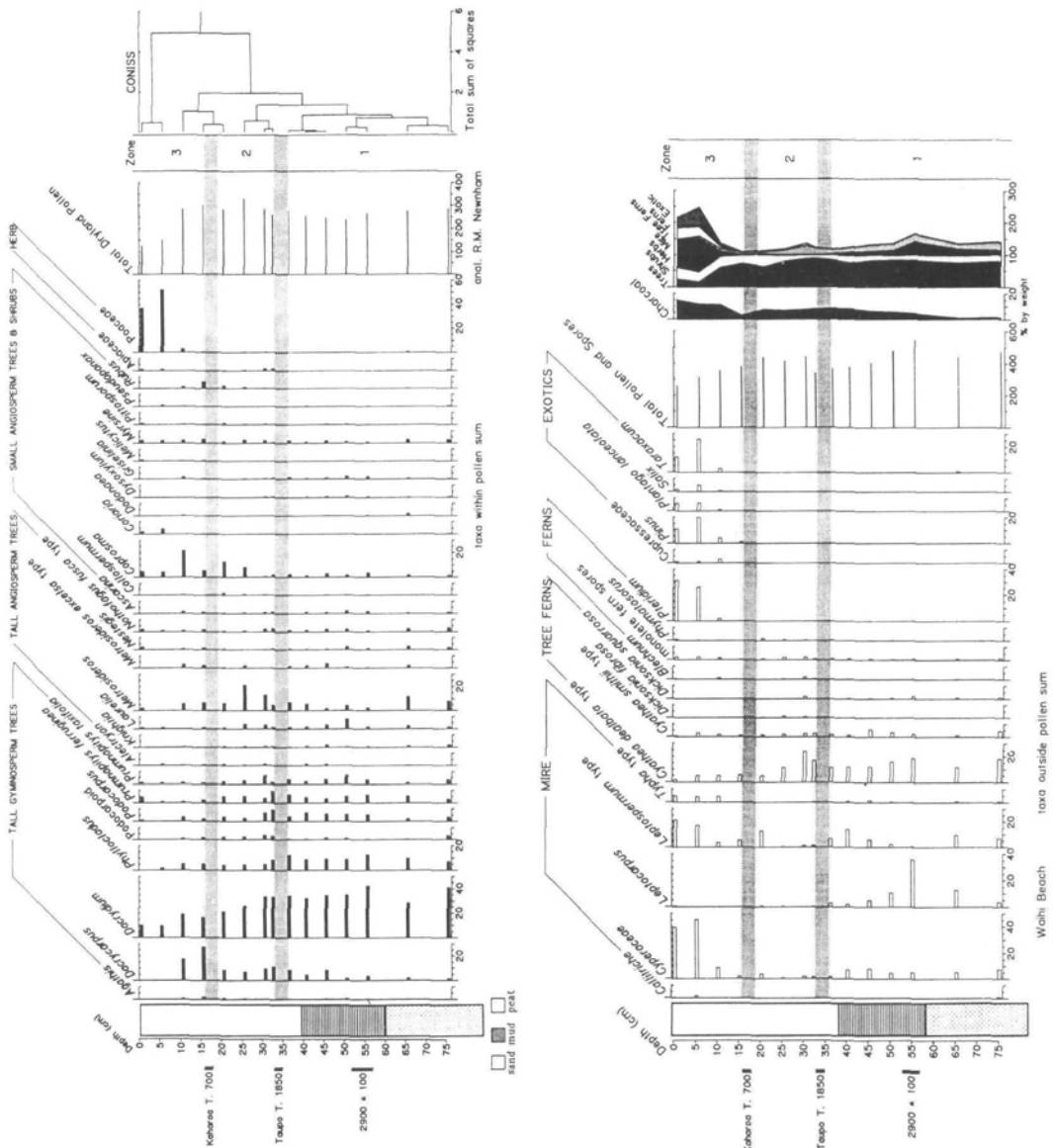


Fig. 6 – Pollen percentage diagram for core WB1, Waihi Beach Swamp.

30% of 'dryland pollen'. Similarly, kahikatea (*Dacrycarpus dacrydioides*) and *Laurelia novae-zelandiae* (pukatea) trees probably grew on swampy ground at the margins of the marsh or bog. The comparatively low (for this taxon) levels of *Nothofagus* pollen suggest that beech forests were present, but at distant localities, probably in the Kaimai or Coromandel Ranges (Newnham et al. 1995). Forests declined during the European era.

Campbell et al. (1973) reported plant macrofossils and tephra layers from cored sediments spanning the last c. 3000 years taken at a site c. 1 km to the northeast of our core site and within the same bog system (Fig. 1B). Peats below the Kaharoa Tephra contained macrofossils derived from a *Baumea*-dominated low moor bog with *Gleichenia*, *Empodisma*, *Cortaderia* and dwarf trees or short-lived seedlings of *Dacrycarpus* and *Laurelia*. Above this tephra

layer, the peat had been greatly altered by farming. These macrofossil data are broadly consistent with the Papamoa pollen data, except that the early coastal communities were not detected in the macrofossil core, presumably because it did not extend to sufficient depth.

Waihi Beach Swamp (Fig. 6)

Time Zone 1: c. 2900 – 1850 yr B.P.

This pollen zone encompasses two sediment types: the greenish grey sands at the base of the core and the overlying sticky brown muds. *Leptocarpus* pollen is abundant although declining towards the top of the zone, while Cyperaceae and *Leptospermum* pollen is common. Numerous other wetland taxa were recorded including *Typha*, *Potamogeton*, *Myriophyllum*, *Callitriche*, *Avicennia* and Apiaceae.

Dryland pollen assemblages are dominated by podocarp taxa, especially *Dacrydium*, and to a lesser extent, *Phyllocladus* and *Prumnopitys*. *Dacrycarpus* pollen levels increase towards the top of the zone. Prominent tall angiosperm tree taxa are *Laurelia*, *Metrosideros*, *Alectryon*, *Knightia* and *Nestegis*, while smaller tree and shrub taxa include *Ascarina*, *Coprosma*, *Dodonaea*, *Dysoxylum*, *Griselinia*, *Myrsine*, *Pittosporum*, and *Pseudopanax*. *Cyathea dealbata* type tree fern spores are common.

Time Zone 2: c. 1850 – 700 yr B.P.

Peat replaced the sticky brown mud of the uppermost part of the previous zone. Palynologically, the major change is the near-disappearance of *Leptocarpus* pollen from the record, and the reduced representation of many of the other coastal marsh taxa of the previous zone.

Few changes are evident in the dryland taxa, but overall there is an increase in smaller tree and shrub pollen, particularly *Coprosma*. Levels of podocarp pollen fall, except for *Dacrycarpus* which increases to a peak of 25% at the top of the zone.

Time Zone 3: c. 700 yr B.P. to near-present

Charcoal concentrations rise steadily and the pollen of exotic taxa, notably *Pinus*, Cupressaceae, *Salix*, *Plantago lanceolata*, and *Taraxacum* are found throughout. Levels of Poaceae pollen and *Pteridium* spores also increase dramatically, as do the pollens of some other herbaceous and shrubby taxa, e.g., Apiaceae and *Coriaria*. At the same time, total tree pollen percentages fall from 80% at the base of the zone to 25% at the top, with most individual tree taxa showing a marked decline, particularly *Dacrycarpus*. In the wetland taxa, Cyperaceae, *Leptospermum*, and *Typha* pollen levels increase markedly.

Discussion

The abundance of *Leptocarpus* and Cyperaceae pollen, and that of associated wetland taxa, indicate that the site was initially occupied by coastal salt marsh communities, probably regularly flooded at high tide. In time, *Leptocarpus* gradually declined, as the nature of the sediment accumulating at the site changed from greenish grey sands to organic brown muds. These changes are likely to be related to gradual coastal progradation, or a falling sea level, or both.

After c. 2000 yr B.P., *Leptocarpus* pollen virtually disappears from the record and peat sedimentation begins at the site. The site was no longer influenced by tidal processes and had become more distant from coastal marsh communities, but closer to kahikatea (*Dacrycarpus dacrydioides*) swamp forest communities.

At some time following the deposition of Kaharoa Tephra (c. 700 B.P.), the local wetland flora changed again, as swamp forest communities declined near the core site to be replaced by eutrophic sedge-*Typha*-*Leptospermum* wetland communities. This last change probably began during the European era, the last 150 years, as it is associated with the rise of adventive pollen.

The dryland pollen spectra indicate that a northern coastal conifer-angiosperm forest

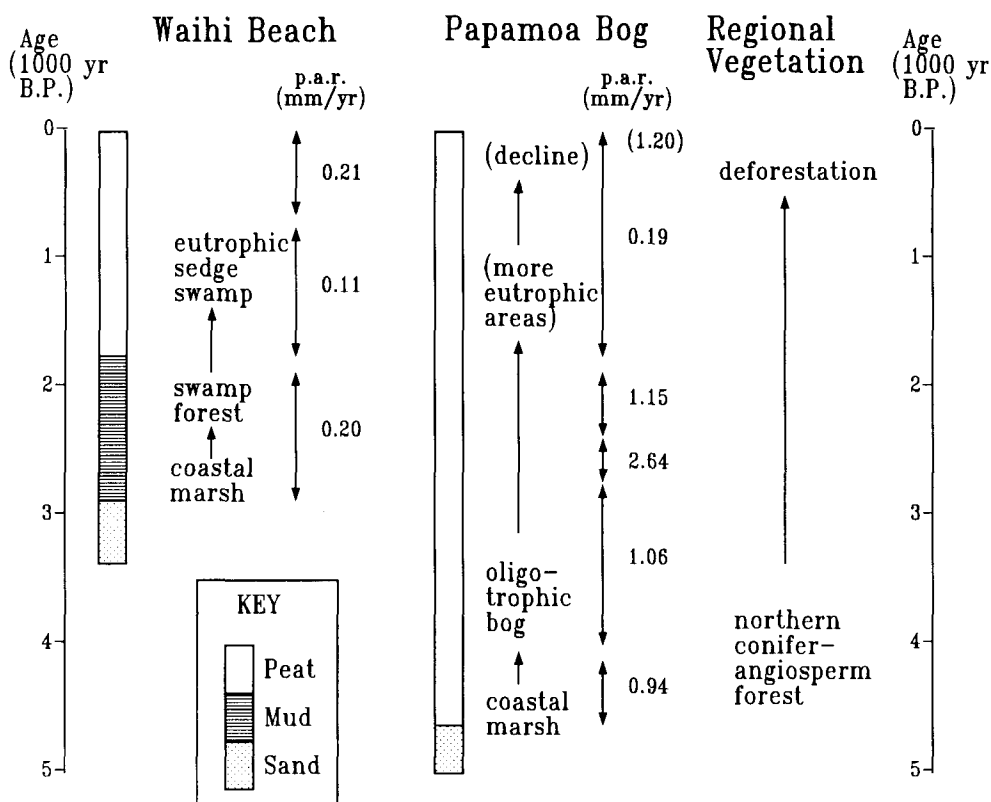


Fig. 7 – Summary of local and regional vegetation history and peat accumulation rates (p.a.r.) from the palynology of cores from Papamoa Bog and Waihi Beach Swamp.

persisted near the site, with few changes apparent until Time Zone 3. Consistently low levels of *Nothofagus fusca* type pollen levels indicate probable long distance transport from upland sources. In contrast, low levels of *Agathis australis* pollen are more likely to represent small populations nearer the site, as *A. australis* pollen does not appear to be as well dispersed as that of *Nothofagus* (Newnham, 1990). There was significant loss of forest during Time Zone 1.

SYNTHESIS: LOCAL AND REGIONAL VEGETATION CHANGES

The local vegetation history at Waihi Beach and Papamoa Bog, and regional vegetation changes in the western Bay of Plenty during the past c. 5,000 years, are summarised in Figure 7. At both sites, organic sediments are underlain by marine or estuarine sands, and the initial local vegetation changes appear to be controlled by either coastal progradation or falling sea level (or both). The basal pollen spectra at both sites indicate local salt marsh or estuarine conditions. At Papamoa, an oligotrophic bog developed at the site soon after c. 4600 years ago and persisted to the present, with considerable reduction during the past 700 years (see below), and an earlier period, between 2800 and 1850 yr B.P., when eutrophic conditions were more prevalent. Except for the uppermost, disturbed peats, peat accumulated rapidly, particularly during the interval 2700 to 2400 yr B.P. At Waihi Beach, the coastal marsh was superseded by kahikatea swamp forest around 2500 yr B.P., which probably persisted until the European era; then a eutrophic mire developed with various sedges and raupo prominent. Peat accumulation here was much slower, especially during the period 1850 to 700 yr B.P. The concurrent development of oligotrophic conditions at Papamoa and mesotrophic or

eutrophic conditions at Waihi Beach probably relate to differences in local geomorphology, rather than to climatic factors. Although peat accumulation rates may also be influenced by factors other than climate, the slower rates evident at both sites during the period 1850 to 700 yr B.P. point to a drier and/or warmer overall climate during this period.

Both pollen records indicate mixed northern conifer-angiosperm forest as the main regional vegetation type during the past c. 4600 years. Lowland forests probably included a scattering of kauri trees, while beech (*Nothofagus fusca* group) was most likely present in adjacent uplands, as it still is. Kauri (*Agathis australis*) populations do not appear to have been expanding during the late Holocene at these sites, which are close to its southern limit today (Allan 1961)

Vegetation disturbance following Taupo Tephra

Both pollen profiles indicate a generally stable forest environment, occasionally interrupted by fires, such as those responsible for the charcoal peak at 240 cm depth or the bracken (*Pteridium*) spore rise at 200 cm. However, more significant disturbance at Papamoa is suggested by the sharp rise in bracken spores and grass pollen in spectra immediately overlying the Taupo Tephra. Similar evidence has been noted at several other pollen sites containing Taupo Tephra but remote from the eruptive centre. At Kohika Swamp, c. 45 km to the southeast of Papamoa Bog and also on the Bay of Plenty coastal plain (Fig. 1), the Taupo Tephra fall was followed by at least 150 years during which fires were frequent, bracken and grass abundant, and alluvium was washed into the swamp (McGlone 1981). Newnham et al. (1989) reported similar evidence from lake sites in the Waikato lowlands, although there, the disturbance was less severe and probably shorter-lived. At Papamoa, charcoal levels do not rise as at these other sites, suggesting that the post-Taupo Tephra disturbance here was not directly related to fire. Evidence for comparable disturbance was not detected in the pollen spectrum immediately overlying Taupo Tephra at Waihi Swamp 50 km northwest of Papamoa, although the sediment changes from sticky, brown organic-rich mud below the tephra to peat above it.

Deforestation and the human era

At both sites, amounts of tree pollen fall as amounts of charcoal, bracken, grass and other herbs and shrubs rise in spectra immediately overlying Kaharoa Tephra. These changes are consistent with those detected at other pollen sites containing Kaharoa Tephra where burning of forests is indicated at around the time of this eruption, that is 700 – 800 yr B.P. (e.g., see McGlone 1989; McGlone et al. 1994; Newnham et al. 1989, 1995). At Waihi Beach Swamp, the rise of charcoal levels in sediments immediately below Kaharoa Tephra is consistent with evidence from Kopouatai Bog, 35 km to the northwest, where significant human influence on the vegetation appears to have begun just before the deposition of Kaharoa Tephra (Newnham et al. 1995). However, at both Waihi and Papamoa, these samples also contain significant numbers of adventive pollen, notably pine, willow, and macrocarpa, from trees introduced during the past 150 years. It seems that these adventive pollen grains have filtered down as far as the Kaharoa Tephra, which lies within 20 cm of the surface at both sites, and may act as a barrier to further movement. Possibly this process has been enhanced by agricultural activity at the surface. The downwards dislocation of modern pollen at these sites blurs any distinctions that might have been made within the human era, in particular distinguishing between the Polynesian and European eras.

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