Impact of tephra fall and environmental change: a 1000 year record from Matakana Island, Bay of Plenty, North Island, New Zealand

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Abstract: Palynological evidence was used to determine the development of vegetation communities on Matakana Island, North Island, New Zealand, over the last 1000 radiocarbon years. The pollen record indicates that changes occurred in the vegetation immediately following fallout deposition of the Kaharoa Tephra approximately 100 km from source at *c.* 665 years BP. Such changes may be a direct response to the impact of tephra fall, although the possibility of anthropogenic disturbance cannot be discounted. As a result of the eruption some taxa (*Leucopogon fasciculatus* and *Tupeia antarctica*) became at least temporarily extinct from the area. Two phases of anthropogenic influence on the environment are recorded in the pollen record: Polynesian, followed by European inhabitation of the island, giving a detailed history of human influence in the area for the millennium.

The North Island of New Zealand has endured an extremely violent volcanic history throughout the Quaternary. Numerous thick pyroclastic deposits, including widespread fallout tephra layers, blanket the central North Island and there is a well established tephrostratigraphic record for the late Quaternary, i.e. the last *c.* 65 000 years (Lowe 1988; Froggatt & Lowe 1990; Wilson 1993; Alloway *et al.* 1995; Donoghue & Neall 1996; see also Newnham *et al.* 1999). The bulk of these deposits were erupted from the rhyolitic volcanic centres of Okataina, Taupo, Maroa and Mayor Island (Tuhua) and the andesitic centres of Tongariro and Egmont (Fig. 1C). Research on the impacts that eruptives from these volcanic centres have had on New Zealand vegetation communities has largely been restricted to localized areas in the North Island with work focusing on proximal volcanic impacts and both short- and long-term effects (e.g. Clarkson *et al.* 1988; McGlone *et al.* 1988; Clarkson 1990; Lees & Neall 1993; Clarkson & Clarkson 1994; Horrocks & Ogden 1998). Some research has also focused briefly on distal volcanic impacts. Palynological studies have shown evidence for the occurrence of forest fires following distal tephra fallout through increases in charcoal fragments and bracken spores immediately above tephra layers preserved in peat bogs and lake deposits in the North Island (McGlone 1981; Newnham *et al.* 1989, 1995*a*; Wilmshurst & McGlone 1996; Newnham & Alloway in press).

Human activity and deforestation began late in New Zealand with the arrival of

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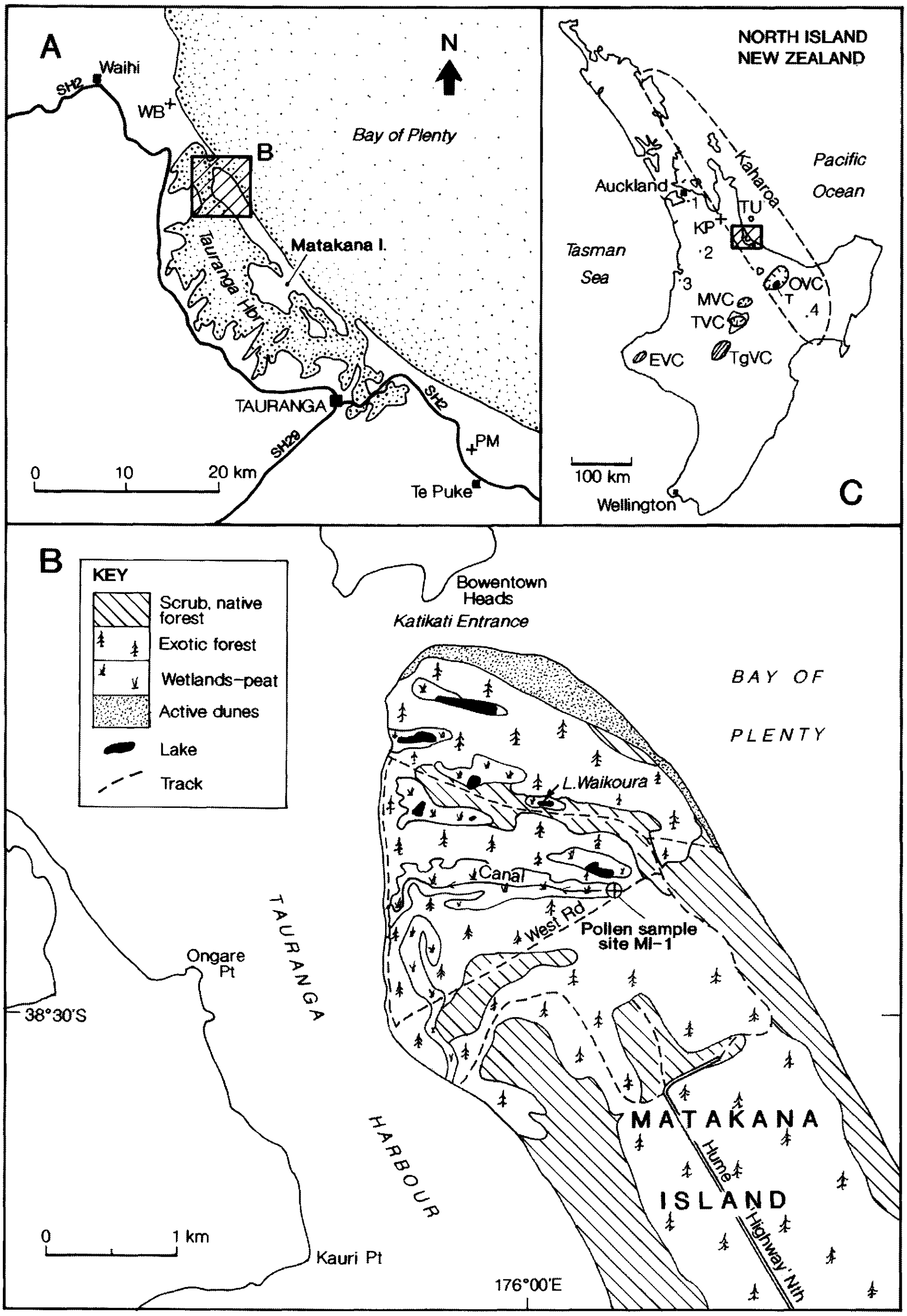

A
Waihi
SH2
WB
N
Bay of Plenty
B
Matakana I.
Tauranga Hbr
TAURANGA
SH2
SH29
PM
Te Puke
0 10 20 km
NORTH ISLAND
NEW ZEALAND
Kaharoa
Pacific
Ocean
Auckland
TU
KP
1
2
3
4
Tasman
Sea
MVC
OVC
T
TVC
EVC
TgVC
100 km
Wellington
C
B
KEY
Scrub, native forest
Exotic forest
Wetlands–peat
Active dunes
Lake
Track
Bowentown
Heads
Katikati Entrance
BAY OF
PLENTY
L.Waikoura
Canal
West Rd
Pollen sample
site MI–1
Ongare
Pt
TAURANGA
38°30'S
HARBOUR
MATAKANA
ISLAND
Hume Highway Nth
0 1 km
Kauri Pt
176°00'E

Polynesians around or after 1000 radiocarbon years BP, with the most severe anthropogenic impacts occurring between 730–500 years BP (McGlone 1989). (Note that throughout the text, ages are reported in terms of conventional radiocarbon years BP; calibrations of ages newly obtained in this study are listed in Table 2.) The combination of frequent and extensive volcanic activity, an excellent tephrostratigraphical record, and the short timespan of human activity provide great potential for studying the distal impacts of volcanism in New Zealand.

In this study, palynological changes in a peat core extracted from Matakana Island in the western Bay of Plenty region, North Island, New Zealand are examined. This work focuses particularly on vegetation changes following deposition of the Kaharoa Tephra *c.* 665 years BP. The preliminary results also reveal important insights into the environmental history of the island over the last 1000 years BP.

The study site

Matakana Island is a large barrier island, 26 km long, enclosing Tauranga Harbour (Fig. 1A). The main part of the island is composed primarily of Holocene sands (Marshall *et al.* 1994; Shepherd *et al.* 1997). The study site is situated at the northwestern end of the island adjacent to the Katikati Entrance of the harbour. This area comprises a dune-dominated landscape (all < 10 m above sea-level, mean high water spring) containing wetland areas and shallow dune lakes bordered by small peaty wetlands, all of which developed during the last *c.* 900 years (Munro 1994). Site MI-1 is located near the eastern end of a small (*c.* 0.5 km^2) low-lying interdune wetland adjacent to West Rd (Fig. 1B). A sluggish canal (*c.* 1 m wide near MI-1), constructed in the 1960s, partially controls the water table level of the wetland. The local catchment of this wetland is very limited, hence any inwashing is likely to be from adjacent dunes. The sampling site is currently dominated by grey willow (*Salix cinerea*) with toi-toi (*Cortaderia*), gorse (*Ulex*) and bracken (*Pteridium*) scrub, but is surrounded by exotic plantation forest (chiefly *Pinus radiata*) established initially in the mid-1920s. (Self-sown exotic *P. radiata* on the island dates from around 1900 to 1910.) Small areas of native forest and scrub still exist on the northwestern part of the island (Fig. 1B).

Archaeological evidence for human impact on Matakana Island has been found at a number of sites (Marshall *et al.* 1994). Pa (fortified village) sites, terraces and shell middens are less common on the northwestern end of the island in the vicinity of site MI-1, possibly because of burial or destruction by shifting sands and rapid erosion,

Fig. 1. (a) The western Bay of Plenty region showing the location of Matakana Island and study area adjacent to Tauranga Harbour. WB (Waihi Beach) and PM (Papamoa) refer to Holocene sites described by Newnham *et al.* (1995*b*). **(b)** The northwestern part of Matakana Island and the location of pollen sampling site MI-1. **(c)** The study area with respect to the rhyolitic Okataina Volcanic Centre (OVC) and Mt Tarawera volcano (T), the source of the 665 years BP Kaharoa Tephra. The dashed line is the 30 mm-thick isopach of Kaharoa Tephra (from Pullar *et al.* 1977). Other recently active volcanic centres shown are Tuhua (TU), Maroa (MVC), Taupo (TVC), Tongariro (TgVC), and Egmont (EVC) (Froggatt & Lowe 1990; Wilson *et al.* 1995). Numbers mark locations of pollen sites currently under investigation: 1, Kohuora crater (Auckland); 2, Lake Rotoroa (Hamilton); 3, Lake Taharoa; 4, Kaipo peat bog (Te Urewera National Park; see Lowe & Hogg 1986). KP marks the location of Kopouatai bog, as described by Newnham *et al.* (1995*a*).

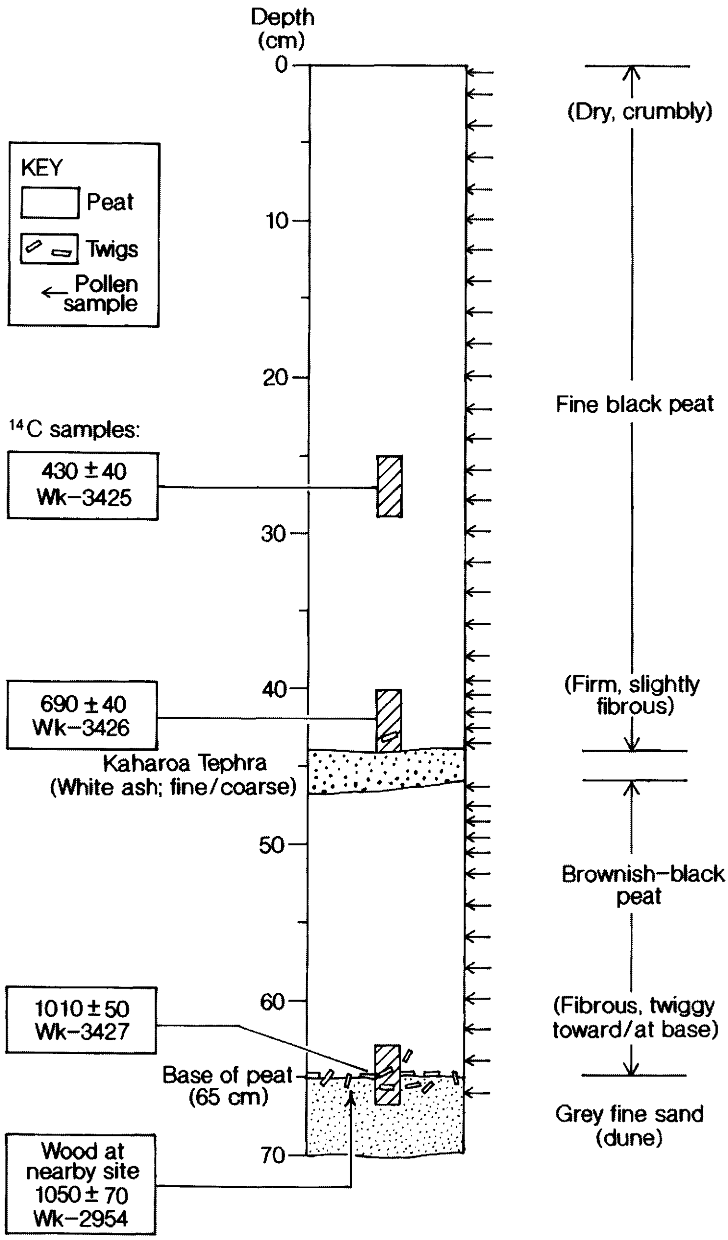


Fig. 2. Stratigraphy and chronology of peat profile for site MI-1, Matakana Island, at U13/758083 (grid references here and in Tables 1 & 2 are based on the metric 1 : 50 000 topographical map series NZMS 260), and pollen sampling positions. Ages are in conventional radiocarbon years BP (see Table 2).

Table 1. *Comparison of electron microprobe analyses of glass[a] in Kaharoa Tephra at Matakana Island with glass sampled at source (Mt Tarawera), Waihi Beach, and Kopouatai (Fig. 1)*

	Matakana Island[b]	Mt Tarawera[c]	Waihi Beach[d]	Kopouatai[e]
SiO_2	77.51 (0.19)	78.34 (0.21)	78.46 (0.40)	78.22 (0.31)
Al_2O_3	12.81 (0.15)	12.50 (0.12)	12.31 (0.11)	12.49 (0.15)
TiO_2	0.10 (0.03)	0.11 (0.02)	0.14 (0.06)	0.13 (0.04)
FeO^f	0.88 (0.10)	0.80 (0.08)	0.88 (0.14)	0.76 (0.26)
MgO	0.09 (0.04)	0.10 (0.01)	0.10 (0.05)	0.09 (0.13)
CaO	0.53 (0.07)	0.61 (0.05)	0.72 (0.17)	0.55 (0.06)
Na_2O	3.80 (0.09)	3.22 (0.15)	3.53 (0.16)	3.42 (0.19)
K_2O	4.12 (0.13)	4.21 (0.14)	3.78 (0.15)	4.22 (0.43)
Cl	0.18 (0.03)	0.16 (0.02)	0.15 (0.03)	0.14 (0.03)
Water[g]	2.31 (1.29)	3.05 (0.93)	2.18 (1.67)	0.93 (0.68)
n	11	11	9	10

[a] Means and standard deviations (in parentheses, calculated to one standard deviation) normalized to 100% loss-free. Analysed by Jeol JXA-733 Superprobe at the Analytical Facility, Victoria University of Wellington. All analyses used beam diameter 10–15 μm, current 8–nA, accel. voltage 15 kV (Froggatt 1983). Anal. 1 calculated from 11×2 s counts across the peak, curve integrated; anal. 2–4 calculated from 3×10 s counts at the peak, meaned. Analyses of TiO_2, MgO, and Cl were below detection in some shards; these values were omitted from the means. n refers to number of analyses (individual shards) in mean.
[b] Core at MI-1 (U13/758083; this study).
[c] Section at V16/177252 in Mt Tarawera crater (from Hodder *et al.* 1991).
[d] Core at U13/702174 in Waihi Beach swamp (from Newnham *et al.* 1995b).
[e] Core at T13/380197 in Kopouatai bog (from Hodder *et al.* 1991).
[f] Total Fe as FeO.
[g] Difference between original analytical total and 100.

or through logging operations. Marshall *et al.* (1994) and Shepherd *et al.* (1997) reported that there is no evidence of human settlement on Matakana Island prior to the deposition of Kaharoa Tephra.

Peat stratigraphy, chronology, sampling and pollen analysis

The stratigraphy at site MI-1 comprises 65 cm of peat overlying aeolian dune sands (Fig. 2). A macroscopic tephra-fall layer 2–3 cm thick occurs at 44–47 cm depth within the peat and is identified here as Kaharoa Tephra, a rhyolitic eruptive from Tarawera volcano in the Okataina Volcanic Centre situated *c.* 100 km southeast from Matakana Island (Fig. 1C). The layer, consisting of fine ash overlying coarse ash, is dominated by biotite (*c.* 85% of the magnetic fraction), which is a diagnostic mineral for this tephra (Froggatt & Lowe 1990). Kaharoa Tephra has been identified at other sites on Matakana Island (Munro 1994; Shepherd *et al.* 1997) and along the western Bay of Plenty coastline including peat bogs at Papamoa and Waihi Beach (Fig. 1A; Newnham *et al.* 1995*b*). The identification is confirmed through major element analysis of its constituent glass by electron microprobe (Table 1).

Froggatt & Lowe (1990) reported an error-weighted mean age of 770 ± 20 years BP ($n = 15$) for Kaharoa Tephra. However, Lowe & Hogg (1992) and Newnham *et al.* (1995*a*) suggested that it was erupted around, or possibly soon after, 700 years BP. The most recent age estimate, based on cluster analysis of 22 age determinations (Lowe *et al.* 1998), is an age of 665 ± 15 years BP (equivalent to *c.* 600 calendar years BP). This age is statistically identical to the age of 690 ± 40 years BP (Wk-3426)

Table 2. *Radiocarbon dates relevant to peat profile sampled and Kaharoa Tephra, Matakana Island*

Lab no.[a]	Sample material[b]	Depth[c] (cm)	$\delta^{13}C$ (‰)	Conventional age (years BP)[d]	Calibrated date AD[e] 1 standard deviation (sd)	Calibrated date AD[e] 2 standard deviations (sd)	Comments
Site MI-1 (U13/758083, see Fig. 2)							
3425	P	25–29	−28.3±0.2	430±40	1445–1519(.73) 1594–1622(.27)	1438–1532(.58) 1547–1635(.42)	
3426	PW	40–44	−27.8±0.2	690±40	1295–1326(.49) 1352–1362(.15) 1366–1389(.35)	1286–1334(.45) 1338–1403(.55)	Directly overlies KT[f]
3427	WP	63–67	−26.8±0.2	1010±50	1005–1006(.01) 1019–1070(.44) 1081–1125(.40) 1136–1154(.15)	993–1163(.92) 1168–1193(.06) 1199–1207(.01)	Base of peat/sand interface
Site *c.* 10 m S of MI-1 (Edge of canal [U13/758082])							
2954	W	40–46	−28.2±0.2	1050±70	905–906(.01) 982–1070(.61) 1082–1126(.27) 1136–1154(.11)	893–927(.07) 939–1209(.93)	Base of peat/sand interface[g]
Sawmill section (U14/847946)							
2820	C	70–71	−25.5±0.2	810±140	1069–1083(.04) 1124–1137(.04) 1153–1327(.78) 1350–1390(.14)	1001–1011(.01) 1017–1426(.99)	Directly underlies KT

[a] University of Waikato Radiocarbon Dating Laboratory (prefix Wk-).
[b] P, Peat; PW, peat with twigs*; WP, twiggy* peat; W, large piece of wood (?root); C, fine charcoal fragments dominated by material from large podocarp trees and potentially with inbuilt age (R. Wallace, pers. comm. 1999). All samples were washed in hot 10% HCl, rinsed, and dried. Fine roots were removed from the peat samples. *Twigs are Podocarpaceae, probably young *Dacrycarpus dacrydioides* (P. J. de Lange, pers. comm. 1994).
[c] Below top of section.
[d] Old half-life basis (5568 yr)±1 sd; × by 1.03 to calculate on new half-life basis.
[e] Based on method B (probability distribution) of Stuiver & Becker (1993) after first subtracting the S. Hemisphere correction factor of 40 years (Vogel *et al.* 1993). Calibration program Rev. 3.04A (Mac test #6). Numbers in parentheses are relative contributions to probabilities.
[f] KT refers to Kaharoa Tephra.
[g] Equivalent stratigraphic position to Wk-3427.

obtained by us at MI-1 (Fig. 2; Table 2) and so we have adopted an age of 665 ± 15 years BP for the Kaharoa Tephra. Two further ^{14}C ages from MI-1 are consistent with the chronostratigraphic position of Kaharoa Tephra (Fig. 2). The basal twiggy peat is aged 1010 ± 50 years BP (Wk-3427), an age corroborated by the statistically-identical age of 1050 ± 70 years BP (Wk-2954) obtained on a piece of wood from an equivalent stratigraphic position at a site close by (Table 2).

The rates of peat accumulation are reasonably uniform and relatively fast, the mean for the entire profile being *c.* 0.61 mm a^{-1}. From *c.* 1000 years BP to 665 BP (base of peat to Kaharoa Tephra) the rate was *c.* 0.55 mm a^{-1}; from Kaharoa to 430 years BP it increased to *c.* 0.72 mm a^{-1}; and from 430 years BP to present day (assumed to be at surface), *c.* 0.63 mm a^{-1}. The last value is likely to be a minimum rate because of possible oxidation and shrinkage of peat at the surface in recent times through drainage.

Samples for pollen analysis were taken from contiguous slices 2 cm thick from the surface to a depth of 39 cm, and from 51 cm to 67 cm; in the interval from 39–51 cm depth the contiguous slices were 1 cm thick (i.e. above and below the Kaharoa Tephra layer; Fig. 2). This finer sampling resolution was adopted to examine any vegetational changes in the area resultant upon fall of the tephra material. From each contiguous slice of peat, 0.5 cm^3 samples were extracted for pollen preparations. Standard palynological procedures were employed (Moore *et al.* 1991), excluding HF acid treatment in order to preserve tephra-derived glass shards in samples. The addition of exotic *Lycopodium* spores permitted the calculation of pollen concentrations. Deteriorated pollen grains were also counted and included in the pollen diagram (Fig. 3). Classification of deteriorated grains was based on Cushing (1967) with crumpled, broken and degraded grains being recorded separately. High levels of deteriorated pollen grains are assumed to be associated with periods of environmental instability and catchment or regional (e.g. wind) erosion. Charcoal fragments and tephra-derived glass shards were counted and expressed in Fig. 3 as percentages of total dryland pollen (250 grains counted per sample) plus total number of glass shards or charcoal fragments counted per sample.

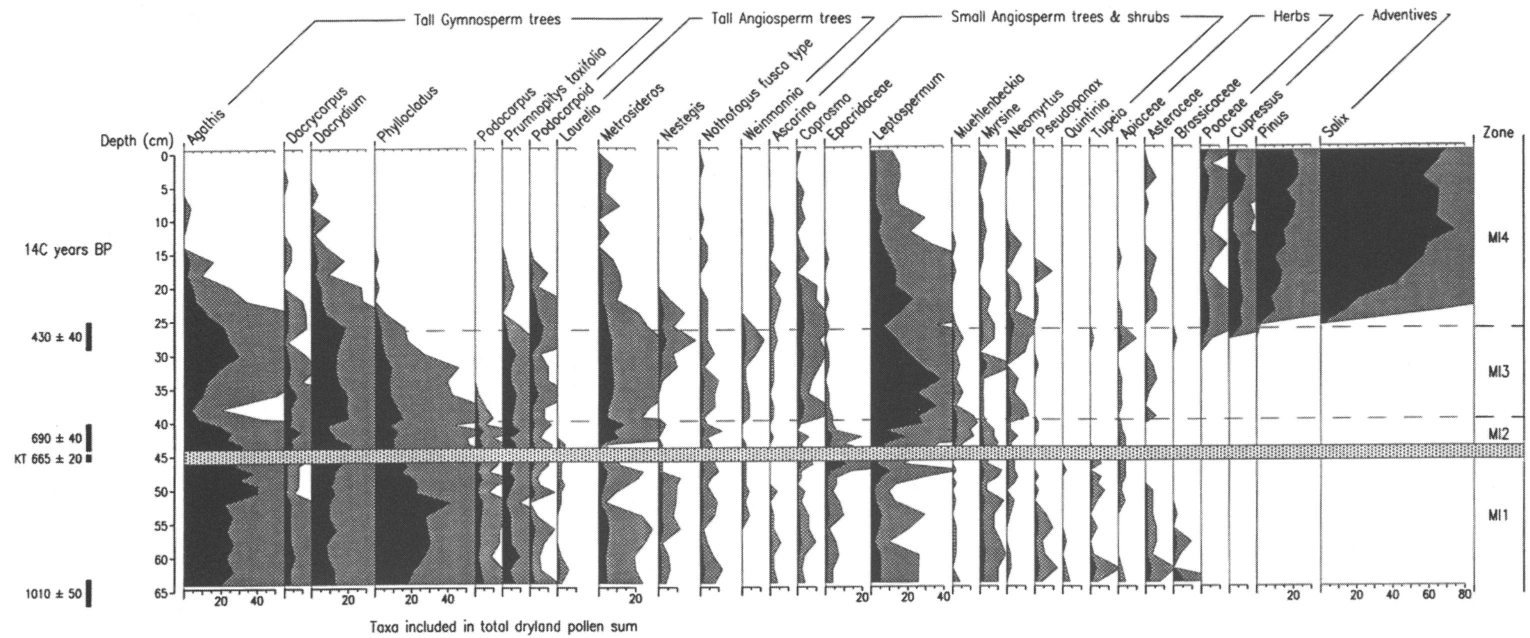
Preliminary results

Pollen data for the 1000 year time span of site MI-1 are presented in Fig. 3. Pollen zones were defined according to major changes in vegetation composition throughout the profile. The changes that are of major interest for this research are those in pollen zones MI1 and MI2 which respectively illustrate the vegetation composition before and just after the deposition of the Kaharoa Tephra.

MI1 (1000 to 665 years BP)

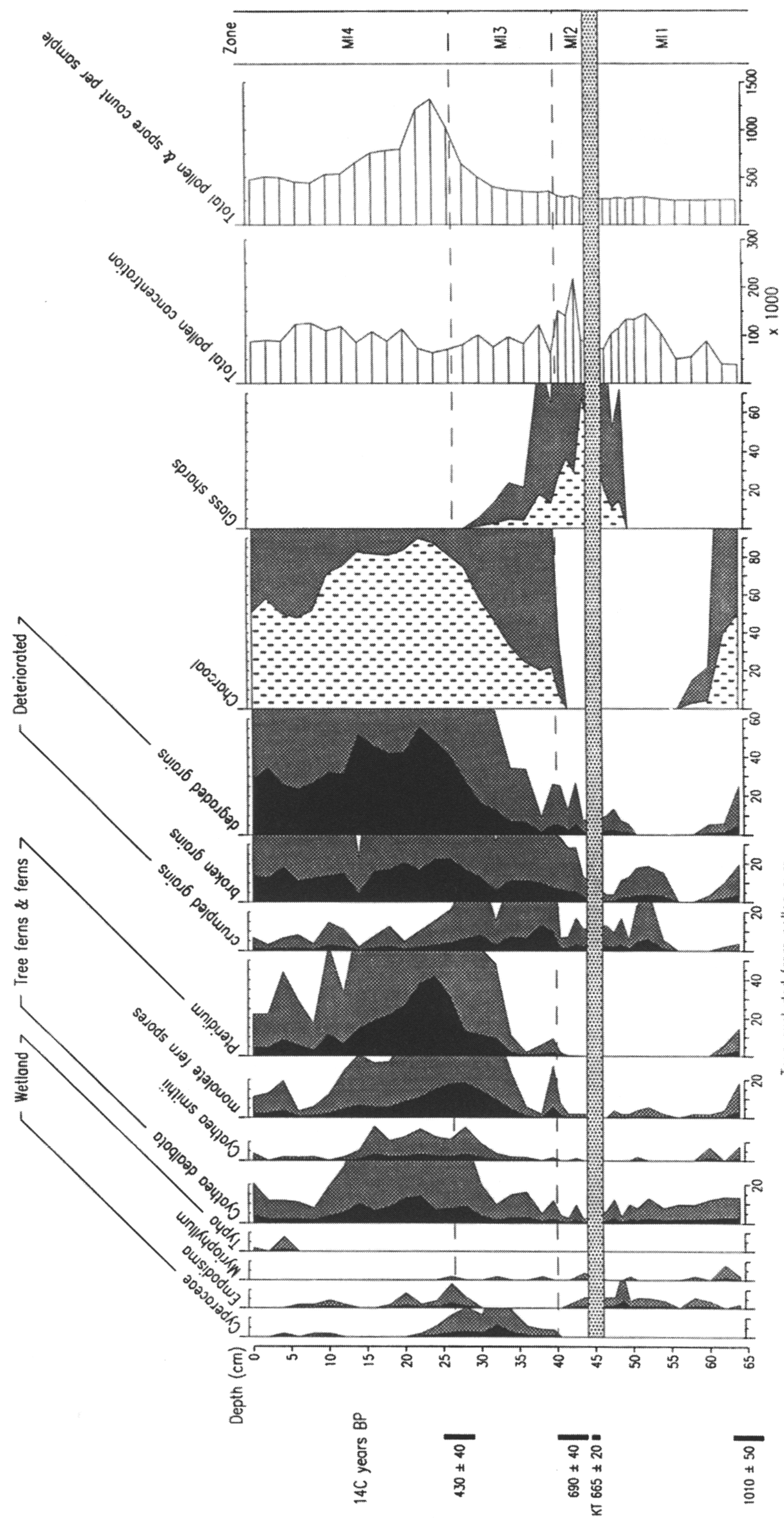
At the base of pollen zone MI1 indications of burning are evident with a peak in charcoal levels and the presence of *Pteridium* spores. This is short lived and does not appear to have had a major effect on the vegetation. *Phyllocladus* pollen rises to dominance along with increasing numbers of *Agathis*, *Dacrydium* and *Dacrycarpus* pollen. These last two species possibly invaded the wetland fringes and lower waterlogged sites (Newnham *et al.* 1989). A period of vegetation stability on the island can be inferred from the diagram, with northern conifer–angiosperm forest well established and *Metrosideros* trees and lianes prominent in the area. Pollen from small angiosperm trees and herbaceous taxa are also present in very small numbers, which may indicate local presence, but not on the site itself.

Towards the top of the zone, a change in dominant species occurs, with *Agathis* pollen increasing while *Phyllocladus* pollen begins to decline, along with *Dacrycarpus*. These changes may reflect competition between the species which has caused the decline of *Phyllocladus* with the younger trees receiving little light due to a close canopy of tall *Agathis* trees. *Agathis* and *Phyllocladus* trees favour drier sites and are tolerant of infertile soils (Newnham *et al.* 1989) whereas *Dacrydium* and *Dacrycarpus* trees thrive on moist, swampy ground and could have invaded the fringes of the wetland area. Deteriorated pollen grains, also present in small numbers, were possibly washed or blown into the catchment from the surrounding dunes during periods of increased run-off, and became incorporated into the peat. A relatively stable environment is inferred from the pollen assemblages represented in zone MI1.



(a)

Fig. 3. Pollen diagram revealing changes in main taxa at site MI-1: (**a**) dryland pollen; (**b**) wetland pollen, spores and deteriorated grains. Silhouette graphs are presented with $\times 5$ exaggeration. Total pollen concentration is expressed as total number of pollen grains and spores per cm^3. Pollen represented as podocarpoid includes grains of *Prumnopitys*, *Podocarpus*, *Lagarostrobos* and *Lepidothamnus* pollen which were indistinguishable. KT represents Kaharoa Tephra. The pollen sampling interval is indicated by the vertical spacing between bars in the 'Total pollen & spore count per sample' curve.


Zone
MI4
MI3
MI2
MI1
Total pollen & spore count per sample
Total pollen concentration
x 1000
Glass shards
Charcoal
Deteriorated
degraded grains
broken grains
crumpled grains
Tree ferns & ferns
Pteridium
monolete fern spores
Cyathea smithii
Cyathea dealbata
Wetland
Typha
Myriophyllum
Empodisma
Cyperaceae
Taxa excluded from pollen sum
Depth (cm)
14C years BP
430 ± 40
690 ± 40
KT 665 ± 20
1010 ± 50

(b)

MI2 (Immediately post-Kaharoa Tephra, c. 665 years BP)

Immediately following deposition of the Kaharoa Tephra, numerous variations in the pollen spectrum point to significant disturbance in the catchment. Levels of broken and degraded pollen grains increase, along with a sharp rise in *Leptospermum* pollen from 7 to 17%. *Metrosideros* pollen levels also increase rapidly and, these species, along with *Leptospermum*, can be invaders following catchment disturbance. Some *Metrosideros* trees also thrive on fresh volcanic surfaces, along with *Dacrydium cupressinum* (McGlone *et al.* 1984; Newnham *et al.* 1989). *Muehlenbeckia* pollen levels rise above the Kaharoa Tephra layer, and may also indicate invasion by these shrubs or lianes onto the tephra surface.

Phyllocladus, Agathis and *Dacrydium* pollen levels decline gradually towards the top of the zone. It is hard to decipher whether the decline in these well-established trees is volcanically induced, as *Phyllocladus* was previously in decline before the Kaharoa eruption. *Agathis* and *Dacrydium* pollen levels follow a similar pattern after the deposition of the Kaharoa Tephra. Initially there is no reaction, but between 42 and 43 cm depth (1–2 cm above the tephra layer) there appears to be a significant decline which occurs a little later in *Agathis* trees. There then follows a very brief period of recovery into zone MI3, until eventually both species are eliminated during the European era (zone MI4). The initial short-lived decline could be attributed to a volcanic cause as it occurs soon after the tephra deposition and is not sustained. In addition, *Podocarpus* also decreases and eventually disappears after deposition of the tephra layer. However, this apparent decline may be an artefact of general deterioration in pollen quality because the taxon podocarpoid (which may include *Podocarpus* and other bisaccate pollen with non-radial sac pattern, and is used when generic distinction cannot be made) increases as *Podocarpus* pollen levels fall.

The hemiparasitic shrub *Tupeia antarctica*, which was growing in proximity to the site before the tephra was deposited, indicated by small amounts of pollen, apparently disappears after the eruption. However, the presence of just one pollen grain from this taxon at approximately 27 cm depth suggests that it may still have been present in the area, but perhaps confined to the mainland in more sheltered locations. *Tupeia* may have been striving to become established in the area, but the deposition of acid-laden tephra may have inflicted stress on the plant, contributing to its decline in the catchment. Similarly, Epacridaceae (mostly *Leucopogon fasciculatus*) pollen began a rapid increase at the top of zone MI1 but, following the Kaharoa Tephra deposition, this taxon declines to insignificant levels. This decline may also suggest possible plant damage by tephra accumulation inhibiting further expansion in the area.

MI3 (665 to 150 years BP)

Charcoal reappears at the top of zone MI2, first at low levels, but rapidly increasing in zone MI3. Minimum counts of *Agathis* pollen coincide with the appearance of charcoal. However, *Agathis* rises to former levels towards the top of the zone only to decline and eventually disappear in zone MI4. *Leptospermum* becomes dominant, with pollen values fluctuating around 40% and *Metrosideros* is also prominent but declines slightly following the peak in values immediately above the tephra. Cyperaceae, *Pteridium* and other ferns become established in the area as the charcoal trend rises. This trend, together with the high numbers of *Leptospermum* pollen and high charcoal levels, indicates invasion of bared surfaces following fire. Increases in damaged pollen grains provide further evidence for run-off and possibly wind erosion due to reduction in forest cover. This evidence, considered together with the inferred age of this zone, points to burning and deforestation for various purposes by early Polynesian settlers in the vicinity.

MI4 (150 years BP to present day)

This zone marks the beginning of the European era. All previously dominant native taxa decline and a significant change in vegetation composition occurs. Wetland plants, tree ferns and *Leptospermum* remain in lower numbers. The abundance of charcoal, together with degraded and broken pollen grains, points to continued catchment clearance by burning of the native vegetation and associated catchment erosion and run-off. Peaks in *Pteridium* spores and charcoal levels coincide, indicating that bracken probably colonized bare surfaces produced by fire. Rapid expansion of adventive species follows because *Salix* becomes dominant, with *Pinus* and *Cupressus* also present in significant numbers. Charcoal levels remain high to the top of the profile indicating sustained extensive clearance of the area up to recent times.

Discussion

Table 3 provides a summary of events at site MI-1 over the last 1000 radiocarbon years. These preliminary results indicate that significant changes occurred after the deposition of the Kaharoa Tephra. The interpretations are put forward with caution and thus cannot yet be attributed exclusively to tephra fallout because other factors, particularly anthropogenic, may have contributed to the changes displayed in the pollen diagrams. The rapid decreases in *Tupeia* and Epacridaceae seem to be connected with the deposition of tephra. It is possible that these shrubs were subjected to acid damage following tephra fall, and/or tephra accumulation on plant leaves, interfering with vital mechanical processes needed for plant survival. This initial damage may have weakened these plants, leaving them susceptible to disease, storm and wind damage and competitive pressure from other species. Increases in pollen of *Leptospermum, Metrosideros* and *Muehlenbeckia* may suggest subsequent invasion of canopy openings and bared surfaces by these shrubs and lianes following the decline of the previous vegetation occupying these sites (e.g. *Phyllocladus, Agathis,* Epacridaceae, *Tupeia*).

The distribution of tephra-derived glass shards immediately above and below the main Kaharoa Tephra layer (Fig. 3) indicates some disturbance in the profile. The spread of shards above the layer may point to increased run-off or wind erosion in the area as *Agathis* and *Dacrydium* trees began to decline, possibly creating gaps in the forest canopy and bared surfaces. Thus the shards may have been washed or blown in from the catchment. This conclusion is supported by increases in deteriorated pollen grains which also suggest catchment erosion and increased run-off or wind erosion. Glass shards are found almost to the top of zone MI3, and may be the result of burning and clearance by early Polynesian settlers causing continued erosion of the area.

Table 3. *Summary of main vegetation changes occurring on Matakana Island over 1000 ^{14}C year timespan.*

Years BP	Pollen zone	Dominant pollen taxa	Vegetation and environment
[a]150–0	MI4	*Salix, Pinus, Pteridium*	European era. Abundant charcoal and damaged pollen grains indicate extensive burning of native species and subsequent catchment erosion.
665–150	MI3	*Leptospermum, (Agathis)*	Recovery of *Agathis* and *Dacrydium*. Polynesian era: charcoal rise, *Pteridium* and Cyperaceae become established.
c. 665 (immediately post-Kaharoa Tephra)	MI2	*Leptospermum, Agathis*	Possible ash-fall induced disturbance. Local disappearance of *Tupeia, Quintinia*, Epacridaceae. Decline of *Agathis* and *Dacrydium*. Invasion by seral species.
1000–665	MI1	*Phyllocladus, Agathis*	Dominant northern conifer–angiosperm forest. Stable.

[a]Age of pollen zone MI4 based on appearance of adventive pollen rather than Wk-3425.

Glass shards have been disseminated below the tephra layer. Such dissemination may relate to the irregular surface of the peat bog on which the ash was deposited, with tephra being reworked physically to accumulate in hollows created by uneven vegetation cover. This would then enable the shards to be displaced below the main tephra deposit and become compressed into the peat following further sedimentation and compaction. Minor bioturbation and possible infiltration down root channels following tephra deposition may also have contributed to the downward spread of shards in the profile, as described for Kopouatai bog by Hodder *et al.* (1991). Further evidence for possible downwards dislocation of microscopic-sized particles is indicated at the base of pollen zone MI4, the European era, defined by the first appearance of adventive pollen (Fig. 3). This era spans the last *c.* 150 years of New Zealand history, yet the peat immediately beneath this zone is dated at 430 ± 40 years BP (Wk-3425). Either the date is in error, or adventive pollen grains have moved down the peat profile, as has been reported at other pollen sites (Newnham *et al.* 1995a).

The marked increase in total pollen concentration levels just above the Kaharoa Tephra (Fig. 3) could relate to two main factors. First, the delayed decline in pollen levels of *Agathis* and *Dacrydium* trees following the eruption could be due to survival mechanisms whereby the trees are in decline but are increasing pollen production levels in order to create new seedlings to replace dying trees. Eventually the trees may have become overwhelmed and weakened by tephra accumulation on leaves and branches with possible acid damage, hence causing temporary decline in both trees and pollen concentrations.

Alternatively, drying of the peat bog through the addition of the 2–3 cm-thick tephra layer may have resulted in slower peat accumulation for the period immediately following the eruption. Meanwhile, airborne pollen influx onto the peat surface may have remained similar to pre-eruption levels, thereby resulting overall in higher pollen levels per cubic centimetre of peat because of a slower rate of accumulation. A temporary slowing in peat accumulation, together with the new source of pollen derived from long distance dispersal by wind, and overland flow, as indicated by the increase in glass shards and deteriorated pollen counts, could explain the short-lived peak in pollen concentrations soon after the tephra layer was deposited.

Pollen zone MI3 is interpreted as the beginning of the Polynesian era with extensive burning in the area, indicated by the rapid rise in charcoal levels and gradual increases in *Pteridium* spores. It appears from Fig. 3 that the commencement of the Polynesian era begins a little later on Matakana Island than in other areas studied around the Bay of Plenty coast and eastern Waikato regions (Newnham *et al.* 1995*a*, *b*, 1998). At Papamoa and Waihi Beach (Fig. 1A), *Pteridium* and charcoal levels rise above the Kaharoa Tephra as tree pollen declines. However, adventive pollen was also found at this level, which Newnham *et al.* (1995*b*) suggested may have been due to contamination within the profile. Thus, no definite conclusions were drawn for either human or tephra impact following Kaharoa Tephra deposition at these sites. At Kopouatai bog (Fig. 1C), increases in *Pteridium* and charcoal commenced just below the Kaharoa Tephra and were interpreted as the result of regional human influence (Newnham *et al.* 1995*a*). It is possible that changes in the vegetation composition in zone MI2 at Matakana Island were the result of volcanic rather than human impact because charcoal and bracken levels do not appear directly above the tephra layer, but a further 4 cm above the boundary. However, the subsequent (presumably anthropogenic) disturbance may be superimposed on any long-term tephra fall impact on the vegetation, so that the extent of damage caused from the deposition of the Kaharoa Tephra cannot readily be seen from this diagram. It is also possible that initial human impacts on Matakana Island were not associated with burning. Thus post-Kaharoa vegetation changes could have been the result of a small population occupying the area exploiting local resources, thus producing a small, but palynologically discernible impact. Further work is required before firmer conclusions can be drawn.

Further work

The use of pollen analysis alone is insufficient to determine the precise effect tephra deposition has had on palaeoenvironments. Geochemical analysis will be undertaken to complement the results already obtained at Matakana Island, in particular to provide a clearer picture of catchment disturbance following deposition of the Kaharoa Tephra as inferred from the pollen data. Further palynological examination of vegetation changes, and geochemical analysis of sediments above earlier tephras deposited prior to human settlement in New Zealand, are required in order to isolate disturbances resulting from tephra-fall impacts.

This site is the first of a suite of tephra sequences from Auckland, Waikato and Bay of Plenty regions of New Zealand to be examined using fine-resolution palynology and geochemistry. These tephra-rich organic sequences provide opportunities to examine the extent to which the vegetation and environmental changes following tephra fall detected at Matakana Island occurred at other sites, and should provide detailed accounts of possible environmental disturbance which could be attributed to the distal impacts of tephra fall from volcanic eruptions in New Zealand.

Conclusions

Because the palynological signals for anthropogenic and volcanogenic disturbance may be similar, it is not yet possible to be certain as to whether vegetation changes occurring above the Kaharoa Tephra layer at Matakana Island are caused by distal volcanic impacts, human activity, or both. However, tentative conclusions inferred from the results show that the deposition of ash-grade fallout tephra may have caused some environmental disturbance on Matakana Island. This is supported by the rapid decline of certain taxa (*Leucopogon fasciculatus* and *Tupeia antarctica*) and the (somewhat delayed) decline in *Agathis* and *Dacrydium* pollen following tephra fall, as well as significant increases in pollen concentration, deteriorated pollen and microscopic tephra-derived glass shards. This evidence is compatible with that presented by Blackford *et al.* (1992) and Charman *et al.* (1995) who suggested that acid loading associated with fallout tephra deposition is a possible cause for palaeoenvironmental change in northern Britain.

The results presented in this report are preliminary, and further work will be undertaken to produce a more detailed record of events at site MI-1. Results of geochemical analysis and discussion of human settlement on Matakana Island will be presented at a later date.

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