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The palynology and sedimentology of a coastal swamp at Awana, Great Barrier Island, New Zealand, from c. 7000 yr B.P. to present

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Pollen and sediment analysis of two Holocene cores from Awana, Great Barrier Island, shows that at 7000 calibrated yr B.P. the local swamp was an estuarine salt marsh dominated by Restionaceae. By c. 6000 yr B.P. the water table was lower, and a fresh water swamp (*Gleichenia-Leptospermum*) had replaced the salt marsh. Regional conifer-hardwood forest c. 7000 yr B.P. was initially co-dominated by *Libocedrus* and *Dacrydium cupressinum*. *Libocedrus* declined from c. 6000 yr B.P. During the period c. 6000–c. 2500 yr B.P., relatively stable environmental conditions ensued with little change in local or regional vegetation. Around 2500 yr B.P., the swamp surface became drier and was invaded by *Dacrycarpus* and *Laurelia* swamp forest. This forest was subsequently repeatedly disturbed (not by fire), indicating climatic change to drier and windier conditions. *Ascarina lucida* was periodically a major component of swamp forest. Disturbance is also recorded in the clastic (mineral) sediments, where beds of sand within finer-grained sediment and peat are interpreted as wind blown material derived from partly devegetated dunes to seaward. The presence of the Kaharoa Tephra allows the timing of major Polynesian deforestation at Awana to be reliably dated to c. 600 calibrated yr B.P. In contrast, we see no evidence in the clastic sediment record of disturbance at Awana since Kaharoa time. We attribute this to the maintenance of stable dunes by a herb/scrub cover despite nearby fires, or to the presence of scrub or forest buffering the swamp from ablating dunes.

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

INTRODUCTION

The Late Quaternary palynology of the Auckland region has received little attention compared with Northland (Dodson et al. 1988, Kershaw & Strickland 1988, Enright et al. 1988, Pocknall et al. 1989, Newnham 1992, Elliot et al. 1995, 1997, 1998, Elliot 1998) and the Waikato region (Harris 1963, McGlone et al. 1978, 1984, Newnham et al. 1989, 1995a). From the Auckland region, Newnham & Lowe (1991) have described a 12000–4000 yr B.P. pollen sequence from Lake Waiatarua on the Auckland Isthmus. Also in the Auckland region, and providing information relating to the currently controversial topic of initial

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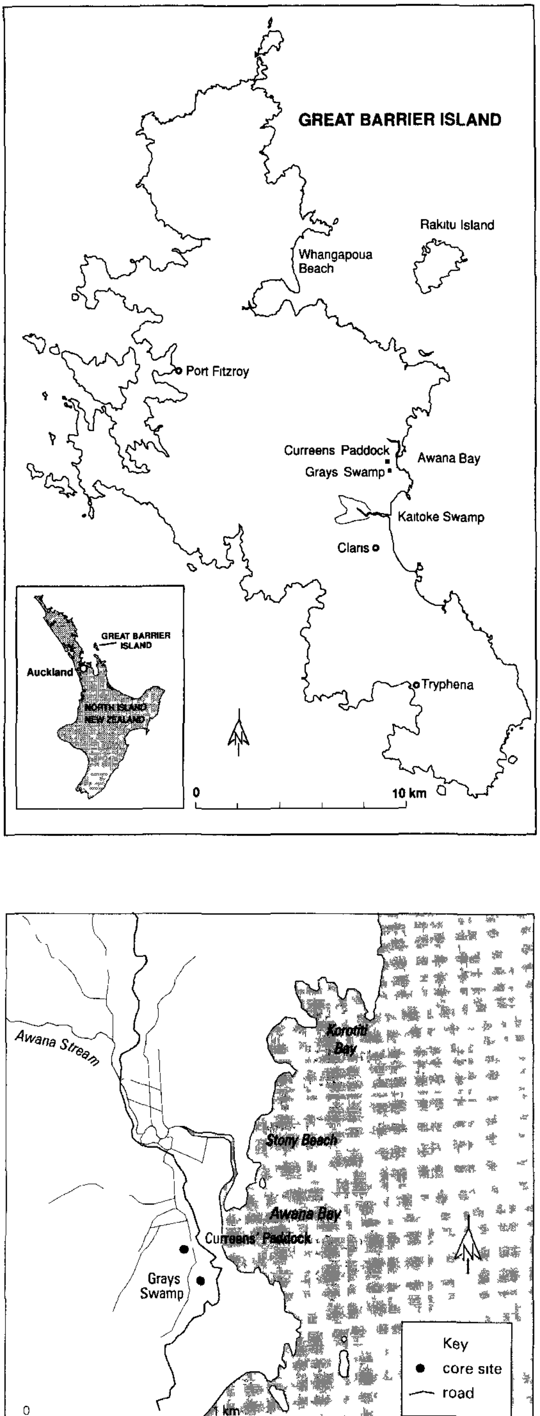

Fig. 1 (A) Great Barrier Island showing location of Grays' Swamp and Curreens' Paddock (B) Central eastern Great Barrier Island showing location of Grays' Swamp and Curreens' Paddock core sites

human contact with New Zealand, Hume & McGlone (1986) and Elliot & Neall (1995) have found palynological evidence for Polynesian deforestation from the Waitemata Harbour (700 ± 100 conventional yr B.P.) and Motutapu Island (980 calibrated yr B.P.), respectively.

We present here the results of pollen and sediment analyses of two sediment cores from the Awana swamp system on Great Barrier Island. Great Barrier is the largest island in the Hauraki Gulf, forming the far eastern boundary of the Auckland region. Swamps impounded behind Holocene coastal dunes on the east coast of the island present an opportunity to investigate the palynological history of this part of the region.

THE STUDY AREA

Great Barrier Island, located in the outer Hauraki Gulf, Auckland, is the largest off-shore island in the New Zealand archipelago (c. 28 500 ha). The island interior is steeply dissected with several craggy volcanic peaks up to 600 m altitude. The base rock is predominantly composed of greywackes and Mesozoic shales from the Jurassic-Permian (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 up to 4.5 km inland into valleys formerly occupied by estuaries. The Awana swamp system is 3 km long in the north-south direction and up to 1 km wide, and is located on the central east coast of Great Barrier (36°13′S, 175°29′E) (Fig. 1). The southern half of the system lies directly behind dunes while the northern half extends inland into the Awana Stream valley behind coastal hills. Most of the swamp has been drained and is now in pasture.

The nearest weather station to Awana is 11 km north-west at Port Fitzroy Mean annual rainfall over the period 1961–97 was 1839 mm (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 over the same period was 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 component of the sub-canopy (New Zealand Map Series 336–02, 1996) Areas of hardwood-podocarp forest are found in the far south and especially in 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* There is some regenerating *Agathis australis* forest, with occasional very large emergent trees, 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 by *Metrosideros excelsa*, *Beilschmiedia taraire*, *B tawa* and *Dysoxylum spectabile*, and 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*, plus *Pomaderris phylicifolia* and *Cassinia vauvilliersii* bushes, with some exotic grasses and *Lupinus arboreus*

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

METHODS

Two sites in the southern part of the Awana swamp system were examined for stratigraphy and pollen profiles The short distance between sites (c 200 m) provides replication As the sites are unnamed, we here informally name them after their respective current owners Grays' Swamp (NZMS 336 02 334513), was sampled with a 50 cm D-section corer to a depth of 3 85 m, and below this depth using a vibracoring system with a continuous aluminium tube to 5 6 m Curreens' Paddock (NZMS 336 02 330518), was sampled using the vibracorer to 2 8 m Site locations are shown in Fig 1

In the laboratory, cores were split lengthwise and the sediments were sub-sampled for grain size analysis Tephric beds were also sub-sampled for geochemical characterisation and correlation studies Sediment sub-samples were 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 Peaty sub-samples were treated with hydrogen peroxide to remove organic material before grain size analysis 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% statistical confidence level Results reported here are for grain size classes expressed as percent of total particle volume, which is equivalent to a mass-based measurement of grain size distribution

Finer resolution of pollen sampling was carried out in those parts of the cores showing frequent sediment changes Site replication allowed coarser sampling resolution in those parts of the cores that showed little visible change in sediment type. Samples were prepared for pollen analysis by the standard acetylation and hydrofluoric acid method (Faegri & Iversen 1989), and bleaching with sodium chlorate and phosphoric acid. The pollen sum was at least 250 grains, excluding herbaceous swamp plants and ferns except *Pteridium*, spores of which are widely dispersed (McGlone 1982). *Leptospermum* and Malvaceae (most likely mainly *Plagianthus divaricatus*) 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 for pollen data manipulation and construction of pollen diagrams (E. Grimm, Illinois State Museum, Springfield, Illinois). The "dinoflagellate" category in the diagrams includes only marine dinoflagellate cysts) 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. Four radiocarbon dates were determined 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.

RESULTS

KAHAROA TEPHRA IDENTIFICATION

Kaharoa Tephra erupted from Mt Tarawera within the Okataina Volcanic Centre is the product of the only rhyolitic (SiO_2 > c. 75% wt %) eruption known in New Zealand in the past 1000 years (Froggatt & Lowe 1990). The land area covered by the 3 cm isopach is 30000 km^2, c. 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-fall deposit that is normal bedded with fine pumiceous ash over coarse pumiceous ash, or as local 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 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 Awana (AT–102 and –172) are indistinguishable from Kaharoa Tephra samples analysed from its Gavin Road Type Section and a distal correlative identified at Whangarei Harbour (AT–95). Kaharoa Tephra has a distinctive glass major element composition (Table 2). Consequently, Kaharoa Tephra and its correlatives can be easily and unequivocally distinguished from stratigraphically older distal tephras also 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. 2).

CORE ANALYSES

Grays' Swamp

Grays' Swamp is currently c. 200 m from the sea in the far southern arm of the Awana swamp system (Fig. 1), one of the few remaining undrained parts of the system. Vegetation in the immediate vicinity of the site is dominated by *Baumea articulata* and *Leptospermum scoparium*. Also present are *Baumea rubiginosa*, *Blechnum minus*, *Isachne globosa* and *Lotus pedunculatus*.

Table 1 Radiocarbon dates from sites at Awana 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 (radiocarbon calibration program REV 3 0 3A, Stuiver & Reimer 1993), allowing also 40 year offset for the Southern Hemisphere

Site	Laboratory sample no	Sample type	Depth (cm)	Conventional yr B P [1]	Calib range B P based on 1 SD[2]
Grays' Swamp	Wk–5653	peat	35–38	890 ± 140	930–660
	Wk–5652	peat	145–148	2550 ± 170	2770–2350
	Wk–6395	peat	387–390	5810 ± 90	6790–6400
Curreens' Paddock	Wk–5561	peat	198–200	6050 ± 80	6980–6760

Table 2 Composition of major elements in glass shards of Kaharoa Tephra 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 (unpub data)

		SiO_2	TiO_2	Al_2O_3	FeO	MgO	CaO	Na_2O	K_2O	Cl	H_2O	n
AT–102	Grays' Swamp	77 70	0 12	12 51	0 83	0 09	0 52	3 99	4 04	0 20	2 16	10
	(42–45 cm)	(0 17)	(0 04)	(0 14)	(0 13)	(0 04)	(0 05)	(0 09)	(0 12)	(0 05)	(2 01)	
AT–172	Curreens' Paddock	77 47	0 12	12 81	0 91	0 09	0 57	3 91	3 94	0 18	2 72	10
	(10–12 cm)	(0 42)	(0 05)	(0 11)	(0 12)	(0 04)	(0 12)	(0 19)	(0 12)	(0 03)	(0 86)	
AT–95	One-Tree Point,	77 87	0 12	12 41	0 82	0 07	0 54	3 94	4 03	0 20	1 39	9
	Whangarei Harbour	(0 15)	(0 04)	(0 04)	(0 09)	(0 02)	(0 03)	(0 07)	(0 08)	(0 04)	(0 85)	
50009‡	Gavin Road	78 21	0 06	12 53	0 75	0 07	0 50	3 81	4 02	—	2 63	9
	Type Section near Mt Tarawera	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)	

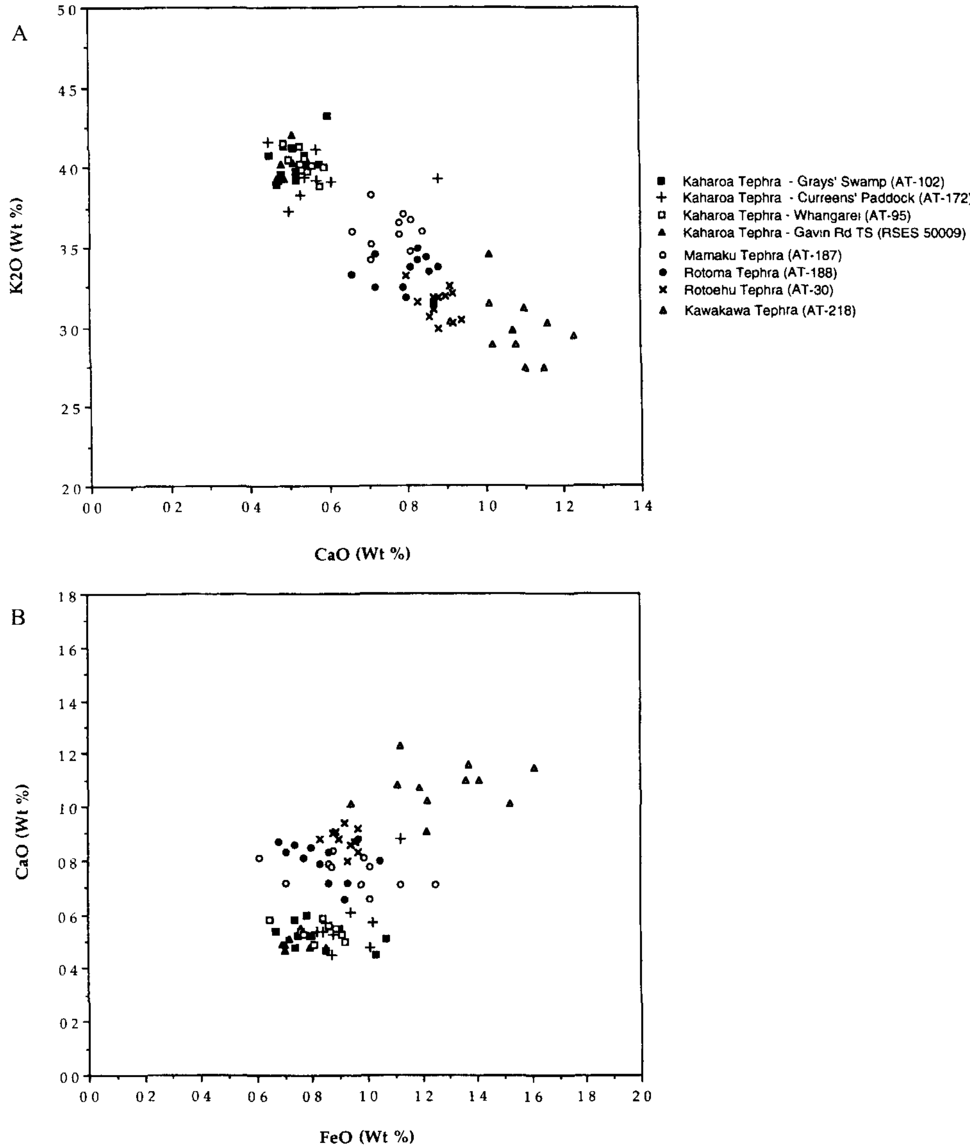

Fig. 2 (A) K2O versus CaO and (B) CaO verses FeO for glass shards (determined by EMP) of Kaharoa Tephra and its distal correlatives, older distal tephras similarly derived from the Okataina Volcanic Centre (AT–30, –187 and –188) and the widespread Kawakawa Tephra (AT–218) derived from the Taupo Volcanic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

Sedimentology (Fig. 3A)

The basal 30 cm of the 5.6 m core comprises clay interbedded with silty, very fine quartzose sand, with bed thicknesses of 2–10 cm. The uppermost sand bed is overlain by a 30 cm thick bed of laminated clay that grades upward to a 5 m thick mix of fibrous and woody peat with local concentrations of clayey silt and silty clay. Within this peat, the mean grain size of the mineral sediment fraction ranges from <1–46 μm. The only major variations in sediment texture within the peat are indistinct lenses of fine sand (mean grain size: 114 μm) preserved between 1 m and 1 3 m, and a distinct bed of fine-grained tephric sand (mean size 160 μm) at 42–45 cm, in sharp contact with the peat This has been identified as a primary deposit of the Kaharoa Tephra with a known date of c 600 calibrated yr B P (665 ± 20 conventional yr B P) (Lowe & Hogg 1992, Lowe et al 1998)

The basal deposit of interbedded clay and very fine sand is interpreted as part of a relatively shallow water deposit that records low energy depositional conditions with episodic influxes of sand, most likely derived from dunes located seaward of the site It is also possible that this sand was transported from a marine source by tidal currents when Grays' Swamp was an estuary open to regular tidal exchange The 5 m thick peat deposit that forms the remainder of the sedimentary succession at this site represents the transformation from an open water environment to a well vegetated and stable fresh water swamp environment that received negligible input of mineral (clastic) sediment from surrounding hill slopes or feeder streams from c 6600–c 2500 yr B P The stability of this swamp environment was disturbed within the last c 2500 years, however, as evidenced by the sandy beds within the upper 1 3 m of core The diffuse sand from 1 0–1 3 m is interpreted as evidence for a period of sediment input from dunes to seaward Such an input of sand would require significant disturbance to dune vegetation cover and an energetic mechanism for sand transport, such as cyclonic winds In contrast, the tephric sand bed at 42–45 cm indicates the sudden disturbance caused by the deposition of airfall Kaharoa Tephra c 600 yr B P

Palynology (Fig 4A)

The pollen profile of Grays' Swamp is divided into four zones, as follows

Zone 1 (Sub-zones 1a and 1b) 568–433 cm, c 7000–c 6000 yr B P

The pollen sum throughout the zone is dominated by tall tree taxa, mainly *Dacrydium* (27–50%) Sub-zone 1a is characterised by high values for Cupressaceae (up to 34%) and Restionaceae, and marine dinoflagellates are present at 555 cm Except for *Leptospermum* type, shrubs, small trees and herbs all record very low values (<5%) throughout both sub-zones, although some swamp taxa have high values – Restionaceae (Sub-zone 1a), Cyperaceae, *Typha* and *Gleichenia* (Sub-zone 1b) *Metrosideros* records one high value (33%) in the upper sample of Sub-zone 1b, but erratic pollen abundance or "over-representation" is not uncommon for insect-pollinated plants (i e , local pollen dispersers)

Zone 2 433–165 cm, c 6000–c 2500 yr B P

Tall tree taxa continue to dominate the pollen sum throughout this zone *Dacrydium* (20–36%) is the main contributor In the lower part of the zone, *Dacrycarpus* appears in significant amounts (up to 7%) for the first time At the same time, *Phyllocladus* increases (up to 13%) and *Podocarpus* declines At the upper zone boundary, *Metrosideros* shows a high level similar to that of Zone 1 but again, this may be an over-representation *Ascarina* increases slightly but significantly (up to 5%) while *Freycinetia* appears significantly for the first time and at high levels in two samples (25% and 35% of the pollen sum) *Leptospermum* type also records high levels and *Gleichenia* shows a sustained increase *Blechnum* is common while *Cyathea dealbata* type declines

Zone 3 (Sub-zones 1a and 1b) 165–36 cm, c 2500–c 600 yr B P

This zone is characterised by abrupt and dramatic changes in several taxa, with *Dacrycarpus*, *Laurelia*, *Ascarina* and *Cyathea dealbata* type recording substantially higher values Small but significant pollen/spore increases or peaks in many shrub and small tree taxa (*Cordyline*, *Griselinia*, *Hebe*, *Freycinetia*, *Leptospermum* type, *Myrsine*, *Rhopalostylis*) and in some fern

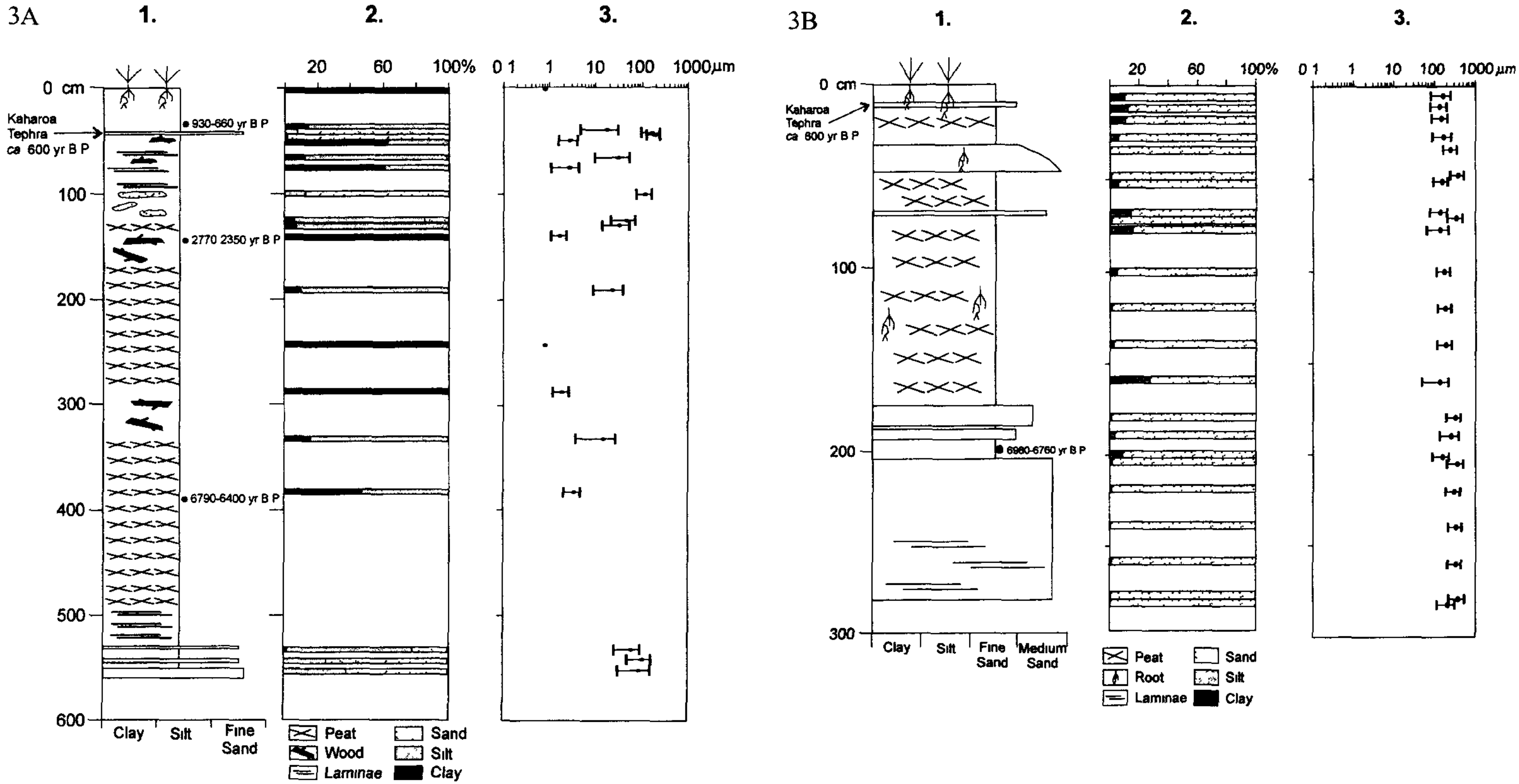

Fig. 3 Sediment analyses of Awana cores (A. Grays' Swamp, B. Curreens' Paddock). 1. Graphic log of core, 2. Sand:silt:clay percentages of clastic sediment fraction, 3. mean grain size of clastic sediment fraction, plus/minus one standard deviation.

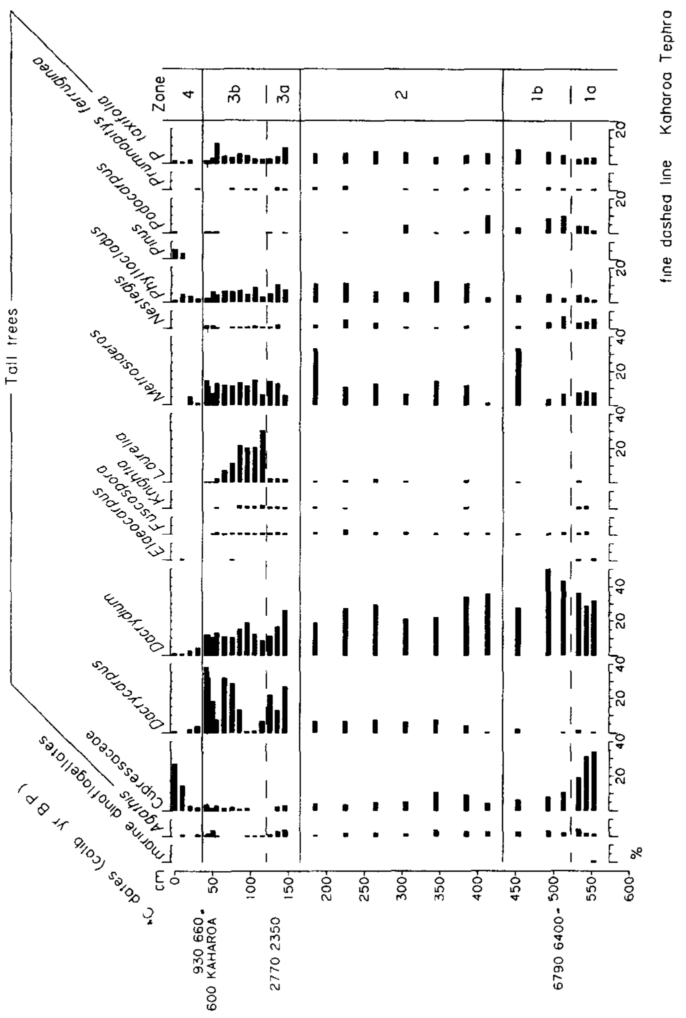

Fig. 4 Pollen diagrams from Awana (A, Grays' Swamp, B, Curreens' Paddock)

taxa (monolete spores, *Phymatosorus*) are recorded. *Leptospermum* and *Gleichenia* decline The Kaharoa Tephra is at the upper zone boundary

Zone 4 36–0 cm, c 600 yr B P –present

This zone is characterised by a sharp and permanent decline in pollen of many forest taxa (*Dacrycarpus*, *Dacrydium*, *Metrosideros*, *Nestegis*, *Ascarina*, *Freycinetia*, *Griselinia*, *Halocarpus*, *Myrsine*, *Astelia*) and the sudden appearance of abundant *Pteridium* spores and microscopic charcoal fragments *Leptospermum* type pollen also sharply decreases while *Typha* increases A radiocarbon date (930–660 yr B P , Wk–5653) of peat 10 cm above the 600 yr B P Kaharoa Tephra suggests some contamination with older carbon, possibly from finely disseminated charcoal (c f McGlone & Wilmshurst 1999) The two upper samples contain exotic *Pinus* and *Salix* pollen, and have high Poaceae values, representing the start of European influence High values of Cupressaceae (15% and 27% of the pollen sum) in these samples almost certainly result from the introduction of exotic cypresses, e g , *Macrocarpa*,

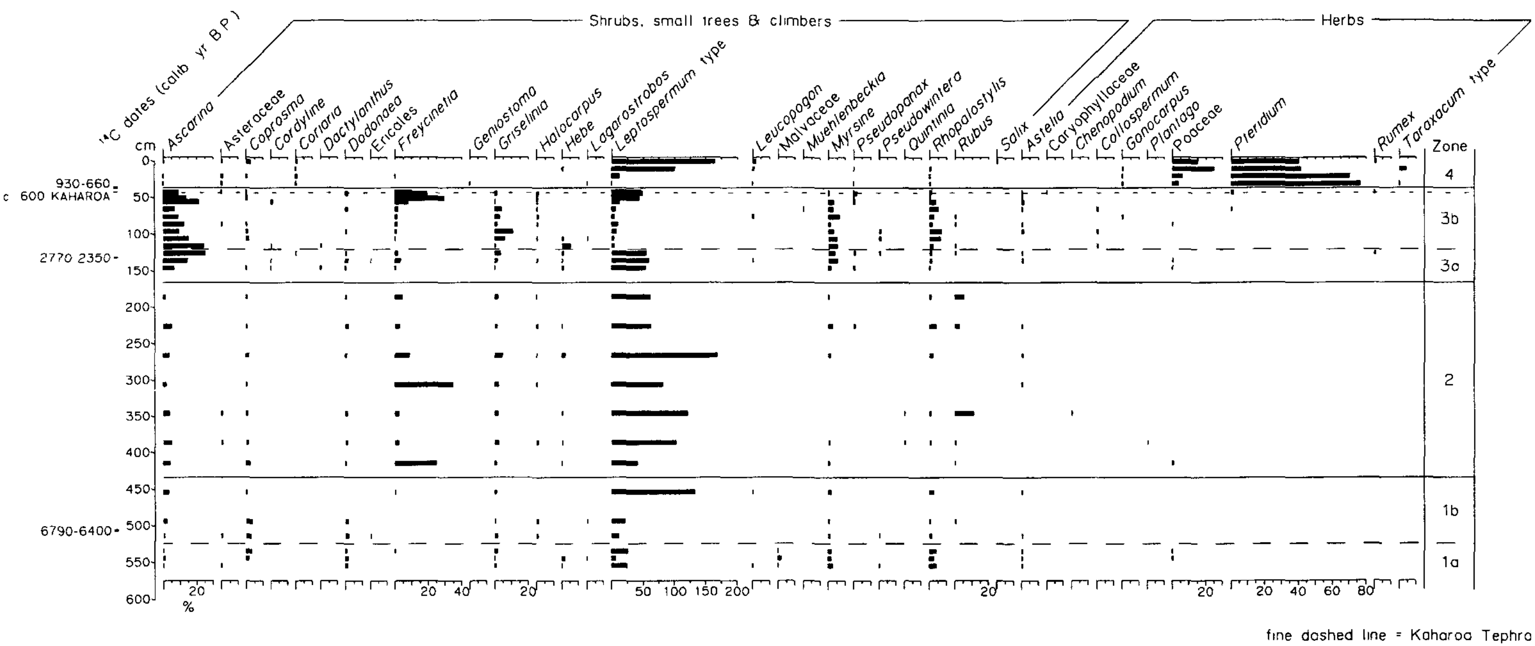

Fig. 4A *(continued)*

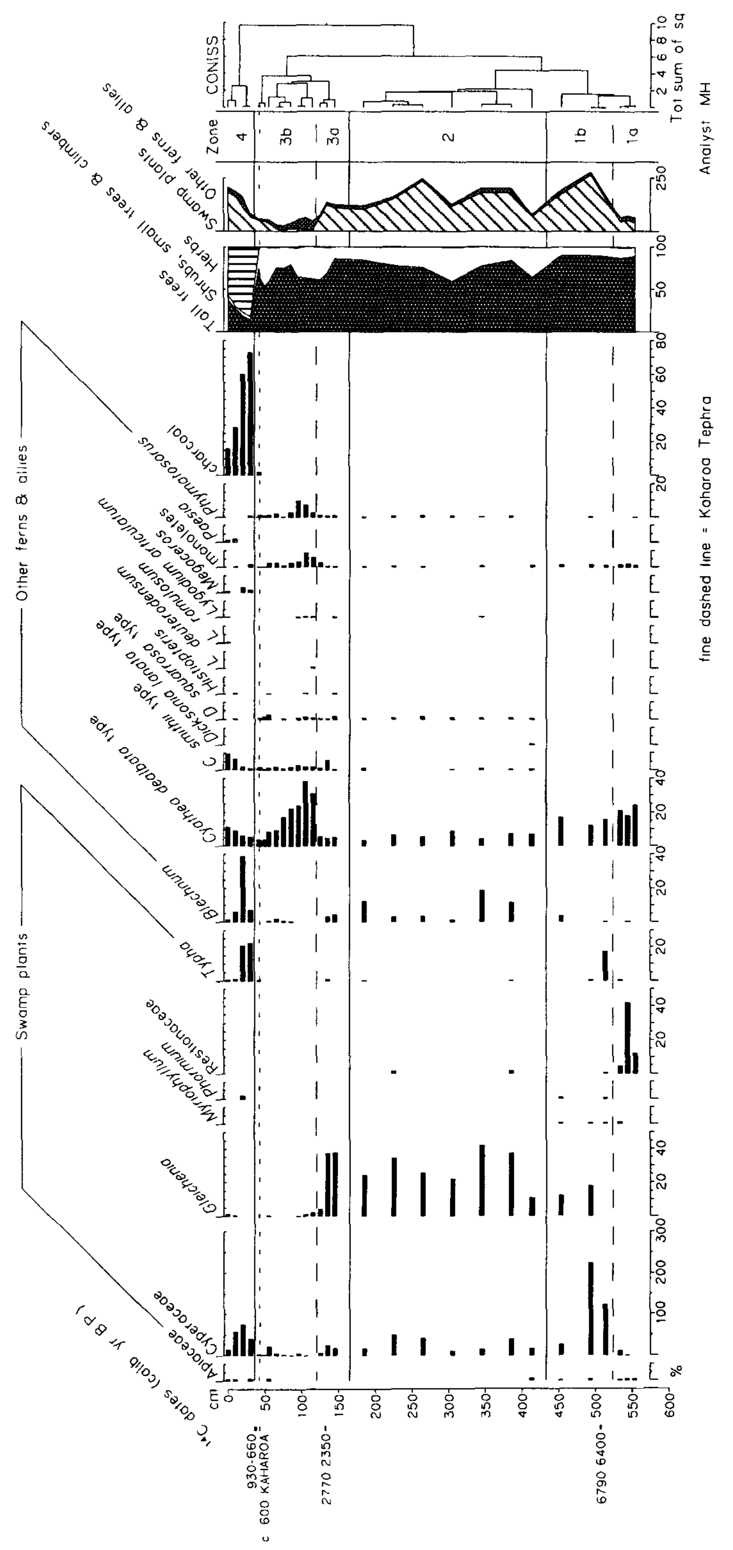

Fig. 4A *(continued)*

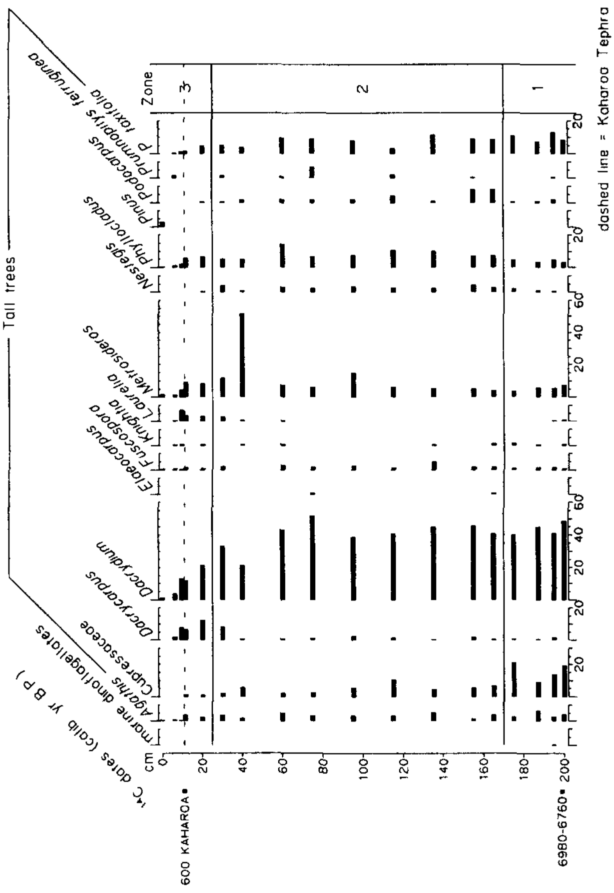

Fig. 4B *(continued)*

rather than from an increase in *Libocedrus*. Several large *Macrocarpa* trees still grow close to the core site.

Curreens' Paddock

Like most of the Awana swamp system, Curreens' Paddock has been drained and is under pasture. The site is c. 200 m north-east of Grays' Swamp (Fig. 1), c. 200 m from the sea and bordered by fixed dunes on the seaward side and by regenerating *Kunzea-Leptospermum* bush (grazed at the margins) on the inland side.

Sedimentology (Fig. 3B)

Core recovery at Curreens' Paddock was 2.8 m. Below 2 m, a bed of well sorted medium-grained quartzose sand (mean size: 307–373 μm), is preserved to an unknown depth. This bed is massive within its upper 45 cm but laminated below 2.45 m, with concentrations of heavy minerals at the base of the core. An abrupt contact at 2 m marks the upwards transition to a 2 m thick deposit of well sorted, fine-grained quartz-feldspathic sand (mean size: 135–189 μm). This fine sand contains four interbeds of medium sand (mean size: 250–378 μm), totalling less than 15 cm thick and in sharp contact with the host sediment. Organic detritus is scattered throughout the fine sand, with local concentrations of silty peat. A primary deposit of the Kaharoa Tephra is present as a diffuse bed of fine-grained tephric sand (mean size: 160 μm) at 10–12 cm depth.

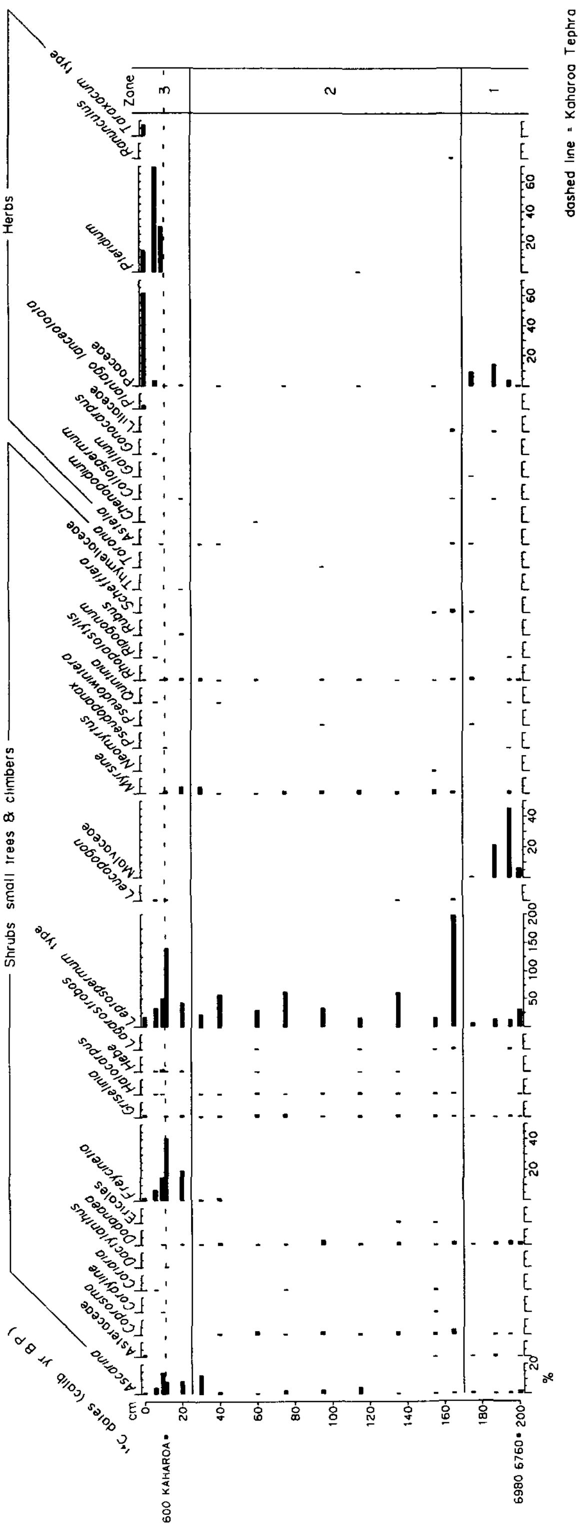

Fig. 4B *(continued)*

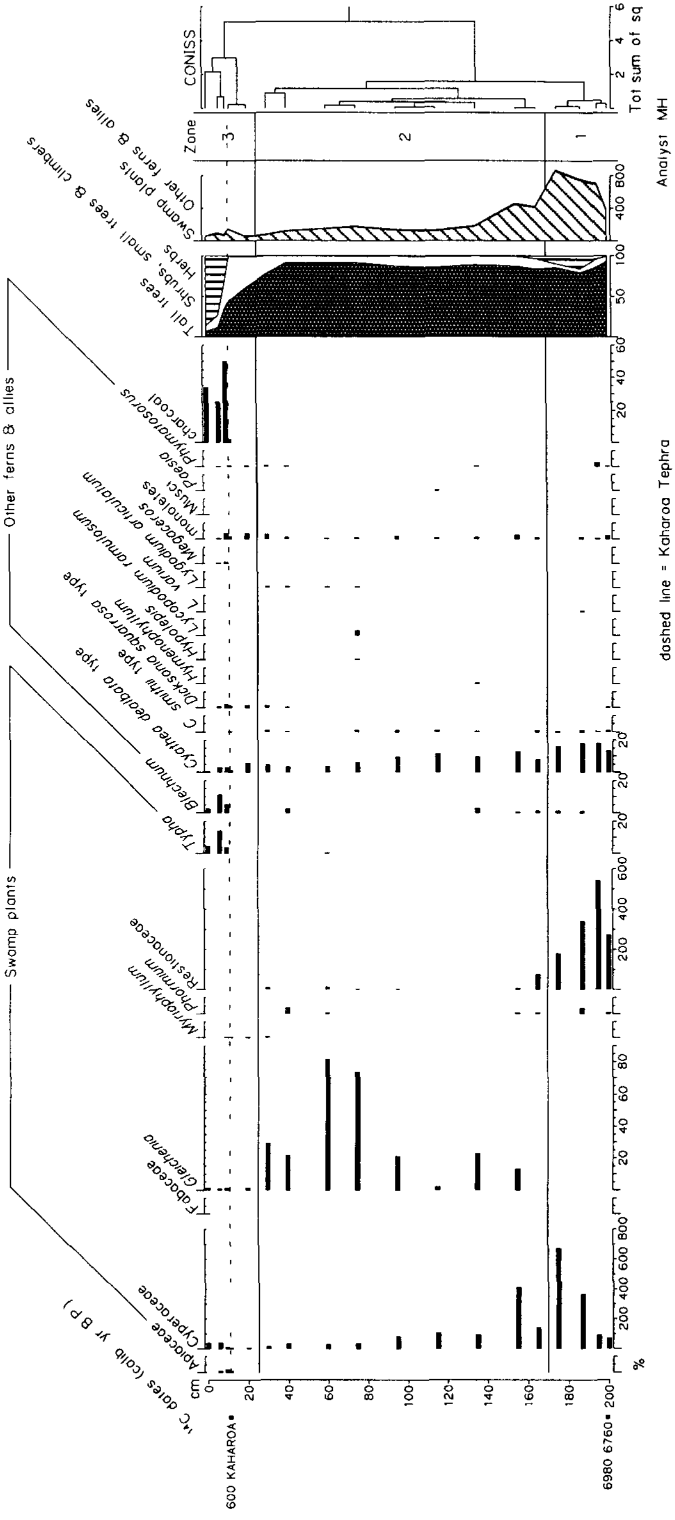

Fig. 4B *(continued)*

The dominance of well sorted sand-sized sediment within this core indicates a relatively energetic depositional environment In addition, the preservation of thin beds of medium sand within the upper 2 m is evidence of episodic fluctuations in depositional energy In the context of the geomorphic setting for this site, it is therefore probable that these deposits are the product of aeolian processes, and variations in sand size are a record of major fluctuations (storm related?) in wind energy and/or changes in vegetation cover on the nearby dunes More specifically, this low elevation site can be interpreted as a back dune flat depression where a mix of sandy sediment and organic detritus accumulated on an initially sparsely vegetated surface that became overgrown with time The 600 yr B P Kaharoa Tephra is much closer to the surface at this site (10–12 cm) than at Grays' Swamp (42–45 cm), presumably due to peat shrinkage following European drainage Swamp shrinkage of 1–2 m is reported since drainage of the swamp during European times

Palynology (Fig 4B)

Three pollen zones have been established in the Curreens' Paddock core, as follows

Zone 1 200–170 cm c 7000–c 6000 yr B P

This zone corresponds to Sub-zone 1a of Grays' Swamp Tall tree taxa, mainly *Dacrydium* and Cupressaceae, dominate the pollen sum Restionaceae, Cyperaceae and Malvaceae record high values and marine dinoflagellates are present at 195 cm Significant Poaceae values (up to 15% of the pollen sum) may indicate that *Spinifex hirsutus* was present on adjacent dunes The absence of *Typha* pollen (found at Grays' Swamp site during the same time period) suggests that this taxon grew patchily on the swamp surface during this period and/or that Curreens' paddock was at an earlier stage of the succession than Grays' Swamp

Zone 2 170 25 cm c 6000–c 2500 yr B P

This zone appears to correspond to Sub-zone 1b and Zone 2 of Grays' Swamp, where peat formation continues under a predominantly *Gleichenia-Leptospermum* association over a relatively long period A sand layer and a sandy peat layer in the upper part of the zone indicate deposition of a "sheet" of aeolian sand onto the swamp surface, matching that laid down at Grays' Swamp site during the same time period The top sample of this zone (at 30 cm) corresponds to the beginning of Zone 3 of Grays' Swamp, with increased levels of *Dacrycarpus*, *Laurelia* and *Ascarina*

Zone 3 25–0 cm 2500 yr B P present

Zone 3 of Curreens' Paddock corresponds to Sub-zone 3b and Zone 4 of Grays' Swamp The much shallower thickness of this zone (20 cm) compared with the Grays' Swamp zones (145 cm) is presumably due mainly to peat shrinkage after this part of the swamp was drained Despite the coarser temporal resolution, a consequence of shrinkage, similar pollen trends are visible Thus, immediately above the Kaharoa Tephra, a sharp decline in several forest taxa (*Dacrycarpus*, *Dacrydium*, *Metrosideros*, *Ascarina* and *Freycinetia*), coincides with the dramatic appearance of *Pteridium* and charcoal Exotic *Pinus* pollen in the surface sample indicates European effects This sample also has a very high Poaceae value (62% of the pollen sum), reflecting the current vegetation (pasture) at the site

DISCUSSION AND CONCLUSIONS

The pre-Kaharoa environment

The pollen and sediment records of the two cores at Awana contain a continuous history of local vegetation and environmental disturbance since c 7000 yr (calibrated) B P , clearly showing successional vegetation changes during swamp development. Marine dinoflagellates indicate an initially estuarine environment. However, tidal influence appears to have rapidly declined as dunes dammed the estuary outlet. Vegetation on the resulting salt marsh surface initially would have been mainly *Leptocarpus similis* (Restionaceae), with *Plagianthus divaricatus* (Malvaceae) and *Leptospermum* on the margins, and *Spinifex hirsutus* on adjacent dunes. Cyperaceae replaced *Leptocarpus* as conditions became less saline. For a short period after c. 7000 yr B.P. (probably <1000 years), dunes were still active, with sheets of wind-blown sand periodically encroaching onto the salt marsh surface. By c. 6000 yr B.P., the water table in the swamp was lower, possibly a result of sea level recession (Naish et al. 1992), and the appearance of *Typha* (albeit briefly) and *Gleichenia* (both at the expense of Cyperaceae) mark the end of estuarine influence and the commencement of peat formation in freshwater. The presence of the aquatics *Myriophyllum* and *Typha* indicates that the swamp surface was frequently inundated by freshwater. The dunes at Awana had probably stabilised by c. 6000 yr B.P. and become at least partly forested, since further dune transgressions are *not evident until c. 2500 yr B.P.*

Vegetation surrounding the swamp c. 7000–c. 6000 yr B.P. would have been conifer-hardwood forest, initially co-dominated by *Libocedrus* (Cupressaceae) and *Dacrydium cupressinum*. However, *Libocedrus* apparently declined significantly during the early part of this period. *Agathis australis*, *Metrosideros*, *Nestegis lanceolata*, *Podocarpus totara*, *Prumnopitys taxifolia* and to a lesser extent *Phyllocladus*, together may have formed a large part of the canopy throughout the period. *Cyathea* tree ferns were probably common in the sub-canopy. *Nothofagus* sub-genus *Fuscospora* (distant dispersers) appears to have been of minor importance during this period (and subsequently), locally and regionally.

The period from c. 6000–c. 2500 yr B.P. at Awana appears to have been characterised by relative environmental stability. Sediment inwash was minimal and pollen taxa comprising local and regional conifer-hardwood forest remain steady. A mainly *Gleichenia-Leptospermum* association, with some Cyperaceae and *Blechnum* (most likely *B. minus*), grew on the swamp surface. The mean water table relative to the swamp surface was probably lower than in the previous zone (J. Ogden, unpub. data). *Dacrydium* continued to dominate conifer-hardwood forest surrounding the swamp. *Phyllocladus* increased in abundance, probably at the expense of *Podocarpus*. *Ascarina lucida* became more abundant in the sub-canopy while *Cyathea* tree ferns declined. *Dacrycarpus dacrydioides* and at times abundant *Freycinetia banksii* probably grew on the swamp margins. Local dunes had apparently stabilised and probably were at least partly vegetated by this forest.

The sudden changes in local vegetation commencing c. 2500 yr B.P. indicate a period of disturbance which continued until major anthropogenic deforestation at c. 600 yr B.P. The water table of the swamp appears to have dropped further during this period, allowing tree species, first *Dacrycarpus* and then *Laurelia novae-zelandiae*, to invade the swamp and form a swamp forest, largely replacing the *Gleichenia-Leptospermum* vegetation. A drier swamp surface could have been facilitiated by sand deposition, since there are sand lenses in the upper metre of both cores. *Dacrycarpus* and *Laurelia* pollen curves at some other sites on the east coast of Great Barrier show a similar increase during the Late Holocene (M. Horrocks, unpub. data). The presence of *Laurelia* and *Cordyline* indicates that an initially acidic substrate had become base rich (Macphail & McQueen 1983), suggesting new sediment input (which is evident at 1.0–1.3 m, see Sedimentology section). *Cyathea* tree ferns and *Ascarina* appear to have been abundant near the site, although *Cyathea* gradually declined. The fluctuating values of these taxa suggest repeated forest disturbance and perhaps subsequent dune instability. Pollen/spore increases or peaks in many shrub and small tree taxa and in some fern taxa also suggest dynamic vegetation processes. Except for an increase in *Ascarina*, surrounding forest probably remained generally similar in composition to the previous zone, i e , *Dacrydium*-dominated conifer-hardwood forest

At Waihi Beach, Bay of Plenty, Newnham et al (1995b) found that the water table of the open coastal marsh had fallen at about the same time (2500 conventional yr B P) as at Awana, and was invaded by the same tree taxa (*Dacrycarpus* and *Laurelia*) They suggested that a fall in sea level and/or a prograding coast was responsible As well as a sea level fall, sediment accretion could explain a lower water table in the Awana swamp system, especially if the swamp was receiving dustings of sand from time to time There is no evidence of a prograding coast at Awana

The apparent resumption of dune activity at Awana c 2500 yr B P and a lower water table, and subsequent repeated disturbance within swamp forest, suggest a climatic change to drier and windier conditions Various lines of evidence agree 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 From the sedimentary stratigraphy of Lake Maratoto, near Hamilton, Green & Lowe (1985) 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 expansion of *Agathis australis* c 3000 yr B P , pointing to increasing dryness as the cause In the Far North, Enright et al (1988) deduced that fires between 2620 yr B P and 2150 yr B P indicate 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 , and interpreted fluctuations in the abundance of forest taxa after c 3500 yr B P as indicating repeated disturbance due to summer droughts and increased frequency of cyclonic winds

Ascarina lucida is a small tree or shrub generally found in the under-storey of conifer-hardwood forest It prefers sheltered sites without a dense canopy cover (McGlone & Moar 1977) *Ascarina* pollen values at Grays' Swamp before c 2500 yr B P (c 5% of the pollen sum) indicate a regional presence, but a sudden increase after this date (over 20%) indicate that *Ascarina* trees were growing close to the sampling site (McGlone & Moar 1977) However, *Ascarina* at some other sites on the east coast of Great Barrier does not show an increase c 2500 yr B P (M Horrocks, unpub data) This supports the notion that the increase in abundance of this species at Awana was partly the result of local influences, and indicates that *Ascarina* was patchily distributed in Great Barrier forests during the Late Holocene The lower water table at Awana c 2500 yr B P may have provided periodically favourable sites for *Ascarina* in newly established swamp forest, especially if more frequent disturbance was creating light gaps More research on the ecology of *Ascarina lucida* is required

McGlone et al (1992) concluded that, between 5000 yr B P and 3000 yr B P , climatic variability associated with increased amplitude of the El Nino/Southern Oscillation (ENSO) began to increase The results presented here suggest a change in the disturbance regime on Great Barrier Island between 3000 and 2500 yr B P , probably involving increased frequency of droughts and cyclones, leading to the invasion of a drier swamp by forest and to repeated disturbance within this forest, and also to ablation of surrounding dunes which had formerly carried forest In Hawke's Bay, Wilmhurst et al (1997) and Eden & Page (1998) found evidence of increased droughtiness and storminess, respectively, from c 2000 yr B P

An alternative explanation for the period of disturbance at Awana commencing c 2500 yr

B P is early Polynesian impact (c f Holdaway 1996), perhaps coinciding with the hypothesised climatic change However, the complete absence in both cores dated to this period of charcoal, and of pollen associated with forest clearance and open conditions (e g , *Pteridium* and Poaceae), does not support this notion

The post-Kaharoa environment

The Awana pollen record indicates that a period of major forest decline, both of the local swamp forest and the surrounding dryland forest, occurred after the Kaharoa eruption This decline appears to coincide with the Kaharoa Tephra, suggesting extensive canopy damage as a result of this event However, pollen values in the sample immediately above the tephra in the finer resolution Grays' Swamp core (at 40 5 cm, included in but not easily seen in the pollen diagram because of fine resolution sampling around the tephra) are similar to values immediately below the tephra (at 43 5 cm) (Fig 4A) We suggest that the very high microscopic charcoal levels commencing *above* the 40 5 cm sample, and coinciding with extremely high *Pteridium* values (up to 77% of the pollen sum), clearly indicate fire (by Polynesians) as the cause of vegetation change (McGlone 1983, 1989) 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

A radiocarbon date of peat from Grays' Swamp sampled from the bottom layer of microscopic charcoal (Wk–5653) indicates that deforestation commenced sometime within the rather broad time span of 930–660 calibrated yr B P However, 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 Awana and possibly the island generally to be reliably dated to c 600 calibrated yr B P (665 ± 20 conventional yr B P) (Lowe & Hogg 1992, Lowe et al 1998) Compared with pollen studies elsewhere in the Auckland region covering this period this is within the range of Hume & McGlone's (1986) inferred deforestation of the Auckland region at 800–600 conventional yr B P , and 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) suggest 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), all known to contain the Kaharoa Tephra, found that Polynesian deforestation also commenced at these sites around the time of deposition of the tephra (or after it)

It is interesting to note that post-Kaharoa forest disturbance at Awana appears not to have resulted in the same scale of dune ablation recorded earlier in the sediment record That is, there is no evidence for dune instability (sand beds) during this period Assuming that at least part of the dune forest was indeed burnt, subsequent dune instability could have been reduced by colonisation of burnt areas by a herb/scrub cover (e g , dense *Pteridium*) (Wilmshurst 1997) Also, suitably positioned patches or strips of unburned dune forest may have formed a buffer between ablating dune areas and the swamp

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