

AN AMS ¹⁴C POLLEN-DATED SEDIMENT AND POLLEN SEQUENCE FROM THE LATE HOLOCENE, SOUTHERN COASTAL HAWKE'S BAY, NEW ZEALAND

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ABSTRACT. Hawke's Bay is a region of New Zealand where earliest settlement of indigenous people may have occurred. A sedimentological and palynological study of lake sediments from a small catchment was undertaken to reconstruct erosion, vegetation, and fire histories to determine human environmental impact, and thus add to knowledge of the timing of initial settlement of New Zealand. Precise dating was an essential facet of the research because of the short time span of human occupation in New Zealand. A chronology is proposed based on accelerator mass spectrometry (AMS) radiocarbon dating of palynomorph concentrates. Known-age tephtras were used as a check on the validity of the ¹⁴C ages obtained using this technique, which is being developed at Rafter Radiocarbon Laboratory. Two episodes of sustained erosion occurred between about 1500 and 1050 BC with a period of ~50 yr at about 1300 BC when no erosion occurred. Five episodes of erosion of very short duration occurred at about 625 BC, 450 BC, 100 BC, AD 950, and AD 1400. Erosion probably resulted from landslides induced by earthquakes or severe storms, with the exception of the last event which coincides with local burning and is probably a consequence of this. A conifer/broadleaved forest surrounded the lake until soon after AD 1075–1300, when a dramatic decline in pollen of forest plants and an increase in charcoal occurred. Forest was replaced by fire-induced scrub, interpreted as a result of anthropogenic burning by prehistoric Polynesians. A further decline in woody vegetation occurred when European-introduced plants appear in the pollen record and extensive pasture was established.

INTRODUCTION

There has been vigorous debate in recent years amongst archaeologists on the time of first human settlement in New Zealand (McGlone 1983; Sutton 1987; Caughley 1988; Anderson 1991; Sutton 1994; Holdaway and Beavan 1999; Anderson 2000; Hedges 2000; Lowe et al. 2000). Three chronologies for first human settlement of New Zealand have emerged from the debate: the short chronology, which suggests that first human settlement occurred no longer than 600 yr ago; the traditional chronology, which suggests that first human settlement occurred about 1000 yr ago; and the long chronology, which suggests that first human settlement occurred at least 1400 yr ago. The shorter chronologies have relied mainly on radiocarbon ages associated with direct archaeological evidence of human presence. Such dates are minimum ages because the site of first settlement may have been missed. Where human occupation has been associated with forest clearance and other disturbance of the vegetation, the palynological signature of these events may be detected in nearby sedimentary deposits without the exact site of disturbance needing to be discovered. Common lines of evidence in these studies, from regions where forest was burnt to clear land for husbandry of domesticated plants, include various combinations of a decline in forest species, an increase in pioneer species, an increase in microscopic charcoal particles, and an increase in the rate of soil erosion (Faegri and Iversen 1992).

In readily datable deposits, the palynological signal of land clearance by burning can provide independent evidence of the time of occupation. A sedimentological and palynological study of lake sediments from a small catchment was undertaken to reconstruct erosion, vegetation, and fire histories to determine human impact, and thus add to the current knowledge of the timing of initial settlement of New Zealand by the indigenous people. Precise dating was an essential facet of the research because of the short time span of human occupation in New Zealand. Accelerator mass spectrometry (AMS) ¹⁴C dating of pollen and spore concentrates and known-age tephtras were used to construct a chronology. The former technique was expected to give a close temporal association between fossil

pollen and spores preserved in the lake sediments and the contemporary vegetation and to provide more accurate dating of late Holocene vegetation changes interpreted from palynological analyses than techniques formerly used, as it avoids contamination by inwashed soil carbon (McGlone and Wilmshurst 1999).

METHODS

Site Selection

Hawke's Bay (Figure 1) is a region of New Zealand where earliest settlement of indigenous people may have occurred (Fox 1982). It has an equable climate suitable for growing the tropical crops introduced by the first settlers of New Zealand from eastern Polynesia (Bulmer 1989). Round Lake, 39°39'S, 176°58'E, was chosen for the study reported here because it fulfills the criteria necessary for recording a detailed vegetation history of a small geographic area from before (presumed) human settlement in New Zealand to the present (Jacobson and Bradshaw 1981). The lake lies on a Pleistocene terrace of gravels, sands, and silts of the Kidnappers Group (Kingma 1970), about 2 km from the Hawke's Bay coast at about 40 m above sea level, and is likely to have been in such proximity for several thousand years (L Brown, personal communication, 2001). The lake has a diameter of 250 m and an associated small catchment of about 0.2 km². Maximum water depth was 7.5 m at the time of sampling. The lake basin is closed with no inflowing or outflowing streams, and is surrounded by extensive pastureland.

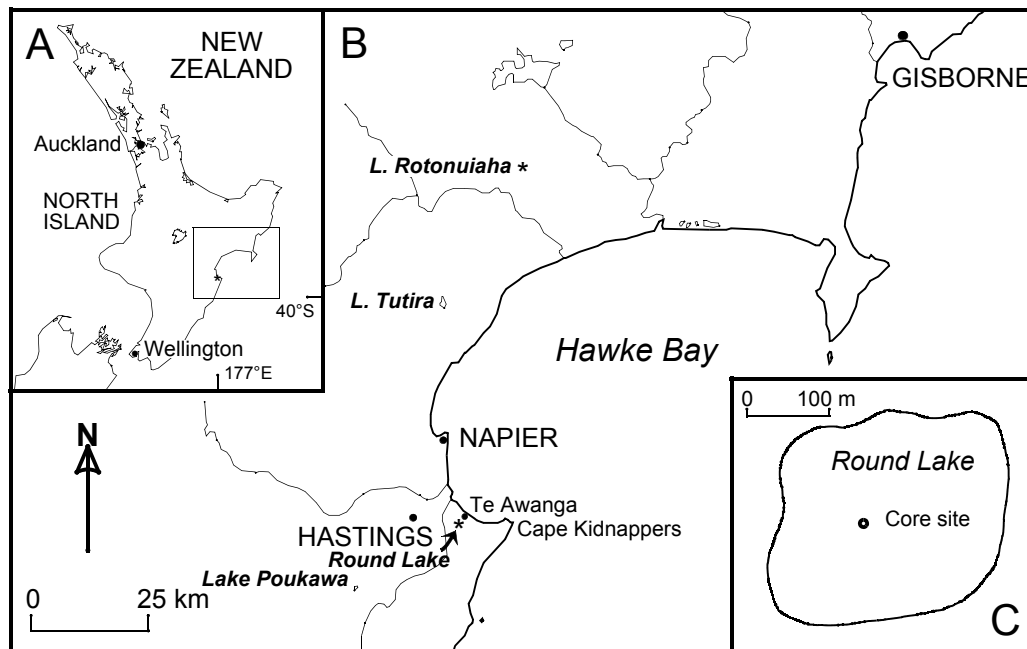


Figure 1 North Island, New Zealand (A), with Hawke's Bay region (B), showing location of places referred to in the text and palynological sampling site (C).

Field and Laboratory Work

A sediment core was collected from near the center of the lake using a hand-operated piston corer. The upper 300 cm were collected as a continuous core. Sampling for dry bulk density, fossil pollen and spores, and charcoal analyses was based on a combination of uniform and structural sampling

principles. Analyses were performed on samples of 1 cm³ of sediment extracted from the centers of 1-cm slices of core. Dry bulk density was measured using a weight loss technique. Samples with elevated dry bulk density values, containing a high proportion of inorganic matter, were examined under a microscope for presence of glass shards. For correlation with known-age volcanic eruptions, the chemistry of single glass shards was examined using a Jeol-733 Electron Microprobe set at a 10-micron beam, 8 nano amp current and 15 kV accelerating voltage. The glass shards were separated from the bulk sample using sodium polytungstate (2.45 g/cc). At least 10 shards were analyzed for each sample, averages made and compared to the analyst's (Alan Palmer) own database of known rhyolite tephtras. A rhyolite glass standard was used for calibration.

A sequence of AMS ¹⁴C ages was determined using a pollen separation technique developed at Rafter Radiocarbon Laboratory. ¹⁴C dating is the predominant chronological measurement tool for assigning ages to palynological sequences. Generally, ¹⁴C ages are obtained on bulk samples of peat or sediment or terrestrial macrofossils. In this study, microfossil pollen and spores extracted from selected palynological samples provide material for ¹⁴C dating. This method directly dates the pollen and spore assemblages used to reconstruct the vegetation history of the region, thus eliminating the risk (resulting from contamination by extraneous carbon contained within bulk samples) of a mismatch between chronology and interpreted vegetation. It may still arise, however, that the interpreted vegetation is not contemporaneous with sedimentation if pollen and spores are redeposited. After initially applying standard chemical palynological preparation techniques, with the omission of steps that use organic reagents, a density separation method was used to concentrate pollen and spores (Prior and Chester 2001). This method is superior to that of Brown et al. (1989, 1992) and Richardson and Hall (1994), whose methods failed to remove chemically-resistant non-pollen organic material, and is quicker than hand-picking (Long et al. 1992) or mouth-pipetting (Mensing and Southon 1999).

Fossil pollen and spores and charcoal particles were prepared for microscopic examination using standard palynological techniques (Faegri and Iversen 1989). Tablets containing a known number of *Lycopodium* spores were added to the samples, allowing pollen, spore, and microscopic charcoal particle concentrations to be calculated (Stockmarr 1971). Thus, the more commonly used relative frequencies and influx rates of the pollen rain could be calculated. Palynomorphs were counted until at least 200 grains of terrestrial taxa had been counted (except for 2 samples with very sparse pollen). Charcoal particle analyses were performed on every microscope slide examined for pollen and spores. Individual charcoal particle areas were measured using a semiautomatic computerized image-analyzing system (Raine et al. 1996). Particles were divided into 2 size classes: 400 μm² and greater, and smaller than 400 μm² (Patterson et al. 1987; Chester 1998).

RESULTS

Sediment Physical Properties

The core sediments comprise mostly a plastic, homogeneous, very fine-grained, highly humified, dark brown to black, highly organic lake mud (gyttja) with 2 clay-rich units near the base of the sequence and thin layers (ranging from 1 to 3 cm thick) of either clay, clay-rich, or sandy material intercalated in the gyttja (Figure 2). Sharp boundaries of the thin layers suggest abrupt environmental changes. With the exception of some thin layers, dry bulk density values are less than 0.4 g cm⁻³ and reflect the organic-rich nature of the sediments. Five thin layers had dry bulk density values greater than 0.4 g cm⁻³ and were found to contain glass shards. Glass chemistry analyses carried out on these samples by A Palmer (personal communication, 2001) indicated that three of these layers represented primary airfall tephtras: the Taupo, either the Mapara or Whakaipo (these two are indistinguishable from their glass chemistry unless both are present), and the Waimihia (Figure 2). Thin layers that do not represent primary airfall tephtras are sediments eroded from the catchment.

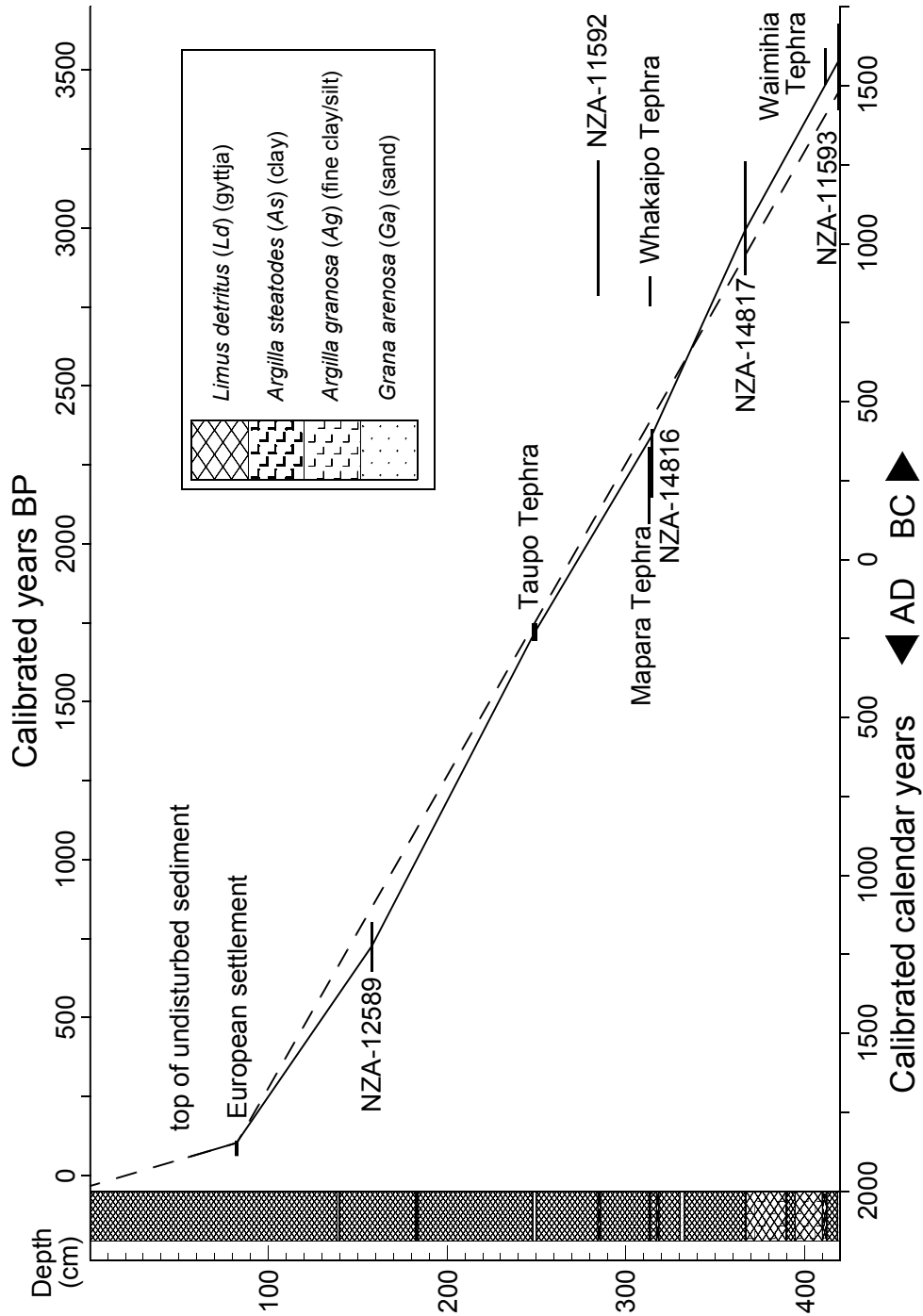


Figure 2. Age/depth plot for Round Lake core. The age/depth function is based on AMS ¹⁴C ages of concentrated palynomorphs, ¹⁴C ages of tephras identified from glass shard chemistry, and an 1850 date for European settlement placed at first appearance of European plants and a rise in microscopic charcoal content. Length of age bars indicates uncertainty of age measurement. The Taupo tephra age is from Sparks et al. (1995) and has a 1 σ confidence interval. Other tephra ages are derived from the error-weighted mean age and pooled error of Froggatt and Lowe (1990, Table 1). These were calibrated in the same manner as the concentrated palynomorphs and similarly have a 2 σ confidence interval. The solid line is a best-fit age-depth function preferred for the archaeological chronology; for comparison, the dashed line is a linear fit between the extreme dates.

Dating

In the samples prepared for dating by density separation, the density fraction with the greatest concentration of pollen and spores was determined by visual inspection under a microscope. In all samples from Round Lake, it was found that the greatest concentration occurred at a specific gravity of 1.15, so this fraction was chosen for combustion and dating. Carbon yields of this fraction were also significantly higher than that for other fractions (Table 1). The carbon content of that part of pollen and spores that remains after fossilization, the external shell (exine), is higher than that of plant cell walls, the other carbon-containing component remaining after density separation. The primary chemical component of the pollen exine, sporopollenin, is a carbon-rich C₉₀ molecule which, although it can vary with taxa, consists of between 60 and 80% carbon (Shaw 1971). Plant cell walls are composed primarily of cellulose. Pure cellulose is about 44% carbon by weight, and when plants, wood, or charcoal are combusted for ¹⁴C dating, they typically yield about 50% carbon. High carbon yields are, therefore, also a guide to pollen and spore concentration in the samples.

Table 1 AMS ¹⁴C ages on density fractions.

Depth (cm)	Fraction dated (sg ^a)	Lab nr NZA-	Carbon yield (%)	¹⁴ C age ^b (BP)	δ ¹³ C (‰)	Calibrated ages (± 2 σ ^c)
158–159	1.15	12589	70.6	786 ± 60	-27.5	AD 1073–1299
284–285	1.15	11636	69.0	2710 ± 60	-27.8	997–795 BC
	1.15	11592	69.0	2866 ± 70	-27.7	1263–838 BC
	1.20	11589	58.0	2794 ± 60	-29.3	1118–818 BC
	1.40	11590	53.3	2850 ± 65	-27.3	1253–835 BC
314–315	<1.20	14816	61.9	2286 ± 50	-24.0	408–202 BC
366–367	1.15	14817	49.7	2882 ± 55	-26.3	1258–907 BC
418–419	1.15	11637	67.7	3201 ± 55	-27.8	1603–1321 BC
	1.15	11593	67.7	3282 ± 60	-27.7	1690–1423 BC
	1.20	11591	61.2	3333 ± 60	-29.5	1747–1459 BC
	1.35	11588	60.1	3243 ± 60	-27.4	1679–1404 BC

^asg = specific gravity.

^b¹⁴C age as defined by Stuiver and Polach (1977).

^c¹⁴C ages were calibrated with WINSICAL (Institute of Geological & Nuclear Sciences) using the atmospheric Δ¹⁴C and ¹⁴C ages from INTCAL98 (Stuiver et al. 1998).

AMS ¹⁴C ages of density fractions are shown in Table 1. In 2 samples (284–285 cm and 418–419 cm), the fraction containing the greatest pollen and spore concentration (1.15 sg) and 2 other fractions containing a greater quantity of other plant remains were dated for comparison. Conventional ¹⁴C ages for the 3 fractions from each sample are statistically identical, indicating that the plant remains deposited in the sediment and the palynomorphs are the same age. Reproducibility of ages in this way increases confidence in the contemporaneity of the dated pollen and spores with the contemporary vegetation that is reconstructed.

¹⁴C ages on 2 samples of 1.15 specific gravity from 284–285 cm and 418–419 cm depth were repeated because the first measurements (NZA-11592 and NZA-11593) were made on targets with a low graphite yield. The second ¹⁴C age obtained for the fraction from 418–419 cm yielded an age statistically identical to that first obtained, but the second age obtained for the fraction 284–285 cm (NZA-11636) is slightly younger. Since the second measurement was made on a graphite target with

an acceptable reaction yield and conforms better to that expected, we have greater confidence in its reliability. Thus, it is used in the age/depth plot (Figure 2).

The age/depth plot was drawn using various chronological markers. Initially, a series of 3 samples were selected from the pollen-analyzed core for AMS ^{14}C dating. The uppermost sample (NZA-12589) was taken from a pollen sample that showed an increase in the abundance of microscopic charcoal particles. A second sample (NZA-11636), taken near the base of the upper continuous 300 cm of core, was selected for ^{14}C dating because it was contiguous with a layer with elevated dry bulk density suspected of representing either a tephra or eroded sediment. The third sample (NZA-11593) was taken from the base of the entire sequence. Results of these ^{14}C determinations indicated a non-uniform sedimentation rate that did not conform to the results expected from sediment analyses. In addition, the age determined from sample number NZA-11636 did not conform to the known ages of either the Mapara or Whakaipo tephtras (Froggatt and Lowe 1990).

A second series of 2 samples from the 314–315 cm and 366–367 cm depths were selected to bracket the lower clay-rich units to provide a rate of deposition for these units, and the tephra identified by glass chemistry as either Mapara or Whakaipo. ^{14}C age measurements on these 2 samples were made on density separation fractions with the highest pollen concentrations. Dating results (NZA-14816 and NZA-14817) indicated that the deposition rate of the clay-rich units was slightly higher than that of the remainder of the sediments which had been deposited almost uniformly, suggesting that the thin intercalated layers of either primary airfall tephra or material eroded from the catchment had been deposited very rapidly. These results match the results of the sediment analyses. A linear age/depth function of best-fit drawn through the chronological markers confirms this. It was also confirmed that the tephra deposited at 313–314 cm was the Mapara; thus, the age of this tephra, 2160 ± 25 BP (Froggatt and Lowe 1990), could be applied to the constructed chronology.

On the basis of this dating, 1 sample, NZA-11636, lies outside the linear age/depth function. This sample was immediately above a thin clay-rich layer (Figure 2). As the layer did not contain glass shards, it must represent sediments eroded from the catchment. The dated sample must have contained reworked palynomorphs and forest litter older than the contemporary vegetation eroded from the catchment; large plant fragments in the 1.40 specific gravity fraction also produced ages that were older than expected. The amount of contamination required by old carbon to increase the age of the ^{14}C age from that expected using the linear age/depth function to that obtained would be small (Caughley 1988). This example demonstrates the necessity of applying multiple lines of evidence to check on the validity of ^{14}C determinations.

Pollen, Spore, and Charcoal Sequence

Only a very few significant taxa of the total taxa counted are discussed here. Pollen spectra are divided into 3 distinct local pollen-assemblage zones based on absolute abundance and relative frequency pollen and spore data and abundance of charcoal particles in the 2 size classes (Figure 3). They are formed to simplify discussion and interpretation of the pollen sequence and facilitate discussion of the vegetational events and comparison with other pollen sequences. The zone boundaries are placed where change in the pollen spectra is most marked, so that the enclosed units are relatively homogeneous and can be juxtaposed with cultural periods.

Zone 3 (420–158 cm) is dominated by tall woody species (mostly *Podocarpus totara* and *Prumnopitys taxifolia*) which represent a conifer/broadleaved lowland forest. A great diversity of small trees was growing close to the lake, but pollen of *Kunzea/Leptospermum* is most frequent. Trees of both these genera have high light requirements for growth. They can only establish on bare ground and

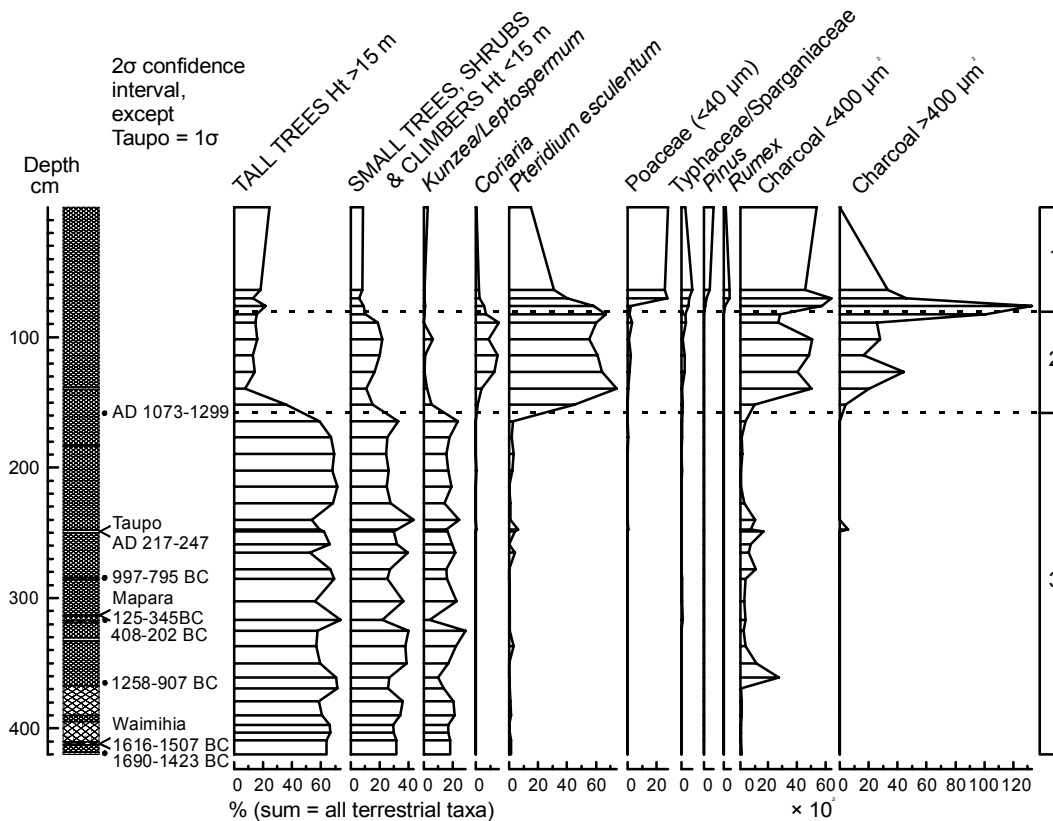


Figure 3 Pollen and charcoal diagram for Round Lake, Hawke's Bay

are not self-perpetuating unless the canopy is open. Their long record suggests that they were growing in an unstable area, perhaps on a flood plain or as a coastal scrub, in swamp and/or perhaps in a damp area close to the lake. *Pteridium esculentum* (the native bracken fern) is sporadic in occurrence, sometimes corresponding to inwashed clay. It is most abundant following the deposition of the Taupo tephra. Charcoal particles in the smaller size class form an almost continuous record but in very low abundance. Particles of the larger size class only occur following the deposition of the Taupo tephra. This may result from a greater frequency of fires in forests of reduced canopy cover and, thus, of greater fire susceptibility.

Zone 2 (158–80 cm) is characterized by a decline in woody taxa, although *Coriaria* and *Pteridium esculentum* increase. Wild grasses (Poaceae pollen with longest axis <40 μm) also increase. *Coriaria*, *Pteridium esculentum*, and grass are light-demanding species, and indicate that the canopy of the lowland forest close to Round Lake was more open. *Coriaria* and *Pteridium esculentum* are also pioneer species and are fire-encouraged. Pollen of Typhaceae/Sparganiaceae also increases, indicating more extensive reeds, probably a response to greater influx of nutrients into the lake. Charcoal particles of both size classes occur in a much greater abundance, indicating a large increase in the frequency and/or intensity of distant and local fires.

Zone 1 (80–0 cm) is characterized by the appearance of the European-introduced *Pinus*, several European-introduced weed taxa (for example, *Rumex*), and an increase in wild grasses. The abundance of the taller woody species remains stable, but the lower woody species decline further.

Typhaceae/Sparganiaceae increases, suggesting that nutrient influx to the lake increases further. A dramatic increase in influx of charcoal in both size classes occurs. This indicates widespread burning both locally and regionally. Notably, the larger size class is not represented in the surface sample; no intentional burning close to Round Lake is known to occur currently.

DISCUSSION

Almost all archaic (earliest) archaeological sites in New Zealand are coastal (McKinnon 1997), so palynological analysis of coastal sites could be expected to better reflect the beginnings of human settlement in the region. Archaic sites have been recorded along the coast of Hawke's Bay (Fox 1982). The oldest dated archaeological site from Hawke's Bay is a rectangular pit, measuring 4×2.5 m and 60 cm deep, from a coastal site (Fox 1982). Rectangular pits are the remnants of semi-subterranean food storage houses that were used for the storage of seasonal crops, mostly of kumara (sweet potato), but also for other crops such as yams (Davidson 1984). The pits were roofed with a ridgepole supported on 2 or 3 central upright posts embedded in a dirt floor. A ^{14}C age obtained from the charred remains of a roof-supporting post from the rectangular pit from coastal Hawke's Bay was originally reported as NZ-1914: 1050 ± 90 BP (Fox 1978, appendix 6). Before 1978, ^{14}C age measurements produced by the Rafter Radiocarbon Laboratory (formerly Institute of Nuclear Sciences, DSIR) were calculated using a set of New Zealand reference standards (Rafter et al. 1972) and the Cambridge half-life of 5730 yr. Ages produced since 1978 have been calculated according to the international reporting conventions suggested by Stuiver and Polach (1977), and during the late 1980s, ^{14}C ages in the DSIR database were recalculated to conform to international reporting standards. Conversion of the age of the post to the international reporting conventions of Stuiver and Polach (1977) results in a conventional ^{14}C age of 1009 ± 122 BP (Prior and Chester 2001), which can be calibrated to AD 771–1272 (1179–678 cal BP) at 2σ confidence interval. The post was made from a tree estimated to be between 75 and 125 yr old based on its diameter and average expected growth rate. There is the possibility that the tree was not freshly cut, so its youngest ^{14}C age could be appreciably older than the date of construction of the storage house (Davidson 1984). However, if the reported age is coeval with the date of construction, this is the earliest known construction of a roofed rectangular food storage house. It can be compared with the date of AD 1170 ± 60 obtained from charcoal on the floor of a rectangular storage pit on the Coromandel Peninsula in the north of New Zealand, where early experiments in the development of this type of storage pit may have been carried out (Davidson 1984). If these 2 dates are an accurate reflection of the time of construction, the development of large roofed rectangular semi-subterranean food storage houses was close to the traditionally accepted date of initial settlement of New Zealand, and there is the possibility that Hawke's Bay was settled early in the original settlement of New Zealand and that it would be palynologically visible.

A widely-known palynological study from the Hawke's Bay region which spans the period of probable initial Polynesian settlement is that from swamps around Lake Poukawa (McGlone 1978, 2002). It was reported that inland central Hawke's Bay was covered with a dense, diverse podocarp-hardwood forest prior to human occupation. Where corresponding pollen percentages were reported to show first signs of the decline of the forest, a ^{14}C determination on a 50-mm-thick slice of peat (0.55–0.60 m) was originally reported as NZ-4162: 1190 ± 70 BP. Another determination on peat, slightly higher in the sequence at 0.40–0.45 m, where forest destruction is more evident, was originally reported as NZ-4163: 980 ± 70 BP. The 2 ^{14}C ages cited by McGlone (1978) have been recalculated to a conventional ^{14}C age of 1156 ± 59 BP (NZ-4162) and 946 ± 59 BP (NZ-4163). These can be calibrated to AD 715–1008 (1235–942 cal BP) and AD 989–1218 (961–732 cal BP) at 2σ confidence intervals, respectively. Charcoal fragments were found in the swamp sediments and

so the deforestation was assumed to have been caused by fire presumed to have resulted from Polynesian settlement. The upper part of the pollen sequence reflects European settlement and the final conversion of the vegetation to grassland. More recent palynological research studied 2 inland lakes in northern Hawke's Bay (Wilmshurst 1997). The more coastal lake is some 10 km from the coast, beyond the dispersal range of most pollen grains (Tauber 1965 calculated that only 5% of pollen in Denmark reaches distances of 5 to 10 km), and prevailing wind is from the southwest (Tomlinson 1976), so these sites also reflect inland vegetation. ¹⁴C dates were rejected for being too old because of contamination, so the sequence was dated by associated tephtras. Deforestation is estimated from sedimentation rates to have begun "about 500 calendar years BP" (Wilmshurst 1997).

It is now generally accepted that a rapid loss of forest and coincident rapid rise and sustained abundance in the pioneer plants of *Pteridium esculentum* and wild grass from about 800 to 600 yr ago resulted from anthropogenic burning. This has been interpreted by some authors to be an indication of initial human impact on the environment of New Zealand and first colonization (settlement) of New Zealand. However, Flenley and Todd (2001) have argued that this may not be the palynological signal of initial human impact, but rather represents establishment of the use of the *Pteridium esculentum* rhizome as a staple food, which allowed people to settle areas previously uninhabitable because of the lack of a suitable crop. They proposed that small and sometimes intermittent occurrences of bracken prior to the rapid increase might reflect early establishment of slash-and-burn agriculture that is, small temporary clearings in the forest, used to grow crops for a few years and then abandoned. In this situation, the bracken is a weed in the abandoned gardens, and may disappear as the forest regenerates. They proposed that colonization was a 2-stage process. In the initial stage, colonization was limited to coastal areas and the north because of the need to grow tropical crops. The second stage occurred after the technology to produce the *Pteridium esculentum* rhizome as a crop and safe food resource had been developed. Following this scenario, the small sporadic occurrences of *Pteridium esculentum* spores in the sequence from Round Lake may be indicative of small coastal settlements in Hawke's Bay prior to AD 1075–1300.

CONCLUSION

Dating extracted pollen and spores directly ages the palynomorphs on which the vegetation history is reconstructed and avoids contamination by inwashed soil carbon. However, in this study, there is not complete agreement between AMS ¹⁴C ages of concentrated palynomorphs and ¹⁴C ages of identified tephtras, probably as a result of a dated sample containing reworked palynomorphs. A most probable solution, using selected dates of both dating methods, has been used in construction of the following site history.

Between about 1600 BC to AD 1200, a diverse conifer/broadleaved forest with either a closed canopy and smaller marginal trees and/or a discontinuous upper story with a lower story of smaller trees existed on the Hawke's Bay lowlands. With the exception of the effect of the deposition of the Taupo tephtra, when forest taxa decline and abundance of charcoal particles increases, evidence for disturbance of this forest is minimal with *Pteridium esculentum* (which may be indicative of small coastal settlements) occurring sporadically and in low abundance. Two episodes of sustained inwash of sediments from the catchment occurred between about 1500 and 1050 BC with a period of about 50 yr at about 1300 BC when no inwash occurred. Above this, 4 episodes of inwash of catchment sediments of very short duration are recorded at about 650 BC, 450 BC, 100 BC, and AD 950. Inwash of inorganic sediments during this period are not accompanied by deposition of charcoal and probably resulted from slumping within the catchment caused either by storms or tectonic movement, and there was no evident contemporaneous disruption of vegetation. Low abundance of charcoal

particles in the smaller size class probably results from distant infrequent fires, either naturally or anthropogenically induced.

At AD 1200, there is abundant evidence that substantial prehistoric settlement began in the vicinity of Round Lake, a dramatic decline in abundance of forest taxa, coincident with a significant increase in the abundance of charcoal particles, in both size classes. The rapidity, magnitude, and constancy of the increased abundance of charcoal particles suggest that anthropogenic burning occurred in the vicinity of Round Lake. There is a corresponding increase of the pioneer, light-demanding, and fire-encouraged taxa of *Pteridium esculentum* and *Coriaria*, and light-demanding grasses. *Pteridium esculentum* is rapidly suppressed by shrubland and forest regeneration; thus, its persistence in the pollen record represents repeated burning, and the presence of a constantly high influx of charcoal particles confirms this. Erosion occurred within the catchment at about AD 1400 and nutrients into the lake increase. This phase of obvious local human impact, commencing AD 1200, is more recent than the initial anthropogenic destruction noted at the inland site of Lake Poukawa at AD 715–1008 (2σ confidence level), but may be contemporaneous with the more evident forest destruction at AD 989–1218 (2σ confidence level). It is earlier than that found at Lakes Tutira and Rotonuihua, estimated to be about 500 yr ago; it may be contemporaneous with the coastal food storage pit (AD 771–1272). The beginning of this phase occurs within the time period when New Zealand is traditionally thought to have been occupied by immigrants from eastern Polynesia (Davidson 1984).

European settlement began at about AD 1850. A further decline in the lower woody vegetation occurred and European-introduced taxa appear. Charcoal abundance increases dramatically and grass pollen becomes abundant as a result of European land clearance for pasture.

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