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PALYNOLOGICAL AND SEDIMENTOLOGICAL EVIDENCE FOR A RADIOCARBON CHRONOLOGY OF ENVIRONMENTAL CHANGE AND POLYNESIAN DEFORESTATION FROM LAKE TAUMATAWHANA, NORTHLAND, NEW ZEALAND[1]

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ABSTRACT. We present pollen diagrams and sedimentological analyses from a lake site within an extensive dune system on the Aupouri Peninsula, Northland. Five thousand years ago, a regional *Agathis australis*–podocarp-broadleaf forest dominated the vegetation, which manifested an increasing preponderance of conifer species. Climate was cooler and drier than at present. From *ca.* 3400 BP, warmth-loving species such as *A. australis* and drought-intolerant species, *Dacrydium cupressinum* and *Ascarina lucida,* became common, implying a warm and moist climate. The pollen record also suggests a windier climate. The most significant event in the record, however, occurred after *ca.* 900 BP (800 cal BP) when anthropogenic deforestation commenced. A dramatic decline in forest taxa followed, accompanied by the establishment of a *Pteridium–esculentum*-dominated community. Fire almost certainly caused this, evidenced by a dramatic increase of charcoal. Sedimentological evidence for this site indicates a relatively stable environment before humans arrived and an increasingly unstable environment with frequent erosional events after human contact.

INTRODUCTION

Although much is now known of the late Holocene vegetation history and archaeology of early settlement of southern regions in New Zealand, little is known of the archaeology of the early settlement of the north (Bulmer 1988). The vegetational history remains sketchy, although several pollen diagrams cover this period (Kershaw and Strickland 1988; Dodson, Enright and McLean 1988; Enright, McLean and Dodson 1988; Newnham 1992). The debate over when first settlement of New Zealand occurred continues to be marked by controversy and remains poorly defined. None of the published palynological investigations from Northland addresses this contentious issue, although discussion in the archaeological literature has been vigorous (Sutton 1987, 1988; Enright and Osborne 1988; Anderson and McGovern-Wilson 1990; McGlone, Anderson and Holdaway 1994). The most preferred position in this argument has been that first human settlement occurred at or around 1000 BP (Davidson 1984); more recently the date has been brought forward to 700 BP (Anderson 1991; McFadgen, Knox and Cole 1994). The evidence for this derives from dated archaeological sites. However, the effect of Polynesian settlement on the vegetation of New Zealand has been profound and palynological analyses from more southern regions of New Zealand have provided evidence of this human impact (McGlone 1978; McGlone, Mark and Bell 1995; Mildenhall 1979; Bussell 1988; Newnham, Lowe and Green 1989). Elsewhere in the Pacific and Southeast Asia, evidence from pollen records, charcoal influx and sedimentological analyses has been used to define the onset and extent of human impact on the environment (*e.g.*, Flenley 1988; Flenley *et al.* 1991; Newsome and Flenley 1988; Kirch, Flenley and Steadman 1991; Kirch *et al.* 1992). We present here similarly derived evidence for one of the first chronologically secure records of human impact on the environment in northern New Zealand.

DESCRIPTIVE BACKGROUND

Lake Taumatawhana is about halfway between Houhora and Te Kao on the west of the Far North Road (Fig. 1). The lake occupies an area < 1 ha on a block of land administered by the Department

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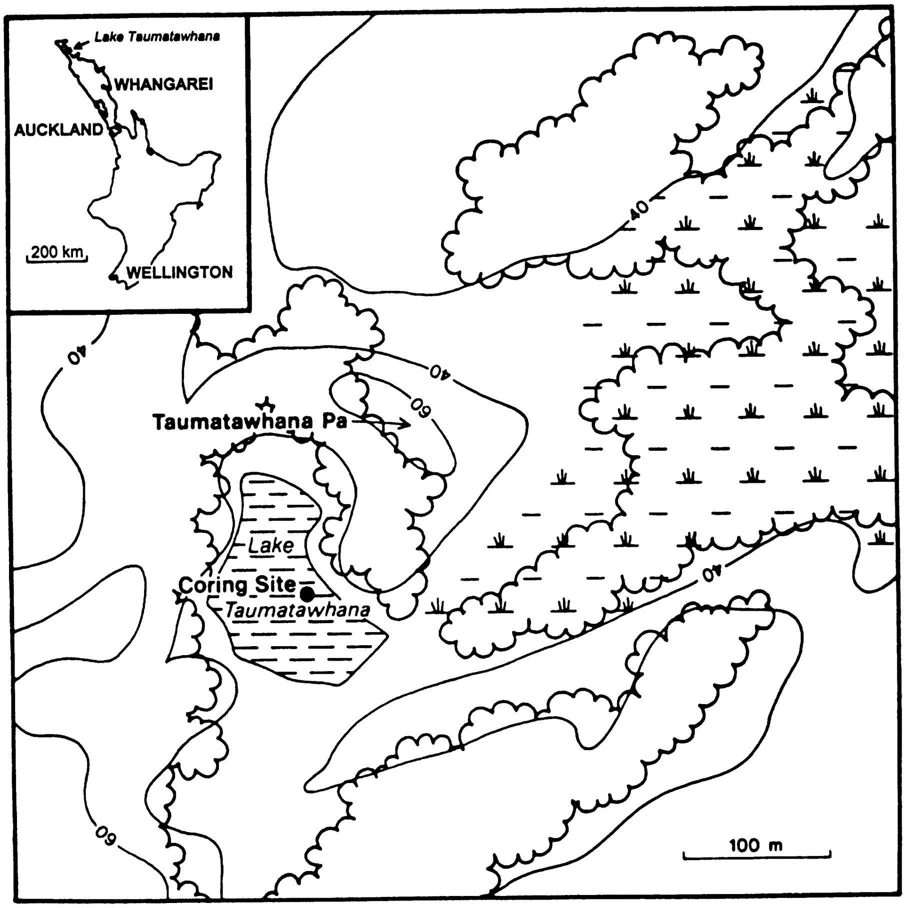

Fig. 1. Lake Taumatawhana, Onepu, Northland

of Conservation within which, adjacent to the lake, is a 9.8-ha parcel designated as a proposed historic reserve (Maingay 1991). A well-preserved double *pa* (Maori fort) site (Fig. 1) overlooks both the lake on the southern side and an extensive area of early Maori gardens that lies to the north (Maingay 1991). The lake is *ca*. 30 m asl and formed as part of coastal progradation processes that followed the postglacial rise in sea level. Prevailing westerly winds formed dunes and created the Aupouri Peninsula, a large tombolo linking the northern archipelago to mainland Northland. Numerous small lakes and peat swamps formed in the trailing arms of parabolic dunes and also between such dunes where drainage has been impeded. Lake Taumatawhana is one such lake in this system, and at its eastern end, drains by seepage into a larger peat swamp lying within a large parabolic dune. ^{14}C dating of basal sediments for both the lake and adjacent swamp yielded ages of 4883 ± 64 BP (NZA-3486) and 4792 ± 70 BP (NZA-2808), respectively (Table 1).

Leptospermum scrub with numerous small *Coprosma* and *Pomaderris* shrubs, scattered *Cordyline australis* and exotic wattles surround the lake. The margins of the lake, in many parts overhung with *Leptospermum*, support a variety of restiads and sedges, as well as clumps of *Phormium tenax*, *Typha orientalis* and numerous aquatic species including *Myriophyllum* that extend out into the water body, forming a fringe floating mat. *Typha orientalis* dominates the adjacent swamp in the wetter areas, and *Leptospermum* the outer, drier zones. *Phormium tenax* and *Cordyline australis*

TABLE 1. ^{14}C Dating of Samples

Depth (m)	NZA-no.	^{14}C (yr BP)	$\delta^{13}C$‰	Cal range BP (2σ)	Material dated
Lake Taumatawhana					
0.29–0.34	3920	1434 ± 77	−29.34	1491–1089	Treated gyttja
0.29–0.34	3823	1741 ± 83	−29.97	1803–1409	Treated gyttja
0.96–1.00	3882	686 ± 72	−27.11	684–521	Treated gyttja
1.10–1.16	3819	913 ± 65	−28.24	912–675	Treated gyttja
1.56–1.61	3820	1928 ± 68	−28.84	1979–1624	Treated gyttja
1.86–1.91	3821	2612 ± 72	−29.51	2784–2368	Treated gyttja
3.06–3.11	3822	2976 ± 67	−29.41	3262–2876	Treated gyttja
4.05–4.10	3486	4883 ± 68	−32.14	5725–5332	Treated gyttja
Taumatawhana Swamp					
2.35–2.40	2808	4792 ± 70	−25.3	5640–5325	Twigs

trees are also present. *Gleichenia dicarpa* and *Blechnum minus* are common and a number of swamp-tolerant forbs persist. Pasture grasses, the commonest species of which are *Anthoxanthum odoratum* and *Pennisetum clandestinum,* cover adjacent sand dunes. There are several plantations of *Pinus* in the surrounding district, including the extensive Aupouri Forest in the west.

A sediment core 4.46 m long was recovered below 6.5 m of water from the deepest part of the lake, using a modified piston mud sampler (Walker 1964) operated from a raft. This core consists of three broad stratigraphic units (Fig. 2).

METHODS

Palynology

Samples were taken at 0.10-m intervals to a depth of 3.95 m. Only one sample was taken from the upper 0.30 m as this part of the core was loose and possibly liable to mixing. Laboratory preparation for pollen analysis of these samples followed standard alkali and acetolysis treatments (Faegri and Iversen 1989). *Lycopodium* marker spore tablets were added at the onset of chemical treatment for absolute pollen-frequency calculations (Stockmarr 1971). Charcoal counts were made by counting all fragments across a traverse in the size range of pollen grains and spores until 10 *Lycopodium* spores had also been counted. Pollen percentages are based on a pollen sum of all dryland plants including ferns and fern allies. In almost all cases, counts exceeded 250 dryland types. Preservation of pollen and spores was generally good. Plant nomenclature follows Allan (1961), Moore and Edgar (1976), Connor and Edgar (1987) and Molloy (1995).

Sedimentology

The sediments were analyzed to a core depth of 3.00 m. All investigations required the same basic sample preparation. First, X-ray photographs were taken to identify any laminar structures present (Baker and Friedman 1969). The variation in laminar structures resulted in the choice of different sample lengths; between 0 and 1.00 m the sample length ranged from 0.04 to 0.135 m; between 1.00 and 2.00 m sample lengths varied from 0.09 to 0.15 m. The entire section from 2.00 to 3.00 m was sampled at 0.10-m intervals. Dry samples were pestled and sieved at 2.0 mm to separate coarse (>2.0 mm) and fine (< 2.0 mm) sediment (Loveland and Whalley 1991).

Sediment texture was analyzed through the grain-size distribution. Samples were oxidized in 30% hydrogen peroxide (H_2O_2) (Day 1965 in Gee and Bauder 1986; Kunze and Dixon 1986). We used a

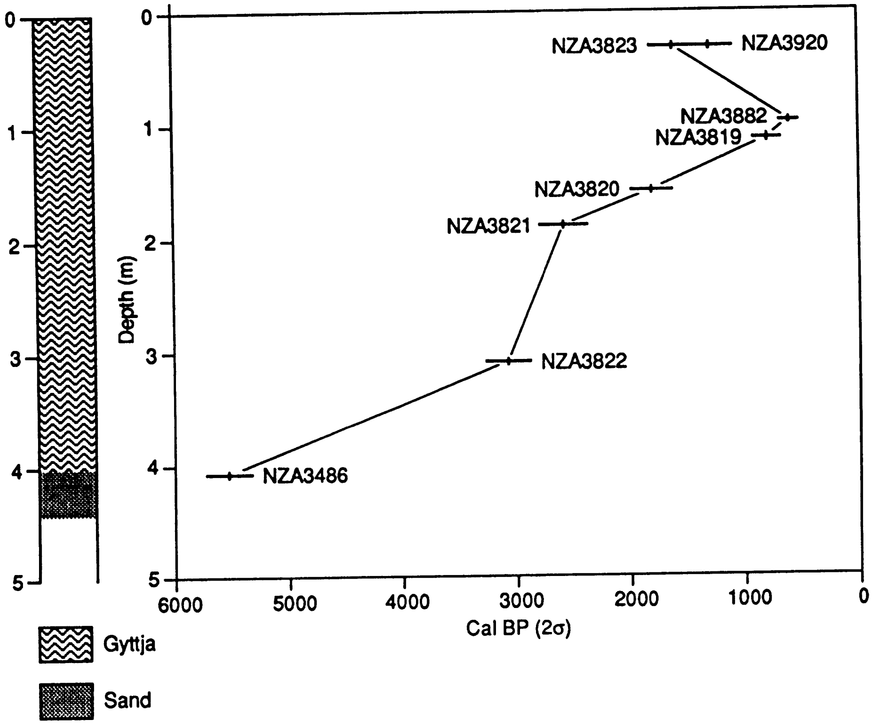

Fig. 2. Stratigraphy of core, and age-depth graph for Lake Taumatawhana. Lithology from top to bottom: black gyttja (organic mud); black gyttja with sand; and sand. The uppermost 0.30 m of the core consists of loose black gyttja. Below this loose layer, black gyttja persists to a depth of 4.00 m. From 4.00 m to 4.11 m the black gyttja contains a trace of sand. The horizontal bars represent the range of uncertainty on the calibrated date chronologies (2σ), and the vertical bars the length of the core sediment used.

particle size analyzer to analyze the silt and clay fractions ("Sedigraph": Micromeritics 1991; Risberg 1989; Berezin and Voronin 1981). The sand fraction (62.5 μm–2.0 mm) was separated from the bulk sample by wet sieving and determined separately. Grain-size-distribution classes chosen for the sedigraph analysis correspond with the Wentworth scale (Heim 1991). A further subdivision of the sand fraction (62.5 μm–2.0 mm) was not carried out as the sample weight for this fraction was too small (average sample weight <1.00 g) for a sieve test on a nest of standard sieves with a frame diameter of 200 mm. Instead, the entire sand fraction obtained by wet sieving was regarded as an individual fraction.

Organic content was determined by loss-on-ignition (after Kretzschmar 1989). Correction factors were applied to these data as organic substances and also some chemically bound water and void compounds are known to evaporate (Håkansson and Jansson 1983). As the bulk of the clay minerals occur in the clay fraction (<1.95μm), Schlichting and Blume (1966) suggested subtracting 0.1% weight per 1.0% weight of clay content from the result of the organic matter content obtained by loss-on-ignition.

Bulk sediment chemistry was analyzed by Plasma Emission Spectrometry (ICP-AES) providing data for 23 elements (Al, As, B, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Se, Si, Sn, Sr and Zn). The analysis was performed on liquid digest. Sample digestion involved a 1:1 concentrated hydrofluoric acid/concentrated nitric acid (HF/HNO_3) solution treatment in combination with 30% H_2O_2 oxidation to destroy the organics of the samples, and hydrochloric acid (2 M HCl) extraction.

We investigated the sediment mineralogy for two different grain-size fractions—the mud fraction (silt and clay fraction, material < 62.5 μm) and the sand fraction (material > 62.5 μm)—at 0.20-m intervals to a depth of 2.80 m. Samples were treated with 30% H_2O_2 solution and wet-sieved at 62.5 μm to separate the two fractions. The mineralogy of the mud fraction was analyzed by X-ray diffraction (XRD). Mineralogical constituents of the sand fraction were investigated by petrographic microscopy.

RESULTS

Dating

Seven samples from the lake and an additional sample from the adjacent swamp were radiocarbon-dated by accelerator mass spectrometry (AMS) (Table 1, Fig. 2) at the Rafter Radiocarbon Laboratory, Lower Hutt, New Zealand. The material dated was bulk sediment obtained from 0.05–0.06-m-length core segments. No dateable plant macrofossils were present. The basal samples from the lake and swamp sediments yielded ages of 4883 ± 68 BP (NZA-3486) and 4792 ± 70 BP (NZA-2808), respectively. The uppermost two dates (NZA-3920 and -3823) appear to have been contaminated by older carbon following deforestation and pasture establishment by European farmers within the lake catchment (*e.g.*, Pennington *et al.* 1976). Non-contemporary forest litter and humic compounds were probably incorporated into the lake sediments. The appearance of introduced species in the pollen record supports this hypothesis. The $\delta\,^{13}C$ values from the anomalous dates are dissimilar to those immediately below, and similar to those from older material in the core, which further supports this interpretation.

Palynology

Figures 3 and 4 show the pollen diagrams displayed as relative frequency and pollen concentration data, respectively. The charcoal data displayed on both of these figures is shown as absolute charcoal influx in grains/cm^3. The pollen spectra are divided into five zones.

1. Zone Ta 4: 4.00–3.30 m depth; ca. *5000–3400 BP*

The terrestrial pollen is dominated by arboreal pollen, the most abundant elements of which are *Agathis australis, Dacrycarpus dacrydioides, Dacrydium cupressinum, Libocedrus, Nestegis, Phyllocladus, Podocarpus, Prumnopitys taxifolia, Ascarina lucida, Coprosma* and *Leptospermum/Kunzea*. Ferns, herbs and aquatics record only low frequencies and charcoal influx is also low. The steady increases in *A. australis* and *A. lucida* are notable.

2. Zone Ta 3: 3.30–1.90 m depth; ca. *3400–2600 BP*

Like the previous zone, this is characterized by an arboreal dominance with a similar composition of species. At the onset of this zone is a very sharp and short-lived decline in *A. australis*, followed by a steady increase before again declining at the top. The curves for *D. cupressinum, Libocedrus, P. taxifolia* and *A. lucida* show similar, though less pronounced, trends. Herbs, ferns and aquatics are again only weakly represented, although the ferns assume slightly more importance than previously.

3. Zone Ta 2: 1.90–1.12 m depth; ca. *2600–900 BP*

As with Zones Ta 3 and 4, a strong dominance is maintained by the arboreal taxa over the relative paucity of herbs, ferns and aquatics. *A. australis* rises steadily upward from a starting point of low abundance through the zone to achieve a significant peak at the top. A similar trend is observed in

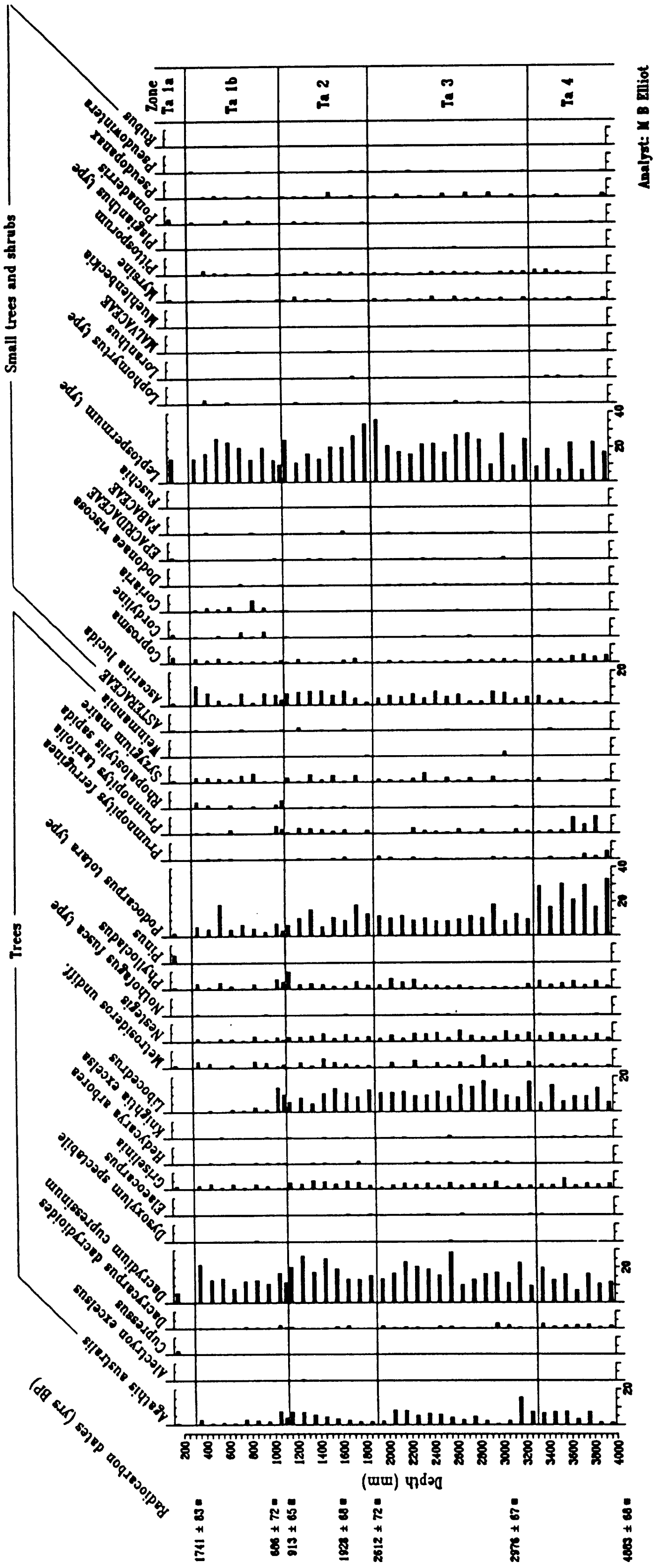

Fig. 3. Lake Taumatawhana pollen percentage diagram. A: Trees, small trees and shrubs.

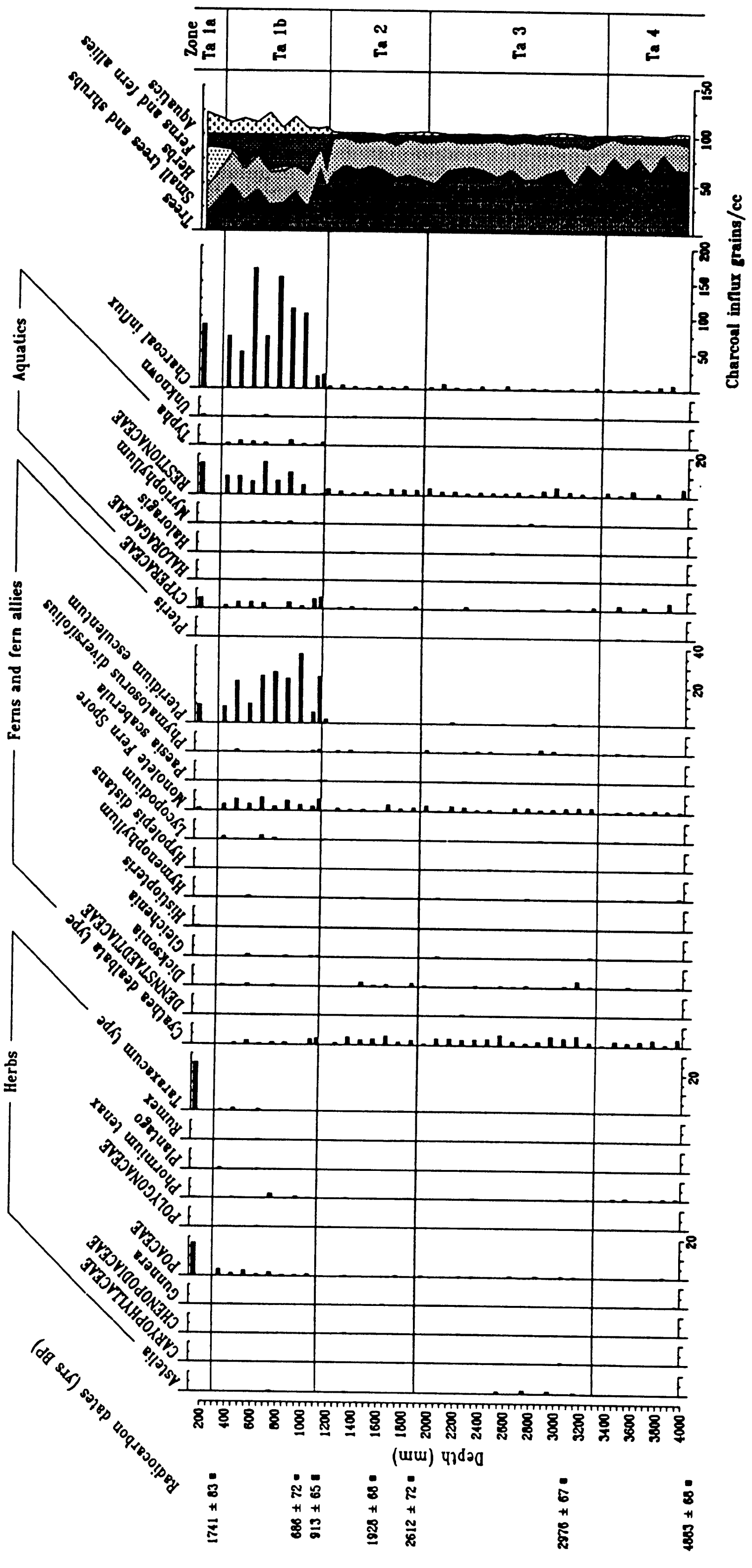

Fig. 3. (cont.) Lake Taumatawhana pollen percentage diagram. A: Trees, small trees and shrubs; B: Herbs, ferns and fern allies and aquatics.

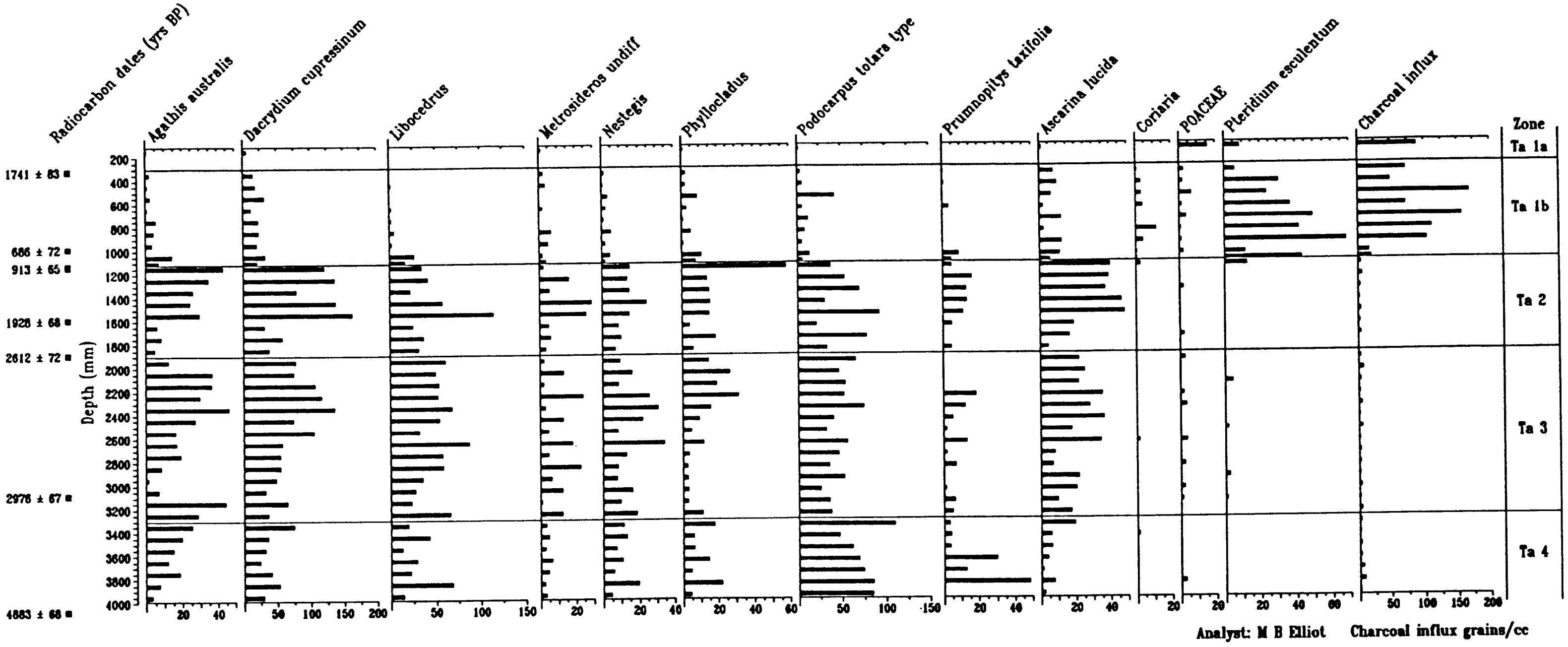

Fig. 4. Lake Taumatawhana pollen concentration diagram, selected taxa only

the *D. cupressinum* curve, but other podocarps do not demonstrate the same pattern although they generally maintain a strong presence. *A. lucida* maintains high abundances throughout, and most other forest taxa are well represented.

4. *Zone Ta 1b: 1.12–0.30 m depth;* ca. *900–250(?)* BP

This subzone is characterized by several significant changes in the pollen spectra. Initially, a short, sharp increase in ferns is observed, attributable chiefly to *Pteridium esculentum*. The arboreal pollen declines in tandem with the above change. This event is followed by an equally brief reverse trend followed by a significant decline in forest taxa. All tree, small tree and shrub taxa other than *Coprosma* and *Coriaria* exhibit dramatic decreases in abundance. Herbs, though still relatively unimportant, increase in abundance, particularly Poaceae members. The *P. esculentum* curve dominates the pollen spectra; other herbaceous ferns represented by the curve for monolete fern spores increase noticeably, and the frequencies for Cyperaceae and Restionaceae members are also increased. The charcoal influx mirrors the *P. esculentum* curve.

5. *Zone Ta 1a: 0.30 m depth to sediment surface;* ca. *250(?)* BP*–present*

This subzone is characterized by low frequencies for almost all arboreal pollen types. Herbs are clearly the dominant pollen group, in particular, Poaceae members and *Taraxacum* type. Exotic European pollen types appear for the first time, notably *Cupressus* and *Pinus*; it is likely that the increases in herb pollen, *i.e.*, Poaceae and *Taraxacum*, are also attributable to introduced European species, but conclusive differential identification is not possible.

Sedimentology

Texture

The grain-size distribution is characterized by two peaks in the sand fraction (Fig. 5). The first peak (35%) occurs at 1.12 m. Prior to this, the sand content is consistently low, averaging 10%. The second peak occurs between 0.61 m and the sediment surface, with an initial value of 14% at 0.61 m, which increases sharply to 27.2% at 0.54 m and achieves a maximum value of 87.2% between 0.13 m and the surface. Low values for clay fractions are coincident with these peaks in sand fractions. Between 0.53 and 0.13 m, clay fraction values range from 29% to 4.3% compared with an average value of 46% for the remainder of the core. Other grain-size fractions remain almost entirely unaffected throughout the core.

Organics

Typically, the organic matter content is *ca.* 50% (by dry weight) throughout the core (Fig. 5). However, a sharp decrease occurs from 0.61 m to the surface (0.00 m) where the organic content is only 6.5%. Lower-than-average values are also noted between 1.12 and 0.61 m (39.3%), and also at 3.00 and 2.00 m.

Mineralogy

The inorganic portion is characterized by only three minerals throughout the core: quartz, feldspar and a mineral that is amorphous to X-ray radiation. In the XRD patterns, quartz is identified by its 1st- and 2nd-order peaks at 24° 2Θ (= 0.43 nm) and 31° 2Θ (= 0.33 nm), respectively, and feldspar is indicated by its 1st-order peak at 33° 2Θ (= 0.31 nm) (Fig. 6). The amorphous material, which is most probably amorphous silica gel (J. Kirkman, personal communication 1995), is indicated by a "hump" in the XRD pattern. The apex of this hump lies in the vicinity of 26° 2Θ (Fig. 6). Most of the core appears to consist of this material, as its XRD pattern shows a distinct trend with depth. The

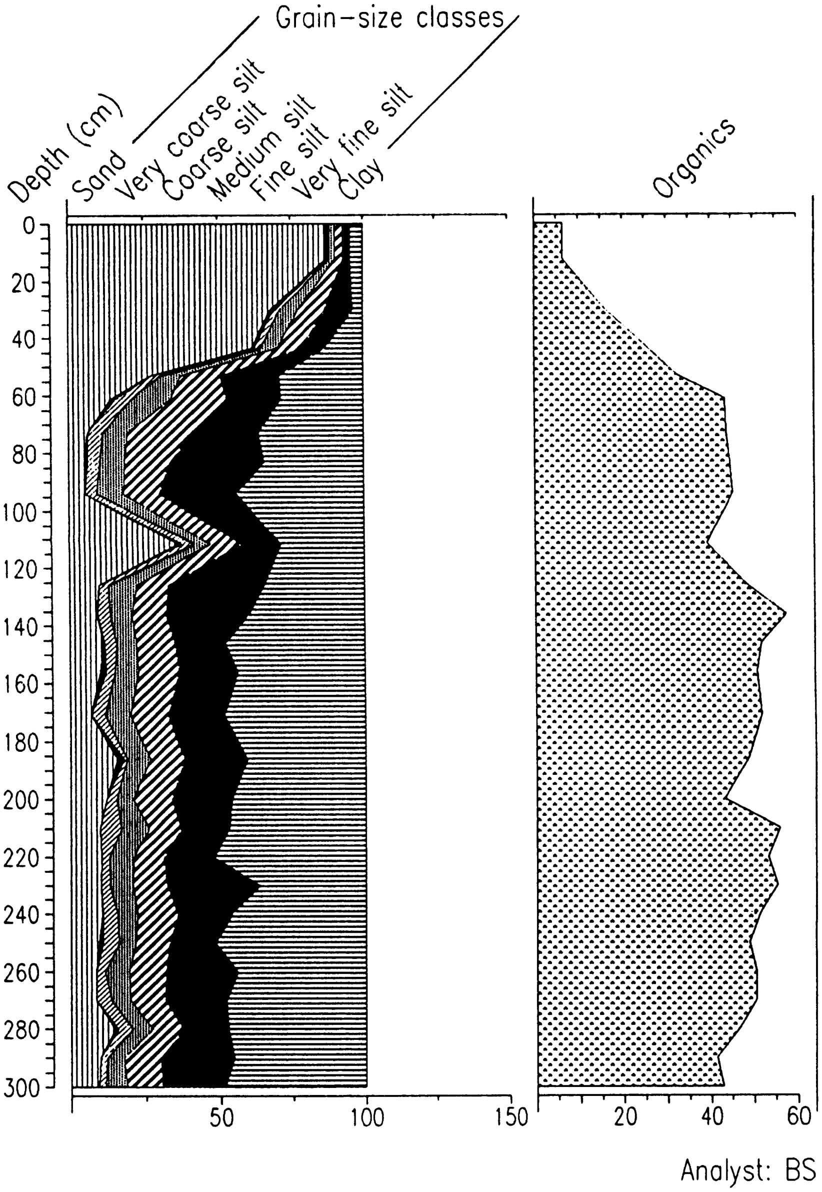

Fig. 5. Grain-size classes and organic matter shown as percentages, Lake Taumatawhana

exception to this pattern occurs in the uppermost section of the core from 0.40 m to 0.00 m, where there is almost no amorphous material. Here the dominant minerals are quartz and feldspar (peaks at 24° 2Θ, 31° 2Θ and 33° 2Θ; see Fig. 6) coincident with extremely low values in the clay fraction (clay content between 0.30 m and 0.00 m of 3.6–4.3%; see Fig. 5). Apart from these three minerals, no other minerals were detected in the XRD patterns despite the relatively high clay content of the core material (Fig. 5). The clay content of the sediment seems to be associated with the amorphous material. From 0.80 to 0.40 m, the clay content decreases steadily from 36.3% to 12.9% with a con-

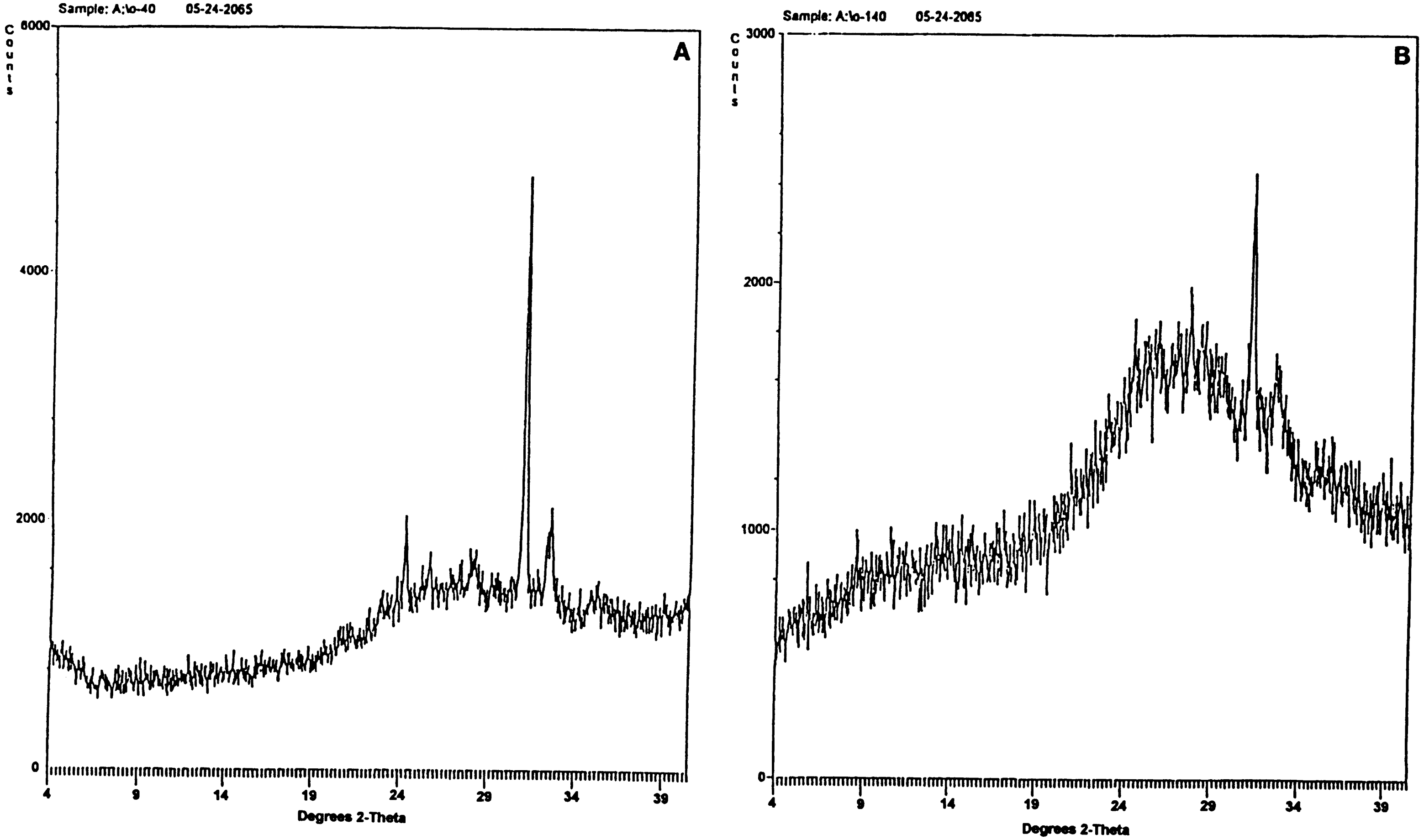

Fig. 6. XRD patterns for sediment mineralogy at 0.40 m (A) and 1.40 m (B), Lake Taumatawhana

current decrease in the amount of amorphous material reflected in a steadily declining hump in the XRD patterns. Further minor fluctuations in the clay content (Fig. 5) are mirrored by the XRD patterns for amorphous material. Microscopic investigation, by point counting, of the sand fraction also revealed an apparent dominance of quartz. The shape of these grains ranges from angular to well-rounded. Apart from quartz, a few iron oxides (probably hematite or magnetite) were also noted. There were also a few feldspars, but in contrast to the mud fraction, their abundances were extremely low; plagioclase feldspars were totally absent.

Chemistry

The elemental assays (Fig. 7) are placed in two main groups, major and minor elements (after Håkansson and Jansson 1983; Mackereth 1965, 1966). Major elements comprise Al, K, Mg, Na and Si. The minor elements are further subdivided into heavy metals elements (As, Co, Cd, Cr, Cu, Mo, Ni, Pb, Sn, and Zn), carbonate elements (Ca and Mg), nutrient elements (P), mobile elements (Fe, Mn and S) and others (B, Se and Sr).

The five major elements show an almost identical distribution pattern of generally consistent "background" concentrations from the base upwards to a depth of 0.75 m. At this depth, increases in concentrations are seen, dramatically so from 0.58 m (Mg excepted) to the surface.

Calcium exhibits several concentration peaks throughout the profile. Peaks are registered between 0 and 0.42 m, at 0.88 m, 1.79 m and 2.39 m. Of the nutrient elements, only phosphorus can be analyzed by ICP-AES. The record for P is stable from the base of the core up to *ca.* 0.70 m depth, from which a rise in concentration is noted, peaking at 0.42 m. Thereafter levels decline. Of the mobile elements, both Fe and Mn show peaks at 0.17 m and 0.42 m. Below this depth, these two elements show reduced but fluctuating concentrations, although Fe has a major peak at 2.99 m. Sulphur behaves somewhat differently. No clear trend is apparent, but peaks in concentration are noted at 0.17 m, 0.42 m, 1.36 m, 2.26 m and 2.99 m. Substantial declines are seen between 0.58 and 0.75 m, at 1.93 m and 2.86 m.

DISCUSSION

Palynology

The pollen record for Lake Taumatawhana extends from *ca.* 5 ka to the present and provides evidence for significant paleoecological changes over time both locally and extralocally. These are summarized in Table 2. Lake formation relates to dune activity and drainage impedance following the attainment of sea level close to present level at *ca.* 6500 BP (Gibb 1986), and the lake has existed for *ca.* 5500 yr. Immediately following lake formation and onset of organic deposition at *ca.* 5 ka, a regional *Agathis australis*–podocarp-hardwood forest dominated the vegetation. This community included all the tall podocarp trees, the most important of which were *Dacrydium cupressinum, Phyllocladus* spp., *Podocarpus totara* type and *Prumnopitys taxifolia. Libocedrus* spp. and *Nestegis* spp. were also significant, and *A. australis* became increasingly dominant from an initial low value. The development of a conifer-hardwood forest through the lower zone is a consequence of increasing stability of the dune environment following sea-level stabilization. Similar trends for *A. australis, D. cupressinum* and *Podocarpus* spp. are reported by Kershaw and Strickland (1988) from a coastal interdune bog in Northland. *D. cupressinum* was a common emergent of the regional forest, and *Podocarpus totara* type was a commonly occurring tree. *A. australis* is regularly under-represented in pollen records (Newnham 1990; Newnham, Ogden and Mildenhall 1993) and thus, its good representation in the present study is significant.

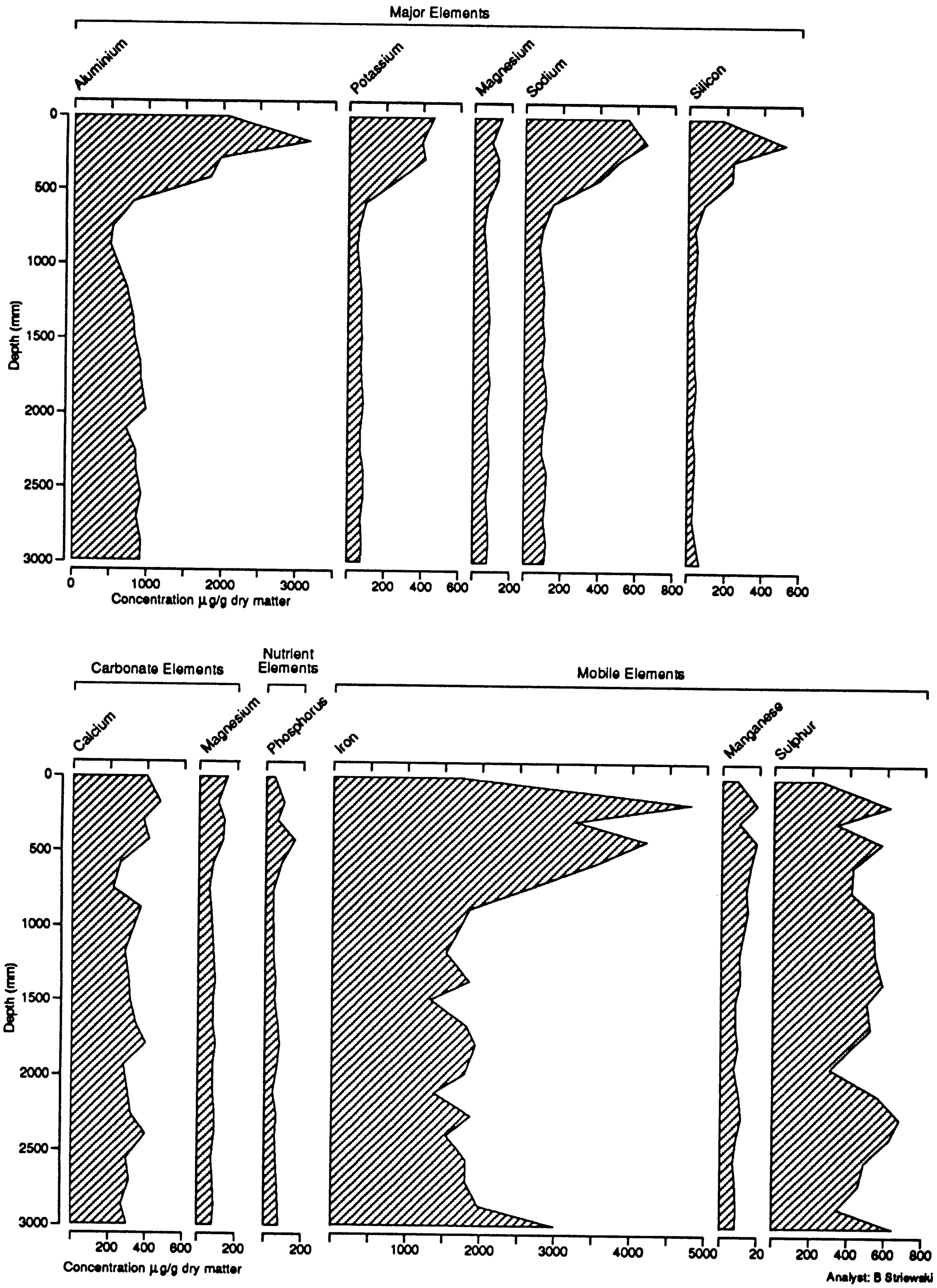

Fig. 7. Chemical stratigraphy for selected elements, Lake Taumatawhana

TABLE 2. Summary of Palynology and Inferred Regional Vegetation since *ca.* 5000 BP

Pollen zone	Yr BP	Key pollen taxa	Regional vegetation	Climate
Ta 1a	150(?) 250(?)	Exotics *Pteridium*-charcoal	Pasture Fernbrake	?
Ta 1b	700 900	*Pteridium*-charcoal Dacrydium	Fernbrake Podocarp-hardwood forest	?
Ta 2	2600	*Dacrydium, Agathis, Libocedrus, Ascarina*	Kauri-podocarp-hardwood forest	Warm, moist
Ta 3	3400	*Dacrydium, Agathis, Libocedrus, Ascarina*	Kauri-podocarp-hardwood forest	Warm, moist, windy
Ta 4	5000	*Podocarpus, Phyllocladus, Agathis, Coprosma*	Kauri-podocarp-hardwood forest	Cooler, drier

McGlone and Topping (1977) describe postglacial climate changes that have some features in common with Zones Ta 4 and Ta 3. After 5 ka BP, northern sites (of the North Island) indicate that *Podocarpus* and *Prumnopitys* became more abundant, responding to a generally harsher climate. This trend is reversed between 3500 and 1800 BP to a more *Dacrydium-cupressinum*-dominated phase (McGlone and Topping 1977) A similar trend can be observed in the Taumatawhana record. The reversion in importance of *D. cupressinum* and *Podocarpus* is accompanied by an increase in abundance of *A. lucida*. McGlone and Moar (1977) report that *A. lucida* was common in the postglacial period from 10 to 5 ka BP, after which a decline in abundance was noted. A period of recovery occurred between 3500 and 1800 BP, when *A. lucida* again became common (McGlone and Moar 1977). This trend is similar to that observed for Taumatawhana and supports the evidence provided by the *D. cupressinum* and *Podocarpus* curves, although these taxa persist for somewhat longer in the time scale. Other Northland pollen diagrams (Kershaw and Strickland 1988; Dodson, Enright and McLean 1988; Enright, McLean and Dodson 1988; Newnham 1992; Newnham, Ogden and Mildenhall 1993) provide a less distinct trend for *A. lucida*. It is likely that drought rather than cold was the limiting factor in the Onepu district given its northern location and the susceptibility of the sand dune communities to moisture deficit.

Drought is also implicated in the cyclic curve of *A. australis,* which requires a rainfall regime between 1000 and 2500 mm per annum for optimum growth (Ecroyd 1982). Windthrow by hurricane(s) during droughtier and windier times could be more devastating on the sand dune country and could account for the destruction of hundreds of kauri (*Agathis australis*) trees at a time (Ecroyd 1982). Under such circumstances, mass synchronous regeneration of *A. australis* under the cover of *Leptospermum*/*Kunzea* scrub could lead to even-aged stands (Ecroyd 1982; see also Ogden 1985 and Ogden *et al.* 1992). Evidence for drier and windier conditions in far northern New Zealand during this period has been advanced by Enright, McLean and Dodson (1988), and Dodson, Enright and McLean (1988).

The most significant change in the pollen record occurs at the boundary between Zones Ta 2 and Ta 1b. A decline of all arboreal taxa is observed, accompanied by sharp rises in the curves for *Pteridium esculentum*, the aquatic species of the Cyperaceae and Restionaceae families, as well as *Typha*. The charcoal influx follows the same trend as *P. esculentum*. Elevated values for *Coriaria* at this time are also significant. This shrub is considered to be an aggressive, early colonizer of fire-cleared landscapes (Wardle 1991). Features of this nature have been recorded at many other sites in New Zealand (Mildenhall 1979; McGlone 1978; McGlone, Mark and Bell 1995; Chester 1986; Elliot, unpublished data). The association between Polynesian deforestation and these features in pollen records is now well established (McGlone 1983, 1989). McGlone, Anderson and Holdaway (1994) propose that such widespread deforestation began *ca.* 600 years ago with a small number of sites dated between 700 and 800 BP. Few sites have been dated rigorously to provide an unambiguous chronology. Analysis of ^{14}C dates associated with moa hunting (Anderson 1989, 1991; Anderson and McGovern-Wilson 1990) suggests human presence after 800 BP. A few dates before 1 ka BP are considered questionable by these authors. ^{14}C dates (NZA-3819 and -3882) bracketing this event in our study indicate that significant anthropogenic disturbance first occurred some time after *ca.* 900 BP (800 cal BP), and by *ca.* 700 BP (600 cal BP), major forest clearance had taken place from which the local/extralocal vegetation has never recovered.

The possibility of old soil carbon inwash exists after forest clearance (Pennington *et al.* 1976). This is probably shown in the dating inversion exhibited by NZA-3920 and -3823 when compared with NZA-3882 (Fig. 2). The dates provided by NZA-3819 and -3882, which indicate the period of first human impact, are not considered to be contaminated in this way.

Sedimentology

The granulometric composition of the Lake Taumatawhana sediments shows two distinct changes in the sand fraction (Fig. 5). The first peak occurs at 1.12 m and the second between 0.61 m and the sediment surface. The coarse granulometric nature of these peaks indicates the high energy level of the depositing medium (Reineck and Singh 1975). Thus, the constituent particles of these peaks must have been deposited during periods of increased erosion.

Pollen data from Zone Ta 1b 1.12-0.30 m and Zone Ta 1a 0.30 m to surface (Figs. 3, 4) suggest that these periods of increased erosion can be attributed to human influence in the form of deforestation. This contention is also supported strongly by the trend of the organic matter content down the core (Fig. 5). Organic-matter content declines sharply at 1.12 m, and also between 0.61 m and the sediment surface. This is thought to represent deforestation accompanied by an increased inwash of (coarse) inorganic matter. Dawson (1990) attributed similar features to periods of increased erosion in lake sediments on Mangaia, Central Polynesia.

The relative abundance of the amorphous material throughout this core is considered a pedological rather than a human-induced feature. The amorphous material forms in the silica-rich sandy parent material of the dune system within which this site is located. Under complete saturation, silica dissolves, and, on reaching the solubility product, it precipitates as amorphous material (J. Kirkman, personal communication 1995). The general tendency of a high content of amorphous material varies only at depth ranges that show markedly higher sand and lower clay contents (Fig. 5).

The chemical stratigraphy of the Taumatawhana core can best be explained if the inorganic fraction of the sediment is regarded as a sequence of soils derived from the lake catchment. The composition of the residues finally reaching the lake bed reflects erosional activity within the catchment or in the lake itself (Mackereth 1966). The chemical composition of the sediments in general does not appear to be subject to alterations due to in-lake processes, although some elements are more or less susceptible to postdepositional modification or predepositional leaching processes within the soils of the catchment, especially phosphorus, sulphur, iron, manganese and calcium (Mackereth 1966).

Elements showing a firm association with the soil and sediment mineral matter seem to reflect the erosive processes within the catchment, eventually leading to the deposition of material into the lake. Because of their abundance in mineral matter, the distribution of major elements (Al, K, Mg, Na and Si) in the lake sediments seems to best reflect the erosional history of the catchment. Of those elements in particular, sodium and potassium are clearly associated with the mineral fraction of the sediment rather than with the organic material (Mackereth 1965, 1966). Both elements show sharply rising concentration values from 0.58 m to the water-sediment interface. The strong relation between the mineral content of the sediment and the Na-K concentration implies that these features are directly proportional to the intensity of erosion to which the catchment was exposed when the sediments were deposited. Thus, the high concentration of K and Na immediately below the surface suggests a period of extremely high erosion within the catchment which continues into the present.

This contention is strongly supported by the chemical stratigraphy of aluminium, magnesium and silicon, which also belong to the group of major elements. Apart from a few minor fluctuations in element concentration within the range 2.99–0.58 m, their overall pattern is almost identical to Na and K. Increased values for phosphorus in the upper 0.60 m of the core coinciding with the major elements may also be related to more intensive erosion, although P is often implicated in biological activity.

The chemical stratigraphy suggests that the erosional history at this site can be divided into two main periods. A period of relatively stable conditions reflected by low rates of erosion existed throughout much of the history of the lake. This is characterized by low elemental concentrations in the sediments. With decreasing depth, the concentration of all major and many other elements starts to increase markedly. While the stratigraphic position of this onset of increasing concentration values is not uniform, the trend is generally initiated between 0.75 and 0.58 m. Thus, 0.75 m marks the boundary between a change from stable to unstable conditions characterized by intense erosional activity.

CONCLUSION

Palynological analysis of sediments from the Lake Taumatawhana site indicates that this region of northern New Zealand has been sensitive to environmental and climate changes throughout the late Holocene. Pollen spectra indicate that while warmer and wetter conditions prevailed from *ca.* 3400 to at least 2000 BP, increased windiness was also a feature of the regional climate. However, the most significant event of the late Holocene has been that of human impact commencing after *ca.* 900 BP (800 cal BP). The coincidence of forest decline, a sharp rise in the incidence of *P. esculentum* and charcoal influx together with related changes in the sedimentological history, which are not evident prior to deforestation, provide the strongest argument for major human-induced environmental change. The date of *ca.* 900 BP (800 cal BP) is somewhat earlier than 700 BP suggested previously.

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