

LATE QUATERNARY VEGETATION
HISTORY OF CENTRAL NORTH ISLAND,
NEW ZEALAND.

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ABSTRACT

23 sites in the central North Island of Otiran and Aranuiian age (Last Glaciation and post-glacial) were pollen analysed. Three regions were examined in detail: Taranaki, Taupo-Tongariro and Bay of Plenty.

For most of the Otiran period (c. 70 000 BP-14 000 BP) the central North Island was covered with scrub-grassland communities. Forest was scarce and scattered. Within this period two major interstadials are recognized.

During an early Otiran interstadial, which reached its maximum at about an estimated 60 000 BP, both podocarp-hardwood forest and *Nothofagus* forest were abundant. Although perhaps 2°C cooler than present, the climate seems to have been mild and moist during this period.

A second interstadial lasted from about 45 000 BP to 25 000 BP. It was a time of diverse vegetation and climates. Although scrub was the dominant vegetation over most of the region, there were substantial areas of podocarp-hardwood forest, *Nothofagus* forest and also some grassland. In some localities it appears that all these vegetation types co-existed. Forest was most abundant from 32 - 27 000 BP. The climate was considerably cooler than that of today with mean annual temperatures up to 4°C lower. Rainfall was lower than at present, but still adequate for podocarp forest growth in some regions.

From after 25 000 BP until 14 000 BP grassland/scrubland associations were almost totally dominant. Some forest survived throughout this period, but mainly in hilly and mountainous regions. The grassland/scrubland associations appear to have been very uniform throughout, and there is no evidence for better developed vegetation

in the northern regions. The climate was much cooler than today, perhaps 5°C cooler but, more importantly, appears to have been harsh and variable. Rainfall was much lower than at present, especially in the east.

In Taranaki, forest dominated by *Podocarpus spicatus* replaced grassland between 13 000 and 12 000 BP. At about 10 000 BP *Dacrydium cupressinum* and *Ascarina lucida* became abundant and remained so until about 5000 BP. After this date *Ascarina* declined while *Knightia excelsa* and *Dacrydium colensoi* spread. After 3000 BP *D. colensoi* became scarce and today is no longer found in the region.

In Hawkes Bay *Podocarpus spicatus/totara* forest replaced the previous grass and scrub communities by 10 000 BP, but probably not much earlier. These forests remained dominant with only minor changes until the Polynesian burnings of the last millenium.

The early Aranuian (14 000 - 10 000 BP) was drier than present, but rainfall was adequate to support podocarp forest in most places, except the drier east coast districts. Increase in rainfall, rather than the well-attested Aranuian warming, was the main reason for the spread of forest. The period from 10 000 BP to 5000 BP was the mildest and wettest of the last 70 000 years. Since 5000 BP there has been a drift to a cooler, droughtier climate.

PREFACE

In this dissertation I have attempted, mainly by means of pollen analysis, to provide an outline of the vegetation history of the Otiran (Last Glaciation) and the Aranuiian (post-glacial) for the central North Island, New Zealand.

For the purposes of this study the central North Island is defined as that area lying south of Port Waikato and the Coromandel Range, and north of Wanganui and Waipukarau; that is between the latitudes of $37^{\circ} .30'$ and 40°S . (Figure 1).

The central North Island was chosen for this study mainly because of the availability of sites in known stratigraphic contexts. The region has five active volcanic centres, and an abundance of widely dispersed tephras. As a result of recent work by soil scientists and geologists the chronology and stratigraphic relationships of these tephras is well understood, and work on the relationship of the tephra to other Quaternary events is progressing. Most of the sites analysed here were brought to my attention by geologists working in the central North Island. To a very large extent this study is the result of close collaboration between these workers and myself. The contributions of my co-workers are outlined in the acknowledgements.

A conscious decision was made at the start of this project to try and obtain a wide spread of sites within the study area, and to cover as completely as possible the time range chosen. Because of this no one area or site has been given exhaustive treatment. I felt, and still feel, that the primary need of Quaternary studies in New Zealand at present is a broad overview of the long-term changes in the vegetation and landscape. There is much scope for further research in the central North Island, especially in relation to the effects of volcanic

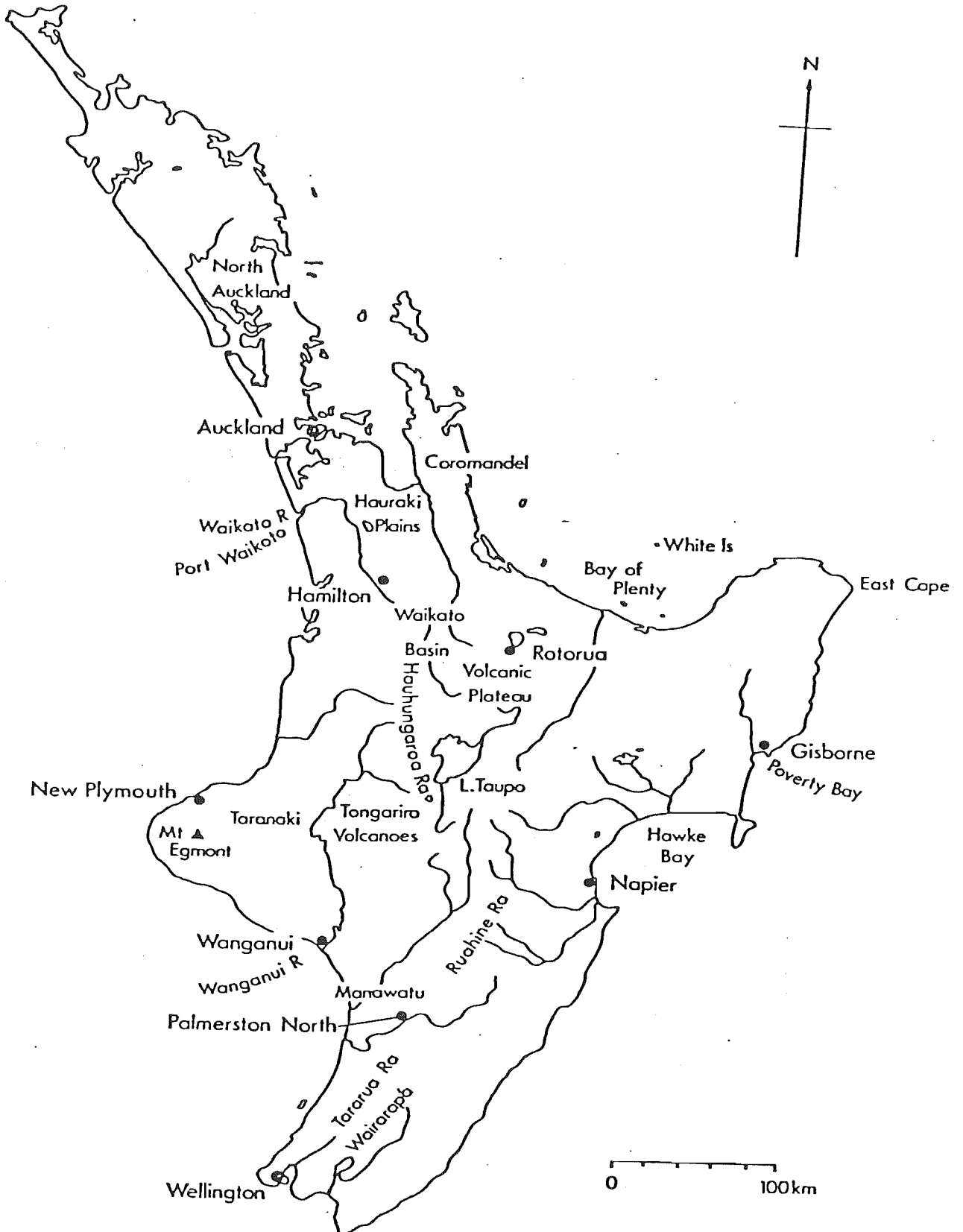


Figure 1. North Island of New Zealand

eruptions on the vegetation.

I have made an attempt to interpret the vegetation history in terms of climatic change. As there is only a small amount of information available concerning the distribution of New Zealand plants and even less about their relationship to climatic factors, this attempt is bound to prove somewhat unsatisfactory. However, the lingua franca of Quaternary studies is climate and therefore the attempt must be made. Without some translation into climatic equivalents the results of this work would become incomprehensible to a large number of Quaternary workers.

Following Moar (1971) I have abandoned the use of the terms 'Holocene' and 'Post-glacial' in favour of the New Zealand stage name 'Aranuian'. The same applies to the term 'Last Glaciation' which is replaced, when reference is made to the New Zealand sequence, by 'Otiran'. The term 'post-glacial' is retained for informal use. The Otiran/Aranuian boundary is taken as being 14 000 BP (Suggate & Moar 1970). As the Otiran is defined in terms of the South Island glacial sequence, and as there is no direct correlation between the North and South Island sequences, I have chosen the Inaha Marine Bench to act as the lower time plane (see section 5.2.1). The Inaha Marine Bench was cut during the last high sea level of the Last Interglacial: the first terrestrial sediments deposited on this surface are considered to belong to the Otiran. The upper time plane is the Taupo Pumice Formation (age c. 1800 BP). It is a widespread, easily recognized tephra that provides a convenient marker horizon close to the present, but outside the time range of human occupation in New Zealand. The arrival of Polynesian man in New Zealand, sometime before 1000 BP, led to extensive destruction of forest in the central North Island. This cultural disruption of the vegetation cover, and associated environmental change is not dealt with

here.

All radiocarbon dates are given in years before present (1950), abbreviated to 'BP'. Dates are calculated according to the 5570 year half-life.

Botanical nomenclature follows Allan (1961) and Moore & Edgar (1970), with the following exceptions (old name in brackets):

Dacrycarpus dacrydioides (*Podocarpus dacrydioides*)

Empodisma minus (*Calorophus minor*)

Nestegis (*Olea*)

The first two chapters of this dissertation give a brief introduction to the physical and biological environment of the central North Island. Some further details are given in the chapters dealing with a particular region. Chapter 3 deals with the methods employed in the collection, preparation and analysis of the pollen samples. It also discusses the derivation of the pollen sum and the layout of the pollen diagrams. Chapter 4 is a discussion of pollen representation in relation to vegetation. Chapters 5-9 give the results of the pollen analysis of sites region by region. Within each chapter the results from the individual pollen diagrams are discussed together, and a vegetational and climatic history attempted.

Chapter 10 is a general discussion of the results from all regions, and a synthesis is made in the light of previously published work on the vegetation history and Quaternary geology of the North Island. Chapter 11 compares the results from the North Island with those from other selected Southern Hemisphere regions, namely South Island, New Zealand, Australia and New Guinea, and Chile. This discussion is limited to southern regions because it is still possible to give a reasonably detailed account of this area. It is also reasonable to assume that these regions were affected by the same broad weather

systems, and are thus likely to show similar patterns of change. The Quaternary literature from the Northern Hemisphere is vast and it is not possible to do justice to it in a necessarily brief discussion.

CHAPTER 1

PHYSICAL ENVIRONMENT OF THE NORTH ISLAND

1.1 GEOGRAPHY AND GEOLOGY

1.1.1 General

There are three major elements of the landscape of the central North Island (Figure 2). First, the rugged axial mountain chain running from north-east to south-west across the island. Second, the extensive, less high, but no less rugged plateau of volcanic rocks that occupies the centre of the region. And third, the lowlands, most extensive in the Waikato and western Taranaki regions, but present as smaller areas in the Bay of Plenty, Hawkes Bay and along the Wanganui coast. The lowlands are almost entirely made up of recent Quaternary sediments.

The landscape is young and geomorphic processes are active. The oldest group of rocks are the greywackes and argillites of Jurassic to Permian age, and it is these that form the axial mountain ranges. The mountains average about 1400 metres in height and are undergoing rapid uplift. As a result there is extensive erosion, and the rivers that drain the mountains often have broad beds and braided channels. To the east and west of the axial mountain chain are younger Tertiary and Quaternary sediments, predominantly soft mudstones and siltstones. These rocks are very susceptible to erosion and in many districts, notably inland Taranaki and Wanganui, this has led to a very dissected landscape.

The Volcanic Plateau, as the extensive area of volcanic rocks and landforms is known, is mostly above 300 metres in altitude with much land lying higher than 600 metres. At the southern end of Lake Taupo, which is itself a volcanic caldera, are the Tongariro Volcanoes, one of which, Mt Ruapehu, is, at 2800m, the highest peak in the North

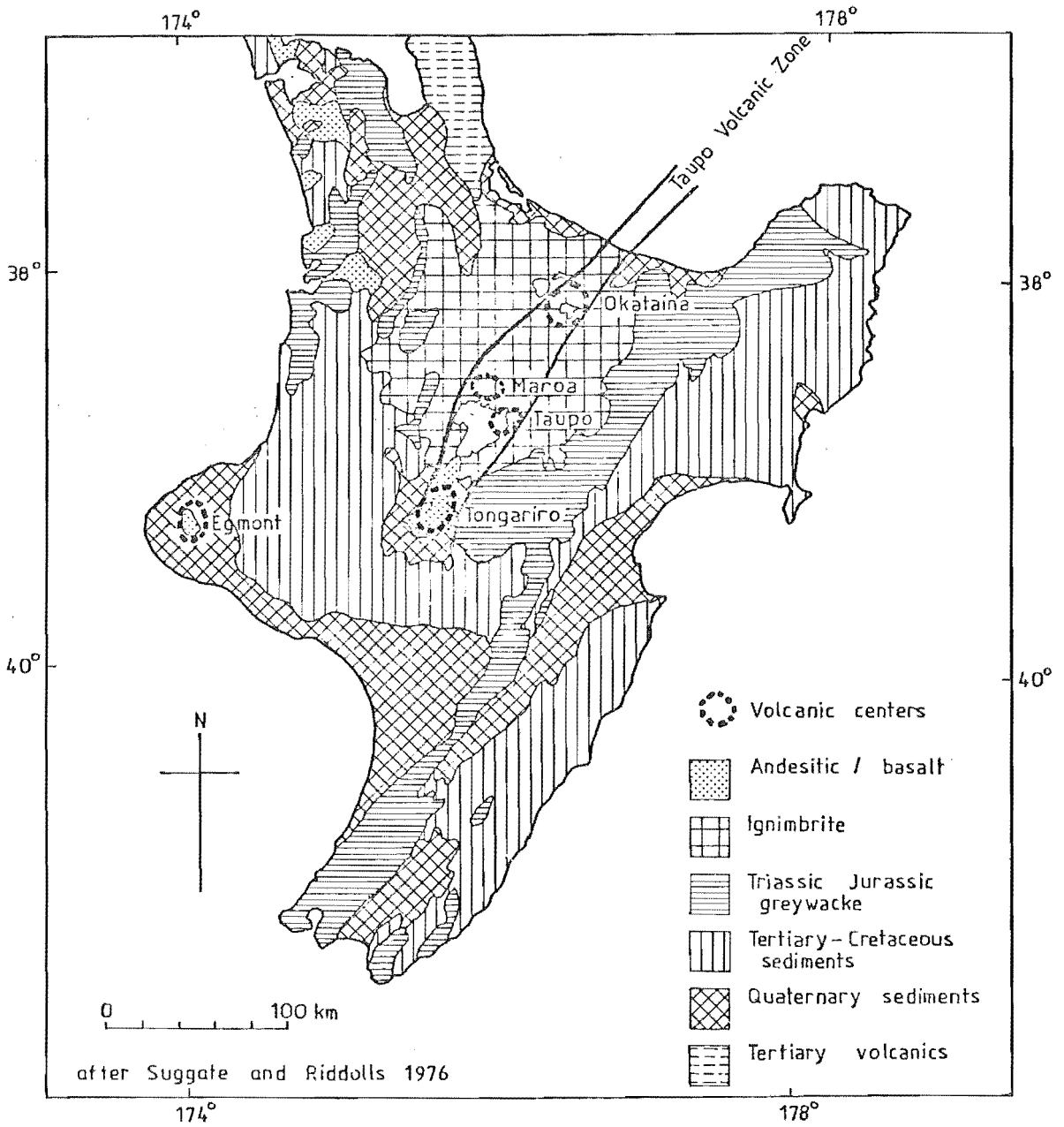


Figure 2. Geology of the North Island

Island. The Volcanic Plateau is largely the product of vast ignimbrite flows from the narrow, north-east trending zone of volcanic activity that extends from Ruapehu in the south to White Island (Bay of Plenty) and beyond in the north. Continual activity in this zone, which is known as the Taupo Volcanic Zone, throughout the Quaternary has blanketed most of the surrounding regions with thick sequences of ash and breccia flow deposits which overlie the older ignimbrite sheets. Activity in the zone has affected more distant regions also, mainly through the deposition of large quantities of ash at irregular intervals of time. The Waikato River, which has its headwaters in the Volcanic Plateau, has been particularly affected by volcanism (Schofield 1965). Much of the Waikato Basin is covered with thick deposits of rhyolitic ash derived from eruptions on the Plateau.

Even where there has not been direct transport of ash down a river system, the widely dispersed ashes have provided the main soil-forming material over much of the central North Island. Only in steepland areas and regions to the south-east, away from volcanic influence, do soils formed exclusively from non-volcanic rocks predominate (Gibbs *et al* 1968).

1.1.2 Tephra

Tephra is defined as pyroclastic material transported through the air (Thorarinsson 1954), but in New Zealand the term has been broadened to include tephra flows and flow breccias derived from *nuée ardente* eruptions because they grade into, and are difficult to separate from, true airfall deposits (McCraw 1975).

Numerous volcanic vents are, or have been active, in the central North Island during the late Quaternary, and these can be grouped into four main clusters or centres (Figure 2). Three of these, the Okataina,

Maroa-Taupo and Tongariro Centres, lie within the Taupo Volcanic Zone (Healy 1964b). The other centre, Egmont, is isolated to the west in Taranaki. Volcanic eruptions from the Okataina and Maroa-Taupo Centres are mainly rhyolitic, paroxysmal, extremely large and infrequent, occurring at intervals of thousands rather than hundreds of years. Rhyolitic volcanoes typically form low-lying volcanic structures, often creating large calderas that form lakes. Most of the relief in a region of rhyolitic volcanism is provided by associated faulting and sporadic cone or dome construction by other types of volcanic activity. Volcanic activity in the Tongariro and Egmont Centres is entirely andesitic (Neall 1974; Gregg 1960), typically producing small, only moderately violent, frequent eruptions. Andesitic volcanoes are usually cone shaped and often very tall. Ruapehu, Ngauruhoe and Egmont, all andesitic volcanoes, are the tallest mountains in the North Island.

As a result of volcanism, most regions within the central North Island have suites of identifiable, discrete tephra beds. Andesitic tephtras are in general not widely dispersed and are therefore of limited use in correlation: rhyolitic tephtras are often widely distributed and can form thick, discrete layers many hundreds of kilometres from source. For this reason most of the tephtras used for correlation in this work are rhyolitic tephtras from Okataina and Maroa-Taupo Centres. Pullar *et al* 1973 give a comprehensive list of named tephtras occurring in the central North Island. Table 1 presents a selective list of the more widespread tephtras that are of especial importance for correlation in this study.

1.1.3 Glacial and loess deposits

As far as is known, permanent ice formed in only two localities in the North Island during the peak of the Otiran - on the highest points of the Tararua Ranges (near Wellington) and the Tongariro Volcanoes (Te Punga *et al* 1973). Mount Egmont, the only other area in the North

TABLE 1WIDESPREAD TEPHRAS

<u>FORMATION</u>	<u>APPROXIMATE AGE (BP)</u>	<u>SOURCE</u>
Taupo Pumice	1800	Taupo
Waimihia Lapilli	3400	Taupo
Whakatane Ash	5200	Okataina
Hinemaiaia Ash	5100	Taupo
Rotorua Ash	13 500	Okataina
Kawakawa Tephra (also known as: Oruanui Formation; Aokautere Ash).	20 000	Taupo
Mangaone Tephra	30 000	Okataina
Rotoehu Ash	42 000?	Okataina

Data from: Pullar et al (1973); Howorth (1975).

Island that is high enough to have had an ice field, has no glacial deposits or landforms. However, there is good reason to believe that the Egmont cone is relatively young (probably the main section of the cone is no more than 7000 years old) and therefore was not in existence during the Otiran (Neall 1974).

Glacial activity in the Tararua Ranges was restricted to five locations along the main ridges. In each case small cirque glaciers formed in south to south-west facing valleys with floors averaging about 1000 metres in altitude (Stevens 1974). Evidence for glaciation of the Tongariro volcanoes is discussed in section 7.1.2.

There are extensive loess deposits in the southern half of the central North Island, especially in Hawkes Bay (Cowie & Milne 1973). Surface deposits are not common in the central area as they are buried by the abundant post-glacial tephra formations. However, numerous loess deposits are found as wedges of tephra-derived silt between layers of late and middle Otiran tephras. Loess is not found further north than Rotorua (see Map 11, Fleming 1975). Loess was deposited at various periods throughout the Otiran in the south-west of the North Island, but deposition ceased by about 12 000 B.P. (Milne 1973). Loess deposition on the Volcanic Plateau ceased before 14 000 B.P. (McGlone & Topping 1977).

1.2 CLIMATE

This section is based on accounts of the climate in Coulter (1975) and Tomlinson (1976). Figures 3 and 4 give basic climatic data.

The lowland climate of the central North Island is mild and humid. At sea level the annual mean temperatures range from about 14.5°C in the north to about 12.5°C in the south. Frost is very variable in both distribution and frequency, being strongly dependent on local

after Tomlinson (1976)

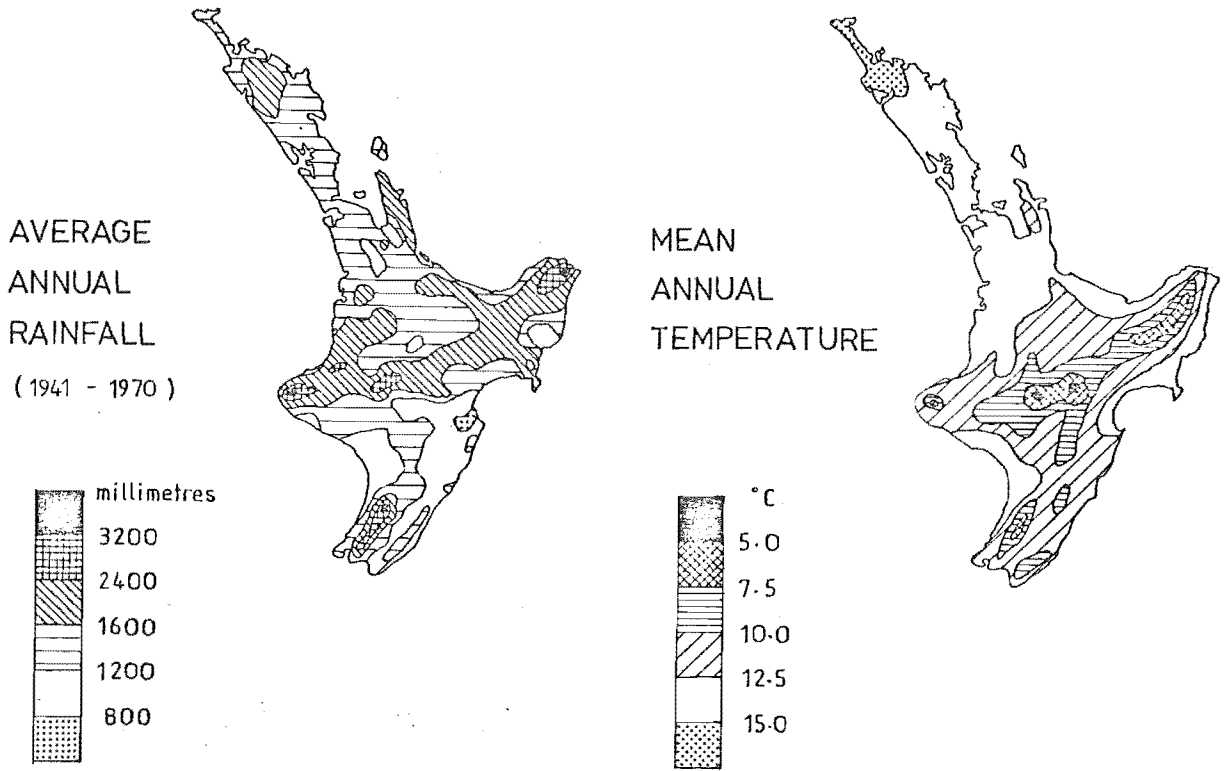


Figure 3. Rainfall and temperature maps for the North Island

Climatic Zones

after Tomlinson (1976)

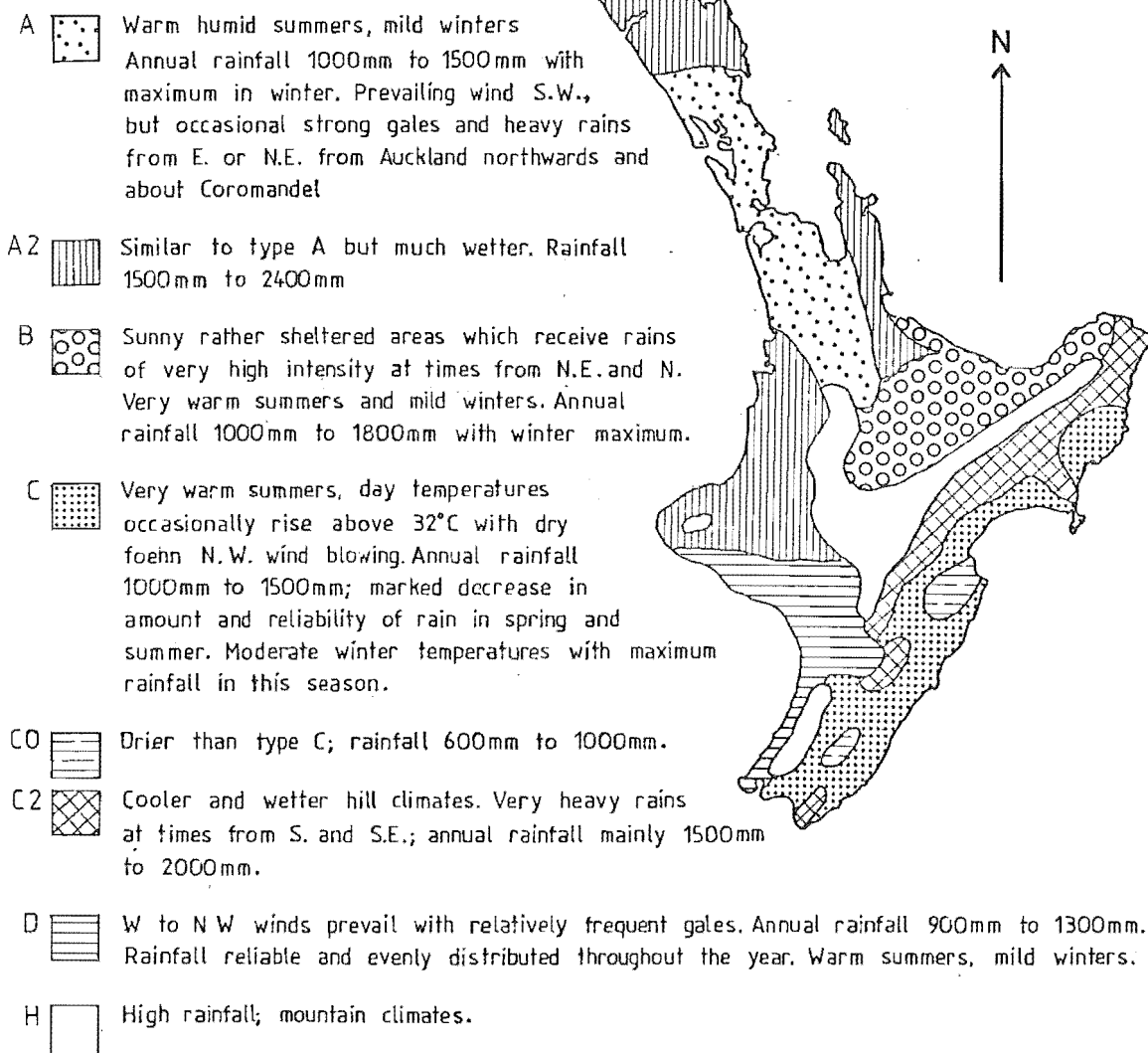


Figure 4. Climatic zones of the North Island

topography. For areas below 300 metres there are generally fewer than thirty days of frost per year. Snow is rare below 500 metres. Rainfall is high and usually adequate for plant growth all year round. Average annual rainfall over the greater part of the region is between 2400mm and 800mm per annum. Drought only rarely inhibits plant growth in most areas and "agricultural droughts" (defined as beginning whenever calculated soil moisture is exhausted, and ending when a day's rainfall in excess of the daily potential evapotranspiration is recorded) are recorded, on average, less than 50 days per annum in most districts. In the east of the central North Island there are generally between 50 and 100 days a year of agricultural drought, and in Hawkes Bay more than 100. The prevailing winds are from the west; south-west windflows are the commonest over most of the region.

The upland climate, that is the climate of those areas above 300 metres, is quite different. Rainfall is much higher. On the higher ranges it can be more than 3000mm per annum, and in some places in excess of 6000mm per annum. Snow is relatively common above 600 metres, but rarely lies for more than a few days at a time, except at altitudes of more than 1500 metres where it can lie for most of the winter. Permanent snow and ice occur above 2500 metres on Mount Ruapehu which has the only permanent snow field in the North Island.

CHAPTER 2
VEGETATION

The region included in this brief survey extends from just south of the Auckland Isthmus to the southern tip of the North Island. The pre-European distribution of the major forest types is given in Figure 5.

The major vegetation formations in the North Island before the arrival of man were forest, scrub, grassland and mire communities. Forest, in one form or another covered most of the landscape. Areas occupied by the last three categories were of limited extent. Aside from its occurrence in successional communities, scrub was found only at or near tree line, in some mires and in exposed coastal areas. Grassland was dominant above tree line on some of the higher ranges, and in a few high altitude valleys. Mires occupied extensive areas, mainly in low-lying basins and plains.

The pattern and composition of the indigenous forests of New Zealand is complicated, and defies any simple analysis. Most classifications are based on the recognition of four major species groups: podocarps or softwoods (generally including only the tall forest trees); hardwoods (often referred to as broad-leaved angiosperms), that is all dicotyledonous trees excluding *Nothofagus*; *Nothofagus*; and, as a separate category, *Agathis australis*. Pure, or near pure, associations of all these four types of forest exist. *Agathis*, which is found only in the northern portion of the central North Island, can form limited areas of forest in which it is the major canopy species (Nicholls 1974). Some podocarp trees, in particular *Podocarpus spicatus*, *P. totara*, and *Dacrycarpus dacrydioides* are found in dense stands on alluvial soils or fertile hill slopes. Such stands are especially common in those regions of the North Island affected by recent volcanism (Nicholls 1963;

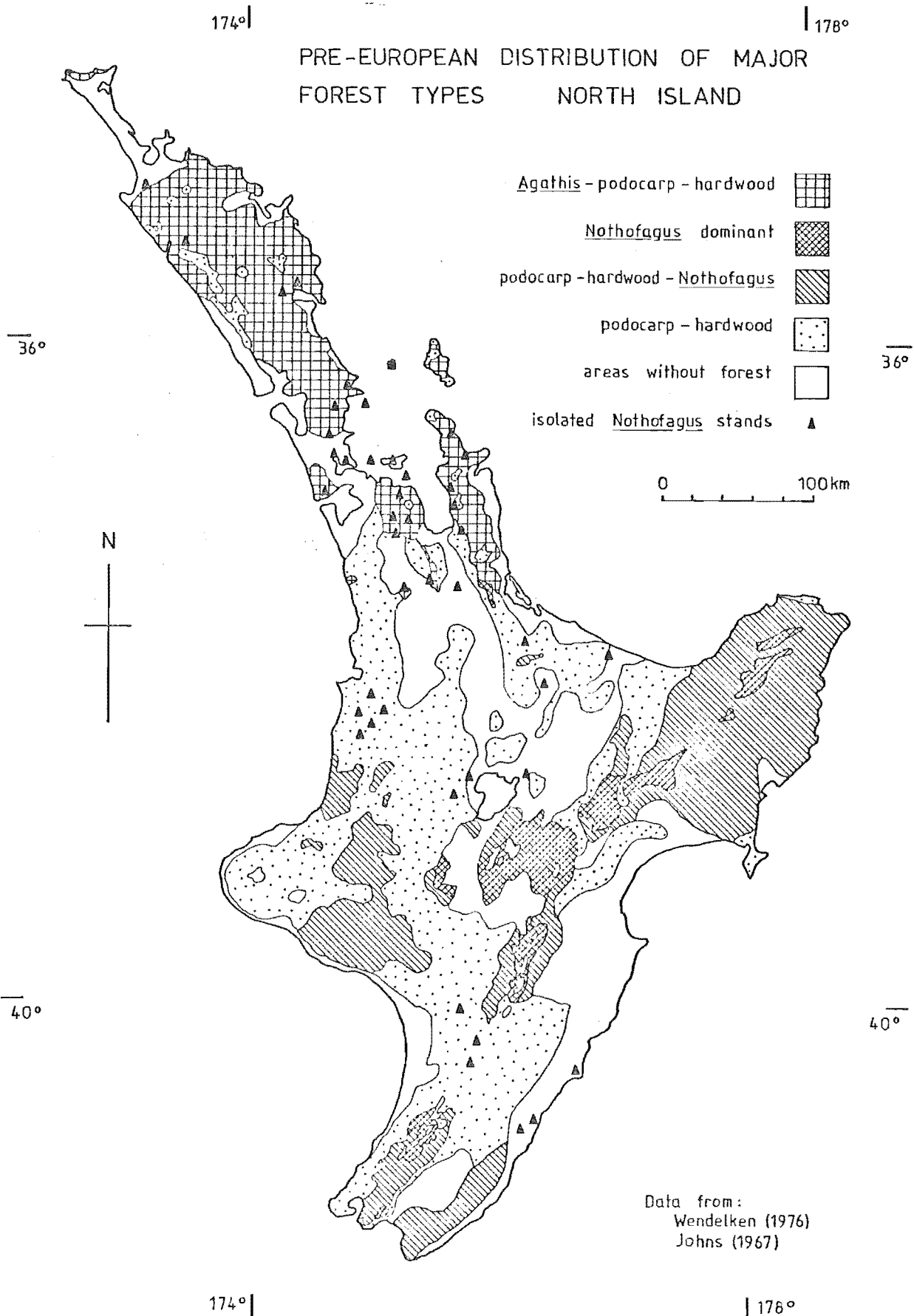


Figure 5. Pre-European distribution of major forest types, North Island

McKelvey 1973). At high altitude on the axial ranges, large tracts of pure *Nothofagus* forest, mono-specific or with a mixture of species, are common (Wardle 1970). Pure hardwood stands, except in cases of regenerating forest, are not common: coastal and some high-montane associations were perhaps the only forest types regularly free from either podocarp or *Nothofagus* associates. Most forest consisted of a mixture of the four species groupings, and a very wide range of mixed forest types occur. Nicholls (1974) estimates that there are about 300 more or less clearly defined forest types in the country as a whole. Only the most widespread and commonly-found associations can be dealt with here.

The most important forest grouping in the North Island is composed of a combination of podocarps and hardwoods. There are many forest types in this group, but a typical structure can be described (Robbins 1962). Mostly the podocarps do not form dense stands; often just a few, tall (20-40 metre) individuals stand emergent. Below them is a closed canopy of dicotyledonous trees together with some of the taller tree ferns. Epiphytes grow on many of the larger trees, and a profusion of lianes drape both emergents and canopy trees. Below the main canopy are further poorly-defined subcanopies consisting of poles of the main tree species, small trees, shrubs and tree ferns. The ground cover is often dense, with a great variety of ferns, seedlings, herbaceous angiosperms and mosses etc. The specific composition of these podocarp-hardwood forests varies from north to south, from coastal to inland areas, with altitude and with soil type.

In areas below 800-900 metres, the principal podocarp tree is *Dacrydium cupressinum*: important secondary species are *P. totara*, *P. spicatus*, *P. ferrugineus* and *Dacrycarpus*. *D. cupressinum* is not abundant in areas subject to drought, nor on light free-draining soils

and tends to be supplanted by *P. totara* or *P. spicatus* in such situations (Franklin 1968). Only a partial list of the hardwood trees and shrubs commonly found in these forests is given here. The major canopy trees are *Weinmannia racemosa*, *Beilschmiedia tawa*, *Metrosideros robusta*, *Elaeocarpus dentatus*, *Knightia excelsa* and *Laurelia novae-zelandiae*. Some of these hardwood species can grow to be very tall, especially *M. robusta* and *L. novae-zelandiae*, and like the podocarps become emergent. There is a multitude of smaller trees and shrubs including: *Pennantia corymbosa*, *Nestegis* spp, *Paratrophis* spp, *Alectryon excelsus*, *Hedycarya arborea* and *Griselinia littoralis*. All of these can be found in the subcanopy and some are regularly found as canopy species. *Melicytus* spp, *Pseudowintera* spp, *Myrsine* spp, *Coprosma* spp, *Geniostoma ligustrifolium*, *Fuchsia excorticata*, *Aristotelia fruticosa*, *Pseudopanax* spp, *Olearia rani*, *Brachyglottis repanda* and *Pittosporum* spp are small trees or shrubs common in the lower layers of the forest or, as seral species on the forest margins. Epiphytes include herbaceous species such as *Astelia solandri*, *Collospermum* and several orchids, some shrubs (*Griselinia lucida* and *Senecio kirkii*), and a wide range of ferns and a lycopod, *L. billardieri*. Lianas and scramblers are common. Among the most common are: *Tetrapathaea tetrandra*, *Parsonsia* spp, *Freycinetia banksii*, *Muehlenbeckia australis*, *Ripogonum scandens*, *Clematis* spp, *Metrosideros* spp and *Rubus* spp.

With increasing altitude many of the common lowland species become rare and, in the absence of *Nothofagus*, are replaced by other podocarp and hardwood species. Above 900 metres the podocarps usually encountered are *Podocarpus hallii*, *P. ferrugineus*, *Phyllocladus alpinus*, *Dacrydium bidwillii*, and *D. biforme*. Along with these podocarps are found *Weinmannia racemosa*, *Griselinia littoralis* and *Quintinia serrata*

among others. In the upper montane and subalpine zones the forest is low and generally has only one tree stratum. In the absence of *Nothofagus*, *Libocedrus bidwillii* is often important and subalpine scrub species begin to play an important role.

Coastal hardwood forests are usually low in stature and contain a distinctive suite of tree species. At the coast (and also at particularly favourable locations inland) *Dysoxylum spectabile*, *Myoporum laetum*, *Corynocarpus laevigatus*, *Macropiper excelsum*, *Rhopalostylis sapida* and *Dodonaea viscosa* are common additions to the tree flora. North from about the latitude of New Plymouth in the west, and Gisborne in the east, *Metrosideros excelsa* becomes increasingly common as a dominant in coastal forest.

Nothofagus forest, in association with hardwood or podocarp-hardwood forest, or alone, is the other extensive forest type in the North Island (Figure 5). Pure *Nothofagus* forest, mainly *N. cliffortioides*, *N. fusca* or *N. menziesii*, is mostly found on the higher areas of the southern mountain ranges of the North Island, the main areas being on the axial ranges stretching from East Cape down to Wellington. The associated flora of pure *Nothofagus* forest is typically quite sparse - mainly shrubs and small trees such as *Griselinia littoralis*, *Pseudopanax colensoi*, *Cyathodes juniperina*, *C. fasciculata* and *Coprosma* spp.

Below altitudes of 600 metres, *Nothofagus* rarely forms pure tracts of forest. More commonly *Nothofagus* is found in close association with podocarp-hardwood forest. In some places this is a mixed association, with perhaps *N. fusca* and *D. cupressinum* the dominants over a hardwood canopy (often of *Beilschmedia tawa*); in others, ribbons of pure *Nothofagus* forest occupy the ridges while the slopes and valleys have hardwood or podocarp-hardwood forest. In general, the more difficult the site, the lower *Nothofagus* descends from the ridges (McKelvey 1973).

Forests of these types - broadly classified as podocarp-hardwood/*Nothofagus* - cover extensive regions of the Wellington-Wairarapa district, inland Taranaki, and East Cape. *Nothofagus* also is found scattered throughout the length of the North Island as isolated patches of forest: western Taranaki is the only substantial area free of such populations. North of latitude 38°S these *Nothofagus* patches are exclusively *N. truncata*, but further south all *Nothofagus* species are involved (Johns 1967).

Tree line varies from about 1500 metres to 1200 metres in the North Island, depending on the locality (Wardle 1973). In the absence of *Nothofagus* the tree line tends to be indefinite, tall forest giving away gradually to subalpine scrub. There are many species in this scrub but *Phyllocladus alpinus*, *Dracophyllum*, *Coprosma*, *Pittosporum*, and *Myrsine* tend to be prominent. In the presence of *Nothofagus menziesii* or *N. cliffortioides* the tree line is often more abrupt with only a narrow, or non-existent, scrub transition zone.

Above the tree line and its associated scrub, there is usually a shrubland extending a little further up slope. This shrubland has a rich diversity of species. Shrubs often include species of *Coprosma*, *Olearia*, *Senecio*, *Hebe*, *Dracophyllum*, *Myrsine*, *Gaultheria*, *Cyathodes* and *Drapetes*. Abundant herbaceous species are associated with this formation, including at least some of the snow grass species *Chionochoa*, plus *Epilobium*, *Gentiana*, *Umbelliferae*, *Astelia*, *Forstera*, *Ourisia* and many others. With increasing altitude on stable sites, thick grassland predominates: in unstable areas far more open, patchy vegetation is found. At the limit to plant growth, scattered cushion plants and tufts of hardy herbs alone are found.

There is a rather abrupt floristic transition that occurs at about 38°S, or approximately the latitude of the Waikato Basin (Cockayne 1928).

At around this latitude numerous species that are abundant in the lowland and montane forests of the north of North Island, disappear and are replaced by species typical of the southern half of the island. A list of these species is given in Clayton-Greene (1978). Those of the northern group that are important to this study are *Agathis australis* and *Persoonia toru*, and of the southern group, *Libocedrus bidwillii* *Nothofagus menziesii*, and, except for one isolated population in the Coromandel Peninsula, *Phyllocladus alpinus*. This abrupt southern limit for so many northern species has been discussed by Bieleski (1959) in relation to *Agathis australis*, and the conclusion reached was that length of growing season was the critical factor.

CHAPTER 3

METHODS

3.1 SAMPLING TECHNIQUE

3.1.1 Pollen sampling

With the exception of a marine core, taken by the New Zealand Oceanographic Institute, and two samples taken at Poukawa by well-drilling equipment, all samples were taken either from exposed sections or from a Hiller borer core.

All sampling was done in the field. Before sampling an exposed section, the face was cut back and cleaned with a spade or trowel. Open sections were always sampled from the base upwards to minimize accidental contamination from debris falling down during sampling. The sampling interval was varied according to the age and type of sediment; in most cases a standard 50mm or 100mm vertical interval was used. In old, compressed lignite at Otamangakau Canal samples were taken at 20mm intervals, while in the fast-growing, uncompressed post-glacial swamp and lake sediments at Poukawa an interval of 200mm was used; these represent the extremes. Wood, non-polliniferous silt, sand and gravel layers, and tephra led to some deviation from a completely regular sampling interval at many sites. The vertical extent of each sample was usually about 10mm, although this too, was subject to some variation. Samples were stored in glass vials or small plastic bags.

3.1.2 Radiocarbon samples

Samples intended for radiocarbon dating were either collected from a cleaned face or, in the case of Hiller borer cores, by means of modified sampling head with a 0.10 metre wide chamber. Radiocarbon samples were stored in clean plastic bags until the return to the laboratory. There, before air-drying, the samples were examined for

obvious contamination, such as rootlets, which were removed. No other treatment was undertaken before the samples were sent to the radiocarbon laboratory for dating.

3.2 SEDIMENT DESCRIPTION

Aranuian peats in New Zealand seem, in general, not to be very variable. In most cases the matrix appears to be an undifferentiated sedge peat with, in the North Island at least, greater or lesser amounts of wood. Older organic sediments often consist of compressed dark-brown peat or lignite, in most cases with flattened layers of wood throughout. Therefore, sediment descriptions given here are not elaborate. Highly organic sediments are referred to as "lake sediment", "peat" or "woody peat", and no further subdivision is attempted. The lignites and woody-lignites of Otiran age seem to be merely compressed equivalents of the prevailing Aranuvian peat type, and pollen analysis suggests that they have been formed in the same manner by the same mire plants. Inorganic sediments are referred to the categories "silt", "sand" or "gravel", according to the dominant size frequency. Compounds are made of all these terms, organic and inorganic, to describe mixed entities such as sandy-peat or silty-sand.

3.3 SAMPLE PREPARATION

Sediment samples were prepared for pollen analysis according to the methods outlined by Faegri & Iversen (1964), with some minor modification. These methods are summarised below.

- 1) Boiling with 10% potassium hydroxide for 5 minutes in a water bath.
- 2) Sieving to remove coarse detritus.

- 3) Treatment with cold 10% hydrochloric acid in the case of carbonate-containing sediments.
- 4) Treatment with 40% hydrofluoric acid at boiling point for up to 2 hours to remove silica.
- 5) Repeated (2-5 times on average) treatment with 10% hydrochloric acid to remove colloidal silicates and silicofluorides.
- 6) Treatment with chlorine bleach (sodium chlorate in solution of acetic acid and sulphuric acid) to remove lignin.
- 7) Acetolysis (mixture of one part concentrated sulphuric acid to nine parts acetic anhydride) at near boiling point for 4 minutes in a water bath.
- 8) Staining with basic fuchsin.
- 9) Mounting in glycerine jelly.

3.4 POLLEN ANALYSIS

Pollen and spores were counted using a Reichert Diapan microscope at a magnification of x 400. Critical identifications were made with an oil immersion objective (effective N.A. = 1.30). In order to minimize the effect of non-random pollen distribution, slides were made up with relatively few pollen grains per unit area, and traverses (on average 10 per slide) were regularly spaced across the whole area of the slide.

An attempt was made to identify each pollen type to the lowest taxonomic level. Harris (1955) and Cranwell (1953) were of assistance in determining pteridophyte spores and monocotyledonous pollen, as were also some unpublished Botany Division, D.S.I.R. keys. All critical identifications were confirmed by comparison with modern reference material.

In practice, pollen was referred to the lowest taxonomic category that it could be reliably placed in. In many cases pollen degradation, as a result of corrosion or breakage, was such that taxa were referred to higher taxonomic levels even though a percentage could be identified at a lower level. This occurred most frequently in the Umbelliferae, *Podocarpus* and Myrtaceae: under conditions of good pollen preservation many of the taxa in these categories can be assigned to either a species or a genus; at most sites however, there was a considerable risk of incorrect determinations.

The system followed here is as follows. If there is no suitable taxonomic category to place a particular pollen type in, it is given the name of a species within the group and the suffix "type". The following types are recognized, and are listed with the species included within the group.

Cyathea smithii type: *C. smithii*, *C. colensoi*.

Dacrydium bidwillii type: *D. bidwillii*, *D. biforme*, *D. kirkii*.

Nothofagus fusca type: all *Nothofagus* spp except *N. menziesii*.

Neomyrtus type: both species of *Lophomyrtus* and *Neomyrtus pedunculata*

Taraxacum type: all species in the tribe Cichorieae.

3.5 CHOICE OF POLLEN SUM

No form of "absolute" pollen counting was attempted here. Absolute pollen counting relies on the assumption of a non-varying accumulation rate or, more commonly, on closely spaced radiocarbon dates to determine what is the true rate of accumulation at any particular point in the column. Most of the sediments used in this study were beyond the range of radiocarbon dating techniques; the Aruanian sediments which could be dated presented other problems in the form of non-

homogenous sediments with frequent layers of wood, scattered tephra and silt, all of which prevent accurate sampling which is essential to the success of the method. Therefore all the results presented here are in the form of percentages based on a pollen sum.

The choice of a pollen sum is not easy. In most cases the primary aim is to find a pollen sum that is stable, while including all taxa that are likely to have played a role in the surrounding vegetation but excluding those of local significance only. The pollen sum chosen for most sites includes all terrestrial gymnosperms and angiosperms, with the exception of those confined to water-logged soils, and excludes all other plants.

The reason for excluding taxa confined to water-logged soils and all non-terrestrial gymnosperms and angiosperms was to eliminate those taxa which are purely local and, while providing information on the hydrosphere, are apt to be over-represented and subject to sudden fluctuations in abundance. There is no clear guide line for determining whether or not a given taxon is restricted to the local mire community. As Birks (1973) points out, each extant pollen and spore type may represent:

- (i) taxa only known at present to grow on well-drained soils
- (ii) taxa which may grow at present on well-drained as well as water-logged soils
- (iii) taxa only known at present to grow on water-logged soils.

Only a few taxa identified in the course of this work can be regarded as obligate water-logged soil dwellers: *Leptocarpus*, *Typha*, *Empodisma*, *Myriophyllum*, *Potamogeton*, *Montia fontana* and *Callitriche* among the herbs; *Eugenia mairi* the sole tree; and *Sphagnum* among the spore-producing plants. There is a much longer list of pollen types that come from taxa unable to tolerate poor soil drainage: *Podocarpus spicatus* is

the most prominent of these but many of the less well-represented pollen types such as *Weinmannia*, *Carpodetus serratus* and *Alectryon excelsum* can be placed in category (i). However, the vast amount of pollen identified belongs to taxa that are best placed in category (ii), that is, derived from species that can grow either on water-logged or well-drained soil, or from taxa that include species that can be placed in all three categories.

There is often some doubt as to whether some of the taxa are best regarded as belonging to the mire community, to a marginal fringe around the mire, or to the non-mire vegetation proper. *Dacrycarpus dacrydioides* is an example of a species where it is impossible to be sure. It can tolerate well-drained hill slopes but can also thrive in sites where for most of the year there is standing water (Wardle 1974). Many other tree and shrub species have nearly as wide a range of tolerance. Some of these, such as *Dacrydium cupressinum*, are commonly found on a wide range of soils: others such as *Dacrydium colensoi* and *D. bidwillii* group, are most often found on poorly-drained soils. Similar examples can be found for all the major plant groupings.

A further complication is that it is entirely possible that one particular pollen type may be derived from completely different species in the course of a pollen diagram that encompasses a considerable length of time. A good example is *Coprosma*: in a shrubland phase it is very likely that *Coprosma* pollen is derived from taxa characteristic of well-drained soils; during a forest phase it is far more likely to have been derived from shrubs on, or at the margin of the mire.

In the end a decision must be made and it inevitably involves choices that are to some extent arbitrary, although based on observation of the behaviour of both fossil and modern pollen grains. In most cases, especially those involving shrubland or a transition from shrubland to

forest, all woody plants were included in the pollen sum. An exception was made in some cases on the grounds of suspected local over-representation. The Stout St pollen diagram (Plate 14) and Poukawa diagram (Plate 15) have a pollen sum of arboreal taxa only; in the Otamangakau and Ohakune diagrams (Plates 5 & 6) both *Leptospermum* and *D. colensoi* are excluded. In the case of herbaceous plants, taxa known to occur in grassland or scrubland are included. There is some reason to believe that the pollen of some of these herbaceous plants, especially *Astelia*, *Epilobium* and Umbelliferae, was at most sites derived from plants growing on the mire. However, largely on the grounds that their representation was never very great, they were left inside the pollen sum.

Ferns, fern allies and other spore-producing plants have traditionally been excluded from the pollen sum in New Zealand. Although this follows the general practice in other countries, tree ferns, some of which rival angiosperm trees in height and are prominent in lowland New Zealand forests, present a special problem. The reason for the exclusion of tree ferns from the pollen sum, although never explicitly stated, is probably because tree ferns in New Zealand tend to be regarded as secondary elements of the forest, and are not therefore given any great importance in forest classification. Whether or not this is the reason for their exclusion, there are other good reasons for leaving them out of the pollen sum. *Cyathea* has abundant spore production but relatively poor dispersal (Pocknall 1979), which can lead to rather erratic distribution of the spores. Furthermore, spores are highly resistant to corrosion (Havinga 1967) and tree fern spores seem to be no exception to the rule. The result is that in samples where some corrosion has occurred, *Cyathea* spores in particular tend to be much over-represented. For these reasons *Cyathea* and *Dicksonia* spores have not been included in the pollen sum.

3.6 DACRYDIUM CUPRESSINUM RATIO

Because of the importance of *D. cupressinum* as an indicator of wet and drought-free climates (see Chapter 2) an attempt is made to assess its frequency in relation to the other tall podocarp trees which, in most situations, are its main competitors. To this end the ratio of *D. cupressinum* to other tall podocarp trees, excluding *Dacrycarpus* because of its propensity to grow on mire surfaces, has been calculated for some of the pollen diagrams. This ratio is called the "*D. cupressinum* ratio" and the figures given represent the number of *D. cupressinum* pollen grains counted per grain of *Podocarpus* types.

3.7 FORMAT OF POLLEN DIAGRAMS

On the extreme left of the pollen diagram, radiocarbon dates obtained from the profile in question are given together with identified tephra horizons. After these come in order: depth column; lithological column; and, if given, summary diagram. The summary diagrams are calculated either on the basis of total pollen and spores counted, or the particular pollen sum used. The summary diagram presents broad categories only; either, *Nothofagus* and tree conifer types, woody plants, and herbs (if the summary diagram is calculated on the basis of the pollen sum); or the above plus mire types, aquatics and ferns if the total pollen sum is used. The summary diagram is only included when it gives information that cannot be readily picked up from the pollen diagram proper.

In the pollen diagram proper, pollen frequencies of the taxa presented are represented by bars: often, if the sampling was irregular, the bars are displaced from their true stratigraphic position (although of course, never from their correct order) to produce a regular presentation. This procedure was adopted because the occurrence of non-

polliniferous layers of tephra, wood or silt in some diagrams led to gaps in the pollen sequence that, when plotted, made the diagram difficult to follow, and gave the impression of sudden fluctuations in abundance. These omissions of non-polliniferous layers are always indicated on the stratigraphic column, and are linked by lines to the pollen frequency columns. In some cases the non-polliniferous layers were so thick as to not be easily represented on the stratigraphic column, and in these cases the layers are represented by breaks.

The scale is not always uniform. In several cases taxa regarded as being local that reach very high frequencies, have been plotted on a reduced scale (usually $\times 0.1$ or $\times 0.2$).

The sequence of pollen types is always in the order, *Nothofagus* and tree conifers; trees; small trees and shrubs; herbs; mire types and aquatics; tree ferns; spores; exotic types. There are two exceptions to this order: *Gleichenia* and *Sphagnum*, although spore types, are considered to be better placed in the mire plant category. Exactly where within any of these groupings an individual taxon is placed depends on several factors including the ease of reading and comparing diagrams. In general, however, an attempt was made to put the types derived from larger, dominant plants first, and the more insignificant and lower-growing plants last.

At the extreme right of the pollen diagram, the assemblage zones are indicated. Where appropriate, estimated ages of the zone boundaries are also given.

3.8 POLLEN ZONATION

The pollen zones as used here are not designed to have more than a very restricted use. They exist primarily to allow clear description of individual pollen sequences, and to permit the discussion and comparison of one pollen sequence with another. They are not designed

either to stand alone as properly constituted "biostratigraphic units" as defined in a formal geologic sense, nor as constituents of a New Zealand-wide pollen zonation scheme. I concur with the statement of the National Committee for Quaternary Research (Gage 1977, page 20) that: "the general conclusion must be one of considerable doubt as to the advantages to ourselves or anyone else of going through an exercise to formalise Quaternary stratotypes".

In all cases the zones are based on pollen content, but in drawing up the zone scheme for each diagram, the division was primarily made on the basis of the ecological interpretation of the pollen assemblage. Not all pollen types are given equal weight therefore. In most cases, for example, mire elements are considered but not given great weight in the final decision on a particular zone boundary. In the case of the Lake Poukawa diagram (Plate 15) where the fluctuations in the level of the lake were considered to be of great importance, two zonation systems, one based on local mire and aquatic taxa, and the other on terrestrial taxa, are used.

Description of each pollen zone is in two parts. First, under the heading of "Description" the pollen basis for the zone is briefly described. Second, under "Interpretation" a simple ecological interpretation and reconstruction of the vegetation represented by the pollen is attempted. Further analysis of the vegetation and climatic interpretations are made when all the pollen diagrams from a region are discussed.

CHAPTER 4

POLLEN REPRESENTATION

No systematic study of modern pollen distribution was undertaken in connection with this study, and therefore this discussion relies for the most part on work already published.

4.1 PODOCARP-HARDWOOD FOREST

Existing studies (Moar 1970; Pocknall 1978, 1979) show that the correspondence between recent pollen spectra and forest composition is reasonably good. Different forest types can be characterized by their pollen spectra, but refined interpretations of the structure and specific composition are impossible. The tall, emergent podocarps predominate; far more pollen of *Podocarpus* and *Dacrydium cupressinum* is found in surface samples than the abundance of these taxa in many forests would suggest. On the other hand, many of the insect and bird-pollinated angiosperm trees are under-represented, some often being noted as single grain records when constituting a sizeable fraction of the forest. Usually a podocarp-hardwood forest has several, common, tree hardwoods, and the occurrence of the pollen of one or two of these in the pollen record, even in very low numbers, is sufficient to indicate fairly accurately the general nature of the forest. However, it is clear that substantial fluctuations in the abundance of hardwood trees may occur without much indication in the pollen spectra.

Beilschmiedia tawa is an extreme, and very important, example of the under-representation of tree hardwoods. *B. tawa* is one of the most common hardwood trees in lowland North Island forests, and forms nearly pure associations with podocarps as well as a wide variety of other forest types. Only one grain of *B. tawa* has ever been identified from a

fossil preparation (M. McPhail pers. comm.) and even preparations of flower buds yield only meagre amounts of pollen. Therefore, there could be major changes involving *B. tawa* without any detectable change in the pollen record. Although this must be kept in mind when interpreting pollen diagrams from the North Island, there is nothing at present that can be done to correct for it: it appears to be an absolute, rather than relative, absence of *B. tawa* pollen.

To summarize: although we can form a satisfactory picture of a podocarp-hardwood forest in general terms from the pollen record, our knowledge of the detailed composition and dynamics of this forest is limited to a few major wind-pollinated species.

4.2 *NOTHOFAGUS* FOREST

Pollen of the *Nothofagus fusca* group (that is all the *Nothofagus* species, except for *N. menziesii*) is the most widely dispersed in the New Zealand region. Pollen of *N. fusca* type is the most common mainland derivative to remote islands such as the Chatham Islands (Dodson 1976; Mildenhall 1976a) and the Antipodes Islands (Moar 1969). However, there is no consistent relationship between distance from source and the percentage of *Nothofagus* pollen recorded at any one site. *N. fusca* group pollen can be recorded at levels of 4% of terrestrial pollen in the Antipodes Islands, 770 kilometres to the south-west of New Zealand, (Moar 1969) and yet be found in only trace amounts in Westland, no more than 50 kilometres from extensive stands of *Nothofagus* forest (Moar 1970). Recent work (Pocknall 1979) has shown that, even within *N. fusca* group dominated areas, there can be considerable variation (from over 45% to 2% of terrestrial pollen), although this variation may have been partly the result of varying age and type of moss polsters used in the study.

It is clear that as *N. fusca* group pollen is the dominant component of long-distance pollen rain any diminution of local pollen production will enhance the percentage of *Nothofagus* pollen, regardless of the position of the site. This enhancement effect will of course occur to any pollen type that manages to be dispersed away from its parent vegetation. However, in New Zealand, as a result of the prominence of *Nothofagus* in the long-distance pollen rain, *Nothofagus* is the only pollen type in which this effect is consistently important. It is therefore often difficult to interpret *Nothofagus* pollen percentages in fossil spectra. In general, if the local vegetation is thought to be forest, especially forest of known high pollen production such as podocarp-hardwood, it is safe to take percentages of *Nothofagus* pollen higher than 20% as indicating a local presence. Naturally it is possible that lower percentages indicate *Nothofagus* also, but in these cases there is always the possibility of long-distance dispersal.

No such statement can be made regarding those sites dominated by scrub or grassland. An example of the type of variation that can be expected in shrubland, even far from *Nothofagus* forest, is provided by Dodson's (1976) work on the modern pollen rain of Chatham Island. Of the three sites in closed scrub-forest that were analysed, *N. fusca* type pollen was recorded in one sample only, and then at the 1% level: in the two open sites in shrubland, levels of 2 and 3% were recorded. Myers (1973) reports another example of variation, this time between sites only a few metres apart. At a site on the Canterbury Plains in open shrubland some 60 kilometres downwind from the nearest *N. fusca* group forest, percentages of 21% and 7% of *N. fusca* type pollen were recorded, the former from an exposed site, and the latter in dense scrub. Such differences over a very short distance underline the problems of interpretation.

4.3 SCRUBLAND AND GRASSLAND

Fossil pollen spectra which are scrub and herb-dominated also pose problems. Many scrub and grassland-dominated fossil pollen spectra have no equivalent in recent pollen spectra. Presence of forest trees, even some distance from a site, tends to drastically lower the percentages for the less well-represented scrub and grassland pollen types (Moar 1970). The inference can be made therefore, for fossil sites, that if pollen percentages of non-forest types are high, forest was rare or absent from the region.

The situation as regards the actual composition of the local vegetation is rather more difficult. Several scrub taxa are usually dramatically under-represented, even when locally dominant. *Dracophyllum* is a good example: even when it makes up most of the ground cover, it may contribute only a few pollen grains to the pollen spectrum (Moar 1974; Pocknall 1979). Compositae are another under-represented group. An example can be taken from the Southern Ruahine Range, where nearly pure *Olearia colensoi* (averaging 1.5-2.0 metres in height) scrubland covers extensive areas of the flat tops. In the middle of *Olearia* scrub, surface samples contained 24-11% *Olearia* pollen; at the transition from the scrub to a small, 50 metre diameter tussock patch within the scrub, only 2%; and in the centre of the same tussock patch, only 24 metres from the nearest *Olearia*, 1% (McGlone, unpublished data). *Dracophyllum* and *Olearia colensoi* formed the canopy at the site of a surface pollen sample analysed by Moar (1970), and the low levels of these types (9% and 3% respectively) do not adequately represent their importance. Even on the Chatham Islands, where the dominant vegetation is entomophilous scrub and low forest, *Dracophyllum* spp were only well-represented to poorly-represented, while Compositae were poorly-represented (Dodson 1976). Much the same remarks can be made about *Hebe*, *Myrsine* and

several other common shrub species. In fact, the only scrub types that appear to have consistent and adequate pollen representation in modern pollen samples are *Phyllocladus alpinus* and *Coprosma* (Pocknall 1979).

Many fossil pollen spectra which are dominated by shrub and grassland pollen types have high levels of pollen of taxa which are, according to modern surface samples, normally very poorly represented. *Dracophyllum*, Compositae and *Myrsine* often make up to 20% of the terrestrial pollen sum of some fossil pollen spectra, an exceptionally high level by present day standards. Even an extremely under-represented taxon such as *Hebe* occasionally attains levels of 10%.

The explanation for the divergence between present day surface sample results and fossil pollen spectra probably involves three factors. Firstly, pollen production of the local vegetation was low at most fossil sites. Second, forest, or other highly productive vegetation was remote from the site. Third, the same taxa that dominated the on-site vegetation were dominant over a very wide area. Only the first of these three factors is of any significance at most present day sites, and this is almost certainly the explanation for the absence of recent pollen spectra that match those of fossil sites.

CHAPTER 5

TARANAKI

5.1 INTRODUCTION

5.1.1 Geology

The Quaternary geology of western Taranaki is dominated by the continuing andesitic volcanism of the Egmont Volcanic Centre (Neall 1974). Volcanism has been active in the region for at least 1 750 000 years, and activity has been progressing southwards along a NNW to SSE trending line. Activity at the point, Mt Egmont, began about 70 000 BP. The present Egmont cone began to build up about 15 000 BP and was completed at around 3000 BP (Neall 1974). Volcanic activity in this region has been associated with volcanic mudflows (lahars), and it is these that have been largely responsible for building up the extensive ringplains, each graded to successive volcanically active areas. Vast flows westward, following collapse of part of the cone, have been a repetitive element in the late Quaternary history of the Egmont Centre, and all but one of the palynological sites described here have been preserved by burial by one or other of these lahars.

The tephras produced by the Taranaki volcanoes are very uniform in mineralogical composition and not widespread so they are of limited use for correlation. Nevertheless some progress has been made with this difficult material through detailed field studies (Neall 1972), and through the use of titanomagnetite analyses (Kohn & Neall 1973). Some of the more recent of these tephras have been used in this study for the correlation and dating of post-glacial deposits.

South-west Taranaki has a well-preserved series of marine-cut benches formed from underlying Tertiary mudstone and siltstone rocks.

These benches have a thick cover of sediments, mostly of volcanic origin, but including some sand dune and peat deposits (Chappell 1975). Recent work by B. Pillans (pers. comm.) on the geology of the marine benches and dating of included wood by amino-acid racemization has led to a clear picture of the age and inter-relationships of the marine benches. Seven benches are now recognized - three Kaiatea benches (older than 300 000 BP); Brunswick bench (240 000 & 200 000 BP); Ngarino (120 000BP); Rapanui (105 000 BP); Inaha (80 000 BP). Only the lowermost bench, Inaha, is directly relevant to this study, but the fact that it occurs in a sequence of dated benches gives confidence that it has been correctly determined and correlated.

5.1.2 Climate

The climate of the Taranaki region (excluding the cone of Mt Egmont which has a cool, wet mountain climate) is mild, wet, and windy (Garnier 1958). Annual mean temperature at sea level is 12-13°C; over most of the rest of Taranaki it ranges between 10 and 12°C. Frost is not common near the coast (6-12 ground frosts a year on average), but inland at Stratford over 70 ground frosts are recorded a year. Snow is an unusual event everywhere. Wind flow is predominantly from the west, but just to the east of Mt Egmont the flow tends more to the north and south, a consequence of the channelling of the wind between Mt Egmont and the Taranaki uplands. Rainfall is even and reliable throughout the year, but there is a distinct difference in the amount of rain received in north and south Taranaki (the dividing line between these two districts runs approximately from just north of Opunake through to Eltham). North Taranaki, except for a very narrow coastal fringe of lower rainfall, averages 1600-2400mm a year, while south Taranaki receives 1200-1600mm a year. Further south towards Wanganui, rainfall is even lower. South Taranaki has a relatively high water deficit in summer.

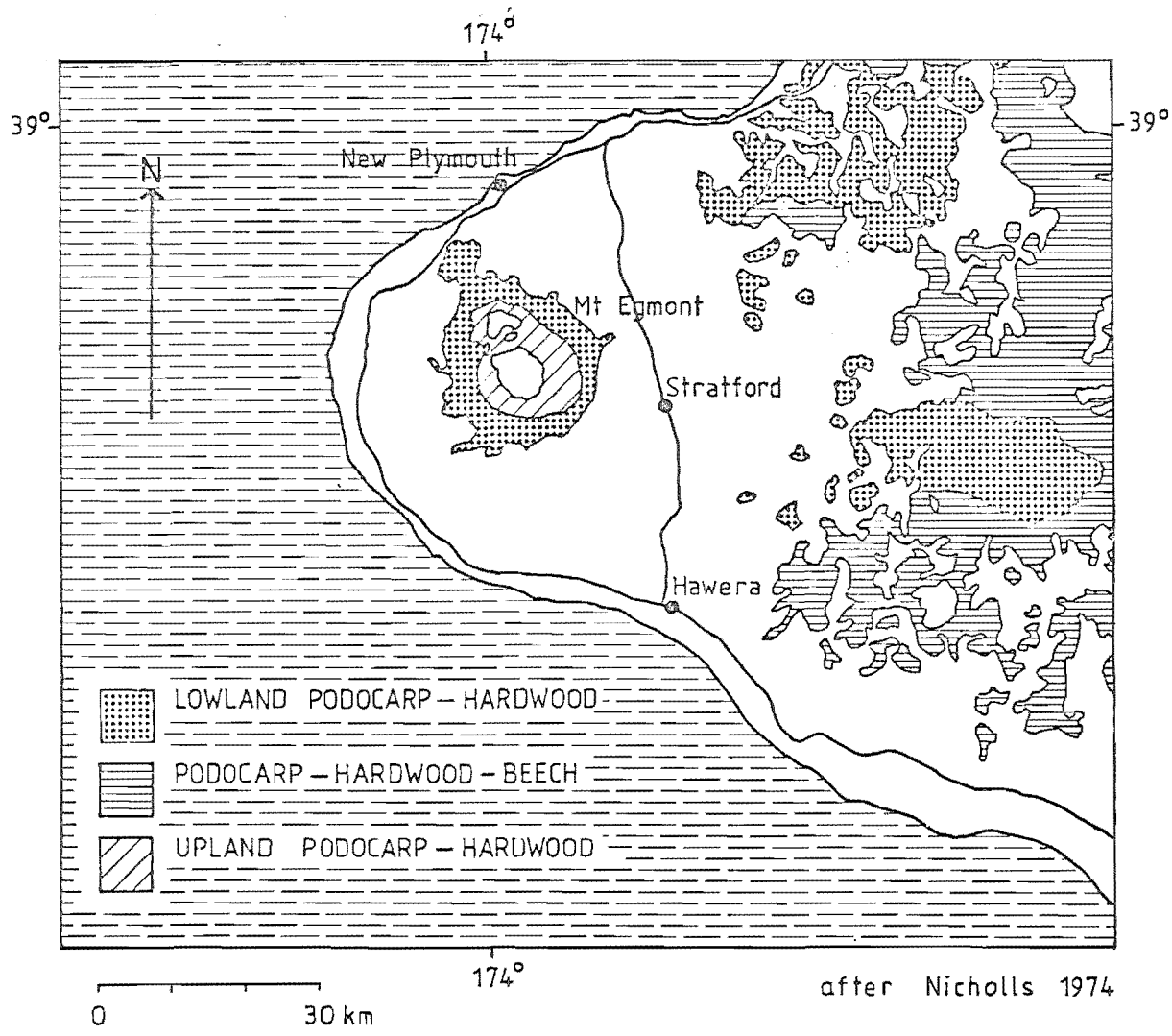
5.1.3 Vegetation

Clearance of the vegetation by Maori and European settlers has left little natural vegetation in the Taranaki lowlands (Figure 6). The only substantial areas of forest remaining are on the upper slopes of the Pouakai and Kaitake Ranges and Mt Egmont. It is possible, nevertheless, to outline a broad reconstruction of the vegetation of the lowland areas. This account is based on the work of A.P. Druce, Botany Division, D.S.I.R. A summary of this work has been published (Druce 1970).

At the time of European settlement, the coastal region had been cleared of forest back from the coast in a strip up to 7.5 kilometres wide in places. In place of the forest there was a dense cover of fern and scrub. Elsewhere, excepting swamps and regions above 1200 metres in altitude, there was dense, tall forest. The principal components of this forest in lowland areas were *Dacrydium cupressinum*, *Beilschmiedia tawa*, *Metrosideros robusta*, and *Weinmannia racemosa*. *Podocarpus spicatus* was common only in the Stratford region. Associated with these dominants was a rich hardwood tree and shrub flora. In swampy areas the forest included *Dacrycarpus dacrydioides*, *Laurelia novae-zelandiae* and *Eugenia maire*. Tree ferns were abundant throughout.

On the upland slopes of Mt Egmont and the Pouakai and Kaitake Ranges, lowland elements gradually give way to other species. *Beilschmiedia tawa* is the dominant hardwood up to c. 750 metres on the fertile south-east side of Egmont, but is of no consequence above 150 metres on the less fertile western flank. Above these altitudes and on the western side of the mountains, right down to the coast, *W. racemosa* is predominant, reaching its peak between 760 and 840 metres, but then rapidly diminishing, and dropping out altogether at about 990 metres. *D. cupressinum* and *Metrosideros robusta* are the main emergents up to

Figure 6. Forest vegetation, Taranaki



750 metres but then drop out of the forest. The extreme limit for *D. cupressinum* on Mt Egmont is at about 880 metres. *Cyathea smithii* reaches its limit some 30 metres lower.

Above 800 metres hardier tree species begin to appear. *Libocedrus* comes in at just above 800 metres but is not abundant until about the 900 metre level, at which point *Podocarpus hallii* also enters the forest. The *Libocedrus/P. hallii* forest does not form a sharp treeline, but gradually gives way to subalpine scrub. The two most important species of this scrub, *Pseudopanax colensoi* and *Senecio elaeagnifolius*, are common as sub-dominants in the montane forest. At 1200 metres forest trees are absent. Scrub, now including abundant *Dracophyllum*, extends another 200 metres. In the higher scrub zones *Hebe* tends to predominate. At about 1400 metres, scrub is replaced by a grassland dominated by *Chionochloa*. The limit to vegetation is at about 1800 metres.

Inland from the Egmont ringplain are the Taranaki uplands, a rugged, dissected complex of mudstone and limestone ridges and valleys. Average altitudes increase from c. 150 metres at the edge of the Egmont ringplain to c. 750 metres in the south-west. The vegetation of this region has been described by Nicholls (1956).

The dominant forest trees are *B. tawa*, *W. racemosa* with various podocarp species, mainly *D. cupressinum* and *P. ferrugineus*, as low density co-dominants. Other species associated with this forest type are *Metrosideros robusta*, *Elaeocarpus dentatus*, *Knightia excelsa*, and *Laurelia novae-zelandiae*. *Nestegis* is common on fertile, alluvial silt soils and *D. dacrydioides* is found on some riparian flats. *P. hallii* is almost confined to ridge tops, and *P. spicatus* occurs only on the most fertile valley soils. *Nothofagus fusca* group species are found throughout

the region. *Nothofagus* forest occurs mainly on the razor-back ridges and spurs that are common throughout the uplands. *Nothofagus menziesii* is in one isolated patch only. *Phyllocladus* is found in the north of the uplands region, in low numbers and at low altitudes. Other than this, *Phyllocladus* species do not occur in Taranaki.

5.2 POLLEN DIAGRAMS

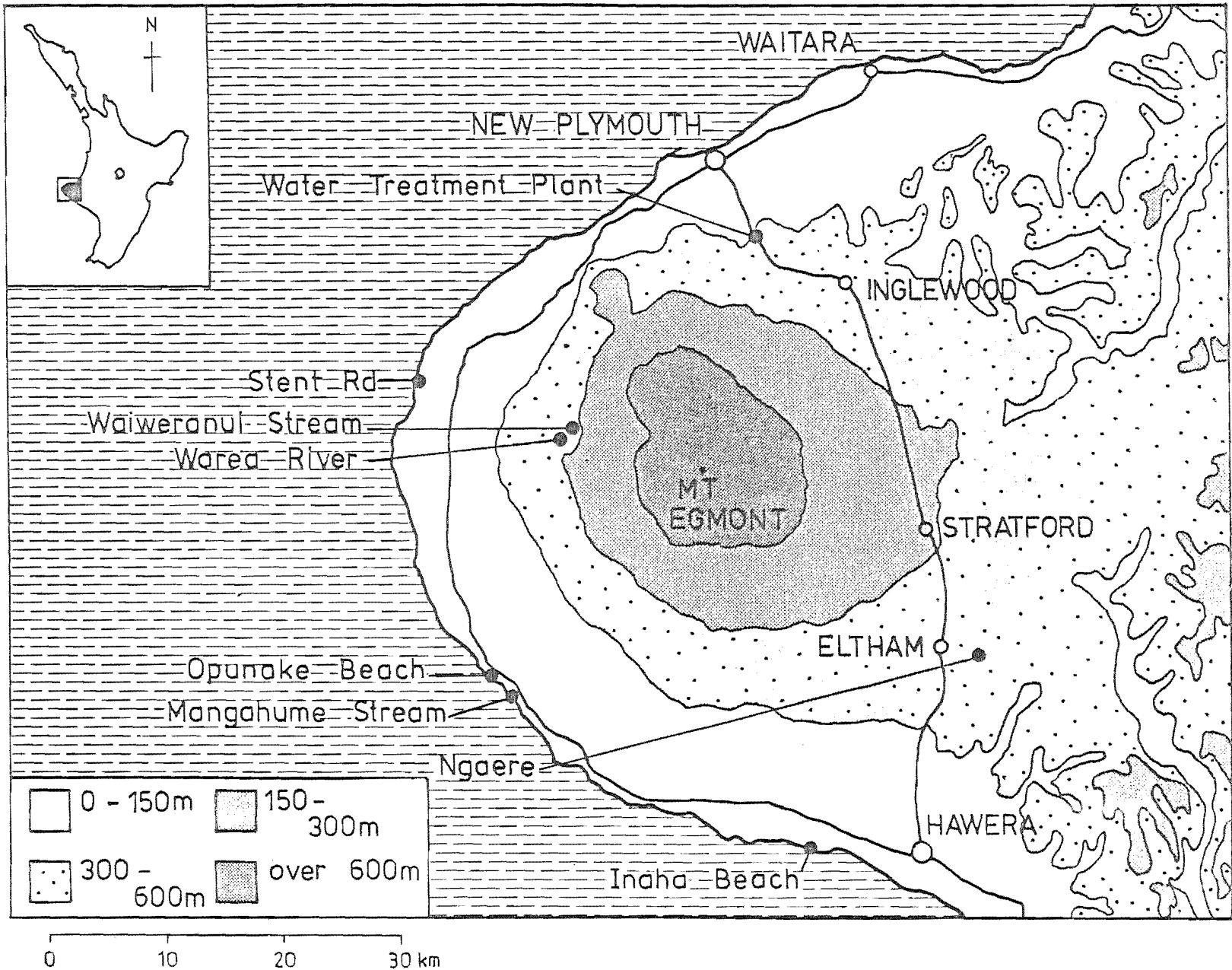
5.2.1 Inaha Beach

Location: NZMS1-N129/748278. Altitude: sea level.

(i) Geology and Chronology

The Inaha Beach section (Figure 7; Plate 1) consists of a 38 metre high coastal cliff. The section extends laterally for 2.7 kilometres before the base dips below sea level in the west, and it has been truncated by fluvial erosion in the east. At the base, the section contains a major angular unconformity between a Pliocene silty sandstone below and Quaternary volcanoclastic beds above. The surface of the Pliocene sandstone has marine-bored boulders on it and is overlain with beach sands. It is therefore interpreted as a marine-cut bench and is given the informal name of Inaha marine bench. Above the beach sands there is a sequence of laharcic and fluvial sands, gravels, and conglomerates. Within the sequence there are numerous tephras, peats and organic silts. At about 11 metres from the top of the cliff there is a thick layer of sand, gravel and conglomerate that contains no organic deposits. This laharcic unit is correlated with the Opunake Formation which was deposited during a more active phase of cone construction and collapse that occurred some time before 20 000 BP (Neall 1974). At about 1.50 metres from the surface of the cliff, there is a tephric loess belonging to a widespread unit that in nearby sections has the

Figure 7. Site location, Taranaki



Aokautere Ash (= Kawakawa Formation, 20 000 BP) near the base. This loess is in turn overlaid by post-glacial tephras from Mt Egmont.

The samples for pollen analysis were taken from organic layers within the beds above the marine sands and below the Opunake Formation. These beds contain many thin organic layers which fall into 6 groups of closely separated horizons (A-F in Plate 1). Although there is no continuous organic sedimentation within some of these groups, the similarity of the pollen spectra derived from the individual layers indicates that each group represents a continuous sequence. The similarity in pollen spectra between groups is very much less, and the vertical separation between them in the section probably represents a significant time interval. I have therefore divided the polliniferous part of the section into 6 separate pollen diagrams and, although they are all presented on one diagram, no time continuity is implied.

The age of these organic layers is not known with any precision. The marine-cut bench is thought to be about 80 000 years old (B. Pillans pers. comm.). An amino-acid racemization date from C2 (at a level about 5 metres above the bench) gave an age of $75\ 000 \pm 20\ 000$ years ago (BJP-010). A wood sample from F3 returned a radiocarbon age of $33\ 280 \pm 1100$ BP (ANU-1887) and an amino acid racemization date of $35\ 000 \pm 10\ 000$ years (BJP-015). The pollen diagrams presented here are between 80 000 and 33 000 years old, but the nature of the sequence makes it impracticable to estimate ages for the undated organic layers on the basis of sedimentation rates.

Not all the samples that have pollen spectra are reported here. Samples that were taken from slightly-organic silts have poorly-preserved pollen and are dominated by tree fern and monolete fern spores. This over-representation of spores has been discussed in 3.5, and seems to be the result of corrosion of other pollen types. Zone B is an

example of an horizon which is marginally suitable for inclusion because of this over-representation. A feature of all the pollen sequences in the Inaha section, except for Zones C3 and C2, is the presence of numerous microscopic charcoal fragments.

(ii) Pollen diagram. (Plate 1)

Inaha A. (not zoned)

Description: Gramineae levels are very high (39-52%), and are among the highest recorded in the entire Inaha section. The moderately high scrub total (40-60%) consists chiefly of Compositae, *Dacrydium bidwillii* type and *Coprosma*. There are minor quantities of *Phyllocladus*, *Dracophyllum*, *Muehlenbeckia* and *Pseudopanax*. Tree pollen levels are extremely low (2-3%), mostly *Nothofagus fusca* type, with only a few records of other tree pollen types. Swamp plants are not well-represented and make up no more than 4-5% of the total. Cyperaceae and *Leptocarpus* are the main contributors.

Interpretation: The regional vegetation was a grassland, but with a considerable amount of scrub. Compositae scrub was probably the local dominant. There can have been no forest in the vicinity of the site and very possibly there was none in the Taranaki lowlands. The low amount of mire herbs suggests that the local environment of deposition was a peaty soil, perhaps forming under scrub, rather than a true mire.

Inaha B (not zoned)

Description: Gramineae percentages are high (34-39%). Scrub levels are moderate (27-39%), the main contributors being *Leptospermum*, *Myrsine*, Compositae, and *Coprosma*. There are minor amounts of *Phyllocladus* and *D. bidwillii* type. *Drapetes* reaches the unusually high level of 2% in one sample. Tree pollen types are relatively common, *D. cupressinum* especially, but nearly all major types are present in at least one of the samples in this zone. *Metrosideros* has exceptionally high levels of

6-8%. Mire plants are represented by low percentages of Cyperaceae. One of the most striking characteristics of this diagram is the large numbers of fern spores, especially *Cyathea smithii* and smooth monolet types.

Interpretation: Pollen concentration is very low, and the samples are from a nearly inorganic silt. Interpretation is confused by the unusually high percentages of spores and tree type pollen. The high levels of spores is a result of corrosion. Most of the tree pollen must have either been re-worked from older sediments, or be the result of long-distance dispersal. If this interpretation is accepted, the remaining pollen types indicate a vegetation type similar to that of Inaha A. Grassland was dominant, but there was also much scrub, mainly *Leptospermum*, Compositae and *Myrsine*. As in Inaha A, the sediments of this layer were probably laid down in a gley or peaty soil, and not in a mire.

Inaha C.

This is the longest sequence of the section and has sufficient complexity to require zoning. Three zones are recognized. The sediments of Inaha C are informally termed the Manaia Lignite.

Inaha C1

Description: This zone is defined by initially high, but rapidly dropping, Gramineae percentages, and by very low tree pollen levels. The scrub pollen percentages, *Leptospermum*, *Coprosma* and *Myrsine* in particular, increase as those of Gramineae decrease. Compositae are well-represented throughout, peaking at 57% in the middle sample of the zone. *D. bidwillii* type is the only other scrub type of consequence: it averages 2-3%. Mire plant pollen, especially that of Cyperaceae, *Leptocarpus* and *Empodisma*, is present in moderate quantities. Except for

the first sample of the zone, spore levels are low. The first sample of the zone also has a high *D. cupressinum* percentage (3%) and it is likely that, as in Inaha B, enhancement of spore percentages by differential corrosion has occurred and also reworking of older pollen or perhaps long-distance dispersal.

Interpretation: During this zone there was a transition from grassland/Compositae scrubland to a *Coprosma/Leptospermum* scrubland. Forest was absent from the immediate district at least. The local environment was a sedge/restiad mire with an open scrub cover.

Inaha C2

Description: At the beginning of the zone there is an upsurge in the amount of tree pollen from the previous level of c. 3% to 66%.

Dacrycarpus dacrydioides, *Podocarpus spicatus* and to a much lesser extent, *Plagianthus c.f. betulinus*, are the main contributors. Pollen of *D. cupressinum*, *Elaeocarpus*, *Pennantia*, *Nothofagus* and *Libocedrus* is regularly encountered, but none of these reach levels of more than a few per cent. Gramineae percentages fall rapidly and are not recorded in the last sample of the zone. The same scrub types as in the last zone are present, but the total amount of scrub pollen is down and *D. bidwillii* falls to trace amounts. During the peak of the tree phase only low percentages of mire herbs are recorded. A large number of uncorroded monolete and tree fern spores are present.

Interpretation: *Dacrycarpus* formed a dense swamp forest at the site during this zone, as shown by the scarcity of mire herbs and scrub. The regional vegetation was forest, probably dominated by *P. spicatus* and including substantial quantities of *Plagianthus*. Not many podocarp-wood forest taxa are found in this zone, or the next, and, compared with post-glacial records from *P. spicatus* dominated forests, the flora is rather impoverished. Nevertheless, the pollen spectra of this, and

the following zone, are the only ones in the entire Inaha sequence that indicate the presence of a complete forest cover. There was an abundance of ferns and tree ferns associated with the forest.

Inaha C3

Description: *Dacrycarpus* undergoes a steady decline, and in the last few samples drops to percentages of 1-2%. *P. spicatus* falls away from the peak values of Zone Inaha C2, but maintains high levels.

Plagianthus and *D. cupressinum* are unchanged, and *Libocedrus* and *Nothofagus menziesii* are consistently present. Gramineae percentages do not rise above 1% in this zone. Scrub pollen levels rise from the low of the last zone: at first *Leptospermum* is the major scrub type, but at the end of the zone *Myrsine* undergoes a sudden expansion. Mire herb pollen (almost all from Cyperaceae) recovers its former levels, and is abundant throughout the zone. There is a peak of *Phormium* in mid-zone.

Interpretation: The previous *Dacrycarpus* swamp forest was replaced by an association of Cyperaceae and scrub. However, *P. spicatus/Plagianthus* forest continued to be the dominant regional vegetation type. The absence of Gramineae suggests that, as in the previous zone, forest and scrub cover was nearly complete.

Inaha C4

Description: Gramineae begin to increase, and by the end of the zone makes up nearly 40% of total pollen. *P. spicatus* drops steadily from a high of 13% to a low at the end of the zone of 3%. *Dacrycarpus*, after a slight recovery from the low values at the end of Zone C3, disappears. *Plagianthus* is unaffected, but there are increases in the later half of the zone in *Libocedrus*, *D. cupressinum* and *Nothofagus*: none of these types exceed percentages of 4%. Total scrub pollen percentage does not change much, but Compositae increase markedly, as do *Coprosma* and *Dracophyllum*, while the percentages for *Myrsine* fall. Cyperaceae become

less abundant, but there is no increase in the amount of the other swamp herbs except for a brief peak of *Phormium* midway through the zone.

Interpretation: The vegetation was returning to a state similar to that of Zone Cl. Grassland and Compositae scrubland spread, and podocarp trees and tree ferns declined. However, tree pollen levels were at about 16%, much higher than the 2-3% of Zone Cl. Forest vegetation still persisted in the region therefore.

Inaha D.

Although there are major changes in some of the more important pollen curves throughout this diagram, the complexity is not such as to demand zoning.

Description: *P. spicatus* averages about 7% for most of the diagram, and *D. cupressinum*, *N. menziesii* and *N. fusca* types are relatively well-represented. *Plagianthus*, *Hoheria*, *Pennantia*, *Elaeocarpus* and *Paratrophis*, although not plentiful, are present. Gramineae percentages are erratic, rising as high as 16% and falling as low as 3% in the middle portion of the diagram. The first sample and the last three are, however, high in Gramineae. *Leptospermum* dominates the scrub pollen total and, with the exception of the first sample of the diagram which has only a trace amount, averages almost 40% of terrestrial pollen. *Coprosma*, Compositae and *Myrsine* are the only other scrub types of importance. Herbs of open places - such as *Epilobium*, *Chenopodium* and *Plantago* - are frequent. Cyperaceae are the major mire herbs, but *Leptocarpus* is common in the first two samples of the diagram. *Myriophyllum* is found throughout, and reaches 16% of the pollen sum in one sample. Tree fern and monolete fern levels are low except in the first and the last three samples. In both cases enhancement of spore percentages by corrosion of susceptible pollen types is likely to be the cause.

Interpretation: Inaha D bears a strong resemblance to Zone C4. The main vegetation cover was shrubland, with fluctuating amounts of grass and scrub. The relatively high *P. spicatus* percentages indicate that there was podocarp forest in the area, but that it was not the predominant vegetation and may have been quite restricted.

Ihaha E.

Description: *P. spicatus* and other podocarps are at levels of 1% or less for the entire diagram, and there are only small amounts of other tree types. Gramineae percentages are high, especially in the first sample of the diagram, fall rapidly to a low of 4% and then climb as rapidly back to an average of 50% for the last section. Scrub pollen is at a peak during the low point for Gramineae, but has high percentages throughout the rest of the zone also. Compositae, *Coprosma* and *Myrsine* are the scrub dominants. *D. bidwillii* type appears in the top half of the diagram, the first substantial record of this taxon since Zone C1. The first sample of the diagram has little mire plant pollen. Cyperaceae and *Leptocarpus*, the latter reaching an exceptional figure of 88% of terrestrial pollen, are the co-dominants for the lower three quarters of the diagram; the upper portion has *Phormium*, *Leptocarpus* and Cyperaceae as the most common mire herbs. *Myriophyllum* and *Potamogeton* are present in low amounts for most of the diagram; *Myriophyllum* has an unusually high peak of 14%. Tree fern spores are rare, monolete fern spores are quite abundant.

Interpretation: There was no podocarp-hardwood forest near the site at this time: there may have been some pockets of *N. menziesii*, but no other form of tree vegetation is likely to have existed in the region. Grassland and shrubland completely dominated the landscape, Compositae scrub being especially prominent. The site itself was a wet sedge swamp at first, but later became a *Phormium*-sedge mire.

Inaha F.

This diagram is divided into three zones.

Inaha F1

Description: This zone consists of one sample only. It has moderately high Gramineae (21%), high Compositae (60%) and very low tree pollen levels. *Leptocarpus* completely dominates the mire herb assemblage.

Interpretation: An open Compositae scrubland was dominant, with either no forest, or only scattered pockets of forest in the region. The presence of *Leptocarpus* indicates that the local site was a wet mire of high nutrient status.

Inaha F2

Description: Gramineae percentages are moderate to high; Compositae are approximately half the level of Zone F1 but still relatively high, and *Coprosma* has moderate levels (4-11%). There is a sharp increase in *D. bidwillii* to very high percentages (51-29%), which are the highest for the whole Inaha sequence. There are only low levels of other scrub and herb types. Cyperaceae is present in some quantity (8-15%), while *Leptocarpus* falls steeply from its high of 60% to about 4%. Tree pollen frequencies are extremely low and mainly of *Nothofagus* and *Libocedrus*.

Interpretation: For the first time in the sequence since Zone A, *D. bidwillii* group became a major scrub element. The continuing low percentages for tree pollen types, and the dominance by Gramineae, *Coprosma* and Compositae indicate that there was no major change in the structure of the vegetation despite the rise of *D. bidwillii* group. The vegetation remained an open shrubland.

Inaha F3

Description: *Libocedrus*, *N. fusca* type, *N. menziesii*, *P. spicatus* and *D. cupressinum* are all relatively common; the first three named attain their peak abundances for the whole sequence in this zone. *D. bidwillii*

type drops to an average of 4% after the first few samples, while *Leptospermum* peaks early at 30% and then drops to low, erratic frequencies. The remainder of the scrub pollen is derived mostly from Compositae, *Coprosma* and *Myrsine*. *Phyllocladus*, last present in Zone F2, reappears in the last 4 samples of the zone. Graminaeae generally remains high but is depressed somewhat in the middle of the zone. In the last sample of the zone it recovers to levels of greater than 30%. *Gleichenia* makes a dramatic appearance at the beginning of the zone, rising quickly to extremely high percentages: it is followed by *Empodisma*, which also attains high levels. Both these taxa are uncommon in the rest of the Inaha sequence. *Leptocarpus* and Cyperaceae remain abundant.

Interpretation: In all probability forest spread slightly during this period. *Nothofagus menziesii* and *Libocedrus bidwillii* are likely to have been the most common trees. Besides this minor increase in the amount of forest in the district, the vegetation cover over the region remained much as before, that is open scrubland. The arrival of *Gleichenia* and *Empodisma* indicates that a peat bog rather than a swamp now occupied the site.

5.2.2 Mangahume Stream Mouth

Location: NZMS1 - N118/463416. Altitude: sea level.

(i) Geology and Chronology

This section is exposed in a roadcutting in a low coastal cliff near the mouth of the Mangahume Stream. (Figure 7; Plate 2). At the base of the section there is exposed part of the uppermost Opunake Formation, a laharcic deposit younger than about 35 000 BP. Above this formation lies 4.50 metres of tephra, peat and buried soils, sampled for pollen analysis. Wood of *Dacrydium biforme* in a 0.4 metre thick tephra layer overlying the palynological horizons, gave a radiocarbon age of

23 000 ± 300 BP (NZ 1257A). Above this dated tephra lies the Okato Tephra (about 12 600 BP), followed by almost 9 metres of post-glacial lahar and tephra deposits, including the Warea and Opuā Formations.

(ii) Pollen Analysis. (Plate 2)

There are four, separate organic horizons in the section sampled for pollen analysis: the basal gravels and sands have two, thin, grey-brown buried soils, and the tephra sequence above these sands and gravels includes two, thick, dark-brown peat layers. Although charcoal was not apparent in the profile, all the pollen preparations contained abundant charcoal shards.

The pollen spectra from the peat and soil horizons are so similar that there is not likely to have been any significant time-break in the sequence. Also, the emplacement of the laharic sediments and the tephra is likely to have only taken a short time. Therefore the pollen spectra from the various layers are treated as if they belong to one, continuous sequence. Three pollen zones are recognized.

Mangahume 1

Description: Tree pollen percentages are low, (3-5% of total pollen), but no one type is dominant. Gramineae are not abundant - they comprise only 6% of the total - but Umbelliferae are common and *Gentiana* and *Chenopodium* are present. *Myrsine*, *Coprosma* and Compositae are the main scrub types. *Dracophyllum*, especially in the two basal samples, and *D. bidwillii* type are moderately well-represented. Except for one isolated peak of over 25%, *Leptospermum* has low levels of 1-2%. Mire herbs are not abundant in this zone. At the beginning *Leptocarpus* accounts for the greater part of the mire herb total, but later Cyperaceae and *Empodisma* occur in moderate quantities. There is a small peak of *Gleichenia* in mid-zone, but otherwise it is not abundant. There

are relatively high values for *Gunnera* and *Phormium*, and both *Potamogeton* and *Myriophyllum* are noted.

Interpretation: A dense scrubland of *Coprosma*, *Myrsine*, *Dracophyllum* and Compositae is indicated. Trees can not have been common, and perhaps existed only as distant pockets of podocarp and *Nothofagus* forest. The site itself was occupied by a sedge-*Phormium* mire.

Mangahume 2

Description: *Nothofagus fusca* type, *N. menziesii* and *Libocedrus* all reach higher percentages in this zone, but none of them becomes more than a minor element in the pollen spectra. Podocarp types maintain their previous levels until mid-zone, at which point they become uncommon. Gramineae expand greatly at the zone boundary, and maintain high, fluctuating values throughout this zone, and the next, while exhibiting no obvious trend. Both *Myrsine* and *Coprosma* lose their pre-eminent position, sinking to frequencies of 5% or less, and are almost entirely replaced by *D. bidwillii* type which undergoes a sudden increase to reach almost 40% in the early part of the zone. *D. bidwillii* type declines as rapidly as it rose, averaging 17% in mid-zone, and then expands again to reach a level of over 41%. *Phyllocladus* becomes a substantial contributor to the pollen sum in mid-zone, but falls towards the end of the zone. Compositae pollen is abundant, but fluctuates quite markedly. *Dracophyllum* retains relatively high, but fluctuating percentages. All mire types, except *Phormium*, attain higher frequencies, and there is a general peak of mire herb types in mid-zone. The dominant taxa are *Gleichenia*, *Empodisma* and, to a lesser extent, Cyperaceae. From mid-zone on, all mire types decline in abundance. *Phormium* barely survives into Zone 2, and *Potamogeton* and *Myriophyllum* are present only at the beginning of the zone.

Interpretation: The local vegetation type changed dramatically during this zone. The initial sedge swamp was replaced by a peat bog, and *D. bidwillii* group spread on the surface of the bog and may have also become the dominant scrub in the surrounding area as well. As a consequence of the spread of *D. bidwillii* group, some other scrub types underwent a decline. *Coprosma* and *Myrsine* were the most affected, Compositae not so much, and *Dracophyllum* not at all. The high levels of Gramineae in conjunction with such taxa as *Drapetes* and *Chenopodium* suggest that there was much open ground near the site, despite the apparently thick scrub cover. Fire may have played a role in producing this vegetation type by creating a mosaic of scrub and grassland in various stages of regeneration. The highest levels of tree pollen for the whole diagram are found in this zone, but this is probably the result of enhancement of the extra-local component of the pollen rain with the spread of the peat bog. If there was any forest in the region at the time, it cannot have consisted of much more than isolated stands of *N. menziesii* and *Libocedrus bidwillii*.

Mangahume 3

Description: *D. bidwillii* type declines throughout, sinking to 19% by the end of the zone, while *Phyllocladus* undergoes a steady expansion and reaches levels of 20%. *Hebe* increases to unusually high percentages. Compositae, *Coprosma*, *Dracophyllum*, *Myrsine* and Gramineae retain much the same levels as they had in Zone 2. Umbelliferae, *Gentiana*, *Epilobium* and *Taraxacum* type make an appearance after being rare or absent in the last zone. Tree pollen types in general, and *Nothofagus* and *Libocedrus* in particular, decline in this zone. There is little change in the mire types except for an overall decrease in abundance.

Interpretation: There was continuing change in the composition of the scrubland. The same combination as before, *D. bidwillii* group,

Compositae and *Dracophyllum*, made up the bulk of the scrubland, but with the addition of *Phyllocladus* (almost certainly *P. alpinus*) and *Hebe*. Although there is no change in the amount of Gramineae pollen, the reappearance of herbs of open habitats implies that the vegetation had become even more open than in Zone 3. The contribution of tree pollen to the pollen sum is even lower in this zone, and this probably reflects a reduction in the total amount of forest surviving in the region rather than simply a change in pollen sedimentation patterns.

5.2.3 Stent Road

Location: NZMS1 - N108/373713. Altitude: sea level.

(i) Geology and Chronology

This section is in a low bank exposed on a beach a few kilometres south of Okato (Figure 7; Plate 3). At the base of the section there is a conglomerate (Pungarehu Formation, *c.* 22 000 BP) that is exposed at the m.h.w. mark. Above the conglomerate is 0.65 metres of peat and wood overlain by pockets of the Okato Tephra (*c.* 12 550 BP) and approximately 1 metre of a post-glacial lahar, the Warea Formation. Above the Warea Formation there is about 1.50 metres of tephra, soil and beach sand, topped by the present day soil surface. The age of the upper layers of the peat is $18\ 350 \pm 380$ BP (NZ 1361 A). The peat began to accumulate immediately after the deposition of the Pungarehu Formation. There is almost no pollen in the uppermost 0.12 metres of peat as a result of severe corrosion. Three pollen zones are recognized.

(ii) Pollen analysis. (Plate 3)

Stent Road 1.

Description: There are very low levels of *Nothofagus* and only traces of other tree pollen types. Gramineae are the single greatest contributors to the pollen sum, 38% of terrestrial pollen at first but falling to 20%,

and Umbelliferae are well-represented. *Dracophyllum*, *Myrsine*, *Coprosma*, and Compositae make up most of the rest of the pollen sum, each averaging between 10 and 20%. *D. bidwillii* type and *Phyllocladus* are present but do not exceed 3% in total. At first, *Myriophyllum* and *Gunnera* have very high percentages (60% and 20% respectively), but these drop to 10% and 3% at the upper boundary of the zone. *Leptocarpus* and *Empodisma* have moderately high frequencies, and *Gleichenia* levels rise steadily from 10% to a high of 150%.

Interpretation: Scrub and grassland were the sole vegetation types near the site. It is extremely unlikely that there was any forest in the region. The site itself was quite wet at first, as can be seen from the levels for *Myriophyllum*, and was occupied by a sedge swamp. Later, as the rising curve for *Gleichenia* indicates, a peat bog established.

Stent Road 2

Description: There is a steady rise of *D. bidwillii* type throughout the zone from 4% to 22%. At the same time *Dracophyllum* and *Myrsine* decline, while *Coprosma*, Compositae, and Gramineae maintain their previous levels. *Gunnera* is reduced to trace amounts only, and *Myriophyllum* continues the decline begun in the last zone. Mire herbs retain approximately the same levels they had at the end of Zone 1.

Interpretation: The only major change is the rise of *D. bidwillii* group: this can be linked with the development of a peat bog and the growth of *Dacrydium* on it. It is also likely that *Dacrydium* also partially replaced *Dracophyllum* and *Myrsine* in the surrounding vegetation.

Stent Road 3

Description: *Libocedrus* is better represented and so is *N. fusca* type, but the changes are slight. Otherwise there are minor fluctuations in the abundance of tree pollen. *D. bidwillii* peaks in the first sample

of this zone at 36%, but then gradually drops to 8%. *Phyllocladus* rises steeply to over 50% in the first half of the zone, and retains high frequencies. Other scrub types are either unchanged, or as in the case of *Dracophyllum* and *Myrsine*, fall somewhat. Gramineae are at only half the levels of Zone 2. *Myriophyllum* almost disappears, and the percentages for the other wetland herbs are more or less static, with the exception of *Gleichenia* which reaches even higher frequencies than in the last zone, peaking at 180%.

Interpretation: There was a rapid replacement of *D. bidwillii* group by *Phyllocladus*, but otherwise little change. These two taxa were the dominant woody plants on the peat surface, but also must have been common in the surrounding countryside to account for the very high pollen percentages.

Stent Road 4

Description: *D. bidwillii* type recovers, rising sharply at the zone boundary, while there is an even more sharply defined drop in the amount of *Phyllocladus* pollen recorded. In the top two samples, *Leptospermum* expands to reach over 20% of the pollen sum. *Dracophyllum*, *Myrsine* and *Coprosma* increase somewhat, while Compositae and Gramineae keep much the same frequencies as in Zone 2. There is little or no change in the mire plants.

Interpretation: Once again the changes appear to be of a local nature with successive partial replacements of *D. bidwillii* group, first by *Phyllocladus*, and then by *Leptospermum*. Despite these rather sudden changes in specific composition, the structure of the shrublands that surrounded the site must have remained very much the same. One indication of this is that the total amount of Gramineae and forest tree types recorded remains much the same from zone to zone.

5.2.4 New Plymouth Waterworks

Location: NZMS1 - N109/692843. Altitude: 150 metres.

(i) Geology and Chronology

This site is in a cutting in a road within the New Plymouth Waterworks reserve (Figure 7). At road level there are several very organic soils separated by tephra deposits. Wood from the uppermost soil (identified as *Nothofagus*; Patel, pers. comm.) has been dated at $30\ 500 \pm 1300$ BP (NZ 1622 A). The soil is overlain by 6 metres of redeposited tephra belonging to the Katikara Formation, a widespread dune formation in northern Taranaki which began to accumulate not long before 16 000 BP (Neall 1975). Above the Katikara Formation there are the Oakura and Okato Tephtras totalling approximately 1.5 metres in thickness.

Only the uppermost buried soil had uncorroded pollen, and only results for it are presented.

(ii) Pollen analysis. (Table 2)

Description: The pollen spectrum is almost completely dominated by just two pollen types: *N. menziesii* and *Cyathea smithii* type. There are some scrub types recorded, but only *Coprosma* at 2% is at all well represented. There are low percentages of monolet fern spores and *Phymatodes diversifolium*, but only traces of other fern types.

Interpretation: Without doubt the site had a nearly pure, closed forest of *Nothofagus menziesii* growing on it. The tree ferns, probably *C. smithii*, were abundant, and the monolet fern spores and *Phymatodes* show that there was a dense ground cover of ferns.

5.2.5 Warea River

Location: NZMS1 - N118/512658. Altitude: 280 metres.

(i) Geology and Chronology

This site is a 5 metre high bank of the Warea River (Figure 7).

TABLE 2

POLLEN ANALYSIS: NEW PLYMOUTH WATERWORKS SITE

<u>TAXA</u>	<u>POLLEN PERCENTAGES</u>
<u>NOTHOFAGUS AND TREE CONIFERS</u>	
<i>Dacrycarpus dacrydioides</i>	+
<i>Dacrydium cupressinum</i>	1
<i>Libocedrus</i>	x
<i>Nothofagus fusca</i> type	1
<i>N. menziesii</i>	94
<u>TREES AND SHRUBS</u>	
Compositae	+
<i>Coprosma</i>	2
<i>Dacrydium bidwillii</i> type	x
<i>Dracophyllum</i>	+
<i>Elytranthe colensoi</i> type	x
<i>Hoheria</i>	+
<i>Leptospermum</i>	x
<i>Myrsine</i>	+
<i>Pseudopanax</i>	+
<u>HERBS</u>	
<i>Empodisma</i>	+
<u>FERNS</u>	
<i>Cyathea smithii</i> type	29
<i>Dicksonia squarrosa</i>	+
<i>Hymenophyllum</i>	1
<i>Lycopodium billardieri</i>	+
monolete fern spores	5
<i>Phymatodes diversifolium</i>	4

Pollen sum: all woody taxa.

+ noted after count completed

x less than 0.5% recorded.

The bank consists of laharic debris originating in flows off Mt Egmont. There are six soil horizons exposed in the bank (Figure 8). They are highly organic and range in thickness from 0.02 metres to 0.23 metres. Soils B and F contain wood of *D. cupressinum*. Except for Soil A, the soils have well-preserved pollen spectra. On the basis of these pollen spectra, the soils fall into 3 groups: F; E, D, and C; B.

Soil F has a radiocarbon age of $12\ 550 \pm 150$ BP (NZ 1143 A).

Soil E, $11\ 300 \pm 210$ (NZ 1255 A). Soil B, 7160 ± 80 (NZ 1142 A).

(ii) Pollen analysis (Table 3)

Soil F. 12 550 BP

Description: The pollen spectrum is dominated by *Podocarpus* (43%), with lesser amounts of *D. cupressinum* and *Dacrycarpus*. The *D. cupressinum* ratio is 0.27. Minor arboreal constituents include; *Pennantia*, *Carpodetus*, *Plagianthus*, and *Neomyrtus* type. Both *N. fusca* type and *N. menziesii* are present, as well as *Libocedrus*. Scrub pollen types are well-represented, *Coprosma* and *Leptospermum* being the most abundant types. *Pseudowintera*, *Pseudopanax*, *Dracophyllum*, *Hebe* and *Phyllocladus* are other noteworthy occurrences. Cyperaceae (23%), *Empodisma*, *Gunnera*, and *Haloragis* and Gramineae (1%) are the major mire species present. Tree ferns are scarce, reaching only to 3% in total, but there are substantial amounts of monolete fern spores (12%).

Interpretation: A podocarp forest dominated by *P. spicatus*, but with substantial numbers of other podocarp trees including *P. ferrugineus*, *P. totara* and *D. cupressinum*, was established near the site. The site itself was poorly drained and supported a sedge-dominated mire with a scrub cover of *Leptospermum*, *Coprosma* and possibly *Lophomyrtus bullata*.
Soils E, D, C. 11 300 BP - >7160 BP.

A Warea River

B Waiweranui Stream

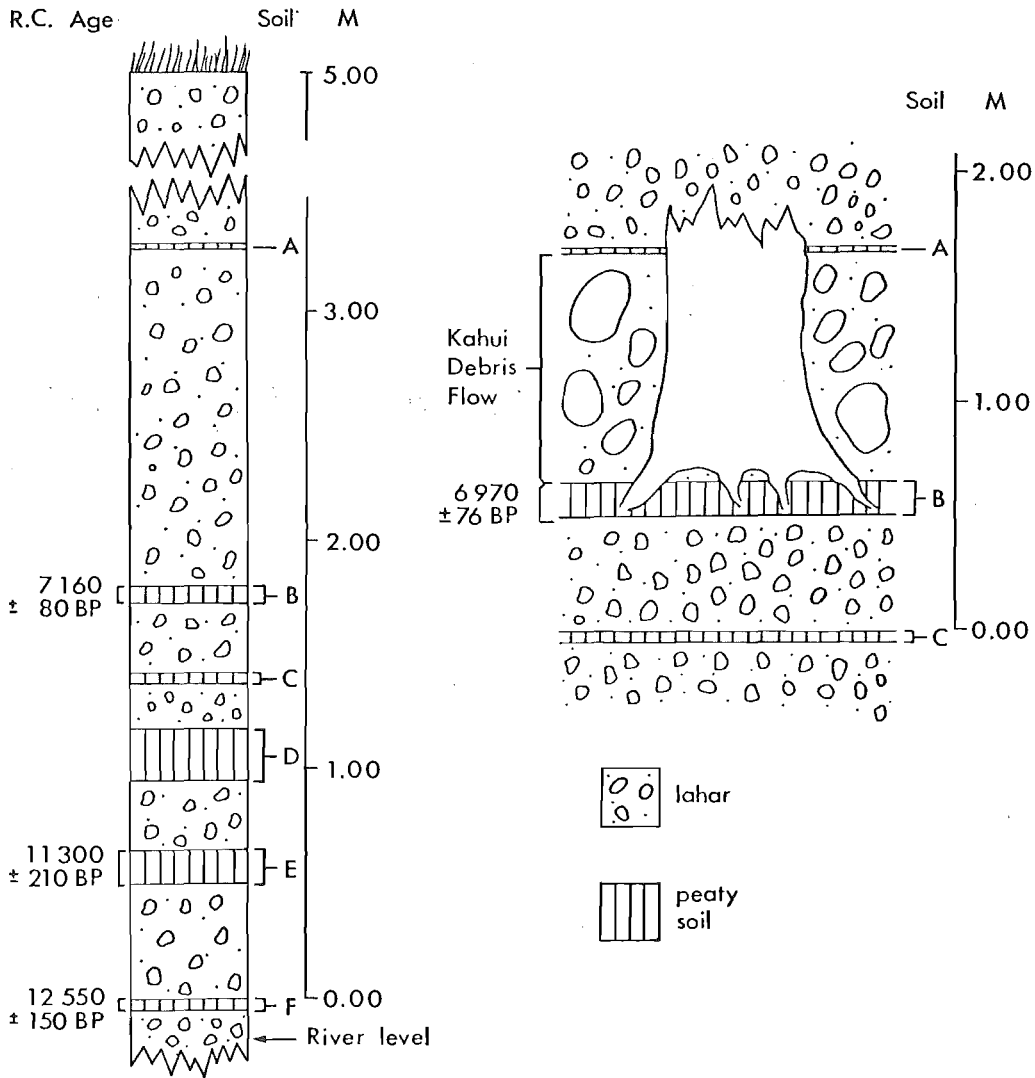


Figure 8. Stratigraphy of Warea River and Waiweranui Stream sites

TABLE 3

POLLEN ANALYSIS: WAREA RIVER; WAIWERANUI STREAM TRIBUTARY;
OPUNAKE BEACH

TAXA	WAREA RIVER					WAIWERANUI			OPUNAKE
	F	E	D	C	B	C	B	A	
Pollen sum: all pollen and spores.									
<i>Nothofagus</i> & tree conifer	41	50	63	64	29	26	44	15	7
Other woody plants	24	6	6	8	19	31	28	45	36
Herbs	1	3	2	x	x	.	.	1	.
Swamp plants	16	18	2	1	1	.	.	3	x
Tree ferns	12	18	22	17	38	38	21	11	48
Fern spores & others	16	3	4	10	13	6	7	25	9
<i>Dacrydium cupressinum</i> ratio	0.27	3.62	3.86	3.12	4.15	11.25	14.17	3.80	
Pollen sum: woody plants and herbs.									
TALL TREES									
<i>Dacrycarpus dacrydioides</i>	6	1	3	4	3	1	1	+	.
<i>Dacrydium colensoi</i>	.	.	2	1	x	.	.	.	.
<i>D. cupressinum</i>	12	59	65	64	45	41	55	20	10
<i>Libocedrus</i>	1	5	1	.	.	.	.	.	.
<i>Nothofagus fusca</i> type	1	1	1	+	x	.	x	+	+
<i>N. menziesii</i>	x	.	.	.	.	.	.	.	.
<i>Podocarpus ferrugineus</i>	6	2	3	2	.	1	1	1	1
<i>P. spicatus</i>	29	11	11	17	8	2	1	2	4
<i>P. totara</i>	8	3	3	2	2	x	1	2	1
Total podocarp	43	16	17	20	10	4	4	5	6
TREES & SHRUBS									
<i>Ascarina lucida</i>	.	.	1	x	34	39	10	6	9
<i>Carpodetus serratus</i>	+	.	+	+	x	+	+	+	.
Compositae	x	1	.	.	+	.	.	1	x
<i>Coprosma</i>	10	x	1	1	.	x	.	1	2
<i>Coriaria</i>	.	.	x	.	.	.	.	61	.
<i>Dodonaea viscosa</i>	.	+	.	.	.	.	.	+	25
<i>Dracophyllum</i>	+	1	.	.	.	.	.	.	.
<i>Drapetes</i>	.	.	.	.	+	.	.	.	.
<i>Elaeocarpus</i>	x	x	1	1	1	.	.	x	.

TABLE 3 (cont'd)

TAXA	WAREA RIVER					WAIWERANUI			OPUNAKE
	F	E	D	C	B	C	B	A	
<i>Griselinia</i>	x	.	.	.	.	.	.	.	.
<i>Hebe</i>	3	.	.	.	.	.	.	.	.
<i>Leptospermum</i>	6	3	2	1	1	.	6	1	x
<i>Metrosideros</i>	.	1	x	5	4	6	8	x	15
<i>Myoporum</i>	.	.	.	.	.	.	.	.	1
<i>Myrsine</i>	1	.	x	2	.	9	8	1	11
<i>Neomyrtus</i> type	3	x	.	.	.	.	.	.	15
<i>Nestegis</i>	+	.	x	.	.	.	.	x	.
<i>Paratrophis</i>	.	.	x	.	x	.	.	.	1
<i>Pennantia</i>	6	1	x	+	.	.	.	x	.
<i>Phyllocladus</i>	x	.	.	.	.	.	.	.	1
<i>Pittosporum</i>	+	.	.	.	.	.	.	.	.
<i>Plagianthus</i>	1	+	x	.	.	.	+	.	.
<i>Pseudopanax</i>	2	3	x	+	.	+	6	x	.
<i>Pseudowintera</i>	1	.	.	.	.	+	+	+	.
<i>Rubus</i>	1	x	x	1	.	.	.	x	.
CLIMBERS, EPIPHYTES ETC.									
<i>Dactyloctenium aegyptium</i>	.	.	.	.	.	.	+	.	.
<i>Freycinetia banksii</i>	.	.	.	.	+	.	.	.	.
<i>Muehlenbeckia</i>	2	+	1	.	.	.	+	.	.
<i>Tetrapathaea tetrandra</i>	.	.	.	.	.	.	.	.	+
<i>Tupeia</i>	.	.	.	.	.	.	x	.	4
HERBS									
<i>Acaena</i>	.	.	.	.	.	.	.	+	.
<i>Astelia</i>	.	1	3	x	1	.	.	1	.
<i>Chenopodium</i>	.	.	+	.	.	.	.	.	.
<i>Collospermum</i>	.	.	.	.	.	.	+	.	.
Gramineae	1	x	.	.	.	.	.	.	.
<i>Haloragis</i>	.	4	+	.	.	.	.	.	.
<i>Plantago</i>	x	.	.	.	.	.	.	.	.
<i>Myosotis</i>	.	.	+	+	.	.	.	.	.
<i>Nertera</i>	.	.	.	.	.	.	.	x	.
<i>Ranunculus</i>	.	.	+	.	.	.	.	.	.

TABLE 3 (cont'd)

TAXA	WAREA RIVER					WAIWERANUI			OPUNAKE
	F	E	D	C	B	C	B	A	
SWAMP HERBS									
Cyperaceae	23	16	3	2	1	.	.	.	1
<i>Empodisma</i>	x	x	.	.	.	.	.	.	+
<i>Gleichenia</i>	.	13	+	.	.	.	.	.	.
<i>Gunnera</i>	1	+	.	.	.	.	.	5	.
<i>Leptocarpus</i>	.	1	.	.	.	.	.	.	.
<i>Myriophyllum</i>	.	.	.	.	x	.	.	.	.
TREE FERNS									
<i>Cyathea dealbata</i> type	x	.	1	.	1	+	1	+	88
<i>C. medullaris</i>	.	+	+	.	+	+	+	x	3
<i>C. smithii</i> type	3	29	28	20	71	66	25	18	20
<i>Dicksonia fibrosa</i>	+	+	.	.	.	1	x	.	.
<i>D. squarrosa</i>	x	1	2	4	5	+	3	.	.
Total tree fern.	3	30	31	24	78	67	29	19	111
FERNS, LYCOPODS									
<i>Hymenophyllum</i>	x	+	+	+	+	+	1	.	.
<i>Lycopodium billardieri</i>	.	+	+	+	x	x	+	.	.
<i>L. fastigiatum</i>	+	x	1	.	.	.	.	.	.
<i>L. scariosum</i>	.	.	+	.	.	.	.	+	.
<i>L. volubile</i>	+	.	+	+	x	.	1	26	.
Monolete fern spores	12	4	5	10	19	6	6	15	20
<i>Phymatodes</i>	12	2	1	3	7	3	1	1	x

. not recorded

+ noted after count completed

x less than 0.5% recorded.

Description: *D. cupressinum* is the major arboreal pollen type: the *D. cupressinum* ratio ranges from 3.86 to 3.12. *Podocarpus* (mainly *P. spicatus*) is the only other tree species of consequence, except for *Libocedrus* (5%). The same range of hardwood taxa are present as in Soil F, but with the addition of *Ascarina*, *Dodonaea* and *Metrosideros*. Of these, only *Metrosideros* is at all abundant. Scrub levels are very low; only *Leptospermum* reaches more than 1%. The percentages for Cyperaceae drop from 16% in Soil E to 2% in Soil C. The only other mire type, *Gleichenia*, is abundant in Soil E but vanishes after that. Tree fern percentages are high (24-31%). Monolête fern spores are common.

Interpretation: *D. cupressinum* replaced *P. spicatus* as the dominant tree, and tree ferns increased greatly. The mire that was present earlier diminished in size, and therefore there was a reduction in the amount of scrub. A dense *D. cupressinum* stand, probably with only a few associated hardwood trees, dominated the area around the site. *Libocedrus* may have been present in the forest during the development of Soils E and D, but, if so, it was eliminated later. The changes that occurred between the deposition of Soil F and Soils E-C did not merely involve the local replacement of the dominant tree; the upsurge in the amount of tree fern, the arrival of *Ascarina* and *Metrosideros* all point to a major change in the vegetation type and structure.

Soil B. 7160 BP.

Description: The dominance of *D. cupressinum* (ratio rises to 4.35) is more complete. *Podocarpus* falls to its lowest value in the whole soil sequence. *Ascarina*, at 34%, becomes one of the most common pollen types. Tree ferns more than double to reach 78%.

Interpretation: Not much reliance can be placed on the further increase of *D. cupressinum* as an indicator of major changes in the forest composition as we are dealing now with a soil formed beneath a forest canopy, and therefore over-representation is to be expected. However,

the great increase in *Ascarina* is of significance as it demonstrates that *Ascarina* was an abundant understorey tree.

5.2.6 Waiweranui Stream Tributary

Location: NZMS1 - N118/526665. Altitude: 310 metres.

(i) Geology and Chronology

Stumps, 1-2 metres in height, of trees of *D. cupressinum* are exposed in the bank of a tributary of the Waiweranui Stream (Figure 8). Three buried soils are preserved in association with the stumps. The lowermost soil, C, is 0.65 metres below the base of the stumps. On top of it is a 0.50+ metre thick lahar flow, followed by 0.15 metres of peaty soil, B, in which the stumps are rooted. On top of the lahar (Kahui Debris Flow) that buried the forest, and at the level of the top of the stumps, is a further thin, buried soil, A. Soil B has a radiocarbon age of 6970 ± 76 BP (NZ 1144 A). All three soils have well-preserved pollen and fall into 2 groups on the basis of their pollen spectra: B and C; A.

(ii) Pollen analysis. (Table 3)

Soils B and C.

Description: *D. cupressinum*, *Ascarina* and tree fern (mostly *C. smithii* type) percentages are very high. *Metrosideros*, *Myrsine* and monoletic fern spores are the only other pollen and spore types that are at all common.

Interpretation: These pollen spectra were derived from a *D. cupressinum* -*Metrosideros* forest with an understorey dominated by *Ascarina* and tree ferns.

Soil A.

Description: The major difference between this soil and the last two, is the decrease in tree pollen types and tree fern spores, and the very

large amount of *Coriaria* (61%), *Lycopodium volubile* (26%), and monolete fern spores recorded. The *D. cupressinum* ratio drops to 3.8, *Ascarina* to 6% and *Metrosideros* occurs at a level of less than 1%.

Interpretation: All the differences between this sample and the other two underlying soils can be attributed to the effect of the Kahui Debris Flow. *Coriaria* is a shrub that flourishes after forest destruction, and *L. volubile* is often found as a scrambler in scrubland or forest margins. The monolete fern spores may have been derived from any of a number of species of fern that favour open or disturbed sites. *Ascarina* and *D. cupressinum* need not have, and almost certainly did not, become less common in the region as a whole. The drop in their pollen percentages reflects the cessation of pollen deposition from trees at the site.

5.2.7 Opunake Beach

Location: NZMS1 - N118/445431. Altitude: sea level.

(i) Geology and Chronology.

This site is exposed in an 18 metre high sea cliff at the northern end of Opunake Beach (Figure 7). The site consists of 0.22 metres of peaty soil directly above the Oakura Tephra. It is in turn overlaid by the Opua Formation. The Opua Formation is of laharcic origin, and is dated by wood lying directly beneath it at 6570 ± 110 BP (NZ 1781 A). Only one sample, from the top few centimetres of the soil, was analysed because the pollen preservation from the lower soil layers was extremely poor.

(ii) Pollen analysis. (Table 3)

Description: Pollen of tall podocarp trees is found only in low amounts and nearly half of this total is *Podocarpus*, the rest being *D. cupressinum*. The most abundant pollen type is that of *Dodonaea*

viscosa (25%). Other significant contributors to the pollen sum are *Metrosideros*, *Ascarina*, *Myrsine* and *Tupeia*. An interesting record is that of *Myoporum* as the pollen of this small tree is rarely seen in fossil preparations. Tree ferns, mostly *Cyathea dealbata*, are very well-represented.

Interpretation: *Tupeia* is common as a parasite on a range of scrub species and also on some trees, but mainly when they are growing in open sites. Its presence indicates, therefore, that scrub was the dominant vegetation at the site. *Dodonaea* is a shrub and is never found in dense forest. A reasonable reconstruction is that a low, scrubby forest made up mainly of *Metrosideros*, *Myrsine*, *Dodonaea* and *Ascarina* grew at the site. The presence of *Dodonaea* in such high percentages, and the occurrence of *Myoporum* is not surprising, as both species are characteristic of coastal regions, although not confined to them.

5.2.8 Ngaere Swamp

Location: NZMS1 - N119/900474. Altitude: 244 metres.

(i) Geology and Chronology

Ngaere Swamp is a large (8 x 12 kilometres) peat-filled basin directly to the east of the township of Eltham (Figures 7 & 9). The swamp is formed at the junction of the Egmont ringplain and the rolling country of eastern Taranaki. The swamp is divided into two nearly equal sized areas; an upper northern and a slightly lower-lying southern segment, separated by a low, east-west trending ridge. The swamp is drained by the Waingongoro River to the west, and by the Ngaere Stream, a tributary of the Patea River, in the north.

In early European times the swamp was partially covered with a dense swamp forest of *Dacrycarpus*, *Laurelia* and other trees tolerant of poor drainage. Towards the centre of the basin there was scrub, mire

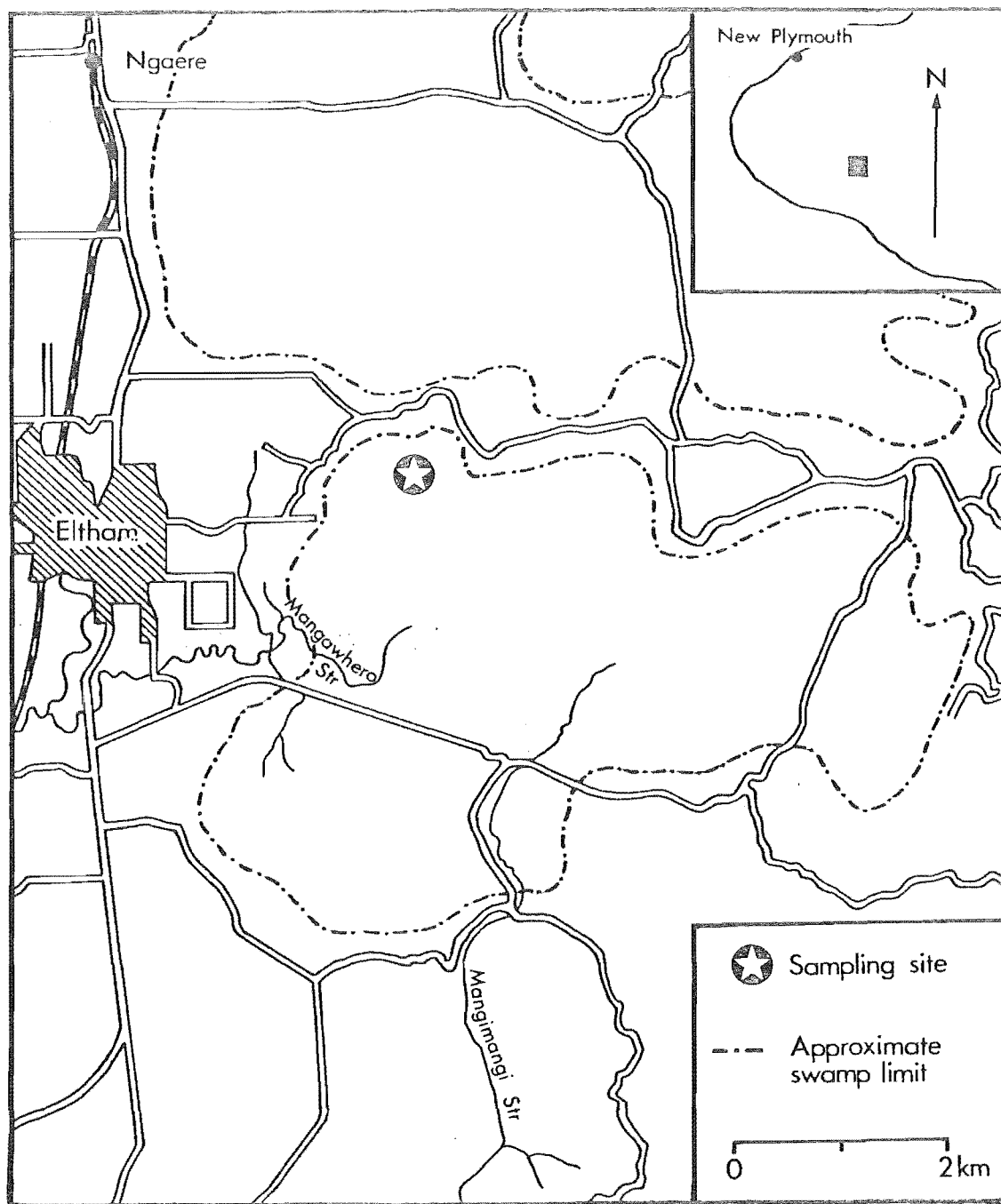


Figure 9. Ngaere Swamp

herbs and, in places, shallow open water lagoons (Every 1974).

Clearance and drainage of the swamp has left only one, depauperate patch of the original swamp forest. This small remnant lies near the western edge of the swamp and includes abundant *Dacrycarpus*, *Beilschmiedia*, and also *Weinmannia racemosa*, *Laurelia*, *Myrsine australis*, *M. salicina*, *D. cupressinum* and *Melicytus*.

Drainage of the swamp has lowered the level of the peat in the basin, through shrinkage and oxidization of the surface peat. Evidence of the higher swamp level can be found in the soils on a low knoll (N119/902475) at the western side of the swamp, close to the drilling site. On the knoll there is a clearly marked transition from gley soils to non-gleyed soils at about 3 metres above the present (1978) swamp surface. This transition level presumably marks the previous height of the swamp surface. Subsidence of the peat surface has not been uniform. In the swamp forest remnant mentioned above, the exposed roots of *Dacrycarpus* suggest that the swamp surface near the edge was only lowered by about 1 to 1.5 metres.

The bore site is in a drain in the western side of the lower swamp, about 450 metres from the edge. The swamp is now in pasture and cultivation has left a very compact top layer of oxidized peat. This layer, and the thick deposits of wood that occur throughout the peat column, made it impractical to attempt a traverse of the swamp to obtain a stratigraphic cross-section. The top 0.60 metres of the peat column was not sampled because of the obvious disturbance as a result of shrinkage, cultivation and stock-trampling. In February, 1974, when the samples were taken, the water-table at the site was 1.45 metres below the peat surface.

Several tephras were found in the peat profile, all andesitic and from Mt Egmont. The identification of these tephras is not straight forward, but the most probable correlation with known tephras in nearby exposures is shown in Figure 10. Several dates have been obtained for some of these tephras that are exposed near their source on Mt Egmont.

Two distinctive tephras, the Burrell Formation (c. 295 BP) and the Newall Formation (c. 400 BP) are found elsewhere in the swamp. At this site, however, the partial destruction of the upper peat layers has reduced them to a barely distinguishable scatter of lapilli. P4 (tephras designated by letters and numbers are yet to be formally described and published), also known as Kaupokonui Tephra, is the first recognizable tephra in the profile. Its age is not known exactly but it lies between 1000 and 2000 BP: most probable age is around 1500 BP. The second tephra down is identified as the Manganui Tephra. On Mt Egmont this tephra has been found in a drill hole in the Ahukawakawa Swamp; it lies between samples dated as 2890 ± 100 BP (NZ 3423 A) and 3320 ± 60 BP (NZ 3139 A). Elsewhere on the mountain it has been shown to be between 4000 and 2000 years in age. P1 and P2 (indistinguishable in the swamp profile) are both younger than 5140 BP, and definitely older than 3300 BP. Correlation on Mt Egmont suggests that the true age for this group of tephras is close to 4000 BP.

Contamination of the upper peat layers by the roots of trees growing alongside the site made it unsuitable for radiocarbon dating. Therefore the ages for the uppermost tephras are of great importance. From the inferred ages of the tephras in the upper 1.0 metre of peat, it seems as though either the peat growth slowed after about 4000 BP, or that most of the shrinkage and loss of peat has taken place in the upper layers. From 0.60 metres to the surface the peat was completely dry, waxy and hard to wet; below this the peat becomes progressively more wet

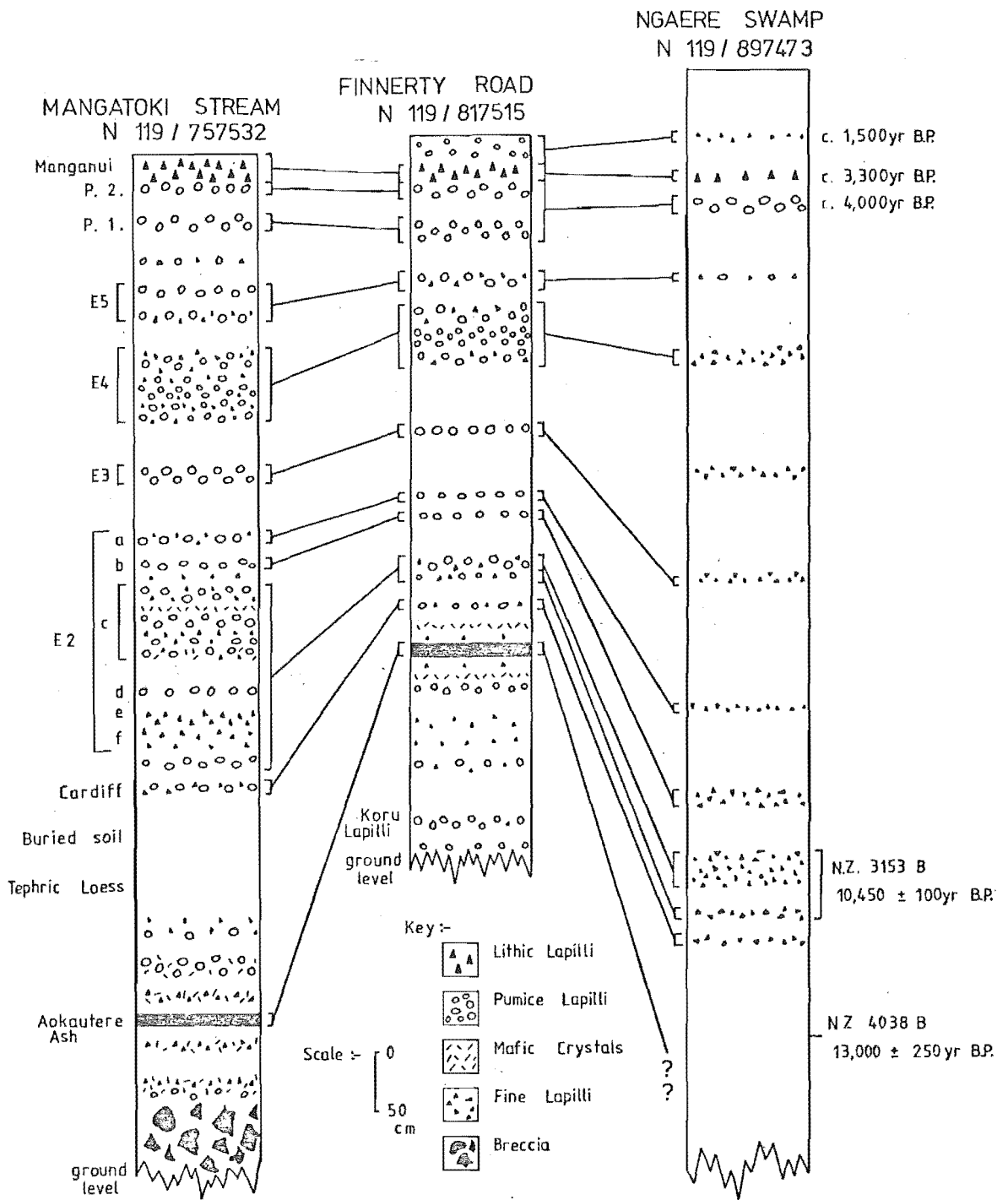


Figure 10. Tephra correlation of exposures within Eltham County (V.E. Neall, unpublished data) with Ngaere Swamp

and the water table, as mentioned above, is at about 1.45 metres in summer. It seems therefore that the loss of peat and shrinkage occurred above the level of the Manganui Tephra as there is unlikely to have been volume loss from permanently wet peat. There may well have been a slower growth rate also but, if the evidence for higher swamp levels noted earlier is taken into account, this need not have been so. If the estimated swamp level before drainage is added to the depth of peat above the P1 and P2 tephra layer, the total peat thickness before drainage would have been close to 4 metres, thus giving a peat accumulation rate of about 1.0 millimetres a year. If the accumulation rate between the lower level of the peat column dated at 10 150 BP (6.80 metres) and the level of the Manganui Tephra (.90 metres) is calculated the result is 0.8 millimetres per year, which is close to the accumulation rate derived for the upper peat layers. Assuming that the accumulation rate in swamp was close to 1 millimetre per year, and reasonably constant, the age of the Zone 5/6 boundary is close to 5500 BP. Similar calculations give approximate ages for the other zone boundaries.

(ii) Pollen analysis. (Plate 4)

The pollen diagram is divided into 5 zones.

Ngaere 1 ? - 8.3m

Description: This zone is defined by the very high levels of Gramineae pollen (over 80% at the peak, and averaging 60-70%) and the absence of all but trace amounts of podocarp-hardwood taxa. Tree taxa are represented by low percentages of *N. fusca* type and *N. menziesii* pollen. There are small quantities of *Coprosma*, *D. bidwillii* type, and a somewhat larger representation of *Phyllocladus*. *Hebe*, *Myrsine*, *Dracophyllum*, *Cyathodes fraseri* and *Drapetes* are present in trace amounts only. Besides Gramineae, there is a varied herb flora. Umbelliferae (mainly *Oreomyrrhis*) is the most prominent type, but others include Cruciferae,

Plantago, *Taraxacum* type, *Epilobium*, *Selliera*, *Gentiana*, and *Geranium*. Mire plants are represented by Cyperaceae and traces of *Gleichenia*, *Empodisma* and *Myriophyllum*. Towards the Zone 1/2 boundary there are traces of some podocarp-hardwood taxa, including: *Carpodetus*, *Knightsia*, *Nestegis*, and *Ascarina*. *Nothofagus fusca* type and *N. menziesii* increase in the top half of the zone.

Interpretation: The high Gramineae levels and very low frequency of woody plants indicates that the Ngaere Basin was covered with an open grassland. It is likely that this grassland extended over much of the Egmont ring-plain as well. Most of the herbs recorded in this zone are characteristic of grassland or open environments. There may have been some shrubs such as *Phyllocladus alpinus*, *D. bidwillii* or *D. biforme* present, as well as low-growing composites and *Coprosma*. *N. fusca* group forest may not have been in the general vicinity of Mt Egmont at all. The trace levels of podocarp-hardwood taxa in the upper portion of the zone are the first indication of the establishment of forest in Taranaki.

Ngaere 2. 8.3-7.4m.

Description: At the beginning of the zone Gramineae account for 45% of terrestrial pollen but by the end of the zone this figure is down to 5%. Other herbs prominent in Zone 1 become scarce. *Phyllocladus*, *D. bidwillii* type, *Hebe*, *Drapetes* and *N. fusca* types either vanish or drop to low levels in the course of the zone. *N. menziesii*, which appeared in the top half of Zone 1, remains at levels of 1-2%. At the same time there is a spectacular increase in *Podocarpus* from 1% at the Zone 1/2 boundary to 55% at the Zone 2/3 boundary. At the same time numerous tree taxa make a first appearance or increase. Chief among these are: *D. cupressinum*, *Dacrycarpus*, *Plagianthus*, *Carpodetus*,

Elaeocarpus, *Paratrophis*, *Nestegis*, and *Libocedrus*. Scrub taxa make a brief surge at the beginning of the zone, reaching a peak of 63% at 8.20 metre level, but then dropping gradually to a total of 26% at the upper boundary. Tree ferns especially show a steady increase from the beginning, and with a steep rise two-thirds of the way through. Cyperaceae rises to dominance early on, but is supplanted later by *Gleichenia*.

Interpretation: Regionally, podocarp-hardwood forest was steadily replacing grassland. There was a brief increase in *N. menziesii*, but the pollen percentages are so low that it is doubtful if there was any *N. menziesii* forest near the site. In the first half of the zone a dense scrub developed. At first it had much Compositae and *Dracophyllum* but they did not persist, and *Leptospermum*, *Myrsine* and *Coprosma* were the main scrub species from midway through the zone. The spectacular increase in tree ferns indicates that forest had either arrived at the site, or was extremely close, as tree fern spores are poorly dispersed. The original sedge and *Phormium* mire gave way to bog vegetation during this zone. The bog probably had a *Leptospermum* scrub cover.

Ngaere 3 7.4-6.8m.

Description: *Podocarpus*, mainly *P. spicatus*, is the dominant tall tree in this zone. *D. cupressinum* increases gradually throughout, rising from 8% to 13%, while *Dacrycarpus* is steady at c. 6%. *N. menziesii* declines and does not persist beyond this zone, but *N. fusca* type maintains the low levels (1% or less) that it had at the end of Zone 2. *Libocedrus* is steady at 1% and, in contrast to Zone 2, is consistently present. *Plagianthus*, *Pennantia* and *Elaeocarpus* are the most abundant hardwood taxa. Tree ferns peak in the first few samples at 40%, but gradually fall away from this high. *Coprosma* and *Myrsine* lose their pre-eminent position in this zone, while *Leptospermum*, after an initial low, is the

dominant scrub type. This is the last zone in which Gramineae is present in every sample: in only one sample in subsequent zones does it reach a level of 1% or more. The main mire plants are the same mixture of Cyperaceae, *Gleichenia* and *Empodisma* established at the end of Zone 2.

Interpretation: A diverse podocarp-hardwood forest was the dominant vegetation type during this zone. The abundance of *Plagianthus* and *Paratrophis*, and the relatively low amounts of *D. cupressinum*, suggest that its closest present day analogues are the forests of the lowland east coast of both islands. There is no reason to believe *N. fusca* group forest was any more abundant or closer to Ngaere than it is at present, but there may have been more *N. menziesii* in the Taranaki region. *Libocedrus* was certainly more common than it is now, and may possibly have been scattered throughout the forest. The mire surface was formed out of a mixture of sedges, *Gleichenia* and *Empodisma*, plus a scrubby cover of *Leptospermum* as before. Some *Dacrycarpus* was likely to have established at the swamp edge.

Ngaere 4. 6.8-6.3m.

Description: There are no major changes in the forest dominants. The *D. cupressinum* ratio is steady at about 0.4, and *Podocarpus* pollen, mainly *P. spicatus*, is still the most abundant tree type recorded. *N. menziesii* is not recorded, *N. fusca* type falls to trace amounts as do *Libocedrus* and Gramineae. *Libocedrus* is only rarely recorded after Zone 4, and *N. fusca* type is usually only noted, or found in trace amounts. *Ascarina lucida*, which was recorded occasionally in Zones 1-3, now has continuous values, and *Alectryon excelsum* is consistently present. Tree fern levels are lower than in Zone 3, but still average 25%. *Leptospermum*, Cyperaceae, *Empodisma* and *Gleichenia* values are little changed.

Interpretation: Although the local changes were restricted to the arrival of *Ascarina*, the spread of *Alectryon* and slight increase in *D. cupressinum*, on a regional scale the changes may have been more far-reaching. From this zone on *N. menziesii* ceased to be of any importance in the region. It may have shrunk to its present restricted distribution in inland Taranaki. Likewise, *Libocedrus*, which was widespread, seems to have retreated. *N. fusca* type pollen is so well dispersed that its decline at the end of this zone certainly represents a regional event. Possibly, during Zone 4 the last remnants of *N. fusca* group forest close to lowland Taranaki were eliminated.

Ngaere 5. 6.3-2.2m.

Description: In the first 5 samples of Zone 5 the *D. cupressinum* ratio increases by more than 6 times. *P. spicatus*, hitherto the dominant tall tree pollen type, is permanently reduced to percentages approximately a third of those prevailing in Zones 3 and 4. *D. cupressinum* frequencies generally remain above 25% and those of *P. spicatus* below 15% for the rest of the diagram. *Plagianthus*, *Pennantia* and *Paratrophis* become less abundant, while *Alectryon* increases in frequency and remains common for the remainder of the zone. *Dodonaea viscosa*, *Ascarina*, *Tetrapathea*, *Tupeia*, *Nestegis* and *Elaeocarpus* reach their greatest abundance within this zone, and *Freycinetia* and *Loranthus* are confined to it. Myrtaceae (mainly *Eugenia maire*) undergoes a sharp increase just after the beginning of the zone, rising from levels of 1% or less to over 50%. Myrtaceae dominance is short lived however, and by the 5.0 metre level, it sinks to 15%. From that point on *Dacrycarpus* is abundant. Mire pollen types undergo a decline at the commencement of the zone, and do not recover. *Empodisma* and *Gleichenia* are found only in trace amounts after the first few samples, and Cyperaceae average no more than 1-2%. *Leptospermum* is effectively eliminated as a major contributor to the pollen sum at the same time: *Coprosma* and *Myrsine* fall also but recover in the top half

of the zone. Tree fern percentages fluctuate between 50% and 10% for the first half of the zone, but from then on are quite steady at about 15%.

Interpretation: From the beginning of Zone 5 on, the Taranaki forests must have closely resembled those of the present. *D. cupressinum* was the most abundant podocarp tree, as it is today, and other podocarps became minor constituents. Some hint is given of the variation within these forests from the hardwood taxa recorded, but there must have been many more species involved. Of all the species recorded, *Ascarina lucida* is the one that marks this zone as distinctive. It was present in the forest surrounding Ngaere Swamp and was one of the major understorey trees. The previous sedge-*Empodisma-Gleichenia* mire association, with its associated scrub cover of *Leptospermum*, was replaced during the beginning of this zone by swamp forest. At first *Eugenia mairi* was the main tree in this forest, but later it was replaced. The subsequent swamp forest was dominated by *Dacrycarpus*, but included many other trees and shrubs including *Elaeocarpus* (probably *E. hookerianus*), *Cyathodes fasciculata* and various *Coprosma* species. The swamp trees supported epiphytes and scramblers among them *Collospermum* and *Freycinetia*.

Ngaere 6. 2.2-0.7m.

Description: This zone is defined by the appearance of continuous percentages of *Dacrydium colensoi* and the decline of *Ascarina*. *Nestegis* values fall and *Freycinetia* and *Tetrapathaea* are not recorded. From mid-way through the zone *Knightia excelsa* appears consistently for the first time and *Dodonaea* becomes rare. The frequency of the major tree pollen types is substantially unaltered.

Interpretation: Although the basic structure of the forest appears not to have altered, some minor but significant changes occurred. *Ascarina* and *Dodonaea* both seem to have become uncommon, while *Knightia* became

established in the surrounding forests. The very marked rise and subsequent fall of *D. colensoi* shows that there was considerable alteration of the swamp forest. For a period, *D. colensoi* must have been the major tree species on the swamp surface. At the same time that *D. colensoi* was dominant, there was a small peak of *Gleichenia*, a mire herb that is virtually absent before and after, and this may indicate that the forest structure was more open.

Ngaere 7. One sample only - 0.60m.

Description: There is a sharp rise in the *D. cupressinum* percentage to the highest level recorded in the whole diagram (60%), and a drop in the percentages of other tree types. Tree ferns rise to their highest percentages since midway through Zone 5, and monolete fern spores attain values more than twice the highest previously recorded percentage.

Interpretation: There was a sudden change in forest composition as a result of the growth of *D. cupressinum* either on, or very near the site. The increase in fern spores suggests the local development of a forest more suited to a drier swamp surface. There is no indication of significant change in the regional forest.

5.3 DISCUSSION

5.3.1 Chronology

The chronology of the Aranui sites, that is the buried soils at Warea River, Waiweranui Stream and Opunake Beach, and Ngaere Swamp, is based entirely on radiocarbon dating. The dates are consistent and there is no reason to suspect contamination of any of the samples.

With the late and mid-Otiran sites the chronology is not as secure. Contamination of material older than 20 000 BP does not have to be great to produce a completely erroneous age. For this reason the dates from

Mangahume (23 000 BP) and the top of the Inaha section (33 000 BP) must be treated with caution.

The two amino acid racemization dates from the Inaha section give only a fairly crude approximation to the true age of the samples. Amino acid racemization dating of the sequence of marine-cut benches in Taranaki (B. Pillans pers. comm.) allows correlation with the sequence of coral reef terraces that have been accurately dated and analysed to produce a long sea level chronology (Bloom et al 1974). On this basis, and the amino acid date for the Manaia Lignite, the Inaha marine bench is considered to have formed about 80 000 BP. The Inaha marine bench therefore provides a time plane and ties the Taranaki sequence into the well-established long chronologies from coral terraces and deep sea cores (Shackleton 1977).

5.3.2 Vegetation history

(i) Nature of the Otiran pollen sequences

The interpretation of the Otiran sites, consisting as they do of thin wedges of organic sediments intercalated between thick deposits of gravel and sand, is not completely straightforward.

The Inaha section has 6 bands of organic sediment, separated by sands, gravels, tuffs and laharic units. As the proportion of organic deposit to inorganic is so low, the question arises as to how much time is represented by the peats and organic silts. No clue is given by the nature of the deposits. The lahar units were obviously emplaced rapidly, but this need not have been so with the other gravels, sands and silts that make up the section. The pollen sequences, however, suggest that the organic horizons, as well as not being contiguous, are separated by substantial time intervals. With the exception of the two lowermost organic beds (A and B) each organic horizon has a sequence from high grass pollen frequencies at the base, through a period of low grass pollen

frequencies, and then a return to high grass frequencies at the top. This pattern of grass pollen abundance creates a 'U-shaped' curve. High grass pollen percentages could be expected in the basal sediments of a given horizon as a result of devastation of the previous vegetation by lahars or other erosion that was producing the inorganic sediments. The same reasoning cannot apply to the rise of grass pollen percentages in the uppermost sediments of a given organic horizon.

It seems therefore that each of the organic horizons, rather than being fortuitously preserved by rapid deposition of inorganic sediments, in fact represents a distinct episode during which the environment favoured both the deposition of organic sediments and also the growth of woody plants. It would appear that for a substantial portion of the time represented by the Inaha section the environment was inimical to woody vegetation, and that during these periods most of the inorganic sediments were laid down.

I will refer to the woody plant dominated episodes as "interstadials". Whether or not they are in fact discrete enough to justify this term is not clear; only a far more continuous record than the one we have could answer this question.

The Mangahume and Stent Road sites do not conform to the general Inaha pattern. In neither of them is there any trace of the U-shaped curve for grass pollen frequency. It may be, therefore, that these sites were fortuitously preserved by lahars that sealed them off from subsequent erosion.

(ii) General Otiran vegetation sequence

The general outline of vegetation change in the Taranaki region from 80 000 BP to approximately 13 000 BP is reasonably clear. It can be assumed that the high sea level that cut the Inaha bench at around 80 000 BP was associated with mild climatic conditions, and therefore

with forest. By the time the first organic sediments were deposited at Inaha, the vegetation was open shrubland, and it is unlikely that there was any forest in the region. At about 60 000 BP there was a well defined interstadial episode (Inaha C) during which podocarp forest was dominant at Inaha and probably throughout lowland Taranaki. This major interstadial was followed by at least three other interstadial events, during which scrub was dominant. The best developed of these interstadials (Inaha F) began before 33 000 BP and persisted until at least 28 000 BP. This interstadial is not as well marked in Taranaki as at other North Island sites, but at least one locality had *N. menziesii* forest (New Plymouth Waterworks). At Inaha there were unlikely to have been substantial areas of forest at this time, but *Libocedrus* and *N. menziesii* definitely underwent a minor expansion.

The Mangahume and Stent Road sites are younger than Inaha F and the New Plymouth Waterworks site and do not contain much tree pollen, although they are scrub dominated. From this it may be concluded that the peak of the Inaha F interstadial was past by 23 000 years ago.

(iii) Otiran scrub and grassland.

Although many scrub pollen taxa are recorded only a few are of value in giving a precise idea of the specific nature of the shrubland. The most important types recorded are; *D. bidwillii* type, *Phyllocladus*, *Leptospermum*, *Coprosma*, *Myrsine*, *Dracophyllum* and *Compositae*. Some of these taxa can be confidently ascribed to a particular species. *Phyllocladus* is certainly *P. alpinus*; *Dacrydium bidwillii* type is either *D. bidwillii* or *D. biforme*; *Leptospermum* is either *L. scoparium*, or less likely, *L. ericoides*; *Myrsine* probably *M. divaricata* or *M. nummularifolia*. The others belong to very large genera (i.e. *Dracophyllum* and *Coprosma*) or a very large family (*Compositae*) in which the pollen of individual species is, for all practical purposes, indistinguishable. Although

Leptospermum, *Myrsine*, *Dracophyllum* and *Compositae* are insect-pollinated, their pollen is as abundant in the record as that of the wind-pollinated taxa.

There are many herbs associated with the scrub phases in the pollen diagrams; nearly all can be identified only to the family or genus level, and with the exception of *Gramineae* and *Umbelliferae*, are so sporadic that they can give only the most generalized clues to the nature of the vegetation.

There are no obligate associations of one pollen type with another. Some types are found together more frequently than others; *D. bidwillii* type and *Phyllocladus*, and also *Myrsine* and *Coprosma*, are cases where this seems to be so. However, there is no indication of readily identifiable, recurring groups. The pattern is rather one of constantly shifting dominance involving the major pollen types listed above.

The abundance of insect-pollinated scrub types; the presence of often large amounts of *Gramineae* pollen; and the small but consistent quantities of herbs of open places such as *Gentiana* and *Taraxacum* all point to the vegetation being very open. Although there is no direct evidence for it, the vegetation was most likely a mosaic of scrub and grassland for much of the time, with constant shifts in dominance as a result of soil or climate changes favouring one species over another.

In structure and composition the vegetation during the Otiran in Taranaki seems to have resembled that which grows above tree line in many places at present. However, this is only a superficial resemblance. Some of the species that made up the Otiran scrubland in Taranaki do not extend above tree line to any significant extent: examples of such species are *P. alpinus*, *D. bidwillii* and *D. biforme*, and *Leptospermum*.

In addition, *Leptocarpus similis* and *Phormium tenax*, two mire plants that were almost certainly present at stages, will not grow at altitudes higher than montane.

The best modern analogues for the Otiran scrubland can be found in those areas below the climatic tree line where a combination of factors, usually including poor soil, exposure and fire, have induced vast areas of scrubland in areas suitable for forest. The best examples of these are found in the inland valleys of the Southern Alps where fire, droughts and frost have encouraged the development of open scrublands with species of Compositae, *Dracophyllum*, *Coprosma*, and Myrsine, as well as *D. bidwillii*, *P. alpinus* and *Leptospermum*. Recent pollen spectra from some of these scrub areas (Pocknall 1979), while tending to have much more tree pollen represented than the Otiran sites, match the Otiran records fairly well.

The possible role of fire in creating the Otiran vegetation pattern in Taranaki needs further discussion. As nearly all the Taranaki Otiran pollen sites have abundant microscopic charcoal fragments in them, fire was frequent. Recovery of low subalpine forest after fire is slow: Calder & Wardle (1969) estimate that it can take up to 200 years before such species as *Dracophyllum longifolium*, *Dacrydium biforme* and *Libocedrus bidwillii* reach maturity. In subalpine scrub the early colonizers after fire are scrubby composites such as *Senecio bennettii* and *Cassinia fulvida*, and various *Hebe* spp, but it takes at least 75 years before *Dracophyllum longifolium* and *Phyllocladus alpinus* regain their original dominance. Calder & Wardle also found that although *Nothofagus solandri* var. *cliffortioides* would regenerate rapidly after fire, there was little tendency for it to invade scrub and grassland beyond the original forest boundaries. Burrows (1977) has shown that there are severe limitations to the establishment of *Nothofagus* seedlings in the

montane grasslands of the Cass Basin, central Canterbury. Grasses compete strongly against the seedlings and, in many years, the summers are too hot and dry and the winters too cold to permit survival. Only in scrubland, and especially *Leptospermum* scrubland, is seedling establishment successful.

From this it can be seen that even relatively infrequent fires could eliminate, or severely reduce the amount of *Nothofagus* forest, restrict the taller, slower growing scrub species such as *Dacrydium biforme* and *Phyllocladus alpinus*, and encourage scrub composites, *Hebe* and other small, fast-growing scrub species and grass. There would tend to be a mosaic of vegetation types produced, with taller scrub in areas sheltered from fire, or not recently burnt, and open grass and composite-dominated vegetation elsewhere.

A feature of both Stent Road and Mangahume sites is the sequence from *Coprosma/Myrsine/Dracophyllum* through to a *Dacrydium bidwillii* group dominant phase, followed by a *D. bidwillii/Phyllocladus* association. This sequence is repeated in Zone F of the Inaha pollen diagram. A pattern very much like this is found in post-glacial pollen diagrams from the central South Island (Moar 1971). Interpretation of this particular sequence is difficult because in most natural successions in relatively well-drained sites *Phyllocladus*, which can colonize disturbed, fresh soils, appears first; only later is it followed by *D. bidwillii* or *D. biforme*, both of which are more at home on old, mature and often gleyed soils. Wardle & Campbell (1976) have proposed that this anomalous behaviour stems from the greater resistance of *D. bidwillii* to low temperatures. Under a warming climate regime, *D. bidwillii* should therefore appear first.

If this interpretation is applied to the Taranaki sites, then both Stent Road and Mangahume indicate that the climate was warming. This

inference is supported to some extent by the record for tree pollen types; their major increase comes about after the first peak for *D. bidwillii* type and not before. However, if the *Dacrydium* in the early phase was *D. biforme* rather than *D. bidwillii*, (the wood identified in some of the sites has been referred to *D. biforme*, although this can never be a certain identification) the situation is reversed as *D. biforme* is far more susceptible to freezing than is *Phyllocladus alpinus* (Sakai & Wardle 1978). The situation as regards this particular sequence is unresolved and it may be that some unidentified factor in the ecology of these species is responsible for the pattern.

(iv) Otiran forest.

The early Otiran forest phase recorded in Zone C at Inaha is the only record of podocarp forest in Taranaki during the Otiran. The forest does not resemble the present day Taranaki forest because of the absence of *D. cupressinum* and the restricted range of hardwood species. It does bear some resemblance however to the early Aranuiian forests in the same area, and also to present day podocarp-hardwood forest from the drier regions of the east coast of the South Island. Failure of *Nothofagus* and *Libocedrus* to spread during this interstadial may reflect the short time the interstadial lasted or, more likely, the unsuitable climatic conditions for these species. A tentative conclusion as to the climate is that it was drier than that prevailing now, with annual rainfall perhaps equivalent to that of coastal areas of the central east coast of the South Island (800-600mm).

During the rest of the Otiran there was little forest in the Taranaki region. There were isolated patches of *Nothofagus menziesii* (the New Plymouth Waterworks site confirms this), *Libocedrus* and possibly *N. fusca* group. It is possible, but less probable, that small areas of podocarp forest survived in favoured areas.

(v) Mire plants.

Throughout the Inaha section the most abundant pollen of mire plants is that of Cyperaceae. *Leptocarpus similis* is present in nearly all the samples but is only sporadically abundant; *Myriophyllum* and *Phormium* exhibit the same pattern. *Empodisma* and *Gleichenia* are present in low frequencies throughout most diagrams but are only abundant in those zones where *D. bidwillii* type and *Phyllocladus* are dominant. *Empodisma* and *Gleichenia* are characteristic of wet, infertile places in general, but they are especially abundant in raised bogs and 'pakihi' soils. As all the levels with an abundance of *Empodisma* and *Gleichenia* are almost pure peat, it seems likely that raised bog development was occurring at these times. *D. bidwillii* in particular can flourish on the surface of raised bogs, and this may explain the association of this pollen type with *Empodisma* and *Gleichenia*.

The possible development of raised bogs may be a consequence of increased landscape stability. *Leptocarpus* and *Phormium* are favoured by sites of high nutrient status, while *Empodisma* and *Gleichenia* are more common in infertile sites (Dobson pers. comm.). While erosion was taking place in Taranaki the constant influx of mineral matter into lowlying wet areas would have encouraged *Leptocarpus* and *Phormium*; with the cessation of erosion, and the consequent build-up of pure peat, raised bog formation may have been initiated.

(vi) Aranuiian pollen sequences

(a) Early Aranuiian 14 000 - 10 000 BP

This period was one of rapid change in the vegetation. At the opening of the Aranuiian (14 500 - 14 000 BP) western Taranaki was devoid of any substantial area of forest. At Ngaere grassland was almost totally dominant. Zone 1 at Ngaere is not comparable to any other zone

in the mid- to late-Otiran record in Taranaki, because of the high levels of Gramineae and absence of all but small amounts of scrub. This sparse vegetation may in part be a consequence of the inland location and altitude (300 metres) of the Ngaere site. What the vegetation was like at the present day coastline is a matter for conjecture, as no site there spans the early Aranuiian; in all probability it resembled that of the Mangahume and Stent Road sites.

After 13 000 BP rapid change took place at Ngaere: Gramineae underwent a sharp decline and herbs of open places were almost eliminated. There was a brief expansion of scrub. An unusual feature of the scrub sequence at Ngaere is that the expansion of *Coprosma*, *Myrsine*, *Dracophyllum* and Compositae took place after, and not before, the dominance of *D. bidwillii* group and *P. alpinus*. This is a reversal of, not only the sequence seen at both Mangahume and Stent Road, but also of post-glacial sequences commonly found in the South Island (Moar 1971).

While the scrub expanded, podocarp forest types increased. To begin with the forest was mainly *P. spicatus*, but *D. cupressinum* expanded steadily. Some of the hardwood taxa that appeared early, such as *Tetrapathaea* and *Alectryon*, are at present restricted to lowland forests. The early Taranaki forests are fully comparable to forests existing at present in lowland and montane regions of the east side of both the North and South Islands. No species typical of cooler conditions than prevail at present are encountered, except for small amounts of *N. menziesii* and *Libocedrus* in the earliest phases.

The Warea River soils confirm this sequence of events. The earliest pollen spectrum (12 550 BP) is dominated by *P. spicatus* with only low amounts of *D. cupressinum*, and as at Ngaere, later soils record increased quantities of *D. cupressinum*. Where the Warea River sequence

does differ from that of Ngaere is that *D. cupressinum* became dominant well in advance of Ngaere. By 11 300 BP the *D. cupressinum* ratio was at 3.6, whereas at Ngaere it did not rise above 0.5 until after 10 500 BP. The explanation for this difference must lie in the fact that Ngaere, being a large area of swampland, received pollen from over a large area and therefore recorded the general increase of *D. cupressinum* in Taranaki. The Warea River site, consisting as it does of soils, indicates the local dominant rather than the regional vegetation. The spread of *D. cupressinum* was most likely by colonization of areas of high rainfall and favourable soil, and by spread from these areas as the climate improved. The Warea River site, being today in a region of relatively high rainfall, was likely to have been one of these areas, and therefore colonized early.

It was during this period that some of the more characteristic species of the Otiran were either restricted in range (e.g. *Libocedrus*) or, as in the case of *Nothofagus menziesii*, *P. alpinus* and *D. bidwillii* group, became extinct in western Taranaki. Not only woody taxa suffered this fate: *Empodisma minor* is no longer found in Taranaki although, as we have seen, it was extremely abundant at times in the Otiran.

(b) Mid Aranuian 10 000 - 5000 BP

The expansion of *D. cupressinum* from an important, but secondary element of the podocarp-hardwood forest, to the dominant podocarp tree, was rapid. The *D. cupressinum* ratio went from 0.3 to 2.0 in about 1000 years. There was several significant vegetational changes associated with the *D. cupressinum* rise. At, or around 10 000 BP *Ascarina*, *Dodonaea* and *Alectryon* all became common. There were major changes in the mire vegetation also. Before 10 000 BP, Cyperaceae, *Empodisma* and *Gleichenia* were prominent peat formers and *Leptospermum* grew on the

peat surface. After 10 000 BP these species were replaced by a *Eugenia/Dacrycarpus* swamp forest. These changes in both terrestrial and mire vegetation can be ascribed to the effects of a major climatic change. The spread of *D. cupressinum* indicates that rainfall increased, probably to present levels or above, and the arrival of frost-tender species such as *Ascarina* suggests that the climate was as warm as that of today, and very likely milder.

This vegetation type and the mild, wet climate persisted for some thousands of years. The Waiweranui and Warea River sites (both dated at around 7000 BP) and the Opunake Beach site (6600 BP) show that *D. cupressinum* and *Ascarina* maintained their dominance well into the mid Aranuian. If the somewhat uncertain dating of the Ngaere Swamp can be trusted, this type of forest lasted at least to 5000 BP.

(c) Late Aranuian 5000 BP to present.

The late Aranuian in the Taranaki region is not marked by major changes in the forest type. *Ascarina* diminished in importance, but there was no catastrophic decline, and *Knightia excelsa* and *Dacrydium colensoi* became common in the local vegetation. The decline of *Ascarina* reflects a climate significantly less equable than that of the mid Aranuian, and the spread of *Knightia* may have been the consequence of structural changes in the forest. However, the significance of the expansion of *D. colensoi* on the peat surface is unclear.

CHAPTER 6
PORT WAIKATO

6.1 SITE LOCATION AND CHRONOLOGY

Port Waikato NZMS1 N51/125938 (37°.24.2'S; 175°.34.1'E)

New Zealand Oceanographic Station N661. Altitude: -41m.

This site is 10 kilometres west of Port Waikato in approximately 41 metres depth of water. Samples were taken with a piston corer by L. Carter of the New Zealand Oceanographic Institute. Two samples were taken from a peat layer included within marine sands and muds. Sample 1 lay 0.72-0.75m below the sediment surface, and Sample 2 0.18-0.22m. The core was disturbed and this precluded detailed sampling of the peat layer. Dating of the samples was done at the N.Z. Radiocarbon Dating Laboratory. Radiocarbon age for Sample 1 is 31 900 ± 1700 BP (R5604/2); and for Sample 2, 27 1000 ± 900 BP (R 5604/1). Radiocarbon numbers are not yet available.

6.2 POLLEN ANALYSIS (TABLE 4)

Sample 1; 0.72-0.75m; 32 000 BP.

Description: The pollen spectrum is dominated by tree and shrub types; herbaceous types make up only 4% of the total. *Nothofagus fusca* type, *Podocarpus spicatus*, *P. totara* type and *Dacrydium cupressinum* provide the bulk of the pollen, and tree types make up over 70% of the pollen sum. Of the smaller tree and shrub types, only *Leptospermum* is recorded in substantial quantities, but the presence of *Phyllocladus*, *Dacrydium colensoi*, *D. bidwillii*, *Dracophyllum* and *Nothofagus menziesii* is noteworthy. The mire herb total is small; *Empodisma* and *Sphagnum* are present in greatest quantity. Tree ferns are rare.

TABLE 4

POLLEN ANALYSIS: PORT WAIKATO

<u>TAXA</u>	#1	#2
<u>NOTHOFAGUS & TREE CONIFERS</u>		
<i>Agathis australis</i>	.	+
<i>Dacrycarpus dacrydioides</i>	+	+
<i>Dacrydium colensoi</i>	3	.
<i>D. cupressinum</i>	14	27
<i>Libocedrus</i>	1	2
<i>Nothofagus fusca</i> type	24	2
<i>N. menziesii</i>	2	2
<i>Podocarpus ferrugineus</i>	6	5
<i>P. totara</i> type	10	11
<i>P. spicatus</i>	12	19
<u>OTHER WOODY TAXA</u>		
<i>Carpodetus serratus</i>	x	+
<i>Colobanthus</i> type	.	x
Compositae	+	+
<i>Coprosma</i>	1	1
<i>Coriaria</i>	x	x
<i>Dacrydium bidwillii</i> type	1	.
<i>Dracophyllum</i>	3	.
<i>Elaeocarpus</i>	.	1
<i>Hebe</i>	+	.
<i>Leptospermum</i>	12	17
<i>Metrosideros</i>	x	x
<i>Muehlenbeckia</i>	x	x
<i>Nestegis</i>	1	2
<i>Pennantia</i>	+	+
<i>Pseudopanax</i>	2	1
<i>Phyllocladus</i>	2	x
<i>Quintinia</i>	+	.
<i>Rubus</i>	.	1
<i>Cyathodes fasciculatus</i>	+	x

TABLE 4 (cont'd)

<u>TAXA</u>	#1	#2
<u>HERBS</u>		
<i>Bulbinella</i>	.	x
Gramineae	1	1
<i>Haloragis</i>	1	2
<i>Selliera radicans</i>	+	1
Umbelliferae	2	2
<i>Urtica</i>	.	x
<u>SWAMP & AQUATIC PLANTS</u>		
Cyperaceae	1	7
<i>Empodisma</i>	3	x
<i>Leptocarpus</i>	.	2
<i>Myriophyllum</i>	1	23
<i>Pediastrum</i>	.	x
<i>Phormium</i>	+	.
<i>Potamogeton</i>	.	1
<i>Sphagnum</i>	2	.
<u>TREE FERNS</u>		
<i>Cyathea dealbata</i>	+	4
<i>C. smithii</i>	1	7
<i>Dicksonia fibrosa</i>	.	x
<i>D. squarrosa</i>	+	x
<u>FERNS & LYCOPODS</u>		
<i>Histiopteris</i>	.	+
<i>Hymenophyllum</i>	.	+
<i>Lycopodium fastigiatum</i>	+	+
<i>L. volubile</i>	+	.
monolete fern spores	2	2
<i>Phymatodes</i>	.	x
<i>Pteridium aquilinum</i>	.	4
<i>Pteris macilenta</i>	5	.

TABLE 4 (cont'd)

<u>TAXA</u>	#1	#2
<u>EXOTIC</u>		
<i>Casuarina</i>	+	.
Pollen sum (total pollen excluding swamp plants & ferns)	399	296

x' = less than 1%

+ = noted after count.

Sample 2; 0.18-0.22m; 27 000 BP.

Description: The pollen spectrum from this sample is similar to that of Sample 1, but there are several major differences. *N. fusca* type is almost completely lacking and *D. cupressinum* has almost doubled its representation. Other significant changes are the elimination or reduction of *Phyllocladus*, *D. bidwillii* type, *Dracophyllum*, *Dacrydium colensoi*, and the appearance of *Agathis australis*. Mire herbs remain at low frequencies, but Cyperaceae are now dominant while aquatics, scarce in Sample 1, are now abundant. Tree ferns have increased sharply from the previous level of 1% to 12%.

Interpretation (Sample 1 and 2): Both samples record a diverse podocarp-hardwood forest. However, it is clear that a major vegetational change occurred between the deposition of these two samples. *N. fusca* group forest was important during Sample 1 time, but later may have been completely eliminated from the region. The increase of *D. cupressinum* and tree ferns and the appearance of *Agathis australis* over the same time span can be contrasted with the elimination or reduction in abundance of *Phyllocladus*, *D. colensoi*, *D. bidwillii* type and *Hebe*. In both samples the local mire vegetation was mainly sedges, with *Sphagnum* and *Empodisma* in the lower sample, over-topped by a cover of *Leptospermum* scrub. In the upper sample the mire may have been somewhat wetter than it was previously, because there is a fair representation of *Myriophyllum* and some *Potamogeton*.

6.3 DISCUSSION

The changes that occurred in the forest between 32 000 and 27 000 BP point to a climatic amelioration. The increase of *D. cupressinum* and tree ferns and the decline of *N. fusca* type indicates a wetter, perhaps milder, climate. The appearance of *Agathis australis*

and the disappearance of *Phyllocladus*, *Dracophyllum*, *D. bidwillii* type and *Hebe* suggests that the climate became less frost-prone, if not generally warmer in the same interval. Mean annual temperature may have remained lower than at present however, as *N. menziesii* grew some 30 kilometres north of its present northern limit. If the *Libocedrus* recorded was *L. bidwillii*, it provides further evidence for a cooler climate. Unfortunately there are no diagnostic taxa in this assemblage that would permit a more precise definition of the limits of climatic change over this period: the direction of change towards a warmer, wetter climate seems clear however.

CHAPTER 7

TONGARIRO

7.1 INTRODUCTION

The climate, geology and vegetation of the Tongariro area has been described in McGlone & Topping (1977). A reprint of this paper is included in the pocket at the end of this thesis.

7.1.2 Glaciation of the Tongariro volcanoes

Glacial features are difficult to recognize on an active volcano partly because of burial and destruction by lava flows and tephra fall, and also because of possible confusion with volcanic landforms, such as lahars. Nevertheless, good evidence exists for glaciation on the Tongariro volcanoes. Mathews (1967) described and mapped moraines on Tongariro (Figure 11), but was unable to give a useful estimate of their age. He also tentatively described South Crater (Mt Tongariro) as a product of glacial erosion. Topping (1974) was able to give more detail as to the age of the moraines, and also described other glacial features on the volcanoes.

The oldest tephra discovered by Topping *in situ* above a moraine was the Rerewhakaaitu Ash (14 700 BP) in the Mangatepopo Valley, on a moraine that terminates at about 1100 metres. On another moraine (not on map) in the Mangahouhounui Valley, the Rotoaira Lapilli (14 200 BP) is the oldest tephra found. It is clear then, that the minimum age for these moraines is around 15 000 BP: older tephtras may have been stripped-off during erosive phases, so there is no certainty that the moraines are not older.

At 1500 metres on the eastern flank of Mt Ruapehu (Topping 1974), a sequence of laminated silts and clays have been exposed by a small stream. The sequence is approximately 8 metres thick, is possibly varved,

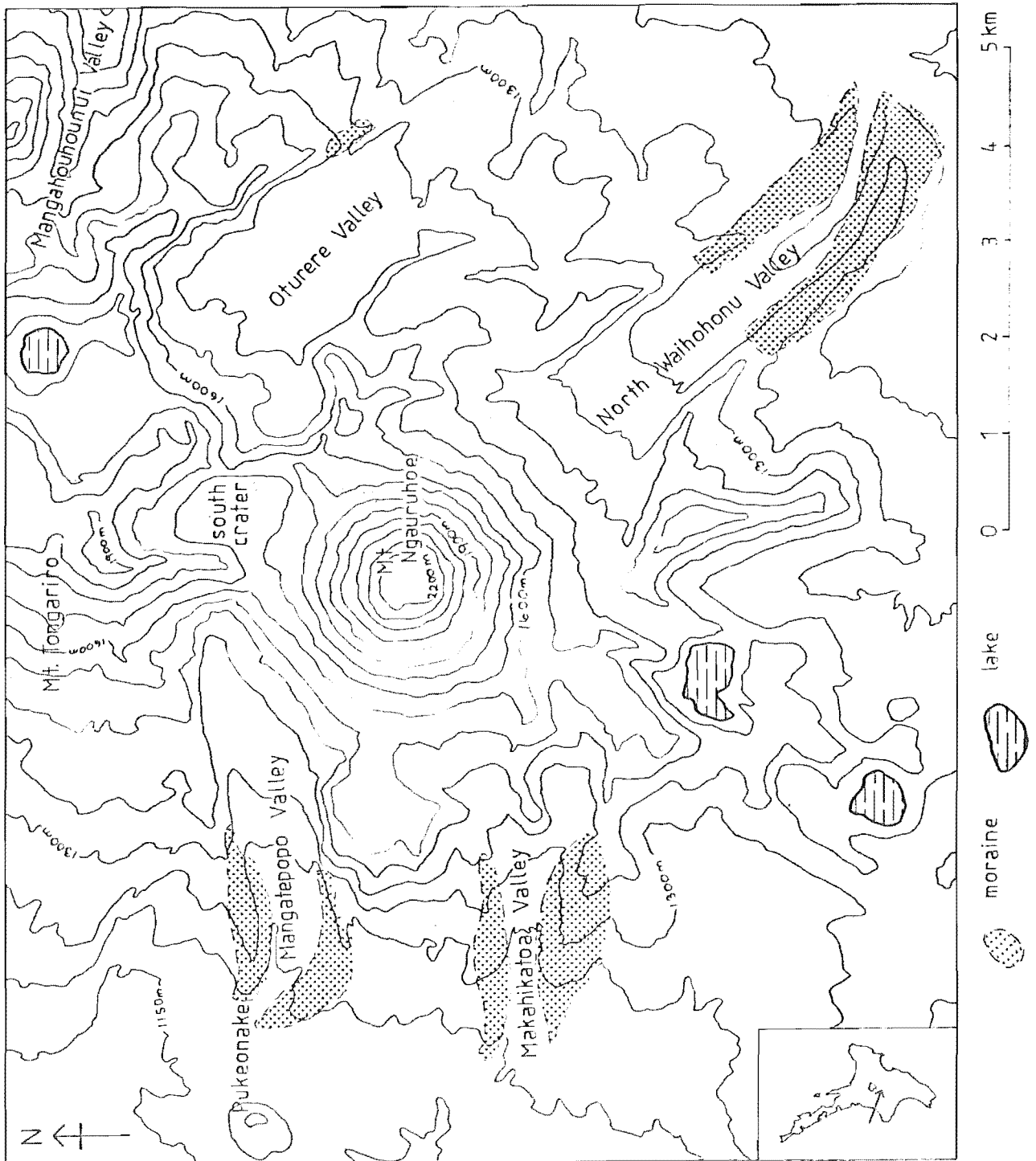


Figure 11. Moraines on Mt Tongariro. Data from Mathews (1967) and Topping (1974)

and appears to have formed in a pro-glacial lake. The base of the sequence rests on till. Within the upper portion of the silts the Kawakawa Tephra (20 000 BP) has been identified. The uppermost sediments have diapiric structures and drag folds which suggest readvance of ice after 20 000 BP.

The crater of the Pukeonake Scoria Cone (Figure 11), on the western edge of the Tongariro Massif, at an altitude of 1200 metres, contains a well-preserved exposure of the Kawakawa Tephra. The tephra is shower-bedded and dips at an angle of 17°. The younger chalazoidite bearing beds of the Kawakawa Formation are separated by water-laid rhyolitic silts from the upper beds of the same formation. It is certain therefore that the Kawakawa Tephra fell into open water, and that there was therefore no year-round cover of snow and ice at that altitude at 20 000 BP.

If it is accepted that South Crater (Figure 11) was formed by glacial action (Mathews 1967), and this seems to be highly likely, both from the shape and orientation of the structure, and also from the orientation of the moraine ridges that lead away from it, an estimate of the snowline can be derived. Assuming that it was an actively forming cirque at the peak of the Otiran (i.e. sometime between 20 000 and 15 000 BP) the floor of the crater should give a rough approximation to the orographic snowline at that time (Flint 1971). The floor of South Crater lies at approximately 1680 metres: present snowline on Mt Ruapehu is at about 2500 metres (Coulter 1975). Depression of snowline at the peak of the Otiran may have been of the order of 800 metres.

7.2 POLLEN DIAGRAMS

7.2.1 Otamangakau Canal (west bank).

Location: NZMS1 - N112/106982. Altitude: 600 metres.

(i) Geology and Chronology

To the west of Lake Rotoaira lies a swampy depression which was once drained by the headwaters of the Wanganui River (Figure 12). Active faults abound in the area, and a prominent, recent fault scarp crosses the basin not far from the sampling site. Recent work on the Tongariro Power Scheme has resulted in several canals and roads being constructed within the Rotoaira Basin, and in the process several sections of the mire deposits have been exposed. Two sections which lie stratigraphically above the Kawakawa Tephra (20 000 BP) and span the last 14 000 years have already been pollen analysed (McGlone & Topping 1977). One of these sections, Otamangakau Canal (east bank), is only a few hundred metres from the site under discussion. Although the two sites are close, and can be correlated directly by means of the Kawakawa Tephra, there is a hiatus of almost 6000 years between the termination of organic deposition at the west bank site and the recommencement of peat growth at the east bank site. For this reason the two diagrams are considered to be separate entities.

The west bank section consists of approximately 2.0 metres of sediment overlain by a thick mantle of Kawakawa Tephra (Plate 5). Basal sediments are made up of fine sands and gravels that could not be investigated further because they lie at water level in the canal. The sands, which contain thin organic horizons, grade upwards into a lignite which has a prominent, unidentified rhyolitic tephra near the base. The lignite grades into progressively less organic beds of silts, until, midway up the section, an almost entirely inorganic horizon of fine sand and silt occurs. No useful pollen spectra were recorded from this horizon. This non polliniferous horizon is overlain by a shallow paleosol which becomes progressively more organic upwards, and at the contact with the Kawakawa Tephra is quite peaty. Chronology is poor at this site as, except for the Kawakawa Tephra, none of the tephras have

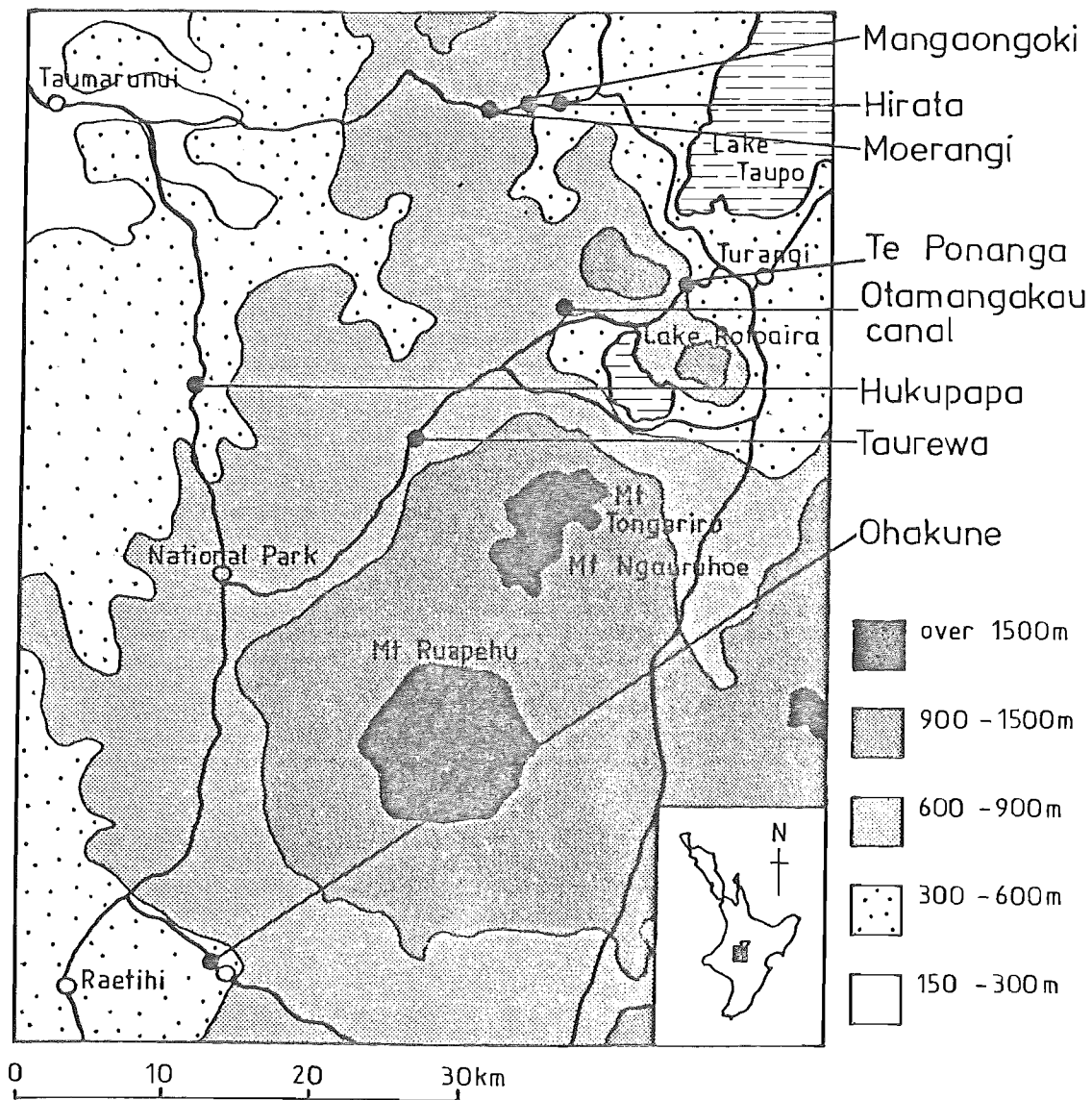


Figure 12. Site location, Tongariro and south-west Taupo

been identified. The top of the lignite band gave a radiocarbon date of greater than 47 000 BP.

(ii) Pollen analysis. (Plate 5)

The pollen diagram is divided into nine zones.

Otamangakau 1

Description: This zone consists of one sample only, but the high Gramineae percentage makes it quite distinct. There are moderate scrub levels (about 40% of terrestrial pollen), mainly of *Phyllocladus* and *Dacrydium bidwillii* type, and low amounts of *Nothofagus* and tree podocarps. Very little pollen from mire plants is recorded.

Interpretation: Scrub/grassland occupied the Rotoaira Basin, and very likely the surrounding hills. There were patches of both *Nothofagus* and podocarp-hardwood forest in the region.

Otamangakau 2

Description: Gramineae percentages fall from 40% to less than 10%, and there is a corresponding increase of woody taxa. *Nothofagus fusca* type triples its representation, but then slowly declines until, at the end of the zone, it has returned to its original value. *Libocedrus* has relatively high, fluctuating levels. *Podocarpus* increases slightly to 15% and then holds to near that value for the rest of the zone.

Dacrydium cupressinum is not abundant, but the *D. cupressinum* ratio rises steadily. Taxa characteristic of podocarp-hardwood forest, such as *Metrosideros*, *Weinmannia*, *Carpodetus*, *Nestegis* and *Ascarina* are scattered throughout the zone. Pollen of scrub taxa is much more abundant than in previous zones. *D. bidwillii* type is the major contributor and increases throughout, reaching a peak at the upper zone boundary. There are also substantial quantities of *Leptospermum*, *Coprosma*, Compositae, *Phyllocladus*, *Myrsine* and *Dracophyllum*. Herbs typical of open places such as *Taraxacum* type, *Chenopodium* and *Selliera* are occasionally

encountered. Mire plant pollen increases markedly: Cyperaceae is dominant at first but is then replaced to a great extent by *Empodisma* and *Gleichenia*.

Interpretation: Forest was now the dominant vegetation type but the Rotoaira Basin itself supported a dense scrubland. *Libocedrus*, probably *L. bidwillii*, was the most common tree species in the immediate vicinity of the site, but *Nothofagus*/podocarp-hardwood forest, with *Podocarpus spicatus* the dominant tall tree, is likely to have been the main regional forest association. A peat mire established in the course of this zone, changing rapidly from a sedge-dominant community to an acid bog.

Otamangakau 3

Description: At the beginning of Zone 3 the *D. cupressinum* ratio rises above 1.0 and, with the exception of two brief periods, remains above for the rest of the zone. No equilibrium between *Podocarpus* and *D. cupressinum* was attained however, and within this zone there are two well defined peaks in the *D. cupressinum* ratio, each reaching more than 2.5. Tree pollen in general undergoes an increase, especially *Podocarpus ferrugineus*, *Libocedrus* and *Dacrycarpus*. *N. fusca* type recovers from a temporary low at the beginning of the zone, and maintains levels of 10-15% throughout. *Nothofagus menziesii*, only sporadically recorded in the first two zones, is consistently recorded in the top two-thirds of this one. There is a great variety of hardwood taxa, and especially abundant are: *Elaeocarpus*, *Quintinia*, *Nestegis*, *Pennantia* and *Ascarina*. *Knightia excelsa* and *Dodonaea viscosa* are noted. *D. bidwillii* type decreases in this zone, and *Phyllocladus* is reduced to levels half those of Zone 2 but, overall, scrub taxa remain abundant. Gramineae is reduced to low, fluctuating levels. *Cyathea smithii* type increases its levels slightly over those of the last zone, and other tree ferns make an appearance. Monolete fern spores increase. Mire

plant pollen consisting almost entirely of *Empodisma* and *Gleichenia* is abundant.

Interpretation: The apparent increase in forest type pollen is in part a result of the fall of scrub percentages: however, the changes in proportions of the various forest trees is real. *D. cupressinum* and *Libocedrus* became the most common trees in the Rotoaira Basin. Later *N. menziesii* became more abundant, and was certainly present in the local forests. Hardwood taxa seem to have increased in both variety and amount. As before, the site supported a dense scrubland characterized by subalpine taxa.

Otamangakau 4

Description: *N. fusca* type pollen slowly increases until, at the end of the zone, it makes up over 30% of terrestrial pollen. *N. menziesii* and *Phyllocladus* increase. The *D. cupressinum* ratio continues a decline begun in the last zone and falls to values as low as those of Zone 2. *P. spicatus* maintains its previous levels, but *P. ferrugineus* declines markedly. *Libocedrus* shows a slightly downward trend. *Nestegis* pollen is rare, *Ascarina* noted once only, and *Dodonaea* is absent. Gramineae rises to levels of 15% or more, while Umbelliferae and *Drapetes* are consistently present. Tree ferns and monolete fern spores are markedly less abundant. There is no decline in the amount of mire plant pollen.

Interpretation: The major change in this zone was the expansion of grassland. In sites already marginal for forest, grassland and scrub may have spread. Equally important alterations took place within the forest communities. *P. spicatus* was one again the dominant tall tree; and *D. cupressinum* became progressively less abundant; *Libocedrus* slowly dropped away from its once pre-eminent position. Hardwood taxa typical of Zone 3 became far less common, and tree ferns were reduced to a minor element. In broad terms the direction of change was back to a

forest similar to that of Zone 2 times. Throughout the zone there was a constant expansion of subalpine and montane taxa at the expense of more typically lowland types. The rise of *N. fusca* type may reflect a general increase of this group in the entire region.

Otamangakau 5.

Description: Zone 4 has the sharpest termination of any in the entire pollen diagram. This appears to be the result of a sudden drop in the accumulation rate rather than a reflection of rapid vegetation change. At the Zone 4/5 boundary nearly all podocarp-hardwood taxa are severely reduced: most drop to 1-2% or less, and none are continuously represented. Of all the podocarp-hardwood taxa of Zone 3 and 4, only *Hoheria* continues on substantially unchanged in Zone 5. With the sole exception of *Myrsine*, which increases, all scrub taxa decline. *N. fusca* -type percentages, after an initial rise to over 50%, are maintained at the levels reached at the top of Zone 4. Gramineae percentages rise throughout the first half of the zone to reach almost 60%, and remain high. There is an abrupt cessation of mire taxa and fern types at the beginning of the zone.

Interpretation: It is difficult to interpret a diagram where grass and *N. fusca* type pollen make up 80% of the terrestrial pollen sum. If the over-representation hypothesis for *N. fusca* type pollen presented in section 4.2 is accepted, *Nothofagus* forest was probably not common in the Tongariro region. The bulk of the *Nothofagus* pollen under this interpretation was derived from scattered patches of *Nothofagus* forest nearby, and from more substantial areas of forest adjacent to the Volcanic Plateau. The absence of significant amounts of scrub other than *Myrsine* suggests that sparse grassland-shrubland was the main vegetation cover in the Rotoaira Basin. The mire community vanished and peat accumulation ceased.

Otamangakau 6.

Description: Pollen production was extremely low in this zone: high levels of spores, especially tree fern spores, suggests that the pollen spectra has been affected by corrosion. The pollen assemblage is very similar to that of Zone 5 except for anomalous increases in *Podocarpus*, some scrub types, *Gleichenia* and *Empodisma*. As the total pollen content of the sediments is extremely low, these changes can only be attributed to the reworking of older deposits, or to long-distance dispersal. *Plantago* and *Gentiana* reach exceptionally high percentages (about 5%) and this emphasizes the low overall pollen accumulation rate. The last 0.12 metres of this zone was almost devoid of pollen: only a few pollen grains, mainly of tree types, were recovered.

Interpretation: Sparse vegetation, probably a very open grassland or herb field existed at this time in the immediate region: nothing useful can be said about areas further afield.

Otamangakau 7.

Description: As in Zone 6, pollen production was low, and the continuing high levels of spores indicates that destruction of pollen had continued. The distinguishing feature of this zone in contrast to the previous one, is the very high percentages of Gramineae pollen and the correspondingly low levels of other pollen types. *N. fusca* type percentages in particular are lower than they have been since the beginning of Zone 3.

Interpretation: Much the same interpretation as was given for Zone 6 applies here. The vegetation was sparse and herb dominated, and there appears to have been a reduction in the amount of *Nothofagus* forest in the region as a whole.

Otamangakau 8.

Description: At the beginning of this zone there is a decrease in the amount of Gramineae pollen and a rise in the *N. fusca* type curve.

N. fusca type peaks at over 30% of the terrestrial pollen sum. However,

Gramineae levels remain very high throughout, averaging just less than 40%, and scrub levels are always low. Most of the pollen of woody plants is derived from only three taxa; *Phyllocladus*, *D. bidwillii* type and *Coprosma*. Podocarp forest types, although never making up an appreciable proportion of the pollen sum, have consistently recorded percentages for the first time since Zone 4. Mire plants account for 10-15% of the terrestrial pollen sum: this is their first substantial representation since Zone 4.

Interpretation: During this zone the vegetation on the site remained fairly sparse, but with some admixture of *Gleichenia* and *Empodisma* indicating wet, and peaty soil conditions. Most of the pollen of woody taxa, and much of the Gramineae contribution, must have been derived from the surrounding hills.

Otamangakau 9.

Description: A few subtle changes define this zone. Gramineae and Umbelliferae increase, whilst there is a slight decrease in the frequency of woody taxa. Otherwise, this zone resembles Zone 8 in nearly all particulars.

Interpretation: These changes reflect trends in the surrounding vegetation on the hills, rather than in Rotoaira Basin itself. The implication is that grassland and herbland spread at the expense of scrubland.

7.2.2 Ohakune

Location: NZMS1 - N121/896504. Altitude: 600 metres.

(i) Geology and Chronology

This section is in a road-cutting a few kilometres west of Ohakune (Figure 12). It consists of almost 4 metres of peat, woody peat, peaty silts and tephra, resting on mudstone of Pliocene age.

Overlying the peat horizons is approximately 3 metres of reworked tephra and mudstone, which was not sampled for pollen analysis. There is a very abrupt and irregular contact between the peat and the overlying reworked material, and some erosion of peat can be presumed to have taken place. A thin layer of the Kawakawa Tephra (20 000 BP) and unidentified tephras of Aranuian age cap the section. Because the section had a dense cover of long grass, it was impracticable to follow the lateral extent of the peat in any detail. From what few exposures there were, it appears the sediments were laid down in a small basin, or valley, about 100 metres wide, cut into the mudstone.

As the Ohakune sequence has the same stratigraphic position as the Otamangakau Canal (west bank) peat, and moreover has a markedly similar pollen sequence, I consider the two sites to be contemporaneous. Both are beyond the range of radiocarbon dating (an age of greater than 40 500 BP has been obtained from the top of the peat horizon, NZ 3881 A) and only further work with amino acid racemization or other techniques could establish their equivalence beyond all reasonable doubt.

The zonation scheme developed for the Otamangakau site is used here also. *Dacrydium colensoi* is excluded from the pollen sum because of its over-representation at this site.

(ii) Pollen analysis. (Plate 6)

Ohakune 1

Description: Gramineae are dominant and *Nothofagus fusca* type is present in moderate quantities. There are low frequencies of podocarp tree taxa and scrub types. Some notable occurrences among the herb and small shrub types are: *Plantago*, *Epilobium*, *Geranium*, *Cyathodes fraseri* and *Epacris alpina*. The mire flora consists of low amounts of Cyperaceae, *Empodisma* and *Gunnera*. The first sample of the zone has a

very high percentage of tree fern and monoete spores and *Lycopodium*, but these levels drop rapidly.

Interpretation: The local vegetation was a grassland/shrubland and the occurrence of such taxa as *Plantago* and *Epacris alpina* suggest that the vegetation was open. However, as there is a fair representation of *N. fusca* type and some podocarp tree types, it can be concluded that there was some forest in the region.

Ohakune 2

Description: Gramineae levels fall throughout the zone to reach a trace amount at the upper boundary. Percentages of scrub types rise steadily, to reach a peak of 80% of terrestrial pollen at the end of the zone.

Dacrydium bidwillii type is most prominent but *Phyllocladus*, *Coprosma* and *Dracophyllum* and Compositae are also common. Tree podocarp and *N. fusca* type levels remain steady, but in the upper half of the zone there is an increase in the *Dacrydium cupressinum* ratio to 0.5.

Libocedrus expands, peaking in mid-zone, but retaining relatively high levels throughout. *Nothofagus menziesii* is consistently recorded.

Quintinia, *Elaeocarpus* and *Nestegis* make their appearance in this zone. *Empodisma* and *Gleichenia* are abundant for most of the zone, but decline towards the end.

Interpretation: This is a transitional zone; grassland was replaced by scrub, mainly *Phyllocladus* and *D. bidwillii* group, but with a fair admixture of other species. *Libocedrus* forest was almost certainly close at hand, maybe in the environs of the site. Regionally, *N. fusca* group forest remained static while *D. cupressinum* underwent a relative increase. A well-developed acid bog community was established during this zone, very likely as a consequence of increased soil stability in the catchment.

Ohakune 3

Description: All tree type pollen percentages increase, except for *Nothofagus* which reaches its lowest values for the entire pollen diagram in this zone. *Libocedrus* is the most abundant tree type but *Podocarpus* and *D. cupressinum* are also common. Many taxa associated with podocarp-hardwood forest (e.g. *Weinmannia*, *Carpodetus*, *Quintinia*, *Nestegis*, and *Pennantia*) are either first recorded, or recorded more often. There is a particularly rich and abundant flora of scrub taxa. *Leptospermum*, *Coprosma* and *Myrsine* are common throughout: *D. bidwillii* type is reduced to low levels in the first few samples being replaced as the dominant scrub/small tree type by *Dacrydium colensoi* which rises to the exceptionally high level of 200% in the first quarter of the zone. Next, *Phyllocladus* is dominant, but then it is replaced by a combination of *Leptospermum*, *Dracophyllum*, Compositae and *Myrsine*. Gramineae is represented in the first few samples, only sporadically present in mid-zone, but recovers in the last quarter of the zone to values varying between 1 and 10%. At the beginning of the zone, mire herb levels are very low; from mid-zone on, Cyperaceae recovers and *Empodisma* and *Gleichenia* attain temporarily high values towards the top of the zone. *Phormium* is relatively abundant from mid-zone on. *Cyathea smithii* type and monolete fern spores increase markedly at the beginning of the zone.

Interpretation: There is no doubt that a mixed *Libocedrus*/podocarp-hardwood forest was established in the immediate vicinity of the site. *Cyathea* c.f. *smithii* and *Nestegis* are present in such quantities that these plants must have been very close to, or even overhanging the site. Although *N. fusca* type pollen is not at all abundant, it cannot be inferred that *Nothofagus* forest was absent. The occurrence of *Elytranthe* (either *E. colensoi* or *E. tetrapetala*) a mistletoe with *Nothofagus* as its primary host, suggests that *Nothofagus* trees were

within the local forest. Podocarps, especially *D. cupressinum*, were the dominant tall trees in the region. This forest type strongly resembles montane forest on the Volcanic Plateau at present.

There is a prominent increase of the *D. cupressinum* ratio in mid-zone, and it is accompanied by a decrease in *Libocedrus* and *D. bidwillii* group. At the same time there is an increase in the amount of *Nestegis*. After the peak of the *D. cupressinum* ratio is reached, it drops rapidly and at the same time Gramineae, *Dracophyllum*, *N. fusca* group and *Nothofagus menziesii* become more common than hitherto. During the period of *D. cupressinum* dominance it seems as though the forest was appreciably less montane in character: later as the amount of *D. cupressinum* in the forest fell, the forest reverted to a higher montane type.

For the first half of the zone various woody species dominated the mire surface; later the mire may have become wetter, as Cyperaceae and *Phormium* became more prominent in the mire community.

Ohakune 4.

Zone 4 has been divided into 3 sub-zones; a, b and c.

Ohakune 4a

Description: There is rather sharp termination to Zone 3. The *D. cupressinum* ratio drops sharply from 1.15 to 0.2; *Libocedrus*, *Podocarpus ferrugineus*, *Dacrydium colensoi*, *Leptospermum*, *Coprosma*, *Myrsine*, and *C. smithii* type, all fall to lower values. At the same time there are increases in *N. menziesii*, *N. fusca* type, *D. bidwillii* type, *Phyllocladus*, *Dracophyllum*, *Cyathodes colensoi*, Gramineae and *Empodisma*. *P. spicatus* percentages show a slight tendency to decline.

Ohakune 4b

Description: To begin with, *Nothofagus* declines slightly, as does *Dracophyllum* and *D. bidwillii* type. There is an increase in the *D. cupressinum* ratio, and *D. cupressinum*, *Hoheria*, *C. smithii* type and

monolet fern spores rise. In the upper 2 samples of the sub-zone, *Libocedrus*, *N. menziesii*, *Podocarpus*, *D. colensoi*, *Leptospermum*, *Phormium* all increase, while Gramineae, *N. fusca* type, *Myrsine*, *Phyllocladus*, monolet fern spores and *C. smithii* type decrease. *Nestegis*, *Weinmannia*, *Cordyline*, *Astelia* and *P. ferrugineus* are all more abundant at this point. *Empodisma*, until now the dominant mire herb, is nearly eliminated. There are small increases in Cyperaceae and *Gleichenia*.

Ohakune 4c

Description: The last two samples of the pollen diagram constitute Zone 4c. *N. menziesii* and Compositae are as abundant as before, and *D. bidwillii* type, *Phyllocladus* and *Dracophyllum* increase. The Gramineae percentage in the last sample of the zone is higher than it has been since Zone 1. *Libocedrus*, *Podocarpus*, *Leptospermum*, *Coprosma*, *Myrsine* and monolet fern spores all decrease. *Empodisma* reverts to Zone 4a levels and *Gleichenia* peaks at high levels.

Ohakune 4a, 4b, 4c

Interpretation: Zone 4 records the encroachment of *N. menziesii* forest and subalpine shrubland around the site. *Libocedrus*, *D. colensoi*, and *Leptospermum* are replaced by *Dracophyllum*, Compositae and other scrub species. On a regional scale *N. fusca* type forest, and possibly grassland/scrubland, expanded at the expense of podocarp-hardwood forest. *D. cupressinum*, besides becoming less common, also appears to have lost ground relative to *P. spicatus*. All these changes occurred in sub-zone 4a and coincide with a sediment change from a peat to a silty peat.

Zone 4b records a partial reversal of the general trend of Zone 4a. Podocarp-hardwood communities recovered, *Libocedrus* became more abundant in the vicinity of the site, and subalpine shrubland appears to have retreated. Tree ferns once again grew near the site, and the mire

surface regained its covering of *D. colensoi*, *Leptospermum*, *Coprosma*, and *Myrsine*. Acid bog species such as *Gleichenia* and *Empodisma* became rare, their place being taken by Cyperaceae and *Phormium*.

Zone 4c represents a reversion to the conditions of Zone 4a, podocarp-hardwood and *Libocedrus* forest once again retreating, and the dense scrub community on the mire surface giving away to a herbaceous cover.

7.2.3 The south-west Taupo paleosols

These sites are all close together (Figure 12) and have very similar pollen sequences and for this reason are not treated individually. Site descriptions are all given in a separate section after this introduction.

(i) Geology and Chronology

The region west and south-west of Lake Taupo is characterized by rugged, low mountain ranges, averaging 600 to 900 metres in height. The main geographic feature of this region is the Hauhangaroa Range, which runs parallel with Lake Taupo in the north and peters out to low hills near the southern end of the lake. Numerous streams and small rivers drain the area; those in the east flow into Lake Taupo, those in the west into the Wanganui River.

At about 20 000 BP a very large eruption from near the north end of Lake Taupo covered the area surrounding the lake with a mantle of tephra. Near Lake Taupo most of the tephra was deposited in the course of several vast breccia flows (Pullar & Birrell 1973). These flows, many metres thick in places (maximum thickness 75 metres), sealed off much of the old land surface. Erosion cut back and redeposited part of the breccia, but the bulk of it remained intact, preserving the underlying ground surface.

In the south-west Taupo region there are many exposures of paleosols beneath this sequence of flows and air-fall deposits which is termed the Kawakawa Formation. Most are pale-brown, weakly organic tuffs devoid of pollen. However, in 6 localities there are dark-brown paleosols and these have well preserved pollen floras. In absolute terms the organic content of these dark-brown paleosols is low: the bulk of the material is tephra derived, and at some of the sites distinct air fall tephra layers are found. The organic content of the paleosols diminishes rapidly with depth below the Kawakawa Formation, and at the base they grade into sandy-silts and gravels. Each paleosol rests on an eroded rock contact. At several sites it is apparent that the polliniferous paleosols were formed in gentle depressions for, wherever the paleosols can be traced for some distance, the dark-brown colours of the pollen-bearing sediments quickly grade into the pale-yellow browns of the non-polliniferous sediments as the paleosol rises.

Three named tephras (Okaia, Tahuna, and Tihoi) have been identified in the polliniferous paleosols, and a further one (Rotoehu Ash) from a tephric loess section at Te Ponanga. These tephras are shown in Figure 13 and their relationship with other tephras from areas to the north and east in Table 5.

Correlation of these tephras permits a rough chronology and history of the area to be worked out. Before deposition of the Rotoehu Ash (c. 42 000 BP) there was widespread erosion that stripped previous sediments from the underlying rocks. At about the time that the Rotoehu Ash was deposited, erosion slowed and soils began to form. These soils were slowly built up by the steady accretion of tephras from the local andesitic volcanoes, tephric loess, and the intermittent addition of rhyolitic tephra from the Taupo and Okataina Volcanic Centres. Vucetich & Howorth (1976) point out that there is little evidence for erosion in

Figure 13. Correlation columns for tephras within sites from south-west Taupo. Data from Howorth & Topping (unpub.)

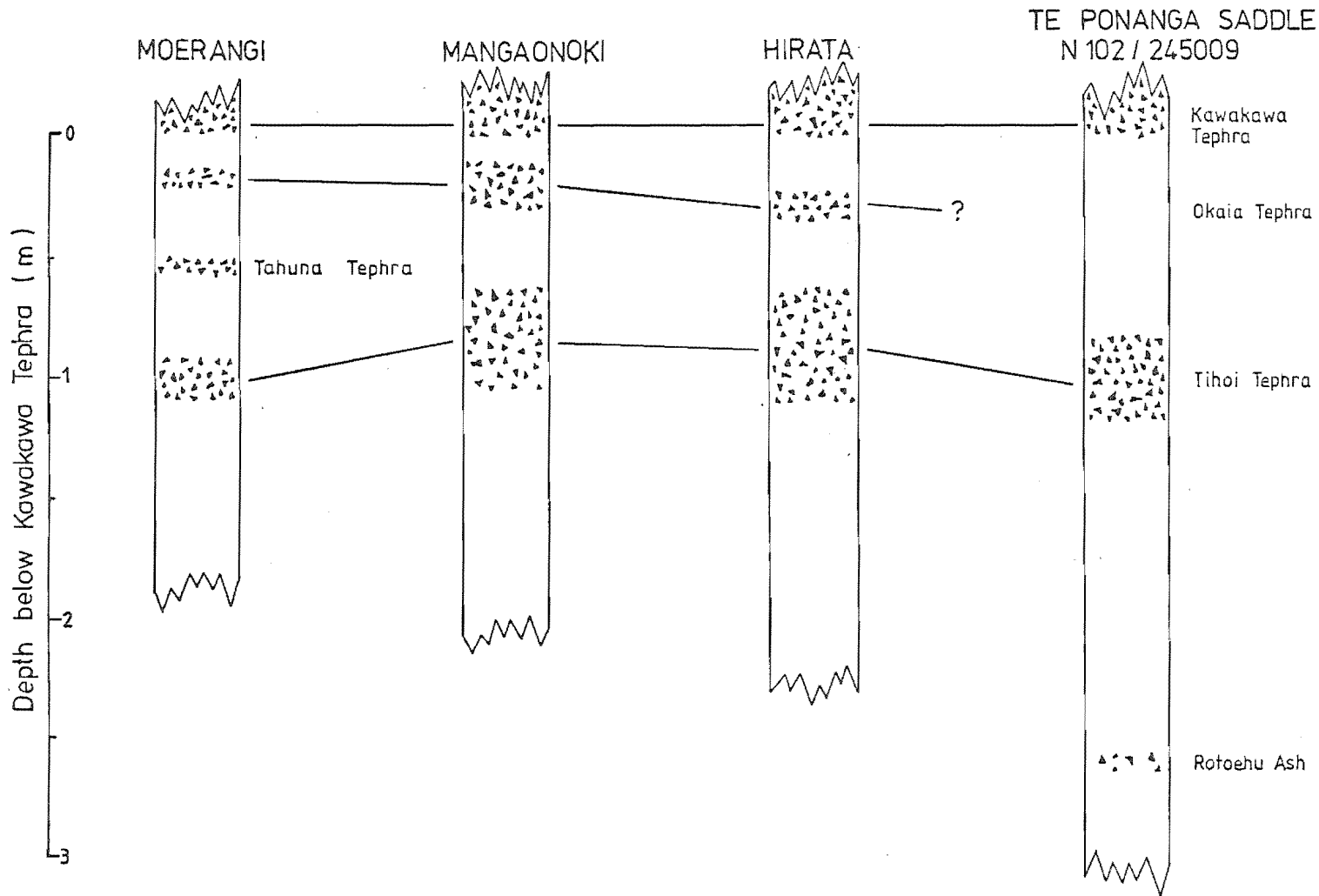


TABLE 5COMPOSITE TEPHRA COLUMN FOR THE MID OTIRAN, CENTRAL NORTH ISLAND

<u>FORMATION</u>	<u>SYMBOL</u>	<u>SOURCE</u>	<u>AGE</u>
Kawakawa	Kk	Taupo	20 000
Poihipi	P	Taupo	
Okaia	O	Taupo	
Omataroa	Om	Okataina	28 000
Mangaone	Mn	Okataina	30 000
Hauparu	Hu	Okataina	
Maketu	Mk	Okataina	
Tahuna	Ta	Okataina	
Ngamotu	Nt	Okataina	
Tihoi	Ti	Taupo	
Rotoehu	Re	Okataina	42 000

Data from: Howorth (1975); Vucetich & Howorth (1976); Howorth & Topping (unpublished).

the period between the deposition of the Rotoehu Ash and the deposition of Poihipi Tephra (see Table 5). This process of accumulation and slow build up of soils was abruptly terminated by the deposition of the Kawakawa Formation. Erosion was widespread after the Kawakawa, and no organic deposits have been found that date from the next 5 to 6 000 years. The next widely-preserved tephra, the Rotoaira Lapilli (c. 14 000 BP), is unconformable with the underlying sequences (McGlone & Topping 1973). These relatively shallow paleosols therefore represent a span of at least 20 000 years.

(ii) Site descriptions

Hukupapa NZMS1 - N111/883913. Altitude: 550 metres.

The Hukupapa section is in a cutting on the western side of State Highway 4, 25 kilometres south of Taumarunui (Figure 12). It is in the narrow valley of the Whakapapa River which has its headwaters in the western flanks of Mt Tongariro, and flows north into the Waikato River. The section consists of 1.80 metres of tuff overlaid by almost 2 metres of Kawakawa Tephra and rests on coarse sands and gravel (Plate 7). The tuff is dark-brown and highly organic just below the contact with the Kawakawa, but it rapidly grades into pale-brown and grey tuffs. There are three distinct bands of fine charcoal in the section at 0.45-0.55 metres below the Kawakawa; 1.45-1.55 metres; and 1.70-1.80 metres. Two unidentified coarse lithic ashes occur also, one at 0.58-0.72 metres and the other at 0.98-1.20 metres.

Moerangi NZMS1 - N102/079135. Altitude: 701 metres.

The Moerangi section is in a cutting on the south side of State Highway 41, in the rolling country on the eastern flanks of the Hauhungaroa Range (Figure 12). Here there is 1.75 metres of paleosol below the Kawakawa Formation, with four distinct tephra layers: 0.14-0.18 metres, Okaia Tephra; 0.55-0.60 metres, Tahuna Tephra; 0.90-1.02 metres, Tihoi Tephra; 1.46-1.51 metres, unidentified andesitic tephra

(Plate 8). The paleosol grades from a thin, dark-brown organic rich layer directly below the Kawakawa Formation, through to pale blue-grey silts and sands derived from weathered ignimbrite at the base of the section.

Mangaongoki NZMS1 - N102/115136. Altitude: 640 metres.

This site is in a road cutting on the south side of State Highway 41, 3 kilometres east of the Moerangi site (Figure 12). Underneath the Kawakawa Formation is 1.02 metres of paleosol, grading from a thin, dark-brown macrofossil-bearing layer to a grey-brown tuff. The tuff rests on gravels (Plate 9). Only one identifiable tephra (Tihoi Tephra, 0.65-0.82 metres) is apparent in the section sampled for pollen analysis, but a few metres along the road cutting there is a non-polliniferous section exposed where both the Okaia and Tihoi Tephra are found in a thin, reddish-brown tuff. The Okaia Tephra is 0.11-0.33 metres below the base of Kawakawa Formation, and the Tihoi Tephra is at 0.60-0.97 metres.

Hirata NZMS1 - N102/137137. Altitude: 579 metres.

The site is in a road cutting on the south side of State Highway 41, 2 kilometres east of the Mangaongoki site (Figure 12). Here 0.06 metres of very dark-brown organic tuff underlies the Kawakawa Tephra, and is above approximately 0.50 metres of pale-brown tuff (Plate 10). The Okaia Tephra occurs at 0.20-0.28 metres and the Tihoi at 0.56-1.02 metres. The section was not excavated below the Tihoi Tephra, but a few metres to one side a non-polliniferous tuff was found beneath the Tihoi Tephra.

(iii) Macrofossils

Mangaonoki has a thin layer of flattened twigs and leaves immediately below the Kawakawa Formation. Most of the macrofossils are cladodes of *Phyllocladus alpinus*, and are referred to the subalpine ecotype (Wardle 1969). Several fruits and some twigs of *Dacrydium*

bidwillii were also recorded (fruit identification, M.J. Bulfin).

(iv) Pollen diagrams. (Plates 7-10)

All the sites analysed yielded well-preserved although somewhat compressed pollen. It was feared at first that the slow growth of the soils would have led to a totally mixed pollen sequence. At the level of detail attempted (10mm thick samples over a vertical interval of 40-50mm) this appears not to have happened. There are many, sharp fluctuations in the abundance of various pollen types which would presumably have been evened out if mixing had occurred. Nevertheless, as the time interval between samples is of the order of 1000 years, the diagrams cannot be interpreted with the same confidence as those from fast-growing peats.

The high *Nothofagus fusca* type percentages in the basal sediments of these sites present some problems of interpretation. In section 4.2 this problem is discussed, and the conclusion reached that high levels of *N. fusca* type pollen do not necessarily indicate local presence of *Nothofagus* forest. This seems to be the case in the south-west Taupo paleosols: in the interpretations that follow it is assumed the bulk of *N. fusca* type pollen was derived from extra-local sources.

Three pollen zones are recognized.

South-west Taupopaleosol 1.

Description: This zone is distinguished by high *N. fusca* type percentages (30-60%). *Myrsine*, *D. bidwillii* type, *Phyllocladus*, *Dracophyllum*, Gramineae and monolete fern spores are the most abundant other pollen types. *Myrsine* is the dominant scrub type at Mangaonoki and Hukupapa, while at Moerangi, although it reaches its highest level in this zone, it is never more than a minor constituent. Gramineae, *Phyllocladus* and *D. bidwillii* type have low to medium levels at Hukupapa and Mangaonoki: at Moerangi they are extremely variable, with no discernible pattern to their fluctuations. Monolete fern spores are

well-represented at all sites, but once more there is great variation at Moerangi. A feature of this zone at Hukupapa and Moerangi is the relatively strong representation of *N. menziesii*, *Podocarpus* and *Dacrydium cupressinum*.

Interpretation: The vegetation during this zone was a scrub/grassland community. It was not a rich flora; the impression is of scattered scrub and grass patches in an only partly vegetated landscape. The specific identity of some of the taxa requires comment. *Phyllocladus* and *D. bidwillii* type were almost certainly *P. alpinus* and *D. bidwillii*. As the *P. alpinus*, from the evidence of the macrofossils, was of the subalpine ecotype, it was probably low-growing and able to survive well in exposed situations. The other major taxon, *Myrsine*, could belong to any of several species but *M. nummularia* and *M. divaricata* are the most likely candidates. *M. divaricata* is a shrub to small tree, which is often found in, but not confined to, subalpine scrub; *M. nummularia* is a prostrate to semi-erect shrub found in subalpine grassland and herb-field. Either of these species would be appropriate in the type of vegetation proposed for this zone. The monolete fern spores may have been produced by hardy ferns, such as *Blechnum penna-marina* and *Polystichum vestitum*, both of which are found in subalpine scrub and grassland at present.

South-west Taupo paleosol 2.

Description: The zone 1/2 boundary is defined by an abrupt fall in *N. fusca* type percentages to levels a half to a third of those prevailing in Zone 1, and by a general increase in scrub types. The percentage of Gramineae is quite variable, both within the zone and between sites. *Myrsine* and monolete fern spores are prominent in the first half of the zone at Moerangi and Hukupapa, but from then on both these taxa are insignificant. At Hukupapa and Mangaonoki a single scrub type becomes

dominant in the latter half of the zone: *D. bidwillii* type at Hukupapa and *Phyllocladus* at Mangaonoki. In both cases there is a clearly defined peak and, at the same time, there is a corresponding rise in the *Dracophyllum* curve. At this point Gramineae is at its lowest level. At Hirata and Moerangi the pattern is not so clear, and no single scrub type achieves the same dominance. Moerangi does not have a well defined low point for Gramineae as do the other three sites: Gramineae fluctuates at this site throughout the zone but, on average, maintains high percentages.

Pollen of forest taxa other than *N. fusca* type maintain low, but constant levels throughout both this zone and the next. *N. menziesii*, *Podocarpus* and *D. cupressinum* are most common but there are sporadic occurrences of several other types. A range of herbs and prostrate shrub taxa (e.g. *Cyathodes fraseri*) are consistently present. At all sites *Lycopodium fastigiatum* is a prominent spore type, and *Lycopodium varium* often noted. Mire herbs are not abundant and the sole indication at all sites but Hirata, is the occasional peak of *Gleichenia* (not necessarily a mire herb) and *Empodisma*.

Interpretation: During Zone 2 times scrub attained its greatest density although, as the continuing abundance of Gramineae and herbs testify, the scrub was never dense. A striking feature of the pollen spectra from both this zone and the diagrams as a whole is the relative abundance of insect-pollinated types such as the dwarf shrubs *Drapetes* and *Cyathodes colensoi*, and the shrubs *Hebe* and *Dracophyllum*. As these types are not well-represented in modern surface samples (see section 4.3) from areas dominated by these taxa, it follows that they were abundant during this zone. Therefore, despite the higher pollen levels of *Phyllocladus* and *D. bidwillii* type, the shrubland as a whole would have been dominated by the minor elements of the pollen spectra, that is

Compositae, *Dracophyllum*, *Hebe*, *Drapetes*, *C. colensoi* etc. Comparison of the four sites shows that no one species or taxon gained dominance over the whole region. The same mixture of species occurred but their relative abundance varied markedly, even over short distances. At Moerangi, for example, the scrub apparently remained very open with constantly changing proportions among the major types: only 3 kilometres away at Mangaonoki *Phyllocladus* was dominant, even to the exclusion of most other shrubs and Gramineae.

There seems to have been two distinct communities present in the first half of the zone. *Myrsine* and monolete fern spores tend to occur together and *D. bidwillii* type, *Phyllocladus* and *Dracophyllum* seem to follow broadly similar patterns. Although the *D. bidwillii*-*Phyllocladus*-*Dracophyllum* community is dominant for most of the time, there are periods when the *Myrsine*-monolete fern community becomes more prominent. These alternations may have occurred right across the whole region. At the level of the Tihoi Tephra at Mangaonoki there is a sharp rise of *Myrsine*, monolete fern spores and also Gramineae. Monolete fern spores rise to a peak at the Tihoi Tephra at Moerangi (and there is a slight rise in *Myrsine*), and although the Hirata section begins at the top of the Tihoi Tephra, and therefore a true comparison cannot be made, both *Myrsine*, monolete spores and Gramineae are relatively abundant. In the middle of this zone at Hukupapa there is a distinct increase in both *Myrsine* and monolete fern spores. There is no Tihoi Tephra at this site but the tephra occurs at approximately mid-zone at the other sites.

South-west Taupo paleosols 3.

Description: Zone 3 is primarily defined by a clear increase in Gramineae and Umbelliferae, and a sharp drop in the abundance of total scrub pollen. Although scrub types declined at every site, the actual pattern of change varied from site to site. At all sites *Dracophyllum* dropped to low levels. At Mangaonoki, *Phyllocladus* percentages dropped steadily

while there was a fluctuating, slight upward trend in *D. bidwillii* type. The reverse trend occurred at the other three sites; *D. bidwillii* type fell away while *Phyllocladus* either underwent a minor increase, or remained static. Several other scrub species underwent expansion towards the top of the zone; they include *Hebe*, Compositae and, at Mangaonoki only, *Myrsine*. Records of prostrate shrub types and herbs increase in this zone also.

Interpretation: Grassland spread during this zone at the expense of scrubland. This can be seen from the increase of many taxa that are characteristic of grassland, as well as from the increase in Gramineae. It was a species-rich grassland, with Umbelliferae, *Epilobium*, *Geranium* and *Gentiana* as common herbs and numerous small and creeping shrubs such as *Cyathodes colensoi*, *Drapetes*. As this grassland spread, the scrub communities of the previous zone became increasingly confined to sheltered, favourably situated locations.

7.2.4 Taurewa

Location: NZMS1 - N112/050895. Altitude: 823 metres.

(i) Geology and Chronology.

Taurewa has much the same relationship to the Kawakawa Formation as do the south-west Taupo paleosols, and consists of a paleosol formed in the same way. The section is on the eastern side of a road cutting where State Highway 47 crosses a low hill on the bottom slopes of Mt Tongariro, the peak of which is about 10 kilometres distant (Figure 12). At the base of the Kawakawa Formation there is a thin dark-brown tuff with abundant fragments of wood. Below this is a pale-brown tuff which was sampled to a depth of 0.75 metres (Plate 11).

(ii) Macrofossils

Beneath the Kawakawa Formation there is a very thin layer of flattened twigs. Some of these have been identified as the wood of

Hebe and *Dracophyllum* (R. Patel, pers. comm.).

(iii) Pollen diagram (Plate 11)

Despite its much higher altitude, Taurewa is very similar in its pollen sequence to the south-west paleosol sites. Most of the description given for those sites applies to Taurewa also. However, there are some differences that justify treating it separately. Only these points of difference are mentioned in the following descriptions. The same zonation system as used for the south-west Taupo paleosols is followed here.

Taurewa 1

Description: The striking difference between the zone here and at the other sites, is the relatively high percentages of *N. menziesii*, *Podocarpus* and (in two samples) *D. cupressinum*. Total tree pollen types reach a level of 70%, far higher than that recorded for any of the other sites. There are also two records of *Ascarina* which suggests that long-distance dispersal is involved.

Interpretation: Much the same vegetation as dominated the south-west Taupo sites occurred here, but the very high levels of tree pollen, a result of over-representation through long distance dispersal, indicates that the vegetation was much sparser than that at lower altitudes.

Taurewa 2

Description: Unlike the south-west Taupo sites, no one scrub taxon achieves even passing dominance. *Myrsine* is abundant throughout the zone, but *Dracophyllum* is never common. *N. menziesii*, *Podocarpus* and *D. cupressinum* are still much more common in this zone than they are in the same zone at the other sites. Gramineae levels are low.

Interpretation: A sparse, predominately woody vegetation of low growing plants existed during this zone.

Taurewa 3

Description: *Hebe* is extremely common and was without doubt the major scrub taxon. Of the other scrub types, both *Myrsine* and *D. bidwillii* drop away in abundance in the top few centimetres of the zone. *Coprosma*, *Phyllocladus* and *Drapetes* either maintain their previous levels or increase slightly. All the tree types are less abundant, and *Podocarpus* and *D. cupressinum* in particular fall to trace amounts or less. As at the other sites, Gramineae and Umbelliferae are very common. Two important records unique to this site, are *Stackhousia minima* and *Forstera*.

Interpretation: How much of the change recorded at this site is local, and how much a reflection of events in the region, is hard to say. As at the other sites it seems as though grassland spread at the expense of woody plants although, as the macrofossils confirm, the area retained a shrub cover. *Stackhousia* and *Forstera* are plants typical of open grassland habitats, although *Forstera* spp can also survive in light forest or scrub.

7.3 DISCUSSION

7.3.1 Chronology

Although the present work, together with that already published (McGlone & Topping 1973, 1977), provides the most continuous vegetation history for the Otiran and Aranuiian from any region in New Zealand, it is by no means complete. There is, first of all, a complete absence of any vegetation record between 20 000 BP and 14 500 BP. Because of widespread erosion that took place between these dates, it can be assumed that the vegetation cover was incomplete, but further than that it is not possible to comment. Moreover, most of the Otiran deposits in this region have not been satisfactorily dated: the Ohakune and Otamangakau

Canal sites are too old for the radiocarbon method and the pre-Kawakawa paleosols are too low in carbon. There is, therefore, no sure way of determining whether or not there are gaps in the Otiran record. Although the various layers that make up the Otamangakau Canal sequence are likely to be conformable, the small number of events, the abrupt termination of the early interstadial and, in particular, the presence of a non-polliniferous bed with little or no carbon content, suggest that the pollen record from this site is incomplete.

Nevertheless, it is possible to piece together a satisfactory interpretation. It should be remembered, however, that those periods with the harshest climates are likely to be missing. The story, as it now stands, is reduced to its simplest elements: two Otiran interstadials and the Aranuiian interglacial.

7.3.2 Vegetation history

(i) Early Otiran

The early Otiran vegetation sequence derived from the Ohakune and Otamangakau sections records one major oscillation. After an initial scrub/grassland period, closed forest dominates: later grassland returns. At the peak of this interstadial, *Libocedrus* (I assume that it was *L. bidwillii*) was the main canopy tree at both sites. Both *N. fusca* group and *N. menziesii* are likely to have been important in the forests at the altitude of the sites. Regionally, podocarp-hardwood forest - and in particular *D. cupressinum* forest - was the main vegetation type. Records of hardwood trees suggest that there was a diverse subcanopy and small tree flora associated with these forests.

Some of the characteristics of these interstadial forests suggest a warm, wet climate and others a cool, wet climate. Support for a relatively mild, wet climate comes from the presence of *Weinmannia*, *Dodonaea* and *Ascarina*. All these trees are sensitive to severe frost

and, except for *Dodonaea*, require a high, evenly distributed rainfall. On the other hand, the dominance of the local forest by *Libocedrus*, a tree most abundant in the North Island today in higher montane forest; the presence of *N. menziesii*; the dense growth of hardy shrubs such as *D. bidwillii* group and *Phyllocladus* on the mires; all these suggest that the climate was similar to that of present day higher montane to subalpine regions in the central North Island - that is cool and wet. The presence of *Nestegis* at the Ohakune site permits an estimate of the annual temperature at the peak of the interstadial. At present this tree is not found at altitudes above 900 metres. (I. Atkinson, pers. comm.). A calculation based on present day lapse rates, and the assumption that *Nestegis* was at, or near its upper limit during this interstadial, restricts the depression of mean annual temperatures to c. 1.8°C below the present.

In all probability the climate was cooler than at present, but no more than 2°C cooler. Given that there were lower temperatures and thus reduced evapotranspiration, rainfall need not have been any higher than the current values of about 2000mm. The impression is of a cool, wet but not extreme climate.

An interesting comparison can be made between the Aranuiian vegetation record from this area (McGlone & Topping 1977) and the early Otiran interstadial. The general pattern is quite similar: in both cases grassland was dominant at first, but then was rapidly replaced by *Podocarpus spicatus*, followed by *Libocedrus* and *Dacrydium cupressinum*. Although the successional stages are very similar in many ways, the culmination of each episode is quite different. While high *D. cupressinum* ratios prevail in both periods, the interstadial forest was dominated by *Libocedrus*, while *Nothofagus* remained common and

D. bidwillii group and *Phyllocladus* scrub was abundant on the mire. In contrast, a complex podocarp-hardwood forest with little *Libocedrus* or *Nothofagus* developed at the peak of the Aranuanian, and *D. bidwillii* group and *Phyllocladus* played only a minor role in the mire vegetation. The peak of the interstadial resembles a wet version of the early Aranuanian and could be regarded as a period verging on an interglacial.

(ii) Mid Otiran

The first vegetation type to establish on the eroded basement rock after an erosive period of unknown magnitude and duration, was a sparse shrubland. Although a variety of shrubs were involved, there is no pattern between sites that would suggest any correlation with altitude and exposure. The prominence of an insect pollinated shrub, *Myrsine*, as well as the high levels of long-distance pollen rain, point to an incomplete ground cover. It is impossible to translate this vegetation reconstruction into accurate estimates of the climate: all the shrubs found at this time are hardy and certain ferns that may have been present can survive far above the tree line. We can be sure, however, that temperatures were not as low as the treeless shrubland might suggest: the presence of *Phyllocladus* and *Gleichenia* ensures that the area as a whole had a mean January temperature of not less than 10°C. On the other hand, the climate must have been variable and subject to extremes in order to induce such a sparse vegetation cover.

With the drop of the *N. fusca* type pollen percentages in Zone 2 we can assume that there was an increase in pollen production and therefore a denser vegetation cover. Bare ground was colonized, scrub spread from sheltered, moist sites into open exposed areas. There were no major floristic changes but scrub became the dominant vegetation at most sites. In some areas scrub must have formed an almost complete canopy while at others, such as Otamangakau, grassland remained

abundant. Loess continued to accumulate in some areas (e.g. Te Ponanga section) throughout this period, and so there was still substantial areas of eroding ground.

The variation between sites in the completeness of scrub cover and the specific nature of the vegetation suggests that local factors related to topography may have been of great importance. In most areas exposure to wind would have been a major influence and, in depressions such as the Rotoaira Basin, cold air drainage from the surrounding hills may have encouraged grassland at the expense of scrub. These local climatic factors such as cold-air drainage, exposure, aspect etc. may have had such a profound effect that the nature of the regional climate is obscured. It is difficult therefore to compare the climate that prevailed then, with that of the present. However, there are some clues.

As we have seen, the mean January temperature can have been no lower than 10°C: how much higher it may have been at the peak of this interstadial episode is a matter for speculation. The vegetation at Taurewa was a sparse shrubland containing less *D. bidwillii* and *Phyllocladus alpinus* than sites at lower altitudes. The impression is that Taurewa was near the altitudinal limit for *Phyllocladus/D. bidwillii* dominant vegetation. If this is true, and the 10°C January isotherm lay at this altitude, or close to it, the maximum drop in altitudinal zones that can be entertained for this period is about 650 metres, equivalent (using a lapse rate of 0.6°C/100m) to a depression of mean January temperatures, compared to the present, of about 4°C. It is possible that the distribution of *P. alpinus* and *D. bidwillii* extended further upslope, but from the present evidence it is unlikely that this involved more than one or two hundred metres of altitude. A reasonable estimate therefore would be that the mean January temperatures for the Volcanic

Plateau at the height of interstadial were no more than 4°C below present, and were unlikely to have been any less than about 3°C below present.

We are on even less secure grounds in estimating rainfall than we were with temperature. The history of the Rotoaira Basin, seen as a whole, suggests that the climate dried significantly after the early Otiran interstade, and did not recover until early Aranuiian times. Mire herbs, abundant in the early Otiran, were reduced to relatively low levels, averaging about 25-30% of the terrestrial pollen sum. The drop in abundance of mire herbs may have been very much greater than comparisons of the percentage sum would indicate: the pollen production of the sparse shrubland that surrounded Rotoaira Basin during this period was certainly many times less than that of mature podocarp-hardwood forest. The sediments in the basin confirm the inferences made from the pollen. During the early Otiran interstadial peat was laid down: in the mid and late Otiran the sediments are mainly silts and sands deposited as loess and tephra on to a slowly-growing soil.

The nature of the scrub cover can support either a "wet" or "dry" interpretation of the climate as most of the species involved have a wide range of tolerance. *P. alpinus*, *D. bidwillii* and *Cyathodes fraseri* are found in areas of low rainfall, such as central Otago, in high rainfall areas on mountain ranges and also in edaphically wet areas such as peat bogs. *Cyathodes colensoi*, *C. fraseri* and *Stackhousia minima* are common in tussock grassland in some inland South Island valleys where rainfall is low as 750mm per year, and drought frequent (Connor 1964). However, all of these species can also thrive in wet regions.

Charcoal fragments, both microscopic and macroscopic were found at nearly all the sites. In contrast, there is an almost complete absence of charcoal from Aranuiian sites in the same area. Hukupapa,

in particular, has lenses of charcoal scattered throughout the profile. Fires were therefore not infrequent during this period. Volcanism is not likely to have been the primary cause of these fires, as the sites nearest to the volcanoes have no more charcoal than those more distant. It seems probable that drought episodes were the ultimate cause of the vegetation burning.

Although none of the information presented above is conclusive, taken as a whole it seems to point to the climate being either significantly drier or more drought-prone during the mid and late Otiran. If rainfall levels had remained unchanged during this period, while annual temperatures fell by 3-4°C, there is no question but Rotoaira, and no doubt other depressions in the region, would have possessed flourishing mire communities and that peat accumulation would not have ceased.

In the last zone of the interstadial there was a shift to a more open vegetation: grassland spread, scrub retreated everywhere. *Phyllocladus*, *Hebe*, *C. colensoi* and *Drapetes* were the most common shrubs in these grasslands. The upsurge of Umbelliferae at nearly all the sites no doubt reflects the establishment of a dense grassland cover. The retreat of scrub and its replacement by grassland indicates that temperatures fell, but by how much, and what other climatic factors were involved in this change, it is impossible to say. There is no indication that the vegetation cover was any less dense than before. The long-distance transport component of the pollen rain seems to have remained steady at the levels prevailing at the height of the interstadial, suggesting that local pollen production was more or less unchanged.

(iii) Forest during the late and mid Otiran

The question of how much forest, and especially how much *Nothofagus* forest, existed in the Tongariro region during the late and mid Otiran is a difficult one. On the basis of the raw pollen data there appears to be

a good case for extensive *N. fusca* group forest existing in the region during Zone 1, if not in the later zones also. A closer examination of the pollen diagrams reveals anomalies that cannot be explained by this simple hypothesis. The highest site, Taurewa (800m) has more tree pollen in Zone 1 than any of the lower sites. *Podocarpus* and *D. cupressinum* in particular are better represented than in any other diagram. In the Otamangakau Canal site *N. fusca* type pollen percentages are never very high: on the other hand they do not show a marked decline in the equivalent of Zone 2, probably because the spread of denser vegetation did not affect this site to anything like the extent of the others. Pollen production in the Otamangakau area was therefore nearly unaffected.

In the light of this analysis, the hypothesis that most of the tree pollen recorded came from distant forest is attractive. Fluctuations in the amount of tree pollen are explained as a consequence of changes in the density of pollen producing vegetation at the sites, and are not, or only marginally, related to expansion or contraction in the amount of forest in the region.

Some support for this interpretation is given by the Kawakawa Tephra. The greater part of the Kawakawa Formation near source was erupted in the form of a *nueé ardente*, that is as a hot, ash and gas flow. Similar *nueé ardentes* that have erupted into forested areas have swept up trees as they moved, and either fully combusted them or reduced them to charcoal. Exposures of the Taupo Pumice, which was erupted from the same source area as the Kawakawa Formation, show many charred logs of all sizes (Healy 1964a). Despite many kilometres of good exposures of the Kawakawa, no charcoal has been found within the Kawakawa Formation (Vucetich; Howorth, pers. comm.). From this it can be concluded that forest, or indeed any plants capable of producing thick,

woody stems, were rare.

Nevertheless there was forest, or trees at the very least, on the Volcanic Plateau throughout the Otiran. *N. fusca*, *N. solandri* and *N. menziesii* are all found in the region today and, as McGlone & Topping (1977) have pointed out, *Nothofagus* must have survived there, even if in a few, restricted localities, at the height of the Otiran maximum. The relatively high percentages of *N. menziesii* recorded at all sites, but especially at Hukupapa, suggests that, in view of its known underrepresentation (McKellar 1973), it was the most abundant tree. Besides *Nothofagus*, there is no definite indication in the pollen or macrofossil record that any other tree species were present.

CHAPTER 8

BAY OF PLENTY AND GISBORNE, POVERTY BAY

8.1 INTRODUCTION

There are 6 sites in this section, 5 scattered in the Bay of Plenty and one at Gisborne, Poverty Bay (Figure 14). All are associated with identified tephras erupted from the Okataina Volcanic Centre. It is because of the correlations that can be made with these tephras that these sites are grouped together in this chapter.

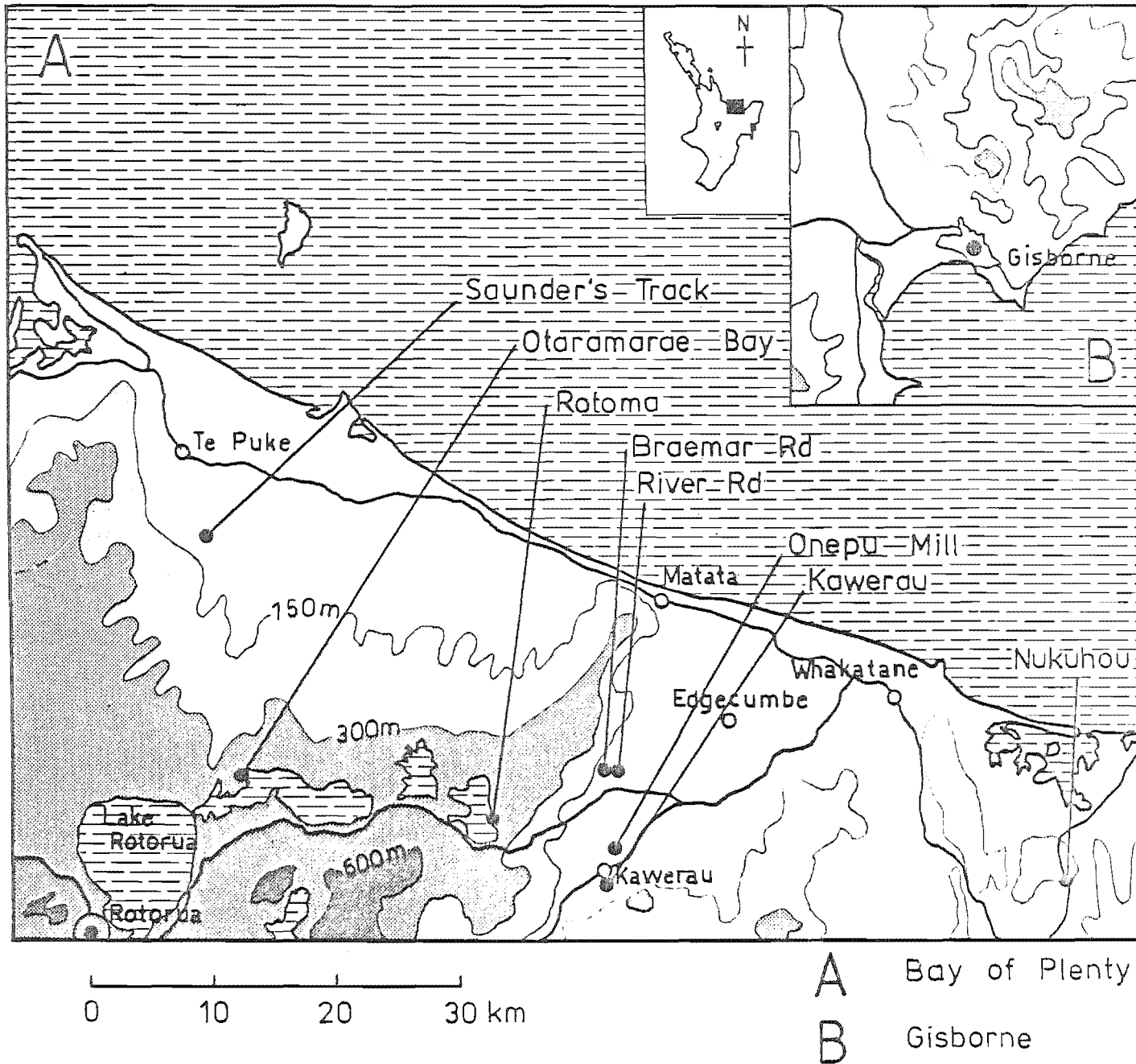
8.1.1 Geography, Geology and Climate of the Bay of Plenty

The Bay of Plenty consists of a narrow coastal plain, not much more than 10 kilometres wide, and an extensive hinterland of dissected hills. The hills are rugged and cut by numerous streams and several small rivers. In the west and centre of this region there are numerous rhyolitic domes and volcanically formed lakes. The hills bordering the coastal plain are 300-900 metres in height.

The main rock type throughout the western and central regions of the Bay of Plenty is volcanic, mostly ignimbrite of Pliocene-Pleistocene age (Shaw & Healy 1962). These rocks are in many places buried by thick deposits of more recent pumice breccias and tuffs. East of Whakatane the rocks are sedimentary, mainly greywackes and argillites of Permian-lower Cretaceous age. The coastal plains are largely built up out of recent unconsolidated alluvium, swamp deposits and sand dunes.

The Bay of Plenty has a mild, wet climate with warm summers and mild winters (Garnier 1958). At the coast annual average temperatures are about 14°C; inland at Rotorua the average is just over 12°C. The coastal regions are among the sunniest in New Zealand with 2300-2500

Figure 14. Site Locations, Bay of Plenty and Gisborne



hours a year bright sunshine, but this total drops to below 2000 hours in the inland areas. Rainfall is high over the greater part of the region, more than 1300mm a year in most places, with the hills bordering the coastal plains receiving generally higher totals of 1800mm to over 2500mm a year. Drought is not common, except in a very narrow fringe along the coast. Rain tends to be associated with wind from the north or north-east, although the predominant wind direction is from the west. The region is one of the least windy in New Zealand.

8.1.2 Geography, Geology and Climate of Gisborne

Gisborne lies on the eastern side of Poverty Bay, on the plain of the Waipaoa River (Figure 14). The hills surrounding the plain average 200-400 metres in height and consist of Miocene-Pliocene mudstones and sandstones. The region is characterized by a warm, moderately wet climate. Summers can be very warm however, especially under the influence of north-westerly winds, and drought is not uncommon in spring and summer (Garnier 1958). Rainfall averages between 1000 and 1500mm a year over the region, and the average temperature at the coast is just under 14°C.

8.2 POLLEN DIAGRAMS

8.2.1 The pre-Rotoehu Ash paleosols

(i) Stratigraphy

Paleosols with a significant organic component are infrequent in Late Pleistocene sequences in the Bay of Plenty and Gisborne areas. Paleosols are usually poorly developed and have a high proportion of loess. However, the very great thickness of the Rotoiti Breccia (flow member associated with the Rotoehu Ash) has preserved three highly organic paleosols in the Bay of Plenty region (Figure 14). In addition

one site has been found outside the area of the Rotoiti Breccia where polliniferous organic sediments have been preserved beneath the Rotoehu Ash. This site, Nukuhou, is described in section 8.2.2. As these four paleosols have a very similar pollen stratigraphy they are treated together here.

(a) Otaramarae Bay

Location: NZMS1 - N76/840187. Altitude: 290 metres

A slip near the western headland of Otaramarae Bay, Lake Rotoiti has exposed a paleosol at 11 metres above lake level.

Stratigraphy is as follows:

<u>Thickness (m)</u>	<u>Unit description</u>
3+	Coarse tephra - Rotoiti Breccia
0.30	Coarse light-brown tephra - Matahi Basalt
0.10	Dark-brown peaty silt, silicified
0.20	Grey-brown silt
11+	Ignimbrite

(b) Lake Rotoma

Location: NZMS1 - N77/052151. Altitude: 316 metres

This section is just above lake level on the eastern shore of Lake Rotoma. Stratigraphy is as follows.

<u>Thickness (m)</u>	<u>Unit description</u>
Not recorded, but 15+ in vicinity	Coarse tephra with calazoidites - Rotoiti Breccia
0.15	Coarse light-brown tephra - Matahi Basalt
0.10	Dark-brown peaty silt, lightly silicified
0.60+	Light-brown silt

(c) Saunder's Track

Location: NZMS1 - N67/818347. Altitude: 120 metres

This site is exposed at the side of a farm track on a spur in the headwaters of the Kaituna River. Stratigraphy is as follows:

<u>Thickness (m)</u>	<u>Unit description</u>
2.0	Coarse white tephra - Rotoehu Ash
0.08	Dark-brown peaty silt, silicified
0.22	Light-brown peaty silt, silicified
0.20	Finely laminated tephra)
	) Pahoa Tephra?
2.30	Fine tephra)
Base	Mamakau Ignimbrite.

There is charred wood in the top layer of the paleosol. A sample of this wood has been identified as *Nothofagus fusca* (Pullar & Patel 1972). However, *N. fusca* is difficult to distinguish from *N. menziesii*, and there is a possibility that the wood was either of these two species.

(ii) Chronology

There is no significant time interval between the Rotoiti Breccia and the underlying Rotoehu Ash (Nairn 1972), nor is there one between the Rotoehu Ash and the Matahi Basalt (Pullar & Nairn 1972). All these tephras are therefore considered to be part of one continuous short lived sequence of eruptive events. The age of the Rotoiti Breccia therefore gives the age for all three tephras. The Rotoiti Breccia has been dated several times, and the results considered most reliable are given below (R. Howorth, pers. comm.).

<u>New Zealand Radiocarbon Number</u>	<u>Age (years BP)</u>
NZ643	> 41 000
NZ877	44 200 ± 4300
NZ1126	41 700 ± 3800

As can be seen from these results, the age of the Rotoiti Breccia is not known accurately. The true age could very easily lie anywhere between 40 000 BP and 50 000 BP. If there has been any contamination at all the actual age of the tephra may be very much older. The stratigraphic position of the Rotoiti Breccia in relation to other dated ashes in the

tephra column gives some confidence however that the commonly quoted age for the Rotoiti Breccia of 42 000 BP is not far wrong, and it is this age that will be used here. There are no dates for older tephras lying below the Rotoiti Breccia in the Bay of Plenty, and therefore there is no way of estimating when paleosol growth commenced.

(iii) Pollen analysis (Plate 12)

The pollen sequences from the three paleosols are so similar that the same zone system can be used for all three. The two samples taken at Nukuhou below the Rotoehu Ash are included in the discussion of the uppermost zone, as they are regarded as being contemporaneous with the uppermost samples in the paleosol sites. The rest of the Nukuhou site is dealt with in the next section. There are two zones. Pre-Rotoehu paleosol 1.

Otaramarae, 0.30-0.15m; Rotoma, 0.70-0.30m; Saunder's Track, 0.30-0.20m.

Description: *N. fusca* type pollen is dominant, making up nearly 100% of total pollen. There are traces of other arboreal pollen types including *Nothofagus menziesii*, *Dacrydium cupressinum*, and *Podocarpus spicatus*.

Tree fern spores are present throughout the zone, but are abundant only in the basal sample at Rotoma. Scrub and mire taxa are rare and herbaceous taxa completely absent. There are low, but consistent, percentages of monolete fern spores.

Interpretation: Lack of herbaceous taxa and the scarcity of mire and scrub pollen types indicates that the forest formed a closed canopy at the sites. Because of this, the influence of pollen rain from outside the immediate vicinity of the sites must have been slight, and therefore firm conclusions cannot be made for the whole region. Nevertheless, almost total dominance of *N. fusca* type pollen at three scattered sites strongly suggests that *Nothofagus* was the most abundant forest type in the Bay of Plenty. The scarcity of hardwood species indicates that

the *Nothofagus* forest was uniform in composition.

Pre-Rotoehu paleosol 2.

Otaramarae, .00-0.10m; Rotoma, 0.00-0.15m; Saunder's Track, 0.00-0.15m; Nukuhou, 0.0 and 0.10m.

Description: *N. fusca* type becomes less abundant from the lower zone boundary attaining an average of c. 50% (averaged over all sites) at the Rotoehu Ash contact. *N. menziesii*, *D. cupressinum*, *P. spicatus* and *P. ferrugineus* all increase, although peak percentages for each species occur at differing levels, there being no consistent pattern for all sites. At the contact with the Rotoehu Ash, *P. spicatus* is the dominant non-*N. fusca* type at Otaramarae; at Rotoma it is *P. ferrugineus*; and at Saunder's Track, *D. cupressinum*. There is a great increase in monolete fern spore levels, but tree fern levels do not vary greatly from those of the previous zone.

Interpretation: The uniform *N. fusca* group forest of zone 1 was invaded by podocarp tree species and *N. menziesii*. At the time of the deposition of the Rotoehu Ash there was a well developed *Nothofagus*/podocarp mosaic.

8.2.2 Nukuhou

Location: NZMS1 - N78/571092. Altitude: 30 metres

(i) Stratigraphy

The Nukuhou valley is shallow and narrow and contains the small, meandering Nukuhou River. Low hills, up to about 300 metres in height, surround the valley. They consist mainly of greywacke overlain by unconsolidated Castlecliffian (Late Pleistocene) sediments.

The section is in a road cutting on the west side of State Highway 2 (Figure 14). The base of the section is at road level and consists of weathered, rounded greywacke river gravels overlain by 0.95

metres of strongly weathered silt and clay which contain some thin organic mud layers, upon which rests a 0.5 metre thickness of the Rotoehu Ash (Figure 15). The upper contact of the ash is eroded and passes up into 0.80 metres of reworked Rotoehu Ash. Above this there is approximately 1.6 metres of tephra, peat and silt. At least 6 separate, identifiable tephtras are included in the peats and silts. Most of them show signs of reworking, as they exhibit cross laminations and contain rounded pumice and mineral grains. It is likely that the tephtras fell into open water, very possibly a lagoon or small lake, and were reworked by wave action. The silt layers are loess or very fine-grained talus. Above the peat and silt layer there is up to 0.5 metres of cross-laminated, discontinuous beds of pumice ash and lapilli, followed by 1.75 metres of pumice belonging to the Mangaone Tephra Formation. Above this is 2 metres of pumice lapilli, identified as the Omataroa Tephra. The upper contact of the Omataroa is eroded in places and passes through to a sandy loess within which is the Kawakawa Tephra.

(ii) Chronology

Approximate ages of some of the identified tephtras is given in Table 5. The Rotoehu Ash is about 42 000 years old, if not somewhat older. There are several dates for the Mangaone Tephra ranging in age from 35 300 to 30 000 BP (Section 8.2.5). The pollen section age range is therefore from at least 42 000 BP to about 35 000 BP.

(iii) Pollen analysis (Plate 13)

The pre-Rotoehu Ash samples from this site have been already considered in relation to the other pre-Rotoehu sites. They form a valuable link with the rest of the Nukuhou diagram. There are no easily discernible trends in this pollen diagram, the picture being one of almost random fluctuations of the major vegetation types. For this reason no attempt has been made to zone the diagram.

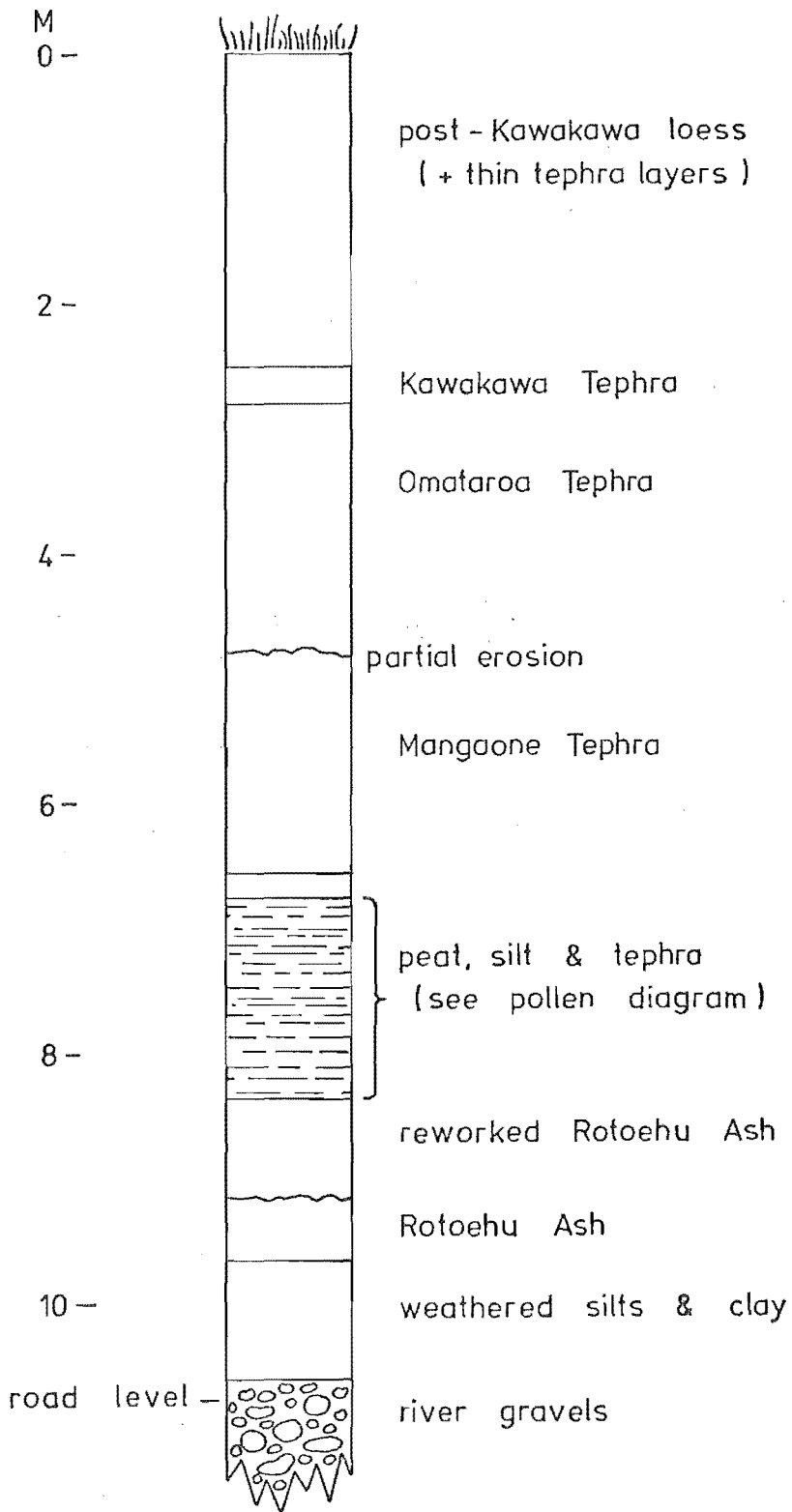


Figure 15. Tephrostratigraphy, Nukuhou, Bay of Plenty

Description: For most of the diagram *Nothofagus*, consisting of approximately equal proportions of *N. fusca* type and *N. menziesii*, provides the bulk of the pollen. There is never less than c. 15% *Nothofagus* and the average for the diagram is near 35%. Podocarp tree taxa, mainly *P. spicatus* and *D. cupressinum*, form a much smaller proportion of the total averaging only 10%. This proportion does not fluctuate very much, but there is a brief interval (0.13-0.30m) where the average rises to 30%. There are isolated occurrences of some other tree taxa such as *Metrosideros*, *Hoheria*, *Plagianthus*, *Fuchsia*, *Agathis australis*, *Persoonia toru*, *Carpodetus serratus*, *Quintinia* and *Nestegis*, but only *Libocedrus* and *Dacrycarpus* have more or less continuous representation. Although there is a wide range of scrub and small tree taxa, most of the pollen is provided by just a few, namely *Coprosma*, *Dacrydium bidwillii* type, Compositae and *Leptospermum*. *Myrsine*, *Hebe*, *Dracophyllum*, *Pseudopanax*, *Muehlenbeckia*, *Pseudowintera*, *Cyathodes juniperina* and *C. fasciculata* are commonly present. The herb flora is relatively rich. Gramineae is most abundant, averaging c. 10%, but fluctuating between 2% and 29%. Other herb taxa found are characteristic of grassland or open ground, especially Cruciferae, *Plantago*, *Taraxacum* type, *Epilobium*, *Gentiana*, *Geranium* and *Rumex*. Cyperaceae and *Empodisma*, which have variable but continuous representation, are the major mire taxa. *Sphagnum* and *Gleichenia* make sporadic appearances. Between the 1.36 and 1.16 metre levels, *Myriophyllum* and *Potamogeton* are abundant but, other than this occurrence, aquatics are rare. Fern spores are not plentiful except as a consequence of pollen degradation during some of the silt sedimentation phases. *Lycopodium*, tree fern, *Phymatodes* and *Ophioglossum* spores are regularly present, but never in large amounts.

Interpretation: The major forest type was *Nothofagus*, mainly *N. menziesii* throughout the period of deposition. Forest was close to the site as there is a significant representation of poorly dispersed pollen types of taxa commonly associated with *Nothofagus* forest. Among these are *Elytranthe* (mistletoes that have *Nothofagus* as their usual hosts) and the shrubs *C. fasciculata* and *C. juniperina*. Podocarp-hardwood forest, consisting mainly of *P. spicatus* but with significant proportions of *D. cupressinum* and other species, existed in the region, perhaps as isolated pockets in favoured sites.

The high levels of grass, plus the occurrence of herbs and shrubs of open habitats, demand at least some open grassland in the vicinity of the mire. Subalpine scrub was present also, as the high levels of Compositae, *Phyllocladus*, *Dracophyllum* and *Hebe* indicate. The mire itself may have had a scrubby cover of *D. bidwillii* type and *Leptospermum scoparium* at times, but it appears to have been mainly an acid bog for most of its existence, although there were times when sedges or open water prevailed.

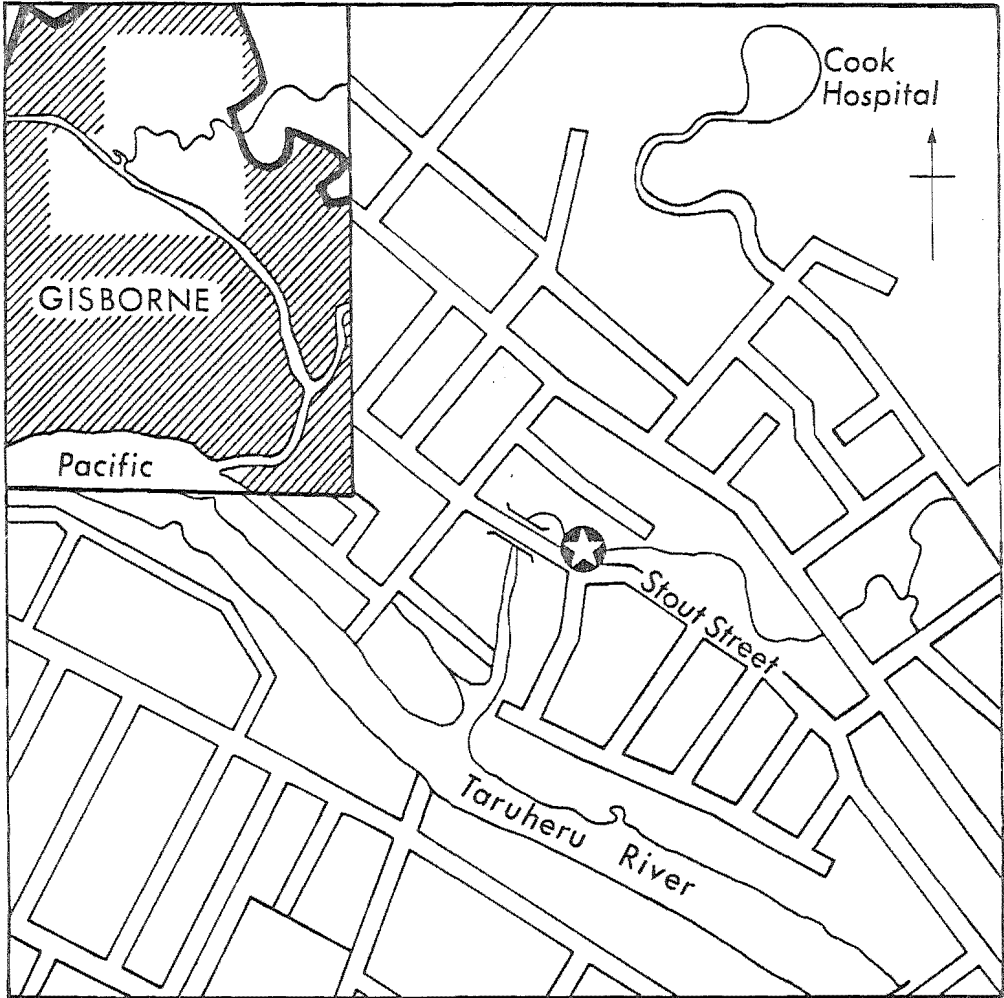
To summarize: the immediate environs of the site at any one time were covered with a mosaic of *N. menziesii* forest, subalpine scrub, grassland and acid bog. Many fluctuations in the abundance of the various components appear to have occurred during the period of deposition, but no overall trend can be seen. Podocarp-hardwood and *N. fusca* type forest need not have been close to the site, but they were certainly in the region.

8.2.3 Stout St, Gisborne

Location: NZMS1 - N98/393392. Altitude: sea-level.

(i) Stratigraphy

The section is exposed on the bank of the Mangapapa Stream in Gisborne City (Figure 16). Mean high tide mark is at the base of the



0 ————— 500m


 Stout Street Site

Figure 16. Site location Stout Street

section. The section consists of tephra layers interbedded with peat, organic silts and muds which pass down to a green-grey silty clay. A diagram of the section with the identified tephtras and associated radiocarbon dates is given in Figure 17.

(ii) Chronology

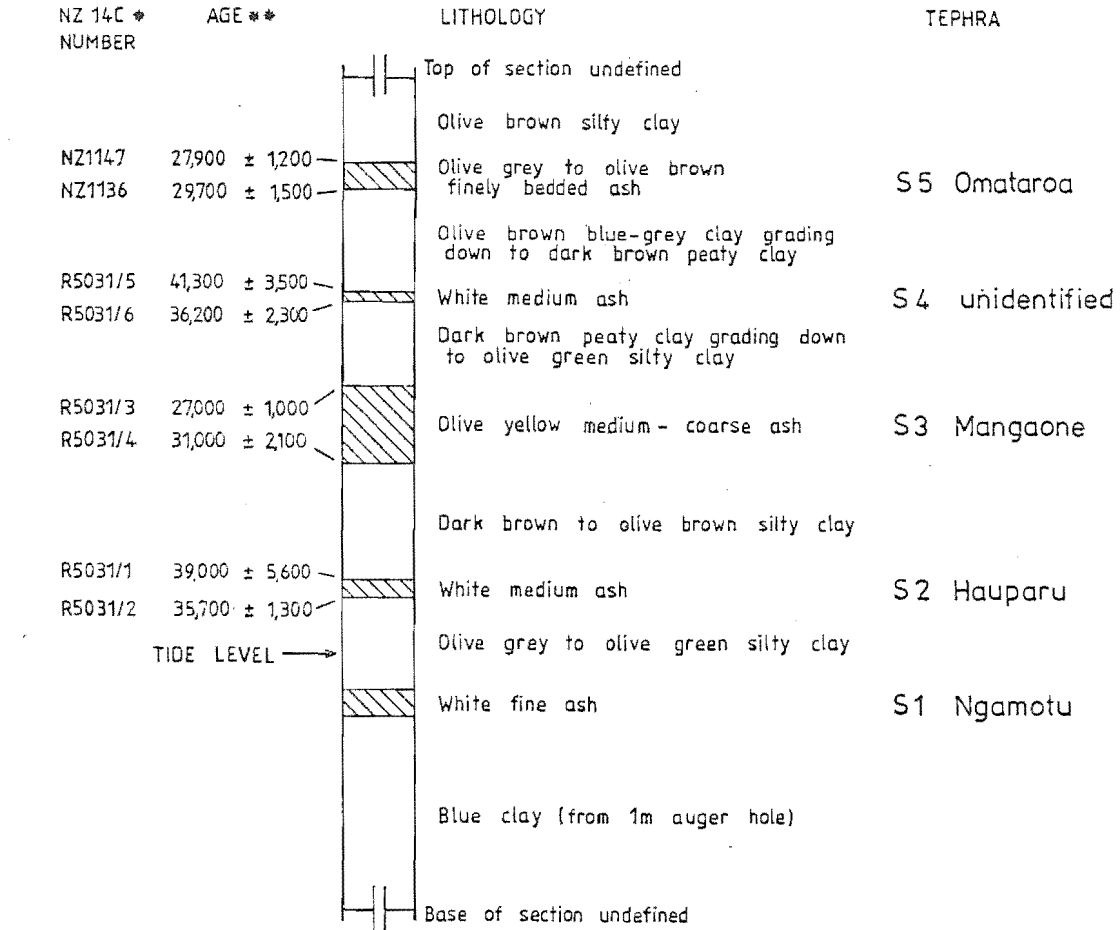
The site is a difficult one to correlate because the correlations depend entirely on a "floating" tephra sequence. Although the Rotoehu Ash is exposed in the Gisborne region, it was not found in the section and is presumably buried deeper. The top of the section is truncated by late Holocene dune sands.

There are a total of eight radiocarbon dates from the site, but these have not proved to be of much assistance. There are two reversals in the radiocarbon sequence and, if the site was taken in isolation, it would be difficult to escape the conclusion that the entire sequence was beyond radiocarbon dating and that all the finite dates were a result of contamination with younger carbon. However, if the errors quoted for the dates are taken into consideration, it can be seen that there is considerable overlap in the ages. It is possible that the apparent reversals are a product of statistical fluctuations inherent in the radiocarbon technique when material at the limit of the method is analysed. Dates for one of the identified tephtras in this section, the Mangaone Formation, from exposures in the Bay of Plenty would tend to support this contention. The dates (see section 8.2.5) range from c. 35 000 to 27 000 BP and therefore compare favourably with the dates of 27 000 and 31 000 BP from Stout St.

The uncertainty surrounding the chronology of the Rotoehu Ash to Omataroa Tephra sequence is unlikely to be resolved by present radiocarbon dating techniques, as the true ages of the tephtras, whatever they are, are very close to the absolute limit of the method as it is now used. However, the uniformity of the dates for the Mangaone Tephra is impressive, given the scatter of localities the dates were obtained


Stout Street section, Gisborne. Compilation of stratigraphy and radiocarbon dates.

Figure 17. Tephrostratigraphy and radiocarbon dates, Stout Street



* New Zealand 14C Number, R-prefixed numbers quoted pending allocation of NZ 14C Number

** Age calculated using old half-life (5568 years)

 Tephra deposit

from and the very different origin of the material dated. Therefore, for the present, the age of the Mangaone Tephra will be taken as being about 31 000 BP.

(iii) Pollen analysis (Plate 14)

Pollen preservation is rather poor at this site, and in some samples pollen is scarce. Where pollen is scarce, spores are usually over-represented, presumably as a result of differential degradation of the pollen. Individual taxa percentages have not been calculated for these episodes, except for an extinct *Nothofagus* type which is of value as an indicator of the influx of secondarily derived pollen.

The pollen diagram is divided into four zones on the basis of changes in the arboreal pollen percentages. The many fluctuations in the scrub and mire taxa percentages are largely ignored for purposes of zonation, as they seem to merely reflect changes in water level. Abundant microscopic charcoal fragments are found throughout the section.

Stout St 1 0.00-0.57 metres

Description: *Podocarpus* (mainly *P. spicatus*), *D. cupressinum* dominate the arboreal pollen sum, but there are also sizeable contributions from *Dacrycarpus* and *Libocedrus*. There is a wide variety of hardwood tree and shrub taxa including *Plagianthus*, *Hoheria*, *Paratrophis*, *Knightia*, *Pseudopanax*, *Pseudowintera*, *Neomyrtus* type and the vine *Tetrapathaea*. Tree fern spores - mainly *Cyathea smithii* type and *C. dealbata* - are abundant.

Arboreal pollen makes up only a small proportion of the spectrum which is dominated by pollen of scrub taxa. Although there is a fair variety of scrub pollen types recorded, almost all the scrub pollen is produced by just three types, *Leptospermum*, *Corprosma* and *Muehlenbeckia*. Only negligible amounts of non-mire herbs are recorded. Cyperaceae.

dominate the mire flora, together with small, fluctuating percentages of *Typha* and *Phormium*. Aquatic plants are represented by *Myriophyllum*, *Potamogeton* and *Azolla* which are sporadically present throughout the zone, but abundant in the first few centimetres only.

Interpretation: Despite the very high levels of scrub pollen recorded, this is without doubt a forest period. The immediate surroundings of the mire/lake was covered with a thick scrub, with perhaps *Dacrycarpus* swamp forest in places, but podocarp-hardwood forest occupied the surrounding hill slopes. There are strong resemblances between this forest and the podocarp-hardwood forest found in lowland eastern areas of both the North and South Islands at present. The only major difference is the relatively high proportions of *D. cupressinum* and *Libocedrus* indicated for the ancient forest.

Stout St 2. 0.57-1.50m.

Description: At the beginning of this zone there is a sustained rise in the ratio of *D. cupressinum* to other tree podocarps, to levels about double those prevailing in Zone 1. At more or less the same time *Metrosideros*, *Libocedrus*, *Alectryon*, *Nestegis*, *Elaeocarpus*, *Pseudopanax*, *Neomyrtus* type, *Aristotelia* and *Urticaceae* increase. Mire and aquatic pollen levels are high in the first few samples of this zone, and then drop to extremely low values.

Interpretation: There was a major change in the podocarp-hardwood forest near the site, as *D. cupressinum*, *Libocedrus* and a range of other tree species became more abundant. At the same time the mire vegetation was completely altered. In place of the previous swamp communities, a low swamp forest, probably with *Elaeocarpus hookerianus* and *Lophomyrtus bullata* as important constituents, established on the site.

Stout St 3. 1.50-2.80m.

Description: This zone has a pollen assemblage very similar to that of Zone 1. One of the few significant differences is that the *D. cupressinum* ratios are, on average, about half those of Zone 1. *Knightia*, *Ascarina*, and *Alectryon* are more common, but otherwise there is little change.

Interpretation: *P. spicatus* was again the dominant forest tree and, in general, the vegetation resembled that of Zone 1. The mire vegetation now consisted of herbs again, and water levels were high.

Stout St 4. 2.80-3.00m.

Description: The pollen spectrum is almost completely dominated by *Blechnum capense* type spores. The small amount of arboreal pollen noted appears to be of the same podocarp-hardwood pollen types that are present in the other zones.

Interpretation: The pollen spectrum of this zone appears to be an exception to the rule that large numbers of fern spores represent the result of pollen degradation. The few pollen grains that are present are in general free from corrosion as are the spores. The spores are nearly all of the one type in contrast to the variety of spores that are encountered when corrosion has taken place. It seems therefore that there was a thick ground cover of *Blechnum* at this time on the mire surface. As far as can be deduced from the other pollen types, there was no major change in the surrounding forest.

8.2.4 Kawerau

Location: NZMS1 - N77/160089. Altitude: 30 metres.

(i) Stratigraphy

Site collected by W.A. Pullar and I. McClean in 1967. This site is exposed in a disused refuse dump on the east bank of the Tarawera River, near the hills bordering the coastal plain (Figure 14). The

polliniferous horizon is a thin, black, buried soil overlying the Rotoehu Ash and beneath member (b) of the old Mangaoni Lapilli Formation. This formation has since been divided into its constituent tephra units: member (b) now corresponds to Maketu, Te Mahoe and Hauparu Tephtras of Howorth (1975). As the site was not revisited, no further details of the stratigraphy are available.

(ii) Chronology

Soft charcoalized twigs in the soil were dated at $36\ 000 \pm 2100$ BP (NZ 1067). The event dated is not entirely clear, but it is likely to be the eruption of either the Maketu, Te Mahoe or Hauparu Tephtras. There is a possibility that there was erosion between the deposition of the Rotoehu Ash and the Mangaoni Lapilli member (b) at this site.

(iii) Pollen analysis

Only one sample was taken from the layer. Pollen is poorly preserved and only a few types are recorded. Results are given in Table 6.

Description: *N. fusca* type is dominant and there are only small amounts of tree podocarps. *Myrsine* is abundant and, together with *Coprosma*, makes up over 40% of the pollen sum. *Phyllocladus* and *D. bidwillii* type each contribute 3%, and there is 5% Gramineae.

Interpretation: Although it lies in the same age range as, and is close to Nukuhou, Kawerau has much more in common with the pre-Rotoehu sites. Being a paleosol it is dominated by the local pollen-producing species, which in this case were *N. fusca* group and *Myrsine*. Little can be said about the vegetation, except that there was either a *Nothofagus* forest with a *Myrsine* understorey, or that the site was a clearing dominated by *Myrsine* scrub in the middle of a *Nothofagus* forest. The small percentage of Gramineae recorded either came from inside this clearing, or was derived from further afield.

TABLE 6POLLEN ANALYSIS: BURIED SOIL, KAWERAU

<u>POLLEN TYPE</u>	<u>PERCENTAGE OF TOTAL POLLEN</u>
<i>Nothofagus fusca</i> type	43
<i>Podocarpus</i>	1
<i>Dacrydium cupressinum</i>	2
<i>D. bidwillii</i> type	3
<i>Phyllocladus</i>	3
<i>Coprosma</i>	7
<i>Myrsine</i>	34
Gramineae	5
Monolete	2

Pollen sum: all types except monolete.

8.2.5 Charcoal from the Mangaone Tephra Formation

(i) Stratigraphy, Chronology and Identifications

Charcoalized wood is common in the pyroclastic flow deposits which form the upper part of the Mangaone Tephra. Near Kawerau there are four exposures of the Mangaone Tephra that contain charcoal. The outcrops are restricted to ridges of late Pleistocene age which were not buried by the post-glacial aggradation of the Rangitaiki and Tarawera rivers. The flow deposits are up to 1.5 metre in thickness and lie about 30 metres above present sea-level. Charcoal identifications were made by Dr B.P.J. Molloy, Botany Division, D.S.I.R.

(a) Braemar Road South

Location: NZMS1 - N77/172186.

Charred logs up to 150mm diameter are common and their long axes are aligned towards to the north-east. One log is identified as *D. cupressinum*. Date: 31 400 ± 1500 BP (R4803).

(b) Bowditch's Quarry

Location: NZMS1 - N77/173171

A photograph of this site is included in Howorth (1975). Lumps of charcoal up to 200mm in diameter, but not identified, were found. Date: 35 300 ± 2200 BP (NZ 1812).

(c) River Road.

Location: NZMS1 - N77/191184

This outcrop contains a few, distinct lumps of charcoal up to 100mm in diameter. Identification and dates reported in Bailey *et al* (1973, 1975) and Bailey & Lee (1972). Charcoal was identified as belonging to *P. spicatus* and dated at 26 100 ± 800 BP (NZ 1556). Further treatment to remove contaminants resulted in a date of 26 800 ± 1400 BP (NZ 1610).

(d) Onepu Mill

Location: NZMS1 - N77/171144.

Charcoal logs are common and aligned towards the north-east. *Phyllocladus c.f. alpinus* and *Leptospermum c.f. scoparium* were both identified from this deposit. No dates.

(ii) Discussion

All the charcoal may have been carried some distance by the tephra flow and therefore is not necessarily a guide to what was growing at the site. However, it is positive confirmation that trees of the four species identified were growing in the Bay of Plenty at the time of the eruption of the Mangaone Formation.

8.3 DISCUSSION

8.3.1 Vegetation and climate

(i) Pre-Rotoehu

The pollen diagrams from the pre-Rotoehu paleosols present a straight forward sequence of events. To begin with there was an almost pure *N. fusca* group forest covering at least part of the hilly regions of the Bay of Plenty. Whether this forest was widespread, or confined to relatively small areas, there is no way of knowing. The record from Nukuhou suggests that forest, at least in the lowlands, had a patchy distribution. It is possible that the paleosols were preserved only in exceptionally stable areas and thus give a biased picture of the vegetation. During Zone 1 times the vegetation pattern may have been complex with *N. fusca* group forest occupying sites with the most favourable soil and climate, while a range of scrub and grassland communities existed in less favoured situations.

At the beginning of Zone 2 there was a progressive invasion by *N. menziesii*, *P. ferrugineus*, *P. spicatus* and *D. cupressinum*. This invasion was not uniform from site to site, nor was there a specific successional pattern. *N. fusca* group forest remained dominant in the region as a whole, although individual podocarp species may have attained a local dominance in some places (e.g. Saunder's Track). It is likely that the most favourable sites within the original *N. fusca* group forest were occupied by the three podocarp tree species, the dominant podocarp being determined at each site by local factors. A peculiar feature of the resultant podocarp/*Nothofagus* forest was the absence of a significant hardwood tree element.

The invasion of pure *N. fusca* group forest by podocarps indicates that the climate had changed to a marked degree. *Nothofagus* forest in general appears to have low competitive ability against tall podocarp forest when these forests are growing on good soils and climatically favoured sites. *N. solandri* var *cliffortioides* forest in particular can stand the extremes of climate and soil better than most podocarp trees. Although often found in areas of high rainfall, it can tolerate both low soil moisture as well as excess soil moisture. However, it has very low competitive ability when compared to most other forest trees (Wardle 1970; Wardle 1967). *N. menziesii* on the other hand has a good competitive ability against *N. solandri* var *cliffortioides*, under conditions of high rainfall, but does not have the same tolerance for harsh climatic conditions (Wardle 1967). If the original forest was mainly *N. solandri* var *cliffortioides* it can be seen that an increase in rainfall would favour *N. menziesii* as well as some of the tall podocarp trees, especially *D. cupressinum* and *P. ferrugineus*. The pattern may have involved an invasion of the best sites by podocarp forest, while

N. menziesii tended to replace *N. solandri* var *cliffortioides* on the poorer sites. The increase of fern spores in the upper zone may also indicate a moister climate at that time.

It is likely that the change to a wetter climate was accompanied by an increase in temperature, which would also tend to favour podocarps, but there is no direct evidence for this. Any increase in temperature was probably small, as the presence of *N. menziesii* suggests that the climate remained equivalent to that of montane regions in the North Island today.

(ii) Rotoehu Ash to the Mangaone Formation

With the exception of the charcoal sites, all the vegetational evidence for this period comes from two sites - Nukuhou and Stout St, Gisborne. The difficulties of interpretation are highlighted by the fact that at first, before critical examination of the tephra stratigraphy at Nukuhou, these sites were regarded as representing a cool and a warm phase respectively of an interstadial complex (McGlone & Howorth 1976). Therefore it is not possible to be dogmatic about the interpretation of these sites in terms of climate; only further sites will resolve the apparent discrepancies between them.

During the period between the Rotoehu Ash and the Mangaone Formation, the Bay of Plenty was covered with a mosaic of forest, scrub and grassland. Podocarp-hardwood forest may have been confined to sheltered, moist, north facing slopes; *N. fusca* group and *N. menziesii* occupied sites that were drier, poorly drained, more exposed, cooler, or in other ways marginal for tree growth. Such areas as frost hollows, exposed ridges, low lying land with impeded drainage, and cold south facing slopes are unlikely to have had forest and, depending on how extreme the local environment was, may have had either a cover of scrub

or grass, or perhaps no vegetation at all.

There is some geomorphic evidence for such a pattern. Road cuttings in the Bay of Plenty occasionally expose a complete cross-section of a west-east tending ridge. It is noticeable that the north-facing slope of such a ridge usually has the tephra sequence of the region intact: the south-facing slope generally has some disturbance. On these south-facing slopes the tephrae have either been eroded away in places or loess deposits separate them (R. Howorth, pers. comm.).

There are areas of New Zealand that have a vegetation pattern much like that hypothesized for the Bay of Plenty. Coastal Fiordland, in the south-west of the South Island, has a climatic regime of cool temperatures (mean annual temperature 9.9°C), high wind speeds, high rainfall and excessive cloudiness. Under these conditions a mosaic of subalpine scrub, grassland, *Nothofagus* and podocarp forest has established in areas not far above sea-level and close to the coast (Wardle et al 1973). It cannot be argued from the limited evidence available that a similar climatic regime produced the Bay of Plenty pattern, but the Fiordland analogue shows that such a vegetation pattern is feasible.

Although *N. menziesii* forest was the dominant vegetation type at Nukuhou, and grassland and subalpine scrub always well represented, podocarp-hardwood forest existed throughout this period in the Bay of Plenty. A wide range of taxa usually associated with such forests are recorded, and two of these are of particular interest: *Agathis australis* and *Persoonia toru*. *Agathis* is a tall forest tree confined to the northern half of the North Island at present, and it reaches its southern limit at Opotoki. *Persoonia* is a small tree to shrub, and also reaches its southern limit in the Bay of Plenty. Although *Agathis* is

wind pollinated, the pollen is either poorly distributed or is produced in small quantities because, even in areas where *Agathis* is abundant, it is not well represented (N.T. Moar pers. comm.). *Persoonia* is insect pollinated and therefore presumably under-represented in pollen spectra.

Only two records were made of *Agathis*, and three of *Persoonia* pollen, but because of their under-representation it is near certain that both these species were growing in the Bay of Plenty. If the southern limit is taken as representing a climatic boundary for these species, it is unlikely that mean annual temperature was lower than at present at that time. However, *Agathis* has been reported as growing and regenerating at altitudes up to 800 metres in the Coromandel Range (Cranwell & Moore 1936) and *Persoonia* is found in montane forests. Therefore, although the inferred presence of these species does not argue for a harsh climate, it does not exclude the possibility that mean annual temperatures were lower.

The Stout St section at Gisborne records a vegetation very different from that in the Bay of Plenty. The site lay in an extensive, scrub-covered mire and the surrounding hills were podocarp-hardwood forest. This podocarp-hardwood forest persisted for the entire period with only minor changes in composition. *P. spicatus* was the major species throughout, except for one episode when *D. cupressinum* and *Libocedrus* were the dominant conifers. Only trace or very low amounts of *Nothofagus* pollen are recorded and there can have been no *Nothofagus* forest near the site. The mire vegetation was not as stable as the forest: there are many fluctuations of the mire herbs, mainly as a response to influx of silt.

There are abundant microscopic charcoal fragments throughout the section, and these must have been derived from frequent fires in the surrounding vegetation. Gisborne may have been subjected to either severe droughts or intense periods of drying weather to produce such a fire frequency. Nukuhou, in contrast, has little or no charcoal in most samples and fire was probably unimportant there.

With the sole exception of *Libocedrus*, the taxa recorded at Gisborne are typical of present day lowland forest in the eastern North Island. If the *Libocedrus* pollen was derived from *L. bidwillii*, the climate is likely to have been cooler, and very possibly wetter than at present. However some of the species recorded rule out the possibility of the climate being much cooler. *Tetrapathaea tetrandra*, *Knightia excelsa* and *Dodonaea viscosa* do not occur above about 550 metres in the central North Island (Nicholls pers. comm.), nor do they extend very far south. *Knightia* does not occur further south than the Marlborough Sounds (S. lat. 41°) and the southern limit for *Dodonaea* and *Tetrapathaea* is Banks Peninsula (S. lat. 44°). The presence of *Alectryon excelsus* and *Ascarina lucida* suggests that the climate was relatively mild and not subject to severe frost.

When the diagrams are compared it is difficult to escape the conclusion that, despite the present day climates being similar, during the mid Otiran Gisborne enjoyed a significantly more favourable climate than the Bay of Plenty. Part of the explanation for this seeming anomaly may lie in the differing position and topography of the two sites. Gisborne is in a sheltered valley and during the mid Otiran was near the sea, if not actually at the coast (Howorth pers. comm.). Nukuhou is in a far more exposed situation and was much further from the mid Otiran seacoast. Local topographic factors may have been far more important in governing the distribution and type of vegetation at that time than the regional climates.

CHAPTER 9

POUKAWA

9.1 INTRODUCTION

9.1.1 Vegetation and climate

The vegetation of the Poukawa Depression has been described in McGlone (1978), a copy of which is in a pocket at the back of this thesis.

The Poukawa Depression and surrounding areas have a sunny climate with warm summers and mild winters (de Lisle 1971). Annual temperatures average just over 12°C. Frost can be frequent in winter, and nearly 30 screen frosts a year are recorded in adjacent valleys. Hawkes Bay is sheltered from the predominately westerly wind flow over the North Island, and is therefore one of the less windy areas. However, in spring and early summer, westerly föhn winds are common. Rainfall is low, averaging 600-800mm a year. Most rain is associated with winds from the east and the variability of rainfall is high. Drought is common, and from November to May rainfall is often insufficient to meet plant requirements.

9.1.2 Geography and geology

The Poukawa Depression is a fault-created basin bordered by two, low (average height 250-300 metres) limestone ranges, Raukawa to the west and Kaokaorea to the east (Figure 18). Lake Poukawa (20 metres a.s.l.) lies at the southern end of the depression and is surrounded by extensive (approximately 100 hectares) peat swamps, now drained and in pasture. Of the original vegetation of the basin, only a much-altered *Typha* community remains, forming a narrow fringe in the shallow water at the lake edge. Most streams in the Depression flow into the lake, which is drained by the Poukawa Stream flowing north on to the

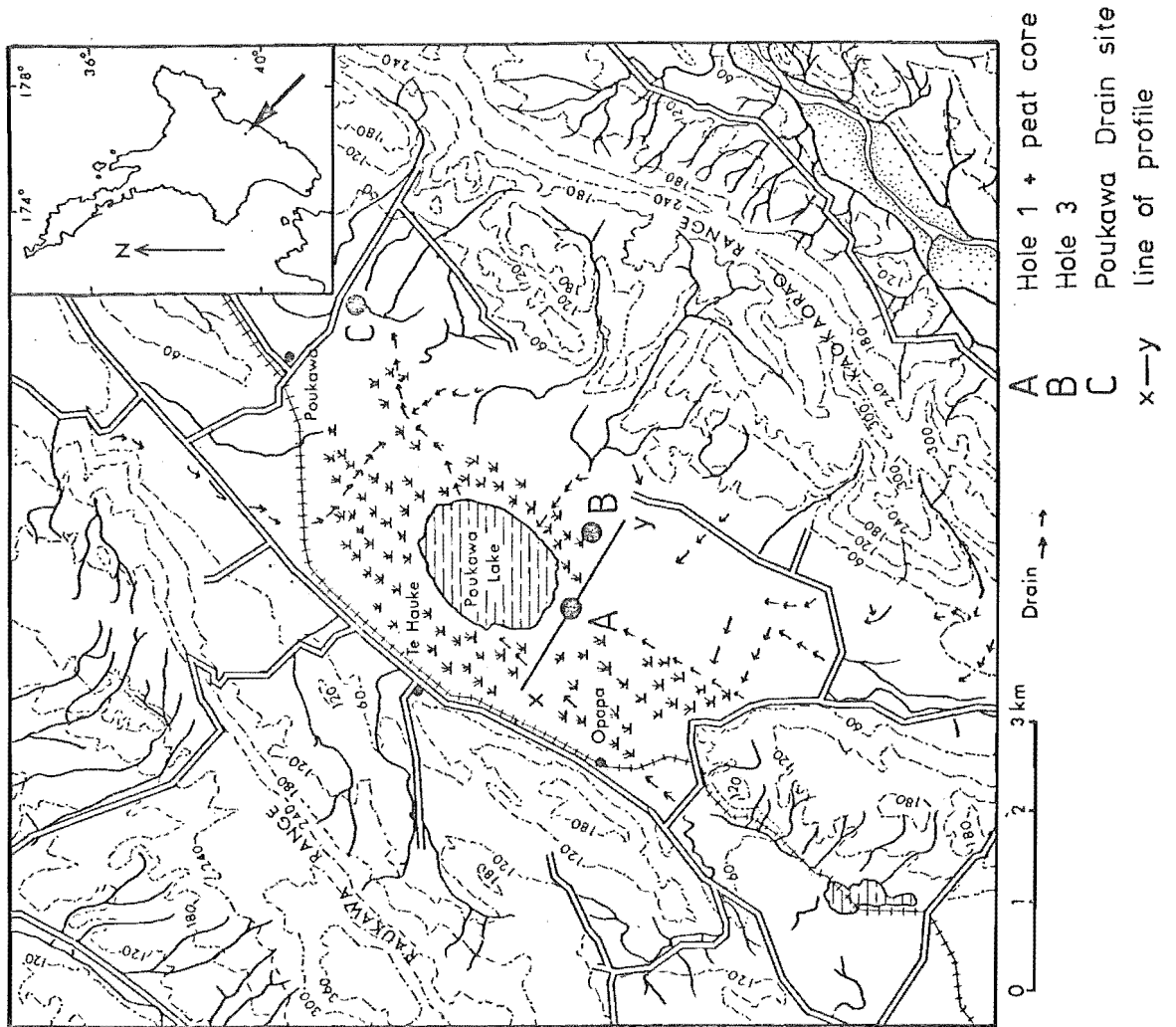


Figure 18. Site location, Poukawa Depression

Heretaunga Plains. The lake is about 1.5km in diameter and is almost circular. It is shallow, usually less than 1 metre in depth. The difference between the maximum recorded lake level and the lowest is only 1.20 metres. However, the floor of the Poukawa Depression is very nearly flat, and small changes in lake level tend to create rather large expansions of the lake surface. For example, in August 1977 the lake expanded as far as State Highway 2 (Figure 18) on the western side of the depression, and occupied an area more than three times its normal size. The lake is drained by a man-made outlet: in the past, lake levels must have risen appreciably higher.

Robertson (1978) and Froggat (1976) have investigated the geology of the recent sediments in the Depression. Their work has resulted in a detailed tephrostratigraphy of the Quaternary sediments in the Depression and also some information on the environmental significance of the various deposits.

Seismic reflection work (Froggat 1976) in the Depression has established its structure (Figure 19). The basin is a syncline with two faults, one recently active (1931), running through the western edge. Near the centre of the Depression 10 metres of peat and wood overlies about 45 metres thickness of fine-grained sand and silt. Below this is 200-300 metres of possibly lower Pleistocene sediments. Basement rocks consist of Te Aute Limestone (Pliocene), the same formation that makes up the surrounding hills.

An east-west Hiller borer transect of the peat in the Depression was made just south of the lake (Figure 20). Several tephras were encountered and also several horizons of calcareous lake sediment. Besides the Hiller transect, three deep drill cores were taken within the Depression (see Figure 18 for locations) which penetrated nearly to the base of the underlying sand and silt formation. Two older tephras

Figure 19. Profile of Poukawa Basin

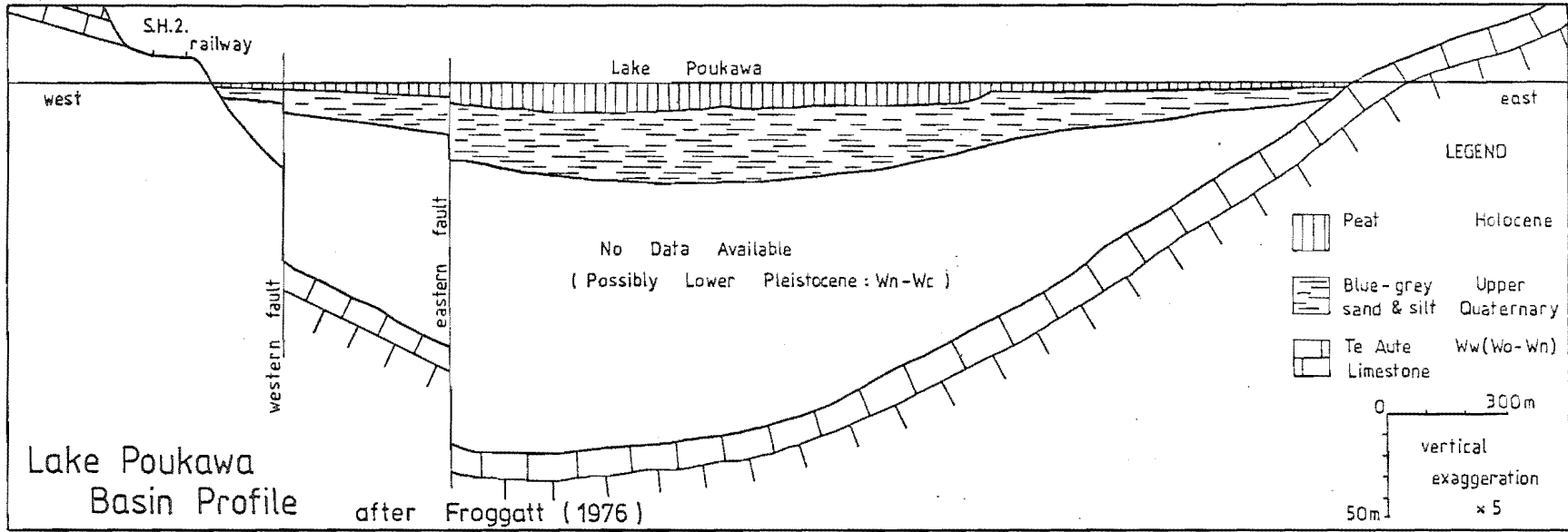
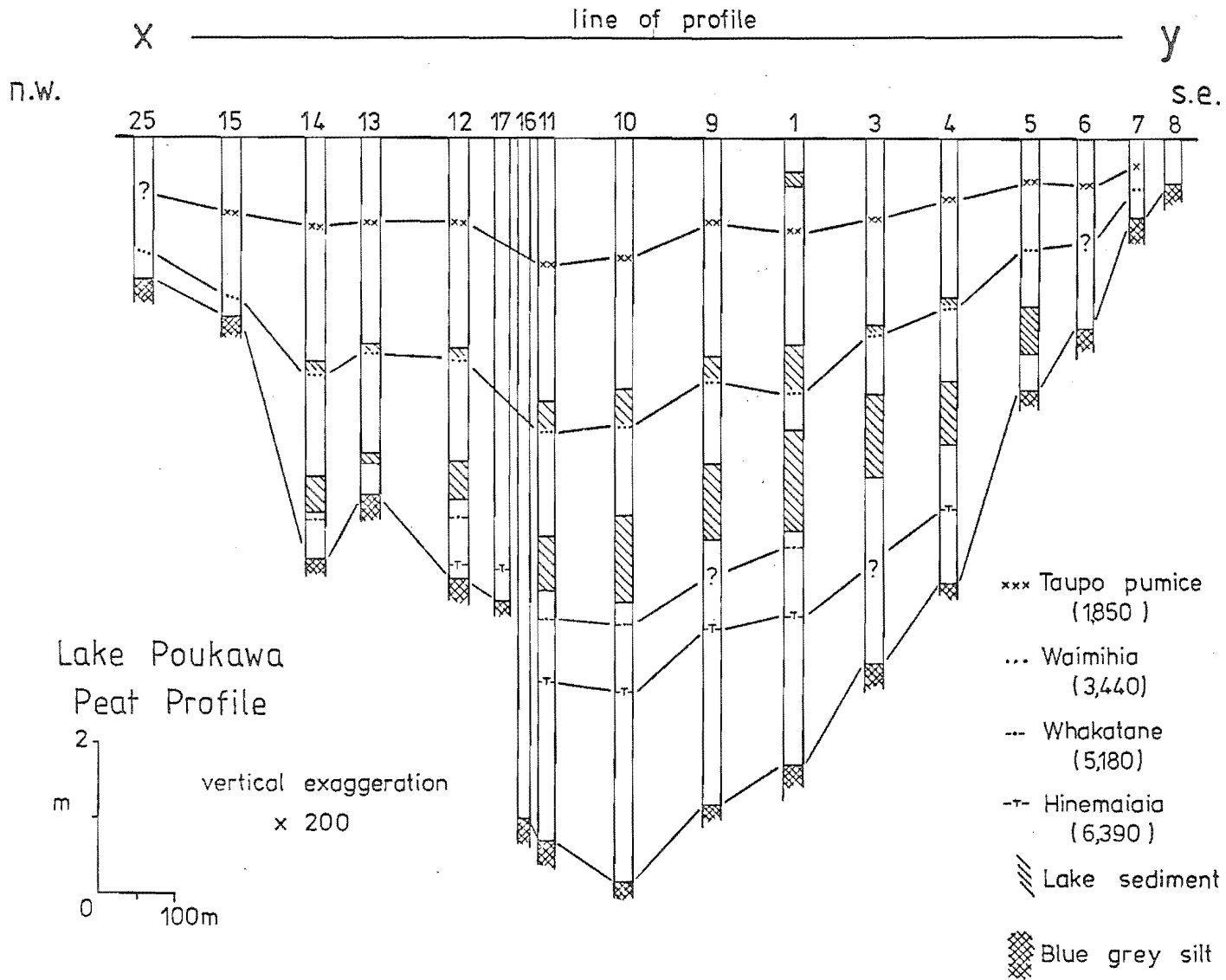
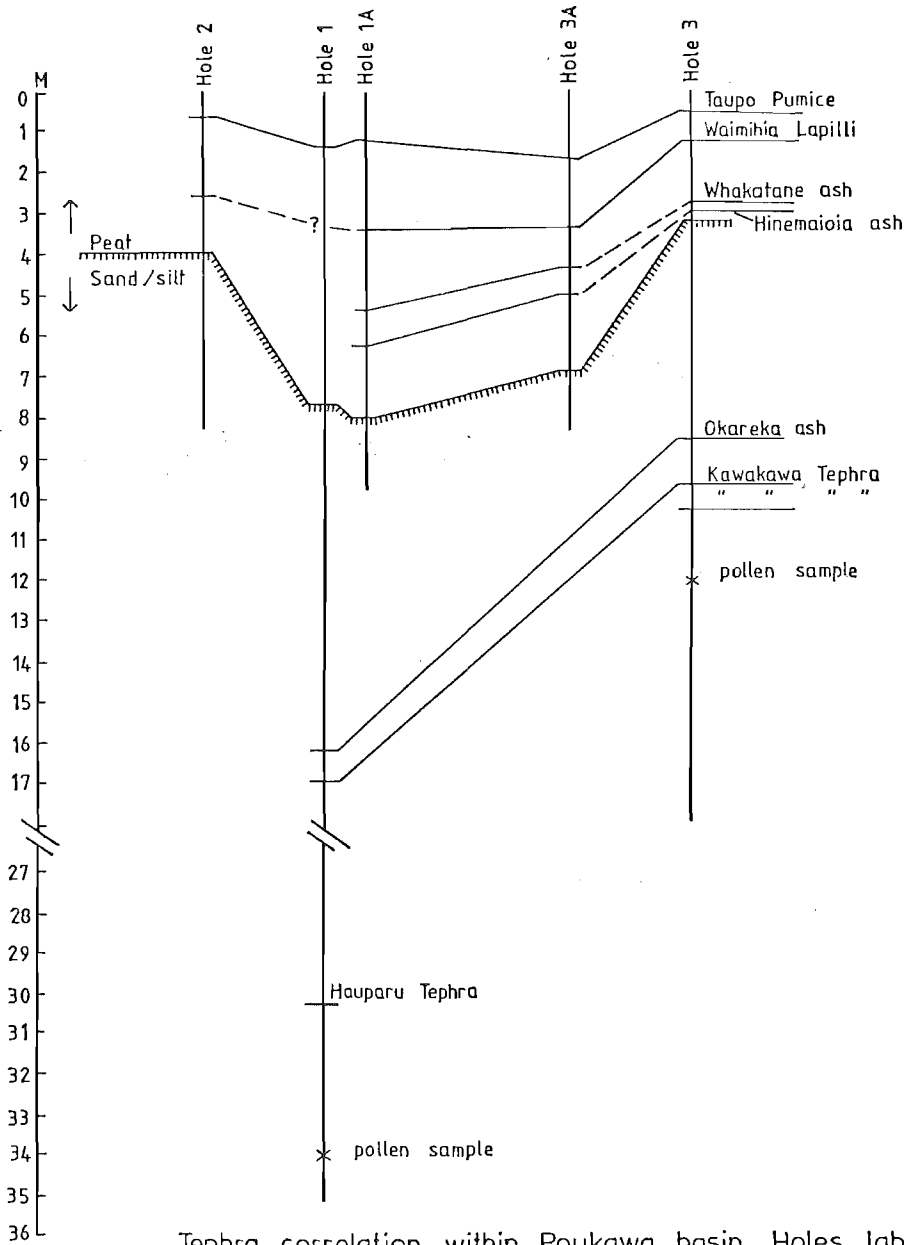


Figure 20. Profile of upper lake and peat sediments, Lake Poukawa





Tephra correlation within Poukawa basin. Holes labelled with subscript 'A' are auger holes drilled beside or close to main holes. Line of section as in peat profile.

after Robertson (1978)

Figure 21.

have been identified from this underlying formation: the Kawakawa Formation (20 000 BP) and the Hauparu Tephra (age c. 37 000 BP). The Kawakawa Tephra is commonly found in loess sections throughout Hawkes Bay. A correlation column for the tephras found within the Depression is given in Figure 21. On the basis of dated layers and tephras within the Depression, the accumulation rate of sediment at the centre is very nearly constant at 1.0mm/year. Accumulation of the sand and silt formation would therefore have begun about 40 000 BP, and of the peat sediments at about 9600 BP.

The lower hills and slopes surrounding the Depression have a mantle of loess, slopewash and colluvium: the Kawakawa Tephra is commonly found towards the base of sections through these cover deposits. Analysis of the silt and sand formation underlying the peat (Robertson 1978) shows that the sediments were also deposited as sub-aerial loess and slopewash (alluvial fan deposits and colluvium). There is no indication of any periodicity in fan deposition, and the process of basin infilling appears to have been relatively constant. Within the limits imposed by the dated layers, the movement of the faults has also been remarkably constant. Vertical displacement has been occurring at a rate of 0.225mm/year. Only the eastern fault is known to have been active in recent times, but the vertical displacement of the base of the peat suggests that the western fault has been continuously active in the past.

9.2 POLLEN DIAGRAMS

9.2.1 Otiran sites

Locations: Site 1 (Hole 3, core 20). NZMS1 - N141/131029
 Site 2 (Hole 1, core 23). NZMS1 - N141/122032
 Site 3 (Poukawa Drain). NZMS1 - N141/158057

(i) Stratigraphy

The stratigraphy of the sediments at Sites 1 and 2 is shown in Figure 21. Both samples came from thin, slightly peaty silts preserved below dense silt layers. Site 3, Poukawa Drain, is a section exposed in the western bank of the Main Drain, just to the north of the lake. Here 3.06 metres of silt and colluvium overlies 50mm of brownish-black peat that contains decomposed wood and plant fragments. The peat is underlain by a thick silty-clay unit.

Preservation of these peaty layers appears to have occurred quite by chance. Thick, silty-clay units overlie them all, and these may have protected them against erosion and biological degradation. Even so, the pollen is poorly preserved and many of the surviving grains are so badly crumpled and torn that they cannot be identified. A further complication is contamination from the limestone sediments that make up the bulk of the matrix of the samples. There is consistently 2-3% of a redeposited extinct *Nothofagus* type present, and it is reasonable to assume that at least some of the other pollen types came from the limestone. Although the results must be treated with some caution because of these sources of error, they are unlikely to affect the conclusions. As the pollen spectra from these three sites are similar, they are considered together.

(ii) Pollen analysis. (Table 7)

Description: Tree pollen types are not common, averaging only 5% of the total pollen count, and about 10% of terrestrial pollen. *Podocarpus* and *N. fusca* type are the most common types, but these are also the types most likely to have been derived from the limestone. There is a range of shrub pollen types present of which the most abundant are *Phyllocladus*, Compositae and *Leptospermum*. *Drapetes*, *Cyathodes fraseri* and *Colobanthus* have unusually high frequencies in Sites 1, 2 and 3 respectively. Herb

TABLE 7

OTIRAN POLLEN ANALYSIS: POUKAWA

<u>TAXA</u>	Site 1	Site 2	Site 3
	% TOTAL SPORES + POLLEN		
<i>Nothofagus</i> + tree conifers	9	5	2
woody plants	49	39	9
swamp plants	15	36	74
herbs	31	22	15
spores	4	3	2
	% TOTAL POLLEN EXCLUDING MIRE PLANTS + SPORES		
<i>Nothofagus</i> + tree conifers	11	8	9
woody plants	60	63	38
herbs	39	37	64
TREES			
<i>Dacrydium cupressinum</i>	x	x	1
<i>Dacrycarpus</i>	.	x	.
<i>Podocarpus</i>	3	1	2
<i>Nothofagus fusca</i> type	7	6	4
<i>Nothofagus menziesii</i>	x	.	1
<i>Nothofagus</i> (extinct)	3	3	2
<i>Casuarina</i>	.	x	.
SMALL TREES + SHRUBS			
<i>Metrosideros</i>	.	x	1
<i>Leptospermum</i>	.	6	3
<i>Phyllocladus</i>	24	6	14
<i>Dacrydium bidwillii</i> type	2	1	.
<i>Coprosma</i>	1	1	2
<i>Myrsine</i>	.	1	.
<i>Muehlenbeckia</i>	.	x	.
<i>Drapetes</i>	3	.	1
<i>Cyathodes fraseri</i>	.	1	.
Compositae	19	38	9
Carophyllaceae:			
c.f. <i>Colobanthus</i>	.	.	17

TABLE 7 (cont'd)

<u>TAXA</u>	Site 1	Site 2	Site 3
HERBS			
Gramineae	18	28	33
Umbelliferae	1	6	4
Cruciferae	9	.	3
<i>Plantago</i>	.	3	x
<i>Chenopodium</i>	1	+	2
<i>Taraxacum</i> type	5	.	3
<i>Gentiana</i>	.	1	1
<i>Selliera</i>	4	.	.
<i>Haloraghis</i>	.	+	.
MIRE PLANTS			
<i>Empodisma</i>	1	1	1
<i>Leptocarpus</i>	7	37	x
Cyperaceae	10	20	308
<i>Gleichenia</i>	x	.	.
FERNS			
<i>Cyathea smithii</i> type	3	1	2
<i>Cyathea dealbata</i>	.	1	4
<i>Dicksonia squarrosa</i>	x	1	.
<i>Ophioglossum</i>	x	x	.
<i>Phymatodes</i>	1	.	.
monolete fern spores	1	1	2
<i>Lycopodium fastigiatum</i>	.	x	.
UNIDENTIFIED	.	11	10
Total pollen + spores counted	268	357	573

+ = noted after main count completed

x = less than 1%

. = absent

levels are high, averaging about 50%, the most abundant type being Gramineae. There are unusually high levels of some herbs, especially *Plantago*, Cruciferae, *Taraxacum* type and in Site 1, *Selliera*. The quantity of mire pollen types is quite variable, but substantial, especially at Site 3. At Sites 1 and 2, *Leptocarpus* and Cyperaceae are co-dominant, and at Site 3, Cyperaceae is the sole dominant. There are several fern types recorded, none in any quantity, and there is a strong possibility that they are all, with the exception of *Ophioglossum*, derived from the Te Aute Limestone.

Interpretation: Much the same conclusion would be drawn from any one of these pollen samples as from the whole three of them. There was no forest, or only exceedingly small pockets of forest, in the area. The local vegetation was most likely an open scrub/grassland mosaic with much bare ground. The presence of low plants usually found growing in open grassland or turf (e.g. *Colobanthus* and *C. fraseri*) and herbs such as *Taraxacum* type, and the fern *Ophioglossum*, suggest that tall plants were infrequent. Denser grassland and scrub was probably confined to sheltered areas with stable soil. The presence of microscopic charcoal particles in large amounts in all the samples suggests that there were regular fires in the Poukawa Depression: the open nature of the vegetation may have been, in part, a consequence of these fires. The occurrence of *Leptocarpus similis* is of interest. At present it has a fairly restricted distribution and, although it can tolerate mesotrophic situations, it seems to prefer eutrophic sites at lake edges, or in fertile mires (Burrows & Dobson 1972). The organic silts that make up the samples were probably deposited in temporary pools or damp spots among the complex of debris fans and loess deposits that made up the floor of the basin.

9.2.2 Aranuian site

Location: NZMS1 - N141/119028

(i) Stratigraphy

This site is at the southern end of Lake Poukawa, approximately 500 metres from the lake edge, in reclaimed swamp land (Figure 18). Drainage of the peat has caused the surface to sink, and cultivation and stock trampling have destroyed the upper layers. From accumulation rates, based on dated tephra layers, it appears that over a metre of peat has been lost. The peat was sampled with a Hiller borer and is approximately 9.0 metres in depth. The stratigraphy and chronology of the tephra layers encountered is given in Figure 20. Near the base of the profile a thin, discontinuous tephra layer was found. It was tentatively identified as the Rotoma Ash (age uncertain, but close to 9000 BP Nairn, pers. comm.). Subsequent sampling has failed to relocate this tephra. As it was deposited at a time when the whole Depression was covered with a dense swamp forest, it is probably discontinuous as a result of falling in an area with a large number of tree trunks and stumps.

(ii) Pollen analysis. (Plate 15)

Sampling this core was made difficult because of the numerous layers of tephra, wood and lake sediment. There are, therefore some unavoidable gaps in the sample sequence. The pollen diagram is presented as a regular sequence however, but the gaps are indicated.

More so than at most sites, a sharp distinction can be made between pollen derived from mire plants, pollen from the surrounding vegetation in the Depression, and pollen from more distant sources. In this sequence the first category of pollen sources are extremely variable: the second and third vary only slightly. The mire vegetation

is important in determining fluctuations in water level within the Depression; the local and distant vegetation gives information about large-scale regional vegetation change. When considering the evidence for climatic fluctuations, both must be taken into account. However, as regards this pollen diagram and its interpretation, they seem to be largely independent. I have therefore used two zonation systems; one is concerned with the mire vegetation and the zones are indicated by letters; the other refers only to the non-mire vegetation and the zones bear numbers.

Mire Zones

Poukawa A

Description: The sediments here are transitional from silty-sands to woody peat. There are high percentages of tree fern spores and monolete spores in this zone. Most are corroded, possibly as a result of a brief phase of soil development that may have preceded peat formation.

Dacrycarpus is at 1% in the first sample, but rises almost immediately to 11%. Scrub, mostly *Leptospermum*, *Coprosma* and *Myrsine*, levels are high, and Cyperaceae is very abundant. *Elaeocarpus*, *Muehlenbeckia* and *Rubus* were noted also, but otherwise only small amounts of other scrub and mire types were found.

Interpretation: A sedge/scrub community occupied the floor of the Depression. There was substantial quantities of *Dacrycarpus* either marginal to, or scattered among, this formation.

Poukawa B

Description: *Dacrycarpus* rises to dominance but the scrub/sedge association is essentially unchanged. At the 8.0 metre level there is a sharp, brief fluctuation in which both sedge and scrub levels rise, while those of *Dacrycarpus* drop. In the top half of the zone *Dacrycarpus* peaks at over 30% of terrestrial pollen, while sedge, but not scrub,

levels are reduced.

Interpretation: During this zone a *Dacrycarpus* forest covered all but the wettest areas of the basin. Canopy cover cannot have been complete because sedge and scrub were common, but the numerous stumps encountered during drilling testify to a substantial, dense swamp forest. The fluctuations in the amount of scrub and sedge point to changes in water levels favouring them over *Dacrycarpus* at times.

Poukawa C

Description: Wood, abundant in the peat in the last two zones, becomes increasingly rare.

Dacrycarpus continues a decline begun in the top of Zone B. It falls from the average of 25% recorded in Zone B, to 4% at the top of the zone. Both mire and scrub taxa increase markedly. *Typha* peaks at 44% in the first sample of the zone, dropping then to lower levels.

Cyperaceae is abundant throughout and *Phormium* well-represented.

Potamogeton appears for the first time in this zone.

Interpretation: Although scrub levels remained high throughout, the retreat of *Dacrycarpus* from the site indicates rising water levels. The abundance of *Typha* and *Phormium* suggests open water was present for at least some of the year. It was during this zone that the first permanent lake established in the Poukawa Depression.

Poukawa D

Description: *Dacrycarpus* reaches a low of 3%: it never recovers to its old levels in subsequent zones. Scrub levels (as a percentage of total pollen and spores) drop from an average of 16% in Zones B and C to one of 7%. These low percentages are maintained, except for brief periods, in following zones. Cyperaceae and, in the last samples of the zone, *Potamogeton*, are abundant. *Typha* averages only 1-3%.

Interpretation: *Dacrycarpus* no longer grew at the site: it was confined

to the shallower, less wet mire at the margins of the basin. Scrub too was probably rare or absent. A sedge community dominated an increasingly wet mire.

Poukawa E

Description: There is an abrupt change to lacustrine sediments, marking one of the clearest zones of the sequence. All mire herbs fall to very low levels, and remain low for the entire zone. In contrast, scrub percentages, although they fluctuate, are at levels of around 6%, which is the approximate average for Zones D, E, F, G, and H. *Dacrycarpus* percentages are also unaffected.

Interpretation: A deep (possibly more than 1 metre in depth at the site), permanent lake filled the centre of the basin. The boundaries of this lake lay well away from the site, as the pollen does not indicate any marginal vegetation. As there is independent evidence for the lake in the form of lacustrine sediments, it is clear that no non-aquatic vegetation could have grown near the site. Therefore the continuing unchanged percentages of *Dacrycarpus* and scrub taxa confirm the inference made earlier that both these groups were not present at the site, but occupied the mire edge.

Poukawa F

Description: The lacustrine sediments are abruptly replaced by sedge peat. There are high levels of Cyperaceae (27-57%), moderate percentages of *Typha* (5-10%) and some *Potamogeton*. Scrub levels are largely unchanged.

Interpretation: With the retreat of the lake, mire vegetation, mainly sedge, *Typha* and *Potamogeton*, returned and peat formation began again.

Poukawa G

Description: There are lacustrine sediments (3.19-3.40m) with an included tephra layer, the Waimihia Ash. This zone is distinguished by

two features only: a fall in the amount of Cyperaceae (from about 50% to 12-25%) and a massive increase in *Typha*.

Interpretation: Once more the lake extended; it was not as deep or as extensive as in Zone E as mire vegetation remains abundant. It is likely that the site lay just within, or just outside, the marginal *Typha* fringe of the lake.

Poukawa H

Description: The sediment reverts to sedge peat, within which are two distinct bands with abundant freshwater mollusc shells. Cyperaceae recovers its former abundance and *Typha* sinks to lower levels. *Potamogeton* is especially common. At the level of the upper shell layer (2.26-2.19m) there is a minor *Typha* peak. The lower shell band (2.88-2.93m) has a pollen flora with no particular distinguishing features.

Interpretation: Once again the pattern of lake expansion and retreat is reflected in the changing proportions of *Typha* and Cyperaceae, Cyperaceae dominating the mire and *Typha* the lake margin. The shell layers reflect brief periods of lake expansion - perhaps too short a time in the lower shell band to effect a change in the swamp community. In the upper band the establishment of a *Typha* dominant community suggests that the lake was enlarged for some decades.

Poukawa I

There is no need to go into detail for this zone. The expansion of *Typha* and the drop in Cyperaceae may indicate a larger lake at this time. However, there is no shell or lake sediment in the core at this point and therefore the site must have lain at the edge of the lake margin *Typha* zone.

Poukawa J

Description: *Typha* levels are moderately high, while those of Cyperaceae, following a peak in a single sample at the beginning of the

zone, are very low (average c. 14%).

Interpretation: Water levels were high, but there was no major lake expansion during this zone.

Terrestrial Zones

In contrast to the many sudden fluctuations of the mire plant pollen, the input of pollen from both local non-mire vegetation and from more distant sources remains remarkably steady. Other than the high proportions of *Dacrycarpus* (which is treated for the purposes of this zonation as a mire plant) causing what is almost certainly an artefactual decrease in the amount of *Podocarpus* at the beginning of Zone 1, there are no major fluctuations in the tall tree pollen percentages until deforestation. The division of the diagram into zones therefore depends on the changes in proportions of minor taxa.

Poukawa 1 10 000 - 5600 BP (Estimated)

Description: *Podocarpus* (mainly *P. spicatus*) is dominant in this and subsequent zones, usually averaging some 70-80% of the *Nothofagus* and tree conifer pollen sum. In lake sediments, where as a result of better pollen preservation the different *Podocarpus* types could be distinguished, *P. totara* type made up 10-14% of the pollen sum. There is a rather restricted range of hardwood pollen taxa including *Weinmannia*, *Alectryon* and *Elaeocarpus*. Tree ferns, mainly *Cyathea dealbata* and *C. smithii*, are steady at values between 1-6% after a period of higher values early in the zone. With the exception of the first two samples, *Dodonaea* is recorded in every sample, reaching 2% on occasion. *Ascarina* is noted four times. *Nothofagus fusca* type and *Dacrydium cupressinum* are steady at moderate levels throughout.

Interpretation: Outside the poorly-drained valley bottom of the Poukawa Depression, a mixed forest, mainly of *P. spicatus* and *P. totara*, covered the landscape. It was very likely a dense forest, as there is a lack of

substantial quantities of either hardwood species or tree ferns. *Dodonaea* was either local, perhaps on cliff-faces or forest-edges, or at the coast. It is a wind-pollinated shrub and produces abundant, well-distributed pollen, so it is not possible to say that it was definitely in Poukawa Depression. It was however much more abundant than it is at present. *Nothofagus* and *D. cupressinum* are both absent from lowland Hawkes Bay, and are most unlikely to have ever been present. Therefore, the modest levels recorded were derived from forests in the interior, nearer the Ruahine Range.

Poukawa 2 5600 - 3400 BP

Description: *Dodonaea* is reduced to levels of 1% or less; *Ascarina* is still sporadically recorded. *Nestegis* is recorded for the first time, and is consistently found from now on. *Paratrophis* is common in this zone. *N. fusca* type has several peaks averaging 10-15% - that is up to twice the average for Zone 1 - during the lake sediment phase, and then drops back to 3% by the end of the zone. Overall its levels rise from the 5.9% average of Zone 1 to 9.2%.

Interpretation: *Dodonaea* became a less important component of the Hawkes Bay vegetation. *Nestegis* and *Paratrophis*, two smallish trees, either became more abundant in Hawkes Bay as a whole, or migrated into the Poukawa Depression. There are few other indications of change in the local vegetation.

The 40% increase in the amount of *N. fusca* type pollen recorded in this zone is of some significance, even though absolute quantities are small. A little of this increase may be a result of over-representation during the lake phase (regional pollen tends to be detected in greater quantities when there is little or no on-site vegetation), but the general upward shift in percentage is noticeable even if the lake

samples are omitted. *D. cupressinum* does not increase in this zone, and its percentages are steady at an average of 8%. As the two major long-distance dispersal types show different trends, it can be assumed that the increase of *N. fusca* percentages is a result of real changes in its abundance at source.

Poukawa 3 3400 - 1000 BP

Description: *Dodonaea*, hitherto recorded in every sample, is noted in only 5 out of 18 samples: *Ascarina* is not found at all from now on. The average for *N. fusca* type drops slightly (by 0.6%), while that for *D. cupressinum* rises by 1.5%.

Interpretation: *Dodonaea* was reduced to what may have been its pre-Polynesian range; that is to small patches along the coast. *Ascarina*, almost certainly never in Hawkes Bay, became very much rarer in its probable source area, that is the higher rainfall areas in the foothills of the Ruahine Ranges. There is no need to postulate great changes in the abundance of *N. fusca* type forest, but there is a real possibility that *D. cupressinum* became more abundant.

Poukawa 4 1000 BP - present day

This zone has been described previously in McGlone (1978), and falls outside the time range of this work.

9.3 DISCUSSION

9.3.1 Otiran

From an estimated 40 000 BP to approximately 10 000 BP, the Poukawa Depression was subjected to erosion of its upper slopes. The products of this erosion were deposited in fans on the lower slopes and in the basin. There is no sign either in the sediments surrounding the depression floor, or in the sediments from the centre of the basin itself of any major hiatus or weathering break (Robertson 1978). As

the floor of the basin slowly sank, as a result of the vertical movement on the faults and associated tilting, sediments built up, and were deposited as sands in low angle fans or as loess.

The flora and fauna of the sediments support this picture of a bare, eroding landscape. Pollen analysis suggests that there was a rather open grassland-shrubland, with considerable bare ground. Analysis of land snail faunas (F. Climo, reported in Robertson 1978) from cores 1 and 2, shows that the land snails were primarily terrestrial and typical of a rather open environment, perhaps grassland with pockets of tussock and scrub. Some species found are especially reliable indicators of tussock grassland, and their nearest relatives are found in tussock habitats in the Chatham, Stewart, Campbell, and Auckland Islands.

The absence of a lake in the basin for the entire period, the near absence of forest or scrub, except for small areas of *Phyllocladus* and *Leptospermum*, the presence of loess and charcoal, all suggest a rather dry climate during this period of the Otiran. Rainfall in the Poukawa Depression at present is low (below 760mm per year) and variability of rainfall is high. In almost all growing seasons there is a soil moisture deficit of at least 36mm at some time during the season (de Lisle 1971). Most rainfall is associated with easterly winds and it is not difficult to envisage a situation where, with increased westerly winds, rainfall in this particular area of the Hawkes Bay could fall to levels below that necessary to maintain forest cover. Even if rainfall remained sufficiently high enough to support forest, increased dry spells as a consequence of strengthened westerly winds would make the vegetation vulnerable to fire. Under these conditions a fire-induced scrubland or grassland is entirely possible.

Nothing very useful can be said about temperatures during the Otiran in Hawkes Bay. At present *Phyllocladus alpinus* does not grow below about 600 metres: its occurrence in lowland Hawkes Bay would tend

Correction: final paragraph.

It is not possible from the Poukawa pollen diagram to establish with any certainty that there was either a real decline in Dodonaea viscosa and Ascarina lucida or if Nothofagus fusca type increased at around 5000 BP.

The implication made here that these changes indicate a frostier and droughtier climate from this time onwards cannot be sustained on the evidence from this site. Pollen evidence from elsewhere suggests such a change, but whether or not it affected the Hawkes Bay region must remain uncertain.

'Lake establishment' here refers to the first unequivocal evidence for the presence of a lake in the form of widespread lake sediments. The pollen record suggests that there was a much smaller lake in existence from at least the beginning of Zone C, that is from about 6400 BP.

the only possible explanation for the establishment of the mire and the stabilization of the upper slopes of the Poukawa Depression.

The evidence is not so clear for the minor changes in water level that have occurred since 10 000 BP. Movement on the faults in the Depression would not be very effective in establishing a long-lived lake. Any hollow created by fault movement would not be very deep as the movement on the fault has tended to be rather steady (Froggatt 1976), and would be rapidly filled in both by peat flow and growth. Also, although the thickest lake sediments lie to the downthrown side of the faults, the sediments extend across the fault scarp. If movement on the faults was the main cause of the expansion of the lake it would be expected that the lake would lie entirely to the east of the faults.

Blocking of the outlet by landslides would seem to be the only mechanism, other than climatic change, that could create a lake. This area of the Hawkes Bay is prone to slipping (Kingma 1971) and so this is a real possibility. Only further investigations of the area could establish if such slipping has occurred. However, the slow development of wetter conditions during the early period of peat accumulation (Zones A to D), culminating in the lake episode of Zone E, argues against a sudden blocking of the outlet to the Depression as a primary cause of the lake. The other minor episodes of high water table seemed to have occurred suddenly and could conceivably be a result of climate change, tectonism or landslides.

The establishment of the lake at about 5000 BP coincides more or less with the decrease of *Dodonaea* and *Ascarina*, and the rise of *N. fusca* type. *Dodonaea* is a shrub mainly found in coastal regions, and has a well-marked southern limit at about the latitude of Christchurch in the South Island. Perhaps the most significant factor in its

distribution is its sensitivity to frost and its preference for warm summers (Dobson pers. comm.). McGlone & Moar (1977) have proposed that the decline of *Ascarina* from 5000 BP on, was a result of more frosts and droughts. This postulated climate change may have affected the abundance of *Dodonaea* also.

The beginning of peat sedimentation in the basin must have involved a sharp increase in precipitation as temperatures, and therefore evapotranspiration rates, were close to present day levels by then. However, it is not as clear that it was increased rainfall that caused the expansion of the lake after 5000 BP. The water budget of the lake/mire system is finely balanced as the lake is only 1 metre or less in depth. It is possible, but not, it must be admitted, likely, that cooler summers with more cloud cover could alter the evapotranspiration rate enough to permit the lake to expand without increased rainfall. In all probability however, the lake expansion did involve higher rainfall, most likely as a result of increased easterly airflow.

Leaving aside the local fluctuations of the lake and associated plant communities, the vegetation history of the Poukawa Depression is unusually simple. The entire area has been dominated by almost unchanging *P. spicatus* and *P. totara* forest for the last 10 000 years. If the samples taken from the sediments within the basin accurately reflect the vegetation during the Otiran, there seems to have been remarkably little change in the previous 30 000 years. The conclusion would seem to be that areas such as central Hawkes Bay suffer rapid and complete vegetation change at the glacial/interglacial boundary but are very stable in their vegetation composition at other times. This phenomenon is almost certainly a consequence of the low rainfall in Hawkes Bay and the reliance of the area on easterly winds for precipitation. Any disturbance of the present wind patterns, especially a strengthening of westerly winds, would have a disproportionate effect.

The alternation of forest and scrubland/grassland may therefore reflect differing wind patterns during glacial and interglacial periods, rather than changes in temperatures.

CHAPTER 10
GENERAL DISCUSSION

All sites referred to in this discussion are indicated on Figure 22.

10.1 QUATERNARY STRATIGRAPHY

There is yet to emerge in New Zealand a Quaternary stratigraphy that has more than just regional application. The glacial sequences of the South Island have the strongest claim but, outside the time range of radiocarbon dating, correlation with stratigraphic sequences further afield is problematical. The loess stratigraphy of the Rangitikei-Manawatu area (Milne 1973) is perhaps more immediately relevant to the central North Island but, as with the glacial sequences, the discontinuous nature of the deposits, the paucity of dates, and the lack of firm correlation beyond the range of radiocarbon dating preclude its wider application. Only two terms defined for the late Quaternary appear to have won widespread acceptance: they are the Aranuiian and Otiran Stages. These stages merit further discussion.

There has been some discussion about the definition and age of the Otiran/Aranuiian boundary. As defined by Suggate (1961), this boundary is placed after the termination of the last major glacial advance (Later Kumara-3) in the central South Island. This event, and the subsequent retreat of the glaciers, is dated as beginning at about 14 000 BP (Suggate & Moar 1970, 1974). Lintott & Burrows (1973) and Burrows (1974) prefer to place the Otiran/Aranuiian boundary at 10 000 BP. Sound arguments have been produced in favour of each view. However, as this study shows and as previous work has shown, different areas reacted at different rates and times to the climatic amelioration that ended the

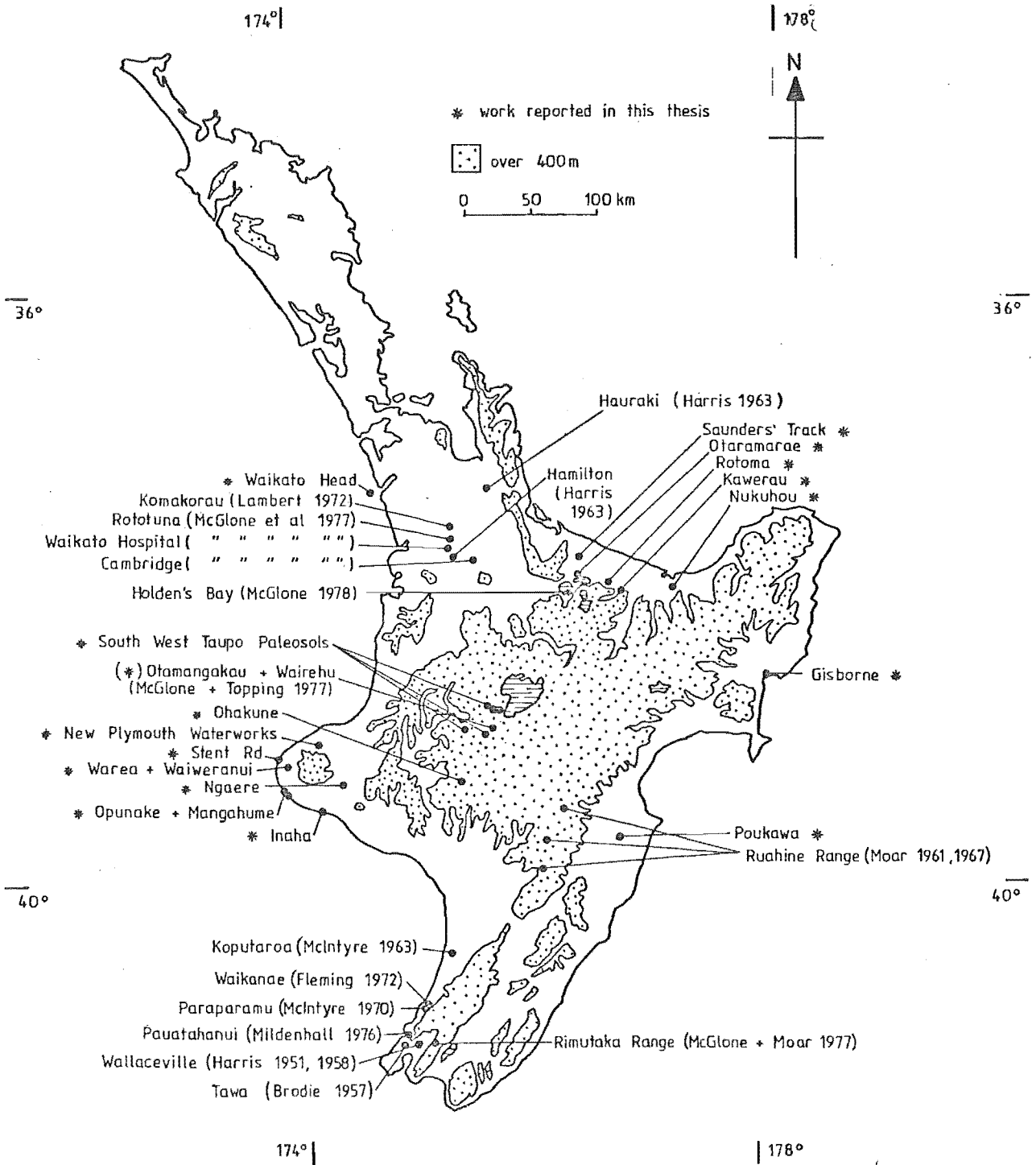


Figure 22. North Island Aranuiian and Otiran pollen analytical sites

Last Glaciation. 14 000 BP and 10 000 BP are not the only dates that could be chosen as a boundary, and the choice appears to be one more of convenience than definition. In the North Island 14 000 BP is the more convenient, and so it is this date that has been used in this study.

The problem of the placement of the lower boundary of the Otiran is more difficult as it involves those rather elusive concepts 'interglacial' and 'interstadial'. Sparks & West (1972) define an interglacial as a period that '.... normally involves the development in the climatic optimum of a vegetation at least as temperate as that we have ... at present. An interstadial implies something less than this.' Suggate (1974) has discussed the problem of recognition of an interglacial in some depth. He defines an interglacial as a period that begins with a warming to full interglacial warmth (i.e. as warm as the present) and continues until a cooling of full glacial severity occurs. Therefore, cool episodes after the main interglacial warmth are considered to lie within the interglacial provided that their temperatures did not fall to substantially those of the Last Glacial, and that the intervening warm episodes had temperatures in excess of the mean temperature of the whole climatic cycle, that is the cycle from full glacial cold to full interglacial warmth.

In this work the main problem has been the placement of the forest-dominated episodes found at the base of sequences at Inaha (Taranaki), Otamangakau Canal (Tongariro region) and also at Waikanae (Fleming 1972). Are they to be regarded as belonging to the Last Interglacial or to the Otiran? The vegetation cover suggested by pollen analysis would not be out of place in those areas today. However, forest development during these episodes did not reach a comparable level to that of the mid Aranuiian. Therefore, although these episodes satisfy the strict criteria for an interglacial, they are

considered here to have never achieved full interglacial status, and to be interstadials. This interpretation is based in part on their stratigraphic position above the marine bench corresponding to the last high sea level. In fact it does not seem to be possible to characterize a deposit as being interglacial without either a long, continuous sequence or a secure correlation to such a sequence. Such a sequence is not yet available in New Zealand and at present the best that can be done is to make tentative correlations with the deep-sea cores and sea-level chronologies that have been analysed elsewhere.

10.2 OTIRAN VEGETATION AND CLIMATE

10.2.1 Introduction

The Otiran, depending on what definition is used and also what estimate of its duration is accepted (for discussion of this point see Suggate 1974), lasted for some 60 000 - 80 000 years. It was a time of extraordinary diversity and change in the vegetation. Therefore it is convenient for the purposes of this discussion to divide the Otiran into three sections; early (80 000?-50 000 BP); middle (50 000? - 25 000 BP); and late (25 000-14 000 BP). These sections are not equivalent either in duration or status. The early Otiran appears to encompass at least one major interstade and two stadials while, in contrast, the middle Otiran and late Otiran are best regarded as an interstadial complex and a stadial complex respectively.

10.2.2 Early Otiran 80 000?-50 000?

Four palynological sites in the North Island are confidently referred to the early Otiran (Table 8). At Waikanae, near Wellington, two lignite sequences have been pollen analysed by D.C. Mildenhall (in Fleming 1972) and reveal an almost complete interstadial cycle. At the peak of its development the interstadial forest was a podocarp-

TABLE 8

PALYNOLOGICAL SITES CONSIDERED TO BE EARLY OTIRAN

Location	Altitude	Vegetation	Author
Waikanae, Wellington	sea-level	<i>D. cupressinum</i> / <i>N. fusca</i> type/ <i>Metrosideros</i> forest	Fleming (1972); Mildenhall (1973)
Tongariro & Ohakune, Volcanic Plateau	600m	<i>D. cupressinum</i> / <i>Libocedrus</i> / <i>N.</i> <i>fusca</i> type	This work
Inaha, South Taranaki	sea-level	<i>P. spicatus</i> / <i>Dacrycarpus</i>	This work

hardwood-*Nothofagus* community, and included abundant *Knightia excelsa* and *Dacrydium cupressinum*. At the top of the sequence this forest passes through into scrub-grassland. This lignite (Waimahoe Lignite) is beyond radiocarbon dating and rests on the Otaki Dunesand, a formation considered to be of late Last Interglacial age. The other three sites of early Otiran age (Otamangakau, Ohakune, and Inaha) have already been discussed in sections 7.2.1, 7.2.2 and 5.2.1.

As all four sites record the only complete forest cover noted during the Otiran in their areas, and as all commence with an unconformity, indicating erosion on the Volcanic Plateau, and high sea levels at Inaha and Waikanae, there is a temptation to correlate them. This interpretation would have them accumulating during an early Otiran interstade following the lowering of sea level after the Last Interglacial and the stadial that began the Otiran. There is also a temptation to identify these forest episodes with the base of Stage 4 of the $0^{18}/0^{16}$ deep sea record, which is thought to have occurred around 60 000 BP (Shackleton 1977), and with the high sea level stand of -28 metres recorded in New Guinea and elsewhere which is believed to be about the same age (Bloom *et al* 1974).

Otamangakau and Ohakune are undoubtedly contemporaneous; both have similar stratigraphy, very similar pollen sequences and are in the same district. There are some points in favour of correlating the other sites also. Both Inaha and Waikanae lie above a surface correlated with the end of the Last Interglacial; both are followed by scrub-grassland episodes; both record a podocarp-hardwood dominant forest at their peak. The Inaha interstade shares a common feature with the Volcanic Plateau sites in that, like them, it bears a strong resemblance to the early Aranuiian sequence in the same region. There is no early Aranuiian site analysed for the Waikanae region, so no comparison is possible in the

case of the Waimahoe Lignite sequence.

Assuming that they do belong to the same early Otiran interstadial, podocarp-hardwood forest must have covered most of the North Island at that time, with *Nothofagus* forest in some areas. Although temperatures must have been somewhat lower than at present the evidence from the Volcanic Plateau sites suggests that at the peak of the interstadial annual average temperatures rose to at least within 2°C of those of the present day. Rainfall was somewhat lower than at present in Taranaki but at the other sites effective precipitation was as high as it is now.

10.2.3 Middle Otiran 50 000? -25 000 BP

The middle Otiran period is near the limit of radiocarbon dating techniques and, because of this, the calculated error is large and it is difficult to establish synchronicity in sites not correlated by other means. Contamination of the dated sample by modern carbon is an ever present hazard which becomes more acute the nearer the real age is to the limit of the method. The chronology of the middle Otiran is therefore not securely based and, although a chronological scheme for the various sites is presented here, it is bound to be modified to a greater or lesser extent in the future.

A feature of the radiocarbon dated middle Otiran sites in the North Island is the number that fall in the time range 28 000 to 33 000 BP (Table 9). Most dates are made on the wood of forest trees, or are associated with forest floras. In contrast, there are no radiocarbon determinations of which I am aware based on wood of forest trees for the period 22 000 to 15 000 BP: only a few dates from this time range are associated with any forest flora whatever. Therefore the evidence suggests that the period 28 000 to 33 000 BP was characterized by widespread organic sedimentation and forested conditions, particularly in contrast to the following 14 000 year period. However, any attempt

TABLE 9

SITES FROM THE NORTH ISLAND IN THE TIME RANGE 45-27 000 BP

Location	Vegetation	Age Yrs BP	Author
North Auckland	<i>Agathis</i> *	35 000	Ferguson & Rafter (1957)
Auckland City	<i>Agathis</i> *	28-29 000	Searle (1964)
Port Waikato; off shore	Podocarpus/ <i>Nothofagus</i> forest	28-32 000	This work
Rotorua, Bay of Plenty (several sites)	Podocarpus/ <i>Nothofagus</i> forest	42 000 +	This work
Nukuhou, Bay of Plenty	Mixed scrub, grass- land, forest	42-28 000	This work
Gisborne	Podocarp-hardwood forest	39-27 000	This work
New Plymouth	<i>N. menziesii</i> forest	30 000	This work
Taranakai, Inaha Beach	Scrub-grassland	33 000	This work
Tongariro, Volcanic Plateau	Scrub-grassland	c.35-30 000	This work
Koputaroa, Manawatu	Scrub-grassland, <i>N. fusca</i> forest	35 000	McIntyre (1963) Results in appendix in this work
Waikanae, Wellington	Scrub-grassland, plus some <i>Nothofagus</i> forest	35 000	Fleming (1972); Mildenhall (1973).

* Evidence based solely on wood

to analyse the entire period of the middle Otiran is frustrated by incomplete sequences and insecure chronology. Nevertheless a tentative outline for this interstadial complex is attempted here.

Both the south-west Taupo paleosols and the pre-Rotoehu paleosols from the Bay of Plenty show that the interstadial complex began a relatively short time before the deposition of the Rotoehu Ash. At Taupo the transition was from an open, eroding landscape to one partially covered with scrub and grassland communities; in the Bay of Plenty, pure *N. fusca* group forest gave way to a podocarp-*Nothofagus* mosaic in which *N. menziesii* was prominent. In both cases there is evidence of climatic amelioration and, in the Bay of Plenty at least, the climate was warmer and wetter than before.

The next few thousand years, from the deposition of the Rotoehu Ash (c. 42 000 BP) to the deposition of the Mangaone Tephra (c. 30 000 BP) is covered by the following sites: Nukuhou (Bay of Plenty); Gisborne; the south-west Taupo paleosols; Inaha (Taranaki); Koputaroa Dunesand (recalculated and complete pollen data given in appendix: original data presented in McIntyre 1963); and Waikanae (western North Island). The vegetation types recorded from these sites range from forest to grassland (Table 9) and this makes it difficult to present a convincing vegetation reconstruction. One thing is clear: latitude and altitude are not good guides to the type of vegetation that existed at a particular locality. Scrub, grassland and forest were mixed together in varying proportions across the whole island.

During the middle Otiran, forest was either present, or at least nearby, at every site. *Nothofagus* forest was abundant nearly everywhere except Gisborne and southern Taranaki. The Bay of Plenty had large amounts of *N. fusca* group forest as well as *N. menziesii*, and the pollen diagrams from the South-west Taupo paleosols suggest that

Nothofagus forest was present in some of the surrounding districts. At Inaha in southern Taranaki, *N. fusca* group forest was not present although its pollen was more common than at any other period in the Otiran, reflecting more forest in the region as a whole. There is a strong possibility that *N. menziesii* forest, albeit in small amounts, grew in the area. Podocarp forest, although not common, was dominant at one locality (Gisborne), co-dominant at times at Nukuhou in the Bay of Plenty, and may have existed in very small scattered areas in southern Taranaki. Several other tree types, such as *Plagianthus* and *Libocedrus*, were common at various times at various localities.

The latter part of the interstadial complex, that is from 33 000 to 28 000 BP is richly provided with fossil localities (Table 9). Large *Agathis australis* logs dating from 28 000 to 29 000 BP have been found in Auckland City (Searle 1964) and, because of their growth form, are claimed to have developed in dense forests. Large logs of *D. cupressinum* and *Phyllocladus alpinus* dated at c. 30 000 BP have been found in the Bay of Plenty (see section 8.2.5.) and Gisborne has *D. cupressinum* dominant podocarp-hardwood forest at about this time. Port Waikato records a mixed podocarp-hardwood forest and at the New Plymouth waterworks site both wood and pollen indicate a *N. menziesii* dominant forest. On the Volcanic Plateau the south-west Taupo paleosols record the densest scrub cover between approximately 30 000 to 27 000 BP. This period represents the best development of forest and scrub in the whole of the middle Otiran.

Besides the clearly marked period centring on 30 000 BP, there is no clear indication of trends during this interstadial. For instance, Nukuhou shows marked fluctuations in the proportions of scrub, grassland and forest whereas at Gisborne only slight vegetational changes occurred during the same interval. Chronologic control is poor at the other

sites, or they are of brief duration, so there is not much information as to the extent of vegetational change with time. Furthermore, although I have termed this period an "interstadial complex" there is the possibility that episodes occurred within it that are better regarded as full stadials. Some of the pollen analyses (i.e. Waikanae and Koputaroa Dunesand) reflect what appears to be an inhospitable climate.

Some estimates can be made as to the climate during the warmest part of the interstadial. The occurrence of *Agathis* forest in Auckland and podocarp-hardwood forest at Gisborne argues for a forest distribution and therefore a climate very like that of the present. On the other hand, much of the Volcanic Plateau and Bay of Plenty were dominated by subalpine scrub and grassland communities. It is reasonable to assume, therefore, that forest did not completely occupy lowland and montane sites, but that the familiar scrub/grassland/forest mosaic of the earlier part of this interstadial remained, even though the area covered by forest had increased. Even at its peak, therefore, the middle Otiran interstadial complex did not match the early Otiran interstadial in completeness of forest cover. Seen from this perspective it is obvious that the climate over the North Island as a whole was by no means as favourable as would be deduced from some of the sites taken in isolation.

Various estimates can be derived for likely temperatures at the peak of this interstadial depending on what plant species are taken as a guide. From the evidence of the south-west Taupo paleosols and from the presence of *P. alpinus* and *N. menziesii* in lowland Bay of Plenty, annual temperatures may have been between 3 and 4°C lower than present. As we have seen, Auckland, Gisborne and Port Waikato plant assemblages seem to argue for annual temperatures similar to those of the present. Perhaps the best conclusion that can be made is that temperatures may have been up to 4°C lower at the peak of this interstadial, but the

actual depression is likely to have been somewhat smaller. There is the possibility that some regions of the North Island enjoyed a milder climate, perhaps because of topographic factors. Rainfall was lower than at present in some regions such as the Volcanic Plateau and Taranaki, but in others there is no indication of any change. Rainfall was high enough over much of the country to support podocarp forest.

After the peak of the middle Otiran Interstadial complex was passed, perhaps by 26 000 BP or before, the climate began to deteriorate. Only the south-west Taupo paleosol sites record this transition in the North Island. Here it does not appear to have been an abrupt event but rather a drift towards a more open vegetation.

10.2.4 Late Otiran 25 000-14 000 BP

Despite the amount of evidence relating to the late Otiran in the North Island only the barest outlines are known of its vegetation and climate. There are two main reasons for this. Firstly, although sites in the North Island that can be confidently ascribed to this period are not rare (Table 10), no site has had continuous organic sedimentation throughout the whole period, nor has any site been discovered that spans even an appreciable fraction of it. In all cases the fossil material either consists of lenses of organic material wedged between erosion deposits, or is included in loess, or is abruptly terminated by such deposits. It is difficult therefore to discover what kinds of change took place during the late Otiran and at what rate. Secondly, as all the sites that are known are associated with the products of erosion, the problem of just how typical these sites are of the North Island as a whole is raised. It would seem logical to suppose that areas not subject to such erosion would have had a quite different vegetation cover.

TABLE 10

NORTH ISLAND SITES IN THE TIME RANGE 20 000 ± 2000 BP

Location	Altitude	Vegetation	Age BP	Author
Hamilton Basin (2 sites)	60m	Scrub-grassland	20 000	McGlone et al (1978)
Tongariro, Volcanic Plateau (5 sites)	500- 800m	Grassland-scrub	20 000	This work
Stent Rd, Taranaki	sea- level	Scrub-grassland	18 000	This work
Lake Poukawa, Hawkes Bay.	20m	Scrub-grassland	20 000	This work
Waikanae, Wellington	15m	Grassland-scrub (with brief <i>N. menziesii</i> phase)	19 000	McIntyre (1970)
Tawa, Wellington	80m	<i>P. alpinus</i> dominant scrub	21 000	Brodie (1957)
Taita, Wellington	30m	Grassland, with <i>N. menziesii</i> phase	20 000	Atkinson (1973), Harris & Mildenhall (1980)

The surprising feature of the sites that have been analysed for the period 20 000 - 14 000 BP, is their uniformity. The same restricted selection of pollen types occur in nearly all sites; *Phyllocladus*, *Dacrydium bidwillii* type, *Coprosma*, Compositae, *Myrsine* and *Dracophyllum* dominate the woody pollen sum; Gramineae, Umbelliferae and a few herbs of open places make up most of the non-woody flora. Mire plants are mainly Cyperaceae, *Gleichenia* and *Empodisma*. Forest pollen is in low amounts at most sites and, when it does occur in any quantity, it is mainly *Nothofagus*. Latitude and altitude appear to have little effect on the vegetation: from the Hamilton Basin (McGlone et al 1978) to the south of the North Island, from lowland Taranaki to the Volcanic Plateau, scrub and grassland communities are dominant. At two localities, Taita (Atkinson 1973) and Waikanae (McIntyre 1970), *N. menziesii* forest was present, but even in these cases the forest phase appears to have been brief.

The only geographic pattern that can be detected is the contrast between eastern and western districts. Most sites are found in the west, and all forest records for this period come from the west also. The very lack of records from the east suggest that conditions on that side of the island were inimical to organic deposition. The one site that does have pollen preserved (Poukawa) indicates an extremely depauperate vegetation with sparse, perhaps fire-swept, scrub.

(i) Forest distribution in the Late Otiran

As we have seen, the fossil evidence is not clear as to the whereabouts of forest during the peak of the Last Glaciation. From the pollen data alone the conclusion is that, aside from the two sites where *N. menziesii* was recorded, forest consisted mainly of isolated patches of *Nothofagus*. The only other direct evidence for forest is one record of *Agathis australis* wood in Auckland city, dated at around 22 000 BP (C. Hendy pers. comm.).

It is worth considering the present day distribution of *Nothofagus* (Figure 5) because it can give some clue as to the late Otiran distribution of forest. The prevailing opinion until recently has been that *Nothofagus* species spread slowly (Wardle 1963; Holloway 1954; Preest 1963). This has been attributed to ineffective dispersal of the seeds by wind (Preest 1963). On the other hand dispersal by water down streams and rivers has been held to be relatively rapid and effective (Holloway 1954; Nicholls 1963). Recently this rather simplified view has been challenged. Burrows (1977) has shown that *N. fusca* seedlings can occur at least 6km from the nearest *N. fusca* forest. Furthermore, in Westland, there are isolated stands of *N. fusca* and *N. menziesii* several to many kilometres from more extensive forest containing the same species (Burrows 1977). Movement of *Nothofagus* in Westland can be shown to have occurred both laterally across slope and also uphill.

It has been suggested recently (Baylis 1979) that the type of mycorrhiza associated with *Nothofagus* could limit its spread. *Nothofagus* spp have ectomycorrhizal fungi, while nearly all of the rest of the New Zealand flora possess endomycorrhizal fungi. New Zealand soils are especially poor in phosphorus, and in plants without mycorrhiza uptake of this element is inefficient. Therefore an isolated *Nothofagus* seedling, far from mature trees, has only a small chance of being inoculated and will not survive unless there is abundant phosphorus in the soil. High levels of phosphorus are usually found only in soils derived from fresh alluvium.

It can be seen, therefore, that during the late Otiran, soil conditions would be at their optimum for the spread of *Nothofagus*. There was an abundance of fresh alluvium and presumably phosphorus-rich soils. With the beginning of the Aranuian and the stabilization of soil and the establishment of complete forest cover, the opportunities for spread of *Nothofagus* would have become more limited. Movement of

Nothofagus into established podocarp-hardwood forest is often very slow indeed, especially in areas where the rainfall is high and the climate mild (Wardle 1964). The possibility of long-distance dispersal of *Nothofagus* succeeding under these circumstances is not high.

In the North Island there are areas that have suitable soils and climates for *Nothofagus* but lack this genus. Mts Egmont and Pirongia are two examples, both being isolated mountains that were surrounded throughout the Aranuiian by dense podocarp-hardwood forest. Both are testimony to the difficulty *Nothofagus* has had in spreading through podocarp forest. The probability of more than one *Nothofagus* species arriving by long distance dispersal to the same isolated site seems improbable. Clayton-Greene (1978) decided on this basis that the stands of *Nothofagus* in the Waikato area originated during the Last Glaciation, and similar statements have been made about *Nothofagus* in the Rotorua area (Nicholls 1963), on the ranges in the Taupo region (McKelvey 1963) and inland Taranaki (Nicholls 1956).

It is likely, then, that the present day distribution of *Nothofagus* indicates those areas where it survived throughout the Otiran. In the Aranuiian there has been some expansion of the area covered by *Nothofagus*, especially in upland areas along the axial ranges (Moar 1967, 1961), but only limited long-distance dispersal. The present day pattern of *Nothofagus* distribution confirms the impression gained by pollen analysis. Lowland areas of gentle topography tended to have little or no *Nothofagus* forest, while hilly regions, even at some altitude, nearly always retained some.

What then, was the vegetation pattern at the height of the Otiran? Much the same type of vegetation, or range of vegetation types, existed from the Hamilton Basin southwards. Herbfield or open ground in the coldest, driest or most exposed areas; scrub and grassland in varying

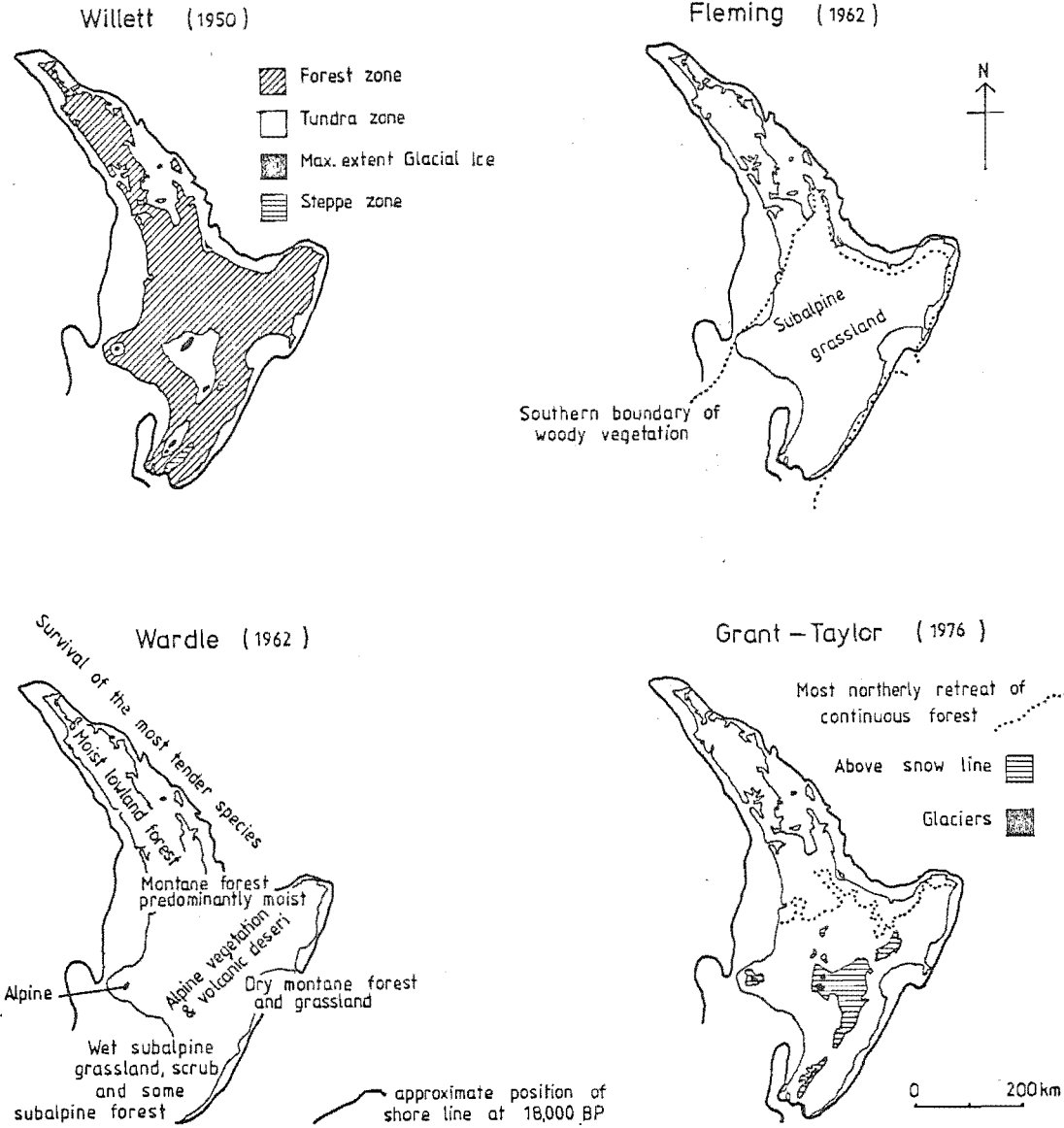
proportions over most of the landscape; forest, mostly *Nothofagus*, and in particular, *N. menziesii*, scattered throughout, but only in the most sheltered, moist and sunny locations. The lowlands were mainly grass-covered, while the lower hills and ranges had a diversity of vegetation depending on aspect, exposure etc. If the erosion of the Kawakawa Tephra is taken as a guide there was little or no vegetation cover above 900m altitude in the North Island (Milne 1973). No doubt there was a great deal of variety in the specific composition of these scrublands and grasslands that reflected north-south latitudinal differences and also altitudinal gradients. However, the broad pattern of universal scrub and grassland, with restricted amounts of forest in favourable locations the length and breadth of the island is likely to be correct.

- (ii) Previous work regarding the distribution of vegetation types during the Late Otiran.

Several attempts have been made to sketch out the distribution of the vegetation of the North Island during the Otiran maximum. The most important of these are: Willet (1950); Fleming (1962); Wardle (1963); and Grant-Taylor (in Fleming 1975) (see Figure 23). In general these attempts have not added very much to our knowledge of the late Otiran, but they have been very influential in the propagation of certain ideas about the climate and vegetation of this period.

The main assumption made in all these attempts at a reconstruction of the vegetation pattern at the height of the Otiran, is that temperature was the main controlling factor in the distribution of vegetation. Therefore, if this assumption is taken to its logical extreme, once an accurate determination of mean annual temperature for a given locality has been made, mean annual temperatures can then be estimated for other localities. From these determinations the theoretical position of the tree line, based on the relationship of present day tree line to

Figure 23. Reconstructions of vegetation at the Otiran maximum



temperature, can be derived. Although a reasonable enough procedure, and one to which there are few alternatives in the absence of fossil evidence, failure to appreciate that there are other climatic variables that have an effect on plant growth, and failure to take account of what was published on vegetation during the Otiran, has led to the production of maps, particularly those of Willet (1950) and Grant-Taylor (1975), that bear little relation to the situation as revealed by the fossil evidence.

In fact, tree line, as we understand it today, simply appears not to have existed during the late Otiran. Once it is realised that rainfall, frost, wind and fire all played important roles during the late Otiran, it is no longer possible to do anything else but indicate those areas where, given the right situation, forest may have existed.

Bearing this in mind, the tree line indicated in Willet's map can be seen to be a theoretical creation bearing little or no relation to the real situation. Fleming's (1962) map is based on fossil evidence for the most part, except for the north of the North Island, where the bulk of the woody vegetation is thought to have survived, and a thin coastal strip of forest. Neither of these regions have been investigated as yet, but there is no compelling reason to believe that the pattern will be very much different from that established for the rest of the North Island. And, as is shown by the distribution of *Nothofagus* at present, many areas depicted as subalpine grassland must have had some forest.

The same general criticism can be levelled at Grant-Taylor's map in Fleming (1975): areas shown as in forest are known to have grassland (e.g. Hauraki Plains and the Hamilton Basin); and other areas shown as grassland almost certainly had at least some forest, even at the peak of the Otiran. Wardle (1963), while recognizing that tree survival was

widespread, indicates that the northern half of the North Island was in moist montane forest. Pollen diagrams published from this area (Harris 1963; McGlone *et al* 1978) show that this area was predominantly in scrub and grassland.

It is hoped that in the future, as more fossil evidence is produced, that it will be possible to produce a vegetation map for the peak of the Otiran. At the moment such a map does not appear to be possible as there are far too many unknowns.

(iii) Climate during the late Otiran.

At present only the vaguest indications as to the climate can be given on the basis of vegetation distribution. Tree limit, in the sense of the 10°C January isotherm (Wardle 1973), as indicated by the presence of shrubs such as *Phyllocladus alpinus* and *Dacrydium bidwillii* group, probably did not fall below about 900 metres: the one or two records of higher altitude stands of *Nothofagus* on the Volcanic Plateau (McKelvey 1963) support this inference, as does evidence presented by Clayton-Greene (1978) from the Hamilton Basin. If the tree limit did not fall below this altitude, the maximum depression of mean annual temperatures below those of the present was of the order of 4°C. McGlone *et al* (1978) estimated the maximum depression of temperature in the Hamilton Basin at about 20 000 BP to be no greater than this.

There are several factors that can upset calculations made on the basis of plant distribution. Perhaps the most important is the seasonality of the climate during the Otiran. If the climate was more continental than at present, and therefore the summers relatively warmer and the winters colder, it is likely that tree limit would provide an estimate of mean annual temperature that is too high. Estimates based on the levels of glacier cirques have generally given greater values than those given above for the depression of temperature at the height

of the Otiran (Gage 1965) and 5-6°C appears to be a standard estimate. The inferred cirque level on Mt Tongariro (see section 7.1.2) indicates a depression of the snow line in the central North Island corresponding to 800 metres or a little less than 5°C in mean annual temperature.

Estimating past precipitation levels is even more risky than estimating past temperatures. The marked east-west difference in vegetation is best interpreted in terms of high drought frequency in the east, perhaps coupled with lower rainfall, a gradient that is apparent at present. The evidence from the south-west Taupo paleosols points, somewhat ambivalently, towards a drier climate. Charcoal is abundant in many, but not all, late Otiran sites, Stent Rd, Mangahume and Poukawa in particular having large amounts. When these sites are compared with Aranuiian sites in the same areas, it can be seen that the incidence of charcoal in Otiran sites as a whole, is very much greater. There is no reason to believe that volcanoes were a primary cause of these fires, as Aranuiian profiles near active volcanoes have only insignificant amounts of charcoal (McGlone & Topping 1977). Therefore it seems as though the vegetation was more fire-prone, and this may have been because of a drier and more drought-prone climate than at present.

Geomorphic reconstructions can be interpreted as supporting the concept of a drier climate. Widespread loess deposits have been found in the lower half of the North Island (see: Cowie & Milne 1973) and, although these have been attributed by New Zealand workers to the effects of a colder climate only, in Europe loess is regarded as being associated with dry climates, as well as with treelessness and severe winters (Frenzel 1973; Sparks & West 1972).

Kennedy *et al* (1978) present a 40 000 year record of the fluctuations of Lake Rotorua, in the Bay of Plenty. The lowest lake

levels persisted from just before 20 000 BP through to about 9000 BP; the very lowest levels were from about 18 000 to 13 000 BP. Lake Poukawa (section 9.3.1) was dry from at least the middle Otiran on, and the first evidence for a permanently high water table comes at about 10 000 BP. Both Lake Rotorua and Lake Poukawa are in regions of active tectonism, but the coincidence of late Otiran/early Aranuiian low lake levels supports a "dry" interpretation of the climate. Further evidence for lower rainfall comes from Taranaki where there are sand dune fields of late Otiran age in areas remote from the then sea level (Neall 1975).

To summarize: although little can be deduced as to the exact nature of the late Otiran climate, the overwhelming impression gathered from the vegetation reconstructions is that it was harsh and variable. Even if the greater estimates of depression of temperature are accepted, much of the North Island lay below what would, given present climate, be the tree limit. The absence of any substantial areas of forest and the ubiquity of scrub and grassland force the conclusion that other factors, low rainfall certainly, fire, and probably wind also, were as important or more so than low temperatures in determining the limits to forest vegetation. Likewise, the distribution of the various scrub and grassland communities were controlled by the same set of climatic factors.

10.3 ARANUIIAN VEGETATION AND CLIMATE

10.3.1 Early Aranuiian 14 000-10 000 BP

There are three pollen diagrams that span all, or nearly all of the early Aranuiian: Hauraki Plains, South Auckland, (Harris 1963); Rotoaira, Volcanic Plateau, (McGlone & Topping 1977); and Ngaere Swamp, Taranaki (section 5.2.8).

At the beginning of each of these long Aranuan sequences a very similar vegetation type is recorded at each site. Scrub, mainly *Phyllocladus*, *Dacrydium bidwillii* group, *Coprosma* and *Myrsine*, together with Gramineae and various herbs was dominant. Arboreal pollen was derived mainly from isolated stands of *Nothofagus*, and only low levels of podocarp tree types are indicated. These scrub/grassland communities strongly resemble those found in the late Otiran and it is reasonable to assume that there was continuity between them. Vegetation cover was presumably incomplete in the initial phases of the Aranuan as silt was still being transported to the basin sites, and loess deposition continued in some areas of the North Island until 12 000 BP (Milne 1973). Major river systems such as the Waikato and Rangitikei, did not stabilize until about 12 000 - 10 000 BP, and continued to deposit gravel and silt over their valley floors.

The scrub/grassland phase was brief, and forest rapidly replaced the open scrubland vegetation. At Rotoaira, forest may have taken less than 300 years to establish nearly complete cover; the transition appears to have been equally rapid at the Hauraki Plains site. At Ngaere the transition appears to have been somewhat slower, but still to be measured in hundreds rather than thousands of years. At all three sites the broad vegetation type that followed the scrub/grassland was the same, that is a *Podocarpus* (mainly *P. spicatus*) dominant podocarp-hardwood forest. Unfortunately, the species which may have been the most numerous of the forest trees, *Weinmannia* and *Beilschmiedia tawa*, are poorly or not at all represented in pollen diagrams. However, the range of hardwood species represented is such that species-rich, diverse podocarp forest communities can be inferred.

Podocarp-hardwood forest species can, in general, be spread effectively and quickly by frugivorous birds (Preest 1963). There is no

Correction: third paragraph.

This argument depends on the date for the Rotoaira and Ngaere sites being accurate. As only about 1000 radiocarbon years separate the beginning of reafforestation at the two sites, there is a possibility that this event was simultaneous. Only further dates for the beginning of reafforestation in lowland Taranaki will clarify this point

Hauraki site, although forest must have been established well before 12 000 BP.

A comparison between the Rotoaira and Ngaere sites is instructive. Although the forest at Ngaere established at least 1000 years later than at Rotoaira, once established it does not reflect a harsher climate, rather the reverse. *Libocedrus*, *Phyllocladus* and *D. bidwillii* group must have been very common plants at Rotoaira, whereas at Ngaere they were rare in the forest phase. *Leptospermum* did not dominate the scrub on the Rotoaira mire until after 10 000 BP and *Dacrycarpus* never became common; both these species were common at Ngaere from the beginning of the forest phase. Despite these differences in vegetation composition, the changeover to *D. cupressinum* forest took place at approximately the same time in both localities, that is around 10 000 BP.

It is generally accepted that there was a sustained rise in global temperatures from about 14 000 BP on, a trend that culminated sometime after 10 000 BP (Burrows 1979). As an all-inclusive climatic explanation for the spread of forest in the North Island the Aruanian increase in temperature fails. It cannot explain why podocarp-hardwood forest, albeit of a cool climate cast, appeared on the Volcanic Plateau before it did in lowland Taranaki. Ngaere Swamp is some 300 metres lower in altitude than Rotoaira and has, at present, an annual average temperature some 1.3°C higher. It would be expected, if rising temperatures were the sole driving force behind the reafforestation of the North Island, that Ngaere would be forested first. A localized low temperature anomaly in lowland Taranaki cannot be invoked because, when forest did appear at Ngaere it seems to have developed under a warmer climate than that at Rotoaira.

If an increase in temperature was not the major cause of this sudden irruption of forest in the central North Island, what was?

Increased rainfall after a late Otiran period of low rainfall and drought seems to be one possibility. A sudden and sustained change in the rainfall pattern, leading to more and better distributed precipitation, certainly could give rise to rapid colonization of a scrub and grassland covered landscape by forest. *P. spicatus*, which seems to have been everywhere the first tall podocarp tree, prefers fertile, well-drained soils, and is more tolerant of drought and low rainfall than is *D. cupressinum*. For this reason it is well adapted for pioneering on alluvial deposits, and the presence of extensive, thickly-stocked stands of this tree on river flats of thick pumice near Taupo has been attributed to this ability (McKelvey 1963). At the beginning of the Aranuiian, many soils, often formed on thick deposits of volcanic ash, loess or alluvium, would have had high fertility and good drainage and therefore would be ideal for *P. spicatus*. A moderate increase in rainfall could therefore have had a disproportionate effect on the composition of the vegetation.

A simple hypothesis invoking an increase in rainfall, but without a change in the geographic distribution of it, will not explain the late spread of forest to Taranaki either. Rainfall in lowland Taranaki ranges from 1200 to 2000mm per year and is evenly distributed throughout the year. The Rotoaira area, although falling into a slightly higher rainfall class, shows the same rainfall characteristics. Hauraki Plains receive 800 to 1500mm and are significantly more prone to drought than both Taranaki and Rotoaira. That Ngaere remained too droughty and dry for podocarp forest while such forest flourished on the Volcanic Plateau is hard to believe, that is if the present day distribution of rainfall and drought is used as a guide.

There are two factors that may have altered this. Firstly, the Rotoaira area is cooler, more cloudy, and has more raindays a year than either Hauraki or Ngaere. Secondly, sea-level was lower at that time and

both Ngaere and Hauraki, but Ngaere in particular, would have been much further from the coast. The combination of these two factors, the first increasing effective precipitation in the Rotoaira area, the second removing the moderating effect of the coastal climate from both Ngaere and Hauraki, may have been decisive.

A further possibility is that the major changes in atmospheric circulation suspected of having occurred at the glacial maximum (Gates 1976) resulted in very different air-flow patterns over New Zealand and changed locations of air masses and depression tracks. The observed anomalies in plant distribution in the late Otiran and early Aranuiian would tend to support this view, but the information is too scanty to provide any real test of this hypothesis.

10.3.2 Mid Aranuiian 10 000-5000 BP

As discussed above, at 10 000 BP or thereabouts, there was a dramatic, and apparently rapid shift in the composition of forest vegetation over most of the North Island. At Ngaere and Rotoaira, *D. cupressinum* became the dominant emergent podocarp tree, and *Ascarina* and *Dodonaea*, two small trees which made their first appearance a little earlier, became far more abundant. At Wallaceville, near Wellington, the same event occurred, *D. cupressinum* and *Ascarina* becoming more common after c. 9000 BP (Harris 1951, 1958). Although there are only a few sites that extend back as far as 10 000 BP, it can be assumed that the *D. cupressinum/Ascarina* association rose to dominance in all but the drier, south-eastern side of the North Island. Sites in the Ruahine Ranges (Moar 1961, 1967), Rimutaka Range (McGlone & Moar 1977), Pauatahanui Inlet, Wellington (Mildenhall 1976b), Rotorua (McGlone in Kennedy et al 1978), all record the *D. cupressinum/Ascarina* association during the mid Aranuiian.

McGlone & Moar (1977) and McGlone & Topping (1977) have discussed the significance of this change from *Podocarpus* dominant forest to *D. cupressinum* dominant forest with *Ascarina*. Their conclusion was that a combination of mild, relatively frost-free growing seasons, with evenly distributed rainfall of at least 1200mm a year, would allow this forest type to establish.

Dodonaea viscosa seems to follow the same pattern of Aranuian change as *Ascarina*. It appeared at the same time as *Ascarina* at Ngaere, and was present in lowland Hawkes Bay (Poukawa) by 10 000 BP. It has been reported from Pauatahanui (Mildenhall 1976b) and also from the Nelson region (Dodson 1978) in the mid Aranuian. It was abundant at Rotorua, where it is now very scarce, at around 5000-4000 BP (McGlone *in* Kennedy *et al* 1978).

Dodonaea is a small tree or shrub that has a generally coastal distribution, although it may be found inland up to altitudes of 300 metres. In such cases it is usually found on north-facing slopes. *Dodonaea* has a limited southern distribution, and does not go further south than Lake Ellesmere in the east (lat. 44°) or Greymouth in the west (lat. 42°30'). Even near the extreme of its southern range it can be found inland e.g. in the gorge of the Waipara River, North Canterbury. Significantly though, these locations are on frost-free north-facing slopes (A. Dobson pers. comm.). Frost frequency and severity are probably important factors in limiting the distribution of this species, and mature plants of *Dodonaea* have been damaged by frost in Christchurch (P. Wardle pers. comm.). *Dodonaea* therefore seems to be restricted in its range by the length and warmth of the frost-free growing season; from its distribution, rainfall appears to be relatively unimportant.

The combination of the environmental requirements of *D. cupressinum*, *Ascarina* and *Dodonaea* goes some way towards characterizing the climate at

the peak of the mid Aranuiian. Temperatures were higher than at present; frost frequency and severity lower; rainfall over 1200mm in most districts; drought rare in all but the drier south-eastern districts. There is no way at present that this qualitative assessment of the climate can be transferred into quantitative terms. Nevertheless, it can be said with confidence that the period from 10 000 to 5000 BP was the longest period of warm temperatures and freedom from drought and frost for more than 80 000 years.

10.3.3 Late Aranuiian 5000-1000 BP

At no point did vegetation stability occur at any of the sites so far examined. At Rotoaira there were constant fluctuations from 10 000 BP on between *P. spicatus* and *D. cupressinum*: at Ngaere, although the proportions of the major tree species were stable, minor elements came and went. Among this constant fluctuation, certain trends in abundance of several species are followed at more than one site and are therefore of more than local importance. Chief among these changes are: the decline in *D. cupressinum*, *Ascarina* and *Dodonaea*; and the increase in *N. fusca* group forest, *Knightia excelsa* and *Dacrydium colensoi*.

Not all pollen diagrams in the North Island show the *D. cupressinum* decline. It is strongly marked at Rotoaira, and apparent at Hamilton and Hauraki (Harris 1963, Lambert 1972); it does not occur at Ngaere; at Poukawa there is a slight increase. In contrast, in those areas where *Ascarina* and *Dodonaea* were common in the mid Aranuiian, there is also a well marked decline in their abundance. *Dodonaea* is eliminated, or has reduced abundance at Rotoaira, Ngaere, Poukawa and Rotorua; other pollen diagrams do not record *Dodonaea*, or their authors fail to include it in their diagrams.

N. fusca group forest increased during the late Aranuan, but the pattern is not straightforward. Nothing much can be gleaned from the most northerly diagram, Hauraki. There *N. fusca* type, after near elimination in the early Aranuan, suddenly reappears but continues at virtually unchanging low percentages for the remainder of the sequence. There is a rather puzzling pattern at Hamilton: *N. fusca* type, absent or near absent for the first part of the diagram, reappears at about the same time as *Ascarina* is first noted. It then continues at low, unchanging levels until, a little after the *Ascarina* and *D. cupressinum* decline, it drops back to trace levels. This pattern is the reverse to the pattern found in more southerly diagrams. At Ngaere *N. fusca* type pollen maintains low levels throughout most of the early Aranuan and then drops to trace levels for the rest of the diagram.

The rest of the North Island sites all show the same general trend. *N. fusca* group forest was present, and in substantial quantities at some sites such as Wallaceville, during the mid and early Aranuan. At, or just after 5000 BP, and at approximately the same time as the *D. cupressinum*/*Ascarina* decline, *Nothofagus* levels rise. Nowhere, however, does *Nothofagus* attain complete dominance as is common in northern South Island sites: rather, there is a gentle increase or even levelling off after the initial expansion. At the very top of the sequences at Wallaceville, Rimutaka and several of the Ruahine Range sites, there is a relative decline in *N. fusca* type.

Knightia, found in quantity only at Ngaere and Pauatahanui Inlet but regularly noted at Rotoaira, undergoes expansion in the latter half of the late Aranuan. Elsewhere it is either not recorded regularly enough to give a reliable indication of its abundance, or is absent or not mentioned.

The reason for the increase of *Knightia* remains unexplained. As this species has a well defined southern limit at Wellington and the Marlborough Sounds, it may well be sensitive to either low temperature or a short growing season. Its appearance during a period when the reactions of other elements in the vegetation suggest that the climate was becoming colder, indicates that temperature change alone is unlikely to be the direct cause of its increase. *Knightia* is not a tree of dense forest, and seems to prefer steep slopes and canopy gaps, areas where there tends to be abundant light (Nicholls pers. comm.). A possible reason for its increase therefore could be that when the mild, humid climate that characterized the mid Aranuiian gave away to the more severe climate of the late Aranuiian, new habitats opened up for the species as dense forests thinned out on marginal sites. However, *Knightia* became common at Ngaere, and possibly on the Volcanic Plateau, long before it did further south at Pauatahanui Inlet (5000 as opposed to 2000 years ago) and appears to have very recently reached the Marlborough Sounds where it is found in only a few areas. Therefore, unlike the *Ascarina* or *Dodonaea* decline, the rise of *Knightia* cannot be attributed solely to climatic change. From the little fossil evidence we have, it appears as though southward migration is also involved. This is possible, because *Knightia* has the ability to spread rapidly given the right conditions (Nicholls pers. comm.).

Dacrydium colensoi is even more restricted in its Aranuiian occurrences than is *Knightia*. At Ngaere *D. colensoi* undergoes a well marked expansion commencing after 5000 BP and apparently finishing before 1500 BP. At Rotoaira *D. colensoi* was always present at the site throughout the Aranuiian. Starting at c. 5000 BP, it underwent a major oscillation from less than 1% to about 20% of the pollen sum, and then back to low levels by 3500 BP. There is a second, and not as clearly defined oscillation just before 1800 BP. Apparently a similar

fluctuation occurred in the Waikato Basin, (although Harris (1963) and Lambert (1972) do not record it), as wood of *D. colensoi* is abundant in some mires, although the tree is no longer found in the region (Gudex 1954).

Not much is known about the ecological requirements of *D. colensoi*. It is most abundant in the west coast of the South Island where it occurs on gley podzols and infertile mire sites (Wardle 1975) and is found on similar soils on the Volcanic Plateau (McKelvey 1963), but is also present at several locations in Northland. Despite its occurrence in Northland, the general distribution suggests a preference for cool, moist climates, perhaps because under those kinds of conditions gley and infertile mire soils are more common. It may be that there was a phase in the late Aranuian when a climate like this established in the North Island, but there is no other supporting evidence, except for the well-attested South Island cooling that took place during this period (Burrows 1979).

McGlone & Topping (1977) and McGlone & Moar (1977) have already discussed the significance of some of these late Aranuian vegetation changes. Their conclusions are that from about 5000 BP on there has been an increase in the overall incidence of frost and drought which has led to a contraction in range of some of the more sensitive species. The additional information presented here from Taranaki and Poukawa supports this interpretation.

CHAPTER 11

SOUTHERN HEMISPHERE COMPARISONS

11.1 SOUTH ISLAND, NEW ZEALAND

There is only one pollen-analysed deposit from the South Island that is likely to be of early Otiran age. At Timaru on the east coast of the South Island, a thin peat horizon intercalated between two loess sheets has yielded a pollen flora dominated by *Podocarpus spicatus* and *Dacrycarpus* (Moar 1973). This peat was at first dated at 31 000 BP (Tonkin *et al* 1974) but further work has demonstrated that this date is too young, and that the true age is either early Otiran or late Oturian. If it is of early Otiran age it is likely to be a correlative of the early Otiran forest phases recorded on the Volcanic Plateau and at Inaha. However, the pollen analysis recorded abundant *Dodonaea*, and as Timaru lies some 50km south of the southern limit of this shrub, this site is more likely to belong to an interglacial.

There is strong evidence now for a mild, mid Otiran interval beginning before 31 000 BP and terminating by 26 000 BP. At Hokitika, on the west coast of the South Island, there was a *Dacrydium cupressinum* dominant forest at 31 000 BP which gave way to *Nothofagus* well before 24 000 BP (Moar & Suggate 1973). At Westport, 70km north of Hokitika, pollen diagrams of mid Otiran age indicate that the region had a grassland/shrubland mosaic, including *Phyllocladus*, *Dacrydium bidwillii* group, *Leptospermum*, *Coprosma* and *Myrsine*, and stands of *Nothofagus* forest are believed to have been nearby (Moar & Suggate 1979). After 26 000 BP there was a gradual encroachment of grassland. The South Island sequence is therefore in strong agreement with the results for the same period of time from the North Island.

The late Otiran (26-14 000 BP) in the South Island was characterized by grassland, herbfield and shrubland associations (Moar & Suggate 1973; Moar & Suggate 1979; Moar 1971; Suggate & Moar 1970). The published pollen spectra from this age range resemble some of those from the central North Island, but by and large, North Island diagrams have less grassland and more scrubland represented. In both regions stands of forest survived.

Forest arrived at most lowland South Island localities at about 10 000 BP (McIntyre & McKellar 1970; Moar 1971; McGlone unpub.). This date coincides with the expansion of *D. cupressinum* in the North Island, and the first peak of *Ascarina*. However, in the Westport area forest spread at about 12 000 BP, a date that is comparable with the timing of the spread of forest in Taranaki, but still much younger than the same event on the Volcanic Plateau. In some localities that did not develop a forest cover until 10 000 BP, there existed a scrub of *Phyllocladus* and *D. bidwillii* group from about 12 000 BP on (Moar 1971). As has been pointed out in both this work and Moar & Suggate (1979), this indicates that annual temperatures were high enough to permit forest growth. Exactly what the factors were that kept the forest out of many of these South Island localities for so long is not known, but frost and exposure may have played a role.

Evidence for a mid Aranuanian "climatic optimum" in the South Island is not strong. Moar (1971, 1966) did not regard the evidence for such an event to be convincing. However, Lintott & Burrows (1973) consider that pollen diagrams and macrofossils from the Cass area, inland Canterbury, indicate that that area was moister, and if not warmer, at least less extreme during the mid Aranuanian. Data for the *Ascarina* decline in McGlone & Moar (1977) supports the idea of a generally milder climate during this period, but the evidence from South Island localities

is not as clear cut as that from further north. Pollen results from north-east Nelson (Dodson 1978) do not provide much support for a climatic optimum either, as the period of maximum abundance of *Dodonaea*, and probably most equable climate, lasted from 5600 to 2500 BP which is within the late Aranuiian. However, this site indicates that the climate was moister after 8500 BP.

Taken as a whole the evidence for a climatic optimum in the South Island is weak, and indicates rather that conditions were much as at present. Molloy (1969) claimed that there was no conclusive evidence for climate change in the post-glacial, other than a general rise in temperature 10 000 years ago. I regard this as an extreme view, and unjustified as regards the North Island. In the South Island it may be that the broad climatic tolerances of the most widespread forest associations have meant that even substantial climatic changes have not resulted in corresponding vegetation change.

As with the mid Aranuiian period, evidence for climate change during the late Aranuiian is equivocal. The effects of *Nothofagus* migration, not only throughout this period but also in the mid Aranuiian, are such that it is difficult to discern climatic change. It may be that some of the *Nothofagus* migration, or spread from local stands, was climate induced or assisted, but in many places *Nothofagus* spread long before the commencement of the late Aranuiian (Moar 1971; Dodson 1978). Once again the pattern of *Ascarina* abundance suggests that events in the South Island were more or less in phase with those in the central North Island (McGlone & Moar 1977; Pocknall 1979).

11.2 AUSTRALIA AND NEW GUINEA

The same problem of lack of adequate dates for sites of early Last Glaciation age that makes correlation within New Zealand so difficult,

makes comparison with other regions of the world a very speculative affair. There are only two sites within Australia, both long lake cores, that offer much hope for correlation. Lynch's Crater in Queensland (Kershaw 1974, 1978) provides a continuous pollen record back beyond 100 000 BP. The pollen data has been used to estimate annual rainfall and the resulting curve agrees well with oxygen isotope and temperature curves from deep sea cores (Kershaw 1978). The suggested rainfall curve has a major peak at 80 000 BP which may be the correlative of the high sea level that cut the Inaha Marine Bench. There is a further minor peak at c. 60 000 BP and this is likely to correspond to the early Otiran interstadial that features so prominently in Taranaki and the Volcanic Plateau.

Lake George, near Canberra, provides a less continuous record than that from Lynch's Crater, and is not as well dated (G. Singh in Bowler *et al* 1976). However, the general shape of the climatic curve derived from the pollen analysis bears a striking resemblance, both in number of events recorded and relative development of the vegetation within each episode, to the sequence at Inaha Beach (Fig 5; Bowler *et al* 1976). The absence of a warm temperate phase equivalent to the upper Zone A (sediments younger than 8000 BP) in the 9 metres of core analysed, tends to suggest that the diagram is entirely within the Last Glaciation. Therefore, although there are no independent dates for most of the core, Zone J of this diagram may be equivalent to the early Otiran interstade. This interpretation assumes that there are no substantial periods of time unrepresented in the Lake George core.

A rather detailed history of the mid Last Glaciation is emerging in Australia and New Guinea. The Lake George core shows that there was a period characterized by cool temperate forest vegetation between an estimated 50 000 BP to 22 000 BP. Annual temperatures during this episode were about 3°C below those at present. The non-wooded phases before and after this episode had lower temperatures and decreased

precipitation.

A pollen diagram from Blake's Opening in Tasmania (Colhoun & Goede 1979) records a Temperate Rain Forest phase which is thought to represent an interstadial event. This interstadial oscillation is dated as having lasted from somewhat before 53 400 BP through to an age a little greater than 41 000 BP.

There are numerous records of high lake levels from south-eastern Australia for the period 40-26 000 BP (Dodson 1977, 1975, 1974; Bowler *et al* 1976). Bowler *et al* (1976) interpret these curves as indicating a cooling trend between 35 000 and 26 000 BP. The Lake George results (quoted in the same work) do show a cooling trend, but it began well before 35 000 BP. Kershaw (1978) records a gradually declining rainfall for north-eastern Australia in the interval 50-20 000 BP, but with a minor increase just after 40 000 BP. Evidence from a long pollen diagram from Sirunki, New Guinea (Walker & Flenley 1979) suggests that there was a warming at about 26 000 BP before the cooling to the glacial maximum.

The evidence for cooling after 35 000 BP in southern Australia, based mainly on lake level curves, seems to contradict the interpretation given to this period in New Guinea, and New Zealand, and also in the Northern Hemisphere (Dreimanis & Raukas 1975). Much depends therefore on whether a correct interpretation has been given to the high lake levels that characterized the middle Last Glaciation in Australia. Street & Grove (1979) point out in connection with a discussion of lake levels from 30 000 to 26 000 BP, that it is '... difficult, if not impossible, to determine whether the expanded lakes resulted from higher temperatures or reduced temperatures.'

There is impressive uniformity of climatic inferences for the period 26 000 to 14 000 BP. Bowler *et al* (1976) show that this was the last major interval of aridity in southern Australia. Cold climate

vegetation was recorded at Lake George and at Sirunki, New Guinea (Walker & Flenley 1979), there is a downward trend in temperatures from 25 500 BP to 16 000 BP. In Queensland rainfall appears to have reached its lowest levels during this period (Kershaw 1978). Hope (1978) has shown that vegetation in north-western Tasmania was growing under a relatively moist climate at 28 000 BP, but that vegetation typical of drier climates spread after 22 000 BP, a development that culminated from 16 000 to 20 000 BP. At Lake Leake in south-eastern Australia (Dodson 1975) the maximum period of aridity occurred from sometime after 35 000 BP and lasted until near 10 000 BP.

As in New Zealand, there appears to have been a period in Australia starting sometime after 15-16 000 BP and continuing through to about 9-10 000 BP of rapid warming accompanied by major vegetation change. Also as in New Zealand, the timing of the response to warmer temperatures and higher rainfall, and the time taken for the vegetation to reach full development, seems to have varied from place to place. Development of a woody vegetation cover began at about 14 000 BP at Lake George. In sites in south-eastern Australia (Dodson 1974, 1977) dry conditions prevailed until just before 10 000 BP. In Queensland, (Kershaw 1975) change to a wetter climate had begun by about 11 000 BP and sclerophyll vegetation was replaced by rain forest just after 10 000 BP. In New Guinea (Walker & Flenley 1979) treeline and temperatures rose rapidly after 16 000 BP, and temperatures were within 1°C of present levels at 13 500 BP. Climatic and vegetational stability was not achieved there until 9000 BP.

The period from 10 000 BP to the present encompasses the interval of greatest precipitation and warmth. In Tasmania (McPhail 1979) this period of most equable climate occurred between 8000 and 5000 BP; in south-eastern Australia (Dodson & Wilson 1975; Dodson 1974) from 7000 to 5000 BP; in Queensland rainforest reached its maximum extent between

7000-7500 BP and 3000-4500 BP (Kershaw 1971). In New Guinea forest grew at higher altitudes than present between 8500 and 5000 BP (Hope & Peterson 1975) and this suggests that mean annual temperatures may have been up to 2°C higher.

At all the sites referred to above, climatic conditions seem to have become less favourable after about 5000 BP. Burrows (1979) shows that in the Southern Hemisphere as a whole, relatively cool periods occurred at 5400 BP, 4800 BP, 3600 BP, 2700-2200 BP and 1800-1500 BP.

11.3 CHILE

A pollen diagram from Río Ignao, southern Chile, provides good evidence for a forest event that is somewhat older than 56 000 BP (Heusser 1976). It is believed to be an early interstadial of the Llanquihue (Last) Glaciation, and may be a correlative of the early Otiran Interstadial recorded in the North Island. At a site in the same locality near Lago Rupanco a date was obtained for a forest event of about 36 000 BP (Heusser 1974). This date is now thought to be in error, and the true age to be much older (Heusser 1976). It is possible that the Rupanco event is in fact a correlative of that at Río Ignao.

Heusser (1974) has constructed a detailed temperature curve for the latter part of the Llanquihue Glaciation and the post glacial. However, the radiocarbon dates on which this curve is based (reported in Heusser 1966) are reversed in two of the sections and some of the other dates on which the zones are distinguished have such large standard errors that many of the dates reported overlap. Because of this unsatisfactory dating the temperature curve can not be used for exact correlations.

The change from full glacial conditions to post glacial appears to have begun in southern Chile about 12 000 BP, although there are indications of fluctuating climates with a general upward trend from about 18 000 BP (Heusser 1974). Forest similar to that of the present appears about 10 000 BP and reaches its maximum development between 9000 and 5000 BP. After 5000 BP the forest changed structure in response to cooler, more humid conditions.

11.4 CONCLUSIONS

There are two major obstacles that stand in the way of valid comparisons between widely separated areas. One is that correlation must in most cases be entirely by radiocarbon dating, which at present limits effective correlation to the last 35 000-30 000 years. Tentative correlation can be made by comparisons with the deep sea oxygen isotope record and with dated sea level curves. However, if this method is to have any chance of success, the sites must have near continuous records. The second obstacle is that given the great variation in climates between the countries of the Southern Hemisphere it is likely that in each area the vegetation is reacting to different components of the weather system. It is by no means clear that the establishment of forest similar to that of the present day in southern Australia, for example, should be regarded as the climatic equivalent of the same event in Chile. Within the range of radiocarbon dating this is not a problem, but it is when older sequences are compared.

Within the range of trustworthy age determinations, that is from 20 000 BP to the present, there is a great degree of agreement between the general climatic history of the central North Island and that of the

Australasian region and Chile. At the broadest level of detail this agreement is near absolute: there are no reports of warm/moist climates before 15 000 BP and likewise there are no indications of cool/dry climates prevailing in the period 8000-6000 BP. All regions report rapid change in the period 15 000 to 9000 BP. Whether this uniformity of response in the 20 000 BP to present period can be used to justify correlations outside the range of reliable age determinations is hard to say. It is a fact that the three long records from the region (Lynch's Crater, Lake George and Inaha Beach) do show a generally similar shaped curve, and this supports the idea of the Southern Hemisphere region being in phase throughout the Last Glaciation.

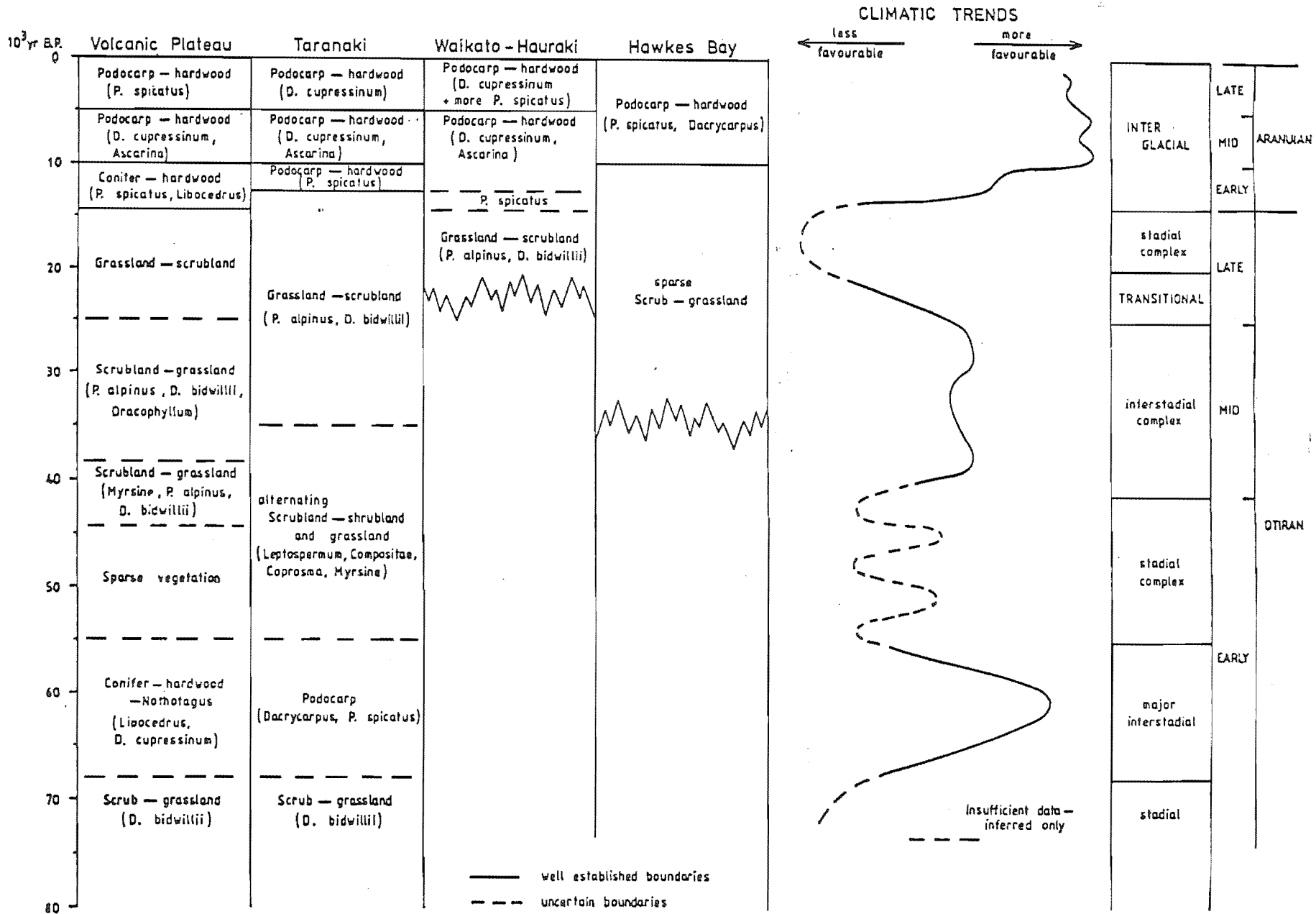
Despite the unreliable dates for the period, it seems as though the period from 30 000 to 26 000 BP had a climate significantly more favourable for plant growth than the period immediately following it. Despite the evidence of glacial activity in the Snowy Mountains, Australia (Costin 1972), and the interpretation put on the existence of higher lake levels in parts of Australia at that time (Bowler et al 1976), I think that the case for a warm/moist interstadial event is well established. As far as the early Last Interglacial interstadial is concerned only an improvement in dating techniques will permit it to be adequately characterised. At the moment there is a grave danger of confusing this interstadial with cooler phases of the Last Interglacial. The deep sea record indicates that there are several events of similar magnitude at the end of the Last Interglacial and the beginning of the Last Glaciation.

SUMMARY

1. Figure 24 summarizes the vegetation history of the central North Island. The curve at the right of the diagram is not meant to be anything else than a guide to the direction and approximate magnitude of climatic changes that affected the vegetation.
2. There was a major interstadial in the early Otiran, perhaps at around 60 000 BP. During this period podocarp-hardwood forest, *Nothofagus* and *Libocedrus* forest covered large areas of the central North Island. Temperatures rose to within 2°C of those of the present day: precipitation was the same as at present, or slightly lower.
3. Scrub and grassland were the dominant vegetation types throughout the rest of the Otiran. The type of scrubland depended on locality and soil type. The most common taxa were: Compositae, *Coprosma*, *Phyllocladus alpinus*, *Dacrydium bidwillii/biforme* type and *Myrsine*.
4. There was a long period in the mid Otiran (45?-25 000 BP) which saw the development of forest in areas such as Gisborne and the upland regions of the Bay of Plenty, and forest/scrub/grassland mosaics in some lowland areas. This mid Otiran interstadial achieved its best development between 32 000 BP and 27 000 BP, an interval of time that is characterised by widespread podocarp-hardwood forest in the north of the central North Island. In other areas, such as south Taranaki and the Taupo-Tongariro region, scrub and grassland remained dominant throughout.

This interstadial did not achieve the completeness of forest cover of the early Otiran event. Mean annual temperatures were 3-4°C below those of the present, and the rainfall appears to have been less in most regions.
5. The period from 25 000 to 14 000 BP saw maximum development of scrub and grassland communities. There is little evidence for forest during this period, but the present day distribution of *Nothofagus* strongly

Figure 24. Summary of vegetation and climate change in central North Island



supports the hypothesis that forest survived in most regions that were hilly enough to provide a range of suitable microclimates. Open and exposed areas seemed not to have any forest.

The climate was harsh and variable, and characterised by extremes of both rainfall and temperature. However, mean annual temperatures did not fall further than 5°C below those of the present.

6. The abundance of charcoal in many Otiran sites suggests that fire was common. Given the prevailing harsh, variable climate, recovery of vegetation after fire would have been slow. Therefore much of the widespread grassland and scrubland may have consisted of seral, fire-induced communities.

7. The spread of forest began about 14 000 BP but did not begin at the same time nor proceed at the same rate in every district. Forest first appeared on the Volcanic Plateau: by 12 000 BP Taranaki, Waikato and Hauraki Plains all had podocarp-hardwood forest. Hawkes Bay seems not to have had forest until about 10 000 BP, and other eastern districts may have had a similar delay. Everywhere *Podocarpus spicatus* was the dominant forest tree in these early Aranuiian forests. *Libocedrus* and *Nothofagus menziesii* were important constituents of these forests in some areas.

The main climatic factor that led to the rapid replacement of the late Otiran grassland and scrub by forest was an increase in rainfall, although milder temperatures must have also played a role.

8. At, or just before 10 000 BP there was a major transformation of the early Aranuiian forests. *Dacrydium cupressinum* rose to dominance in those areas where it was not already the major podocarp tree species, and *Ascarina lucida* and *Dodonaea viscosa* became abundant. Of the sites examined, only Poukawa in Hawkes Bay retained *P. spicatus* dominant forest.

This alteration in forest type is thought to be the result of an increase in rainfall and temperature, creating a mild, moist, frost and drought-free climate over most of the North Island.

9. From about 5000 BP on a series of changes set in that gradually altered the nature of the forest. *P. spicatus* became more common in some areas and *Ascarina* and *Dodonaea* were almost eliminated in regions where hitherto they had been extremely common. These changes are attributed to a gradual deterioration of the climate, with rainfall becoming less regular and frost more common, as temperatures fell from their mid Aranuian maximum.

There were some changes in forest composition that are yet to be satisfactorily explained. Among them are the spread and sudden demise of *Dacrydium colensoi* and the upsurge of *Knightia excelsa*.

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APPENDIX

POLLEN ANALYSIS OF THE KOPUTAROA DUNE SAND PEAT

<u>POLLEN TYPE</u>	L2816	L2817	L2815
<i>Nothofagus fusca</i> type	26	22	20
<i>N. menziesii</i>	2	2	3
<i>Dacrydium cupressinum</i>	2	tr	1
<i>Podocarpus</i>	6	4	8
<i>Dacrydium colensoi</i>	-	tr	tr
<i>Dacrycarpus</i>	-	-	tr
<i>Metrosideros</i>	1	-	-
<i>Hoheria</i>	-	tr	tr
<i>Pseudowintera</i>	-	-	x
<i>Phyllocladus</i>	tr	tr	tr
<i>Dacrydium bidwillii/biforme</i> type	26	19	17
<i>Leptospermum</i>	6	13	tr
<i>Aristotelia</i>	-	tr	-
Araliaceae	tr	-	-
<i>Dracophyllum</i>	2	1	3
<i>Myrsine</i>	4	8	9
<i>Coprosma</i>	8	9	10
Compositae	10	10	17
<i>Hebe</i>	tr	-	1
<i>Coriaria</i>	-	tr	-
Gramineae	2	7	6
Cruciferae	-	tr	tr
<i>Haloragis</i>	2	1	3
<i>Gunnera</i>	-	-	tr
Umbelliferae	tr	-	tr

APPENDIX (cont'd)

<u>POLLEN TYPE</u>	L2816	L2817	L2815
<i>Gentiana</i>	x	-	x
Ranunculaceae	-	-	tr
Cyperaceae	1	3	3
<i>Calorophus</i>	tr	tr	1
<i>Gleichenia</i>	very many	96	108
<i>Dicksonia squarrosa</i>	-	-	tr
<i>Pteridium</i>	-	tr	-
<i>Lycopodium volubile</i>	9	2	-
<i>L. scariosum</i>	19	15	11
monoletate fern spores	8	10	9
unidentified tricolpate	2	tr	tr
Pollen sum	379	448	504

These results have been recalculated from McIntyre's original counting sheets. A pollen sum of total woody plants plus herbs, but excluding all spores and mire-dwelling plants, has been used. *Paesia scaberula* was recorded in the original paper on the pollen analysis of the Koputaroa Dune Sand peat McIntyre (1963), but was not recorded on the counting sheets.

The date for the Koputaroa peat is: 35 000 ± 1700 yr BP (NZ522).

Data from the sheets was provided by D.C. Mildenhall, Geological Survey.

Plate 2
MANGAHUME, Taranaki

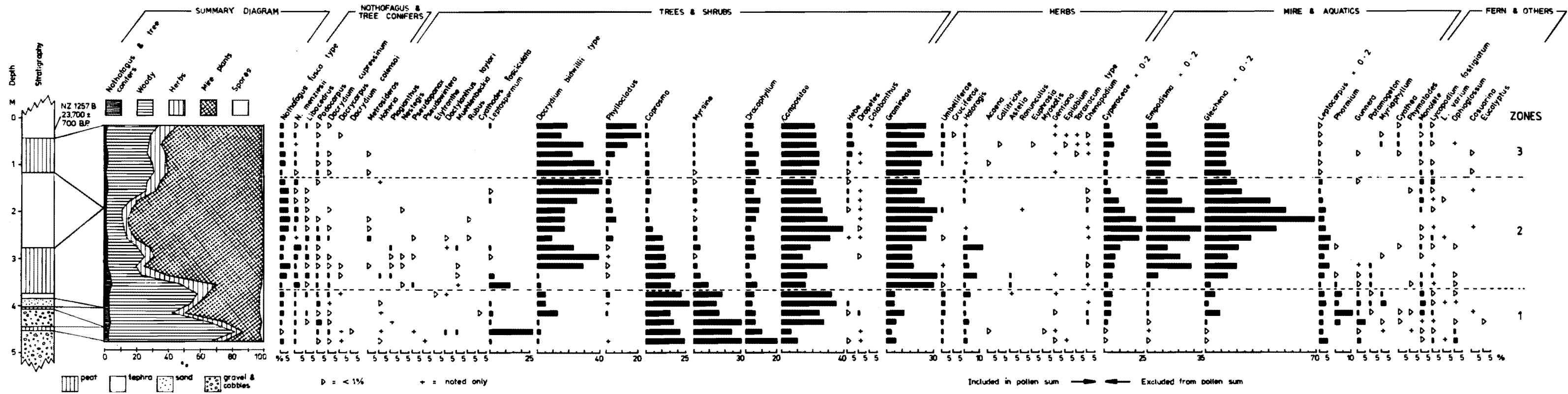


Plate 3
STENT ROAD, Taranaki

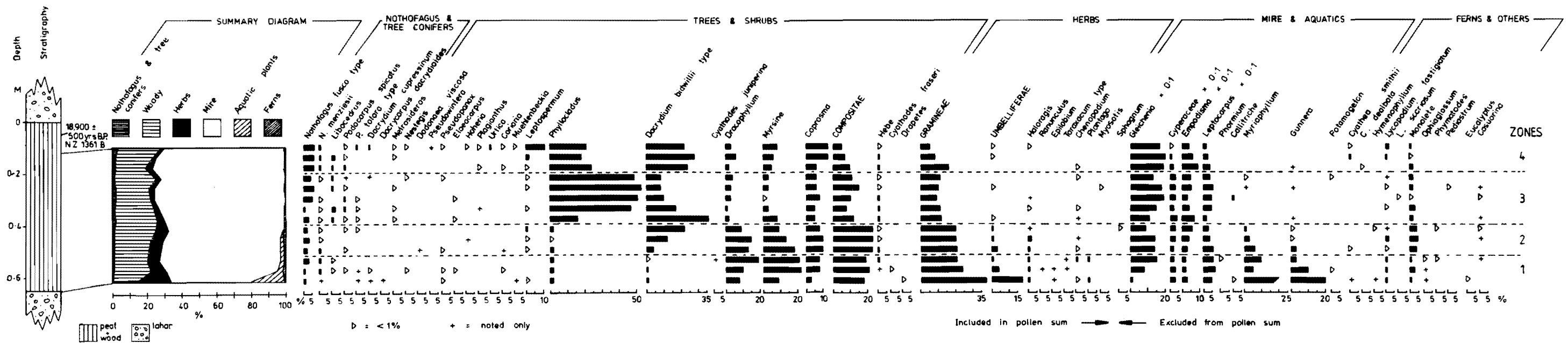


Plate 7
HUKAPAPA, S.W. Taupo

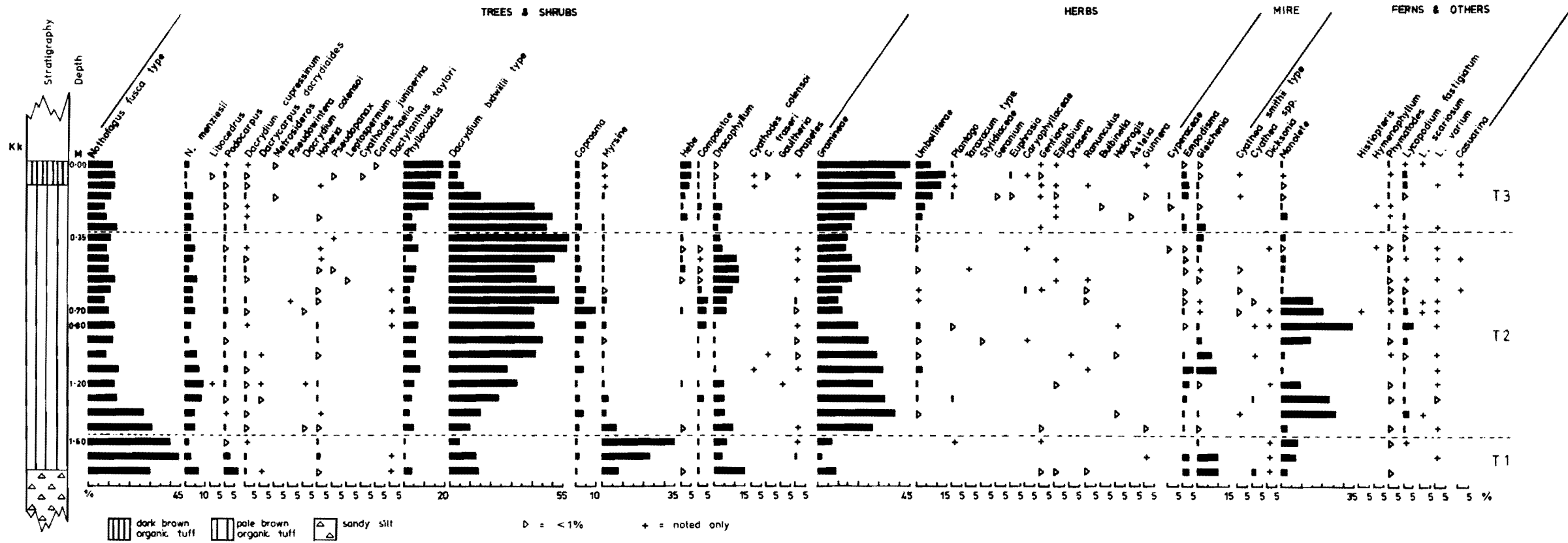


Plate 8
MOERANGI, S.W. Taupo

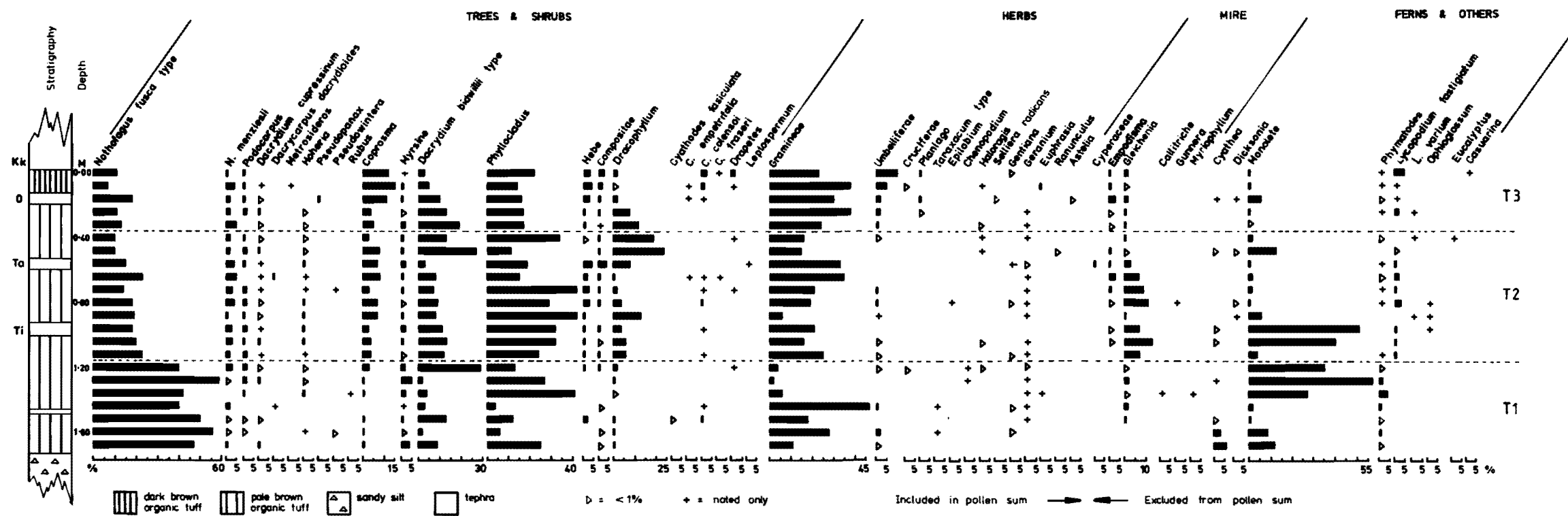


Plate 10
HIRATA, S.W. Taupo

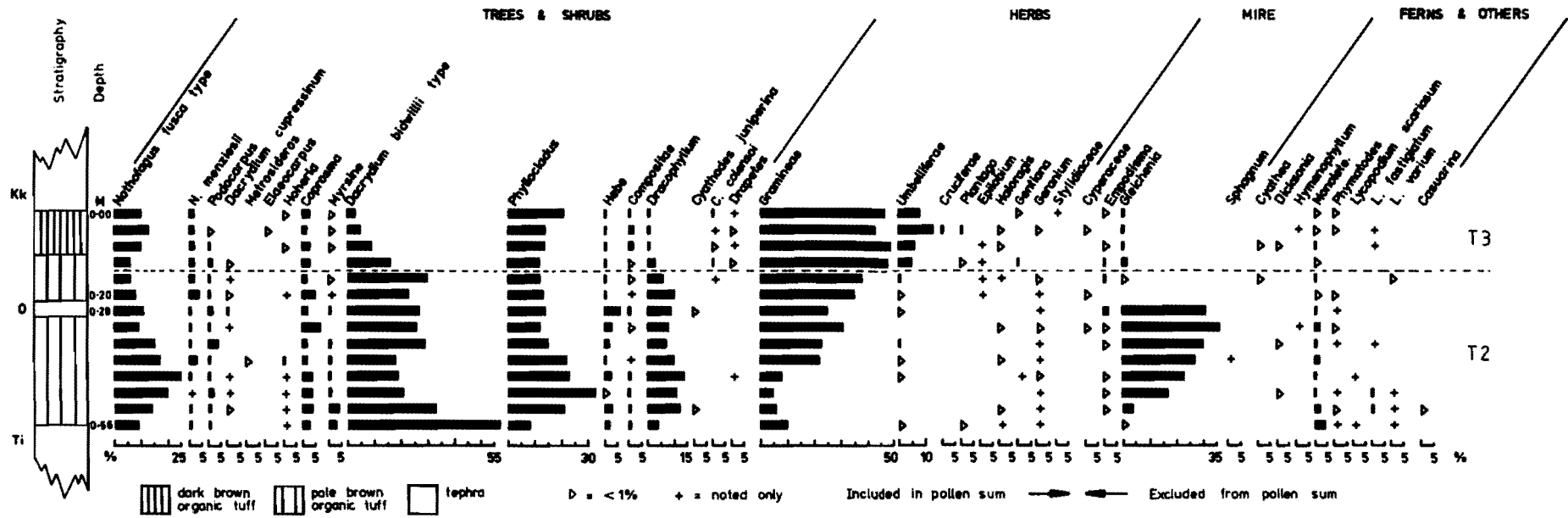


Plate 11
TAUREWA, S.W. Taupo

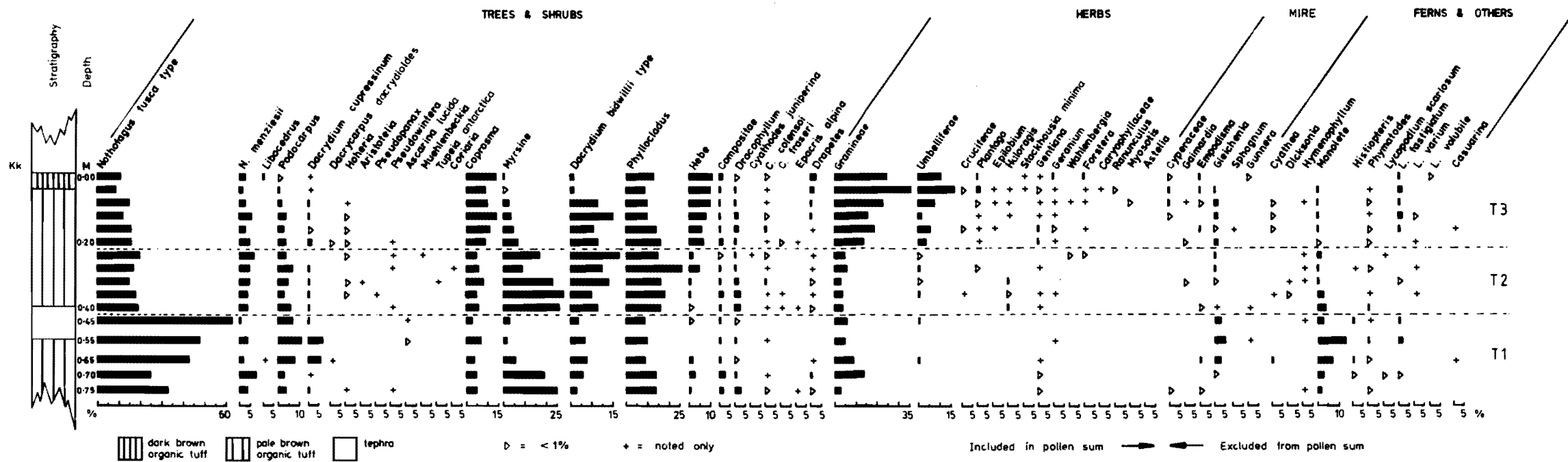
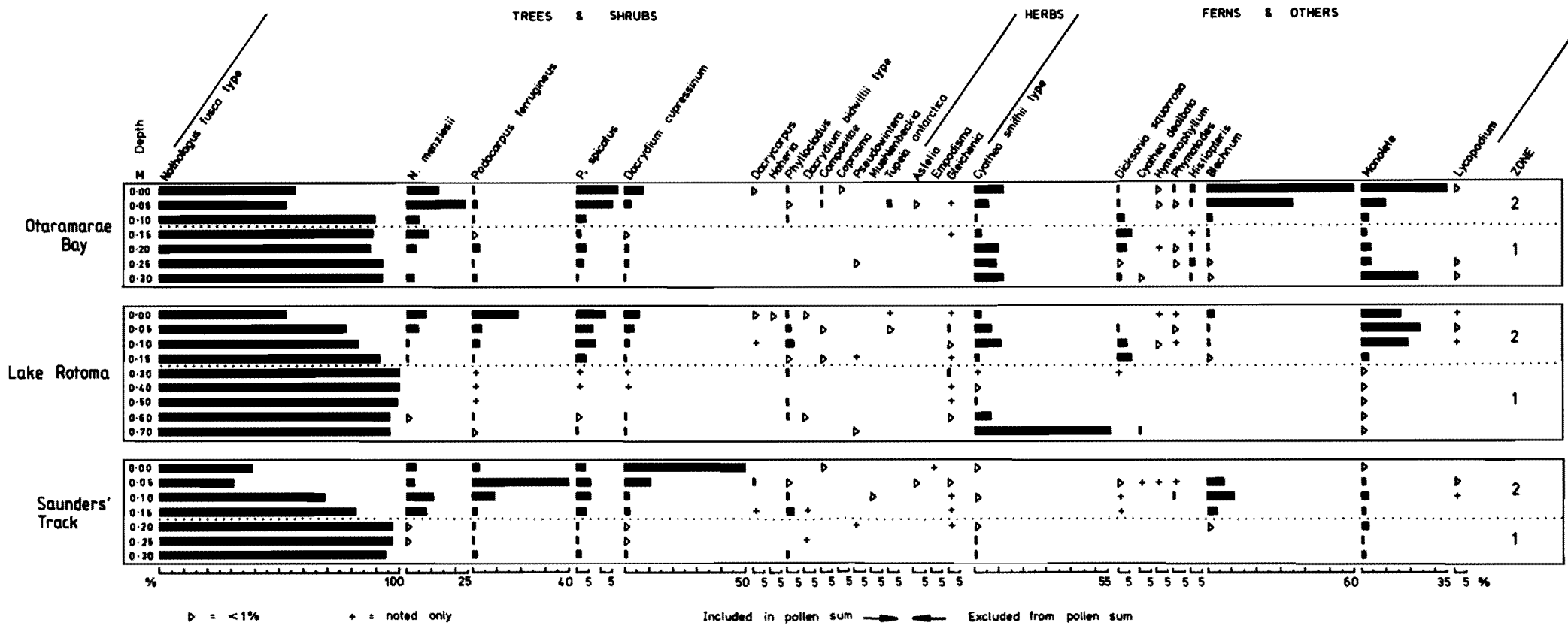


Plate 12
 PRE-ROTOEHU ASH PALEOSOLS, Bay of Plenty



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Forest Destruction by Early Polynesians, Lake Poukawa, Hawkes Bay, New Zealand

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Abstract

Pollen analysis of two sites in the swamps around Lake Poukawa shows that deforestation began just before 1 000 yr BP. Charcoal fragments found in the swamp sediments indicate that deforestation was caused by fires which probably resulted from Polynesian settlement.

INTRODUCTION

Polynesian settlement had a profound effect on the vegetation of New Zealand. Early European records testify to the vast amount of forest destruction which had occurred before the milling and burning of historical times (Cameron 1964). Ages of wood charcoal found in soils of the South Island (Molloy *et al.* 1963) show that there were widespread fires from *c.* 1 000 yr BP onwards, a date that is similar to those derived for the earliest undoubted Polynesian occupation sites (Moore and Tiller 1975). Although much forest destruction also occurred in the North Island, there is very little evidence as to when it began.

In this paper I present dated pollen diagrams from Lake Poukawa, extending from approximately 2 000 yr BP to the time of European settlement, and record the deforestation of that region.

POUKAWA DEPRESSION

Poukawa Depression (Fig. 1) is bordered by two, low (average height 250-300 m) limestone ranges, Raukawa to the west and Kaokaoroa to the east. Lake Poukawa (21 m a.s.l.) lies at the southern end of the depression and is surrounded by extensive peat swamps, now mostly drained and in pasture. Most streams in the depression flow into the lake, which is drained by the Poukawa Stream flowing north to the Heretaunga Plains. Lake levels vary greatly; in some summer seasons the lake dries out entirely, whereas in others it remains full or, as in 1976, covers much of the surrounding farm land.

VEGETATION AT THE TIME OF EUROPEAN SETTLEMENT

Early European accounts of the 1840s and 1850s (see Wilson 1939, 1951, and Elder 1949) emphasise the lack of forest cover in lowland Hawkes Bay. Much of the low-lying country was occupied by extensive swamps, mostly dominated by raupo (*Typha orientalis*), flax (*Phormium tenax*), and toe-toe (*Cortaderia* spp.). The hills were mainly covered with bracken (*Pteridium esculentum*) and varied scrub, commonly including tutu (*Coriaria* spp.). On the steeper ranges, in the foothills of the Ruahine Ranges, and to the south, large areas of dense forest remained. These forests had dense stands of matai (*Podocarpus spicatus*), totara (*Podocarpus totara*), and on poorly drained

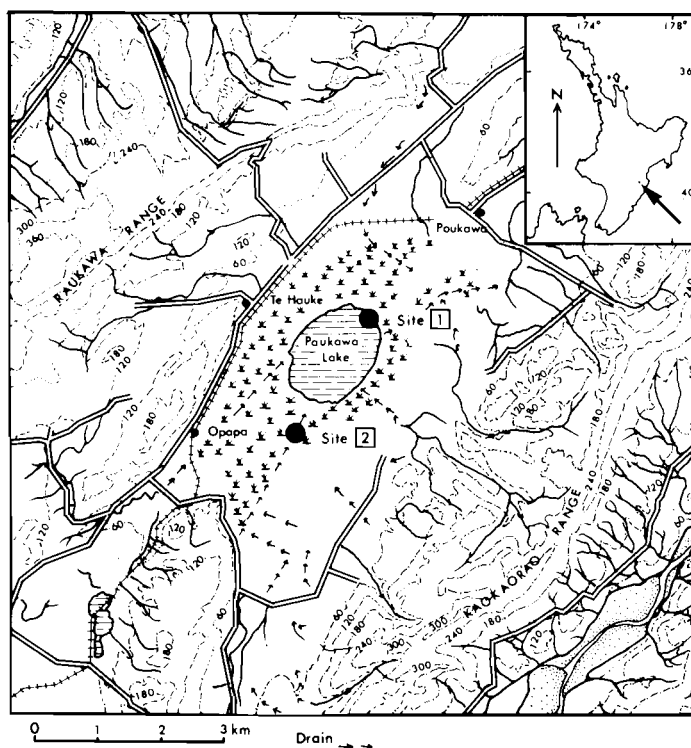


FIG. 1 — Locality map of the Poukawa Depression. Solid circles show positions of sites 1 and 2.

ground and swamp margins, kahikatea (*Dacrycarpus dacrydiodes*). Beech forest (*Nothofagus* spp.) was absent from most lowland areas, and rimu (*Dacrydium cupressinum*) occurred only inland towards the Ruahine Range and south towards Dannevirke (Franklin 1968). Many hardwood trees must have been associated with the podocarp forests, but they are generally unrecorded.

Poukawa Depression contained most of the elements of the regional vegetation. Dense raupo and flax communities occupied low-lying areas, and only since recent drainage and cultivation of the swamp has raupo become restricted to its present narrow fringe about the lake. Accounts of the various sheep and cattle stations taken up in the area in the 1850s (*see* MacGregor 1970) indicate that the country to the east and north of the depression was covered with scrub and fern, while Raukawa Range was partly covered with forest. Te Aute and the surrounding area to the south had extensive stands of matai, totara and kahikatea.

Settlement of Hawkes Bay by Europeans was not on a large scale until the 1850s, although whalers and traders operated along the coast throughout the 1840s. Evidently the Maoris adopted European-style agriculture early on, since by the mid-1840s large quantities of maize and wheat were being exported (Wilson 1939). European settlement resulted in the rapid conversion of forest, scrub and fern to grassland. Forest was milled and burnt, while scrub and fern were eliminated by burning and grazing. Present-day vegetation of central Hawkes Bay is almost entirely grassland; only very small remnants of the pre-European vegetation remain.

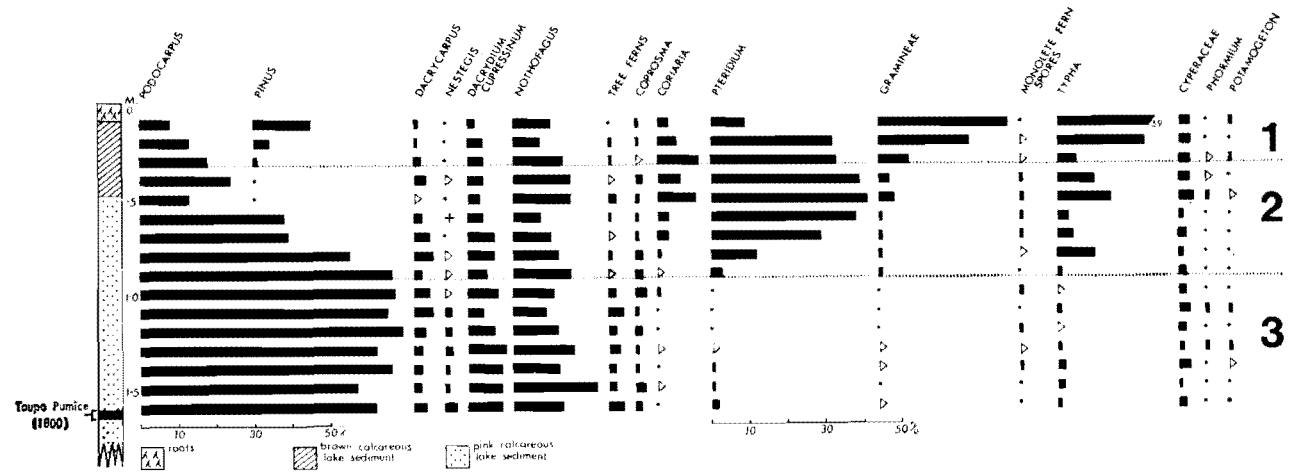


FIG. 2. — Pollen Diagram Site 1. Triangles represent percentages less than 1%, crosses indicate that pollen type was recorded after completion of count, and dots indicate pollen type was not recorded.

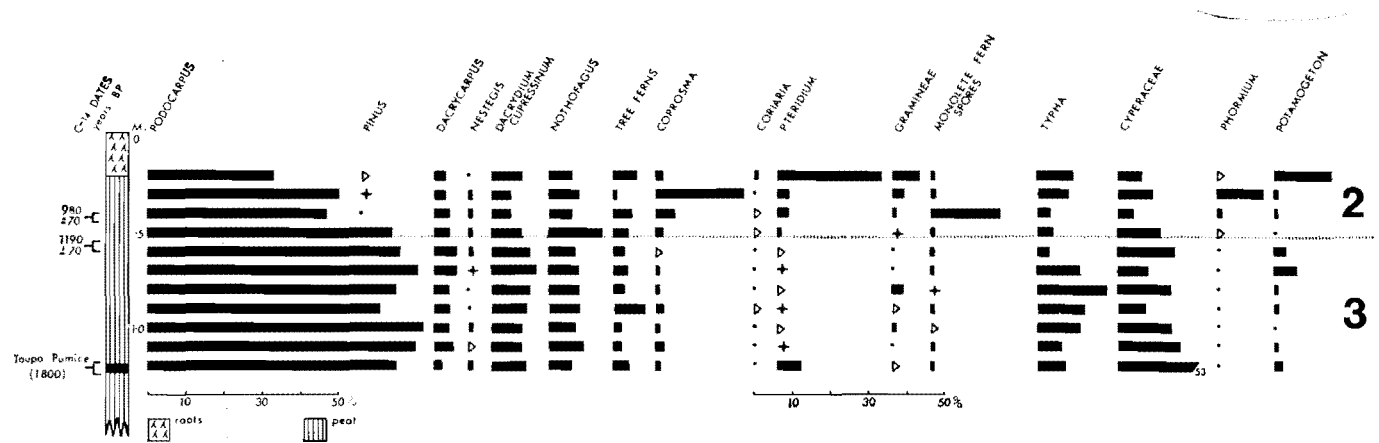


FIG. 3. — Pollen Diagram Site 2. Symbols as in Fig. 1.

SITES AND METHODS

Two sites have been pollen-analysed within the Poukawa Depression (see Fig. 1). There is a considerable depth of lake and organic sediments (up to *c.* 10 m) in the depression, and several tephras erupted from the central North Island are preserved in them. For the purpose of this paper, only sediments above the Taupo Pumice (*c.* 1800 yr BP) are considered.

Site 1 (Grid. Ref. (N.Z.M.S. 1) N141/133047; Fig. 2). This site is in the marginal raupo zone at the northern end of Lake Poukawa, some 50 m off shore. At the sampling site the water depth was about 0.5 m.

Stratigraphy

Depth (m)	Sediment type
0.00-0.10	raupo roots
0.10-0.50	pale brown calcareous lake sediment with frequent mollusc shells
0.50-1.60	pale pink calcareous lake sediment with abundant mollusc shells
1.60-1.63	coarse pumice layer (Taupo Pumice)

Site 2 (Grid Ref. (N.Z.M.S. 1) N141/119028; Fig. 3). This site is at the southern end of Lake Poukawa, approximately 500 m from the lake edge, in reclaimed swamp land. Drainage of the peat has caused the surface to sink, and cultivation and stock trampling have destroyed the upper layers. From accumulation rates, based on dated tephra layers deeper in the peat, it appears that over a metre of peat has been lost.

Stratigraphy

Depth (m)	Sediment type
0.00-0.12	grass roots
0.12-0.20	structureless grey peat with frequent roots
0.20-1.23	dark brown fibrous peat
1.23-1.27	coarse pumice layer (Taupo Pumice)

Samples for pollen analysis and radiocarbon dating were taken with a hand-operated borer.

Preparation of samples for pollen analysis was by treatment with potassium hydroxide, hydrofluoric acid, acetolysis mixture, and bleach (Faegri and Iversen 1964). Pollen preservation was excellent in the lake sediments but poor in the peat.

The percentages in the pollen diagrams are based on a pollen sum which includes all terrestrial pollen types and excludes those pollen types derived from swamp and aquatic plants. Only the more significant pollen types are shown in the diagrams.

CHRONOLOGY

Relevant radiocarbon dates are listed below. All dates are based on a half-life of 5 730 years.

On the basis of these dates, the age of the Zone 2/Zone 3 boundary (beginning of forest destruction) is approximately 1 090 \pm 70 yr BP.

Horizon	Date (yr BP)	Radiocarbon Number
Site 2, 0.40-0.45 m	980 \pm 70	NZ 4163B
Site 2, 0.55-0.60 m	1 190 \pm 70	NZ 4162B
Taupo Pumice	1 824 \pm 24	(see Healy 1964)

THE POLLEN DIAGRAMS

Although pollen percentages of sedges (Cyperaceae), *Potamogeton* and raupo are generally higher in the swamp than the lake, the pollen diagrams are very similar and the differences between them can be explained in terms of differing depositional environments.

The lake diagram (Site 1) can be divided into three clearly-defined zones.

Zone 1: European agriculture.

Zone 2: Forest destruction.

Zone 3: Undisturbed forest.

The swamp diagram (Site 2) has Zone 3 and part of Zone 2, but Zone 1 appears to have been destroyed.

Zone 3. Undisturbed Forest

(Site 1: 1.60-0.90 m; Site 2: 1.23-0.50 m).

This zone is dominated by *Podocarpus* pollen, mainly matai but with a sizable proportion (usually *c.* 10%) of totara-type. Rimu, beech, kahikatea and maire (*Nestegis* spp.) are also common. Tree ferns (mainly *Cyathea dealbata* and *C. smithii*) average *c.* 4%. Many other species were recorded, although they do not contribute much pollen. Among them are titoki (*Alectryon excelsus*), broadleaf (*Griselinia*), putaputaweta (*Carpodetus serratus*), lacebark (*Hoheria* spp.), horopito (*Pseudowintera* spp.), milk-tree (*Paratrophis* spp.), wineberry (*Aristotelia* cf. *serrata*), bush lawyer (*Rubus* spp.), New Zealand passionfruit (*Tetrapathaea tetrandra*) and *Muehlenbeckia* sp. This assemblage suggests that the Poukawa region was completely covered with a dense, diverse podocarp-hardwood forest typical of present-day lowland forest in the east of the North Island. Rimu and beech have not been recorded from the Poukawa region, and their relatively high pollen levels came from forests nearer the Ruahine Ranges or even further afield.

Zone 2: Forest Destruction

(Site 1: 0.90-0.30 m; Site 2: 0.50-0.20? m).

At the beginning of Zone 2 three significant changes occur; the percentage of *Podocarpus* pollen falls steadily; there is a corresponding increase in the percentage of non-arboreal pollen, mainly bracken and scrub; and microscopic fragments of charcoal, only occasionally encountered in Zone 1, become increasingly common. These events resulted from burning of the forest and its replacement by bracken and scrub communities. Deforestation was not the result of one devastating fire but a gradual process, as the steady decline of the podocarp percentages testifies.

A significant difference between the two pollen diagrams is that the major scrub type at Site 2 was *Coprosma* while at Site 1 it was *Coriaria*. This difference is somewhat surprising as the sites are so close together, but it probably reflects local responses to deforestation.

A striking feature of Site 1 is the increase of raupo, suggesting either that the lake became shallower or that nutrients released from the surrounding hills by deforestation stimulated the growth of raupo.

Zone 1: European Agriculture

(Site 1 only: 0.30-0.00 m).

Zone 1 is characterised by rising levels of pine (*Pinus* spp.), willow (*Salix*), and grass (Gramineae), and a decrease in the percentages of bracken and scrub. European weeds make an appearance, including plantain (*Plantago*), sorrel (*Rumex*), and thistle (*Cirsium* group). There is also a further increase in the amount of charcoal. These changes reflect the conversion of the surrounding hills to grassland, planting of pine shelter breaks, and the establishment of willows along stream banks. Elimination of bracken required yearly burning, which accounts for the increase in charcoal.

CAUSE OF DEFORESTATION

Although Hawkes Bay is subjected to regular droughts (de Lisle 1971) and annual average rainfall in the Poukawa region is not high (760-1 000 mm),

the progressive reduction in forest and its replacement by bracken and scrub requires a far higher frequency of fires than is likely from natural causes. Pollen analysis of the underlying 8 m of peat at Site 2 has revealed no deforestation nor any charcoal levels comparable to those of Zones 1 and 2.

Burning by early Polynesian settlers is the most likely explanation for deforestation. Some clearance of forest near settlements for cultivation of crops would be expected, but the burning of vast areas of Hawkes Bay was probably to encourage the growth of bracken. Bracken root (*aruhe*) was a staple in the diet of the Maori. Even in areas where kumara and taro were grown, bracken root was a prominent food item, especially in times of food shortage (Shawcross 1967). The extensive fernlands of Hawkes Bay may appear to have been more than sufficient for the local populations, but only a relatively few sites which had a deep, light soil produced a useable root (Colenso 1880). No doubt a considerable amount of forest destruction was an accidental by-product of cultivation of bracken.

The Polynesians had cleared most of central Hawkes Bay by the 1840s. Subsequent European occupation simply continued the process.

AGE OF POLYNESIAN SETTLEMENT

The beginning of forest destruction gives a rough estimate for the arrival of man, bearing in mind that Polynesians may have been in the Poukawa region for a considerable time before deforestation was sufficiently advanced to be registered in the swamp. On the basis of the uncorrected radiocarbon dates, man entered the Poukawa area some time before $1\ 086 \pm 70$ yr BP. With secular correction (which cannot be precise in this case because of the relative thickness of the peat slices dated) the date is reduced to $1\ 030 \pm 60$ yr BP or possibly as recent as *c.* 920 A.D. Thus the date for forest destruction (using \pm two standard errors) lies between 910 and 1 150 yr BP, and a best estimate for the arrival of man in the Poukawa region would be some time before 1 000 yr BP or in the early decades of the tenth century.

The oldest dated archaeological material from Hawkes Bay, a pit post at Te Awanga Pa, has an age of $1\ 020 \pm 90$ yr BP (Fox 1974). From this an estimate of 1050 A.D. for the earliest recorded occupation of Te Awanga has been derived.

Price (1963, 1965) claimed to have found traces of human occupation in the form of worked timber, bird bones and midden deposits beneath the Taupo Pumice (*c.* 1 800 yr BP) and the Waimihia Lapilli (*c.* 3 400 yr BP) at an archaeological site in the swamp to the north of Lake Poukawa. Subsequent work (Pullar 1970), confirmed the identity of the volcanic ash layers and suggested that artefacts found below the Waimihia Lapilli would be *in situ*.

This suggestion that man has been in the Hawkes Bay region for over three thousand years is not supported by the results of this study. It seems most unlikely that man could have existed for two thousand years prior to 1 000 yr BP, in a dry, somewhat drought-prone region, without detectable influence on the vegetation as indicated by the pollen record. However, this is negative evidence only, and confirmation or rebuttal of Price's claims can only come from further examination of the archaeological site.

ACKNOWLEDGMENTS

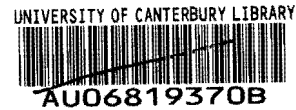
The work reported here forms part of a continuing project on the Quaternary history of Lake Poukawa, organised by the Geology Department, Victoria University of Wellington, and supported by U.G.C. Grant 74/73. Members of the Victoria University Geological Society gave assistance in the field. Dr R. Howorth, Dr P. Wardle and Dr C. J. Webb suggested improvements to the manuscript. Juliet Shand drafted the figures.

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Aranuian (post-glacial) pollen diagrams from the Tongariro region,
North Island, New Zealand



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ABSTRACT

Retreat of glaciers on the Tongariro Volcanoes began before 14 000 yr B.P. By 14 000 yr B.P., podocarp-hardwood forest had begun replacing the previous scrub and grassland communities. We recognise three major post-glacial pollen zones.

(i) 14 000-10 000 yr B.P. *Podocarpus spicatus* forest was dominant. Annual temperatures may have been only 2-3°C lower than present, but the climate was substantially drier.

(ii) 10 000-5 000 yr B.P. *Dacrydium cupressinum* forest was dominant and the climate much wetter and milder than present.

(iii) 5 000 yr B.P.-present. Return of *Podocarpus spicatus*-dominant forest, increase of *Nothofagus*, and a general trend away from the mild climates of (ii) to a more drought- and frost-prone climate.

The present pattern of *Nothofagus* forest on the Volcanic Plateau originated during the last glacial maximum when forest was confined to small relict areas. The development of milder climates, and the post-glacial expansion of podocarp-hardwood forests kept the *Nothofagus* forest confined to small, scattered localities. Only in the last 5 000 years has there been significant expansion of *Nothofagus* forest, but the large rhyolitic eruptions of the last 3 500 years have tended to delay this spread.

INTRODUCTION

Recent work on tephra deposits has established a detailed tephrochronology for the central North Island (Pullar *et al.* 1973, Vucetich & Pullar 1973). This chronology is proving invaluable to many other workers because tephra deposits are ideal for the dating and correlation of events over wide areas.

The Tongariro region has many exposures of tephra sections, some of which also contain peats and organic silts. A tephrochronology is now available for the andesitic tephtras of the Tongariro Volcanic Centre (Topping 1973), and also for interbedded tephtras of the more widespread rhyolites (Topping & Kohn 1973). The present paper results from the pollen analysis of some sediments associated with those tephtras.

The last Quaternary stage in New Zealand, the Aranuan, began with the beginning of ice retreat

from the Poulter glacial advance c. 14 000 years ago. Aranuan is used here in place of "Post-glacial" or "Holocene", although the general term "post-glacial" is retained for informal use.

Tongariro environment

Climate

The Tongariro region has a cool-temperate climate with an annual average temperature at 600 m of c. 10°C (de Lisle 1962). Frosts are common in winter and snow falls frequently although it does not lie on the ground for more than a few days at a time. Annual rainfall is generally in the 1 800-2 500 mm range, distributed throughout the year, but with a winter maximum. Water deficits occur in summer, although drought is rare. Weather patterns over the central North Island are strongly influenced by the regular passage of cyclonic depressions from the

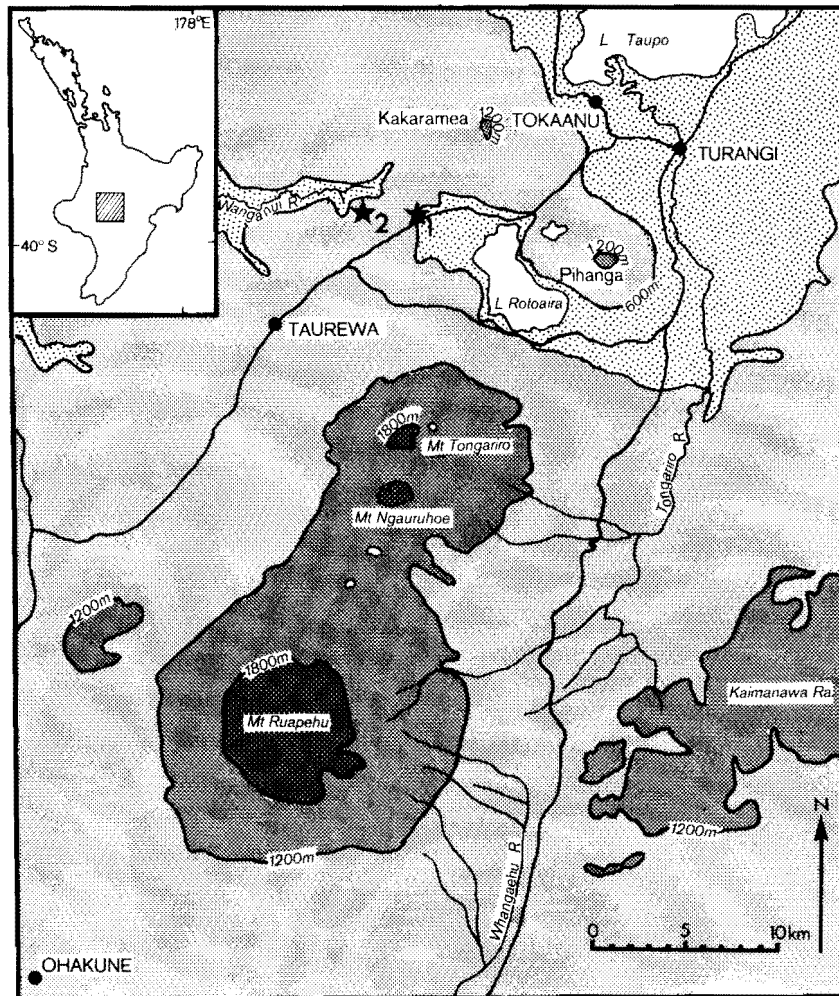


Fig. 1 Tongariro region showing locality of Sites 1 and 2. Inset: North Island, New Zealand; study area hatched.

west and north-west, and most rain is associated with winds from these directions. The Tongariro Volcanoes are sufficiently high to cause a rainshadow effect, with annual precipitation rising higher than 3 500 mm on their western flanks, but with much reduced levels (1 200 mm or less) to the south-east.

Geology

The Tongariro Volcanoes, lying at the southern end of the north-east striking Taupo Volcanic zone, dominate the study area (see Fig. 1). There are five major volcanoes — Mts Ruapehu (2 797 m), Tongariro (1 968 m), Ngauruhoe (2 291 m), Kakaramea (1 300 m), and Pihanga (1 325 m) — all of which are andesitic. Ruapehu and Ngauruhoe are active and Tongariro has erupted in the historic past. Kakaramea and Pihanga are not active. Tongariro and Ruapehu have built up extensive ring plains of lahar debris,

lava, and tephra; formerly ring plains also surrounded Kakaramea, but these have since been eroded, leaving only small remnants. Volcanism in the Tongariro area dates only from the early Quaternary, and Tertiary mudstones, sandstones, and limestones underlie the whole region. The Kaimanawa Range and Mt Taurewa are formed of Jurassic-Permian indurated greywackes.

Except for those areas that have been eroded there is a blanket of tephra over the Tongariro region which can be up to several metres thick. The tephra referred to here are listed in Table 1. Formation member (if applicable), and radiocarbon age are given for each tephra. Data in the table are from Pullar *et al.* (1973), Vucetich & Howorth (1976), and Topping & Kohn (1973).

Present vegetation of the Tongariro region

In pre-Polynesian time nearly all the central

Table 1 Tephtras of the Tongariro region.

Tephtra	¹⁴ C age	New Zealand radiocarbon no.
Taupo Pumice	1 824 ± 24	a
Waimihia Lapilli	3 540 ± 90	NZ 505B
Mangamate Tephtra	10 020	b
Rotorua Ash	(above) 10 000 ± 200	NZ 1372B
	(below) 12 700 ± 250	NZ 1187B
Rotoaira Lapilli	13 550 ± 350	NZ 1186B
Rerewhakaaitu Ash	14 200 ± 300	NZ 1559B
Kawakawa Tephtra	15 150 ± 250	NZ 716B
	20 400 ± 400	NZ 1056B

a = average of many dates (Healy 1964).

b = inferred date.

North Island, with the exception of swamps and the limited areas above timber line, was heavily forested. Since then the forest has been greatly reduced in extent by burning and felling, and has been replaced by reduced or cultivated grassland, or exotic forest plantations. Most of the surviving natural forest cover in the Tongariro region lies in the cool-temperate or montane zone of Wardle (1964). Only on limited areas above 950 m does sub-alpine forest occur.

McKelvey (1963) has described the forest associations of the Volcanic Plateau in some detail. Podocarp-hardwood associations are the basic forest cover of the montane zone, *Podocarpus spicatus* and *Dacrydium cupressinum* being the commonest large podocarp trees, with *Podocarpus ferrugineus* less frequent. These trees reach a maximum altitude of 950 m on the Volcanic Plateau, and this altitude may be taken as the boundary between montane and sub-alpine forest. On the thick, recent deposits of Taupo Pumice podocarp trees can form a very dense canopy over a well developed hardwood subcanopy. Elsewhere the podocarps tend to stand as individual emergents, or in scattered groups, over a canopy of hardwood tree species of which the commonest are *Weinmannia racemosa*, *Beilschmiedia tawa*, *Nestegis*, *Eleocarpus lentatus*, and *Eleocarpus hookerianus*. Associated with these, but seldom achieving heights of more than 10 m, are shrubs and small trees, the most prominent genera being: *Aristolelia*, *Brachyglottis*, *Carpodetus*, *Coprosma*, *Fuchsia*, *Griselinia*, *Hedycarya*, *Meliclytus*, *Myrsine*, *Olearia*, *Pennantia*, *Pittosporum*, *Pseudopanax*, *Pseudowintera*, and *Quintinia*. Generally the forest contains many lianes and epiphytes, and numerous tree ferns of the genera *Cyathea* and *Dicksonia*. *Metrosideros robusta* is a common emergent tree where there is little or no pumice cover.

In wetter areas *Dacrydium dacrydioides* forms a dense swamp forest. On soils with impeded drainage *Libocedrus bidwillii* tends to enter the forest, but only occasionally forms a pure association. On very boggy or semi-swamp soils *Dacrydium colensoi*, *Dacrydium*

bidwillii, and *Phyllocladus alpinus* may form open scrub or low forest. True mires are dominated by various sedges, *Calorophus*, or the fern *Gleichenia*.

In the southern and central North Island, sub-alpine forest is usually dominated by species of *Nothofagus*. *Nothofagus* forest, however, is of restricted occurrence on the Volcanic Plateau, and so the sub-alpine zone tends to have dense associations of hardwood trees, especially *Weinmannia racemosa* with some *Podocarpus hallii* interspersed. *Nothofagus* forest dominates over limited areas of Ruapehu, the Kakaramea-Pihanga massif, and the Kaimanawa Range. The main species are *Nothofagus fusca* (present only in the lower half of the sub-alpine zone) and *Nothofagus menziesii*, and *Nothofagus solandri* var. *cliffortioides* which forms the timber line. On Ruapehu an admixture of *Libocedrus* with *Nothofagus* dominates the lower part of the zone, with *Nothofagus solandri* var. *cliffortioides* the sole tree species at the timber line. Commonly associated with *Nothofagus* forest are: *Griselinia*, *Pseudopanax*, *Coprosma*, *Cyathodes juniperina*, *Cyathodes fasciculata*, *Podocarpus hallii*, and the parasitic shrub *Elytranthe*. Tree ferns are absent from the sub-alpine zones.

The present climatic limit to tree growth on the Volcanic Plateau is at c. 1 500 m, but most timber lines in the region are actually lower, because of fire or browsing by mammals. At most intact timber lines there is a zone of dense scrub extending 30 m above the forest proper. Characteristic genera of this scrub are: *Phyllocladus*, *Dracophyllum*, *Dacrydium* (*D. bidwillii* and *D. bifforme*), *Olearia*, *Cassinia*, *Coprosma*, *Pseudowintera*, *Pseudopanax*, *Hebe*, and *Myrsine*. Ferns (mainly *Blechnum* and *Polystichum*) and various lycopods are associated with the scrub. A shrubland extends above the timber line scrub, giving way gradually to pure grassland, and then fellfield, with increasing altitude. Genera common in these communities are: *Epacris*, *Cyathodes*, *Gaultheria*, *Dacrydium* (*D. laxifolium*), *Podocarpus* (*P. nivalis*), *Dracophyllum*, *Hebe*, *Ranunculus*, *Gentiana*, *Dra-*

petes, *Euphrasia*, *Epilobium*, *Acaena*, *Plantago*, *Taraxacum*, and several genera of the families Cruciferae and Umbelliferae.

Disturbance to forest in the montane zone, such as by fire, will often result in a dense growth of *Leptospermum* scrub that will remain dominant for relatively long periods before being overtopped by re-invading forest. In areas of low fertility or repeated fires, *Pteridium* or tussock grassland may become established.

Pollen analytical sites

The sites are in a swampy, low-lying area to the north-west of Lake Rotoaira, which is (or was) drained by the headwaters of the Wanganui River (see Fig. 1). The lake is drained by the Poutu River, a tributary of the Tongariro River. There are recent faults downthrown towards the lake on both the eastern and the western sides, and the whole basin has been formed by subsidence (Gregg 1960). Recently work has been undertaken in the area, as part of a power generation scheme, to divert water from the headwaters of the Wanganui River into Lake Otamangakau and through to Lake Rotoaira. In the process two canals have been cut through the basin, providing sections of the swamp deposits.

Site 1. Wairehu (Grid ref. NZMS 1 N112:146983; c. 610 m; Fig. 2)

This section is in a road-cutting near the control gate on the Wairehu Canal c. 1 km west of the Te Punanga Road. The section consists of 4.07 m of silt, tephra, and woody peat resting on the Kawakawa Formation.

Site 2. Otamangakau Canal, east bank (Grid ref. NZMS 1 N112:107982; c. 600 m; Fig. 3).

This is a section exposed on the eastern bank of the Otamangakau Canal, and is nearly 4 km to the west of Site 1. As with Site 1 it consists of peat, with interbedded tephra, developed on reworked Kawakawa Tephra. However, it was a faster growing, less woody peat, and consequently there is more detail in its tephra stratigraphy. In particular the site contains many local andesitic tephra, not recorded in Site 1. This site could not be sampled beyond the beginning of Zone A4, because of the overburden deposited during construction of the canal.

METHODS

Sampling and preparation

Samples for pollen analysis were taken from freshly cleared faces of the cuttings. The sampling interval varied from 0.02 to 0.10 m, depending on the

nature of the sediment: the irregular sampling interval apparent in the pollen diagram for Site 2 (Fig. 3) is due to the much greater number of tephra layers.

Samples were prepared for pollen analysis by the standard method using hydrofluoric acid and acetylation (Faegri & Iversen 1964). In most cases treatment with bleach was also necessary.

Pollen diagrams

The pollen sum (from which the percentages in the pollen diagrams are calculated) includes all pollen counted, apart from taxa regarded as belonging primarily to the swamp-forming vegetation. Excluded therefore are: Cyperaceae, Restionaceae, *Phormium*, *Gunnera*, *Myriophyllum*, *Potamogeton*, and a spores. *Dacrydium colensoi* and *Leptospermum* are also excluded, even though they often occur in non-swamp situations, because it is clear that they grow on the swamp surface. The pollen sum was mostly 250–300 grains and never less than 200. After counts were made on slides they were scanned at low magnification for taxa not recorded in the initial count.

Several pollen taxa are described as "type". The species included in such taxa are:

Cyathea smithii type: *C. smithii*, *C. colensoi*.

Dacrydium bidwillii type: *D. bidwillii*, *D. bifurcatum*, *D. kirkii*.

Nothofagus fusca type: all *Nothofagus* spp. except *N. menziesii*.

Taraxacum type: all tribe Cichorieae.

Two ratios are presented in conjunction with the pollen diagrams. Firstly, the ratio between *Nothofagus fusca* type pollen and pollen of all other tree taxa. This is an attempt to assess the proportion of *Nothofagus* to other forest trees only, so that trends can be followed more easily. Secondly, the ratio between *Dacrydium cupressinum* pollen and pollen of other tree podocarp species (*Podocarpus spicatus*, *P. ferrugineus*, *P. totara*, and *P. hallii*). *Dacrydium cupressinum* differs from the other tree podocarps (excluding *Dacrydium*) by its tolerance of waterlogged soils and its intolerance of drought (Franklin 1968). Therefore, changes in the *Dacrydium cupressinum* ratio are likely to be correlated with changes in the frequency and intensity of drought.

Chronology

The same pollen zonation system is used for both Sites 1 and 2, and we assume that the zones are synchronous. Where tephra layers permit correlation this assumption appears to be justified.

Because both sites overlie reworked Kawakawa Tephra (c. 20 000 yr B.P.) they cannot be older than it. Because the Rerewhakaaitu Ash was not recorded from either site, Zone A1 probably did not begin by

fore 15 000 yr B.P. This leaves more than 5 000 years after the deposition of the Kawakawa Tephra without a sedimentary record, a gap due no doubt to the harsh climate. We have a date from Site 2 of 14 450 \pm 250 yr B.P. (NZ 1774B) for the beginning of Zone A2, and the zone is terminated by the Rotoaira Lapilli (14 200 yr B.P.). Sediment growth slowed after the deposition of the Rotoaira Lapilli and, on the basis of the known ages for the Rotorua Ash and Te Rato Lapilli, it averaged 0.63 mm/year at Site 2. Using this rate, the estimated age for the A3a/A3b boundary is c. 11 400 yr B.P., whereas the A3/A4 boundary is at c. 10 300 yr B.P. Peat growth at Site 1 was steady at c. 0.23 mm/year after the Te Rato Lapilli, and on this basis the date for the A4a/A4b boundary is c. 9 000 yr B.P. and Zone A5 began at c. 5 000 yr B.P. Because the peat profile is disturbed above the Taupo Pumice we cannot derive an age for the A5/A6 boundary, except to say that it was later than c. 1 800 yr B.P.

SITE 1. WAIREHU (Fig. 2)

Zone A1: 4.07–3.88 m 15 000?–14 500 yr B.P.

The sediment comprises silts and sand, mostly reworked Kawakawa Tephra, with a very low organic content. Very high levels of Cyperaceae are recorded, which together with the presence of *Gaimardia*, *Myriophyllum*, *Gunnera*, and *Haloragis* suggest a wet sedge swamp. Non-aboreal pollen forms 70–80% of the pollen sum, and shrubs dominate with *Dacrydium bidwillii* type, *Phyllocladus*, *Coprosma*, and Compositae well represented. Gramineae and Umbelliferae levels are high. *Nothofagus* (both *N. fusca* type and *N. menziesii*) dominates the arboreal pollen. There are only low levels of podocarp tree types.

The local vegetation was probably an open shrubland, an inference supported by the presence of *Plantago*, *Taraxacum* type, *Gentiana*, *Selliera radicans*, and Cruciferae, all of which are common in open environments. The nearest forest may have been scattered stands of *Nothofagus*.

Zone A2: 3.89–3.63 m 14 500–14 200 yr B.P.

Towards the top of Zone A1 Cyperaceae decreases sharply, *Gleichenia* increases markedly but the semi-aquatic taxa, such as *Myriophyllum*, decline. The swamp vegetation of Zone A1 gave way at this boundary to a peat bog community. Herb frequencies gradually reduce throughout the zone, from 23 to 3%; however, the variety of herb taxa is maintained. Shrub percentages also reduce, from c. 50 to 25%. Towards the upper boundary of the zone *Nothofagus menziesii* is nearly eliminated, and *N.*

fusca type and Gramineae drop to low levels. Throughout, the podocarp forest types (mainly *Podocarpus spicatus*) increase steadily from 24 to 64%, and *Dacrydium cupressinum*, although not abundant in absolute terms, has a sharp rise in its ratio. *Libocedrus* begins to make a significant contribution in the upper half of the zone, and so also do the tree fern genera *Dicksonia* and *Cyathea*. Some podocarp-hardwood taxa make their first appearance here, including *Metrosideros*, *Rubus*, *Aristolelia*, *Nestegis*, *Pseudowintera*, and *Tetrapathaea*.

Widespread forest cover was first established during this zone. The local forest was a *Libocedrus* dominated, podocarp-hardwood association. *Nothofagus* forest was nearly eliminated from the region, and probably became as scarce as it ever has been subsequently. Thick scrub may have covered large areas of the Rotoaira basin.

Zone A3: 3.64–3.20 m 14 200–10 300 yr B.P.

The sediment type changes to a grey-brown peat with a high tephra content.

Gleichenia maintains high levels, and *Calorophus* becomes abundant in the upper half of the zone. Scrub levels, mainly of *Dacrydium bidwillii* type, are steady, but *Phyllocladus* continues a downward trend begun in Zone A2. Herb taxa no longer contribute significantly to the pollen sum and, from the middle of the zone onwards, herbs, such as *Gentiana* and *Plantago*, occur only rarely. *Libocedrus* reaches its greatest values but decreases sharply at the upper zone boundary. The *Dacrydium cupressinum* ratio stabilises, and *Nothofagus fusca* type recovers slightly from its low level in Zone A2. *Cyathea* and *Dicksonia*, which increased steadily throughout Zone A2, continue at relatively high levels in this zone. *Ascarina*, *Dodonaea*, *Alectryon*, and *Carpodetus*, shrubs and trees characteristic of mild climates, make their first appearances.

The forest was still a podocarp-hardwood/*Libocedrus* association but was becoming, as suggested by the first appearance of *Ascarina*, etc., less montane in character.

Zone A4: 3.21–1.15 m 10 300–5 000 yr B.P.

Much wood was found in the peat. Four samples of wood from here, and Zone A5, are of *Dacrydium colensoi* (R. Patel, pers.comm.).

The *Dacrydium cupressinum* ratio and the curve for *Cyathea* and *Dicksonia* rise sharply at the A3/A4 boundary. *Ascarina* becomes more abundant, forming continuous percentages, and *Dodonaea* and *Alectryon* were consistently recorded. *Griselinia*, *Knightia*, *Weinmannia*, and *Cordyline australis* are first noted in this zone. *Dacrydium bidwillii* type declines to low levels

at the A3/A4 boundary, and *Phyllocladus*, already a minor element, becomes scarce. *Dacrydium colensoi* and *Leptospermum* become more abundant, replacing *Dacrydium bidwillii* type and *Phyllocladus* as the local bog vegetation.

Although the forest bore a strong resemblance to that found at present, the presence of *Dodonaea*, *Ascarina*, and the high *Dacrydium cupressinum* ratio makes it a distinctly different type. Although not lowland forest, it seems to have existed under milder conditions than occur at present.

Zone A4 has been subdivided into two subzones, A4(a) and A4(b), on the basis of marked changes in the peat bog vegetation.

Zone A4(a): 3.21–2.06 m 10 300–9 000 yr B.P.

This zone has a very high scrub component (c. 40%) which includes *Leptospermum*, *Coprosma*, *Myrsine*, and *Cyathodes juniperina*. The high scrub level, along with an increased herb percentage, was almost certainly due to the deposition of the Mangamate Formation on the peat surface, providing a solid surface for them to root in. *Sphagnum* was the main peat former on the new surface.

Zone A4(b): 2.07–1.15 m 9 000–5 000 yr B.P.

Scrub levels fall as the peat becomes thicker and the *Sphagnum* is replaced by *Gleichenia* and *Calorophus*.

Zone A5: 1.16–0.20 m 5 000–? yr B.P.

The *Dacrydium cupressinum* ratio falls steadily throughout the lower half of the zone, but recovers slightly between the Waimahia Lapilli and Taupo Pumice layers. *Ascarina* drops below 1% and *Dodonaea* and *Alectryon* become less frequent. The *Nothofagus fusca* type ratio increases and scrub and swamp tree species, such as *Dacrydium colensoi*, *Leptospermum*, and *Dacrydium bidwillii* type, become more abundant than previously.

During Zone A5 there was a change towards a forest more like that of the present.

Zone A6: 0.19–0.00 m (undated but later than 1 800 yr B.P.)

The peat above the Taupo Pumice is shallow and has been disturbed by grazing or drainage.

Gramineae and *Pteridium* are abundant, indicating an increase in open country. *Lycopodium* and *Leptospermum* reach very high levels immediately above the Taupo Pumice and may reflect the response of the local peat vegetation to the 0.30 m of tephra

deposited. The top three samples contain much introduced *Taraxacum* and also traces of introduced Papilionaceae.

The record preserved in this zone is most likely incomplete, and may only record the effects of burning by Polynesians, and European agriculture. Any earlier records may have been obliterated by reworking of pollen down the peat profile.

**SITE 2. OTAMANGAKAU CANAL,
EAST BANK (Fig. 3)**

Zone A1: 4.95–4.61 m 15 000?–14 500 yr B.P.

The sediment is a grey-brown peaty silt.

Gleichenia dominates the swamp vegetation. Initially high Gramineae percentages and *Nothofagus fusca* type ratios fall, whereas scrub taxa and podocarp trees increase. Plants of open environments, such as *Plantago*, *Drapetes*, and *Gentiana*, are consistently present.

As recorded at Site 1, the vegetation was open shrubland with *Nothofagus* the nearest forest type. Higher percentages of Gramineae are recorded in the basal sediments here than in Site 1, indicating that accumulation began somewhat earlier.

Zone A2: 4.62–3.72 m 14 500–14 200 yr B.P.

The sediment type changes to a fibrous peat.

Cyperaceae values increase at the beginning of Zone A2 whereas *Gleichenia* declines. Cyperaceae remains the dominant peat former for the rest of the profile. *Nothofagus fusca* type, *N. menziesii*, *Phyllocladus*, and *Dacrydium bidwillii* type percentages fall throughout the zone. Podocarp forest types, *Libocedrus*, and the *Dacrydium cupressinum* ratio rise steadily. *Ascarina*, *Dodonaea*, *Cordyline*, *Tetrapathea*, *Griselinia*, and *Dicksonia squarrosa* make an appearance. Taxa indicative of open environments decline in abundance towards the top of the zone.

During this zone the previous shrubland and *Nothofagus* communities were replaced by podocarp-hardwood/*Libocedrus* associations.

Zone A3: 3.73–1.32 m 14 200–10 300 yr B.P.

Libocedrus remains common, the *Dacrydium cupressinum* ratio more than doubles at Zone A2/A3 boundary but fluctuates only slightly from then. *Nothofagus fusca* type falls to its lowest levels at the beginning of the zone and *N. menziesii* is recorded only occasionally thereafter.

The forest was a podocarp-hardwood/*Libocedrus* association, as in the last zone, but probably existed under milder climatic conditions.

Two subzones, A3(a) and A3(b), are recognised.

Zone A3(a): 3.73–1.97 m 14 200–11 400 yr B.P.

Great fluctuations occur in the percentages of Cyperaceae, Gramineae, and *Dacrydium bidwillii* type. A negative correlation exists between the Cyperaceae curve on one hand and the *Dacrydium bidwillii* type and Gramineae curve on the other. Cyperaceae-dominated periods indicate wetter swamp conditions than those periods dominated by Gramineae and *Dacrydium bidwillii* type. It is likely that a major cause of these fluctuations was the deposition of tephra on the swamp, giving a temporarily firmer and drier surface. During this zone there are also marked changes in the percentages of forest taxa, and they are, in general, depressed below the levels applying at the end of Zone A2 and in Zone A3(b). Because there are no changes of consequence in the *Dacrydium cupressinum* ratio, nor in the curves for tree ferns, we can assume that these effects are due solely to fluctuations in the pollen production of the bog community, and not to forest destruction by tephra air-fall.

Zone A3(b): 1.98–1.32 m 11 400–10 300 yr B.P.

There are no great fluctuations of the local swamp flora as in Zone A3(a) and there are no thick interbedded tephra layers in the peat. At the beginning of the zone the *Dacrydium cupressinum* ratio reaches a peak, but declines towards the upper boundary. *Ascarina* occurs continuously, and *Dodonaea* becomes more common. *Phormium*, almost certainly *P. tenax*, is first recorded here, and is common thereafter.

Zone A4: Zone A4(a): 1.33 m–0.00 m 10 300 yr B.P.

At the beginning of the zone the *Dacrydium cupressinum* ratio rises sharply from 0.50 to 1.20, and the tree fern curve (*Cyathea* and *Dicksonia*) rises also, more than doubling in percentage. At the same time there is an increase in scrub, particularly Compositae and *Coprosma*, but not *Leptospermum* as in Site 1. There are associated rises also for Gramineae, Umbelliferae, Cyperaceae, and *Lycopodium*. *Libocedrus*, *Nothofagus menziesii*, *N. fusca* type, and *Dacrydium bidwillii* type fall to low levels at the A3/A4 boundary.

Two major influences were at work. The first was a continuing trend from a forest, somewhat montane in character, towards a more lowland type as emphasised by the severe reduction of *Libocedrus* and *Nothofagus menziesii*. The second is the devastation of the forest and swamp by the deposition of the Mangamate Formation. Besides promoting the

growth of scrub and herb communities on the swamp surface, it doubtless accelerated the existing process of change by destroying most of the older forest in the area.

DISCUSSION

Vegetation and climate

The sedimentary record in the Tongariro area between 20 000 and 14 300 yr B.P. is incomplete because of several erosion breaks. Surviving sediments include tephras, water-laid tephras, glacial deposits, and loess (Topping 1974). The loess beds are of limited distribution, thin (0.28–0.40 m), and interbedded with tephras older than the Rotoaira Lapilli and younger than the Kawakawa Tephra. Up to three loess beds can be recognised in any one section, separated by erosion breaks. These breaks are irregular and often lined with subangular to rounded cobbles from nearby lavas. Any conclusion as to the vegetation at that time must be speculative, because there are no plant fossils in the beds, but the vegetation cover was probably incomplete and allowed much surface run-off. During this same period Tongariro was extensively glaciated (Mathews 1967, Topping 1974). The oldest tephra found overlying glacial deposits on Tongariro is the Rerewhakaaitu Ash in the Mangatepopo Valley, and the Rotoaira Lapilli in the Mangahouhounui Valley. Glacial retreat was therefore underway by 14 200 yr B.P. and maybe before. As we have pointed out (McGlone & Topping 1973), the Rotoaira Lapilli is the first tephra layer in the region to be concordant with the present-day surface, and no significant erosion has occurred since its deposition.

The climate between 20 000 and 14 000 yr B.P. was harsh; certainly cold and possibly dry. Temperatures cannot have fallen too far, because *Nothofagus* forest persisted in relict stands on the Volcanic Plateau throughout this period. A 6°C fall in annual temperature, as suggested by Willett (1950) and Gage (1965), is as low as is consistent with the survival of *Nothofagus* at such altitudes.

Zone A1 is very much a transitional period from the presumably open scrub/grassland prevailing after the Kawakawa Tephra to the closed forests of later zones. Although there was abundant grassland it is clear that this was not owing to a lowered timber line. Two of the scrub types present at the site, *Phyllocladus* and *Dacrydium bidwillii*, do not grow more than a few metres above the regional timber line at present and, although the pollen percentages of *Nothofagus fusca* type and *Nothofagus menziesii* are small, they must have existed as scattered pockets of forest in the area. Podocarp pollen percentages are

low also, but it is likely that podocarp forest had gained a foothold during Zone A1. The landscape is visualised as being covered with a mosaic of grassland, scrubland, and isolated, but spreading, pockets of forest. Two factors are responsible for this unique vegetation type. Firstly, the very slow migration rate of *Nothofagus* prevented it from taking full advantage of the ameliorating climate. Secondly, although temperatures may have been relatively high, the climate was still too dry and drought-prone to allow significant establishment of podocarp-hardwood forest.

During Zone A2 the steady increase of podocarp tree pollen and the appearance of several taxa confined to podocarp-hardwood forest indicate that the previous grassland/scrubland mosaic was rapidly being replaced by forest adapted to milder conditions. Although the bulk of the pollen is derived from a few wind-pollinated tree conifers, it does not necessarily follow that they dominated the forest. Most hardwood species are insect-pollinated and produce small amounts of poorly distributed pollen; therefore low percentages, or even occasional pollen grains of such species, may indicate that they were abundant in the surrounding forest. The podocarp-hardwood forests of Zone A2 were probably quite complex in structure and would have possessed many species. We do not envisage the spread of podocarp-hardwood forest as a migratory "wavefront", but rather as nuclei of podocarp forest establishing themselves in the more equable, moister sites and then invading the grassland/scrubland areas as the climate improved.

Charcoal of *Dacrydium cupressinum* was reported from underneath the Rotoaira Lapilli (which terminates Zone A2) on the east flank of Pihanga at an altitude of 410 m (McGlone & Topping 1973). On present-day lapse rates this would imply that the maximum possible temperature depression at that time was c. 3°C; if *Dacrydium cupressinum* was at the altitude of Rotoaira Basin, which seems reasonable from the pollen evidence, the temperature depression may have only been 2°C.

At the Zone A2/A3 boundary the *Dacrydium cupressinum* ratio doubled and *Libocedrus* increased markedly, indicating the onset of somewhat moister conditions. From that point on forest cover was complete. The forests of Zones A2 and A3 are not readily assigned to any present-day community. A higher montane to subalpine classification is suggested by the relatively high percentage of *Libocedrus* and the continuing dominance by *Dacrydium bidwillii* and *Phyllocladus* of the woody bog vegetation. On the other hand, the dominance by *Podocarpus spicatus*, the persistent occurrence of *Pennantia corymbosa*, and isolated records of *Alectryon excelsum*, *Dodonaea viscosa*, *Tetrapathaea tetrandra*, and *Paratrophis* suggest a forest more lowland in character, perhaps similar to those of the eastern North Island. It is possible that

there is no close present-day equivalent to this forest type, and that the climate was also of a kind not experienced at present. Although it is impossible to be precise, the average annual temperature must have been within 2°C of the present and the climate considerably more drought-prone.

At the A3/A4 boundary the forest character changed abruptly. *Dacrydium cupressinum* became the major forest species and the pollen spectra, with their continuous percentages of *Ascarina lucida* pollen, strongly resemble those from present-day lowland forests of the West Coast. *Dodonaea viscosa* and *Alectryon excelsum*, species generally found in coastal situations, extended their range inland and from this we can infer a moist drought-free climate, with only slight frosts. Climatic change is reflected in the bog vegetation by the replacement of *Dacrydium bidwillii*, to a very large extent, by *Leptospermum* and *Dacrydium colensoi*. Wood is much commoner in the peat than hitherto, indicating a denser woody growth. Although a change to equable, moist conditions is strongly suggested by the vegetation record, there is no clue as to whether the annual temperature rose. All the changes described above can be easily attributed to a greater, better distributed rainfall. From the evidence from ¹⁸O/¹⁶O analysis of speleotherms (Hendy & Wilson 1968), the temperature rose rapidly at 10 000 yr B.P., and such a rise certainly would have contributed to the vegetation changes.

During Zone A4 there were cyclical changes in the forest composition as shown by the fluctuations of the *Dacrydium cupressinum* ratio. When this ratio was low, *Dacrydium bidwillii* was more abundant and vice versa. In view of the resistance of *Dacrydium bidwillii* to frost damage (Wardle & Campbell 1976), during the periods of *Dacrydium cupressinum* dominance the rainfall was possibly higher, skies cloudier, and temperatures perhaps warmer. Under these conditions, when frosts are uncommon, *Dacrydium bidwillii* could not compete effectively against the other bog vegetation; with the return of drier, frostier conditions it would become competitive against more frost-sensitive species. Although it was interrupted regularly by periods of somewhat less equable climate, Zone 4 was the longest interval (5 000 years) of mild, moist climate in the Aranuian. It was undoubtedly the wettest also and, although this cannot be directly inferred from the vegetation data, probably the warmest.

Whether or not there was a post-glacial climatic optimum has been debated in New Zealand for some time. Harris (1963) recognised a warm period which was terminated by a cooling c. 2 500 yr B.P. Moar (1971) concluded that there was no evidence for such a period of sustained warmth. The view that there has been no significant climatic change since 10 000 yr B.P., only small-scale climatic fluctuations, has been

compounded by Molloy (1969). Whereas the date of 5000 yr B.P. for the end of the climatic optimum is clearly unsatisfactory, our evidence strongly suggests that there was a period from c. 10 000 through to 5000 yr B.P. when the climate was substantially milder and wetter than at present. There were fluctuations during this period, but nothing of the magnitude of those occurring post 5000 yr B.P. Recent work on the South Island glaciers (Wardle 1973, Burrows 1977) has shown that the latest phase of activity began c. 5000 yr B.P. Although the ages of early post-glacial advances are not known with precision, it appears that the period 8000–5000 yr B.P. lacked glacial activity. The glacial history, then, provides strong support for the concept of a mid post-glacial warm period.

Many changes in forest composition occurred in Zone 5, but not as rapidly as those at the beginning of Zone A4. *Dacrydium cupressinum* gradually lost its pre-eminent position and, although there is a period between the Waimihia and Taupo eruptions where it recovers some of its former abundance, it is never as common again. *Ascarina lucida*, *Dodonaea viscosa*, and *Alectryon excelsum* all become scarce whereas *Dacrydium bidwillii*, *Nothofagus fusca* type, *Nothofagus menziesii*, and *Phyllocladus* all increase. Clearly then, all these changes can be interpreted as a trend from the mild conditions of Zone 4 towards a drier, frostier climate more like that of the present-day. Although the evidence at these sites is weak, the period between the Waimihia and Taupo eruptions may have been a brief remission.

As mentioned previously, the pollen record from Zone A6 is not complete and covers only the effects of man on the vegetation, and so no climatic interpretation is possible.

Table 2 summarises our view of the climatic changes over the last 14 000 years.

Table 2 Climatic changes in the Tongariro region.

Years B.P.	Climate
14 000–10 000	Colder (up to 3°C lower annual temperature) and drier than the present
10 000– 5 000	Warmer and wetter than the present, but with marked fluctuations
5 000– 3 500	Cooler and drier; possibly approaching present conditions
3 500– 1 800	A recovery to slightly wetter and perhaps milder conditions
1 800–0	No reliable data

Comparisons with North Island pollen diagrams

There are not many published Aranuiian pollen diagrams from the North Island and radiocarbon

dates are scarce. The Taupo Pumice and Waimihia Lapilli are very widely distributed and somewhat offset the disadvantage of having few dates but, even so, conclusions as to the timing of events must be speculative. There are only four localities from which diagrams covering much of the Aranuiian have been published. They are: Hauraki Plain and Hamilton (Harris 1963); Ruahine Ranges (Moar 1961, 1967); Wallaceville, Hutt Valley (Harris 1951, 1958).

The two northernmost diagrams (Hauraki and Hamilton) bear a strong resemblance to each other and also to the Wairehu diagram. The Hauraki sequence begins with a grass-scrubland phase in which *Dacrydium bidwillii* type, *Phyllocladus*, *Coprosma*, *Nothofagus fusca* type are common. These give way to podocarp forest, in which, after a brief period of *Podocarpus* dominance, *Dacrydium cupressinum* becomes the most abundant species. Over the next few metres *Podocarpus* falls to its lowest levels, recovering at about the level of a prominent, unidentified pumice layer. A few centimetres from the surface there is a sudden increase in Gramineae and fern spores, indicating human settlement. Two radiocarbon dates have been published for the site (Grant-Taylor & Rafter 1963). One, for a point just above the transition to *Dacrydium cupressinum* dominant forest, is 12 250 ± 750 yr B.P. (NZ 334B); the other for the unidentified pumice layer is 5 530 ± 100 yr B.P. (NZ 333B). These dates bracket Harris' Zone 4, a period of maximum warmth. The Hamilton diagram appears similar to that from the Hauraki Plains, but does not extend back beyond the *Dacrydium cupressinum* phase. Zone 4 in the Hamilton diagram is characterised by a high *Dacrydium cupressinum* ratio, and also by abundant *Ascarina*. Zone 4 of Harris (1963) appears to be the same period as Zone A4 of the Wairehu diagram, with a somewhat similar vegetation.

At Wallaceville (Harris 1951, 1958) peat accumulation began at c. 9000 yr B.P. with a *Podocarpus* dominant phase, but with *Nothofagus menziesii* a significant element. *Dacrydium cupressinum* increased rapidly, and a *Dacrydium cupressinum* dominant forest with a consistent and appreciable percentage of *Ascarina* appears to have flourished over the period represented by the next 3 m. *Nothofagus fusca* type increased its representation slowly throughout the later part of the podocarp phase, and at the 4-m level its proportion rose sharply whereas *Dacrydium cupressinum* decreased. *Nothofagus fusca* type, probably *N. solandri*, dominates the remainder of the profile. On peat accumulation rates the date for the *Dacrydium cupressinum* decline could be c. 4600 yr B.P.

The Ruahine diagrams, both Northern and Western, are very similar to that from Wallaceville despite their higher altitude (1400 m as opposed to 140 m). There is the initial phase with high podocarp levels and consistent *Ascarina* percentages, giving

way rather gradually to a *Nothofagus fusca* type phase before the Waimihia Lapilli in the Northern Ruahines, and between the Taupo Pumice and the Waimihia in the Western Ruahines. In the Western Ruahines diagram there is evidence for a rise in the timber line between the deposition of the Waimihia and the Taupo tephras. During that period *Ascarina* reappears.

To summarise: there were widespread grassland and shrubland communities in the North Island before 14 000 yr B.P., and in some places perhaps for some thousands of years afterwards. Peat accumulation seems not to have begun in most areas until c. 10 000 yr B.P., for only in the relatively extensive basin sites of Rotoaira and the Hauraki Plain do older records occur. The initial forest type everywhere was *Podocarpus*. Later, exactly when depending on the site, *Dacrydium cupressinum* rose to dominance and *Ascarina* became common. After 5 000 yr B.P., in response to a general change towards a harsher climate, *Nothofagus fusca* type forest spread, especially in the south, and in the northern sites *Podocarpus* became more abundant. There was a reversion between 3 500 and 1 800 yr B.P. to vegetation more characteristic of the *Dacrydium cupressinum* dominant phase.

Nothofagus distribution patterns

The unusual pattern of *Nothofagus* forest distribution in the central North Island has attracted some comment. All species of *Nothofagus* are rare on the Volcanic Plateau, and, indeed, absent over large areas. On the nearby ranges, however, such as the Ureweras, Kaimanawas, Ahimanawas, and the Northern Ruahines, there are well developed montane *Nothofagus* forests.

Nicholls (1963) stated that in the Rotorua district *Nothofagus* forest is confined to a few patches on the Mamakau Plateau to the north-east of Rotorua, generally on swampy or infertile soils. Because *Nothofagus* disperses very slowly, except by waterways of which none are favourably aligned, Nicholls concluded that *Nothofagus* forest must have once been continuously distributed across the district, either during a period of harsher climate and/or infertile soils. As the environment improved, either by a warming of the climate or improvement of the soil by subsequent ash showers, competition from podocarp-hardwood forest restricted *Nothofagus* to isolated pockets of poor soil. To the east and south catastrophic rhyolitic eruptions from the Okataina Volcanic Centre completely destroyed the forest, and *Nothofagus* did not reinvade. Because *Nothofagus* is absent from altitudes over 550 m, Nicholls claims that its scarcity is unlikely to result from the generally warmer conditions prevailing over the last 15 000 years.

McKelvey (1963) also noted a general absence of *Nothofagus* in the West Taupo forests he studied. The Hauhangaroa Range has two small pockets of *Nothofagus menziesii* at c. 850 m, and there are patches of *N. fusca*, *N. menziesii*, and *N. solanum* var. *cliffortioides* on the Tihia-Kakaramea Mass forming a low timber line at 1 200 m. McKelvey suggests that the summits of the Hauhangaroas and the Tihia-Kakaramea Massif were once clothed with montane *Nothofagus* forest but that the Taupo eruption destroyed all but a few remnant patches. By virtue of their greater mobility, podocarp and hardwood species supplanted the previous *Nothofagus* forest after the ash-fall. McKelvey found the absence of *Nothofagus fusca* surprising and suggested that it may have never been present in the Hauhangaroa Range and that the *N. menziesii* represents remnants of an upper forest zone that existed under cold Pleistocene conditions.

Nicholls and McKelvey, although stressing the role of volcanic destruction in restricting the distribution of *Nothofagus*, may have underestimated the effects of climate. From the pollen evidence obtained from the Otamagakau and Wairehu sites it appears that *Nothofagus* forest was nearly eliminated from the Tongariro region before 14 000 yr B.P. The initial advantage that *Nothofagus* had by being actually scattered in the non-forested areas during the late Otiran was outweighed by the far greater dispersability and greater competitiveness of podocarp and hardwood species under an ameliorating climatic regime. *Nothofagus* forest, almost certainly not forming a continuous vegetation zone in any case, was reduced to scattered patches on poorer soils. Its absence from high altitude areas may be a consequence of the limited time it had to spread from its refuge areas before being overwhelmed by podocarp-hardwood associations.

The pattern of montane *Nothofagus* forest found outside the Volcanic Plateau in the North Island is relatively recent. Pollen diagrams from the Northern Ruahine Range (Moar 1961, 1967) show a steady rise of *Nothofagus fusca* type pollen before the Waimihia Lapilli. At a point where there is a drop in abundance of both *Dacrydium cupressinum* and *Ascarina*, the *Nothofagus* curve rises rather sharply to become the dominant pollen type. This sequence is similar, in broad outline, to that recorded from the Wairehu site, although the Ruahine site lies at much greater altitude (1 400 m), and may reflect the effect of the drier and frostier climates of Zone A. It is likely that similar developments have taken place on most of the higher mountain ranges of the North Island. The effect of volcanic eruptions, especially the Taupo, has been to retard this expansion of *Nothofagus* that has occurred elsewhere. If the present climate deteriorates further, or if there are no volcanic

eruptions for a considerable time, invasion of *Nothofagus* from regions marginal to the Volcanic Plateau, and from remnant *Nothofagus* patches on it, will take place. A small-scale example of the type of development likely can be seen in the dispersal, by means of watercourses, of *Nothofagus solandri* var. *cliffortioides* down the flanks of Ruapehu and out on to the Waimarino Plain.

Influence of volcanism on the vegetation

Most large tephra eruptions have a marked effect on the local bog vegetation. The changes in vegetation are particularly noticeable after the deposition of very thick deposits such as the Taupo Pumice or the Mangamate Formation. The actual changes that take place vary according to the thickness of the tephra deposit, and the climate at the time of its deposition. In general there is an increase in the amount of local, woody vegetation, mainly *Coprosma*, *Myrsine*, *Dacrydium bidwillii* type, *Leptospermum*, and Compositae. Gramineae may appear or increase and there are nearly always sharp changes in the proportions of swamp-inhabiting taxa such as Cyperaceae, *Gleichenia*, and *Sphagnum*. Most of these changes can be related to the destruction of the old swamp vegetation and the provision of a fresh, solid surface. Large tephra falls may also cause temporary changes in water levels owing to damming of outlets. Before 10 000 yr B.P. *Dacrydium bidwillii* type was the main pioneering species on fresh tephra surfaces; since then it has been *Leptospermum*. The effects of a thick tephra deposit, such as the Mangamate Formation, may be long lasting: the *Leptospermum* community established after the Mangamate Formation appears to have been dominant for at least 500–700 years.

Changes in forest composition are hard to detect against a background of large fluctuations of the local bog vegetation, and ratios are therefore the most reliable indicators of change. Significant fluctuations in the *Nothofagus* and *Dacrydium cupressinum* ratios occurred after the Taupo, Waimihia, and Mangamate eruptions and may be related to actual destruction of forest. The nature of the change in forest type depends on the prevailing climatic trends: the *Dacrydium cupressinum* ratio increased after the Waimihia and Mangamate events but decreased after the Taupo Pumice eruption.

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