Quaternary Vegetational, Environmental and Climatic History of the Lower Taieri Plain, East Otago, New Zealand.

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ERRATUM SHEET

References made to McGlone and Wilmshurst (1999) on the following pages refer to McGlone and Wilmshurst (1999a)

Page 57, 2nd paragraph, 15th line
Page 60, 2nd paragraph, 11th line
Page 138, 1st paragraph, 11th line
Page 140, 1st paragraph, 11th line
Page 148, 2nd paragraph, 12th and 21st lines
Page 149, 2nd paragraph, 16th line

Page 72, 2nd paragraph, 11th line - the text reference should read Macphail and McQueen (1983) not Macphail and Mckellar (1983).

Page 102, 3rd paragraph, 9th line - text reference should read Flenley and Velasco (1996) not Flenley *et. al.* (1996).

Page 55, 2nd paragraph, 11th line - text reference should read McGlone *et. al.* (1997b) not McGlone *et. al.* (1997).

Page 21 - Figure 2.4 - text reference should read after Tauber, 1965, not Tauber, 1968.

Page 33 - Figure 3.3 - text reference should read Pillans, 1991, not Pillans, 1999.

MISSING REFERENCES

The following references were inadvertently left off the reference list:

Assarson, G., and Granlund, E. (1924). En metod for pollenanalys av minerogena jordarter. *Geol. foren.* Stockh. forh. **46**, 76-82.

Ehrenberg, C. G. (1838). Beobachtungen uber neue Lagen fossiler Infusorien und das Vorkommen von Fichtenbeluten neben deutlichem Fichenholz, Haifischzahen, Echinoiden und Ifusorien in Vohynischen Feuersteine der Kreide. - *Monatsber. Berliner Akad* **1838,** 104.

Erdtman, G. (1966). Sporoderm morphology and morphogensis - A collection of data and suppostioins. *Grana Palynology* **6,** 318-323.

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Hughes, J. (1999). A diatom based paleoenvironmental history of the Taieri basin, Otago. Victoria University of Wellington, BSc Hons.

Imbrie, J., Hays, J.D. Martinson, D.G., McIntyre, A., Mix, A.C., Morely, J.J., Pisias, N.G., Prell, W.L. and Shakleton, N.J. (1984). The orbital theory of Pleistocene climate: support from a revised chronology on the maritime O18 record*In*: Berger, A.L. *et al.* (eds) *Milankovitch and Climate Part 1.*

Libby, W.F. (1955). Rediocarbon Dating (2nd Ed.). Chicago Publ. Phoenix Science Series.

ADDITIONAL COMMENTS

Page 16, 1st paragraph, 8th line - *Callitriche* is actually tricolpoid or tetracolpoid. Another example of an inaperturate grain from the New Zealand flora is *Beilschmiedia tawa.*

Page 31, 1st paragraph, 5th line - Asteraceae is now known to have been in New Zealand since the Oligocene.

Page 75 - the diagram depicting the core stratigraphy shows a silt/clay band extending from 61.76m to approx. 50m. This is incorrect, the silt/clay band should extend to 54.48m.

ABSTRACT

This project presents the palynology of the 154m Waipori 99-1 long core taken from the Lower Taieri Plain, east Otago, New Zealand. The current vegetation and climate are reviewed along with the geological and geomorphological setting of the Taieri Basin. Reviews are given on the history of New Zealand's vegetation since the Late Cretaceous and on the late Pleistocene and Holocene vegetation and climate of southern New Zealand. The field and lab techniques used in the course of this project are detailed.

The Waipori 99-1 long core contained a number of extensive glacial aggradational gravel sequences. These are separated in places by interbedded fine sediments which were found, for the most part, to have been deposited during warm climate periods. Subsidence within the basin has determined which sediments survive in the record. Periodic subsidence and fluvial erosion have resulted in a discontinuous sedimentary sequence. Polliniferous sediments were found only above -103m. Pollen analysis suggests that the sediments may date back as far as the mid Quaternary. Dating on the core poorly constrains sediments which pre-date the Holocene. The pollen evidence presented in this project is used to create a number of possible chronological lines along which to interpret environmental information derived from the core. No particular line is fully endorsed by the project however.

As many as four, and possibly five, warm climate pollen assemblages are recognised. Pollen analysis suggests that during these warm periods, podocarp-broadleaf forests occupied the basin. *Prumnopitys taxifolia* was the most consistently common podocarp in the region. *Fuscospora* beeches appear to have once been more common in the area in contrast to the present day. *Dacrydium cupressinum* was apparently absent from the area during the mid to late Quaternary, expanding into the basin only in the mid Holocene. The Holocene vegetational, climatic and environmental record is in agreement with others published from southern New Zealand.

ACKNOWLEDGEMENTS

I would like to thank my supervisor Professor John Flenley, who introduced me to the study of Quaternary biogeography and encouraged me to continue in this field. His guidance and support throughout this project has been greatly appreciated, along with his anecdotes on life.

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I'd also like to acknowledge the support of Assoc. Prof. Patrick Hesp, Dr Mike Shepherd and Richard Heerdegen. Their interest in my work and encouragement throughout my postgraduate studies has been greatly appreciated.

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Chapter One:

INTRODUCTION

INTRODUCTION

1.1 Purpose of the Study

This thesis presents the palynology of the Waipori 99-1 long core from south-east Otago. This core was taken as part of a collaborative, ongoing project which began in 1997, the purpose of which is to core five terrestrial sites along a north-south transect through New Zealand. The analysis of these cores will provide benchmark records for the late Quaternary and generate regional palaeoclimate parameters such as mean annual temperature, mean annual rainfall and wind velocity and direction for at least the last 125000 years. It is hoped that this approach will allow for the identification of long term trends in the intensity and position of the westerly flow over New Zealand. These data will in turn be used in global circulation models to reconstruct the climate of New Zealand and the South Pacific (Dickinson *et al.*, 2000).

1.2 Thesis Aims

This project aims primarily to reconstruct the past vegetation of the Lower Taieri Plain through the analysis of the fossil pollen sequences held within the sediments of the Waipori 99-1 long core taken near Henley. From the results of the pollen analysis, past climatic and environmental conditions will be inferred. The information will be critically analysed and interpreted with reference to New Zealand-wide vegetation and climate changes of the late Quaternary. Special reference will be placed on how the Holocene history of this area relates to that of other parts of southern New Zealand.

1.3 Location

The Lower Taieri Plain is situated south of Dunedin in a tectonic depression, flanked to the north-west by the Maungatua ranges, which reach 895m a.s.l. and the coastal Chain Hills which lie between 200 and 450m a.s.l. to the south-east (Figure 1.1). The Plain lies between sea-level at its southern end and 40 m a.s.l. at its northern end stretching 40 kilometres from Invermay in the north to the southern end of Lake Waihola in the south with a width varying between 5 and 8 kilometres and a surface area

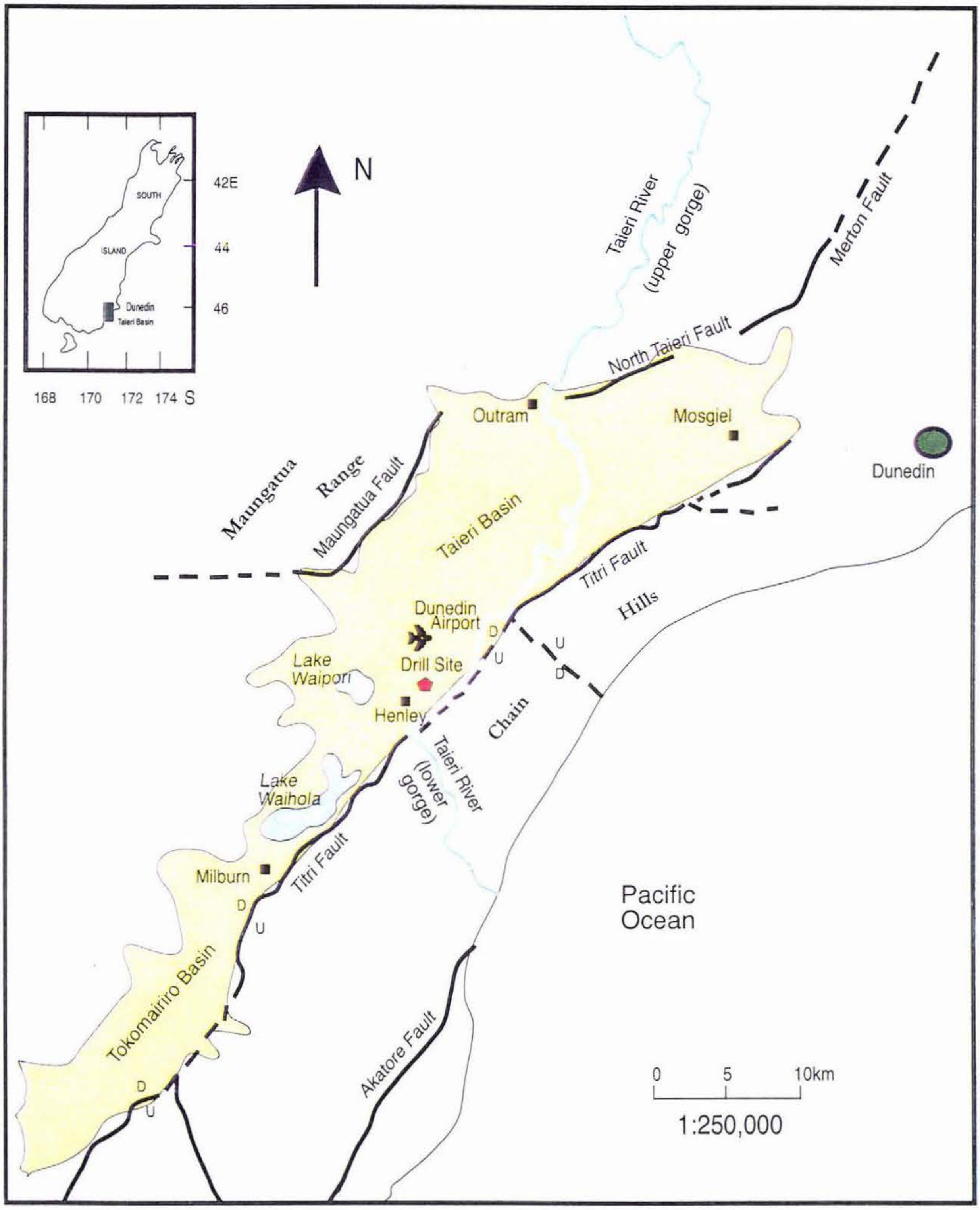

Figure 1.1 Map of the Taieri Basin, showing the Waipori 99-1 drill site and the position of faults in the region and their relative movements (after Hughes, 1999).

of 180 kilometres^2 (Keiller, 1994). Two freshwater lakes (Lakes Waipori and Waihola) occupy the southern end of the of the basin (Plate 1.1). The Taieri River emerges from the Upper Taieri Gorge at Outram and assumes a meandering form across the plain to Henley, where it exits the plains through the antecedent Lower Taieri Gorge to reach the coast. Down cutting in the gorge has been sufficient to allow tidal movements up the gorge and into the lakes and the lower Taieri above Henley (Craw *et al.*, 1998). This is evidenced geomorphologically by deltas which have formed at both the inlet and outlet of Lake Waipori. Two less significant tributaries to the basin are the Waipori River, and Silver Stream.

The Waipori 99-1 drill site is situated on the Horne property at Henley toward the southern end of the plain at grid reference NZMS 260 I45-901677. The property is currently used for dairy farming. This south-central site was selected by Drs Jamie Shulmeister and Warren Dickinson in the hope of avoiding the gravel sequences which had dominated bore holes drilled on parts of the plain further north. A more central position on the Plain would also reduce the likelihood of encountering alluvium shed off the Titri and Maungatua blocks.

1.4 Climate

The Waipori 99-1 drill site is located four kilometres south-east of Dunedin airport, where climatological measurements have been recorded since 1962. The Lower Taieri Plain has a sub humid climate (Cox, 1968) with micro-climatic variations within the plain (Beecroft *et al.*, 1991). The area receives a mean annual rainfall of 659mm/yr and has been recorded as ranging between 495 mm/yr and 817 mm/yr. This rainfall is reasonably well distributed throughout the year. The average annual temperature is 15.7 °C with a recorded range between -8.7 °C and 34.5 °C. Ground frosts occur on average 105 days per year, with air frosts occurring 65 days per year, though Beecroft *et al.* (1991) note that there is a large spatial variation in the incidence of frost on the Taieri Plain. The area receives, on average, 1676 hours of sunlight per year. Snow falls on average, 7 days per year. Fog covers the area 64 days per year on average. 63 km/hr or more winds buffet the area, on average, 68 days per year, while wind speeds of 96 km/hr or more are experienced, on average, 6 days per year. The most common wind direction is from the south-west (New Zealand Meteorological Service, 1980).

Plate 1.1 View of the Lower Taieri Plain looking to the north west from on top of the Chain Hills. Lake Waihola lies in the foreground, while Lake Waipori can be seen in the distance to the right. The southern end of the Maungatua Range lies just behind Lake Waipori. The drill site is not quite visible in this photograph, but lies two kilometre east of Lake Waipori.

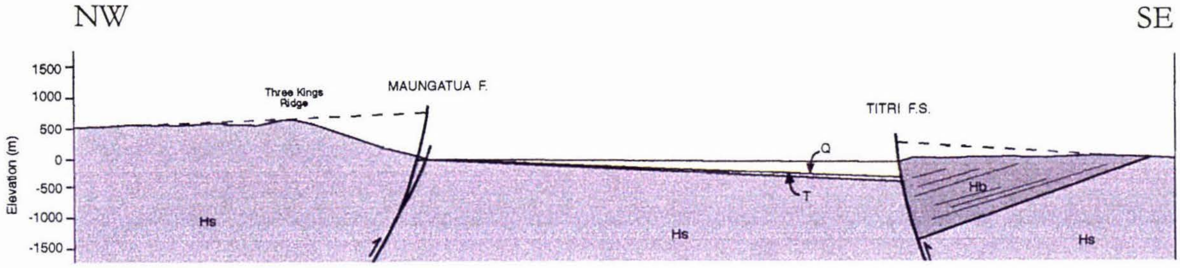

Figure 1.2 Geological cross-section of the Taieri Basin taken 500m north of the Waipori 99-1 drill site. The transect runs north west to south east. Hs ~ Haast Schist, Hb ~ Henley breccia, T ~ Tertiary deposits, Q ~ Quaternary deposits (from Litchfield, 2000).

1.5 Geological setting

The lower Taieri Basin is a graben bound by the Titri fault along the eastern foot of the Chain Hills and the Maungatua fault complex which runs along the base of the Maungatua Range to the west (McKellar, 1966)(Figure 1.2). The Titri fault was first active in the Late Cretaceous upthrowing the Taieri Plain block under normal fault movement. A subsequent period of fault re-orientation led to reverse faulting during the late Miocene. This caused the Maungatua block and Chain Hills-Saddle Hill block to be up thrown, creating a depression between the two blocks which defined the Lower Taieri Basin. This basin has been subsequently infilled (a process still continuing) with sediments from the Taieri and Waipori catchments. The basement rock beneath the Plain is schist belonging to the Haast Schist group (early to mid Mesozoic). Haast Schist forms the basement throughout both catchments, with quartz-feldspathic gravels dominating the alluvial deposits of the Plain. In the upper Taieri catchment, Tertiary sedimentary rocks and lignites overlie the basement. Basalts belonging to the Waipiata volcanics are extensive at the surface near Waipiata (Mutch, 1963). There are also minor areas of un-metamorphosed Torlesse greywacke within the catchment. Alluvium sourced from these parent materials may also be encountered on the Taieri Plain.

The basement schist of Chain Hills block is overlain by the Henley Breccia south of Otokia creek. The breccia is comprised of Haast schist, Abbotsford mudstone, and Caversham sandstone conglomerates (Barrell *et al.*, 1999). The deposition of this unit dates back to the Upper Cretaceous. Further North the Chain Hills are capped by basaltic rocks of the mid- to late Miocene aged Dunedin volcanic complex. Volcanics belonging to this group can be found in parts of the Taieri and Silver Stream catchments.

1.6 Geomorphology and soils

Barrell *et al.* (1998) mapped a number of Quaternary aged landforms on and around the Lower Taieri Plain (Figure 1.3). The main geomorphological features within the basin are the alluvial fans found along the margins of the basin. In the absence of an effective correlation and/or dating method, these have been differentiated simply into young, intermediate and old fans based on their relative height and degree of dissection (Barrell *et al.*, 1999). The bottom margins of many intermediate and old fans have been truncated, probably by wave action during past high sea level stands within the basin. The alluvial fans of the Taieri River and the Silver Stream coalesce at the northern end of the basin. A number of frontal faults basinward of the Titri fault have uplifted older well dissected fans along the western edge of the Chain Hills during the Quaternary.

Beecroft *et al.* (1991) found that the northern part of the Lower Taieri Plain had a complex suite of soils which were related to a number of landform units. After correlating borehole information in the area, Barrell *et al.* (1999) favoured a threefold classification which identified the Wingatui Surface as representing very young alluvial surfaces underlain by silty deposits and the Dukes Surface as representing older alluvial surfaces underlain by gravel. These surfaces are characterised by fertile gleyed alluvial soils with poor drainage. Lastly the Gladfield surface represents swampy ground underlain by peat, characteristic in low lying areas.

1.7 Vegetation

The vegetation of the Lower Taieri Plain and surrounding hills has been substantially altered by both Maori and European settlement. Today only small remnants remain on and around the plain. These remnants have been reasonably well documented (Anon., 1985; Forrest, 1963; McEwen, 1987; Ross, 1978; Wardle and Mark, 1956). Forrest (1963) mapped the distribution of forest and swamp remnants of east Otago at the time of

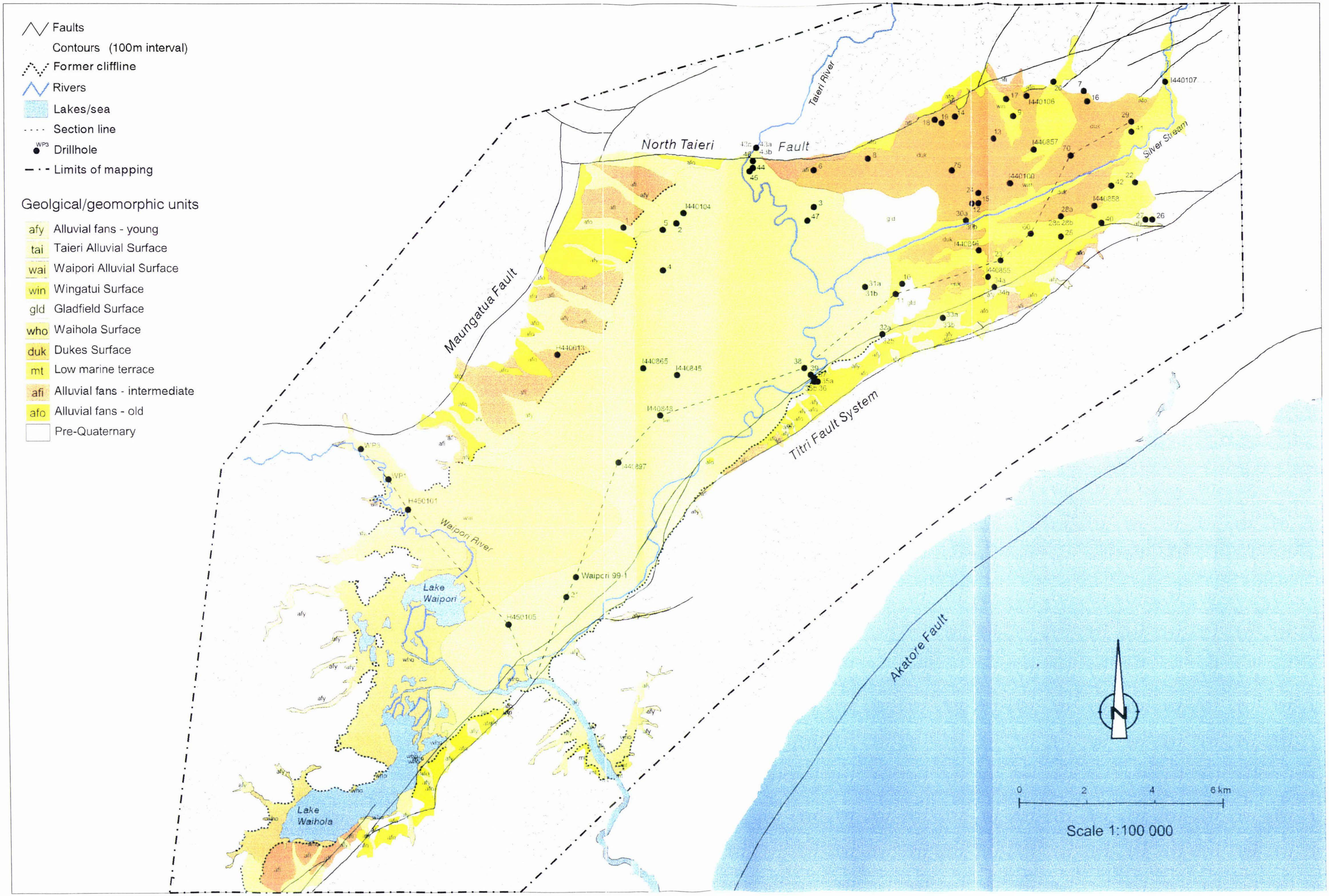

Figure 1.3 Surface Geology and geomorphology of the Taieri Basin, including borehole transect across the Plain (see Chapter Six) (from Barrell *et al.*, 1999)

European arrival using historical accounts. He was unable to comment on the composition of these remnants. From the historical accounts of Shaw and Farrant (1949), Beecroft *et al.* (1991) report that swampland with canal-like waterways and open lagoons, covered much of the Taieri Plain, though patches of drier ground were more common toward the north. Dominant swampland species included the cabbage tree (*Cordyline australis*), flax (*Phormium tenax*), toetoe (*Cortaderia richardii*) and raupo (*Typha orientalis*). Swampland has since been drained and the bush cleared. Wetland areas are now confined to the margins around and between Lakes Waipori and Waihola.

The character, dynamics and recent history of the remnant vegetation in the area surrounding Dunedin, including the Maungatua Range is best described by Wardle and Mark (1956). Their vegetation maps are shown in Figure 1.4. They split the vegetation types into four categories - Beech, conifer-broadleaf, shrubland, and grassland. Silver beech (*Nothofagus menziesii*) is the only beech species found in the area. The nearest *Fuscospora* beech community (*N. fusca*) is over forty kilometres away in the Blue Mountains. *Nothofagus menziesii* dominates remnant forests on the eastern mid-slopes of the Maungatua range, and can be found in association with horopito (pepper tree - *Pseudowintera colorata*) in the deeper, more sheltered valleys of the Waipori catchment (Ross, 1978). A small but important stand exists on Silver Peak where it appears to be actively colonising an area previously dominated by kaikawaka (mountain cedar - *Libocedrus bidwillii*) and papauma (broadleaf - *Griselinia littoralis*). Aside from this there are only small disjunct stands found near the Taieri River mouth and on Mt Cargill near Dunedin.

Of the lowland forest associations, kamahi (*Weinmannia racemosa*) / southern rata (*Metrosideros umbellata*) / broadleaf forest remnants are confined to the south extending as far north as Akatore Creek, 7 kilometres south of the Taieri River mouth. *Weinmannia racemosa* is found in association with rimu (*Dacrydium cupressinum*), miro (*Prumnopitys ferruginea*), montane totara (*Podocarpus cunninghamii*), mahoe (whiteywood - *Melicytus*), *Griselinia littoralis* and *Pittosporum* spp. at the Taieri mouth, but drops out of this association in similar coastal remnant stands further north along the Chain Hills (McEwen, 1987). Podocarp-broadleaf forests are found in the Waipori gorge, with *Prumnopitys ferruginea*, matai (*Prumnopitys taxifolia*), totara (*Podocarpus totara*) being the dominant podocarps. Isolated specimens of *Dacrydium cupressinum* are also present.

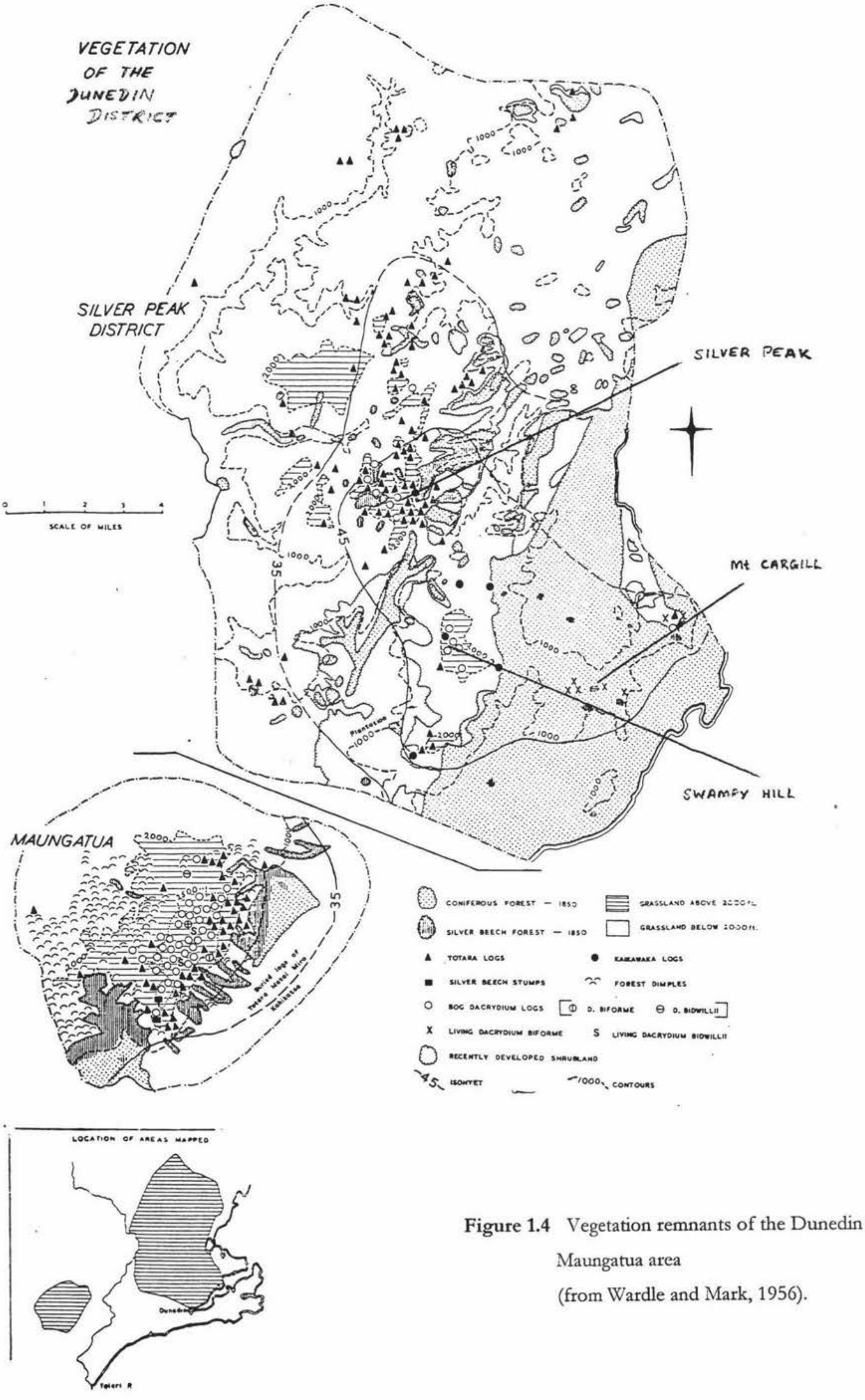

Figure 1.4 Vegetation remnants of the Dunedin Maungatua area (from Wardle and Mark, 1956).

Broadleaf species dominate and include mapou (*Myrsine australis*), *Griselinia littoralis* putaputaweta (marbleleaf - *Carpodetus serratus*), tarata (Lemonwood - *Pittosporum eugenioides*), black mapou (*Pittosporum tenuifolium*), Houhere (lacebark - *Hoheria sextylosa*), narrow-leaved lace bark (*Hoheria angustifolia*), *Melicytus*, and kotukutuku (*Fuchsia excorticata*). A similar podocarp-broadleaf assemblage exists at the north-eastern end of the Maungatua Range, though *Dacrydium cupressinum* is more numerous. In the Upper Taieri Gorge near Outram, *Prumnopitys taxifolia*, *Podocarpus totara*, and *Dacrycarpus dacrydioides* form the dominant podocarps over a broadleaf canopy, while a similar association minus *Podocarpus totara* is found in small remnants along the low hills between Outram and North Taieri (McEwen, 1987). Beecroft *et al.* (1991), after Shaw and Farrant (1949) add pokaka (*Elaeocarpus hookerianus*), ribbonwood (*Plagianthus regius*) and kowhai (*Sophora microphylla*) to the broadleaf canopy species listed above. Most lowland forest trees have a well defined upper limit between 400 and 500m in the area.

In the Silver Peak District, *Libocedrus bidwillii* and *Podocarpus cunninghamii* become the most common podocarps above 400m. Bog pine (*Halocarpus bidwillii*) has a disjunct distribution between Mt Cargill and the summit of the Maungatua Range. The distribution of *Halocarpus* logs in upland areas now cloaked in snow-tussock (*Chionochloa rigida*) suggests it had a more widespread distribution in the recent past. Significant stands of mountain toatoa (*Phyllocladus alpinus*) are found only on Mt Cargill.

Scrublands of kanuka (*Kunzea ericoides*) and manuka (*Leptospermum scoparium*) are widespread throughout the district, growing under a range of environmental conditions, though they most commonly occupy altitudes between 300 and 600m (Wardle and Mark, 1956). Both species are light demanding and are believed to be playing a successional role in areas where original clearings have been allowed to regenerate. Both species are unpalatable and tend to form dense stands which provide protection for more shade-tolerant seedlings which may, in the absence of browsing or other disturbances, form a more permanent community. In *Kunzea* scrub near the Waipori Gorge, Ross (1978) noted that *Myrsine australis* was the first broadleaf species to appear often in association with a lower tier of round-leaved *Coprosma* (*Coprosma rotundifolia*). Wardle and Mark (1956) noted *Dacrydium cupressinum*, *Podocarpus cunninghamii*, and *Nothofagus menziesii* seedlings amongst such scrubland in the Silver Peak area. Sub-alpine scrub containing inanga (*Dracophyllum longifolium*), *Hebe buxifolia*, golden cottonwood

(*Leptophylla fulvida*) and a few remnant specimens of *Halocarpus bidwillii* form the vegetation on the summit of the Maungatua Range. Remnants of *Chionochloa rigida* tussockland occur in the western high country, replacing what appear to have once been forests of *Podocarpus cunninghamii* and *Halocarpus bidwillii* and *Halocarpus biformis* (Wardle and Mark, 1956). On the upper eastern slopes this scrub is found in association with *Chionochloa rigida,* and it is suggested that this scrubland is slowly out-competing the tussocklands. Silver (*Poa cita*), hard (*Festuca novae-zealandiae*) and red (*Chionochloa rubra*) tussockland remnants occur throughout the lower hills.

1.8 Review chapters and their purpose

The following chapters aim to give the reader a firm background with which to appreciate and comment on points made in the discussion. Chapter Two introduces the principles of palynology, particularly the application palynology to palaeoenvironmental studies. This includes comments on pollen morphology, production, dispersal and sedimentation. As this project deals with pollen and spores from time periods outside the confines of the last glacial-interglacial cycle, a background on how long-term changes in climate and geology have influenced the distribution of environments and vegetation across New Zealand is useful. With this in mind, Chapter Three provides a review of New Zealand's vegetational, geological, and climatic history since the Late Cretaceous. Chapter Four takes a closer look at changes in vegetation and climate in southern New Zealand over the last 20000 years. This provides important contextual information within which to place the Holocene pollen data from the Waipori 99-1 core. This information also provides analogue data for past interglacial periods. As this project uses pollen as a proxy indicator of vegetation (and climate) it is important to have an understanding of how plant types and associations are represented in the modern pollen rain. Chapter Five looks at the differential production and dispersal of pollen (and spores) by various New Zealand plants. The interpretation of fossil pollen assemblages is meaningless unless such relationships are taken into account. Chapter Six discusses the stratigraphy of the Waipori 99-1 core and comments on the sedimentary environments represented in the core. The environmental information contained within the sediments is useful for creating a down-core chronology for the Waipori 99-1 sequence. Pollen data can be used to create or test proposed chronologies. Palynological techniques may vary from lab to lab, and between workers. It is therefore important to disclose the techniques employed, as varying techniques may produce varying results. Chapter Seven details the various field, laboratory, microscope, computer and dating techniques used in this project.

Chapter Two:

PRINCIPLES OF PALYNOLOGY

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2.1 Palynology and Palaeopalynology: An overview

Palynology, in its broadest definition, is the study of pollen grains (produced by seed plants, angiosperms and gymnosperms) and spores (produced by pteridophytes, bryophytes, algae and fungi). It is concerned with both the structure and formation of pollen grains and spores, and also with their dispersal and preservation under certain environmental conditions (Moore *et al.*, 1991). Pollen grains and spores in both their contemporary and fossil forms have been studied by a number of disciplines as a means for solving particular scientific problems. The applications of palynology today are wide ranging. They include taxonomy (Scheel *et al.*, 1996), genetic and evolutionary studies (Muller, 1970), honey studies (melissopalynology) (Moar, 1985), forensic science (Mildenhall, 1990), allergy studies (Scheiner *et al.*, 1997), tracing vegetational histories of both individual plant species and plant communities (Bennett, 1989; Webb *et al.*, 1983), correlation of deposits and the assigning of tentative dates (Leeder *et al.*, 1990), climatic change studies (Flenley, 1998) and the study of past human impact on vegetation (Wilmshurst, 1997). Moore *et al* (1991) group the last four applications under the heading of palaeopalynology. This report uses the palaeopalynological approach to reconstruct a Quaternary vegetational, climatic and environmental history for the Lower Taieri Plain.

Pollen grains and spores have a number of unique characteristics that lend themselves well to the study of palaeoenvironments. Firstly, their outer cell wall is composed of a very resistant natural polymer, which allows them to survive for long periods in sedimentary sequences (given suitable conditions). Secondly, they are produced in profuse amounts and may be dispersed over large areas. Thirdly, they can be retrieved in large numbers from sedimentary sources. Fourthly, variation in the form and surface sculpture of the outer cell wall between the pollen and spores of various taxa means their affinity can be ascertained to at least the family level, often to the generic and sometimes to the specific level.

2.2 The History of Palaeopalynology

Palaeopalynology was pioneered in Scandinavia during the 19th Century. Goppert (1836) and Ehrenberg (1838) were the first scientists to observe fossil pollen grains in Quaternary deposits. The real potential for the method was realised when Lennart von Post presented the first lecture on modern percentage pollen analysis in Oslo in 1921. von Post discovered that by assessing the kind and number of microfossils contained in samples from different stratigraphic levels in bogs, a history of climate change could be deduced. Following World War One the palynological method of investigation spread outside Scandinavia, with great contributions by workers such as Gunnar Erdtman. Two technical refinements to the preparation of sediment samples helped to broaden the applications of palynology. These were the introduction of HF treatments by Assarson and Granlund (1924) making it feasible to analyse deposits wholly or partly minerogenous and the development of the acetylation method by Erdtman in 1934, permitting the removal of a major part of the organic material within a sample (Fægri and Iversen, 1989).

In more recent years conceptual advances have been made in the statistical treatment of pollen data. Arguably one of the most important developments has been that of an absolute pollen count. Until the early 1960s relative (or percentage) palynology was the only technique available for assembling pollen data. This meant that the individual pollen sums for different taxa were interdependent on each other because the total of all pollen sums must equal one hundred percent. Therefore in the relative diagram the percentage of a taxon will be affected by the changing frequencies of other taxa (see Chapter Seven). In 1962, Benninghoff published a novel method for calculating the concentration of pollen and spores in various sediments. This method involved adding a known quantity of exotic pollen grains to the sample, the number of which permits the calculation of the proportion of the added exotic grains to that of the fossil pollen and spores. This then meant that changes in taxa were the result of a change in input and not frequency. Pollen influx information could also be derived using this absolute technique.

Developments in microscopy have allowed palynologists to identify pollen grains to lower taxonomic levels through the finer analysis of surface textures and apertures. In the last twenty years electron microscopy has transformed the study of pollen morphology, but as pointed out by Faegri and Iversen (1989) these techniques have had a less direct impact on regular analysis due to the time and money involved in sample preparation. It is hoped that in the future automated techniques will streamline the pollen preparation process and provide a more objective and efficient means by which to identify and count pollen grains and spores. Some advances have already been made in this field (Li and Flenley, 1999)

2.3 The Pollen grain and the spore: Structure, morphology and function

Pollen grains are the microspores of seed plants, and are produced in large numbers, usually in the pollen sac. They are formed as a result of meiosis of somatic pollen mother cells. Spores are homologous with pollen grains. They are also produced by sporophyte generation following meiosis and are haploid. On germination they develop into the haploid gametophyte (Blackman *et al.*, 1984).

The wall of the pollen grain is an important structure designed to protect the male gametophyte of seed plants, angiosperms and gymnosperms during passage from the anther to the stigma. Once on the stigma germination may take place whereby a pollen tube emerges from the grain, taking the sperm nucleus down to the ovarial complex. In lower plants such as pteridophytes and bryophytes, the spore wall serves a similar purpose, though in this case the course of passage is from the sporophyte, to a suitably moist location for germination. Because of the external nature of these reproductive systems, plants have had to evolve fairly sophisticated and very resistant structures so as to ensure the successful delivery of the gametophyte to an appropriate receptacle. The cell wall (exine) of the pollen grain and the fern spore provides this function.

2.31 The Exine

The living pollen grain of an angiosperm has a wall that is made up of two layers (Figure 2.1). The outer layer is called the *exine*. It is composed of a substance called sporopollenin, a complex polymer of carotenoids and carotenoid esters with oxygen (Brooks and Shaw, 1968), and is one of the most resistant organic compounds known. The inner wall is called the *intine*, and is made of cellulose. The interior of the pollen

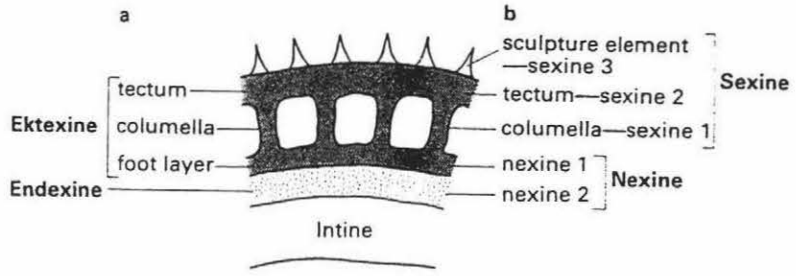

Figure 2.1 The prevailing terminologies used to define the pollen grain exine a) after Faegri (1956) and b) after Erdtman (1966).

grain holds the cytoplasm. In most cases the pollen grain will fail to reach its designated destination, in which case the living cell soon perishes. During the fossilisation process the cytoplasm and the intine are quickly destroyed, leaving the more resistant exine. It is this layer that is of most value to the palynologist, as this layer carries the characteristic form and sculpture which permits identification.

The exine can be further subdivided into an outer sculptured layer known as the *sexine*, and an inner unsculptured layer called the *nexine*. These terms were coined by Erdtman (1952) and differ slightly to Faegri's (1956) *ektexine* and *endexine* respectively. The sexine consists of small, radial, rod-like elements, the development and distribution of which allow for the range of morphologies exhibited within the exines of various species. These rod-like elements may support a roof-like structure known as the *tectum*. The tectum may be complete (tectate), partial (semi-tectate) or absent (intectate). Where the afore-mentioned rod-like elements support the tectum or any part of it, they are known as *columellae*. Where they are free standing they are given the name *bacula*. Gymnosperm pollen appear to have a wall stratification similar to that of the angiosperms, though there has been relatively less work done on these grains. Spores of pteridophytes and bryophytes do not resemble angiosperms in their wall structure. Their walls often appear laminated throughout and bear no columellae. Spores may however contain a *perine* which is a layer outside the exospore (Devi, 1980).

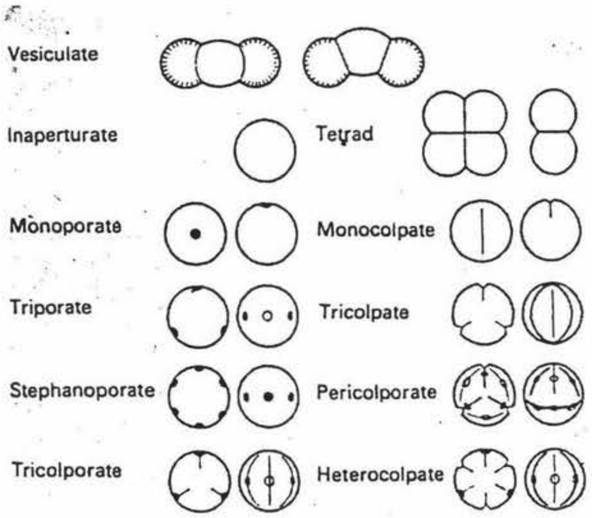

Figure 2.2 Examples of the more common morphological classes based on the arrangement of apertures. The left hand drawing in each pair shows the polar view, while the right shows the equatorial view (from West, 1971).

2.32 Apertures

The outer wall of a pollen grain may contain areas where the exine is thin or missing. Such features are known as apertures. The shape, size, number and distribution of apertures are of great use in the classification and identification of pollen grains (Figure 2.2). There are two types of apertures - *pori* (pores) and *colpi* (furrows). Pores are generally circular in shape, while colpi are long, boat shaped features, usually with pointed ends. Grains with pores are termed *porate*, while those with colpi are known as *colpate*. Grains may contain both aperture types, and where these overlap they are termed *colporate*. Pollen grains without apertures are termed inaperturate (e.g. *Callitriche*). The number of apertures may vary from one (e.g. *Ascarina lucida*), to over fifty (e.g. Convolvulaceae). Grains are usually classified initially using the number of apertures present. The prefixes mono-, di-, tri-, tetra-, penta-, and hexa-, are attached to the above terms to indicate the number of apertures present. Those with more than six apertures are given the prefix poly-. In most cases the apertures are located at equal distances around the equator of the grain. This arrangement is given the prefix stephano-. If the apertures are scattered all over the surface it is given the prefix peri-.

By definition spores do not have apertures, as these are features of the sexine and nexine. Instead spores have fissures called *laesurae*, which are found on the proximal face. These are usually formed at the junction where the spores adjoin in the tetrad.

Three laesurae occur if the spore has formed in tetrahedral tetrads (trilete spores e.g. *Cyathea*), while only one is present on spores formed in trigonal tetrads (monolete spores e.g. *Phymatosorus*) (Large and Braggins, 1991).

The function of apertures is rather a moot point. Three reasons are suggested by Faegri and Iversen (1989). Firstly, they form a weak section in the pollen wall through which the pollen tube can emerge at germination. Secondly, they accommodate for changes in volume under differing hydrologic conditions. Thirdly, they facilitate the exchange of substances between the grain and its surroundings, especially recognition proteins which ensure the pollen grain germinates only on a compatible stigma (Barnes and Blackmore, 1986).

2.33 Sexine sculpturing

Aperture and laesurae character is often the first criterion for classifying pollen grains and spores (Cranwell, 1982). Pollen grains and spores can be further divided by examining the sculpturing of the sexine. As stated earlier, the sexine is composed of columellae and/or bacula. The shape and size of these elements can facilitate further classification (Figure 2.3). Where grains are intectate and the bacula are club shaped they are termed *clavae*; sharply pointed bacula are termed *echinae*; bacula with swollen heads are termed *pila*; while short globular elements are termed *gemmae*. The sexine elements are not always rod-like. They may resemble small warts (*verrucae*), tiny irregular lumps (*scabrae*) or smaller features (*granules*). An apparently smooth surface is termed *psilate*, though under the electron microscope these grains usually have very fine surface features. On some grains the occasion arises where the columellae join in two directions to form winding walls, known as *muri*. The spaces created between the muri are called *luminae*. This pattern may form a vast network across the grain's surface. Where the resulting pattern is polygonal it is termed *reticulate*. If the muri and lumina run parallel to each other it is termed *striate*, while *rugulate* is the name given to patterns which fall between these two.

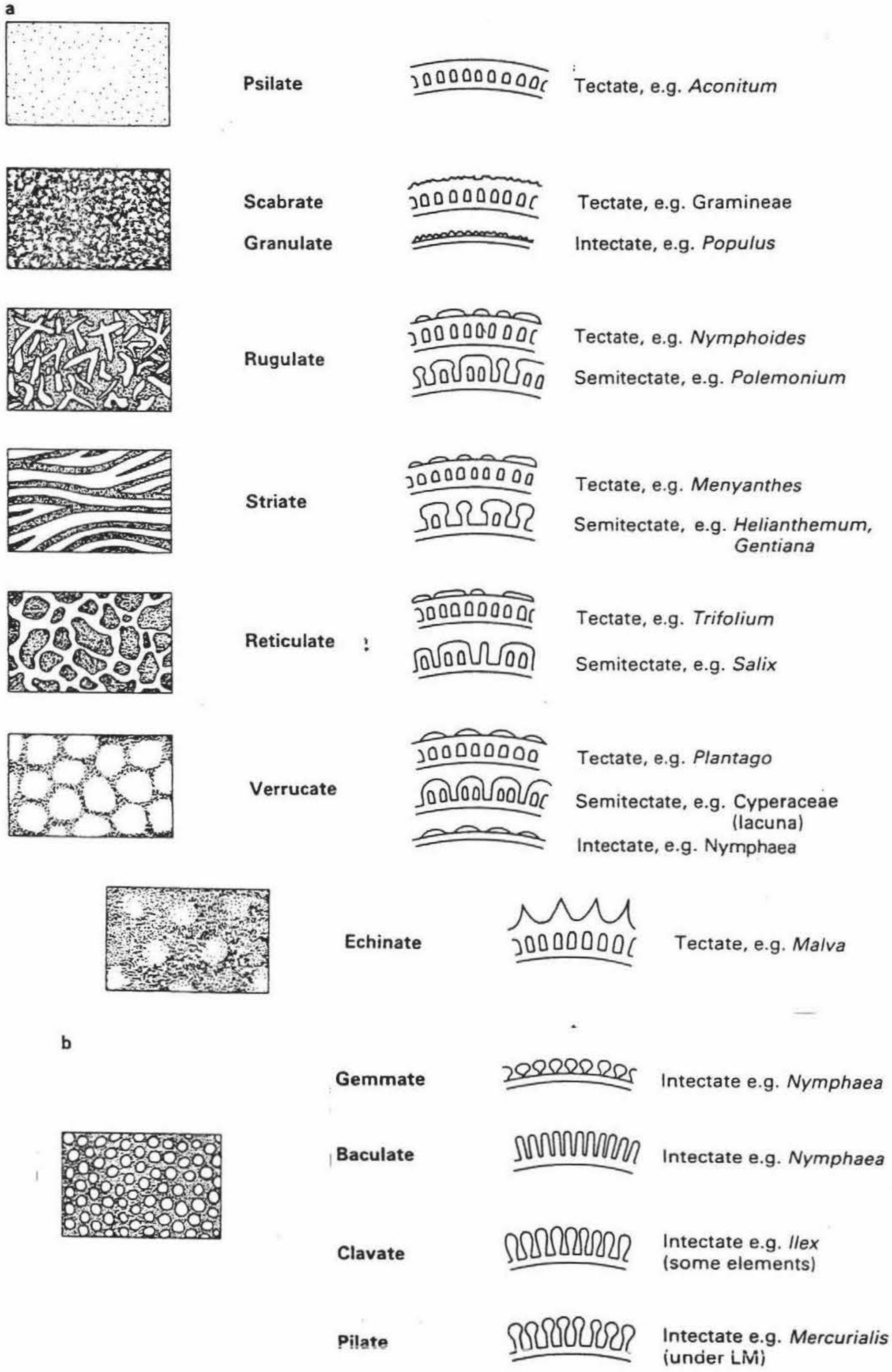

Figure 2.3 Diagrams of sculpturing elements visible in surface view and optical sections showing possible underlying exine types. Raised areas are shown as light areas in the left hand drawings (from Moore *et al.*, 1991).

2.34 Size and shape

Pollen grains and spores fall typically into the size range between 10 and 80 microns (µm). Size cannot always be relied upon as a feature for distinguishing between different species given the high degree of variability exhibited, even within a species (Harris, 1956). There are, however, some exceptions. For example, *Prumnopitys ferruginea* may be differentiated from other New Zealand podocarps on the basis that the corpus breadth and total length ranges of its pollen grains do not over lap with the same dimensions on the grains other podocarp species (Pocknall, 1981b).

Shape may also be used in making basic distinctions between pollen groups (though shape may be subject to a degree of variability also). Shape is often influenced by the position and number of aperutures and laesurae. The most frequently occurring morphology is the tricolporate form of which there are many New Zealand examples (e.g. *Pseudopanax* spp.). Shape may be helpful but not always diagnostic in differentiating between tricolporate grains. Some tricolporate grains are more triangular in polar view (e.g. *Leptospermum*) while others are more circular in polar view (e.g. Pittosporaceae). Pollen of the Podocarpaceae family have a characteristic vesiculate morphology, with characteristic wings or air bladders known as *vesicules* or *sacci*. Pollen grains of the New Zealand members of the Fagaceae family are stephanocolpate and may appear as hexa- to pentagonal in polar view. New Zealand also has a number of species with composite tetrahedral grains (e.g. *Dracophyllum* spp.).

By using the above features it is possible to confidently identify both recent and fossil grains and spores.

2.4 Pollen production, dispersal, sedimentation and preservation

The interpretation of fossil pollen assemblages cannot begin until one has considered the dynamics of pollen production, dispersal, sedimentation and preservation and how these vary between taxa and between sites. Unfortunately pollen percentages do not correspond directly to vegetation percentages. In addition to random error, pollen percentages are affected by production bias and dispersal bias (Prentice, 1985). Preservation bias should also be added to these when studying fossil assemblages. This predicament has been a major problem for the palaeopalynologist. Modern pollen rain studies have come some way toward making this problem somewhat less perplexing. These studies are discussed in this section.

2.41 Pollen production and dispersal

The production of pollen by different species is variable and is dependent on the mode of pollination (West, 1971). The aim of pollination is to transfer pollen from the male reproductive organs to the female ones. This involves the transfer of pollen from the anthers to the stigma in angiosperms and from the microangiophores to the micropyle in gymnosperms. There are four recognised methods of pollination: self-pollination (autophily), pollination by water (hydrophily), pollination by animals (zoophily) and pollination by wind (anemophily). Generally taxa which subscribe to the most specialised modes of pollination produce the least pollen. Autophily and hydrophily can be considered the most specialised modes of pollination. The exines of such pollen grains tend to be very thin. This, combined with low primary production, means that they are rarely encountered in fossil sequences. Pollen types belonging to the other two pollination modes are the most important in palaeopalynology as they are most frequently encountered in the analysis of pollen bearing sediments. Some zoophilous species may, however, exhibit a high degree of specialisation in terms of the pollination vector they select i.e. they may depend on one particular animal only to transfer their pollen. Some zoophilous species may however produce large amounts of pollen, such as to be comparable with anemophilous species. Thus, zoophilous flowers comprise all types from species never to be expected in pollen analysis to those regularly encountered (Fægri and Iversen, 1989). Insects (entomophily), birds (ornithophily) and bats are the most common zoophilous pollinators.

Because of the nature of wind pollination, anemophilous species generally produce the greatest quantities of pollen so as to facilitate a regular distribution of grains over a wide area (Fægri and Iversen, 1989). As well as being produced in large amounts, their pollen is well dispersed. The pollen of anemophilous species is therefore well represented in the pollen rain and it follows that they are also the most commonly encountered in the analysis of fossil sequences. The pollination vectors of New Zealand taxa are discussed in the modern pollen rain section (Chapter Five).

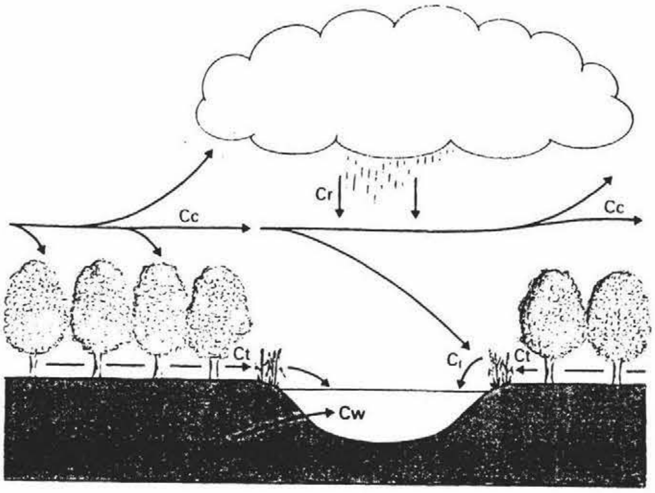

Figure 2.4 Diagram showing the various sources of pollen influx to a small lake or swamp within a forested landscape (after Tauber, 1968 and Moore *et al.*, 1991) **Cc** ~ canopy component **Ct** ~ trunk space component **Cl** ~ local component **Cr** ~ rain component **Cw** ~ secondary component transported by water.

2.42 Pollen dispersal dynamics

Any interpretation of fossil pollen assemblages needs to take into account the dynamics of pollen dispersal. Such knowledge will help determine the pollen catchment area. Pollen grains may travel along any of a number of pathways before eventually becoming incorporated into a deposit. Henrick Tauber made the first major contribution to the study of taphonomy (pollen dispersal). Tauber (1965) developed a model to account for pollen movements in forested areas. He identified three main components - trunk space, canopy and rain components (Figure 2.4). The trunk space component (Ct) consists of that pollen which falls from the canopy or is produced by shrubs and herbs beneath. It is carried along by sub canopy air movements. The canopy component (Cc) contains pollen produced in the canopy (or any pollen which escapes from below). It is moved along by air currents above the canopy. Deposition will eventually occur where a break in the canopy is large enough to create an adequate aerodynamic interruption (e.g. a reasonably sized lake) (Moore *et al.*, 1991). In some cases turbulent thermals may lift grains into the upper atmosphere where they can travel very long distances. The last component is the rain component (Cr). This component comprises pollen removed from the atmosphere by the condensation of water vapour around pollen grains which fall to the earth as rain drops.

Moore *et al.* (1991) add a local component and secondary component to Tauber's model. The local or gravity component (Cl) consists of pollen from local sources i.e. plants growing on or in very close proximity to a site. These are commonly aquatic and wetland species. The secondary or inwashed component (Cw) accounts for pollen brought to a depositional site by water courses outside the immediate area of study. This component can be very important and should not be overlooked. In one particular study, Jacobson and Bradshaw (1981) found that 85% of the pollen deposited in a small lake was derived from a stream which flowed into the lake. Inwashed components can be useful where the aim of the study is to create a regional vegetation history, provided tributaries are not delivering older grains eroded out of older deposits in the catchment. In some cases derived pollen can be detected due to its corroded state. In other instances derived pollen may be found to belong to species that have long been extinct (provided the sediment being studied post-dates that of the known extinction). Pollen grains belonging to the *Brassospora* group are often encountered in sites around New Zealand, where inwash components exist. Such grains are almost certainly derived from older sedimentary deposits as it is known that this taxon has been extinct in New Zealand since the early Pleistocene (Mildenhall *pers comm.*). Sites with numerous or significant tributaries should be avoided where a project aims to detail the local vegetation history.

Jacobson and Bradshaw (1981)have shown that the size of a site can influence not only the amount of pollen delivered to an area, but also the provenance of that pollen with reference to the above components. Their model (Figure 2.5) shows that larger receiving bodies get a greater proportion of their pollen from regional sources, with significant contributions from the canopy and rain components. Smaller sites receive greater amounts of pollen from more localised sources, with larger contributions from the trunk space and local components. The degree of inwashed pollen will invariably be influenced by the number and/or size of water courses running into the area.

In terms of distance most studies show that unless the air is turbulent, a large proportion of pollen reaches the ground within a few tens of metres from its source, with tall emergent trees' pollen settling furthest away. 95% of all pollen settles well within 1km of the source (Traverse, 1988). Faegri and Iversen (1989) state that the natural limit of aerial pollen dispersal is somewhere between 50 and 100km, though they

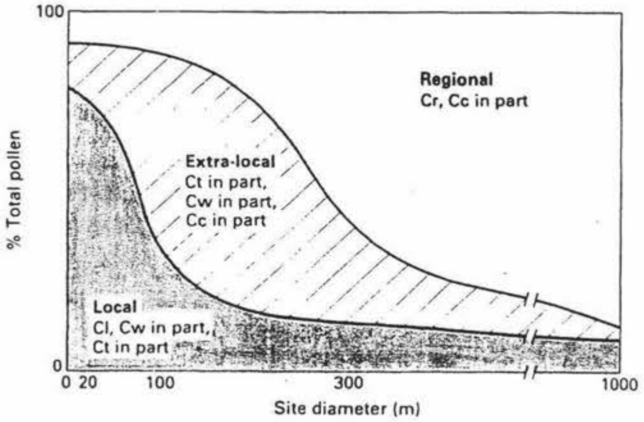

Figure 2.5 Relationships between the size of a site (with no inflowing streams) and the various sources of pollen entering it (after Jacobson and Bradshaw, 1981).

also acknowledge the fact that the greatest quantities are deposited long before this limit is reached.

2.43 Pollen sedimentation and pollen preservation

Not all sites are suitable for pollen analysis. The best sites are those in which pollen preservation is good and disturbance is minimal. The exine of the pollen grain may be rapidly degraded under oxidising conditions, and/or conditions in which microbial and invertebrate activity is high. Where such conditions are at a minimum e.g. anaerobic, saline or very dry conditions, pollen exines and spore coats will survive (Moore *et al.*, 1991). Preservability is also dependent on the amount and quality of sporopollenin in the exine (Traverse, 1988). Ideally the sediments at a site should have developed in a stratified manner with a minimum of disturbance and erosion, so as to represent a temporally continuous sequence of deposition. Sedimentary sites most predisposed to these conditions are peat bogs and lakes. For this reason palaeopalynologists have used these sites primarily for the investigation of past vegetations, climates and environments.

Sedimentary environments are typically divided into two types based on the origin of the constituting material. *Allochthonous* environments are those consisting of material which has originated elsewhere and has been deposited or redeposited. *Autochthonous* environments are those consisting of the remains of the vegetation and other organisms that once lived on the actual site of deposition (Fægri and Iversen, 1989). Lake sediments typically contain greater amounts of allochthonous material, while the material forming peat bogs can usually be regarded as autochthonous, though in reality each may contain components of the other e.g. a peat bog may have an inflowing stream bring material into the depositional environment, or a lake may have a floating mat of vegetation growing around the periphery which may be incorporated into the lake sediment, along with other resident micro organisms. Peat bogs can be further classified into three groups based on their development in relation to the water table. Where peat is formed below the water table it is termed *limnic*; in the periodically submerged zone between the low and high water levels it is termed *telmatic*; and where it forms above the high water level it is known as *terrestric*. A peat bog may progress through all of these stages as it grows. Further classification may be made by assessing the pH of the bog.

Open water environments are classified on the basis of nutrient availability. *Oligotrophic* bodies of water are low in nutrients, and thus have low levels of organic productivity. Water bodies that are high in nutrients are termed *eutrophic* and have correspondingly high levels of organic production. Organically rich muds, such as those found in eutrophic lakes, are ideal for pollen analysis, as they tend to accumulate slowly and pollen well preserve. The productivity of a basin is controlled by climate and topography. A shallow basin, with a warm climate, will be the most productive all other things being equal. Marine deposits are usually eutrophic, while in some enclosed brackish water basins nutrient concentrations can reach very high levels (*saprotrophic*) inhibiting organic production in which case a characteristic pungent anaerobic mud forms. Marine sediments on the whole are disappointing in terms of their pollen contents, though estuarine and deltaic sediments form exceptions (Fægri and Iversen, 1989).

Both peat deposits and lake sediments develop as stratified sequences, such that depth is related to time, though this relationship is rarely linear. Lake sediments may be subject to a degree of reworking, due to either detritus feeding animals (bioturbation) or due to the interaction of surface waves and other currents with the lake floor. This may result in recently deposited pollen being mixed with pollen of an older age as was noted at Lady Lake, Westland, by Pocknall (1980). The mixing of sediments from several years can be advantageous however as it may integrate annual differences in pollen production (Jacobson and Bradshaw, 1981). However, it may be a disadvantage in fine resolution palynology where the objective is to study vegetation dynamics over short periods of time (Green, 1983).

Other pollen bearing matrices of some importance to this study are soils and alluvium. Pollen preservation is generally poor in soils due to the prevailing aerobic environment. Where pollen does preserve it has usually been subject to vertical mixing through the profile by soil organisms. Pollen is more likely to preserve in soils with a pH less than five (Moore *et al.*, 1991). Pollen grains contained in alluvial and floodplain sediments are often derived from secondary deposition of eroded substrates (Cw) and should be interpreted with care and consideration. The secondary nature of alluvial pollen assemblages means they cannot be regarded as an immediate reflection of the contemporaneous vegetation, but gross trends can provide a record of vegetation history (Moore *et al.*, 1991).

Chapter Three:

THE HISTORY OF NEW ZEALAND'S VEGETATION

THE HISTORY OF NEW ZEALAND'S VEGETATION

Wardle (1991) states that the floristic history of New Zealand has been greatly influenced by four major events in time.

1) The break up of the Gondwana super-continent and the subsequent separation of New Zealand from the Australian and Antarctic landmasses in the Late Cretaceous.
2) The peneplanation of New Zealand during the early to mid Cenozoic and an accompanying marine transgression which subsequently reduced New Zealand to a number of small, warm, low lying islands.
3) The Kaikoura orogenic event and accompanying cooler climates of the Pliocene and Pleistocene which witnessed recurrent glaciations and periodic volcanic activity.
4) The arrival and impact of humans over the last thousand years.

These points, and their influence on the distribution of New Zealand's flora, are discussed in this chapter.

The modern vegetation of New Zealand is relatively depauperate in terms of its generic and specific diversity. It is characterised by a high degree of endemism with 85% of seed plant species being endemic, while just 12% of genera are endemic. There are estimated to be around 2300 species of vascular plants in New Zealand (Wardle, 1991) which compares rather poorly with Japan (a similar latitude north of the equator) which has 6000 species and New Caledonia, a much smaller landmass, which has 3000 species. Of the 100 genera of purely lowland habitat there are less than 130 species - an average ratio of 1.3 compared to a world average of 12.5 (Milliner in Mildenhall, 1980). The paucity of taxa in the New Zealand flora has been accredited to its isolation, glaciations of the Plio- and Pleistocene, and rapid post-late Miocene speciation of a relatively small number of genera to occupy a large variety of habitats to the exclusion of other taxa (Mildenhall, 1980). The New Zealand flora contains a large number of relict plants such as *Nothofagus*, *Agathis*, *Podocarpus* and *Dacrydium*. This is also thought to bear testament to New Zealand's isolation along with the persistence of moist temperate conditions since the Cretaceous (Fleming, 1975).

As the vegetation has been influenced so heavily by changing climate, marine transgression, and orogenic displacement, comments on these are integral in understanding the biogeography of New Zealand and have thus been incorporated into the discussion. It should be pointed out that many of the inferences on climate are derived from the information inferred by palynofloras.

3.1 THE MESOZOIC

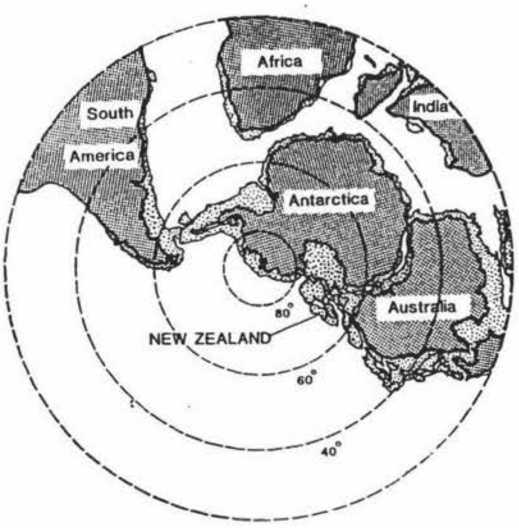

Figure 3.1 Gondwanaland configuration during the Late Cretaceous, after the commencement of continental rifting (from Singh, 1982).

3.11 The Late Cretaceous (c.98-67 million years ago)

According to Grindley (1978) New Zealand lay between the latitudes of 78° and 68°S during the Late Cretaceous. At this point in time it was attached to the Gondwana super-continent (Figure 3.1). The vegetation was probably subjected to low temperatures and long winter nights with high rainfall and cloud cover, as reflected by the dominance of palynofloras belonging to the temperate podocarps and beeches, along with high percentages of spores belonging to ferns and fern allies. The Late Cretaceous flora of New Zealand was very similar to that found in Australia, South America, and Antarctica at this time.

The Tasman Sea began to open around 90 million years ago, with final separation being achieved by 80 million years ago. By the end of the Cretaceous the mountainous terrains created by Early Cretaceous tectonic activity (Rangitata orogeny) had been substantially worn down by peneplanation. A marine transgression, initiated during the Late Cretaceous began to submerge much of New Zealand as it drifted north to reach more-or-less its present position relative to Australia (longitudinally) by the Paleocene (Crook and Belbin, 1978). The increasing isolation of New Zealand from the continents of Gondwanaland is reflected in the terrestrial flora which became increasingly endemic through the Cenozoic (67 million years ago to the present).

3.2 THE TERTIARY[1]

3.21 The Paleocene (c.67-58 million years ago)

Aside from speciation on the New Zealand landmass during the Tertiary (67 million to 1.7 million years ago) the flora was enriched by the accretion of further modern genera, the majority of which have affinities with Melanesia, Queensland and Malaysia (Wardle, 1991).

It has been logically suggested that the climate became increasingly oceanic and less seasonal, tending toward more temperate climes during this period. According to Mildenhall (1980) the podocarps were still common, though there was a decline in the palynofloras of *Fuscaspora* affinity. *Casuarina* and Proteaceae pollen are commonly encountered in Paleocene sediments. *Leptospermum* and *Metrosideros* referable pollen also appear in assemblages dated to this period. McGlone *et al.* (1996) by analogy, suggest that the proliferation of Proteaceous pollen during this period could indicate that New Zealand had highly leached soils and a dry or seasonally dry climate. This would work to restrict the more cool temperate *Nothofagus* taxa.

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[1] The Cenozoic Era has here been split into the Tertiary (Paleocene - Pliocene Epochs) and the Quaternary (Pleistocene and Holocene Epochs) Periods.

3.22 The Eocene (c.58-47 million years ago)

A trend toward falling temperatures around the world began in the early Eocene as evidenced by oxygen isotope data (Shackleton and Kennett, 1975) (Figure 3.2). This time also saw an emerging gap establish between the Australian and Antarctic continents, initiating the westerly ocean circulation and enhanced westerly airflow which have been characterised the region ever since (Kemp, 1978).

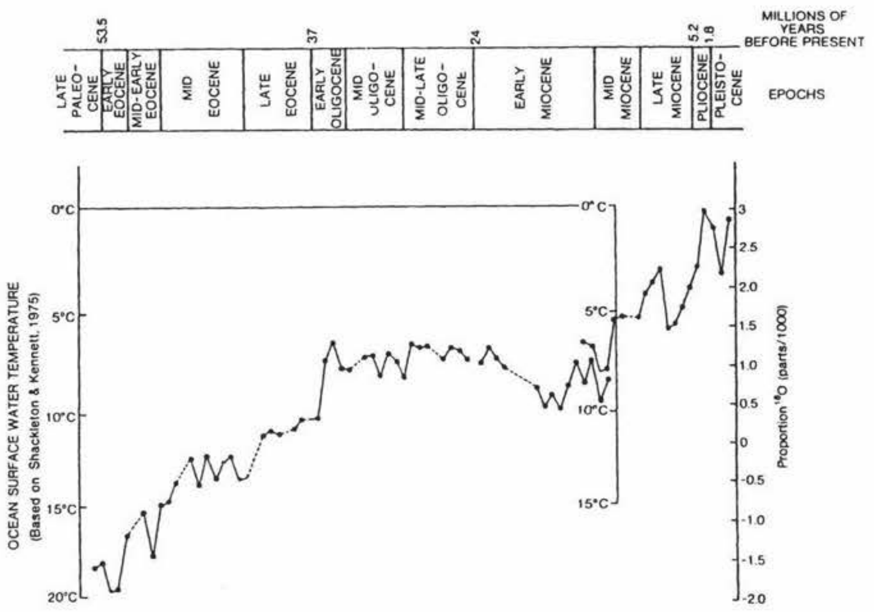


Figure 3.2 Cenozoic ocean sea surface temperatures based on Shackleton and Kennett (1975) in Singh (1982).

Beeches became dominant through this period, with pollen of *brassii* and *Lophozonia* (of which *Nothofagus menziesii* is the only remaining modern species) groups appearing for the first time in the record along with *Phyllocladus* and *Dacrycarpus*. The early dominance of *Fuscospora* beech was later supplanted by that of the *Brassospora* beech. By modern analogues with *Brassospora* species growing in the montane regions of New Guinea and New Caledonia, the climate has been inferred to be more aseasonal with moderate temperatures, low variability and high humidity (McGlone *et al.*, 1996), rather than strictly one of warmth. There appears to have been little floral diversity over New Zealand at this time with the assemblages of the North and South Islands being comparatively similar. A distinct cooling at the end of the Eocene is thought to have resulted in the extinction of many of the tropical and subtropical elements including a number of Proteaceous taxa (Mildenhall, 1980).

3.23 The Oligocene (c.37-24 million years ago)

The Oligocene saw the New Zealand landmass migrate north from 41°S to 35° S. The marine transgression initiated in the late Cretaceous was now at its greatest extent over New Zealand which was now reduced to a low lying archipelago, with possibly only Otago and Southland remaining above sea-level (McGlone, 1985). This Oligocene landscape was now an ancient remnant of that which separated from Gondwanaland. It was infertile, leached and everywhere close to the sea (McGlone *et al.*, 1996).

Temperate taxa were common including Lophozonia beeches, *Weinmannia*, *Pseudowintera*, Ranunculaceae and Apiaceae. Pocknall(1989) found evidence to suggest a great proportion of what now forms the southern half of the South Island was covered by large tracts of coastal swamp dominated by *Sparganium*, palm and angiosperm genera now found only in the subtropics. *Brassospora* beeches were rapidly diversifying under moist, equable conditions which clearly suited their proliferation. New genera to appear included *Myrsine*, *Coprosma*, *Laurelia*, and the Restionaceae family.

3.24 The Miocene (c.24-4.8 million years ago)

New Zealand now began to emerge from the marine transgression that had insidiously submerged much of the terrestrial environment over the previous 75 million years. A wide range of floral assemblages occurred during the early Miocene, dominated by *Brassospora* beeches which diversified further, Myrtaceae, *Casuarina*, Podocarpaceae, Palmae, *Macaranga*, Sparganiaceae and tree ferns (Mildenhall, 1980). This increasing floral complexity is thought to have been related to the increasing surface area and elevation available in the early mid-Miocene and the complex and dynamic environments that this created (McGlone *et al.*, 1996).

The mid- to late Miocene saw marked fluctuations in temperature (Fleming, 1975) (refer to Figure 3.2). Late Miocene pollen assemblages show a distinctive change with many herbaceous taxa appearing and temperate taxa becoming prominent (Mildenhall and Pocknall, 1989). The appearance of the genus *Halocarpus* is attributed by Mildenhall (1980) to a change in habitat or speciation of *Dacrydium* rather than migration from offshore. A number of angiosperms first appear in the Miocene, including *Fuchsia* and importantly Asteraceae (Tubuliflorae - shrub type), while the pollen of Asteraceae (Liguliflorae - herb type) was absent in pollen assemblages until the latest Miocene. Other important first appearances include *Alectryon*, *Pittosporum*, *Muehlenbeckia*, *Haloragis*, *Melicytus* and Chenopodiaceae.

The *Brassospora* group of beeches decline in both abundance and diversity toward the end of the Miocene and the beginning of the Pliocene. According to McGlone *et al.* (1996) the *Fuscospora* group became more abundant, but no more diverse.

3.25 The Pliocene (c.4.8-1.7million years ago)

The temperature fluctuations of the late Miocene gained in tempo and intensity during the Pliocene, while a new phase of tectonic activity (Kaikoura orogeny) began to uplift the Southern Alps, which were subsequently subjected to glaciation during cool periods. For much of the early late Miocene and early Pliocene, the south of the North Island (below 39 ° S) remained submerged apart from a number of islands in the eastern Wairarapa (Kamp, 1992).

An increased variability in the climate of the Pliocene is suggested by the rapid changes in vegetation types within sequences dating to the time. Shrubland and grassland communities were becoming more prevalent at times and are believed to have periodically extended to sea level. Through the Pliocene the flora was gradually depleted of taxa with tropical and subtropical affinities (McGlone, 1985). This included the *Brassospora* beeches which retreated to the north of the North Island before their final demise (Mildenhall, 1980). In late Pliocene and early Pleistocene sediments only occasional *Brassospora* pollen (usually *N. cranwelliae*) are encountered, the majority of which are thought to be recycled. Wardle (1968) suggests that their extinction in New Zealand resulted from their failure to keep pace with climatic fluctuations of the period, rather than intolerance to cold climates *per se*. Generally the flora was dominated by podocarp - beech forest (*Dacrydium* and *Fuscospora* especially) in which cool temperate taxa such as Myrtaceae, were assuming a greater dominance. New taxa to appear include *Wahlenbergia*, *Gentiana*, and *Epilobium*. Mildenhall (1999) found Araucariaceae (*Agathis?*) dominated assemblages within the Kowai Formation in the Mackenzie basin, suggesting, by modern analogues with Kauri forests in the North Island, that average annual temperatures could not have been too much lower than 13°C with a minimum annual rainfall of no less than 1000mm. It is noted that edaphic conditions may have had some influence on their distribution and should be considered when inferring climate parameters. The presence of *Acacia* (Mildenhall, 1972) from the late Pliocene until the mid-Pleistocene suggests that the conditions may have been dry during the cold periods (Singh, 1982).

3.3 THE QUATERNARY

The environmental record improves through this period and indeed into the Holocene, due to the greater survivorship of younger polliniferous sedimentary deposits. Thus, the spatial resolution and temporal continuity of pollen diagrams around New Zealand is greatly improved, especially in the late Quaternary, allowing for a more detailed assessment of the floral and climate history. This body of information will underpin many of the findings presented in this project.

3.31 The early to mid-Pleistocene (c.1.7-0.128 million years ago)

The Pleistocene was characterised by a number of recurrent cold glacial and warm interglacial climates, upon which were superimposed shorter periods of cooling and warming of a greater frequency, but generally smaller amplitude, known as stadials and interstadials respectively. It has been suggested that as many as 20 cycles occurred during the last 2 million years, based on glacio-eustatic sea level curves (Beu and Edwards, 1984). Orbital parameters, through their effect on insolation changes, are regarded as one of the major forcing functions for global environmental changes through the Quaternary glacial-interglacial cycles. Three major components are recognised, firstly the eccentricity of the orbit, operating on a cycle of about 96000 years, secondly axial tilt, which operates on a cycle of about 42000 years and the procession of the equinoxes with a periodicity of about 21000 years (Dodson, 1998). There is abundant terrestrial evidence for cycling cold and warm climates in New Zealand during this period. Suggate

(1990) provides a good review of the stratigraphic evidence found in the New Zealand landscape. Milne's (1973) pioneering work on loess deposits covering terrace surfaces of the Rangitikei River formed the basis for later loess and palaeosol chronologies which have been summarised by Pillans (1991). Other evidence can be found in glacial moraine deposits and cirque-floors (Gage, 1965). In the marine record glacial and interglacial cycles have been detected using oxygen isotope curves calculated using ratios of ^{18}O to ^{16}O in carbonaceous marine organisms (Shackleton, 1987). Oxygen isotope (OI) stages (Figure 3.3) are more commonly used for discussing Quaternary climates as they can transcend local nomenclatures.

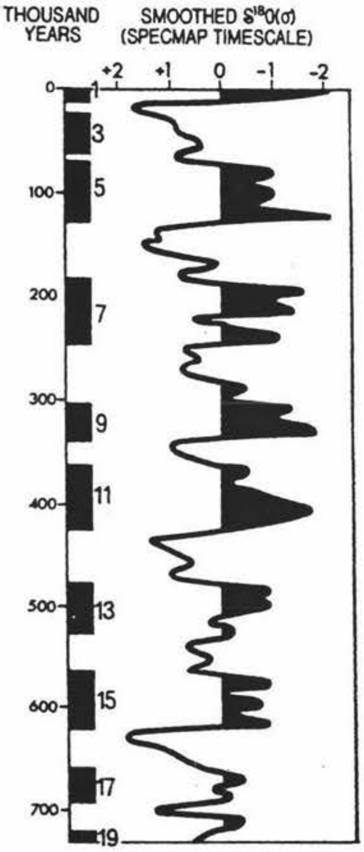


Figure 3.3 Oxygen Isotope stages, with negative values indicating warmer periods (after Imbrie *et al.*, 1988 in Pillans, 1999).

The recurrence of cool and warm climates on such a regular basis had a marked impact on the vegetation, forcing lowland and often montane forest species to contract and retract, while effectively eliminating many of the last remnant tropical and subtropical taxa from the archipelago. A diverse range of palynofloras from the early Pleistocene reflect a more variable climate. As mentioned above, *Acacia*-Myrtaceae assemblages probably indicate arid environments in the north, while shrublands dominated by *Phyllocladus* and the now extinct alpine conifers *Microcachrys* and *Microstrobos* covered much of the South Island (Mildenhall, 1973). Details of the flora (and flora inferred climate) of the early and mid-Pleistocene are somewhat fragmented due to the removal (or partial removal) of pollen bearing sediments of this age from the sedimentary record by the physical processes of proceeding climatic cycles. Deposits from earlier glacial activity are most likely to survive only if subsequent events are of a lesser magnitude (Burrows, 1978). Tectonic uplift may, however, preserve older deposits from high stand marine erosion, as it has in southern Taranaki and Wanganui districts (Bussell, 1990; Bussell and Pillans, 1992). Discontinuous sedimentation is a particular problem for researchers working on terrestrial sites where unconformities in the stratigraphic sequence can represent unspecified lengths of time. Such problems were encountered with the Waipori core used in this project and are discussed in chapters 6 and 9. Palynology can often be called upon to solve unconformable breaks in older sedimentary units where extinct palynomorphs can be recognised and a minimum date assigned. Extinctions have been limited in the mid- to late Quaternary, though here a suite of relative and absolute dating techniques can be called upon. In terms of continuity, the most ideal sites for assessing the floras of the Pleistocene appear to be from the deep sea. Newnham *et al.* (1999) point out the advantages of offshore cores, but also note that they tend to represent a blend of onshore vegetation from different ecological regions. Samples generally contain a high proportion of robust pollen and spore types derived from vegetation growing close to rivers and the coast as opposed to that growing further inland. This should be borne in mind when assessing Heusser and van de Geer (1994) continuous pollen record spanning four glacial-interglacial cycles from 350 000 years BP to the present from an off shore drill site on the Chatham Rise. Their findings are reviewed here along with a number of terrestrial long cores and fragmented short cores representing shorter segments of time from the late mid-Pleistocene.

Temperatures cooler than the present are thought to have prevailed for 90% of the Pleistocene. Low sea-level stands exposed large portions of the continental shelf and land bridges connected the North and Stewart Islands to the South Island (see Figure. 3.6). According to Singh (1982), most of the changes in flora resulting from the

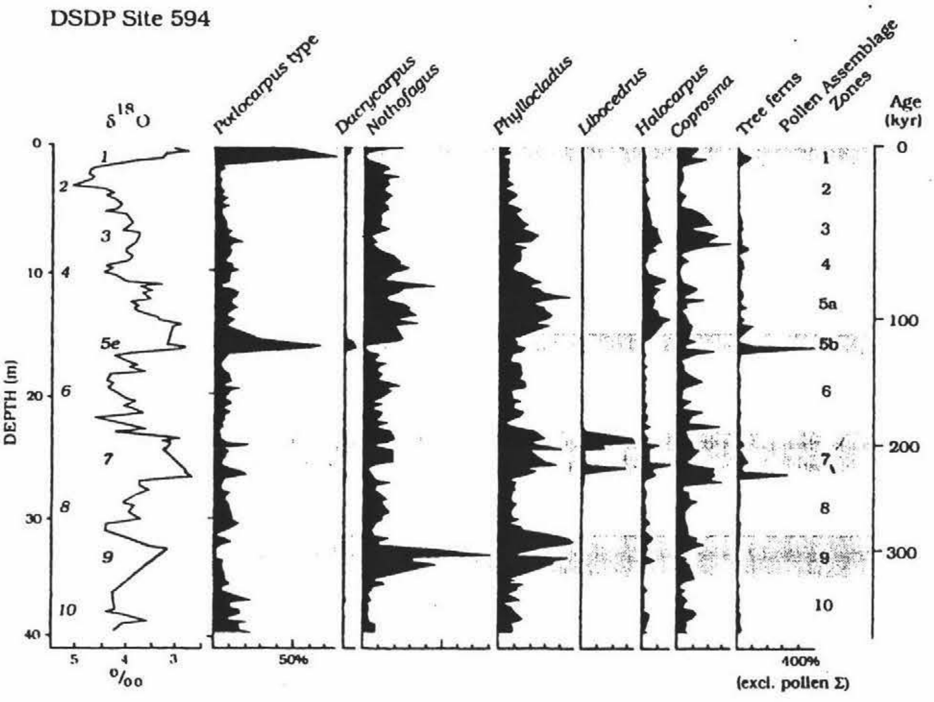


Figure 3.4 Arboreal pollen curves from offshore DSPD site 594, Chatham Rise, for the last c. 350000 years (Heusser and van de Geer, 1994).

lowering of temperature had already been accomplished by the early Pleistocene, so that the vegetation during the earliest interglacials had already started to look like that of the present. Mildenhall (1995) found a good correlation between pollen assemblages from the Hutt Valley basin and the oxygen isotope curves after transforming pollen assemblages using Harris *et al.* (1976) smoothed discriminant function analysis. This 300m discontinuous terrestrial core taken from Petone dates back as far as OI stage 11. Interglacials are generally recognised by full forest palynofloras dominated by *Dacrydium cupressinum*. *Nothofagus* shows a great deal of variation between interglacials, but tends to be at its lowest levels at both the coldest and warmest intervals of a glacial cycle, and most dominant during the intermediate phases, such as interstadials and the cooling phases of interglacials (McGlone *et al.*, 1996). Heusser and van de Geer (1994) found that the interglacial palynofloras of the mid- to late Pleistocene were characterised by notably different associations, in which one or more of the podocarps, beech, *Coprosma* and tree fern were found to dominate (Figure 3.4). Conversely the vegetation of the glacial periods tended to be dominated by similar assemblages of Asteraceae, Poaceae and a number of other herbaceous elements. The pollen percentages of forest taxa as a whole were found to exceed 20% during the cold glacials. This is thought by the authors to represent pollen influx from warmth demanding taxa taking sanctuary in sheltered coastal sites, possibly on the continental shelf. This is perhaps the first clear evidence in New Zealand for glacial refugia. Shulmeister *et al.* (1999) however, found little evidence to support a cooler penultimate interglacial (OI stage 7) on Banks Peninsula, where *Prumnopitys taxifolia* dominated the palynoflora, with understorey elements of *Coprosma* and *Myrsine* compared with Heusser and van de Geer's *Halocarpus - Libocedrus* dominated assemblage. The disagreement between the records has been attributed to differing marine and terrestrial sources of pollen (Shulmeister *pers. comm.*). At Banks Peninsula, OI stage 6 is characterised by initial abundance of *Prumnopitys taxifolia*, but this eventually gives way to what they term an unusual but not novel association between *Plagianthus* and *Phyllocladus*. Near Hawera, Bussell (1990) found a similar trend, with early peaks in podocarp and beech pollen, followed by a large peak in the Poaceae curve, though generally the assemblage is dominated by shrubs. These findings seem to point to a somewhat mild penultimate glacial period.

3.32 The late Pleistocene (128 000 yr to 24000 yr ago)

Published pollen data dating from the last interglacial - glacial cycle (OI stage 5-1) is somewhat more abundant for reasons discussed earlier. The vegetation movements and climatic inferences from this last cycle have often served, rightly or wrongly, as an analogue for previous glacial-interglacial cycles.

The last interglacial, known as the Kaihinu (Suggate, 1990) interglacial occurred between c.128000 and 80000 years (OI stages 5e - 5a). There is evidence to suggest that this period included three identifiable periods of milder climate as represented by the three marine terraces in South Taranaki which Pillans (1983) dated to this period and the oxygen isotope stages 5e, 5c and 5a. Near Westport, Moar and Suggate (1979) found that the palynoflora of the early Kaihinu interglacial were dominated by *Nothofagus menziesii*, later giving way to *Fuscospora* beeches and *Metrosideros*. Offshore, Heusser and van de Geer (1994) found pollen assemblages from OI stage 5e to be dominated by Podocarp pollen with associated peaks for *Dacrcarpus dacrydioides*, *Coprosma*, and tree ferns (refer to Figure 3.4). Bussell (1990) records a similar clearly warm climate flora in Taranaki, where initial abundances of *Dacrydium cupressinum*, *Ascarina lucida*, *Dacrycarpus dacrydioides* and *Metrosideros* are surpassed by *Prumnopitys taxifolia* suggesting a drier and less equable climate toward the end of OI stage 5e. On the west coast of the South Island, cooler, stadial conditions during the mid-Kaihinu interglacial, are reflected by the dominance by *Nothofagus* and increases in *Halocarpus*, Asteraceae and Poaceae (Moar and Suggate, 1996). Dickson (1972) records the final decline of forest taxa marking the end of the Kaihinu interglacial near Hokitika. Here *Fuscospora* beeches, *Dacrydium cupressinum*, and *Phyllocladus* give way to grassland taxa.

McGlone and Topping (1983) published pollen diagrams from the Tongariro region detailing the palynofloras of two interstadial periods. The first interstadial culminated around c.80000 years BP, and probably equates to OI stage 5a. The pollen record reveals a vegetation assemblage similar to that currently found in the upper montane zones of the plateau, namely *Libocedrus*, and other podocarps, especially *Dacrydium cupressinum* and *Halocarpus*. The climatic inference is cool and wet with temperatures as much as 2°C lower than present, based on modern analogues for the upper montane zone. Offshore moderate influxes of *Nothofagus* and *Phyllocladus* pollen characterise this period (Heusser and van de Geer, 1994). At Wellington *Dacrydium cupressinum* appears to have remained present locally throughout OI stage 5. In what is thought to be OI stage 5a, full podocarp forests, with traces of *Quintinia* and *Ascarina lucida* appear to represent a reasonably mild climate (Mildenhall, 1995).

Most authors agree that the period of marked cooling that heralded the Otiran Glacial (OI stages 4-2) began sometime prior to 70000 years BP. In the Tongariro region a period of harsher, cooler and drier climate (OI stage 4) is signalled by the initiation of severe erosion and by the spread of grassland-shrubland (McGlone and Topping, 1983) and anomalously high percentages of *Fuscospora* pollen which are attributed to fluctuations in and between local production and long distance dispersal of this pollen type. Several diagrams from the Bay of Plenty show that *Fuscospora* beeches (*solandri* var. *cliffortioides*?) were prevalent during OI stage 4. This assemblage gives way to one where *Nothofagus menziesii*, *Prumnopitys ferruginea*, *Prumnopitys taxifolia* and *Dacrydium cupressinum* become more widespread, a feature McGlone *et al.* (1984) attribute to a wetter climate, with an associated increase in temperature and equability. Such a warming probably represents the beginning of the following interstadial period (OI stage 3) which post-dates the deposition of the Rotoehu Ash, dated at ~55000 years BP (Wright *et al.*, 1995). In the Tongariro region this interstadial appears to have been somewhat harsher than OI stage 5a, with a sub-alpine shrubland - grassland dominating, the most abundant shrubs being *Halocarpus*, *Phyllocladus*, *Cyathodes*, and *Dracophyllum*. McGlone and Topping suggest a relatively cool (but no more than 3°C below present) and dry climate.

From an integrated interpretation of core data from offshore sites north east of the North Island, Wright *et al.*(1995) split OI stage 3 into two zones. Evidence from the earlier zone (OI 3b - c.57000-43000 years BP) suggests an apparently warmer period, where full conifer/hardwood forest covered the Northland Peninsula. *Agathis australis* and *Dacrydium cupressinum* were dominant, while *Libocedrus plumosa* and *Cyathea smithii* were also important features in the flora. In the Bay of Plenty pollen sequences from this time reveal a partially forested landscape in which *Nothofagus* and sub-alpine scrub was common, while in the Gisborne area podocarp/hardwood taxa predominated (McGlone *et al.*, 1984). Offshore, OI 3a (43000-24000 years BP) represents a period of gradual cooling in which the afore-mentioned elements decline, while *Fuscospora* and *Halocarpus* expand along with a number of species common in shrubland-grassland assemblages. This seems to correlate with pollen data from the west coast of the South Island, where *Dacrydium cupressinum* dominant forest was being replaced from 30000 years BP by the *Fuscospora* beeches, and eventually *Nothofagus menziesii* at Hokitika (Moar and Suggate, 1973). In the north-west Wairarapa, a regional *Nothofagus menziesii* forest prevailed between 41000 and 24000 years BP, suggesting a cool montane climate (McLea, 1990).

3.33 The Last Glacial Maximum (c.25000 - 15000 years BP)

A number of reviews (McGlone, 1988; McGlone *et al.*, 1996; McGlone *et al.*, 1993) cover New Zealand's vegetational history from the Last Glacial Maximum (LGM) to the present. These reviews are combined here along with other papers to give a broad pattern of vegetation change over the last 25000 years covering both the harshest and warmest periods of climate known in the late Quaternary.

During the LGM annual temperatures were some 4-5°C lower than present. Snowlines in the Southern Alps were depressed 800m below those of the present (Porter, 1975; Soons, 1979) with similar estimates given for the Volcanic Plateau. Glaciers covered much of the Southern Alps, extending to sea-level on the central west coast of the South Island, while there is geomorphic evidence to support the presence of a reasonably extensive ice cap on the volcanoes of the Central North Island (McArthur and Shepherd, 1990). The evidence remains equivocal for the presence cirque glaciers on the Tararua Range (Shepherd, 1987). Below the altitudes of permanent snow and ice cover, periglacial processes were in operation eroding the steep uplands and supplying voluminous amounts of material to river systems which responded by aggrading to form many of the lower terrace treads found throughout many central and southern New Zealand river catchments. Wind blown silts picked up off these braided rivers formed thick deposits of loess upon terrace treads (Heerdegen and Shepherd, 1992). Though there is little direct evidence for changes in precipitation, cooler ocean temperatures would be expected to have reduced the amount of moisture carried by the wind (McGlone, 1988).

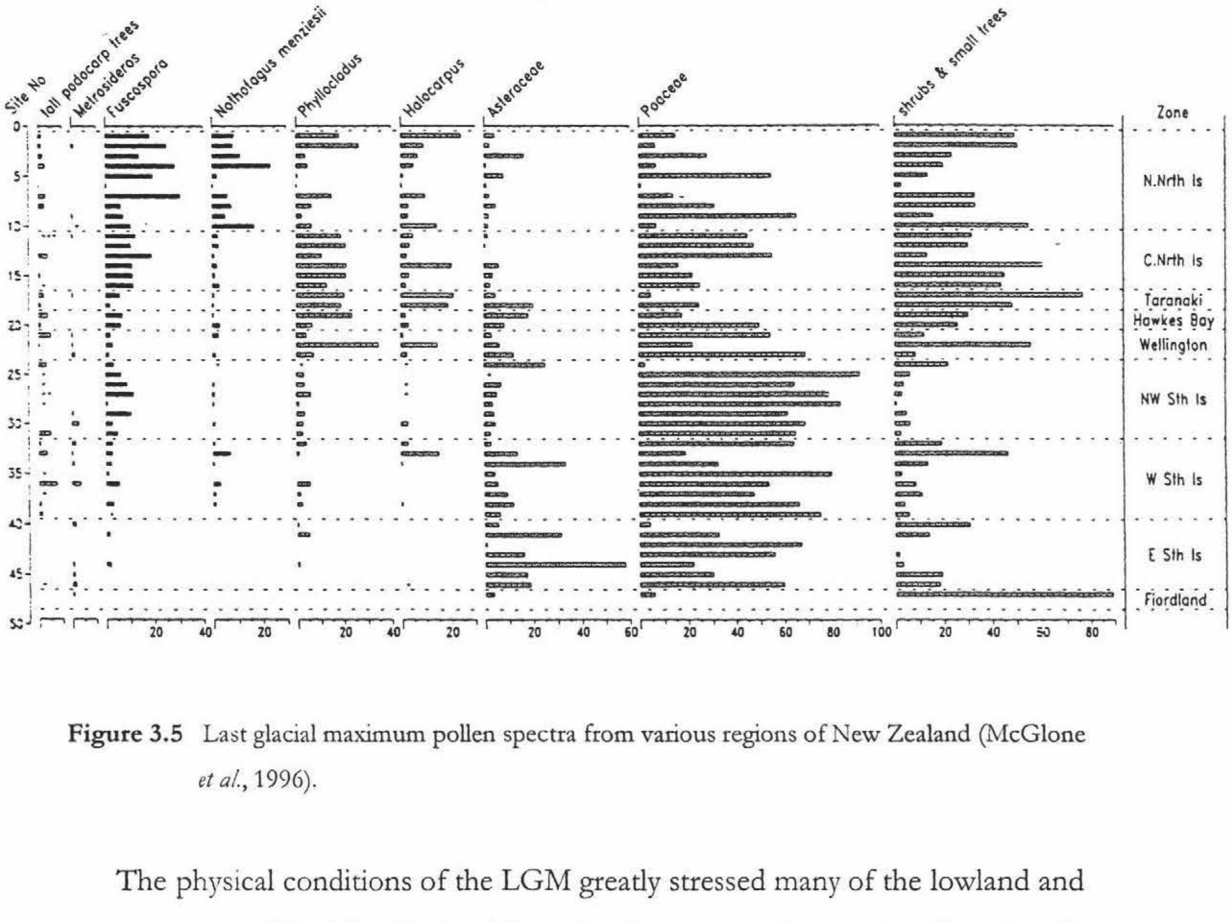


Figure 3.5 Last glacial maximum pollen spectra from various regions of New Zealand (McGlone *et al.*, 1996).

The physical conditions of the LGM greatly stressed many of the lowland and montane taxa of the New Zealand flora, forcing them to become locally extinct by retreating to the north or to contract into sheltered, relatively frost-free, north facing refugia. From the limited number of sites available dating to this period, most show a flora dominated by grass- and shrubland communities (McGlone *et al.*, 1996) (Figures 3.5 and 3.6). Shrubland was more prominent in the west, while grasslands were more

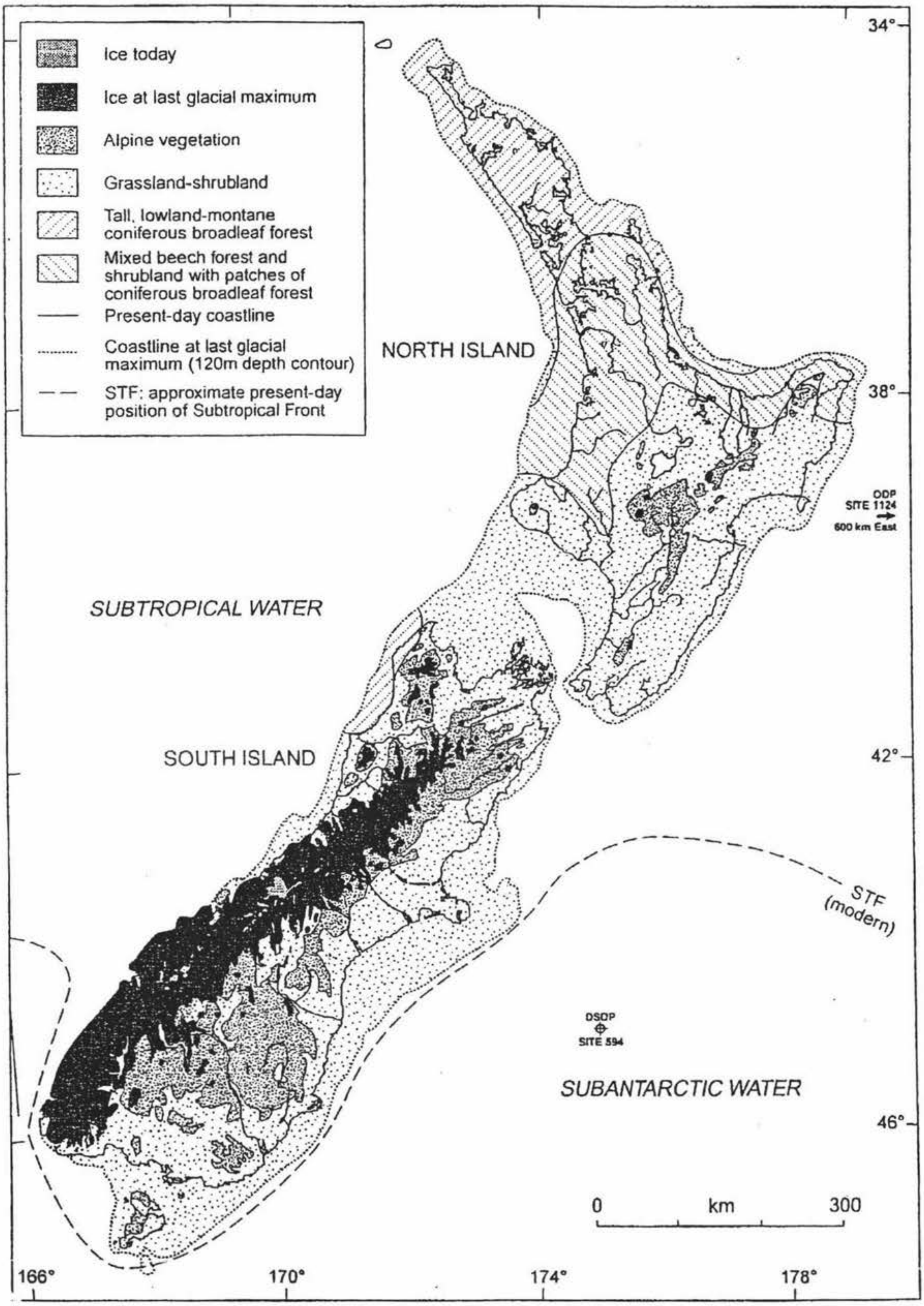


Figure 3.6 New Zealand vegetation and coastline position at the last glacial maximum - c. 20000 years BP (from Newnham *et al.*, 1999).

prolific in the east, a pattern attributable to lower rainfall and increased frequency of fire in the east (McGlone *et al.*, 1993). The main floral elements in these communities were Poaceae, Apiaceae, Cyperaceae, the podocarp shrubs - *Phyllocladus* and *Halocarpus*, *Coprosma*, *Myrsine*, *Dracophyllum*, *Hebe* and Asteraceae (both the shrub and herb types) (McGlone, 1988). *Nothofagus* is the most abundant tree taxon during this time, but rarely dominates the pollen rain except in the northern North Island where *Fuscospora* dominates at Hikurangi (Newnham, 1992) and in Waikato where *Nothofagus menziesii* predominates (Newnham *et al.*, 1989). At Cape Reinga, Dodson *et al.*(1988) found that full forest persisted at LGM in which *Dacrydium cupressinum* and *Metrosideros* dominated the pollen rain. In localities further south tree pollen is commonly recorded in low levels suggesting they were not entirely eliminated from these areas, but survived in patches where the local climate was favourable. It has been pointed out that a 4-5°C temperature depression would not have eliminated forest from as great an area as is suggested by the pollen evidence. Using modern analogues a temperature depression of 8°C would be required to create the observed distribution. According to McGlone (1988) such a depression can be discounted on the basis of macrofossil evidence. Instead other climatic forcers have been suggested such as drought, frequent outbreaks of cold polar airmasses, an intensification of the southern westerly winds (Heusser, 1989) and low atmospheric carbon dioxide values (Dodson, 1998). These may have augmented a temperature depression in restricting forest taxa (McGlone *et al.*, 1993).

3.34 The late Glacial (15000-10000 years BP)

The late glacial saw the rapid retreat of ice from those areas it had previously occupied (Suggate, 1990) and a warming of temperatures by about 4°C (McGlone *et al.*, 1996). The landscape became increasingly stable and rivers began to incise through their glacial deposits in response to a decrease in the load of material being supplied from the uplands. The postglacial marine transgression (PMT) was in progress, fed by the melt water of the world's glacial ice caps, submerging much of the continental shelf and recreating a multi-insular New Zealand. This period saw the progressive afforestation of much of New Zealand beginning in the north, where these early forests were dominated by podocarp-broadleaf species in which *Libocedrus*, *Nothofagus menziesii* and podocarp shrubs were well represented (Newnham *et al.*, 1989). *Prumnopitys taxifolia* was the most common podocarp tree, with *Dacrydium cupressinum* becoming increasingly well represented (McGlone, 1988). McGlone (1985) is quick to point out that there was no hint of a migratory influx and suggests that these taxa had survived locally and expanded from local centres as the climate permitted their release. Another interesting feature is that it appears that upland sites gained forest cover at the same time as or even slightly earlier than lowland sites in the same regions (McGlone *et al.*, 1993). Figure 3.7 shows the dates for the initiation of major increases of arboreal pollen. Close to 90% of the North Island was forested by 12000 years BP, though these montane forest associations were different from those that would prevail in the Holocene. According to McGlone and Topping (1977) the annual temperature seems to have been within 2°C of the present.

At 12000 years BP, afforestation of the central west coast of the South Island began, with the initial species being *Weinmannia* and *Metrosideros* (Moar, 1971; Moar, 1972; Moar and Suggate, 1973; Pocknall, 1980). Dense shrubland replaced the ubiquitous grassland throughout much of the south and south-eastern South Island between 12000 and 10000 years BP (McGlone, 1988). There appear to have been no significant reversals in vegetation trends between 12000 and 10000 years BP as have been detected in the Northern Hemisphere and possibly in South America (McGlone, 1995; Singer *et al.*, 1998). A brief but pronounced increases in *Nothofagus* and *Halocarpus* pollen curves at the expense of *Dacrydium cupressinum* and *Agathis australis* during this time in the offshore cores from the north-east North Island (Wright *et al.*, 1995) may provide evidence for a cooling event. This may, however, fall more neatly into the period of the Antarctic Cold Reversal which preceded the Younger Dryas by at least 1800 years (Blunier *et al.*, 1997).

3.4 THE HOLOCENE

3.41 The early Holocene (10000 - 7000 years BP)

Afforestation was near complete by 10000 - 9000 years BP with tall conifer-broadleaf forest expanding to cover much of the country (Markgraf *et al.*, 1992) with the exception of Central Otago which retained its dry grass- shrubland (McGlone and Moar, 1998) (see chapter four). *Dacrydium cupressinum* asserted itself as the most dominant podocarp in the west and north of the North Island and the west coast of the South Island where it could

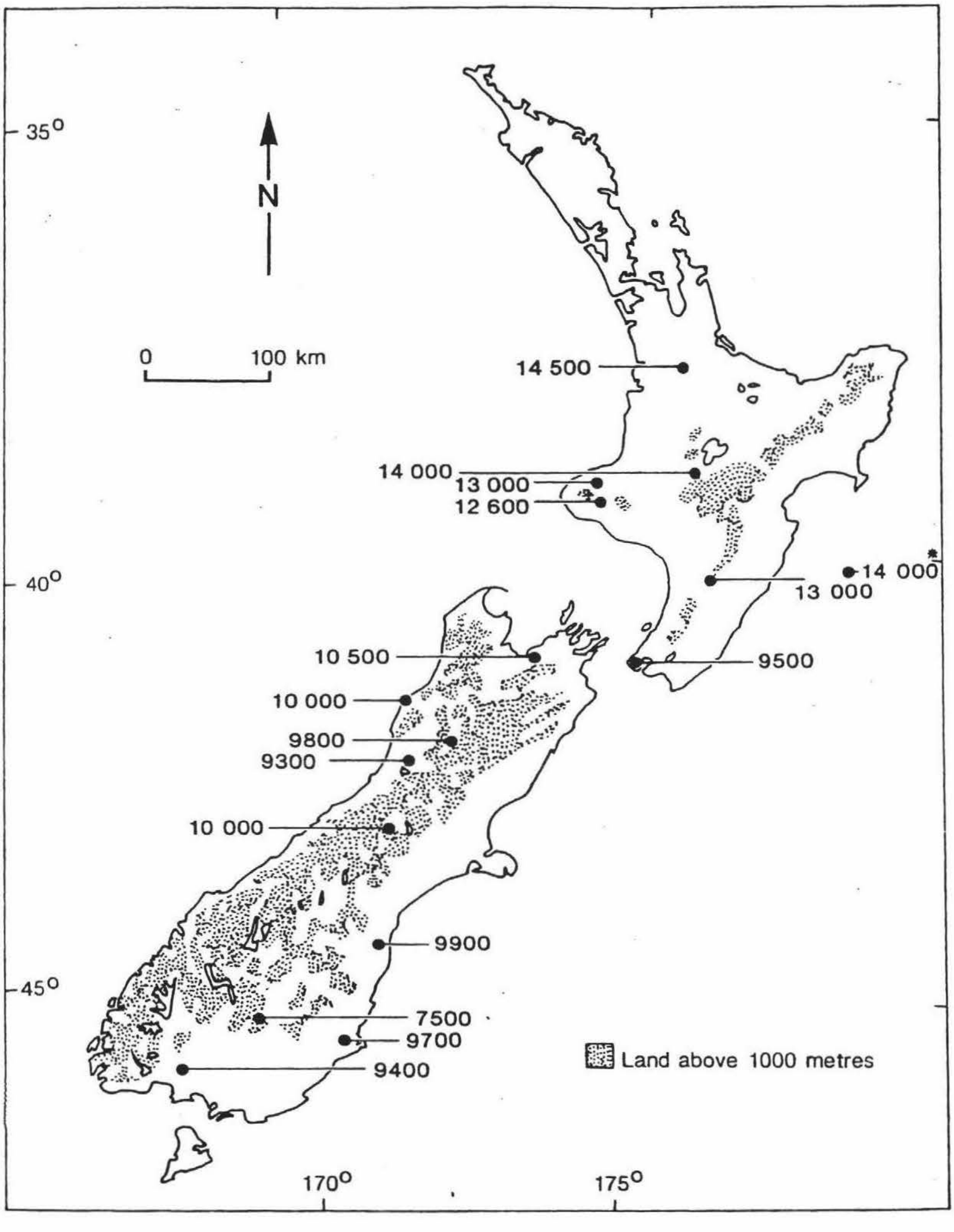


Figure 3.7 Dates (years BP) for the initiation of major increases in arboreal pollen (from McGlone, 1988).

be found in strong association with *Weinmannia* and tree ferns. Other common broadleaf elements were *Metrosideros* and *Ascarina lucida*. *Agathis australis* was dominant in the far north, while in the north-east forests were dominated by *Podocarpus-Prumnopitys* species (McGlone *et al.*, 1993). In the south-east effective precipitation was still lower than present, perhaps 30% less in some parts (McGlone and Bathgate, 1983), giving a competitive advantage to the drought tolerant podocarps - *Podocarpus totara* and *Prumnopitys taxifolia*, while *Dacrycarpus dacrydioides* spread onto fresh alluvial soils lying near to the water table. Common sub-canopy elements included *Hoheria*, *Plagianthus regius* and *Griselinia littoralis* (McGlone, 1988). According to McGlone *et al.* (1996) *Nothofagus* forests were restricted to edaphically or climatically unfavourable sites in the early postglacial due to competition from these complex tall and tree-fern rich conifer-broad leaved forests in the lowlands and by a variety of conifer low forests in the upland and interiors. In a number of places *Nothofagus* became regionally extinct, creating a number of so called "beech gaps" e.g. central Westland and Taranaki. The causes of such disjunctions (among others) are not simple and have been debated in the literature (Hasse, 1990; McGlone, 1985; Wardle, 1988a; Wardle, 1988b). The predominance of the emergent *Dacrydium cupressinum* and the canopy tree *Ascarina lucida* at a wide number of sites throughout this period is taken as evidence to support a mild, equable, frost free climate which was almost certainly less windy (McGlone and Moar, 1977; McGlone *et al.*, 1993). A number of publications based on varying types of evidence suggest temperatures were 1-2°C warmer than the present (Salinger, 1983). The synoptic explanation for the more equable, aseasonal climate is that the westerly and southerly wind-flow over New Zealand weakened, allowing northerly, anticyclonic systems to probe further south.

McGlone (1988) noted a number of important features regarding the nature of postglacial afforestation in New Zealand. The change from grass- or shrubland to forest appears to have been abrupt at any given site. Afforestation seems to have taken place at a regional scale, with altitudinal gradients appearing to play no great part in the progress of afforestation. In contrast, there is evidence that latitudinal gradients did have an effect (refer to Figure 3.7). Precipitation gradients appear also to have had no influence, with the expansion of central Westland podocarp forest occurring at the same time as those in Coastal Otago. From this McGlone concludes that though the gradients of temperature and precipitation influenced the type of forest which spread, they did not control the rate or time of spread. It is suggested that inhibiting aspects of the environment such as episodic unseasonal outbreaks of cold polar air, strong persistent winds and fire were responsible for keeping forest taxa in check, and that once these ceased or were reduced, forests were liberated from refugia and quickly spread at a rate related to the rate of successional processes within various environments.

3.42 The mid-Holocene (7000 to 3000 years BP)

From 7000 years BP the forests of New Zealand went through a series of changes in terms of their composition and structure. These are summed up by McGlone *et al.* (1993). Low forest replaced grass- and shrubland in all but the driest inland valleys of Central Otago. These forests were composed largely of *Prumnopitys taxifolia*, *Podocarpus cunninghamii*, *Phyllocladus alpinus*, and *Nothofagus menziesii.* In the coastal districts of the south-eastern South Island, *Dacrydium cupressinum* and *Nothofagus menziesii* began to spread indicating a significant increase in rainfall, with the entry of *Nothofagus menziesii* implying climatic cooling (McGlone and Bathgate, 1983; McGlone and Wilmshurst, 1999b; McIntyre and McKellar, 1970)(see Chapter Four). This is supported by expansion of *Libocedrus bidwillii* in the inland valleys of the Southern Alps. In the North Island a number of conifer and broadleaf species began to increase. Most notable of these is *Agathis australis*, which is believed to have spread from local pockets in which edaphic factors limited competition with other forest taxa. *Phyllocladus trichomanoides*, *Libocedrus plumosa*, *Knightia excelsa* (Mildenhall, 1979), *Nestegis*, and *Quintinia* were expanding at the expense of *Dacrydium cupressinum*, *Ascarina lucida* (McGlone and Moar, 1977) and *Dodonaea viscosa* (Moar and Mildenhall, 1988).

Perhaps the most definitive feature of the mid Holocene forest dynamics is the near ubiquitous spread of *Nothofagus* in upland areas (Figure 3.8). After being so limited during the early Holocene, *Nothofagus* began a period of locally well defined expansive phases in areas of moderate to high rainfall (McGlone, 1988). In the central and southern North Island and the northern South Island *Fuscospora* forest expanded greatly. This spread appears not to have been synchronous (due to the variety of species involved and their differing ecological requirements), but seems to have occurred most strongly after 6000 years BP. At a number of locations, complex, diverse podocarp- broadleaf forests were overwhelmed by often near monospecific forests of *Nothofagus* (McGlone *et al.*, 1996). As noted above, it was *Nothofagus menziesii* that expanded rather than the

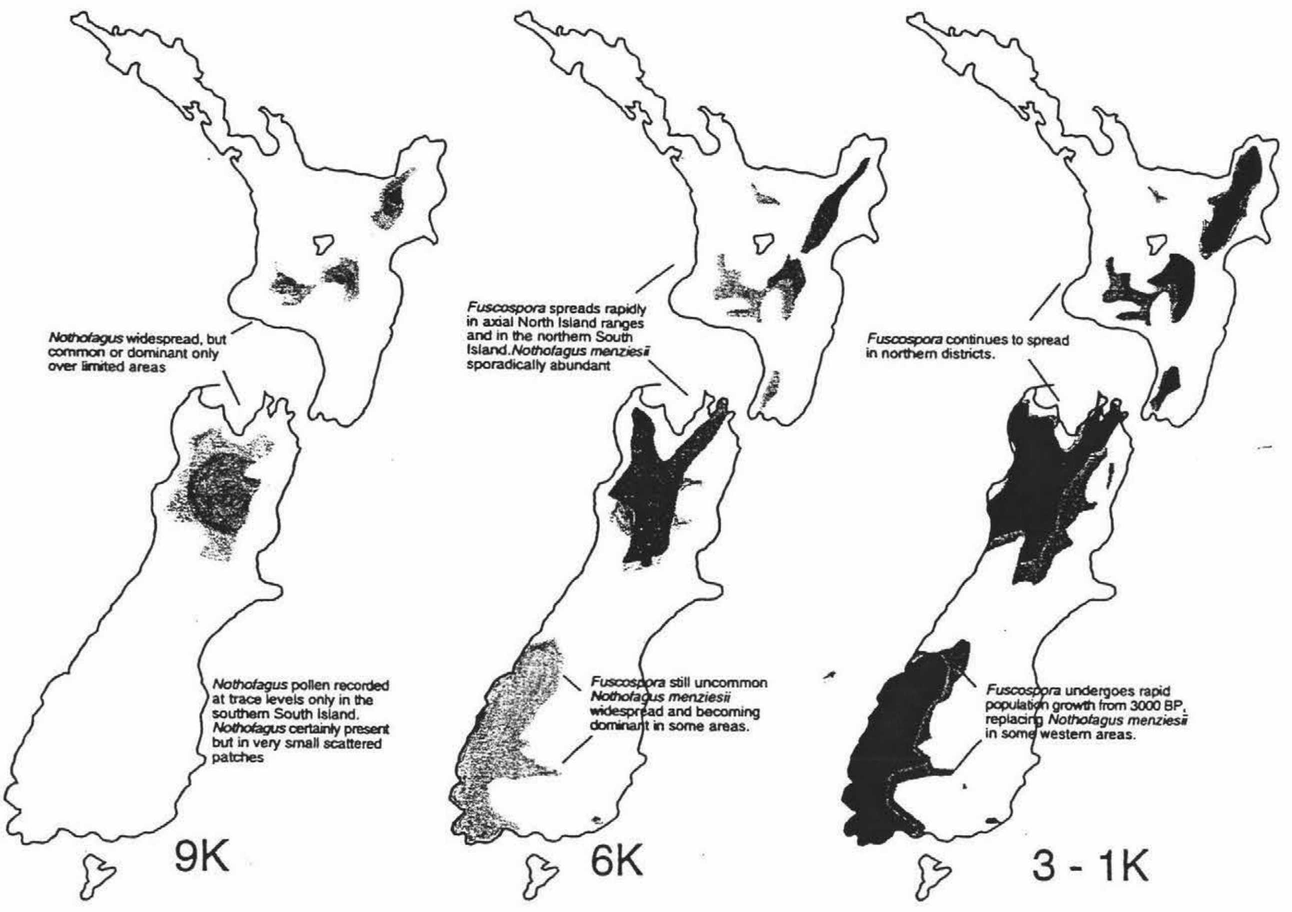


Figure 3.8 The Holocene expansion of *Nothofagus* (from McGlone *et al.*, 1996).

Fuscospora beeches in the south of the South Island. This phase of *Nothofagus* expansion does not appear to have affected the beech gaps which were maintained in more or less a similar state throughout this period.

The above mentioned species which expanded in the mid-Holocene have three common attributes (McGlone, 1988). Firstly, all except *Phyllocladus trichomanoides* have wind dispersed seeds, a relatively uncommon dispersal mechanism amongst New Zealand trees, with most forming dense cohorts after disturbance. Secondly, none regenerate well under low-light conditions, with all preferring relatively open sites such as ridges or slopes. Thirdly, all tolerate poor, low fertility soils with the exception of *Nothofagus fusca*. The abruptness of these mid Holocene changes in forest composition is related by McGlone to a radical climate alteration, especially of rainfall, which changed both soils and vegetation. The late commencement of organic deposits in eastern areas is cited as additional evidence for this. These climate patterns are symptomatic of an increased westerly and southerly wind flow bringing rain to eastern districts of the South Island, while tending to give fine, drier, but cooler weather to the west (Salinger, 1983). Evidence for the expansion of glaciers around 5000 years BP (Gellatly *et al.*, 1988) supports this, with a cooler climate, probably 1-1.5 °C cooler (Williams *et al.*, 1999). It has been stated that there is no evidence for a higher treeline during the early Holocene in New Zealand (Markgraf *et al.*, 1992). Raeside (1948), however, found totara logs 150m above the present treeline in Canterbury. Under such conditions sites characterised by poor drainage, infertile soils, exposure to strong winds, and exposed ridges once dominated by thick podocarp-broad-leaved forest under the mild climates of the early Holocene were subject to invasion by species which had been previously restricted and excluded (McGlone, 1988).

3.43 The late Holocene (~3000 years BP)

The late Holocene saw the continued spread of *Nothofagus* in a handful of locations around the south and south-west of the South Island and the southern North Island. In many areas however there appears to have been a relative stasis, with *Nothofagus* reaching an equilibrium with the podocarp-broad-leaved forests under a presumably constant climate of variability as described above. *Nothofagus solandri* var. *cliffortioides* and *Nothofagus menziesii* formed the timber line throughout the country except in central Westland and Taranaki, where montane podocarp-broad-leaved forests passed upwards into sub-alpine shrublands (McGlone, 1989). At about this time, there is a growing body of evidence suggesting natural fires were common along the eastern South Island (Burrows, 1996; McGlone, 1973). This evidence seems to contradict that above which suggests a wetter east coast. An intensification of the westerly flow, which would promote summer drying via the foehn winds, in inland basins and on the Canterbury Plains, is given to explain this. The south-eastern parts of the South Island may have been spared burning due to rainfall received from southerly frontal systems which may not have brought as much effective rainfall to the north east and inland areas of the South Island (see Chapter Four).

3.44 Maori Clearance (750 years BP)

Human impact occurred comparatively late in the Holocene, causing radical changes to the flora and the extinction of many faunal elements (McGlone, 1989). The date for the arrival of Polynesians in New Zealand is contentious. The discovery of bones belonging to the Pacific rat, *Rattus exulans* (Kiore - a species introduced across the pacific by migrating Polynesian mariners) below the Taupo ash layer dated at 1720 years BP, and complementary radiocarbon dating by Holdaway (1996) seems to support at least Polynesian contact before this date. A number of pollen diagrams reveal relatively early (1300 - 2300 years BP) disturbances to the vegetation (Chester, 1986; Empson *et al.*, in press; Striewski, 1999; Elliot, unpubl.). These early disturbances may reflect the presence of a small contingent of people, who would have undoubtedly lived on a diet of various avifauna and seafood of which there were a plethora (McGlone, 1989). Archaeological evidence has not yet been able to support such an early arrival, though it could be reasoned that early impacts were minimal due to the presumably small number of people that were involved, and their apparent nomadic lifestyle. Other indices such as cyclones and natural fires have been suggested to explain pre-750 years BP disturbances in the vegetation. Which ever date one subscribes to for Maori clearance this early founding population eventually grew and expanded into different parts of New Zealand. As they grew they placed increasing pressure on the food resources, as is reflected in the decreasing proportions and size of animal bones and shells in middens. The increasing competition for resources is believed to have led Maori to form more consolidated factions (tribes) within given areas, the resources of which could then be utilised and controlled. It seems liasons between different tribes were at times hostile, creating the need to build fortified villages, known as *Pa.* Eventually population pressure exhausted many avifaunal food resources such as the moa, and more reliable food sources were sought in the vegetation. According to McGlone (1989), the perception of the economic worth of forests may have changed radically when the bird stocks in them declined. It was soon learned that once forests were cleared by fire, other food sources became available, the most common of which were the bracken fern (*Pteridium esculentum*) and the Cabbage tree (*Cordyline australis*), parts of which formed a valuable source of carbohydrate. Both of these were widespread in the regenerating fern and shrublands. Flenley (in press) believes that it is the spread of this knowledge, rather than the sudden expansion of people through New Zealand that saw the reasonably synchronous period of deforestation, which is widely agreed to have occurred between 750 and 550 years BP (McGlone and Wilmshurst, 1999a).

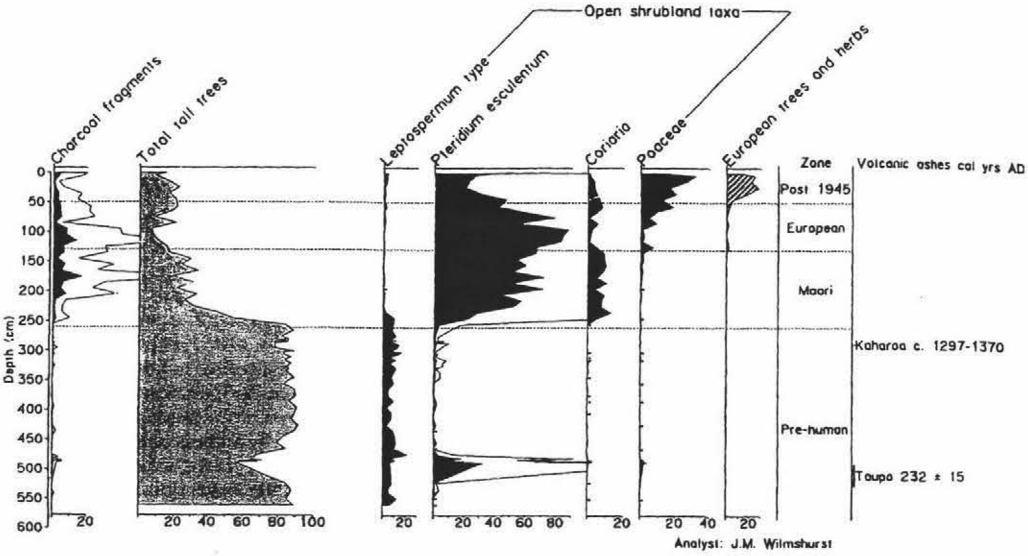


Figure 3.9 A pollen diagram from Lake Rotonuiaka, eastern North Island, depicting the classic hallmarks of Maori and European clearance (from McGlone, 1989).

Unfortunately there are few specific pollen indicators for human presence in New Zealand. Maori introduced but a few crops (kumara - *Ipomoea batatas* - being the most widely cultivated) of which none produce abundant or widely distributed pollen (McGlone and Wilmshurst, 1999a). Other indicators have been sought to infer the activity of Maori in an area. Maori clearance has a number of characteristics which set it apart from other disturbances, such as natural fires. Anthropogenic fires are most often recognised by a continuous and often massive influx of microscopic charcoal, with an associated decline in forest taxa and a subsequent spread of bracken (*Pteridium esculentum*), *Coriaria* and grassland (McGlone, 1989). As can be seen in Figure 3.9 once cleared, a seral scrubland assemblage was maintained by regular firing. Regression back into full forest has been rarely documented. Logically, the lowland coastal sites where a greater proportion of Maori lived, were the first to be burned extensively, while much of the wetter inland hill country remained forested (McGlone, 1989). Some inland areas appear to have been burned on a less regular basis, possibly by fires which spread inland from nearer the coast (O'Brien, in press). In the 400 years between AD 1200 and AD 1800, Maori destroyed nearly half of the New Zealand lowland and montane forests (Figure 3.10).

3.45 European Clearance

Though New Zealand was visited on occasion in the seventeenth and eighteenth centuries, it wasn't until 1830 that an influx of permanent settlers began. In the space of 150 years New Zealand's population would grow from 200000 to 3 million. Their impact on the New Zealand flora and the environment as a whole would be severe. Europeans cleared much of the remaining lowland forest and a significant proportion of that found in the more accessible parts of the hill country. Native plants were displaced by crops, introduced pastures and *Pinus* forests (Wardle, 1991). What forest remained was and still is being selectively grazed by feral animals such as deer and opossums. In some parts of the country native timbers are still being logged. European colonisation has also seen the expansion of naturalised plants, originally introduced to provide food, fodder, shelter, timber, or simply for ornamentation. Fortunately as pointed out by Wardle (1991), the success of these species is largely in habitats created by humans, but also reflects the low competitiveness of native species in some natural habitats such as flood plains, dunes and lakes. Although the periods of human settlement have seen some radical changes to the New Zealand flora, 60% of New Zealand retains some form of native vegetation, of which more than a quarter is protected in National parks and reserves.

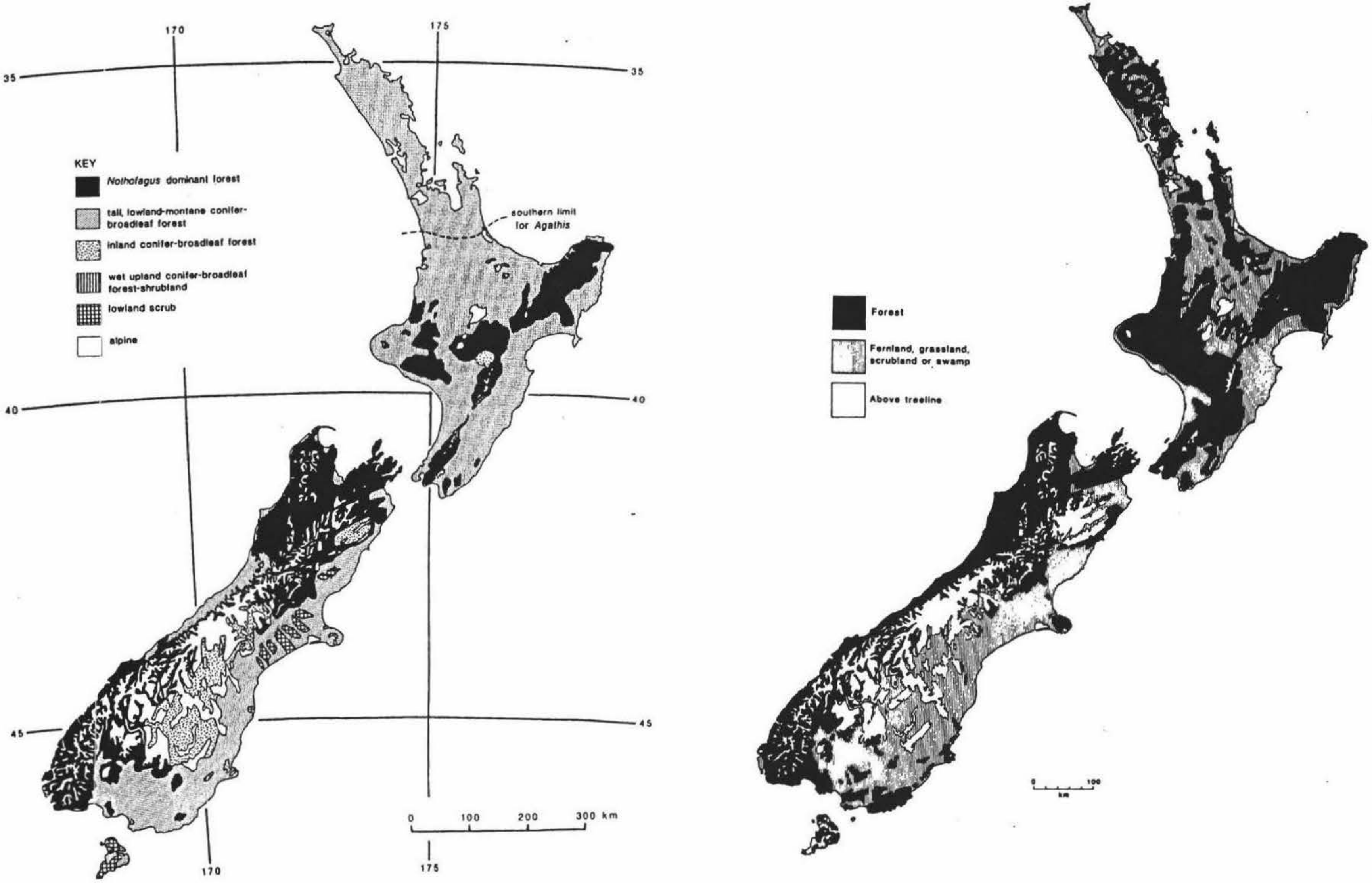


Figure 3.10 The left diagram depicts the New Zealand vegetation at c.3000 years BP. The right diagram shows the extent of forest clearance at the time of the first European surveys AD 1840-1860 (from McGlone, 1989).

Chapter Four:

THE VEGETATION AND CLIMATE OF SOUTHERN NEW ZEALAND DURING THE LATE PLEISTOCENE AND HOLOCENE

THE VEGETATION AND CLIMATE OF SOUTHERN NEW ZEALAND DURING THE LATE PLEISTOCENE AND HOLOCENE

This chapter takes a closer look at the changes in vegetation and climate which occurred over the last 20000 years in southern New Zealand. Southern New Zealand is here defined as Otago, Southland, southern most Fiordland, Stewart Island and the sub-antarctic islands. From the discussion in Chapter Three it was revealed that the vegetation and climate of southern New Zealand had a rather different history, when compared with the rest of the country. For example, in the late Holocene, *Dacrydium cupressinum* spread throughout much of the region, while in other parts of New Zealand it contracted. The study area for this project falls within the confines of this region, and must therefore have been subject to the dynamics of these climate and vegetation changes. The degree to which these changes are reflected at the study area will be discussed in later chapters.

A number of explanations have been put forward to explain the divergent character of the southern New Zealand climate and vegetation. It has been suggested that because the region lies at about the latitude of the subtropical convergence zone it has been particularly responsive to shifts in the boundary between the south-westerly frontal circulation and the subtropical high pressure zone especially since the Last Glacial Maximum (McGlone and Bathgate, 1983; McGlone and Wilmshurst, 1999b). The prevalence of either a zonal or meridional flow over New Zealand appears to have had major influence on the local climates of southern New Zealand and an associated influence on biogeographical distributions of native floras sensitive to changes in precipitation, temperature and fire regime.

A number of pollen diagrams have been published from southern New Zealand - Campbell Island (McGlone *et al.*, 1997b), Auckland Island (McGlone *et al.* in press), Stewart Island (McGlone and Wilson, 1996), Preservation Inlet, south Fiordland (Pickrill *et al.*, 1992), Southland (McGlone and Bathgate, 1983; Vandergoes *et al.*, 1997), Central Otago (McGlone *et al.*, 1995; McGlone and Moar, 1998; McGlone *et al.*, 1997a) and east Otago (Leslie and McGlone, 1973; McGlone and Wilmshurst, 1999b; McIntyre and McKellar, 1970). As far as I am aware no diagrams have been published from eastern

Southland, though McGlone *et al.* (1996) makes reference to unpublished data from Ajax hill in the Catlins. All post-date the Last Glacial Maximum, reflecting the fact that throughout the region there has been a hiatus in the sedimentary record (poor sediment survival) spanning the time between the early Quaternary and the LGM. These papers form the basis for this review of the vegetation and climate history of southern New Zealand during the stated time period.

4.1 Late Glacial (15000 - 10000 years BP)

Few, if any sites from the terrestrial southern South Island contain polliniferous sediments that date back to the Last Glacial Maximum. This probably reflects the fact that the pollen influx was very low due to the sparseness of source vegetation, and the fact that any pollen present would have been poorly preserved in the mineral deposits which characterise the sedimentary environments of the LGM.

The earliest record of vegetation in the region comes from Preservation Inlet in south-west Fiordland (Pickrill *et al.*, 1992). At c.18500 years BP, a low scrub and shrubland containing Asteraceae, *Coprosma* and *Myrsine*, began to develop in association with isolated patches of low *Metrosideros* forest (presumably *M. umbellata*). Grassland and herbfields probably occupied the least hospitable terrain, while ground ferns formed a dense ground cover in damp areas. At this time glaciers still occupied the upper valleys, and sea water had not yet transgressed into the fiord. A temperature depression of 4°C is suggested by Pickrill *et al.* (1992) at this time. From this time on the low forest of *Metrosideros* began to replace shrubland, becoming dominant in the period between 14500 and 12000 years BP. *Cyathea*, *Griselinia littoralis*, and *Pseudopanax colensoi* were common understorey elements. Between 12000 and 9500 years BP, the forest composition was altered by the appearance of *Weinmannia racemosa* which became co-dominant with *Metrosideros umbellata* (Pickrill *et al.*, 1992).

Climates conducive to peat formation began relatively late in southern New Zealand, with most dates indicating initiation between 12600 years BP (Vandergoes *et al.*, 1997), and 10000 years BP (McGlone and Wilson, 1996). In drier areas, such as Central Otago, peat development was particularly late beginning after 8000 years BP (McGlone and Moar, 1998; McGlone *et al.*, 1997a).

Prior to 11750 years BP the vegetation of Campbell Island (c. 52°S) was characterised by macrophyllous forbs with limited areas of sedge and grassland, implying a mean summer temperature depression of around 6°C, supporting a 5°C lowering of mean annual temperature based on geomorphic evidence from cirque floors (McGlone *et al.*, 1997b). It is suggested that the woody vegetation present on the island today, may have survived these temperature depressions because of a sunnier, drier and perhaps less windy climate, though long distance dispersal is not entirely ruled out. Grassland began to spread between 11750 and 10600 years BP.

In Southland, the late glacial period was characterised by open grassland- herbfields with small groups of low growing shrubs dominated by *Coprosma* and Asteraceae (McGlone and Bathgate, 1983; Vandergoes *et al.*, 1997). An ameliorating climate under which rainfall was more abundant, saw shrubland featuring *Hoheria*, *Metrosideros*, *Coprosma*, *Myrsine*, Asteraceae begin to spread from about 12000 years BP with *Dracophyllum*, *Halocarpus bidwillii*, and *Nothofagus menziesii* common in upland areas (McGlone and Bathgate, 1983). Further amelioration during the late glacial period, saw what Vandergoes *et al.* (1997) term "bushland", consisting of low broadleaf taxa including *Griselinia littoralis* and *Muehlenbeckia*, spread in sheltered areas near the Takitimu Mountains, while further south tree ferns proliferated.

Upland alpine sites from Central Otago show that during the late glacial (12000 - c.10000 years BP) such sites supported grassland/shrubland vegetation in which *Coprosma* and Asteraceae were prominent (McGlone *et al.*, 1997a). The presence of charcoal suggests that fires commonly swept across these sites, and may have worked to maintain the dominance of grass. Nearer the coast, an open mosaic of shrubs and short tussock grassland persisted at this time (McGlone and Wilmshurst, 1999b). Groves of *Plagianthus regius* are thought to have formed the only substantial forest cover. Once again influxes of charcoal were common during the late glacial. A similar conclusion was reached by McIntyre and McKellar (1970) at Swampy Hill, near Dunedin, though charcoal was not noted.

Clearly environmental conditions during the late glacial in southern New Zealand were at least harsh enough to prevent the development of significant shrubland anywhere until 12000 years BP, with the exception of Fiordland. McGlone and Bathgate (1983) suggest that the prior to this time the climate over the region was characterised by extreme variability and increased continentality, where droughts, outbreaks of freezing air during the growing season, and increased windiness may have corroborated to restrict woody vegetation. From about 12000 the climate appears to have ameliorated, with temperatures warming and rainfall increasing, but not appreciably (McGlone and Wilmshurst, 1999b).

4.2 The early Holocene (10000 - 6000 years BP)

The early Holocene saw a number of widespread changes in vegetation composition occur in association with further warming. From 9500 years BP, *Dacrydium cupressinum* becomes increasingly common in the *Metrosideros-Weinmannia* forests of southern Fiordland, and is co-dominant by 6000 years BP (Pickrill *et al.*, 1992). At about this time the Post-glacial Marine Transgression had culminated, and the fiords assumed their present morphology in relation to sea-level. On Campbell Island, grassland with patches of low scrub containing *Coprosma* and *Myrsine* persisted until around 6700 years BP when *Dracophyllum* expanded along with the afore-mentioned shrubs (McGlone *et al.*, 1997b). Various temperature indices suggest that early Holocene temperatures were 1-2°C warmer than present at these latitudes, yet shrubland does not spread on Campbell Island until 6700 years BP. McGlone *et al.*(1997) appeal to a climate under which increased cloudiness during the growing season reduced insolation and daily maximum temperatures, retarding evapotranspiration and increasing soil moisture. Such conditions had ended by 7000 years BP allowing woody vegetation to proliferate. Auckland Island, 1.5° of latitude to the north appears not to have been subject to these cloudy climates. Here scrubland spread from 11000 years BP, and was succeeded by a low forest of *Metrosideros* and *Pseudopanax* around 4000 years BP (McGlone *et al.* in press). On Stewart Island many early Holocene sites record a scrub and tree fern association of *Coprosma*, *Hebe*, *Griselinia*, *Myrsine*, Asteraceae, *Dracophyllum*, *Cyathea smithii*, *Dicksonia fibrosa* and *D. squarrosa*. From 9000 years BP, *Metrosideros*, *Weinmannia* and *Leptospermum* become major components in the vegetation, with *Prumnopitys ferruginea* and *Dacrydium cupressinum*, the latter of which may have survived the last glacial on the island, forming a small podocarp presence in these early forests (McGlone and Wilson, 1996). Tree ferns were also abundant. As southern Fiordland and Stewart Island formed the same low stand coastline, and was therefore exposed to similar weather systems it is suggested that *Metrosideros umbellata* and *Weinmannia racemosa* followed similar patterns of expansion on sheltered western sites of Stewart Island to that which occurred in the southern Fiords.

Shrubland-grassland associations were rapidly replaced by tall podocarp forest at sites throughout lowland Southland between 9800 and 9400 years (McGlone and Bathgate, 1983; Vandergoes *et al.*, 1997) and by 8700 in upland sites (McGlone and Bathgate, 1983). These forests were dominated by *Prumnopitys taxifolia*, with other podocarps including *Prumnopitys ferruginea*, *Dacrycarpus dacrydioides* and *Podocarpus totara* being common. The treeline was likely to have been composed of a low forest in which *Phyllocladus alpinus* was becoming increasingly prominent, replacing *Halocarpus biformis* at altitude as the climate warmed (Vandergoes *et al.* 1997). As mentioned, the sudden expansion of forest at this time reflects the cessation of unseasonal passages of freezing air over the south, shortly before 9400 years BP. Thus, although temperatures and precipitation had been gradually increasing during the late glacial, forest taxa were kept in check by these cold snaps during the growing season. The restriction of the moisture demanding podocarp *Dacrydium cupressinum*, the national distribution of which follows the 1000mm/yr isohyet (Franklin, 1968), suggests that conditions were relatively dry. McGlone and Bathgate (1983) propose a figure between 700mm and 1000mm per year in lowland Southland given that *Prumnopitys taxifolia* is found in drier parts of Canterbury where annual rainfall amounts to 650mm (Cox and Mead, 1963).

Forest taxa did not expand in Central Otago until 7500 years BP (McGlone *et al.*, 1995; McGlone *et al.*, 1997a), though *Halocarpus* and *Phyllocladus* were both present from 9500 years BP. *Phyllocladus alpinus*, *Halocarpus*, *Prumnopitys taxifolia*, and *Podocarpus* (probably *cunninghamii*), were prominent in these semi-arid forests, with the former two taxa being common in upland areas (McGlone *et al.*, 1997a). Isolated stands of *Nothofagus menziesii* may also have been present in these early forests. The late spread of forest in Central Otago is, according to McGlone *et al.* (1995), due to the persistence of a drier, more fire prone regime - a product of the area's continentality. This is given additional support by the cessation of peat growth at a number of dated sites between 9000 and 7000 years BP (McGlone *et al.*, 1997a). It was suggested by Burrows and Russell (1990) that after 9500 years BP, a more meridional flow prevailed bringing increased precipitation from the north-east during the summer. McGlone and Moar (1998) however propose that increased evapotranspiration under warmer summer temperatures and decreased winter precipitation associated with such a flow, deprived the soils of effective moisture. Such a regime would have allowed the spread of shrubland, but restricted forest taxa to wet hollows or south facing slopes. From 7500 years BP an increasingly zonal flow was developing - temperatures were gradually decreasing and precipitation increased allowing the soil to retain more moisture and forest to spread.

Near Dunedin, podocarp forest (probably consisting mainly of *Prumnopitys taxifolia*) spread close to 10000 years BP to be widespread in association with *Dacrycarpus dacrydioides*, *Halocarpus* and *Phyllocladus* by 9000 years BP (McIntyre and McKellar, 1970). The latter two taxa would have undoubtedly been more common with altitude. At the southern end of the Maungatua range (upper Waipori river catchment) forest seems to have spread somewhat later (McGlone and Wilmshurst, 1999b). Between 9600 and 6900 years BP a scrubland vegetation in which *Coprosma*, *Myrsine* and *Muehlenbeckia* were common, characterised the area. Low, but continuous pollen curves for *Prumnopitys taxifolia* and *Nothofagus menziesii* suggest that these species could be found, locally in small groves, and/or in the lowlands to the east. The pattern of forest expansion in this area is more akin to that which occurred in Central Otago in that it did not occur until 7000 years BP (McGlone and Wilmshurst, 1999b). *Prumnopitys taxifolia-Dacrycarpus dacrydioides* dominant broadleaved podocarp forest grew on the lowlands up to 300-400m, above which sub-alpine-montane low forest of *Libocedrus bidwillii-Podocarpus cunninghamii* and conifer scrub (*Halocarpus* and *Phyllocladus*) grew. McGlone and Wilmshurst (1999) argue for a reasonably marked rainfall gradient with highest rainfall at the coast and increasingly less within a few tens of kilometres of moving inland. The presence of *Libocedrus bidwillii*, a species characteristic of humid to superhumid climates with high rainfall suggests that upland areas were frequently shrouded in cloud as they are today, and that wet organic soils were beginning to develop.

Further north near Timaru an early Holocene shrubland in which *Coprosma*, *Plagianthus*, *Myrsine*, *Phyllocladus* and *Muehlenbeckia* were common, was being invaded by podocarp forest, in which *Prumnopitys taxifolia* must have been prominent (Moar, 1971). This podocarp forest became fully established around 6700 years BP.

4.3 The late Holocene (6000-1000 years BP)

This period of the Holocene saw further changes in the composition of the vegetations across the region. The most notable features are the spread of *Dacrydium cupressinum* in lowland coastal sites, and the near ubiquitous spread of *Nothofagus menziesii* in response to a cooler, wetter climate regime. At Preservation Inlet, *Dacrydium cupressinum* consolidated its position in the vegetation, while *Nothofagus menziesii* and

Fuscospora beeches (presumably mainly *Nothofagus solandri* var. *cliffortioides*) expanded throughout the fiord. The expansion of *Nothofagus*, a notoriously hardy genus, is believed to be indicative of increasingly variable climate, in contrast to the equable, mild climes of the early Holocene under which *Dacrydium cupressinum* - *Weinmannia* rainforest proliferated (Pickrill *et al.*, 1992). The dates for the expansion of both *Nothofagus* and *Dacrydium cupressinum* are not well constrained in this paper, but it is suggested *Dacrydium cupressinum* spread between 6000 and 4000 years BP and that both *Nothofagus* types spread synchronously around 2000 years BP, to become the dominant forest trees in this part of Fiordland. On Stewart Island, *Dacrydium cupressinum* and *Prumnopitys ferruginea* began to expand between 5500 and 4700 years BP. *Metrosideros* and *Weinmannia* gradually declined as this podocarp association spread to become dominant by 3000 years BP (McGlone and Wilson, 1996). *Nothofagus* is currently not found on Stewart Island and pollen evidence tends not to support the physical presence of *Nothofagus* on the island at any time during the Holocene. The contemporary biogeographic (and hence historical) differences between the vegetation of Southland and Stewart Island are assigned to differences in substrate and climate (McGlone and Wilson, 1996). The late spread of podocarp forest on Stewart Island is attributed to a cloudier climate during the early Holocene growing seasons, conditions which favoured, at least in terms of competition, the broadleaved taxa and tree ferns. The late Holocene was then apparently less cloudy, especially in summer under an increased south-westerly airflow. In the deep south, *Dracophyllum* dwarf forests increased their range from 6000 years BP, developing within the sheltered, well drained gullies along the eastern coastline of Campbell Island. It is suggested, from macro remain evidence, that temperatures were 0.5 °C warmer than present (McGlone *et al.*, 1997b). Elsewhere, *Dracophyllum-Myrsine-Coprosma* scrub spread. At around 3000 years BP there occurred both a decline and an altitudinal retreat of such scrub and dwarf forest, while grass and sedge taxa increased. This is thought to reflect an increase in the frequency of cold south-westerly winds from this time on.

In Southland, *Prumnopitys ferruginea* began to expand around 7000 years BP. *Dacrydium cupressinum* was present, but showed no real sign of expansion until around 4000 years BP, at which time there was a commensurate proliferation of *Nothofagus menziesii* (McGlone and Bathgate, 1983; Vandergoes *et al.*, 1997). This expansion appears to have been complete by 3000-2500 years BP. McGlone and Bathgate (1983) suggest that from 7000 years BP, the climate became increasingly cold and wet given the ecological preferences of these three trees for wet conditions and their ability to grow under cool montane climes. The findings of Vandergoes *et al.* (1997) from inland Southland support this suggestion. At about 2500 years BP the current climatic regime in Southland is believed to have been established. Both Vandergoes *et al.* (1997) and McGlone and Bathgate (1983) record low but continuously increasing values of *Fuscospora* pollen from 4000 years BP, rising rapidly after 2500 years BP. This fits the timing for the spread of *Fuscospora* beeches in Fiordland (Pickrill *et al.*, 1992), though *Nothofagus menziesii* appears to have expanded earlier in Southland. It is likely that *Nothofagus menziesii* was replacing conifer low forest in montane regions and that later *Nothofagus solandri* var. *cliffortioides* was increasing its presence in upland forests of western Southland. *Dacrydium cupressinum* was probably restricting *Prumnopitys taxifolia* and *Podocarpus* to warmer more well drained sites in the lowlands. The fate of *Dacrycarpus dacrydioides* which appears to have succumbed to a fairly major decline in this period suggests that it too may have suffered through competition with *Dacrydium cupressinum* on sites with marginally poor drainage. The impacts on the early Holocene lowland podocarp forests of inland Southland by *Dacrydium cupressinum* appear to have been less severe, probably owing to greater continentality. McGlone and Bathgate (1983) suggested that this vegetation pattern reflects a regime of cool summers, cold winters and frequent storminess, symptomatic of an intensifying south-westerly which was well established by 4000 years BP. The expansion of *Fuscospora* beeches (probably *N. solandri* var. *cliffortioides*, though possibly *N. fusca*) some 1500 years later is postulated to have been in response to an increasingly variable weather pattern under which more extreme events such as drought and storms may have opened up podocarp forest to invasion (McGlone, 1980).

From 6000 years BP, *Nothofagus menziesii* began to expand into montane and sub-alpine areas, replacing *Phyllocladus alpinus* in upland areas of Central Otago (McGlone *et al.*, 1995; McGlone *et al.*, 1997a), though it appears to have never been an important element in the Mackenzie Basin to the north, where *Phyllocladus* remained dominant (McGlone and Moar, 1998). This spread of *Nothofagus menziesii* culminated around 3000 years BP. From 5000 years BP there is evidence that the vegetation was opening up in the Mackenzie Basin. Grassland was replacing shrubland and *Halocarpus*, which appears to have been more tolerant of dry conditions and possibly fire, began to replace *Phyllocladus*. Rising charcoal levels from about 5000 years BP at a number of sites reflect an increasing incidence of fire. Large fires are recorded in the pollen record by abrupt declines in tree taxa, and rapid expansion of grassland. Burrows (1996) has abundant evidence for natural fires during the middle to late Holocene in Canterbury. Pollen and charcoal evidence suggests that deforestation of the lowlands was well under way by 2000 years BP (McGlone *et al.*, 1995). From 3000 years BP, *Fuscospora* beeches appear to have spread into the region. It is likely that this was *Nothofagus solandri* var. *cliffortioides* (though it should be pointed out that Molloy *et al.* (1963) identified both *N. solandri* var. *cliffortioides* and *Nothofagus fusca* charcoal in western Otago) and was proliferating partly due to the destruction of competing vegetation (McGlone *et al.*, 1997a). In terms of climate the palaeoenvironmental record creates a rather enigmatic situation. On the one hand evidence such as the spread of the moisture demanding podocarp *Dacrydium cupressinum* throughout much of the southern region of New Zealand points to an increasingly wetter climate, while evidence for the spread of grasslands and the increasing incidence of fire from inland areas such as Central Otago suggests a drier climate. McGlone and Moar (1998) suggest that drought and fire would be compatible with increasing rainfall if the increase came mainly from a higher frequency of southerly fronts in winter and a more south-westerly flow in general. This would then allow *Dacrydium cupressinum* and *Nothofagus menziesii* to expand and upland bogs to form in moister areas where summer droughts are not frequent or intense. Wetter winters would seldom prevent severe summer water deficits in inland areas such as Central Otago and the Mackenzie basin. The line appears to be fine between their synoptic argument for forest spread in the middle Holocene and forest decline in the late Holocene, but possibly so too was the threshold.

Tall podocarp forest in which *Prumnopitys taxifolia* was dominant culminated around 4000 years BP in eastern Otago. There is evidence to suggest that *Nothofagus menziesii* was engaged in competition with the upland conifer taxa from 4000 years BP. Infrequent fires seem to have favoured it over *Libocedrus*. From 2200 years BP, *Nothofagus menziesii* became dominant in upland areas and was more than likely pushing down into the lowland, replacing *Prumnopitys taxifolia* and a number of other podocarp and broadleaved species (McGlone and Wilmshurst, 1999b). About 40km north on Swampy Hill, *Nothofagus menziesii* appears to have been absent or sparse in the late Holocene (McIntyre and McKellar, 1970). *Dacrydium cupressinum* became the dominant podocarp around 5500 years BP. *Phyllocladus* appears to have been widespread in upland areas. In spite of this it is argued by McGlone and Wilmshurst (1999) that decreasing winter solar radiation, a manifestation of increased winter cloud cover and precipitation gave *Nothofagus menziesii* the competitive advantage over the slower growing podocarps. Annual weather variations associated with El Nino Southern Oscillation fluctuations rather than an average climate regime for this period are used to explain the late Holocene environmental anomaly which allows more numerous fire events, but a concurrent spread of *Nothofagus menziesii*, the explanation for which requires a generally wetter climate according to McGlone (see above publications).

4.4 The human disturbance period (c. last 1000 years)

Polynesian arrival in the area could have occurred as early as 2000 years BP, though the generally accepted date is sometime between 1000 and 750 years BP with marked vegetation disturbance evident from around 750 years BP (McGlone and Wilmshurst, 1999a). The timing and nature of Polynesian disturbance was reviewed in Chapter Three. Forests of south Fiordland appear not to have been disturbed by Maori. These forests were probably spared due to the inhospitable terrain and climate. Maori probably did not reach Campbell Island during the last millennium. But during the last century European introduction of sheep and fire saw the destruction of a large proportion of the *Chionochloa* tussock grassland. Toward the end of the Twentieth Century, *Dracophyllum* scrub spread after grazing animals were removed. It is suggested that a 1 °C increase in temperature during this century aided this spread. By extrapolation of radiocarbon dates, increased levels of firing are thought to have begun around 1400 years BP on Stewart Island, though McGlone and Wilson (1996) suggest rather unscientifically, that this might be better revised to 800-600 years BP so as to be in line with dates of Maori clearance on the mainland. Maori clearance appears to have been very localised and was probably unsustained, as evidenced by forest recovery. From AD1870 Europeans began to log many of the tall podocarps growing in the more accessible parts of the island.

On the mainland, forest disturbance begins around 900 years BP in south-west Southland and is evidenced by reductions in the pollen influxes of *Prumnopitys taxifolia* and *Dacrycarpus dacrydioides* (McGlone and Bathgate, 1983). From 700 years BP, *Pteridium esculentum*, and Poaceae pollen are consistently recorded. Forest disturbance is recorded somewhat later in inland Southland, where the pollen curves for *Prumnopitys taxifolia*, *Nothofagus menziesii* and *Dacrycarpus dacrydioides* fall in association with charcoal peaks from 600 years BP (Vandergoes *et al.*, 1997). The low increases of *Pteridium esculentum* suggest that forests near the site of investigation (Takitimu Mountains) were not actually cleared and that this drop in tree pollen may represent a reduction in the amount of long distance dispersed anemophilous tree pollen to the site from the south. In Central Otago a similar date of 600 years BP records Maori clearance (McGlone *et al.*, 1995).

Anthropogenic fire is confirmed by the sustained abundance of *Pteridium esculentum* spores, often in association with grassland pollen, in which *Aciphylla* was rich. In natural fires, which had been in effect in Central Otago since 5000 years BP *Pteridium esculentum* played a more transient successional role. Maori clearance appears to have re-initiated peat development in a number of topogenous bogs which had previously stopped accumulating due to dry conditions. It is suggested that increased runoff and nutrient loading triggered this renewed period of peat growth (McGlone *et al.*, 1995; McGlone *et al.*, 1997a). This trend continued with European clearance and grazing from AD1860. In eastern Otago, repeated firing destroyed nearly all forest and scrub in the Waipori catchment area around 700 years BP (McGlone and Wilmshurst, 1999b). An initial post-fire bracken-fernland was succeeded by grassland. Historical records suggest that extensive, dense stands of *Dacrycarpus dacrydioides* survived firing on the wetlands of the lower Taieri Plains (Shaw and Farrant, 1949).

4.5 Summary

The late glacial and Holocene have seen a number of broadly synchronous trends in climate and vegetation change, which would probably be better termed diachronous. As noted in McGlone and Bathgate (1983), Cranwell and von Post (1936) proposed the first model for vegetation development in the south of the South Island:

I Grassland period ~ late glacial severe climate, invariably cool and dry

II Podocarp period ~ uniformly wet and, probably, warm

III *Nothofagus* forest-grassland mosaic period ~ climate deteriorates, with local variations between districts

Using pollen data from Swampy Hill near Dunedin, McIntyre and McKellar (1971) assigned radiocarbon dates to these periods, with period I ending about 10000 years BP and period II ending around 4000 year BP. Figure 4.1 attempts to integrate the published vegetation histories for the south of the South Island, in so doing, partially updating and extending a similar exercise done by Vandergoes *et al.* (1997). Grassland, with locally varying proportions of shrubland characterise the late glacial in the region. The timing and composition of forest expansion varies between districts. *Weinmannia*-

Holocene Vegetation Changes in Southern New Zealand

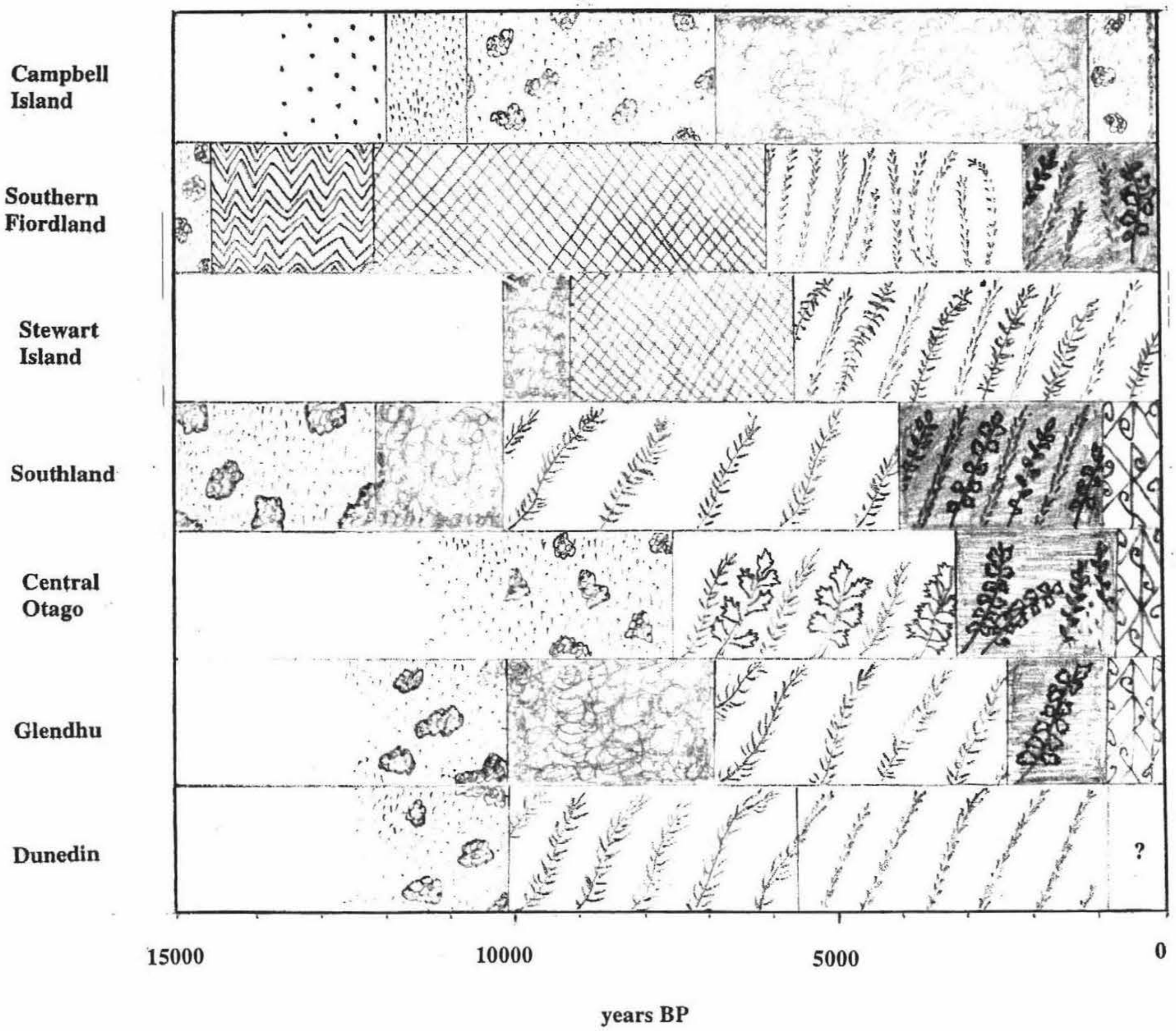
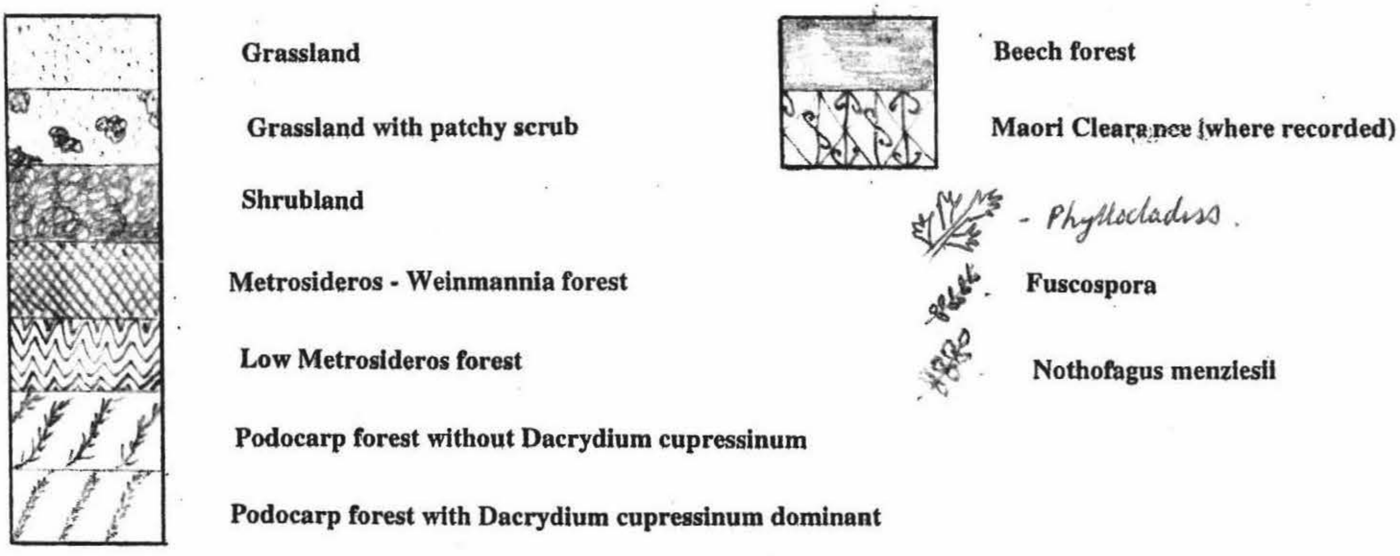


Figure 4.1 Composite diagram of late Pleistocene and Holocene vegetation change in southern New Zealand.



Metrosideros forests proliferate in south-west Fiordland from c.12000 years BP, while similar forests spread on Stewart Island around 9000 years BP. In Southland and Otago, it was podocarp forest that spread, dominated by *Prumnopitys taxifolia.* The initiation of this spread varies considerably in time - c.10000 years BP in Southland and near Dunedin, 7500 years BP in Central Otago, 6900 years BP in south-eastern Otago (Waipori river catchment). Cranwell and von Post (1936) did not make a subdivision in their model based on the sudden increase in *Dacrydium cupressinum,* due to the fact that they didn't differentiate this distinctive pollen type from the other podocarps (McIntyre and McKellar, 1970). On Stewart Island *Dacrydium cupressinum* expands from 5500 years, while a similar date of 6000 years BP is suggested for its expansion in south-west Fiordland. The spread of *Dracophyllum* dwarf forest on Campbell island at 6700 years BP may have heralded climatic conditions conducive to the spread of *Dacrydium cupressinum* further north. In Southland, *Dacrydium cupressinum* expands around 4000 years BP, 1500 years after it became dominant at Dunedin. *Dacrydium cupressinum* was denied access to the drier inland areas through this period and indeed all of the Holocene. The late Holocene expansion of *Nothofagus menziesii* occurred firstly in Southland where it expanded synchronously with *Dacrydium cupressinum* at 4000 years BP. It was present in Central Otago around 6000 years BP, though it wasn't widespread until 3000 years BP. *Nothofagus menziesii* expansion in Fiordland was associated with *Nothofagus fusca*-type, and is estimated to have occurred around 2000 years BP. In eastern Otago *Nothofagus menziesii* spread expanded greatly in the upper Waipori catchment at 2200 years BP, while it did not apparently reach Dunedin in any significant number. The last, presumably natural, vegetation change is the suggested spread of *Fuscospora* beeches through the region (probably from local refuges within the region). *Fuscospora* pollen is produced in abundance and disperses long distances (see Chapter Five). In many of the diagrams it is difficult to ascertain a local presence, but *Fuscospora* certainly became more common in the region, most likely in the west where it may have been spreading out from the south-western mountains. *Fuscospora* pollen rises rapidly around 3000 years BP to levels which would suggest a local presence in Central Otago. Increases in *Fuscospora* pollen occur around 2500 years BP in Southland and at 2000 years BP in Fiordland. In east Otago a very low signal is recorded from 2000 years BP suggesting it was absent.

These diachronous vegetation trends must have important ramifications when attempting to understand gross changes in synoptic weather patterns across the region during this period, and when extending back in time any model based on late glacial -

Holocene vegetation change. The way in which synoptic scale weather patterns interact with local topography in this part of the country should then be a major consideration when attempting to form a synoptic model. Such a model should then be able to explain these local variations and account for the timing of vegetation change once edaphic and successional factors have been accounted for.

Chapter Five:

THE MODERN POLLEN RAIN OF NEW ZEALAND'S VEGETATION

THE MODERN POLLEN RAIN OF NEW ZEALAND'S VEGETATION

It is widely known that a poor linear relationship exists between the modern pollen rain and the producing "parent" vegetation. Furthermore, differences that exist between species pollen productivity and dispersal are of consequence to the palaeopalynologist as they affect the likelihood of a particular taxon being represented in a fossil assemblage (Moore *et al.*, 1991). The study of modern pollen samples reveals the quantitative and/or qualitative relationship between the composition of the modern pollen rain and the composition of the vegetation that produced it (Chester, 1986). In general terms, present day ecologies are assumed to be valid for taxa producing identical pollen in the Quaternary (Bussell, 1988). General aspects of pollen production and dispersal have been discussed in Chapter Two. This chapter looks at the character of the New Zealand pollen rain, with a view to using this information to help interpret the fossil assemblages examined in the Waipori long core.

To reiterate, the quantity of pollen produced by a particular species and subsequently deposited per unit area (and time) depends on several factors according to Faegri and Iversen (1989):

1) The frequency of the species in the region (usually the problem under study).

2) Its absolute pollen production, which may vary both specifically and individually according to the conditions under which the specimen grows, e.g. open or closed stand.

3) The dispersal mechanism.

Davis (1963) went some way toward quantifying the relationship between a species' abundance in the vegetation and its representation in the pollen rain, by creating a ratio of pollen found in a surface assemblage to the abundance of that taxon in the surrounding vegetation. This ratio was termed the R-value. This value has a number of limitations. For one, it requires the stipulation of the catchment area from which the pollen is believed to have come, a difficult parameter to establish given the long distance dispersal capabilities of some taxa; two, a minimum trunk size has to be stipulated when surveying the vegetation; three, r-values are based on percentages, which vary from place to place depending on the composition of the vegetation and therefore may not be reproducable. For these reasons Pocknall (1978) suggested that such values were of limited use in the New Zealand vegetation where anemophilous shrub species with small trunk circumferences such as *Coprosma* were being severely over-represented. It was also felt that R-values ignored the differential effect of varying distances of pollen dispersal. Thus, in New Zealand at least, the R-values have tended to be treated case by case in conjunction with more qualitative data which, in turn, allow for the many factors affecting representation which tend to manifest themselves differently at different localities. Dispite this Norton *et al.* (1986) attempted with limited success to link pollen data with a number of climatic variables using multiple regression analysis to calibrate transfer functions. Attempts to correlate pollen types with temperature effectively broke down due to anomalously high values of lowland pollen at upland sites.

Ideally, sites which are being studied for fossil pollen analysis of Quaternary age should have a modern pollen rain study conducted in conjunction with the fossil studies. In the case of this project, a modern pollen rain study was not conducted for a number of reasons. The current environmental conditions at the site of drilling are significantly different from those which prevailed in the past, having been radically altered by deforestation and the development of land for pasture. The hydrological conditions prevailing over the site are likely to have changed markedly (i.e. from alluvial, to marine, to estuarine, to swamp and back) during the time span covered by the sediments present in the core. These changes will have had a major influence on the source area of pollen incorporated into the sediment (see chapter 2) and may be independent of any climate change (Macphail and McQueen, 1983). In addition, the Taieri River is a substantial water course which flows into the basin. It has almost certainly brought inwashed pollen from throughout the catchment to the site for possibly hundreds of thousands of years. It would be difficult to account for this inwash component using moss-polsters or pollen traps, an important point noted by Bussell (1988). Thus any single study at the site would be of limited value. Ideally a study of modern pollen spectra from a number of vegetation remnants throughout the catchment coupled with an analysis of the pollen content of Taieri River water would have gone some way to providing analogues with which to interpret the fossil pollen of the core. Due to the time constraints, such an exercise (which would be extremely time consuming) could not be conducted. Instead, the above environmental considerations will be taken into account when interpreting the presence, absence, and abundance of pollen in the fossil sequence.

Fortunately, many trends in the pollen rain of New Zealand's flora are re-producable, regardless of location and have been well documented. Published pollen rain studies from various parts of New Zealand are discussed in this short review. This chapter presents a commentary on the more widespread and important, definitive taxa in the New Zealand vegetation.

5.1 Pollination vectors

As has been discussed, the pollination mechanism of species has a direct bearing on how far its pollen is dispersed. Anemopholous species usually produce abundant, well dispersed pollen. Notable New Zealand exceptions that are anemophilous but do not disperse well include *Dacrycarpus dacrydioides* and *Nothofagus menziesii* (Macphail and McQueen, 1983; Pocknall, 1980). Anemophily is uncommon in New Zealand plants. Of the trees, only the conifers, *Nothofagus*, and *Laurelia* are wind pollinated, while of the shrubs a handful of examples include *Ascarina*, *Dodonaea*, and *Coprosma*, with *Gunnera*, Cyperaceae, Poaceae, and Restionaceae representing the main anemophilous herbs (McGlone, 1988).

Entomophilous species tend to produce small amounts of pollen that is dispersed over shorter distances. Insect pollination is by far the most common means of pollen dispersal among New Zealand plants, with common examples including Asteraceae, *Weinmannia*, *Pseudopanax*, *Pittosporum*, and *Pseudowintera*. Entomophilous species include those with extremely limited production (e.g. *Beilschmiedia* (MacPhail, 1980)) to those with abundant production (e.g. *Weinmannia*). As a group, their abundance in the pollen rain is variable. *Fuchsia* and *Phormium* form the two ornithophilous species in the New Zealand flora, though bird pollination of *Metrosideros* has been reported. The epiphytic *Collospermum* is one of the few species pollinated by bats. Autophilous and hydrophilous species are uncommon and as they are almost never encountered in fossil sequences, they are not considered in this discussion.

5.2 Determining vegetation associations using pollen spectra

A number of pollen rain studies have been conducted in New Zealand with the intent to characterise forest types and vegetation associations from the pollen spectra found at sites in or near the confines of the association. The main floral associations have proved difficult to define using modern pollen spectra (Macphail and McQueen, 1983; Pocknall, 1982b). This is largely because pollen of the most abundant taxa are widely dispersed and tend to dominate the pollen spectra regardless of the plant community present at the study site. Lowland vegetation associations can, however, be more or less characterised by carefully assessing the abundance of dominant pollen types derived from the canopy layer and those derived from taxa emergent above the canopy. There are also a number of so called "key" species which are good indicators of an association's character. The general complexity of a forest is, however, never clearly indicated in the pollen spectra (Moar, 1970).

Podocarp-broadleaved forests form the most diverse and complex forest association in New Zealand. The structure of these dense evergreen forests tend to block the free movement of pollen through the trunk space, exacerbating the under-representation of entomophilous trees within such associations at sites of deposition outside the forest (McGlone, 1988). The grains of podocarp species, particularly *Dacrydium cupressinum* are well represented outside such associations, whereas the representation of canopy trees may be increasingly variable with distance. McGlone (1982) found that the pollen of podocarp trees and *Metrosideros* was not well represented in the pollen spectra inside forests where they were numerous, when compared with the *Weinmannia* canopy and *Libocedrus*. A similar conclusion was made by Randall (1990) for the pollen of emergent podocarps in a number of Westland valleys. In this study, absolute counts for *Dacrydium cupressinum* and *Prumnopitys* were greater by a factor of three in upland sites than they were in the lowland sites where they were most common. *Weinmannia* is known to be a prolific producer of pollen, but this pollen is poorly dispersed. Thus its presence in the pollen record indicates that *Weinmannia* forest was in close proximity to the site, and can be used to distinguish forest associations from other vegetation associations (McGlone, 1982). Other canopy species which fall into this category include *Metrosideros* and *Quintinia*.

Beech forests tend to be structurally simple and are floristically poor in comparison with podocarp-broadleaf forest (McGlone, 1988). There are two morphological pollen types within the *Nothofagus* genera - *Fuscospora* (or *Nothofagus fusca*-type) which includes *Nothofagus fusca*, *Nothofagus truncata*, *Nothofagus solandri* var. *solandri* and *Nothofagus solandri* var. *cliffortioides* the pollen of which is widely considered indistinguishable; and *Nothofagus* *menziesii.* Myers (1973) and McKellar (1973) conducted the first studies on the dispersal of *Nothofagus* pollen in the eastern South Island. *Nothofagus menziesii* pollen was found to be under represented in the pollen rain, and it was concluded that low values cannot necessarily be taken to indicate its absence. Numerous studies have since confirmed this and it is generally felt that values of 5% or greater indicate a presence. On the other hand, *Fuscospora* beeches produce copious amounts of extremely well dispersed pollen, as is indicated by the presence of their pollen in surface assemblages collected on offshore islands where they don't exist (Pocknall, 1982a). There is evidence to suggest that *Nothofagus solandri* var. *cliffortioides* pollen may not be as effectively dispersed as other species in the *Fuscospora* group (Pocknall, 1982b). In sites adjacent to *Nothofagus* forest, *Nothofagus* pollen values may approach 100% (McGlone, 1988; Moar, 1970). Randall (1990) concluded that the dispersal pattern of *Nothofagus fusca*-type pollen is such that it is not possible to distinguish between a few trees near the sample site and many trees at a great distance.

A characteristic of the spectra from sub-alpine and alpine areas is the high frequency of pollen derived from anemophilous trees growing in montane or lowland assemblages, effectively masking the open character of the local vegetation, the components of which are commonly entomophilous, with the notable exception of the grasses (Poaceae) (McGlone, 1982; Moar, 1970; Pocknall, 1982a). This over-representation was originally thought to be a function of the low pollen production and dispersal of the alpine flora, but Randall (1990) found evidence from absolute counts mentioned above to show that a number of particularly emergent forest species may disperse a greater proportion of their pollen to upland sites, other factors being equal. This probably exacerbates the poor representation of local taxa in the pollen spectra at upland sites. Herbaceous taxa, which are common at higher altitudes, are generally under-represented, though *Gunnera*, Apiaceae, and *Plantago* form exceptions. McGlone (1982) found that shrubland and grassland sites could be distinguished from forest sites, in spite of them having similar pollen spectra, by the presence of *Dracophyllum* and members of the Asteraceae family. Tussock-sedgeland could be distinguished by a higher than average percentage of Cyperaceae, and by a greater number of herbaceous pollen types.

In many cases the habitats and ecology of the various species constituting a palynoflora are so different that there is little possibility of confusion if other elements of the pollen spectrum are taken into consideration (McGlone, 1988).

5.3 Qualification of the New Zealand pollen rain

The most conventional way to classify the pollen production/dispersal power of a species in the modern pollen rain has been to assign it a qualitative value. This value takes into account the quantified R-value, but also makes allowances for anomalous data. The qualitative representation of some of the more common or important pollen types encountered in this study are given here using the terms and information provided in Macphail and McQueen (1983) where:

W ~ well to over-represented, **U** ~ under-represented and

SU ~ severely under represented.

I TREES

W ~ *Dacrydium cupressinum* (LD[1]), *Fuscospora* (LD), *Prumnopitys taxifolia*, *Prumnopitys ferruginea*, *Podocarpus*, *Metrosideros*

U ~ *Libocedrus*, *Dacrycarpus dacrydioides*, *Nothofagus menziesii*

Given that such a high proportion of New Zealand's forest tree taxa are well- to over- and in the cases of *Dacrydium cupressinum* and *Fuscospora* beeches, severely over-represented, it needs to be borne in mind that the pollen frequencies for these trees will often exaggerate their actual importance in a palynoflora, while the most numerically abundant trees may at times form only a small proportion of the pollen spectra (McGlone, 1988). *Dacrycarpus dacrydioides* is a low pollen producer which may suffer from poor preservation (Pocknall, 1980). Pocknall (1978) found that *Prumnopitys taxifolia* and *Prumnopitys ferruginea* varied from well- to under-represented in the pollen rain and suggests that low frequencies cannot necessarily imply an absence. *Metrosideros* is often well represented as it may be present in sampling areas as a liane. In such cases it would not be recorded in the vegetation survey accompanying the pollen rain study (Pocknall, 1980). However, where *Metrosideros* is emergent, as in the case of *Metrosideros robusta*, it tends to be well represented. Opinions vary on the representation of *Libocedrus*. Pocknall (1982b) found it to be frequently under-represented and noted that it often does not preserve well. To the contrary, Bussell (1988) found it to be an abundant producer and a good disperser. McGlone (1982) found it to be well represented in close

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[1] Capable of extremely long distance dispersal.

proximity to where it grew. Local conditions may produce variances in production which could explain these discrepancies. *Podocarpus cunninghamii* is thought to be well represented in areas where it grows, but is a poor disperser. Its pollen is rarely encountered further than 50m from its parent.

II SMALL TREES AND SHRUBS

W ~ *Coprosma*, *Phyllocladus*, *Pittosporum*, *Quintinia*, *Ascarina*

U ~ *Aristotelia*, Asteraceae (Tubuliflorae), *Elaeocarpus*, *Griselinia*, *Halocarpus*, *Muehlenbeckia*, *Myrsine*, *Pseudopanax*

SU ~ *Pseudowintera*, *Hoheria*, *Dracophyllum*, *Fuchsia*, *Plagianthus regius*, Epacridaceae

The presence of *Ascarina* pollen grains on Stewart Island, several hundred km away from its nearest known occurrence in Westland suggests that its pollen is able to travel long distances (Pocknall, 1982a). Similar conclusions were made by Bussell (1990) and Mildenhall (1976). At open upland sites McGlone (1982) found *Pseudopanax* and *Myrsine* pollen in reasonable abundance, suggesting that their pollen is capable of travelling some distance. *Dracophyllum* was found to be an abundant producer, but poor disperser, making it a good indicator of shrubland. McKellar (1973) noted consistent, but low levels of *Halocarpus* in a pollen trap set near Dunedin. *Halocarpus* does not grow on or near the site, thus implying that though it may be a low producer, its pollen can disperse reasonable distances. Pocknall (1982b) found *Phyllocladus* to be a large producer, but poor disperser of pollen, contrary to Macphail and McKellar's (1983) findings. This may relate to differences between species, with Pocknall referring to the upland *Phyllocladus alpinus*.

III HERBS

W ~ Poaceae

U ~ *Haloragis*

SU ~ Apiaceae, *Gentiana*, *Geranium*, *Gunnera*

As noted above, herbs tend to be extremely low pollen producers, and their presence in the pollen spectra is thus invariably low. The exception is the grasses, of which *Chionochloa* spp are well represented.

IV FERNS AND FERN ALLIES

W ~ *Cyathea smithii*-type, *Blechnum* (most common monolete), *Lycopodium fastigiatum*, *L. scariosum*, *L. varium*, *Phymatodes*

U ~ *Cyathea dealbata*-type, *Dicksonia*, *Histiopteris*, *Hymenophyllum*, *Lycopodium deuterodensum*, *Pteridium esculentum*

The spores of ferns and fern allies are commonly encountered in the pollen spectra. *Cyathea* species have been found to be prolific producers of spores, though it is thought that this is not matched by their dispersal ability (Bussell, 1988). *Lycopodium* spores are in most cases very well-represented.

V AQUATICS

W ~ Cyperaceae, *Myriophyllum*, *Typha*

U ~ *Phormium*, Restionaceae

McGlone (1982) found the pollen of the ornithophilous *Phormium tenax* to be extremely under-represented. Thus its presence in the fossil record usually suggests a local presence.

5.3 Conclusion

In all studies of the New Zealand pollen rain pollen representation is not in proportion with the source species' abundance in the vegetation (Pocknall, 1982b). Variations in the production of pollen by a species is effectively controlled by ecological and physical constraints placed on a plant leading up to flowering, which will vary spatially and temporally. There will inevitably be variations in the dispersal of pollen and spores owing to such factors as topography, vegetation cover and structure, meteorological conditions, grain morphology, and the height of the source. Aside from this, factors specific to the sampling site which are in part controlled by the researcher who selects the site of investigation, need to be taken into account.

Chapter Six:

WAIPORI 99-1 CORE STRATIGRAPHY AND SEDIMENTARY ENVIRONMENTS OF THE LOWER TAIERI PLAIN

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The Waipori 99-1 long core was drilled on farmland near Henley (grid ref. NZMS 260 I45-901677). The core penetrated 154.3m of sediments with a 64% recovery rate (Dickinson *et al.*, 2000). The Waipori 99-1 core presents sediments from the deepest drill hole to have been drilled in the basin. This chapter presents a short description of the core stratigraphy and comments on the sedimentary environments represented by the core sediments.

6.1 Core stratigraphy

As a full graphical log of the Waipori 99-1 core has been published by Victoria University (Dickinson *et al.*, 2000), only the summary log is presented here. The summary log (Figure 6.1) does not indicate the core losses. Core losses were most commonly encountered in the unconsolidated gravel sections of the core, and are therefore assumed to have been composed of similar material. The general textural units are defined in Table 6.1.

Barrell *et al.* (1999) defined four units within the core. Coarse gravel sediments below 67m were grouped as *Waipori 99-1 lower alluvium*. The unit comprising of the lignite and predominantly fine sediments between 67m and 55m, within which the *Hyridella* (fresh water mollusc) shell was found, was identified as the *Waipori 99-1 lacustrine unit.* The gravels and inter-bedded fine sediments between 55m and 22m were identified as the *Waipori upper alluvium*, while the overlying, thick, shell-bearing, fine grained unit between 22m and the surface was named the *Waihola silt/sand.*

Discontinuous sedimentation and the erosion of deposits down the core are evidenced by abrupt textural changes and erosional contacts. Such unconformities are common in terrestrial Quaternary aged sedimentary deposits (Burrows, 1983), and need to be considered carefully when establishing a down core chronology.

Summary Log

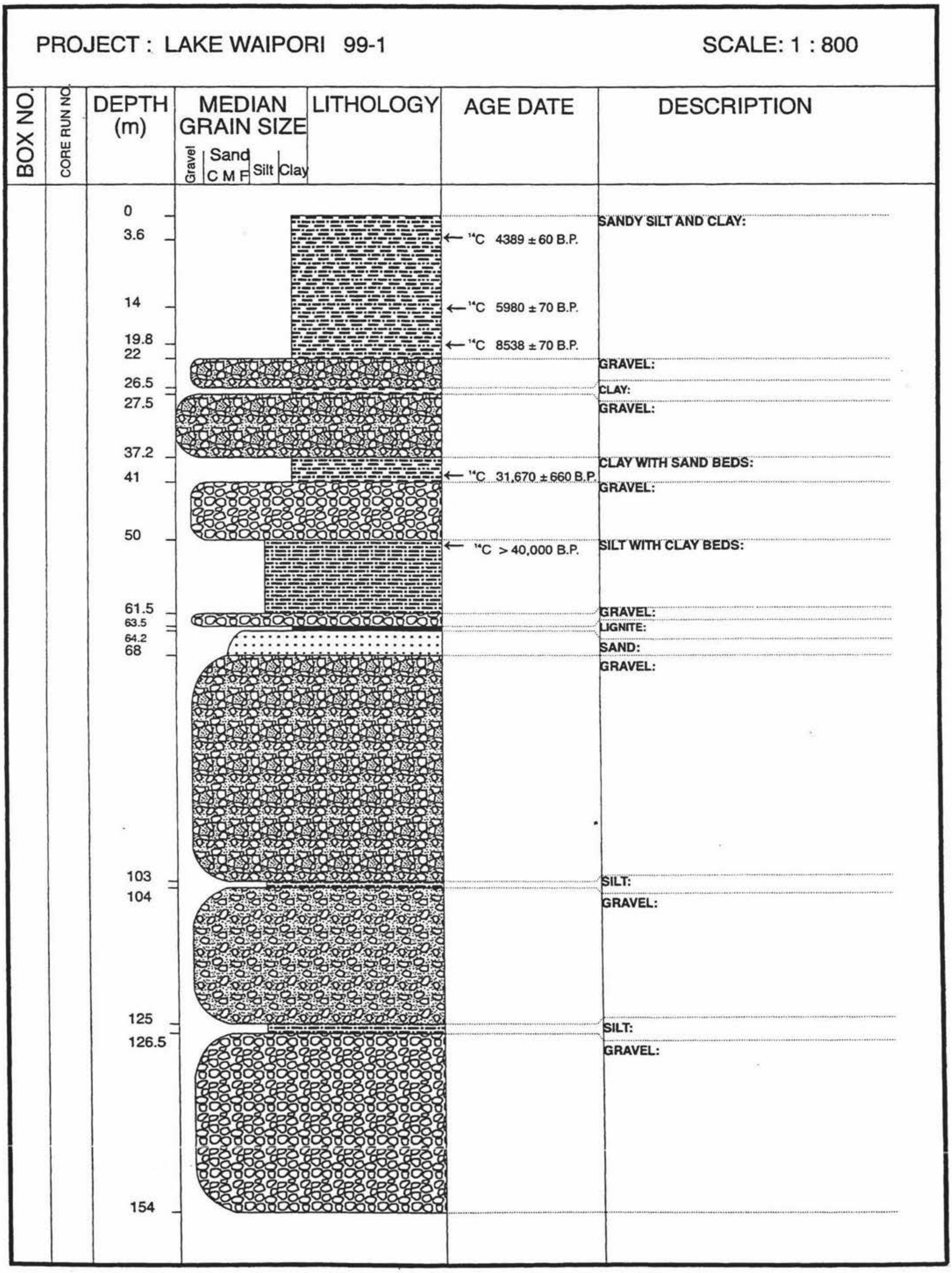

Figure 6.1 Summary log for the Waipori 99-1 core (from Dickinson *et al.*, 2000).

Depth	Composition
0.0-9.29m	Sand and silt
9.29-18.13m	Clay and silt
18.13-20.53m	Sand, clay, and silt
20.53-22.25m	Sand
22.25-26.30m	Gravel with interbedded sands
26.30-27.61m	Silt and clay beds
27.61-37.42m	Gravel
37.42-46.88m	Alternating bands of silt sand and clay
46.88-54.48m	Gravel with interbedded sands
54.48-61.76m	Silt and clay beds - bivalve at 59.1m
61.76-63.65m	Gravel
63.65-64.23m	Lignite
64.23-66.74m	Sand with some silt/clay bands
66.74-72.03m	Gravel
72.03-72.72m	Silt band
72.72-103.16m	Gravel with oxidised sections
103.16-104.03m	Silt
104.03-121.50m	Gravel with oxidised sections
121.50-126.68m	Silt and sand (oxidised)
126.68-154.3m	Gravel (oxidised) with interbedded sands

Table 6.1 Summary lithology of the Waipori 99-1 core. The dimensions differ slightly to the summary log (Figure 6.1) due to the limited detail allowed by the 1:800 scale.

Lab Reference	Core Depth	Material	^{14}C Age (yrs BP) & U-Th date*
NZA 10162	3.60m	Shells	4389 ± 60
NZA 10107	14.02m	Wood	5980 ± 70
NZA 10137	19.25m	Wood	8538 ± 70
NZA 10442	40.80m	Wood	31670 ± 600
Wk 7076	50.61m	Wood	>40000
Victoria Uni.	63.66-68.98m	Lignite	>350000*

Table 6.2 Summary of dates from the Waipori 99-1 core (after Dickinson *et al.* 2000).

6.2 Core dating and sedimentation rate

The upper 40m of the core can be constrained using radiocarbon dating. Five radiocarbon samples and one U-Th sample, were submitted for preliminary radiocarbon dating. The results are given in Table 6.2. From these an age-depth graph (Figure 6.2) could be plotted to calculate the rates of sedimentation from 40.80m to the surface. The degree to which these rates are affected by the removal of previously deposited material within this sequence is difficult to assess. These values should be treated as minimum rates of sedimentation, offset only by compaction. The average sedimentation rate above 40.80m equates to 2.18mm/yr, with a maximum rate of 6.9mm/yr occurring between 14.02 and 3.06m and a minimum rate of 0.7mm/yr occurring between 3.06m and the surface. Dates below 40.80m are inconclusive, but strongly suggest, as expected, that the sedimentation rate in the basin has not been linear for reasons discussed above. Tectonics and eustatic sea-level change over geological periods of time, have controlled the depositional and erosional history of the basin. These have in turn determined which sediments are preserved in the Waipori 99-1 sequence.

6.3 Quaternary sedimentary history of the Lower Taieri Plain

Barrell *et al.* (1999) published a report reviewing the present knowledge of the Quaternary stratigraphy of the Lower Taieri Plain. This report was published specifically

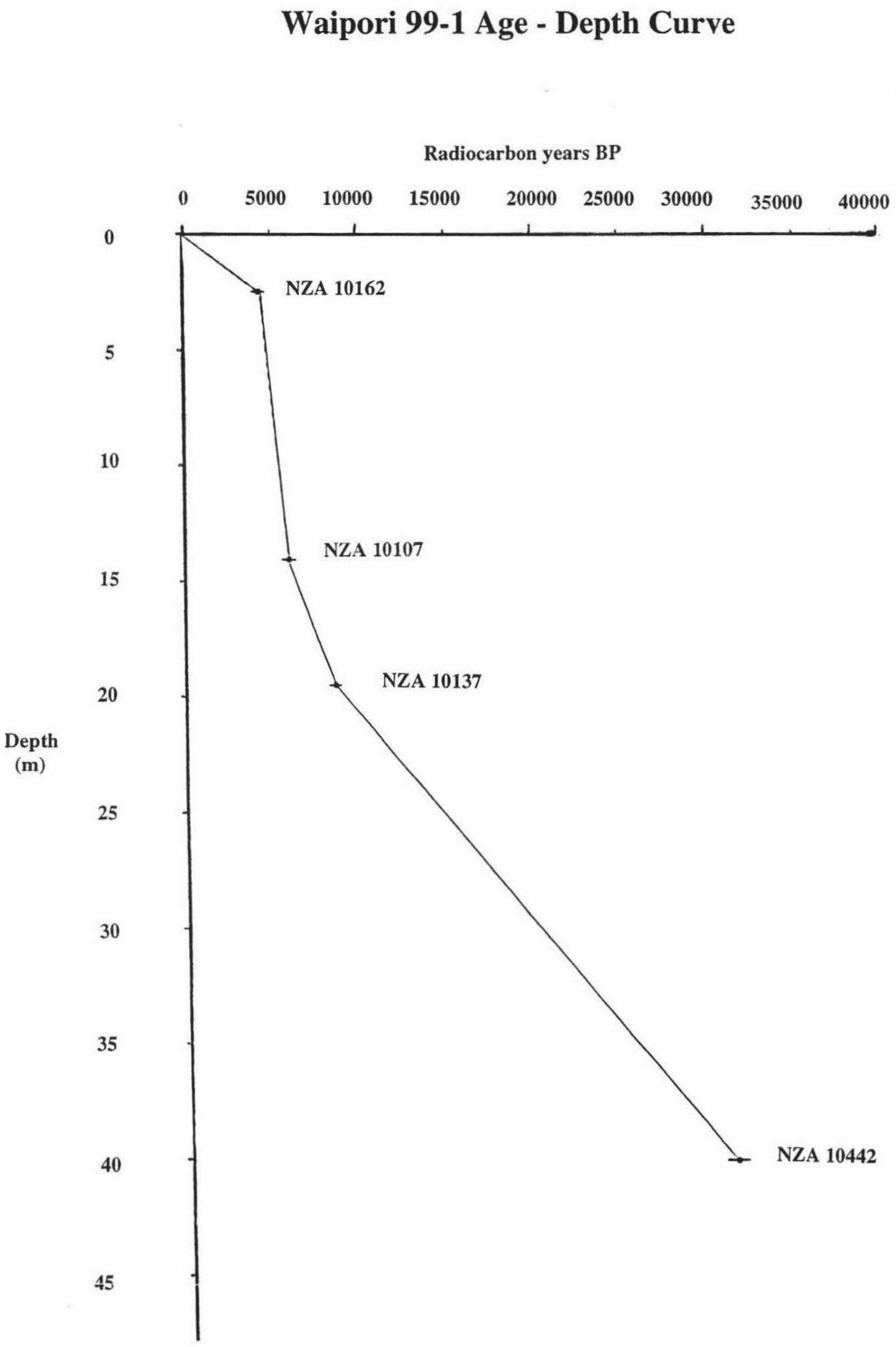

Figure 6.2 Age-depth curve for the upper 40.80m of the core as constrained by four radiocarbon dates. A date from 50.61m yielded a date beyond the ^{14}C range.

to provide a stratigraphical context in which to place the sediments of the Waipori 99-1 core. The main points of this report are outlined here, along with a number of personal comments.

In the drill site area, seismic refraction indicates that there are about 250m of sediments above the schist basement rock (Stevens, 1999). The sediments are believed to have been deposited discontinuously since the Taieri basin block began subsiding and/or the Titri block began to be uplifted, around nine million years ago. Without conducting a major deep drilling transect, there is no practical way to assess the age of the lower sedimentary units of the basin. The oldest surface exposures of sedimentary rocks are probably less than 1 million years old (Gladstone Road gravel) (Barrell *et al.*, 1999).

Barrell *et al.* (1999) analysed the drill hole logs from bore holes drilled across the Lower Taieri Plain. From this they divided the basin sediments on textural grounds into dominantly coarse units (gravel) and dominantly fine units (silt, and/or sand, and/or clay). From the correlation of drill holes across the Lower Taieri Plain (Figure 6.3), it can be seen that the thickness of these layers varies considerably across the plain. Sequences tend to be thicker toward the south-eastern end of the basin (refer to Figure 1.3). A laterally extensive layer of shell hash provides a good marker bed for correlating the *Waihola silt/sand* unit. This unit represents Holocene sedimentation. The abrupt textural boundary between the fine Holocene sediments and the gravels below defines the upper limit of the *Waipori 99-1 upper alluvium* unit and is encountered in many bore holes across the plain. The thickness of this unit is known only in the vicinity of the Waipori 99-1 core. This is also the case for the *Waipori 99-1 lacustrine and lower alluvium units.* Nothing is known of their lateral extent across the basin. The relationship of the lower alluvial unit to similar oxidised gravel deposits lying near the schist basement along the western margins of the basin (where the basement lies closer to the surface) is not commented on in the report.

Sediment deposition, texture, and survival within the basin has been controlled by the influence that differential tectonic movement and climate controlled eustatic sea-levels have had on the hydraulic gradient of the Taieri River. Rates of tectonic movement are poorly constrained in the coastal Otago region. Average uplift rates on the Titri block during the late Quaternary are thought to be between 0.1 and 0.2mm/yr

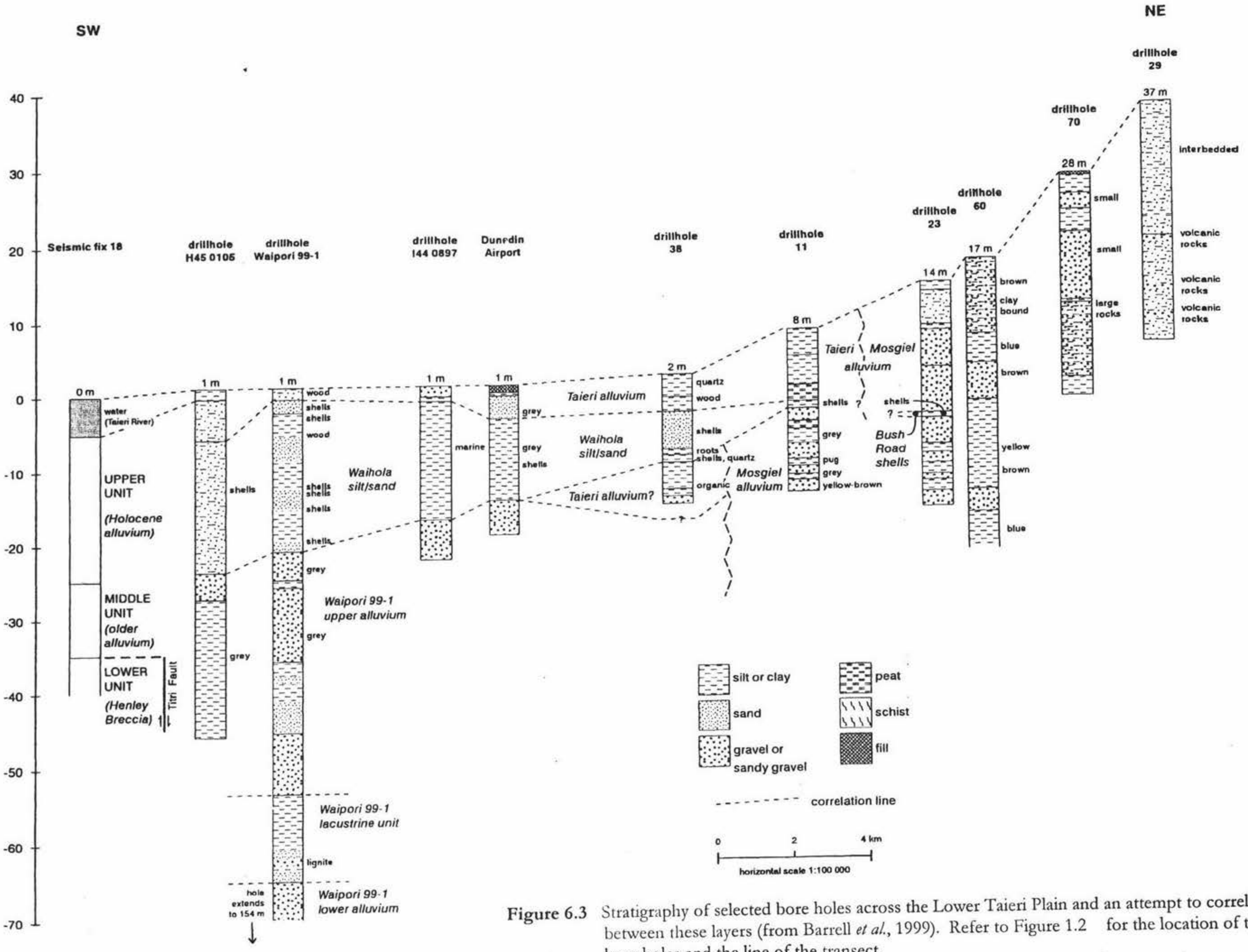

Figure 6.3 Stratigraphy of selected bore holes across the Lower Taieri Plain and an attempt to correlate between these layers (from Barrell *et al.*, 1999). Refer to Figure 1.2 for the location of these bore holes and the line of the transect.

based on the heights of OI stage 5 marine terraces in the Lower Taieri Gorge. In the absence of evidence to the contrary, similar rates of subsidence are suggested for the Taieri block. The working hypothesis of Barrell *et al.* (1999) is that these rates of uplift and subsidence are representative of the "long term". It is pointed out that such an assumption should be regarded as tentative given the tendency for faults in the region to undergo pulses of repeated rupture, followed by periods of inactivity (Beanland and Berryman, 1989; Litchfield *et al.*, 1997).

A seismic profile conducted along the upper reach of the Lower Taieri Gorge has shown that during past eustatic low sea-level stands the Taieri River incised up to 35m below the present river level. During low sea-level stands associated with glacial climates, the Taieri River travelled an extra c.40km across the comparatively steep and exposed continental shelf to reach a shoreline some 130m below present sea-level (Chappell and Shackleton, 1986). Eustatic sea-levels are known to have responded rapidly to changes in Quaternary climate. In New Zealand, rates in the order of 15mm/year have been calculated during the transgressional phase associated with climatic warming following the Last Glacial Maximum (Gibb, 1986). Barrell *et al.* (1999) suggest that cyclic eustatic sea-level changes have exerted the strongest influence on sediment deposition within the Taieri basin. Tectonic factors have been less important as they operate at comparatively slower rates in this area. During cool periods, such as the Otiran, a lower sea-level would have forced the Taieri to increase its gradient. This allowed the river to flush presumably abundant, coarse, gravel sediments across the plain. The lower base-level through the Lower Taieri Gorge would have caused the river to incise across the plain, increasingly so as it neared the entrance to the gorge. The surface of a ten metre thick aggradational gravel sequence lies at -25m in the gorge, and probably represents the level at which the river flowed during glacial periods. Lateral as well as vertical erosion was probably occurring during these periods, carving out a broad valley. During the late glacial and early interglacial periods, a transgressing sea level would have moved up the Lower Taieri Gorge. Further transgression would have flooded the valley which existed on the plains, reducing the gradient of the Taieri River and thus its capacity to transport coarse sediments. The culmination of sea-level rise would have seen an open body of salt water occupy much of the basin. Wave action at the margins of this water body would have further widened the basin laterally, as is evidenced geomorphologically by the truncated toes of alluvial fans along the foot of the Maungatua range (Barrell *et al.*, 1998). A period of infilling would ensue. Interglacial stratigraphies should reflect these changes with a progression from marine, to estuarine, to deltaic, and finally alluvial or peaty sediments.

Although each glacial-interglacial cycle may be similar in terms of eustatic sea-level change, fluvial response, and gross sedimentation patterns, the dates and stratigraphy provided by the Waipori 99-1 core suggest that the duplication of each event in the sedimentary record is far from similar or complete. Barrell *et al.* (1999) point out that such a model of simple glacial-interglacial fluvial response to climate change does not explain the preservation of the substantial thicknesses of gravel in the Taieri Basin. Displacements along the Titri fault system are integrated with a primarily eustatically controlled fluvial system, to provide a mechanism for trapping gravely sediment within the basin. Their proposed stratigraphic model is outlined here. I have modified their model somewhat in-light of results from a recent radiocarbon date at 40.80m. Because of the increasing age uncertainty with depth down the core, the model attempts to trace the sedimentary history from the Holocene back into the Pleistocene (i.e. known to unknown).

Holocene (OI stage 1)

At 10000 years BP eustatic sea-level was -32m MSL (Gibb, 1986). Sea-level flooded the basin around 8500 years BP (Dickinson *et al.*, 2000). Associated fine sediments accumulated within this shoaling basin. Infilling is still occurring at the southern end of the basin in the vicinity of Lakes Waihola and Waipori.

Otiran Glacial (OI stage 2-4)

During this period low sea-levels would have lowered the Taieri River profile across the plain. Theoretically, the -35m floor of the Lower Taieri Gorge provides the probable limiting depth down to which Otiran sediments can be found. As Holocene fine sediments are known to lie above -22m, these depths should bracket sediments belonging to the Otiran. Otiran sediments will extend below -35m if the basin experienced subsidence during this period, which seems likely.

Kaihinuan Interglacial (OI stage 5) and older

The Kaihinuan interglacial sea-level high stands ranged between +5 and -60m above and below present sea-level during OI stage 5 (Chappell and Shackleton, 1986). By analogy with the Holocene, Kaihinuan sediments were probably fine and deposited as a 20-30m sequence, attaining greatest thicknesses within the confines of an incised river valley. Barrell *et. al.* (1999) suggest that at the maximum rate of subsidence - 0.2mm/yr - such a deposit would lie between -17 and -47m. More conservative rates of subsidence (0.1mm/yr) would place these sediments between -35m and -5m. Obviously, a rate greater than this is required to preserve any part of this layer. A fine unit exists in the Waipori 99-1 core between 46.88m and 37.42m, but a radiocarbon date at 40.80m yielded an age of 31670 ± 600 years, suggesting that minimum subsidence rates have been in the order of 0.8mm/yr (40.80m-22.25m/31670yr-9000yr) assuming this unit was deposited at the level of the incised Taieri Gorge i.e. during a low sea-level stand. It seems more likely that it was deposited during the OI stage 3 inter-stadial intermediate sea-level (-46m according to Chappell and Shackleton, 1986) when the river gradient was reduced somewhat, as reflected by the finer grained unit. The palynoflora from this unit supports, at least, the proposition that it was deposited during a warm period (see chapter nine). This suggests that on average subsidence on the Taieri block has occurred at a greater rate than known rates of uplift on the Titri block.

Sediments lying below the -35m incised entrance to the Lower Taieri gorge will be effectively preserved, protected from fluvial and marine erosion. Dickinson *et al.* (2000) propose a working model under which gravels dominate the glacial deposits within the basin during low sea-level stands, while estuarine muds dominate during the interglacials. The survival of finer units will depend on the rates of subsidence occurring during and following their deposition. Greater rates will allow more sediments to be brought below the -35m threshold of erosion. Thus, the presence of fine units in the sedimentary record will be related to the rate of subsidence, thickness of the deposit, and time elapsed before the proceeding low sea-level stand. Given the unpredictable rupturing of fault systems in the region, it seems feasible, that some units could be preserved during more active periods of subsidence, while other units maybe partially or totally removed by fluvial erosion associated with glacial low sea-level stands during less active periods of subsidence.

This point poses a problem in establishing a Quaternary chronology for the sedimentary deposits of the Lower Taieri Plain. Simply assuming alternating coarse and fine grained units follow a continuous chronology is inappropriate given the factors that control sediment survivability. It is not known for sure whether OI stage 5 sediments are present in the core. What Barrell *et al.* (1999) identified as the *Waipori lacustrine unit* lies 20-30m below the -35m buried floor of the Lower Taieri Gorge. This value represents the differential tectonic movement that has occurred since the deposition of the unit. Given the fine texture of this unit, it must have been deposited during a high sea-level stand. Two scenarios can explain the survival of this unit.

1) Assuming low rates of subsidence, fluvial erosion during ensuing glacial low stands did not erode away these fine deposits, leaving them high on a strand above the incised valley. Subsequent subsidence over an unknown period of time and glacial-interglacial cycles inevitably allowed the unit to be subsided beneath the -35m baseline. This seems unlikely given the extent of lateral fluvial and marine erosion that must have taken place during low and high sea-level stands respectively.

2) Assuming higher rates of subsidence, part of this fine unit could have subside below the -35m baseline before the ensuing erosional period. This scenario could support the assumption that the *Waipori lacustrine unit* is of a more recent age i.e. Kaihinuan.

The lacustrine units which survive could have been sourced from any level between the base of the incised valley and the surface. It is, however, difficult to ascertain the base level of this incised valley. This level determines the depth to which former deposits can be eroded. A maximum value of -35m is inferred from fluvial incision in Lower Taieri Gorge. As mentioned, 10m of aggradational gravels lie within the gorge, placing the river level, and thus the base of the gorge at -25m prior to marine transgression. In the Waipori 99-1 core, this aggradational surface, and presumably the base of the formerly incised valley, lies at -22m. A hydraulic gradient of c.1m/1km therefore existed between the gorge and the drill site during the last glacial. The 22m provides a depth at which sedimentation may begin during high sea-level stands, but it cannot be reliably assumed to be the baseline of erosion, as the river may have incised below this point during the early stages of a glacial period and have subsequently aggraded to this level. A base level of -32m (i.e. -35m at the gorge minus the 3m gradient between the sites) is calculated for the Waipori 99-1 core. It should be pointed out that this value predicts more conservative levels of subsidence on the Taieri block.

Given the apparently low rates of subsidence in the basin, it is unlikely that the surface of any fine, interglacial deposits had subsided below the -32m baseline before the following erosional period. If the Holocene *Waihola silt/sand* is used as an analogue for past interglacial deposition, the "room" for sedimentation is around 22m. The presence of 7.28m worth of fine sediments between 61.76m and 54.48m in the Waipori 99-1 core suggests that the top c.15m were eroded away before they could be subsided below the baseline of erosion. This is a maximum value as compaction is not accounted for. Had these not been eroded the top of the sequence would have existed at -39m. A subsidence rate between 0.33mm/yr and 0.56mm/yr (61.76m-22.25m/128000-9000years to 61.76m-22.25m/80000-9000) would be required to assign this unit to the Kaihinuan. These figures are lower than those calculated for the unit between 46.88m and 37.42m, but are still higher than those calculated by Barrel *et al.* (1999). If correct, the stratigraphy then records part of OI stage 5. It is likely to record the early stages of a transgressional event and may not contain the later stages of infilling which occur after the culmination of the marine transgression. The lignite layer presents a different problem. It can be reasonably assumed that this unit was accumulating near present sea-level, at depths similar to peats which have accumulated above the *Waihola silt/sand* east of Outram. The palynoflora within the lignite suggests that the peat accumulated during an interglacial period, probably after the culmination of a high sea level stand when basin infilling was close to complete. It is therefore suggested that the lignite remain separate from the *Waipori lacustrine unit* because it is, stratigraphically, out of depositional sequence. It probably represents an earlier inter-glacial high sea-level stand. The U-Th date of >350000 years fits such a conclusion. An erosional contact exists between the lignite and a superposed gravel unit. This gravel unit must represent a low sea-level stand given the gradient required for the Taieri River to transport gravel loads. Its limited thickness in comparison to other glacial gravel units is perplexing, as is the absence of any appreciable transgressional sequence below the lignite.

Chapter Seven:

TECHNIQUES

TECHNIQUES

This chapter details the various techniques employed in this project. These techniques can be separated into four categories - field techniques, laboratory techniques, microscopy, and computational data analysis and compilation.

7.1 FIELD TECHNIQUES

Fieldwork provides not only the material basis for the work that is to follow, but also the foundation upon which conclusions are built. The aim is to obtain for subsequent analysis uncontaminated material representative of the deposit under investigation (Fægri and Iversen, 1989). Fieldwork for this project was carried out between January 24th and February 10th 1999. The fieldwork team consisted of two drillers and four scientists, including the author.

7.11 Drilling procedure and core recovery

The core was excavated using a truck mounted U.D.R 650 drilling rig (Plate 7.1). The core was removed from the drill hole using a wire line triple tube barrel fitted with a PQ (core diameter - 83mm) diamond core bit. At a depth of 73.50m the core barrel size was reduced to HQ (core diameter - 75mm). 64% of the core was recovered, with the majority of core loss occurring in the extensive unconsolidated gravel sections down the core. The drill hole was cased every five to ten metres so as to minimise core loss and reduce the chance of contamination. Due to substantial losses in the top 14m of the Waipori 99-1 core (Wai 99-1), a second core (Wai 99-1a) was drilled to recover this section at a distance less than one metre from the Waipori 99-1 drill site.

7.12 Core handling

After the cored sediments were brought to the surface and the drillers had assigned start and end depths to it, it was transported with care to the work station situated a safe distance away from the exclusion zone around the drill rig. The work station consisted of two tents - one in which to store the logged cores, and the other in which magnetic susceptibility measurements, core splitting, description and sealing were carried out. These processes are detailed here.

Plate 7.1 The truck mounted U.D.R. drilling rig in action at the Waipori 99-1 drill site, Henley.

I Core Depth Recording

The unsplit core was placed on a set of mounted rolling pins. Using a measuring tape the core run was measured. This measurement was then checked against the length calculated when the start (or top) depth was subtracted from the end (or bottom) depth. Any difference was ascribed as a loss or gain to either the top of the run or the bottom according to information supplied by the drillers. The PVC piping (aka plastic storage split) which held the core was then labelled accordingly. The run number and the above statistics were noted on the core log sheet.

To facilitate storage in the final casing boxes the cores often had to be cut to maximise storage space. A second piece of PVC piping was laid over the core which would eventually hold half the core after splitting. The designated point for truncation was marked on this piping and the one below, along with the depth at which this occurs. The piping was then removed and set aside until after the magnetic susceptibility measurements were taken.

Plate 7.2 Magnetic susceptibility measurements taken in the field.

II Magnetic Susceptibility Measurements

Magnetic susceptibility measurements were taken in the field by passing unsplit runs of core through a Barlington susceptibility meter (magnetometer loop) and were recorded on a laptop computer (Plate 7.2). Measurements were taken manually at 5cm intervals along the core. Susceptibility is a dimensionless measure of how easily the core can be magnetised, and therefore represents the concentration of magnetic minerals in the core. High susceptibility indicates a high concentration of minerals, such as could be expected in zones of soil formation (palaeosols) or in tephra layers. The dissertation of Billings (1999) should be consulted for a full account of this method and the results obtained from the Waipori 99-1 core.

III Core Splitting

After taking the magnetic susceptibility measurements, the pre-measured overlay of PVC piping (see above) was placed on the core. If the core required cutting this was now carried out using a hacksaw. This blade was cleaned thoroughly after each truncation using industrial alcohol.

The core was then turned so that the cutting device could be inserted along the 'seam' where the two plastic PVC splits met. The core was then dissected into two identical sections using a knife and/or spatula (both of which were carefully cleaned after each cut using industrial alcohol). The core was then rotated to allow the two sections to be gently pried apart. Missing core intervals were identified and labelled using plastic spacers. In the sections of the core containing loose open work gravels this splitting process was obviously very difficult and more care had to be taken to minimise disturbance to the stratigraphy. The lignite section (63.65m - 64.21m) was not split in the field. One half of the split core was retained for description, while the other half was wrapped, sealed and boxed (refer to below).

IV Core Description

This step involved visually logging a number of physical parameters and the depths at which these parameters change (Plate 7.3). The parameters were basically colour, grain size and composition. Other important features were also noted such as shell layers, pieces of wood and worm casts. The core was logged at a scale of 1:20, fitting around 3.5m of core to the page. Core logging duties were rotated round between the four workers, meaning there is some degree of subjectivity. Because of the shear length of the core, it was impractical to carry out a detailed description of the core in the field. Instead gross stratigraphic units and peculiarities were noted. It was of major importance to insure that the losses and gains throughout the core were recorded on the log and that the start and end of each run were ascribed the correct depths as these form the basis for later correlation and interpretation.

Plate 7.3 Logging the physical attributes of the core runs.

Grain size was generally ascertained by sight or by feel between the fingers. In extreme cases the mouth was used to determine whether a layer was predominantly silt or clay. Standard geological logging symbols and practices were employed, with clay layers being drawn as a thin column, and the coarsest gravel layers drawn as a thick column. The nature of the contacts between different sedimentary units were noted, i.e., whether it was sharp or gradational. The lithologies and degree of rounding of the constituent gravels were also recorded, along with width, length and breadth measurements of the largest clast. If matrix material was found to be supporting a gravel unit its grain size character was also noted.

A Munsell soil colour chart was used to assign a colour to the sediment being described. This process is also open to subjectivity between describers, but a general impression could be gained.

Potential material for radio carbon dating was also removed at this stage and placed in carefully labelled plastic bags. These samples were oven dried back at the motel.

V Core Sealing and Boxing

The split cores were sealed to protect them from drying out and also from any contamination. The cores were firstly wrapped in gladwrap. They were then inserted into an open ended, cut-to-fit, layflat plastic sock, the ends of which were doubled over and sealed using ductape. The top and bottom depths for the core were written on the ductape, along with an arrow pointing toward the end of the core which was closest to the surface. The bagged and labelled split core was then placed with its identical other half in custom made boxes held in the storage tent. The top and bottom depths for the cores were marked on wooden spacers which were placed between the core runs in the casing box. Once a box was full, the top was nailed on and the front was marked with the project name and the top and bottom most depths of the cores held in the box. At this point the core was ready for transport and storage until subsampling.

7.2 LABORATORY TECHNIQUES

This section details the procedures followed from the time the core reached the laboratory to the time concentrated samples of pollen were mounted on slides ready for identification and counting using the microscope.

7.21 Subsampling

Subsampling was conducted in March 1999 in the controlled atmospheric environment of the soils laboratory at the Research School of Earth Sciences, Victoria University. The core boxes were opened and the plastic half splits containing the core were unsealed and laid out on the lab benches. At this point all depths and were checked, and plastic spacers placed at the top and bottom of each run to record their respective depths.

There were a number of considerations to be made both before and during the subsampling procedure. These were how many samples to take, where to take the samples from, and at what interval. It was decided to take as many samples as possible within reason, as this was the most opportune time to carry out subsampling. A decision could be made at a later date as to which samples to submit for pollen analysis (see below). A total of 240 sub-samples were taken from the core. Sediment nature was a major determinant in deciding where to sample. It is well known that pollen tends to accumulate and preserve well in finer grained sediments as well as in organic materials. Where layers such as these were present in the core they were sub-sampled in greater detail. Sandier sediments and gravel layers were sub-sampled in less detail. Occasionally within the gravel units, small fine layers could be found. These layers were more often sub-sampled than the gravels themselves. Sample interval varied throughout the core from every cm in the lignite to up to 2m in the gravel units. Generally in the silt and clay layers sample intervals were between 10 and 30 cm depending on the pollen bearing potential of the sediment and the location of other workers' excavations.

Subsampling was carried out using the Kryzwinski method outlined in Faegri and Iversen (1989). This method involves pushing an open ended syringe directly into the exposed core. It has the advantage that a known volume of sample can be taken and also that it negates the need to cut into core with other cutting devices which may increase the chance of contamination. Once inserted the sample can be virtually sucked out due to the vacuum created within the syringe as the sample is extruded from the core. In most cases the volume of sediment removed was around 7 cubic centimetres. The sample, held in the syringe barrel, was then placed in a sealable plastic bag labelled with the sample number and the depth. The position of the sample was then recorded on the core log, along with any necessary comments on the nature of the sediment and any other points of note.

Obviously the Kryzwinski method was not suitable for all sediments present in the core. Gravel samples were extracted using a spatula and placed in sealable labelled plastic bags. As the gravels were believed to yield negligible amounts of pollen, large volumes of sample were taken in the hope that by increasing the sample size a greater yield may be obtained. The lignite section of the core was sampled at a very fine resolution. Because this layer was very fibrous it had to be cut using a scalpel. One cm wide half discs of lignite were cut. These were then cut into sectors, one half of which was taken for phytolith analysis, the other for pollen analysis. The scalpel was rigorously cleaned with industrial alcohol after each cut. Once again these samples were placed into sealable labelled plastic bags, and their position recorded on the core log as above.

Core runs were then photographed using a digital camera. Following this the sub-sampled cores were re-wrapped (as in the field) and placed back in the core boxes. The core is currently stored at Victoria University.

Bagged sub-samples were then tied into batches and transported to the palynology laboratory at Massey University where they were stored at 3 degrees Celsius in a refrigeration unit until preparation. Storing samples at low temperatures prevents conditions favourable for microbial activity which may in turn affect the exines of the pollen grains and/or increase the number of fungal spores in the sediment.

7.22 Sample preparation - pollen concentration

As pointed out by Moore *et al.* (1991) obtaining pollen in a countable form from polliniferous sediments does not so much involve extraction as it does concentration. The techniques used in the process are aimed mainly at disintegrating, dissolving or other wise removing the non-pollen matrix in the sediment, with the ultimate aim of obtaining a pollen rich concentration. A successful preparation should permit the accurate identification of as many as possible of the grains encountered and allow the counting of an adequate sample of pollen grains and spores so as to provide a representation of the total population in the original sample (Moore *et al.*, 1991). In this study, as in many, there existed a wide range of sediments down the core. This range meant that all samples had to be treated more or less individually, adopting a tailored approach to the preparation process. The inspection of water mounts on microscope slides were essential for determining which treatments should next be applied to each sample at various stages in the preparation process. In saying this samples were usually prepared in batches of 16 or 32 (centrifuge portals number 16) at a time. Where samples required differential treatments they were removed from the batch for the duration of that treatment. As it is impractical to detail the preparation steps for every sample a brief overview of each process is given here. Not all samples were subjected to all of these procedures, though some may have undergone a particular procedure several times. A coded list of the preparation steps for each sample is held in the appendix One.

The first step was to decide what volume of sediment to submit for preparation. Generally if the sediments were fine or looked to contain organic material a small sample was taken - typically 1cm^3. In coarser sediments (silt - sand size) 2-6cm^3 samples were taken, while gravel sample volumes were typically 20cm^3 for reasons discussed earlier. Sample volumes could be accurately measured since the scale along the syringe was marked off in cm^3. For the lignite section samples were cut to fit a 1cm^3 piece of plastic tubing. The gravel volumes were measured using a small beaker. All samples were prepared in ten ml plastic test tubes that were clearly labelled with the sample depth, number and batch preparation number (1-16). The labels were made of adhesive paper and were covered with sellotape. These survived the duration of the preparation well and are recommended by the author. When two batches of 16 samples were being prepared simultaneously each batch was colour coded to avoid confusion. A total of 108 samples were prepared.

Lycopodium spore tablets were added to all samples at the outset as suggested by Maher (1972). Lycopodium spore tablets (batch No.12469) were manufactured by the laboratory of Quaternary Biology at the Department of Quaternary Geology, Lund University, Sweden. Each tablet contains a mean value of 12542 acetolysed Lycopodium grains with a standard deviation of +/- 416 grains. The addition of exotic marker grains is necessary to form an absolute pollen count as demonstrated by Stockmarr (1971) who was the first to use and subsequently mass produce Lycopodium tablets for this purpose. The principle of the method is to add a known number of marker grains to a known volume of sample material. Because the numerical relation between the native pollen of the sample and the markers is constant for every depth sampled, the total number of fossil pollen grains in the sample is given by the formula:

$$\text{Total fossil pollen} = \frac{\text{Fossil pollen counted} \times \text{Total number of markers}}{\text{Markers counted}}$$

The marker Lycopodium spores are morphologically different from the spores of those Lycopods naturally occurring in the New Zealand flora. In addition, the marker spores are already acetolysed, so have a very dark appearance after preparation.

PREPARATION TECHNIQUES

I Centrifugation

Each step in the various processes was usually followed by centrifuging to concentrate the pollen suspension and/or to allow the pouring off of clays. Centrifuging was carried out at 3000 r.p.m. for three minutes.

II Water Washes

Water washes were used after most treatments to neutralise the sample. Distilled water was used at all times.

III Agitation

Samples were agitated using 7ml plastic pipettes except for when in the hotblock where plastic stirring rods were used. A procedure was put in place to insure that pipettes and stirring rods were never confused between samples.

IV Carbonate removal

A 10% hydrochloric acid (HCl) wash was used to remove carbonates and also to dissolve the tableting agent in the Lycopodium tablets.

V Humic Acid Removal and Deflocculation

A 10% potassium hydroxide (KOH) treatment was used to remove humic acids (unsaturated soil colloids). Samples were placed in the hot block for 3-4 minutes. The KOH treatment was combined with a hot sodium pyrophosphate treatment to form a

50/50 mixture within the test tube. Bates *et al*(1978) recommend the use of sodium pyrophosphate ($Na_4P_2O_7$) as a deflocculant. Some samples required further deflocculation. In such cases samples were subjected to a 20 minute hot sodium pyrophosphate treatment with the addition of 2 or 3 drops of sodium laurel sulphate ($C_{12}H_{25}OSO_3Na$). Following these treatments, the samples underwent a series of water washes until the supernatant was clear indicating the removal of humic acids and a proportion of the clays.

VI Coarse Particle Sieving

This process removed any large unwanted organic or mineral materials such as plant macrofossils and gravel. This was done by washing the sample through a 300 micron terylene gauze into a flask with a jet of distilled water. This was usually carried out after removing samples from the hot block following the KOH treatment. Where coarse particles were present these were retained and placed in labelled petri dishes.

VII Silica Removal

There are several documented methods for removing silicious material - sand, silt and clay. The hydrofluoric acid (HF) treatment was used in this study. As HF is an extremely corrosive acid, strict safety procedures were followed. Sodium hydrogen carbonate ($NaHCO_3$) was used as a neutralising agent. Samples were first washed in 10% HCl to ensure all carbonates have been removed as HF reacts violently with these, and also to raise the hydrogen ion concentration so as to prevent the formation of fluoride crystals within the sample. 5ml of 40% HF was added to each sample. Samples were then placed on the hot block[1] for up to 20 minutes, stirring occasionally. Samples were then topped with heated 10% HCl, stirred and then centrifuged after putting lids on the test tubes. The decanted supernatant was poured into a large beaker of neutraliser.

VIII Sand Fraction Removal

In cases where a high proportion of large silt to sand sized mineral material remained after HF treatment, the sample was subjected to a decanting process as suggested by

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[1] Hot block was set between 95 and 97° Celsius.

Jemmett (1995). Decanting involved thoroughly agitating the sample and then leaving it to settle. After one minute the supernatant of the sample was transferred to a new test tube, while the heavier sand grains were retained in the bottom of the original test tube. This process was repeated three times or until the supernatant became clear, suggesting that all finer particles including pollen had been removed. The residual sands and silts were discarded. Random water mount checks on the residual sand left at the end of the process were found to be pollen free.

IX Cellulose Removal

Acetolysis was used to remove the cellulose of any plant fragments that a sediment may have held. In a water-free medium this can be done with concentrated sulphuric acid. To dehydrate the samples they were washed in 10% acetic acid (10%CH_3COOH), followed by a wash in glacial acetic acid (100%CH_3COOH). In a separate beaker, 81ml of acetic anhydride ($(CH_3CO)_2O$) was mixed with 18ml of concentrated sulphuric acid (H_2SO_4), initiating a violent reaction. This was then added to each of the samples (this mixture treats 16 samples) after which they were placed on the hot block for five minutes. The reaction was then stopped by adding glacial acetic acid. After centrifuging and decanting this was followed by a 10% acetic acid wash and several water washes.

X Lignin Removal

In some cases acetolysis was not effective in removing all unwanted organic material. This was especially the case in the lignite section of the core. To remove this fraction oxidation was employed. Oxidation can be harmful to the exines of pollen grains and spores and therefore this process had to be carried out with care. There are several different documented methods for oxidising material. In this study the sodium chlorate ($NaClO_3$) method proved most effective. The sample was suspended in 4ml of glacial acetic acid. 5-6 drops of sodium chlorate were added followed by 1ml of concentrated hydrochloric acid. This immediately bleached the sample. After four seconds the contents of the sample were poured into a small beaker of distilled water to stop the reaction. Several water washes were carried out to insure that the oxidation process had finished.

XI Removal of Fine Particles (<6 microns)

The last step in most pollen preparations is fine sieving. This involves washing the finer particles out of the sample through a fine mesh. In this study 6 micron nylon filters were placed on top of a Sartorius filter holder with the sample being poured into the upper chamber. A vacuum was created by attaching a series of rubber hoses from the filtering device to a standard sink tap. When the tap was turned on it effectively siphoned air through the system, drawing the water and fine particles in the sample through the filter. Jets of distilled water were used to move the sample across the filter and maximise the opportunity for fine material to pass through. If a sample clogged the filter the vacuum could be reversed. Sodium pyrophosphate could also be added to deflocculate the sample. In bad cases a new gauze had to be used. If clogging persisted then a ten micron filter was used followed again by a six micron filter. The Sartorius apparatus had to be dismantled and thoroughly cleaned after each sample was sieved so as to avoid any possibility of contamination. New filters were used with each new sample.

XII Alcohol Dehydration - Preparation for Mounting

Alcohol dehydration is necessary for pollen samples which are to be mounted in silicone oil. In this process samples were washed in industrial alcohol (95% ethanol - 95% C_2H_5OH), absolute alcohol (100%C_2H_5OH) and a 50:50 mixture of absolute and tertiary butyl alcohol (TBA - $C_4H_{10}O$). Finally the samples were washed in pure TBA and transferred to carefully labelled 2ml vials. Silicone oil (AK2000) was then added, the amount depending very much on the volume of sample retained at the end of the preparation process. The greater the volume present the more silicone oil added. This is so as to create a ratio of silicon oil to sample suitable for mounting and subsequent counting. The samples were then stirred and centrifuged. Following this a tissue was placed over the open vials which were then placed in an oven (at 40°C) overnight to evaporate off the excess TBA. The vials were then removed from the oven, sealed with caps and stored until mounting.

7.23 Mounting

The final procedure before counting is to mount a portion of the concentrated pollen sample on a microscope slide ready for microscopic analysis. As discussed the mounting medium used in this study was silicone oil. Silicone oils were first used by Anderson (1960) as a mounting medium. It is a more or less permanent medium, with a refractive index of 1.4 - suitably lower than that of pollen and spore exines which are typically between 1.55 and 1.60 (Fægri and Iversen, 1989). The main advantage of using silicone oil as a mounting medium is that it allows grains to be rolled by applying pressure on the cover slip. This is very helpful when trying to identify unknown or damaged grains as it allows for the observation of the total grain surface, not just one angle. Its main disadvantage is that grains have a tendency to migrate beneath the coverslip, meaning that if one needs to record the location of a grain for future reference or identification it will often have moved from that point by the time counting has finished (usually not distances great enough to cause concern about counting the same grain twice).

Two slides were made for each depth. These were labelled with the site name, the sample depth, the sample number and the letters A and B to differentiate between the two. Microscope slides were placed on an electrothermal slide drying bench. Using a thin glass rod a drop of sample was transferred from the vial to the slide, where it was spread about the slide a little and then left for a few minutes until any air bubbles had evaporated. A cover slip was then placed on top of the sample which would immediately begin to spread in a circular pattern under the pressure. This spread was checked by injecting paraffin wax under the coverslip and lifting it off the drying bench allowing the wax to cool and set, effectively sealing the sample. Mounted samples were stored in custom made cardboard cases until counting.

7.3 MICROSCOPY

This section details all techniques used when identifying and counting pollen grains and spores under the microscope.

7.31 Equipment

Sample pollen and spores were identified and counted using a Zeiss Axiophot transmitted light photomicroscope. As the name suggests the microscope has the capability to photograph slide material. This microscope was equipped with a graduated (Vernier scale) mechanical stage and coaxial controls for x and y movements. A filter magazine could be used to create contrast, along with a condenser. Focusing through grains could be achieved using a coaxial coarse/fine focusing control. The microscope was equipped with binocular eye pieces, for which a range of magnifications existed (x10 magnification was used in this study). One of the eye pieces contained a micrometer which could be used to measure grain features. Four objective magnifications were available - x5, x10, x20 and x40. Optovar magnifications ranged from x1.25 to x2.5. For routine counting a magnification of x400 was used (x10 eye piece, x 20 objective and the x2.0 optovar). For closer analysis a magnification of x800 was used (using the x40 objective). When photographing a x200 magnification was used.

7.32 Identification

The pollen grains of New Zealand dicotyledonous plants were identified as per Moar (1993). Pollen grains of New Zealand gymnosperms were identified as per Pocknall(1981a; 1981b; 1981c). Spores of New Zealand ferns and fern allies were identified as per Large and Braggins (1991). MacPhail's unpublished photographic record of New Zealand pollen grains and spores was also used as a general reference. The pollen and spore reference collection of modern material held in the Palynology Laboratory at Massey University, was often referred to in cases where the affinity of a grain was not obvious. Dr Dallas Mildenhall (IGNS) was consulted for the identification of a number of unknown pollen grains. Dr Mark Large (Institute of Molecular BioSciences, Massey University) was consulted for the identification of a number of unknown spores. Professor John Flenley and colleagues in the Palynology Laboratory at Massey University were also consulted on occasion.

7.33 Counting Procedure

A decision had to be made on how many grains to count per depth. This decision had to take into account the following. In pollen analysis there always exists a trade off (in terms of time) between the number of grains that can be counted and the number of samples that can be prepared and counted, i.e., the more time taken to prepare a greater number of samples, the less time available for counting or vice versa. Also, in order that the final count of pollen grains and spores be as representative as possible of the true proportions of pollen types at a particular sediment depth, sampling errors need to be kept to a minimum. This is best achieved by duplication at each sampling stage and by counting as large a number of pollen grains and spores as possible. There exist however, feasibility limits in terms of the time required to reduce the sampling error. This needs to be offset against the law of diminishing returns. The number of grains counted will then inevitably depend on the number of grains available, the objects of the study, the adequate representation of those plant components which are of special interest and sampling errors (West, 1971). Barkley (1934) found that little or extra validity was gained from counting above 200 grains per slide. Given the specific aims of this study and taking into account the level of diversity of the New Zealand flora it was decided that a count of 200 grains would be sufficient. Such counts were made for all samples where the pollen concentration allowed for this. In cases where the pollen yield was small a more modest count was made. Such depths are interpreted with a degree of caution, as low counts are not statistically significant in terms of their representation of a pollen flora.

It is well known that pollen grains and spores are not evenly distributed beneath the coverslip. Brookes and Thomas(1967) found that the migration of pollen under the weight of the coverslip was inversely related to the size of the grain. Any counting procedure needed to take this into account. In this study counts began along a traverse through the middle of the sample. Subsequent traverses were made alternately one millimetre either side of this and so on, until a count of at least 200 grains was reached. If a count of 200 grains was not reached on one slide, then a second slide was counted in the same way. All grains in the field of view were counted, with care taken not to move off the original line of traverse. Any grains which could not be identified due to lack of reference material were placed in an unknown category. Broken grains and poorly preserved (beyond recognition) grains were excluded from the count. In cases where fern spores dominated a sample, a greater number of non-fern spore taxa were counted. The locations of all unknown grains were marked using the Vernier scale and an England finder. In a number of cases unknown grains were photographed. These steps were taken to allow for later identification by the afore-mentioned consultants. Identified grains were marked on a tailored counting sheet.

Actual pollen and spore counts are held in the Appendix Two.

7.34 Charcoal identification and counting

Charcoal is an amorphous inorganic compound which results from the incomplete combustion of plant tissues (Patterson *et al.*, 1987). Iversen, in a number of publications was the first to use charcoal fragments in pollen preparations as evidence of the history of fires in the vegetation, relating changes in both vegetation and fire regime to landuse. Patterson *et al.* (1987) give an excellent overview on microscopic charcoal and its use as a fossil indicator of fire, including comments on taphonomic processes. Clark (1984) studied the effects on charcoal of pollen preparation techniques, where it was found that all processing techniques affect the amount of charcoal present, some steps singly or in combination, more than others. She recommended that all samples then be prepared identically. Unfortunately this was not feasible in this study due to the diverse range of sediments present down the core. Ideally, separate samples should have been prepared using a different set of preparation techniques, but due to time restrictions this was not possible.

Another problem with counting charcoal is identification. Microscopic charcoal fragments are often featureless and may be confused with black particles of sediment such as pyrite and other minerals amongst other things. In this study the presence of charcoal-like opaque ferromagnesian minerals and iron oxides such as magnetite weathered out of the basalts in the catchment made the positive identification of charcoal very difficult. Minerals forming under anoxic conditions within the basin were also opaque. The charcoal curves have therefore been titled charcoal and black particles to disclose the fact that it is likely these curves may contain both. This was a solution employed by Flenley *et al.*(1996) to solve a similar quandary on Salas y Gomez. Craw *et* *al.* (1998) noted high pyrite (FeS^2) concentrations in soils which had formed on older sedimentary substrates in the Taieri catchment.

There are a number of different methods by which to count charcoal. These are reviewed in both Clark (1982) and Patterson *et al.* (1987). The two most common methods are to simply count the number of particles or to measure their area on a grid. In this study the former was used. Size class distributions were determined by measuring the maximum dimension of each particle encountered. This method could be carried out quite efficiently. Charcoal was counted as a ratio to added Lycopodium spores and are expressed on the diagram as particles per cc.

7.35 Dinoflagellate Cyst identification and counting

Dinoflagellate cysts (also known as Pyrrhophyta) are single-celled organisms generally between 20 and 150 microns long. They are generally considered to be 'plants' though they do have some 'animal' characteristics. Dinoflagellates exist in the fossil record as cysts, a dormant stage achieved by only a number of modern genera during the winter period. With the amelioration of spring conditions the motile stage evacuates (excysts) through an opening known as an archaeopyle, to leave behind the resistant phragma for the fossil record. Dinoflagellates have a wide temperature tolerance (1-35°C) with an optimum for most species of 18-25°C. Most genera live in salt or brackish water conditions and are sensitive to changes in water mass, including salinity changes (Brasier, 1980).

In this study the dinoflagellate cysts were not identified specifically or generically, but were merely counted as one category where and when they were encountered. They are appended as absolute values on both the relative and absolute pollen diagrams.

7.4 COMPUTATIONAL DATA ANALYSIS AND COMPILATION

This section details the tabulation and processing of the pollen data and outlines the components of the pollen diagram.

7.41 Tilia

Pollen data was assembled, transformed and presented using the *Tilia* computer program, developed at the University of Minnesota by Eric Grimm. Pollen counts were loaded into a master spreadsheet, from which smaller files could be created to form more manageable segments which would eventually form individual pollen diagrams from different sections of the core. The program recalculates the pollen counts as a percentage of the total pollen sum. For absolute pollen diagrams the program recalculates the pollen counts as proportions in relation to the added marker grain (see below).

7.42 Pollen Diagrams

The pollen diagram presents the information held in the spreadsheet in a more wieldy form. It has two basic dimensions - an x-axis along which every taxon identified is plotted as a histogram (the length of which relates to its numeric importance) and a y-axis which gives the core depth (cm - units of the tilia program). Taxa have been split into basic physiognomic groupings - trees, small trees and shrubs, herbs (including grasses), fern and fern allies, aquatic plants (which includes wetland plants) and exotic and unknown pollen. Dates are provided along the left hand margin. Two types of diagrams are used in this presentation - relative and absolute diagrams.

I Relative Pollen Diagrams

As mentioned, relative diagrams use percentages to present the pollen data, where the count for each taxon has been divided by the total number of pollen counted at that depth. This means that the data portrayed is not independent, as a change in the frequency of one taxon must induce a change in all other taxa, thus the incidence of a species is a function of not only the frequency of that species, but also the composition i.e. total pollen production of the vegetation community (Fægri and Iversen, 1989). This aside the relative pollen diagram is still a useful and widely used way to present pollen data. The x-axis values are then percentages. On the far right of the diagram are presented the pollen totals. A summary diagram combines the pollen percentages of the dryland physiognomic groups. The aquatics and unknown/exotic curves are excluded from the summary diagram mainly because the aquatic pollen curves are strongly influenced by local environmental change, and may mask regional trends of the dryland taxa. In Figures 8.3a, 8.4a and 8.5a, fern and fern allied taxa were excluded from the calculation of percentages for the diagrams due to their predominance in the counts at the depths represented in these diagrams.

II Absolute Pollen Diagrams

The absolute diagrams use proportions in relation to the added Lycopodium spores (the number of which is known within a standard deviation) instead of percentages. The x-axis values are in grains per cc of sample material. Summary diagrams for each physiognomic group are drawn separately this time, and are found on the right hand side of the diagram. Pollen influx can be broadly inferred from these diagrams. Ideally pollen influx data need to be constrained by a suitable resolution of dating to calculate the number of pollen grains per cc per year. Unfortunately only a limited number of dates are available.

III Zonation and Coniss

The pollen diagrams have been divided into a number of zones as an aid to describing and interpreting the pollen curves down the core. These zones are effectively biostratigraphic in nature, being based primarily on their pollen flora. They have been placed in such a way as to maximise the variation between zones and minimise the variation within the zone, as outlined by Yarranton and Ritchie(1972). This could be done quite effectively by subjectively looking at the diagram and placing boundaries on the diagram using the above criteria. Pollen data does however, lend itself well to statistical analysis, which has the advantage of objectivity.

The tilia program contains a statistical package called *Coniss*. Coniss carries out stratigraphically constrained cluster analysis where coefficients are calculated using incremental sum of squares (Grimm, 1987). Cluster analysis is a multivariate procedure for detecting groupings in data, whereby similar objects appear in the same cluster and dissimilar objects appear in different clusters. Coniss achieves this by calculating a measure of dissimilarity between the pollen assemblage at each sample depth. The clustering is usually constrained by depth, so that the clusters can only contain stratigraphically adjacent samples. In an agglomorative clustering procedure samples are combined at a certain level of dissimilarity. A low coefficient means the samples are similar. The dissimilarity coefficient is increased until eventually all the samples belong to a single group.

The results of the agglomorative cluster analyses are presented as dendrograms at the far right of most of the diagrams. The dissimilarity coefficient is plotted along the x-axis, with the joining of individual samples (or clusters) occurring at a height corresponding to the approximate x-axis value. The final definition of zones using the dendrogram still requires the arbitrary selection of a dissimilarity coefficient value at which to place the zone.

7.5 DATING TECHNIQUES

The dating of material from the core was not carried out by the author. But a brief review of the techniques used to date the core is provided here along with the constraints and problems associated with each technique.

7.51 Radiocarbon Dating

Carbon-14 (^{14}C) is a radioactive isotope formed continuously in the upper atmosphere by the action of cosmic rays. Upon forming it undergoes continual decay. The time taken for half the isotope to decay can be measured by a fixed constant called a half-life. The best estimate of this half-life was given by Godwin (1962) as 5730 +/- 40 years. The earlier half-life calculated by Libby (5568 +/- 30 years) is, for the sake of consistency, used by most workers. Dates calculated using the Libby half-life can be easily converted to the more accurate figure by using multiplier of 1.03. Radiocarbon dates are commonly given as years before the present (yrs BP) with 1950AD taken as being the present.

^{14}C is taken up continuously by plants and other living organisms, an exchange which maintains the equilibrium between the ^{14}C in the atmosphere and the living tissue of the organism. Once the organism dies the equilibrium is lost, and the radiocarbon will decay without the replenishment of new ^{14}C.

The radiocarbon dating method was developed to measure this decay, with the aim of ascertaining the time the organism ceased to live. Several methods have been developed and are detailed in Pilcher (1991). The two most common - gas proportional counting and liquid scintillation counting, measure the radioactive emissions from ^{14}C. A third method called accelerator mass spectrometry (AMS) is a more expensive method but has the advantage that smaller volumes of sample can be analysed. This method differs from those above in that rather than measuring ^{14}C emissions, the ^{14}C atoms are detected by the difference in their mass.

Radiocarbon dates are quoted with an estimate of the error associated with the radioactive measurement. This is usually given at the 68% confidence level (one standard deviation), though when discussing and interpreting the results it is better to use the 95% confidence interval (two standard deviations) (Pilcher, 1991). The effective limit for radiocarbon dating is 40000 years. For material older than this, the amount of radioactive decay is very difficult to measure due to it being particularly small. Older samples are then more susceptible to contamination by modern carbon. Contamination of samples within the sediment is a common problem. The penetration of roots may introduce younger carbon into stratigraphically older sediments. Bioturbation and other forms of reworking will reduce the stratigraphic control of radiocarbon dates in a core sample. Interpretation of dates also needs to take into consideration the time that has elapsed between the death of an organism and its incorporation into the sediment.

Due to the variation in atmospheric ^{14}C through time, radiocarbon years deviate from calendar years. Radiocarbon dates should be calibrated, where possible, with empirical data such as that supplied by dendrochronologists. Unfortunately calibration curves do not extend back as far as the limits of radiocarbon dating, so many pre-Holocene radiocarbon dates cannot be calibrated. The calibrated dates are given in calendar years BC or AD.

7.51 Uranium-thorium Dating

Uranium-thorium dating falls under the wing of uranium series dating. This form of dating is isotopic, involving the decay of a parent isotope to a daughter at a known rate. Chemical differences between various elements in the series give rise to separation during weathering, transport and deposition in the hydrosphere. Thorium is strongly absorbed onto clay surfaces, while uranium may move as a complex ion in solution causing a disequilibrium between longer lived nuclides. Once isotope migration ceases and the system becomes closed, there is a slow return to equilibrium and it is this that is employed to determine sample age (Smart, 1991). The uranium-thorium (^{230}Th/^{234}U) method is the most versatile and useful of the uranium series methods, and can be applied to a wide range of materials, including molluscs, lacustrine sediments, and peats. It has the potential to date back as far as 350ka.

The uranium thorium method makes two assumptions. Firstly, that there is no Th_{230} incorporated in the crystal lattice upon deposition. Secondly that the system should remain closed to the migration of uranium and thorium after deposition. There are mechanisms for assessing instances where these assumptions are not valid. In this study the ^{230}Th/^{238}U dating method was used to date a lignite layer.

7.52 Thermoluminescence Dating

Some minerals such as quartz and feldspars, calcite and clays are thermoluminescent, meaning that they emit light when heated below the temperature of incandescence (Wintle, 1991). This results from the release of energy stored as electron displacements in the minerals crystal lattice, with the amount of thermoluminescence being proportional to the number of electrons. By monitoring the amount it is possible to estimate the constant rock temperature imposed by a former climatic environment and therefore calculate the length of time since the change of temperature occurred in the rock's environment. The time range for this dating technique is very much dependent on the material and the amount of time it was exposed to light before burial. Generally it is only employed reliably for samples younger than 300ka.

Chapter Eight:

RESULTS

RESULTS

This chapter presents the results from the pollen analysis of sediments contained in the Waipori 99-1 core. The core is divided into the stratigraphic units defined by Barrell *et al.* (1999). These units are further subdivided here based on their respective palynological characters. In a number of cases these subdivisions have been split into zones with the aid of a multivariate statistical program (Coniss). In some cases the suggested boundary calculated by Coniss has been subjectively overruled where the character of an appearing taxon is more important than any changing frequency.

The results are presented chronologically from the base of the core to the surface. Both relative and absolute pollen diagrams are presented here. It should be borne in mind that the results present the facts, or the raw pollen data and do not seek to make inferences about the prevailing vegetation associations or climates. Such hypotheses are reserved for discussion. The results section comments on important trends exhibited among the taxa present.

8.1 Waipori 99-1 Lower Alluvium (154.30 - 66.60m)

A number of fine clay laminations and gravel sections were sampled amongst the Waipori 99-1 lower alluvium. Of the nineteen samples submitted for preparation from the section between 64.85m and 154m, only six samples yielded a count of more than ten grains. Samples with low counts have been included only in the absolute analyses. Two silt beds within the Waipori lower alluvium did however yield statistically viable counts.

I Pollen bearing layer (103m)

Figure 8.1a (relative pollen diagram) and 8.1b (absolute pollen diagram) present the pollen and spore assemblage from the silt bed between 103.81 and 103.16m. Of the five samples taken in this layer, three yielded a suitable count. These samples came from the top 30cm of the bed. This diagram is left unzoned because there is no appreciable change in the pollen curves of the taxa present. The diagram is characterised by low percentages of tree pollen and a relatively diverse selection of shrubby and herbaceous pollen types. *Phyllocladus* pollen is the most abundant pollen type recorded. Other well recorded shrub pollen types include Asteraceae, *Coprosma*, *Hoheria*, and *Plagianthus regius*.

Poaceae pollen is abundant in all three samples, while *Gunnera* and Haloragaceae pollen appears continuously. Monolete fern spores and Cyperaceae pollen are also prominent throughout. After the formal count one extinct spore taxon, *Polypodiisporites radiatus* was identified by Mildenhall (*pers comm.*). *Haloragacidites harrisii* (*Casuarina*) was noted in the formal count.

II **Pollen bearing layer (72m)**

The pollen and spore assemblage present in the silt layer between 72.20m and 72.65m is presented in Figure 8.2a and 8.2b. Pollen analysis reveals an assemblage lacking in diversity. The layer is characterised by large amounts of Poaceae and Asteraceae (Lig.) pollen. Asteraceae (Tub.) and *Pseudopanax* pollen are the most commonly encountered of the shrubby taxa present. Tree pollen and fern spore percentages are negligible. Values for Cyperaceae pollen are high. Several extinct grains were encountered after the formal count. These have been identified as *Haloragacidites harrisii*, *Rhoipites alveolatus* and *Polypodiisporites radiatus* by Mildenhall (*pers comm.*). *Nothofagidites cranwellae* (*Brassospora*) was also noted in the formal count.

8.2 Waipori 99-1 Lacustrine Unit (66.60 - 54.50m)

Two pollen diagrams attempt to detail the palynoflora of this unit. The Waipori 99-1 lacustrine unit is a predominantly fine grained unit located between the depths indicated above.

I Waipori lignite section

A 56cm lignite deposit overlies a 2.4m thick deposit of interbedded sand and silt between 66.61m - 64.21m. Only one sample of three taken from the bed below the lignite yielded a usable sample. This was a sample from the silt bed taken at 64.35m. It is included in the pollen diagrams, even though it does not actually come from the lignite. An erosional contact exists between the lignite and a 2m thick overlying gravel unit.

Figure 8.3a and 8.3b present the pollen spectra recovered from this section. As fern spores form a large proportion of the pollen count, they have been excluded from the calculation of percentages for tree, shrub and herb taxa in the relative pollen diagram. Fern percentages are then calculated against the sum of the combined tree, shrub and herb counts. This takes out the masking effect that these often prolific (particularly in the case of ferns which produce monolete spores) local pollen/spore producers have on the regional pollen/spore rain, whilst enabling other less prolific pollen producing local taxa to be more prominent. This is an accepted practice when presenting pollen data, as outlined in Faegri and Iversen (1989). The diagrams have been split into four zones.

ZONE I (64.35m - 64.18m)

Zone I is defined by low absolute pollen values (see Figure 8.3b).

ZONE II (64.18m - 63.95m)

There is no appreciable change in the composition of the palynoflora in Zone II, aside from the loss of *Pseudowintera* and *Aristotelia*. *Fuscospora* becomes increasingly prominent in the pollen spectra through Zone II. The pollen curve for *Dacrycarpus dacrydioides* peaks at the start of Zone II, and then progressively declines. *Prumnopitys taxifolia* peaks at 64.02m at which point *Halocarpus* enters the pollen diagram. Pollen curves for both *Prumnopitys ferruginea* and *Prumnopitys taxifolia* undergo a short decline above this, while *Dacrycarpus dacrydioides* and *Fuscospora* reach small peaks at 63.97m. *Halocarpus* continues to increase, whilst low percentages of *Nothofagus menziesii* pollen are present fleetingly at this depth. The curves for the spores of *Cyathea* and *Dicksonia* increase markedly at this depth. There is a small but noticeable peak in the pollen curve for Poaceae. This depth also sees a peak in the pollen curve for Cyperaceae.

ZONE III (63.95m - 63.67m)

Zone III sees an initial peak in the curve for *Halocarpus* at 63.93m, after which it declines, to become absent at 63.84m. The curves for the podocarp trees increase somewhat along with that for *Fuscospora*. The exception to this trend is *Dacrycarpus dacrydioides*, which declines. *Ascarina lucida* pollen is continuously recorded through this zone, with the exception of two samples. There is an unprecedented sharp peak in the pollen curve of Haloragaceae at 63.84m. Monolete fern spores become increasingly dominant in the pollen spectra throughout this zone. *Halocarpus* reappears at 63.80m to become the most well represented shrub in the pollen rain. *Phormium tenax* makes a notable appearance at the top of this zone.

ZONE IV (63.67m - 63.63m)

One sample at 63.65m defines the last zone. The pollen curves for all tree and tree fern taxa decrease. The Poaceae pollen curve increases markedly, along with the curves for monolete fern spores and Cyperaceae. *Aristotelia*, Myrtaceae, and *Phyllocladus* reappear, after discontinuous appearances in lower zones, while *Halocarpus* continues to increase.

II Waipori lacustrine Section

As mentioned above, a gravel unit overlies the lignite section, separating it from what is termed here, the *true* Waipori lacustrine unit. Core loss between the top of this gravel unit and the base of the *true* Waipori lacustrine section cannot be accurately defined. It is here taken to be the base of a sandy layer at 61.76m. Interbedded silt and clay form the stratigraphy between 61.50m and 54.78m. Clay layers are more numerous and extensive between 61.50m and 57.04m, while a uniformly silt layer extends from 57.04m to 54.78m. The Waipori lacustrine section is capped with a 0.30m sand layer, between 54.78m and 54.48m. The whole section is characterised by black flecking, presumably of organic origin. An articulated bivalve (freshwater mollusc - *Hyridella*) was also encountered at 59.10m. All samples yielded a suitable number of pollen and spores for useful analysis.

Figures 8.4a and 8.4b present the pollen assemblage from the Waipori lacustrine section. The ferns have been excluded from the primary percentage calculations as per above. The diagrams have been divided into three zones.

ZONE I (61.50m - 59.93m)

This zone is characterised by high values for Poaceae, Cyperaceae, and shrubby taxa. *Plagianthus regius*, *Hoheria*, *Coprosma* and Asteraceae (Tub.) are the most well represented of the small tree and shrub taxa. The pollen of all major tree species are sporadically present with the exception of *Dacrydium cupressinum*, which is absent. Monolete fern spores are also very common throughout this zone, a feature which characterises the whole diagram.

ZONE II (59.93m - 57.62m)

Low pollen influx is a characteristic of this zone. The fossil pollen spectra are lacking in diversity and are dominated by Poaceae pollen and monolete fern spores. *Plagianthus regius*, *Hoheria*, *Myrsine*, Asteraceae (Tub.) and Epacridaceae (*Dracophyllum*?) are the most well represented shrubs through this zone. Of the trees, *Fuscospora* and *Podocarpus* undifferentiated (*P. cunninghamii*?) are best represented through this zone, but tree pollen is generally uncommon.

ZONE III (57.62m - 54.83m)

This zone is defined by the proliferation of tree pollen, in particular *Podocarpus* undifferentiated, *Prumnopitys ferruginea*, and *Prumnopitys taxifolia*. Peaks in the pollen curve of *Prumnopitys taxifolia* are associated with drops in the curves of *Podocarpus* and *Prumnopitys ferruginea* and vice versa. Such trends are also recognised on the absolute diagram. *Griselinia*, *Halocarpus* and *Hoheria* curves follow the trend of *Prumnopitys taxifolia*, while *Coprosma* follows that of *Podocarpus* and *Prumnopitys ferruginea*. *Coprosma* and *Plagianthus regius* are the most well represented shrubs/small trees through this zone, while Asteraceae (Tub.), Epacridaceae, *Hoheria*, *Myrsine*, *Griselinia*, *Halocarpus* and *Pittosporum* are present at near continuous levels. *Pseudowintera* enters the diagram at 56.20m and remains more or less present to the top of the zone. Relative levels of Poaceae pollen decrease, but influx values show a variable increase. Tree ferns, *Gleichenia* and *Cystiopteris* are continually represented through this zone. Monolete fern spores are still common. *Phormium tenax* is more or less continuously represented, with *Myriophyllum* present in a number of upper samples in the zone.

8.3 Waipori 99-1 Upper Alluvial Unit (54.50 - 22.25m)

The Waipori upper alluvium is characterised by sequences of gravel with interbedded fine layers. Core loss is a major feature, particularly between 45.19m and 40.79m, and 37.04m and 33.00m. Several diagrams document the palynology of the Waipori upper alluvial unit section. Though there were a number of fine layers (mainly sand and silt) few of these were extensive enough to provide any useful record. In many cases the counts were low, and of limited use. Samples such as these have been included only in the absolute diagrams.

I **Spot samples (54.50 - 45.19m)**

Figure 8.5a and 8.5b present the palynology of several spot samples taken from small interbedded fine layers within the gravel unit between 54.50m and 45.19m. Of the five samples prepared, only three produced useful counts, though it is acknowledged that these counts are low (50-100 grains). Preservation was reasonably poor in these layers. About 3m of gravel overlie the Waipori lacustrine unit. The lower sample at 50.70m comes from one of two small sand layers which were noted to contain organic material. The sample contains the pollen of four podocarp trees, a selection of shrubs, notably *Coprosma*, *Pittosporum*, *Plagianthus regius* and *Pseudopanax*, and the pollen of several herbaceous taxa. Pollen concentrations are low in this layer.

About 3m of gravels separate the sand layers just described and another fine layer which lies between 46.88m and 45.19m. Within this fine unit, layers of silt and sand are interrupted by two small layers of gravel (less than 20cm thick). Samples taken from a silt/sand layer at 46.50m and 46.35m contain similar assemblages. The only recorded tree pollen in the sample at 46.50m was that of *Podocarpus* undifferentiated. It is not recorded in the sample above, where *Dacrycarpus dacrydioides*, *Nothofagus menziesii*, and *Prumnopitys ferruginea* pollen are encountered at very low amounts. Shrub pollen is dominated by *Myrsine* and *Halocarpus*. Poaceae pollen and particularly fern spores are most abundant in these two samples. As the counts are very low, the absolute pollen diagram (Figure 8.5b) provides the most reliable information for this unit.

II **Pollen bearing bed (40.80m - 37.42m)**

The pollen sequence presented in Figures 8.6a and 8.6b comes from a layer of clay, interbedded between two sandy layers and lies between 40.80m and 37.42m. This generally fine layer overlies 4m of mainly unknown material (because of core losses). It is presumed to have been either sand or gravel material, as such sediments were most susceptible to being lost during core recovery in the field.

The sequence has not been zoned because there is little appreciable change in the pollen frequencies for almost all taxa in the diagram, nor is there any marked change in composition. Four samples were taken from the basal layer of this unit, which contained a mixture of interbedded sand and silt. The basal sample at 40.63m was taken from a small clay lamination and records a palynoflora very similar in frequency and composition to that present in the samples taken from the clay layer between 39.76m and 38.18m. Of the three samples taken above this basal sample, and within the confines of the sandier basal layer, a sample taken at 40.00m was the only one to give a reasonable count. This count revealed little change in the relative frequencies of the taxa present. The absolute pollen diagram (Figure 8.6b) reveals very low pollen concentrations, suggesting a rapid sedimentation rate.

The pollen diagram is characterised by relatively high and reasonably stable percentages for the main tree taxa present. *Dacrycarpus dacrydioides* exhibits two small peaks at 39.76m and 38.18m. These peaks are separated by declining values to 38.60m. The pollen curves of *Prumnopitys ferruginea* and *Prumnopitys taxifolia* exhibit similar trends. Pollen of the latter tends to be more abundant. *Dacrydium cupressinum*, *Metrosideros*, and both *Nothofagus* pollen types are discontinuously present in small amounts throughout the unit. The most notable small tree and shrub taxa are Asteraceae (Tub.), *Coprosma*, *Halocarpus* and *Plagianthus regius*, all of which are more or less continuously represented at all depths. The most notable feature of the diagram is perhaps the peak in the pollen curve for Haloragaceae at 39.35m. Tree fern spores are abundant and are continuously present, along with monolete fern spores. A number of other ferns and fern allies are commonly encountered at most depths. These include *Cystopteris*, *Histiopteris*, *Lycopodium fastigiatum* and *Lycopodium volubile*. *Phormium tenax* pollen is encountered in the top sample only.

III **Spot samples (37.42 - 22.25m)**

The fine unit described above is overlain by a thick c.9.5m sequence of gravels, devoid of any fine layers, though there are 4m worth of unaccounted material between 37.04m and 33.00m. A 1.3m fine layer lies between 27.61m and 26.30m. This layer fines upwards into what is believed to be a palaeosol. Five spot samples were prepared from this fine layer. Only two of these yielded counts suitable for inclusion in the relative diagram (Figure 8.7a, Zone I). All five samples are included in the absolute diagram (Figure 8.7b, Zone I). The two samples shown on the relative diagram came from the palaeosol. These two samples are reasonably similar in composition. Both samples are dominated by tree fern and monolete fern spores. Poaceae pollen is also common. *Plagianthus regius* is the most common arboreal pollen type. Other taxa present in low frequencies include *Coprosma*, Epacridaceae and *Prumnopitys*.

8.4 Waihola silt/sand unit (late glacial and Holocene)

A 4m gravel layer overlies the palaeosol described above. The top of this gravel layer lies at a depth of 22.25m. An uninterrupted (i.e. by gravel) sequence of fine sediments extends from this depth to the surface. Radiocarbon dates place these sediments within the time frame of the late glacial and Holocene. A sand layer extends between 20.53m and 22.25m. Five samples prepared from this layer yielded extremely low counts making them inappropriate for inclusion in the relative diagram. These samples are, however, included in the absolute pollen diagram (Figure 8.7b).

The pollen diagrams have been split into five zones. Zone I has been described above. The results presented in this section begin with Zone II. Many of the samples taken in this fine unit contained opaque particles, and in some cases these particles had formed inside the pollen grains making identification and counting difficult. This was a problem in a number of samples throughout the core, and was a great source of error for the charcoal count. In the relative diagram presented here, trees have been excluded from the percentage calculations, so as to give a clearer picture of local vegetation trends.

ZONE II (19.77m - 15.53m)

This zone is characterised by the sudden rise of tree pollen, in particular, *Dacrycarpus dacrydioides*, *Podocarpus* undiff., *Prumnopitys ferruginea* and *Prumnopitys taxifolia*. The initial peaks in the curves of the latter three taxa at 19.45m are curtailed in the samples at 18.53m and 18.03m. The curves for *Podocarpus* undiff. and *Prumnopitys ferruginea* peak sharply at 17.53m, while *Prumnopitys taxifolia* consolidates to become the most well represented podocarp at 16.28m. *Dacrycarpus dacrydioides* remains reasonably stable through this zone. *Dacrydium cupressinum* is encountered in low amounts from 17.53m in this zone. *Coprosma*, *Halocarpus*, *Phyllocladus*, *Plagianthus regius* and *Pseudowintera* are the most well represented of the small tree and shrub taxa. These taxa tend to peak at times when tree taxa fall. Other taxa within this group which are more-or-less continuously represented include Asteraceae (Tub.), Epacridaceae, *Griselinia*, *Hoheria*, *Muehlenbeckia*, and *Pseudopanax*. A reasonably diverse range of herbaceous taxa are represented in this zone. Poaceae pollen is recorded consistently throughout the zone. *Cyathea* spores are very well represented through this zone, while *Dicksonia* is recorded in considerably less quantities. Monolete fern spores are prolific. In general, there is a diverse range of spores from the fern and fern allies grouping. Restionaceae pollen makes several appearances in this zone.

ZONE III (15.53m - 13.75m)

Zone three is defined by four samples (15.28m - 13.98m). It is characterised by an abrupt decline in tree pollen, particularly *Prumnopitys taxifolia*, and increases in the pollen curves of *Coprosma*, *Plagianthus regius*, *Pseudowintera* and *Cyathea* at 14.78m. There is a large influx of fine (<50µm) charcoal and other black particles at 15.28m, and a relatively large influx of larger sized (>50µm) charcoal and other black particles at 15.78m. Dinoflagellate cysts enter the diagram in this zone.

ZONE IV (13.75m - 3.40m)

A sandy layer overlies the lower clays from 9.29m, and extends to 4.45m. The four samples taken in this sandy layer yielded low counts. One sample taken at 5.33m contained little pollen and has not been included in the relative pollen diagram. The coarser nature of the upper ten metres of the core, and the zones of core loss meant that the resolution of sampling has not been as high through this section.

Zone IV is characterised by the expansion of *Dacrydium cupressinum*. It becomes the most well represented emergent tree in this zone. The large peak in *Dacrydium cupressinum* at 8.53m is, however, a function of the relative diagram. A count of 100 grains was made, and 66 of these grains were identified as *Dacrydium cupressinum*. It may have been preferentially preserved or incorporated into the sandy layer. All podocarp trees (and shrubs) are well represented through zone IV. *Nothofagus menziesii* enters the diagram at the top of this zone, and its pollen is represented continuously from this period on. *Pseudowintera* remains one of the most well represented shrubs up until 9.33m. Many of the better represented small tree and shrub taxa decline between 11.72m and 9.33m. The tree ferns exhibit a similar trend, particularly *Cyathea*. Dinoflagellate cysts peak in this zone at 11.72m and then decline to become absent in the sample at 9.55m.

ZONE V (3.40m - 0.0m)

The three samples which form Zone V come from a small silt layer between 3.18m and 3.62m and the modern soil horizon. Barren sands and core losses extend between the lower silt layer and the soil.

This zone is characterised by the wholesale decline in tree pollen for all tree taxa at 3.28m, with the exception of *Nothofagus menziesii*. Asteraceae (Tub.), *Coprosma*, *Halocarpus*, *Phyllocladus* and *Plagianthus regius* undergo a decline also. A number of small tree and shrub taxa increase however. These include *Hoheria*, *Myrsine*, *Pseudopanax* and *Pseudowintera*. *Coriaria* is represented for the first and only time in the Holocene section. A relatively diverse range of herbaceous taxa appear at this depth including Brassicaceae, Chenopodiaceae, *Epilobium* and Liliaceae. Poaceae pollen peaks at this depth. The curve for *Cyathea* spores drops somewhat, while *Pteridium* appears in the record for the first time. Cyperaceae follows a similar trend to Poaceae throughout this zone, with a peak at 3.28m. *Typha orientalis* appears in the record at this depth.

The upper two samples show a rise in the pollen curves for many of the taxa which experienced a decline at 3.28m, while those which increased at 3.28m decrease at 1.03m. This trend is reversed again at 0.28m. One of the more notable exceptions is *Dacrydium cupressinum*, which increases in both relative and absolute terms. *Nothofagus menziesii* pollen is not represented at 0.28m. Notable additions at this depth include Myrtaceae pollen of both *Leptospermum/Kunzea* type and the *Lophomyrtus/Neomyrtus* type.

Chapter Nine:

DISCUSSION

DISCUSSION

This project aimed to reconstruct the Quaternary vegetation of the Lower Taieri Plain district and to make inferences on the climates of the period. In the course of the project a set of new challenges presented themselves. Preliminary dating on the core poorly constrained sediments below 40m. At the time of writing, material has been submitted for thermoluminescence dating, but the preliminary ages are not expected to be through for another three months. This has meant that instead of the dates providing temporal context for the pollen data, pollen data has had to be used to infer a temporal context. The core does, however, provide a reasonably complete and good quality Holocene record.

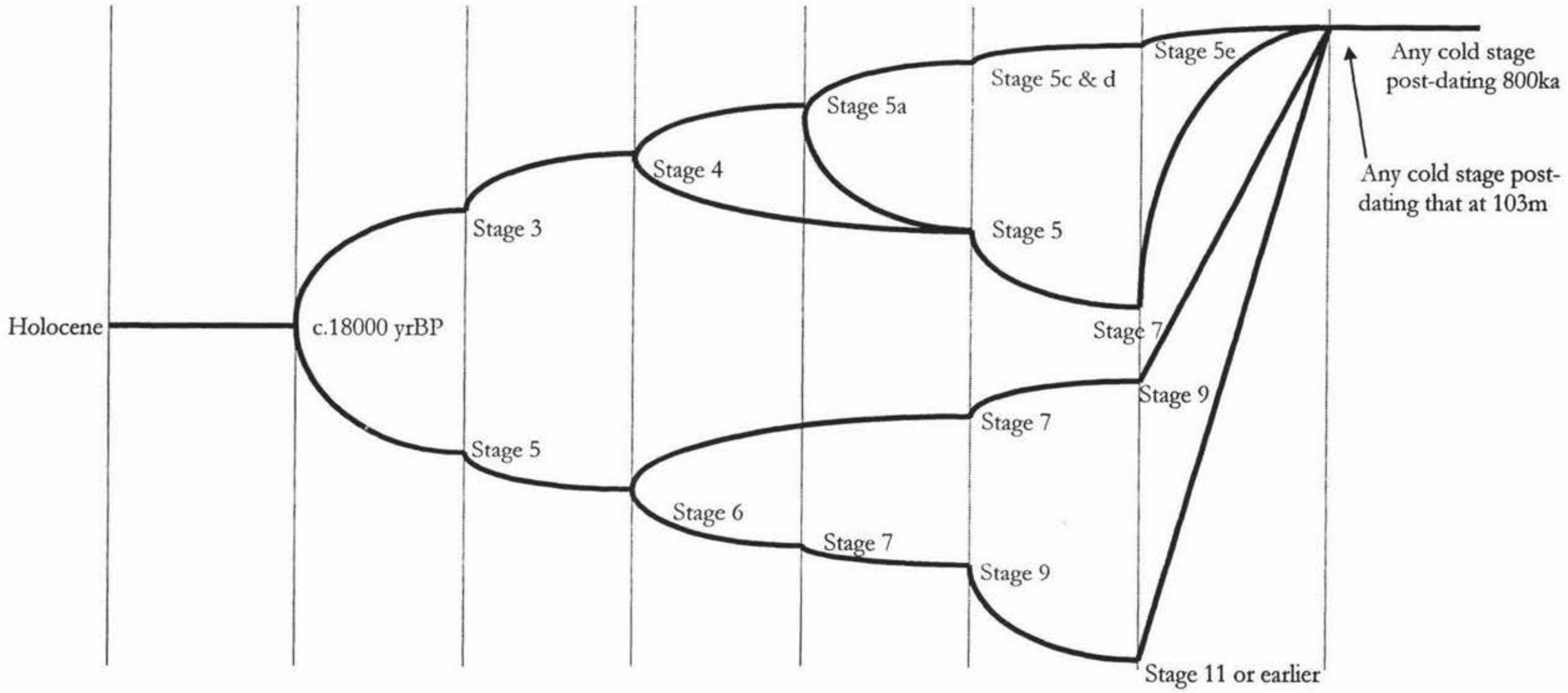
The results are discussed here in chronological order as is convention in the presentation of historical information. It is pointed out, however, that due to the enigmatic chronology and the need to use the Holocene record as an analogue for past interglacials, references will be made to data which may superpose and therefore post-date the results being discussed. It is the fine grained layers within the sequence that have been used as datum, as these provide the necessary pollen data from which to infer whether a layer has been deposited under cool or warm conditions. By applying the "counting back" method, a series of possible chronologies have been created and related to the oxygen isotope stages. To aid the reader in this discussion a flow-diagram (Figure 9.1) has been drawn to account for the possible chronological lines along which sedimentation may have taken place. This diagram takes into account the current dates available, stratigraphical information, the subsidence information of Dickinson *et al.* (2000), Litchfield (2000) and Barrell *et al.* (1999) and the pollen data provided in this project. Mildenhall (1995) pointed out that such chronologies will break down where there has been a hiatus or erosional event in the sedimentary record. The diagram does not claim to account for all possible chronological lines of sedimentation, but covers what are perhaps the most likely. The possible chronologies will form a major moot for this discussion.

9.1 The Waipori 99-1 lower alluvium

As noted in above chapters, the Waipori lower alluvium is characterised by an 87.7m thick sequence of predominantly gravely sediment between 154.3m and 66.60m. These

Possible Chronologies for the Waipori 99-1 Core

Depth	0-22m	26-27m	37-41m	45-46m	50m	54-61m	64m	72m	103m



Climatic Inference	Warm	Cool	Warm	Cool	Warm	Cool then Warm	Warm	Cool	Cool
Palynoflora	Full forest	Fernland	Full forest	Shrubland	Forest?	Shrub/grassland into full forest	Full forest	Grassland - herbfield	Shrubland - grassland

Figure 9.1 Possible chronologies for the sediments of the Waipori 99-1 long core.

gravels did harbour some comparatively small interbedded fine layers between 126.68m and 121.50m, 104.03m and 103.16m, and 72.03 and 72.65m. The lower most (and most extensive fine layer in the Waipori lower alluvium) did not yield a count greater than seven grains in the four samples taken. Spot samples taken in the gravels in the lower 50m did not yield any pollen.

Several samples taken between 103.50m and 103.30m did, however, yield a good sample of pollen grains (for the sake of brevity this term will include fern spores unless otherwise stated) (refer to Figure 8.1a and b). This fine bed is characterised by a cold climate pollen assemblage dominated by shrubby alpine and herbaceous taxa. The palynoflora are particularly diverse. Tree taxa are particularly poorly represented in the samples. *Metrosideros*, *Fuscospora*, *Podocarpus* and *Prumnopitys* are all well dispersed pollen types, and it is therefore likely that these low percentages represent dispersal from a distal source. *Libocedrus* may have been locally present in the vegetation. The sediment character and pollen assemblage suggest that a marshy bogland existed on the lower Plain. A *Phyllocladus* dominated shrubland grew on or in close proximity to the site. This shrubland contained a diverse selection of hardy shrubs including members of the Asteraceae family, *Hoheria*, *Myrsine*, and *Plagianthus regius*. *Coprosma* was probably also common, though it should be remembered that its pollen is often over-represented. A locally damp and cool environment can be inferred given the relatively numerous and diverse range of herbaceous taxa present. Various species of grasses and sedges were probably prolific in open areas, along with a number of ground ferns, as is indicated in the high percentages for Poaceae, Cyperaceae, *Gleichenia* and the monolete fern spores. Both *Lycopodium fastigiatum* and *Lycopodium scariosum* are commonly found in damp sub-alpine environments, further suggesting a cool environment. Pollen concentration values are consistently between 40000 and 45000 grains per cc.

Spot samples at 93.70m, 89.85m and 83.85m did not yield any pollen. Three samples taken between 72.42 and 72.22m did, however, yield low, but useful counts. These samples reveal a cool climate assemblage (refer to Figure 8.2 a & b). The palynoflora is less diverse than the layer previously described, with herbaceous pollen dominating the assemblage. This suggests that an open grassland - herbfield existed across the plain at this time. Continuous levels of Apiaceae pollen may indicate the presence of *Aciphylla* (speargrass) in this grassland. A patchy shrubland consisting of tree/mountain daisies (*Celmisia* and/or *Olearia*?), *Coprosma*, Epacridaceae (*Dracophyllum*?), *Hebe* and *Pseudopanax*, may have been present in less exposed valleys along the foot of the Maungatua Range and the Chain Hills as suggested by the low influxes of shrub pollen. Groundferns and fern allies appear to have been more restricted in this assemblage, with only the more hardy *Cyathea smithii*, *Lycopodium fastigiatum* and monolete fern spore taxa (probably *Blechnum* spp.) present. The presence of *Phormium* pollen in the top sample may indicate that it was also growing in locally wet hollows close to the site. Influx values between 10000 and 45000 grains per cc, a lack of diversity and restricted levels of shrub pollen suggest that the climate of this cool period was more severe than that portrayed at 103m.

The harsh environments created by these glacial periods would have been further accentuated by the increased continentality provided by a lower sea-level, the shoreline of which would have been some 40km east of the Chain Hills. Though terrestrial conditions would have been drier on the whole, the morphology of the basin would have focused drainage onto the plain. Lower air temperatures would have decreased evapotranspiration, allowing for the maintenance of a boggy surface upon which these characteristically herbaceous taxa grew.

It is difficult to assign a date to these layers given that a reliable chronology has not yet been established for sediments below 22m. Local geologists from Otago believe that the deeper gravels below the Lower Taieri Plain date back to the late Tertiary period (Litchfield, *pers comm.*). The fact that the pollen assemblages have been deposited under clearly cold climates suggests that they must have been deposited no earlier than the mid- to late Pliocene when global cooling and the glacial-interglacial cycles began. This creates absolute maximum age of 2.5 million years for the assemblage at 103m. As a number of taxa are known to have become extinct in New Zealand during the late Tertiary and early Quaternary, the samples were checked for extinct pollen and spore taxa by Dr. Dallas Mildenhall (IGNS), a specialist in pre- Quaternary palynology.

Dr. Mildenhall found *Polypodiisporites radiatus* in a sample at 103.50m. Aside from this *Haloragacidites harrisii* (*Casuarina*) was noted by the author at 103.30m. Four extinct palynomorphs were found in the samples at 72m. These were *Nothofagidites cranwellae (Brassospora)*, *Haloragacidites harrisii*, *Rhoipites alveolatus*, and *Polypodiisporites radiatus*. *Nothofagidites cranwelliae* is found in the Castlecliffian and last appears about 500000 years ago. It is believed, however, to have become extinct well before this (c. 1.5 million years ago) in the South Island. *Haloragacidites harrisii* became uncommon in the South Island from about 1 million years ago. Comparable grains of *Casuarina* have been documented as traversing the Tasman Sea from Australia. A trans-Tasman provenance for grains appearing here cannot be totally disproved. *Rhoipites alveolatus* became extinct about 1.8 million years ago. *Polypodiisporites radiatus* occurs well into the Pleistocene becoming extinct within the last 200000 years. From what is known of the palaeoecology of these taxa, it appears they can be found in both cool and warm climate assemblages (Mildenhall, *pers comm.*). The presence of these extinct taxa is undeniable, but whether they have been deposited *in situ* is a point for debate. The upper Taieri catchment contains some extensive Tertiary sedimentary deposits and lignites. It is likely that the tributaries to the Taieri River have eroded material out of these deposits and brought them down the river.

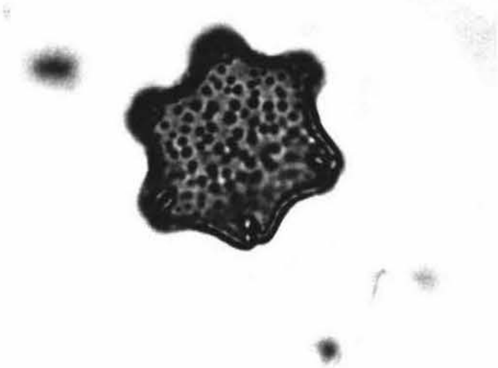


Plate 9.1 An example of a *Brassospora* - *Nothofagidites*-type grain from the Waipori 99-1 core found at 61.40m.

Following discussions with Dr. Mildenhall, a number of points suggest that these taxa are indeed recycled. *Nothofagidites cranwellae* was rare, and in a condition which could not rule out recycling. *Haloragacidites harrisii* was more common. The ratio of *N. cranwellae* to *H. harrisii*, is not unlike that found in Miocene coal measures in the basin, though at a much lower order of course. *Rhoipites alveolatus* is a robust grain which would readily endure the rigours of recycling. *Polypodiisporites radiatus* fits into a similar category. Dr. Mildenhall felt that such cold climate assemblages should have included the alpine conifers *Podosporites parvus* (*Microcachrys*) and *Podosporites erugatus* (*Microstrobos*). These became extinct about 1.4 million years and 800000 years ago respectively. This suggests that either these layers are younger than this or they are much younger and the other extinct taxa are recycled. The regular appearance of easily recognisable *Brassospora* (Plate 9.1) and *Casuarina* (Plate 9.2) grains in samples throughout the sequence (including the Holocene) provides firm evidence that recycling of older palynomorphs has been and

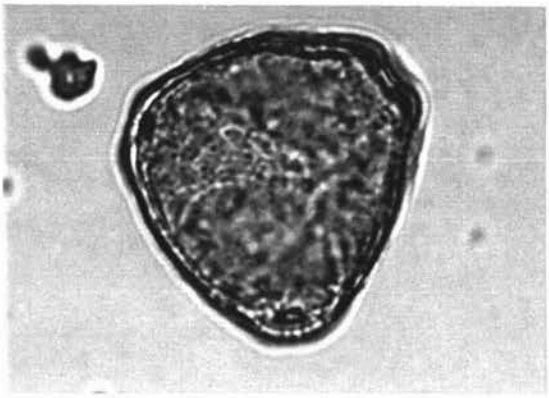


Plate 9.2 An example of a *Haloragacidites harrisii* (*Casuarina*) grain from the Waipori 99-1 core found at 39.40m.

still is occurring. Further support is given by the fact that the lignite layer, which was deposited as a peat, outside the direct influence of the Taieri River, has no extinct taxa recorded in it.

It seems reasonable to place a tentative maximum age of 800000 years on these units given the absence of *Microstrobos*. An upper age bracket can be provided only after assessing the palynology of the superposed beds in the core.

9.2 Waipori 99-1 lignite section

The Waipori lignite overlies a 2.4m bed of sand and silt. Its palynoflora (refer to Figure 8.3 a & b) is markedly different from those previously discussed in that it exhibits a warm climate assemblage with full forest conditions indicated. Pollen concentrations fall typically between 200000 and 300000 grains per cc. It is likely that this peat layer was deposited during the peak of an interglacial period given the taxa present and eustatic conditions needed for peat formation in this setting. Sea-level was likely to have been near the present level or even slightly above. Such a peat would have been deposited at or above sea-level, presumably after a postglacial marine transgression and a period of infilling. There are no obvious marine or brackish water macrofossils in the fine sediments below the lignite to indicate a marine transgression. Unfortunately diatom analyses were not carried out in this layer. The fine nature of these basal sediments may suggest, though not convincingly, that these are interglacial deposits. The Holocene transgressional sequence is 22m thick. The total depth of the sequence between 66.61m and 63.65m is just under 3m. Compaction could account for the comparatively limited sequence. The depositional sequence does however resemble that of the Holocene where initially sandy sediments are superposed by silts and clays laid down in deep, stratified, anoxic, waters. These fine beds are superposed by sands laid down during a rapid period of infilling. Fine silts form the top 4m of the Holocene sequence. Had the basin not been drained and cleared for farmland, a peat swamp would probably have developed as the shallow lakes at the southern end of the basin infilled. One major difference is that unlike the transgressional sequence of the Holocene, pollen was not preserved in the silts and sands below the lignite, though only two samples were taken. One sample taken in the silt bed at 64.35m did yield a quality sample and is included in the pollen diagram.

As mentioned, pollen analysis of the lignite reveals a pollen assemblage which indicates that the basin was fully forested during this period. Pollen analysis suggests that this forest was a mixed podocarp-beech forest with a number of broadleaf taxa. *Prumnopitys taxifolia* was the most dominant of the podocarps, though *Prumnopitys ferruginea*, *Podocarpus* (probably both *P. totara* and *P. cunninghamii*) would have been common emergents. *Dacrycarpus dacrydioides* probably grew in dense cohorts on swampier ground across the plain. *Fuscospora* beeches (*N. fusca* or *N. solandri* var. *cliffortioides*?) may have been interspersed with the podocarps, but it is perhaps more likely that they were growing on the mid slopes of the Maungatua Range. *Metrosideros* pollen is present in low levels which probably suggests that it was part of the regional vegetation.

Zone I contains two samples characterised by low pollen influx - c.40000 grains per cc at 64.35m and c.80000 at the base of the lignite - 64.23m. This may represent either rapid sedimentation, variable preservation or a limited source population. Rapid sedimentation should have been somewhat offset by effects of compaction. Preservation was not particularly good in these samples. A limited vegetation source suggests that these lower samples represent migration out of refugia. This could only be the case if the peat was deposited during the early stages of an interglacial as the climate ameliorated. This would follow if the fine basal sediments which underlie the lignite are found not be those of a transgressional event. If this is the case then it is difficult to explain the presence of a peat layer, containing a warm interglacial flora, overlying any other form of sediment. If we use the Holocene sequence as an analogue, at least 10000 years of warm climates would have occurred before infilling had been sufficient to allow peat development. Unless interglacial sedimentation within the basin was not influenced by marine incursion at this time, the low pollen concentrations may represent a problem with pollen preservation. The palynoflora of the lower Zone is somewhat comparable with that which is found in Zones II and III. *Nothofagus menziesii*, *Aristotelia*, *Hoheria* and *Pseudowintera* are in a relative sense, more common in Zone I. These can be regarded as more hardy tree and small tree species. This may lend support to the hypothesis that this is an early postglacial assemblage. The tree ferns - *Cyathea* and *Dicksonia* are well represented in both absolute and relative terms. The mountain tree fern (*Cyathea smithii*) is also present fleetingly in the basal sample. *Phymatosorus* spores are also well represented. These spores are fairly robust grains which tend to preserve well.

Zone II is characterised by an early peak in the curve for *Dacrycarpus dacrydioides*. Its tendency to be the most under-represented of the podocarps suggests that it was growing locally on the site. It is likely that it was one of the first trees to grow on the newly forming terrestrial swamp surface, as is represented by this early peak. Its values decline in succeeding samples, as the values for *Prumnopitys* increase. *Prumnopitys taxifolia* and *Prumnopitys ferruginea* became increasingly important on the Plain, probably moving onto the drier northern and marginal parts of the basin, where fresh alluvial soils lay above the water table. A number of broadleaf taxa were present on the basin at this time. *Coprosma* spp., *Griselinia*, *Hoheria*, *Myrsine*, *Neomyrtus* (*pedunculata*?) and/or *Lophomyrtus* (*obcordata*?), and *Plagianthus regius* were probably common understorey and canopy taxa. The top of this zone sees a decline in the curves of *Prumnopitys taxifolia* and *Prumnopitys ferruginea*. This decrease is associated with an increase in *Fuscospora* pollen and the brief appearance of *Nothofagus menziesii*. *Halocarpus* also becomes more prominent at the top of this zone, along with Poaceae, the tree ferns, and Cyperaceae. These changes seem to point to some sort of environmental change or disturbance within the basin. A change to cooler wetter conditions could be postulated, with both *Nothofagus menziesii* and *Fuscospora* beeches out competing *Prumnopitys taxifolia* and possibly *Prumnopitys ferruginea* on the mid-slopes of the Maungatua Range. *Halocarpus* may also have increased its range in inland and upland areas. A cooler climate cannot however account for the increasingly common appearance of *Ascarina lucida* (Plate 9.3) from this depth. This small tree is well renowned as an indicator of equable climates (McGlone and Moar, 1977). It is sensitive to frost and drought. Today it is found only on the West coast of the South Island, parts of the Marlborough Sounds and in isolated patches around the North Island. It is generally absent from the east coasts of both Islands. *Ascarina lucida* is a notoriously

Plate 9.3 An *Ascarina lucida* pollen grain from the Waipori 99-1 lignite section (63.97m).

good disperser of pollen (Mildenhall, 1976). Its presence in the lignite at levels between 1 and 2% may not provide conclusive evidence that it was growing on the Plain. Similar percentages are recorded at a number of sites in the late Holocene, when it was believed to be in decline due to a changing climate regime (McGlone and Moar, 1977). If it was growing in the region, it is more likely to have been found on the eastern aspect of the Chain Hills close to sea-level where frosts would have been less common, and rainfall more reliable. Given its current distribution, it is peculiar for it to occur this far southeast, if indeed it was growing locally or even regionally.

The early part of Zone III sees a general expansion of the *Fuscospora* beeches, along with *Podocarpus* and *Prumnopitys ferruginea*. *Prumnopitys taxifolia* falls to levels which suggest that it may have become co-dominant with the afore-mentioned podocarps. *Prumnopitys taxifolia* is the most competitive podocarp in drought prone areas. Its subordination to the *Fuscospora* beeches, *Podocarpus*, and *Prumnopitys ferruginea* may be indicative of a consistently wetter climate. The marked increase of monolete fern spores (predominantly ground ferns) and steady values for Cyperaceae may also be related to a wetter climate. The tree ferns appear to have been prolific throughout this Zone. *Dicksonia squarrosa* was more prominent than *D. fibrosa*, and was probably common on poorly drained soils. The genus *Coprosma* is well represented, and was probably a common element in the understorey. The presence of *Ileostylus* may reflect this, as it is commonly parasitic on a number of *Coprosma* species (Webb *et al.*, 1990). A number of new shrubby taxa enter the palynoflora. These include the shrubby Asteraceae, *Pittosporum* and *Quintinia*. *Quintinia* (Plate 9.4) is another small tree which does not, today, grow on the east coast of the South Island. It is common in the podocarp forests of

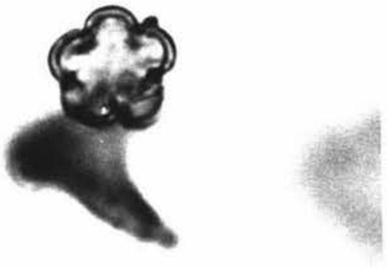


Plate 9.4 An example of a *Quintinia* pollen grain from the Waipori 99-1 core found at 63.77m.

Westland, where it can be found growing from seal-level, up into montane regions. *Quintinia* is another excellent pollen disperser (Macphail and McQueen, 1983). The possibility that these pollen grains have been transported over the Alps cannot be entirely ruled out. McGlone and Bathgate (1983) encountered trace amounts of *Quintinia* pollen in Holocene samples taken at Longwood Range in Southland.

A conspicuous feature in Zone III is the sudden decline of *Halocarpus* between 63.93m and 63.80m. Its pollen was not encountered at all in the sample at 63.84m. This decline coincides with increasing percentages of *Fuscospora*, *Podocarpus* and *Prumnopitys ferruginea* pollen. Increases in these taxa have been attributed above to a wetter climate. *Halocarpus* is likely to have been the most common shrub in alpine and inland areas, as its current and Holocene distribution attest (McGlone and Moar, 1998; Wardle and Mark, 1956). It is documented by McKellar (1973) as being a very good disperser of pollen. It is unlikely to have been common below 400m in the basin. Its decline must relate to some form of disturbance at higher altitudes and in areas further inland. Fire is an obvious candidate, though there is no indication of this in the charcoal record. As much of the *Halocarpus* pollen would have come from distal sources, possibly west of the Maungatua Range, it seems reasonable to suggest that a charcoal signal need not have been recorded, especially as the depositional environment was a peat bog, meaning that water courses such as the Taieri River would have been less likely to bring inwashed charcoal after the event. The absence of small airborne charcoal counts against this however. The dramatic increase in the curve for Haloragaceae at 63.84m may or may not be coincidental. *Haloragis erecta*, a possible parent source, is found in pioneering vegetation, though normally in disturbed lowland and coastal sites (Wardle, 1991).

Gonocarpus is common in open damp sites from the lowland to the sub-alpine (Wardle, 1991). A burning event may have encouraged a sudden proliferation of these herbs, but they are commonly under-represented in the pollen rain (Macphail and McQueen, 1983), and it therefore seems more likely that this peak represents a localised infestation. The amount of time represented between the samples at 63.93m and 63.80m would help determine the scale of this event, but unfortunately this is almost impossible to determine. It will depend upon the initial rate of accumulation and the amount of compaction which has occurred. Whatever the disturbance event, *Halocarpus* recovers, and is prominent through the top of this Zone.

Fuscospora beeches appear to have been most prolific at 63.77m, at which point they are the most well represented tree taxon. This is the only time in the whole core that *Fuscospora* beeches dominate the palynoflora, suggesting that they were at their greatest extent in the area at this time. More locally, *Dacrycarpus dacrydioides* appears to have become less prolific on the swampland. This probably relates to the changing hydrological conditions on the swamp surface. The presence of *Phormium tenax*, a severely under-represented taxon, in the upper samples of this Zone, may indicate that it became more competitive with *Dacrycarpus dacrydioides.* Another possibility is that *Dacrycarpus dacrydioides* was being out-competed by both *Prumnopitys* and *Podocarpus* species in areas where peat accumulation had brought the surface sufficiently above the water table and/or fresh alluvium had been deposited over the peats.

Zone IV seems to indicate a cooling event. Tree taxa decline markedly, as do the tree ferns and a number of shrubby taxa. *Halocarpus* remains at the levels it did at the end of Zone III. *Aristotelia*, *Phyllocladus* and *Lophomyrtus* and/or *Neomyrtus* appear in this Zone. A grassland/fernland seems to have been expanding within the region.

An interesting point to note is that *Dacrydium cupressinum* is absent from the podocarp assemblage of the lignite. *Dacrydium cupressinum* is New Zealand's most drought intolerant podocarp (Franklin, 1968). Given the climatic inferences suggested here, Zones I and II may have been too dry for it. The wetter conditions inferred in Zone III should have allowed it to grow in the basin. If indeed *Ascarina lucida* was growing in the region, the absence of at least trace levels of *Dacrydium cupressinum* pollen is perplexing. *Dacrydium cupressinum* can be found at the present day, growing in coastal Otago. It is no where dominant however, though this may be in part related to logging. In the Holocene, *Dacrydium cupressinum* expanded characteristically late in response to wetter and cooler conditions (refer to Chapter Four and below). Its expansion was coupled in many places with that of *Nothofagus menziesii.* The non-appearance of the former and limited appearance of the latter may indicate that though total rainfall increased, summer droughts were still common. *Nothofagus menziesii* is a low pollen producer, so its presence in the vegetation in Zone III cannot be ruled out. Another possibility is that is that *Dacrydium cupressinum* had not migrated into the area from its glacial refugia. The early proliferation of the other podocarp trees, beeches and broadleaf taxa, may have made it increasingly difficult for *Dacrydium cupressinum* to migrate, especially into these marginal dry eastern areas. According to Franklin (1968) *Dacrydium cupressinum* follows the 1000mm/yr isohyet. The Taieri basin currently receives between 600 and 700 mm of rain per year. Thus it is not entirely unreasonable for it to be absent.

9.3 Waipori 99-1 lacustrine section

It is difficult to determine the amount of time which had passed between the deposition of the lignite and the deposition of the Waipori lacustrine unit. The lignite is truncated by a c.2m gravel layer. These gravels were presumably deposited during a glacial period, or at least a stadial, when sea-level would have been between -60 and -120m lower, increasing the gradient of the Taieri River. The level to which sea-level needed to have dropped to cause gravel mobilisation on the Lower Taieri Plain is not known. A reasonable estimate can be determined if we use Holocene sedimentation as an analogue. The base of the fine sediment fill of the Holocene is found at a depth c.-22m. A radiocarbon date at 19.25m provided a date of 8538 ± 70 years BP. Using the sedimentation curve provided in Figure 6.2., the depth at 22m corresponds to an age of around 11000 years BP. Sea-level at 11000 years BP can be estimated to have been about -45m below present sea-level by extrapolating Gibb's (1986) Holocene sea-level curve (Figure 9.2) suggesting that sea-levels lower than this will mobilise gravels on the Lower Taieri Plain. Theoretically, the comparatively small gravel layer between the lignite and the Waipori lacustrine unit could belong to a stadial event within an Interglacial, for example Oxygen Isotope stage 5d, during which sea-levels were up to -62m according to Chappell and Shackleton (1986). It is inevitably subsidence which controls sediment survival in the basin, so such postulation may be dangerous.

The Waipori lacustrine section is divided into three zones based on the pollen evidence presented here. The lower two zones are characterised by low influxes of tree pollen and typically high influxes of shrubby and herbaceous (mainly Poaceae) pollen and

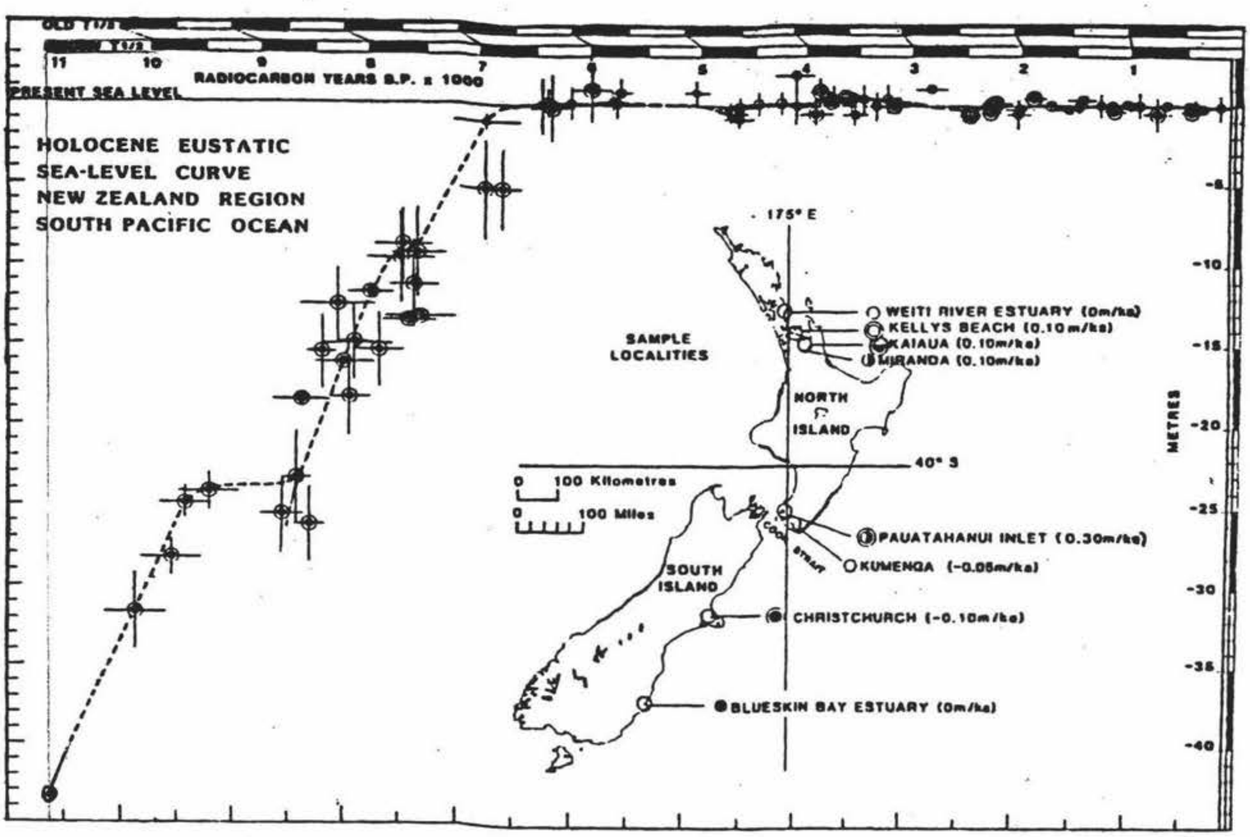


Figure 9.2 New Zealand eustatic sea-level curve with an extrapolation to 11000 years BP (after Gibb, 1986).

fern spores. In contrast the upper Zone (III) contains higher influxes of tree pollen. It should be noted that the depositional environment in this unit is lacustrine - possibly lagoonal and/or estuarine in contrast to the peaty lignite below. Salinity and/or water depth were unable to be ascertained due to the absence of diatoms. This will have had a bearing on the pollen catchment. A peat bog biases toward incorporating more local pollen, though admittedly, that will depend on how open the bog is, and the type of vegetation growing on it. Lacustrine environments are likely to incorporate a more regional signal, especially, if the lake is large (see Chapter Two). Tributaries such as the Taieri and Waipori Rivers, may have contributed a potentially significant inwash component to the fossil assemblage.

The pollen assemblage of Zone I portrays a cool climate assemblage. Tree pollen is registered in low levels. Such low levels of typically over-represented taxa such as *Prumnopitys taxifolia*, *Prumnopitys ferruginea*, *Podocarpus*, and *Fuscospora* suggests that these trees were absent from the area or that there were only scattered individuals in the basin.

Long-distance dispersal from coastal refugia could also attribute to this pattern. The discontinuous appearance of *Libocedrus* and *Nothofagus menziesii* pollen may be taken as evidence to support their presence within the basin. A number of insect pollinated shrubs are common in the pollen assemblage, suggesting that a local shrubland could be found around the margins of the basin. This shrubland was quite diverse and included Asteraceae shrubs, *Coprosma* spp., *Elaeocarpus*, *Dracophyllum*, *Griselinia*, *Halocarpus*, *Hoheria*, *Myrsine*, and *Plagianthus regius*. These are all particularly hardy taxa and can be found today growing at reasonably high altitudes. A number of herbaceous taxa are present. *Gunnera* is continuously represented from 60.90m. Members of this genus are commonly found around lake edges or among tussock grasses and sedges (Johnson and Brooke, 1989). High levels of anemophilous Poaceae pollen occur throughout the diagram, though it is particularly common in this Zone. Tussock-grasslands probably extended along the mid-slopes of the Maungatua Range and the Chain Hills. During cool periods like this, they may also have been prolific in the interiors. Continuous and abundant influxes of charcoal and opaque particles occur throughout the diagram, but are most notable in these lower two zones. The regular occurrence of natural fires under a cool, dry climate may have maintained grass and fernland in the region, particularly in inland areas. This would have prevented the proliferation of shrubs like *Halocarpus* and *Phyllocladus* in these upland and inland areas. A diverse range of ferns are present in Zone I. Both *Cyathea* and *Dicksonia* are present, and were probably growing on swampy ground. A number of fern and fern allied taxa present in this Zone provide proxy evidence for a cooler and possibly dry climate. The mountain tree fern - *Cyathea smithii*, was probably locally present. *Cystopteris* is a common fern in montane and sub-alpine areas. *Hymenophyllum* spp. are essentially plants of damp bush, but Brownsey and Smith-Dodson (1989) comment that many species can tolerate long periods of drought. *Lycopodium fastigiatum*, as stated above, is a clubmoss commonly found in sub-alpine scrub and alpine herbfields. All fern and allied taxa require a reasonably humid environment. This group of plants may have been more common in areas where poor local drainage was conducive to their water requirements.

Zone II is characterised by low pollen concentrations. Pollen preservation was not particularly good, with robust tree fern and monolete fern spores dominating the Zone. The palynoflora does not change appreciably in terms of its constituent taxa from that in Zone I. *Prumnopitys* is not represented, except in the sample at 57.75m, while a few grains of *Podocarpus* were noted mid-way through this Zone. *Dracophyllum*, *Hoheria*, *Myrsine* and *Phyllocladus* are the best represented small tree and shrub taxa. *Plagianthus regius* is most common at the base of this Zone and toward the top. Poaceae pollen is continuously represented. It is difficult to comment on the environmental conditions prevailing at this time, given the low counts and the dominance of monolete fern spores in the sample. It is likely that conditions were similar to those described for Zone I. Poor preservation is likely to have been related to some limnic phenomenon, which may be disclosed when a full mineralogical study has been done on these sediments.

The depositional model for the basin suggests that fine sediments are deposited during warm periods and that gravels are deposited during cold periods. The cool climate indications provided by the pollen analysis of the bottom 4m of fine sediment in this lacustrine unit, do not seem to fit this model. The pollen indicates that a cool climate prevailed during the deposition of the clays between 61.76m and 57.04m. Pollen evidence suggests, however, that this cool period was not as harsh as those inferred by the palynofloras of the fine layers at 103m and 72m. It seems it was cool enough to restrict tall tree taxa, but that shrubland species persisted. That *Fuscospora* became restricted along with podocarps may be taken as evidence to suggest that it was *Nothofagus fusca* that was being registered in the pollen record here and in the lignite, rather than the hardy, *Nothofagus solandri* var. *cliffortioides*. The latter would have surely persisted with other shrub taxa in the climatically unfavourable conditions. The inference that the climate was cooler, but not cool enough to create the pollen assemblages characteristic of the presumably full glacial conditions represented at 103m and 72m raises the possibility that the sediments between 61.76m and 57.04m were deposited during a stadial event. This is one of the only ways to reconcile a cool climate palynoflora with fine lacustrine sediments. A stadial sea-level could exist up to -45m and not change the depositional conditions in the basin (i.e. enough so as to bring gravels into the sedimentary record). The broad, gentle, slope of the continental shelf off the coast of eastern Otago should have also negated the effects of an abrupt gradient change in the lower Taieri system during any postulated intermediate eustatic sea-level stand.

Zone III effectively records an afforestation event. *Fuscospora* beeches are poorly represented in this fossil pollen assemblage, suggesting that they were no longer an important constituent of the local, or perhaps even regional vegetation. With regard to the tree taxa, the pollen diagram reveals two conspicuous features of note. Firstly, the peaks in the pollen curve of *Prumnopitys taxifolia* are cyclic, with highs appearing to be related to lower influxes for *Podocarpus* and *Prumnopitys ferruginea* pollen and vice-versa. Four cycles can be recognised in Zone III. High influxes of *Prumnopitys taxifolia* pollen are accompanied by increased appearances of *Griselinia*, *Halocarpus* and *Hoheria* pollen. High influxes of *Podocarpus* and *Prumnopitys ferruginea* pollen tend to be accompanied by the increased appearance of *Coprosma* and *Dracophyllum*. The second conspicuous feature of note is the near absence of *Dacrycarpus dacrydioides*.

Prumnopitys taxifolia was the first podocarp tree to expand into the basin. Its rapid expansion ahead of the other podocarp trees may have related to an early ameliorating climate. Drier conditions would have given it a competitive edge over the other podocarps, especially *Prumnopitys ferruginea*. The onset of a wetter climate, may, in turn, have favoured the expansion of *Prumnopitys ferruginea* and *Podocarpus* to the competitive detriment of *Prumnopitys taxifolia*. It is difficult to determine the affinity of the *Podocarpus* undifferentiated pollen grains. The most likely parents are *Podocarpus totara* and *Podocarpus cunninghamii*. The latter has a much wider current distribution in the region (Prebble, *pers comm.*). It occupies similar habitats to *Podocarpus totara*, but becomes more common at higher altitudes. It can be reasonably suggested that the cycling dominance between the two associations is related to climate changes from warm and dry to cooler and wetter. If this is so, four distinct climate cycles may be represented in the pollen diagram. It is and will be almost impossible to determine the kind of time scale on which these vegetational and inferred climatic changes were occurring. If compaction has been substantial these changes could reflect cycles working over thousands of years. A finer resolution of samples, and greater number of counts would be required before any meaningful conclusion can be made. Once again, *Dacrydium cupressinum* appears not to have been part of the regional forest assemblage. Its absence probably relates to one of the factors described in the previous section. *Ascarina lucida* and *Quintinia* are not recorded in this diagram as they were in the lignite section.

The second peculiar feature of note is the discontinuous and comparatively poor representation of *Dacrcarpus dacrydioides* in this zone. In the lignite section it was consistently represented at levels between 5 and 20%. An obvious explanation is that the depositional environment is different. *Dacrycarpus dacrydioides* is a low pollen producer. Higher values should be expected on a peat swamp, where it would most likely have been growing near by. Its pollen would be less likely to be encountered in a lacustrine depositional environment due to the over-representation of the regional anemophilous elements in the vegetation, and its poor production. Though this is probably true, pollen analyses from lacustrine layers between 40.80m and 37.42m, and the Holocene reveal a continuous presence of *Dacrycarpus dacrydioides* pollen at levels between 2 and 20%. This suggests that the low influxes observed in this diagram reflect the fact that it was not an important tree in the basin during this period. *Dacrycarpus dacrydioides* is the ubiquitous tree of New Zealand's swamplands. Its apparent scarcity in the basin could suggest that the lake/s of the lower Plain had a well drained peripheral environment, though this seems unlikely when viewing the modern situation around Lakes Waihola and Waipori and the historical reports of Shaw and Farrant (1949). Local hydrological conditions will very much depend on the extent of infilling which had and was occurring in Zone III. It seems that such conditions did not favour *Dacrycarpus dacrydioides*, but that they in turn favoured *Phormium tenax*. As discussed above, *Phormium tenax* is characterised palynologically by its extremely limited pollen production and dispersal. Its near continuous representation at values between 1 and 5% can be taken as strong evidence to suggest that *Phormium tenax* was more than common in the basin. The hydrological conditions of low-lying areas in the basin may have suited the proliferation of flaxland as opposed to *Dacrycarpus dacrydioides* dominated swamp forest. A higher water table would have favoured *Phormium tenax* over regenerating *Dacrycarpus dacrydioides* (van Essen, *pers comm.*).

Monolete fern spores, Poaceae and Cyperaceae become less important in relative terms, but the absolute diagram (Figure 8.4b) suggests that these elements were still important in the region during Zone III. A reasonably diverse range of ferns and allied taxa were present, including those which were formerly used to infer cooler climates in Zone I, such as *Cystopteris*, *Cyathea smithii* and *Lycopodium fastigiatum*. The humid montane environments of the upper slopes of the Maungatua Range may have provided a suitable habitat for these taxa. *Gleichenia* may also have been growing on typically wet acid bogs in cool upland areas, though it could just have well been growing in lowland areas. Its absolute peaks appear to follow those of *Prumnopitys ferruginea* and *Podocarpus*, as do the curves for many of the fern taxa including the tree ferns, and the afore-mentioned *Cystopteris* and *Cyathea smithii*. This may lend support to cooler, wetter climates prevailing during times when *Prumnopitys ferruginea* and *Podocarpus* peak. *Pseudowintera* enters the diagram for the first time in Zone III. Its ecological preferences are wide ranging, but is most commonly found in wet areas and/or at forest margins. It is particularly frost tolerant with the ability to grow in sub-alpine areas. It may have expanded above the forest limit on the Maungatua Range at this time.

9.4 The Waipori 99-1 upper alluvium

The Waipori 99-1 upper alluvium lies between 54.50m and 22.25m. It is a predominantly gravel sequence containing only one significant fine bed between 40.08m and 37.42m. Outside this fine unit a number of spot samples were taken. The first of these came from a sand bed between 50.93m and 50.42m. This sand bed contained detrital organic material which yielded a radiocarbon date beyond the range of the technique (>40000 years). It is once again difficult to determine the amount of time that elapsed between the top of the Waipori lacustrine unit and this sand unit. The small bed yielded a low count of pollen grains and spores. Unlike most low counts in the core which are dominated by fern spores, the pollen assemblage here is dominated by podocarp pollen. The assemblage shows a characteristic lack of diversity. Only a small number of shrub taxa are represented. Tree fern spores are poorly represented and Cyperaceae and Poaceae are of equal unimportance. This spot sample appears to be registering a warm climate, full forest assemblage. Pollen preservation in sandy matrices like the one from which this sample was taken is typically poor. This is reflected in the low pollen concentration in this sample. Such an apparently warm palynoflora should have been associated with a more extensive fine unit if the working model holds true. The absence of any apparent silt or clay sediment could be explained if this unit was deposited during a period of tectonic senescence. If an interstadial, or even interglacial, occurred during a period when subsidence in the basin was nil, then it will not be registered in the sediment record. This is problematic when attempting to create a chronology using the "counting back" method. The small sand layer here may represent a poorly represented interstadial or interglacial.

Several samples were taken within two fine beds between 46.88m and 45.19m. Pollen analysis reveals a cool climate assemblage. Poor preservation was a common feature. It is likely that a shrubland - grassland - fernland mosaic existed around the basin at this time. *Halocarpus*, *Myrsine*, *Phyllocladus*, *Pittosporum*, and *Plagianthus regius* were the most common shrubby elements. *Nothofagus menziesii* and *Dacrycarpus dacrydioides* may also have been present. *Podocarpus* and *Prumnopitys ferruginea* may have been present regionally. Grassland probably extended to low levels, with ground and tree ferns common in damp low-lying hollows, which may also have provided a habitat for the sedges.

An extensive fine (presumably lacustrine) layer exists between 40.80m and 37.42m. Pollen analysis of this layer reveals a warm, full forest palynoflora. A podocarp-broadleaf forest appears to have occupied the basin at this time. *Prumnopitys taxifolia* was the dominant podocarp in this assemblage, though *Prumnopitys ferruginea* and *Podocarpus* were prominent. *Metrosideros* may have been present locally, though probably in very limited numbers. *Fuscospora* pollen is at levels which once again suggest that it was not growing in the area. Extensive stands of *Dacrycarpus dacrydioides* were probably growing on peripheral swampland around the shoaling lake that presumably existed over the site at this time. The most common broadleaf understorey elements within these two forest types appear to have been members of the Asteraceae family, *Coprosma* spp., *Fuchsia, Griselinia*, *Myrsine*, *Pittosporum*, *Plagianthus regius* and *Pseudopanax*. Tree ferns were probably also growing in the understorey. *Halocarpus* was likely to have been the most common shrub at higher altitudes on the surrounding hills and in the interior. Grassland appears to have been more restricted. The apparently low influxes of Cyperaceae pollen seems to indicate that wetland environments were restricted, though this does not fit with the high influxes of *Dacrycarpus dacrydioides*. It may be reflective of a fully forested basin which was lacking in sufficiently wet and open areas. A similar explanation can be used to explain the restriction of grassland. Haloragaceae pollen is almost continuously represented throughout this layer. It peaks prominently at 39.34m. This family contains many wetland taxa. The peak here may have been in relation to a temporary fluctuation in the lake level such as shoaling around the margins. There appears to have been a diverse range of ferns and allied taxa growing in the basin at this time.

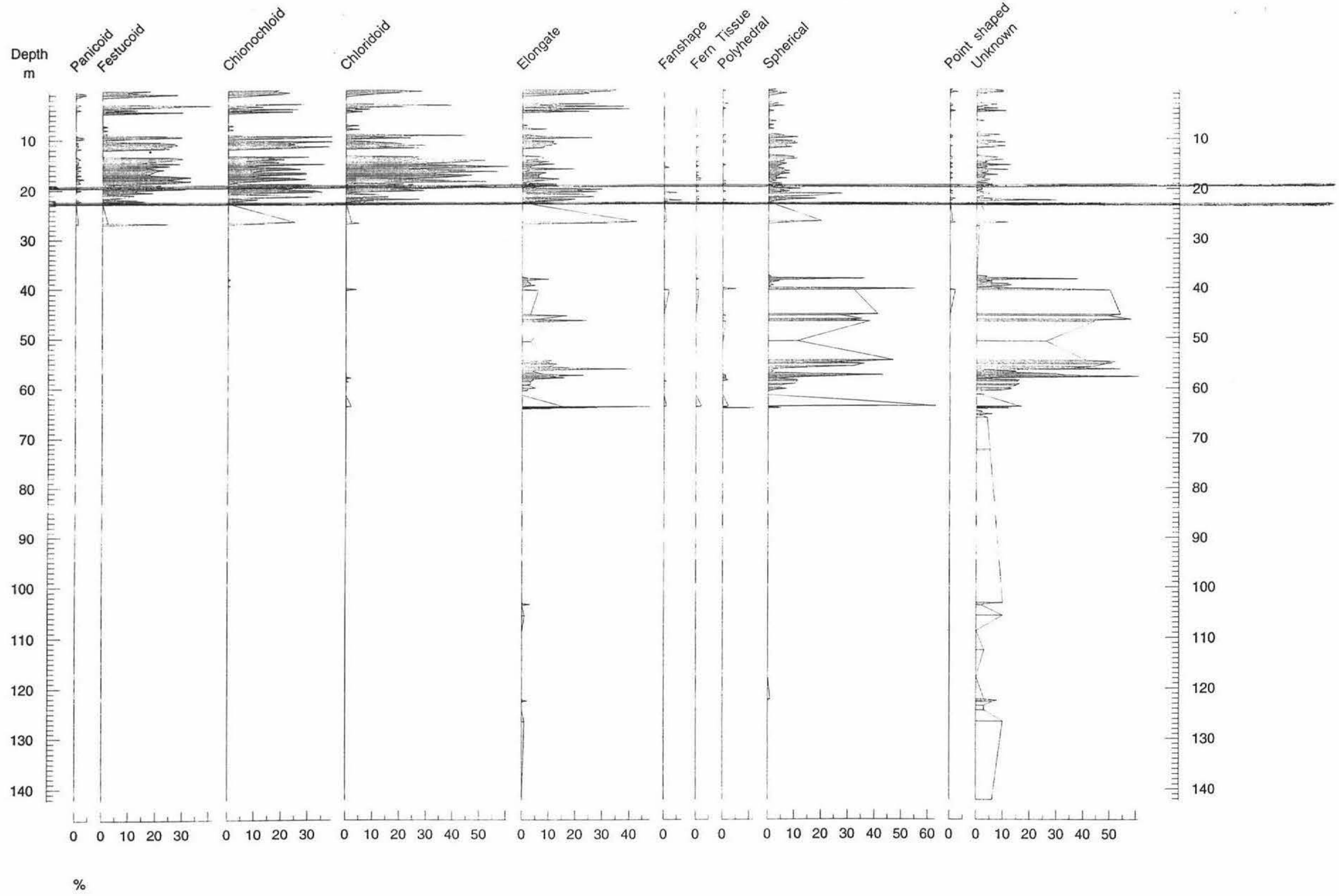
Low, but continuous influxes of *Dacrydium cupressinum* pollen may indicate that it was present within the region. This is quite significant, as previous warm climate palynofloras failed to register its pollen in any continuous fashion. This may suggest that conditions were wetter during this period, allowing it to spread presumably further up the coast from the wetter parts of Southland. It may have survived ensuing glacial periods by taking shelter in re-entrants along the south-eastern coast.

9.5 The Waihola silt/sand unit (late glacial and Holocene)

Several spot samples were taken in a fine palaeosol interbedded in the 9.5m worth of gravel that separate the fine unit just described and the Holocene sediments. The counts were low and preservation was poor, but it appears that a fernland characterised the vegetation at this time. The tree ferns - *Cyathea* and *Dicksonia* -were most prevalent, though high values of monolete fern spores attests to a large ground ferns component in the local area. The comparatively high influx of entomophilous *Plagianthus regius* pollen may suggest that it was growing locally in small deciduous groves. All anemophilous tree species appear at values which suggest they were not growing in the basin. This presumably sparse, cool climate assemblage would have been deposited at or near the level of an incised late glacial Taieri River, possibly between 18000 and 9000 years BP. McGlone and Wilmshurst (1999) and McIntyre and McKellar (1970) found *Plagianthus regius* in small quantities in late glacial pollen assemblages. In these studies it was found in association with a range of shrubs such as *Coprosma*, Asteraceae, and *Myrsine*. Late glacial fernlands were recorded on Stewart Island (McGlone and Wilson, 1996) and on the Longwood Range (McGlone and Bathgate, 1983), though these were commonly in association with other shrubs. It may be that preferential preservation in the palaeosol favoured these robust fern spores and the relatively thick exines of echinate grains such as *Plagianthus regius* and that any attempt to re-create a vegetation may hold little scientific credibility. If this were a late glacial assemblage, then the gravels which overlie this unit may represent a final pulse of gravel down the Taieri River, as increased precipitation stripped periglacial material off the slopes of the interior and the basin. In this case the 4m thick gravel sequence may represent an aggradational event rather than capture by subsidence

1.77m of sand overlie the afore-mentioned gravels. Samples taken within these sands yielded no pollen. The pollen record suggests that postglacial warming, and the proliferation of full forest began some time between the deposition of the sediments at 20.28m and 19.45m. A piece of wood at 19.25m yielded a radiocarbon date of 8538 ± 70 years BP. By extrapolating off the sedimentation curve in Figure 6.2, a date of around 9000 years BP can be estimated. Phytolith records between 19.70m and 22.23m found high counts of tree/shrub produced spherical forms (Figure 9.3) (Prebble, *pers comm.*). This seems to indicate that extremely bad pollen preservation has meant that the

Figure 9.3 A preliminary phytolith record from the Waipori 99-1 core. The double lines indicate the zone where pollen preservation was poor, but the phytolith record picks up a strong signal for spherical forms produced by shrubs and trees (Prebble, unpubl.).



actual afforestation event has not been recorded in the pollen record. It is difficult to ascertain, however, whether these spherical forms represent a shrubland or a full forest assemblage. By extrapolation, the depth at the base of the sand layer at 22.25m equates to c.11000 years BP. This probably represents a maximum age for afforestation in the basin. The date fits well with the well dated core taken from Swampy Hill (alt. 740m a.s.l - approx. 40km north-east) where dates indicate that peat development began around 11500 years BP with afforestation beginning around 9700 years BP (McIntyre and McKellar, 1970). It seems reasonable to suggest that afforestation would have occurred in the low-lying Taieri Plain before it occurred in these higher altitude sites, though McGlone (1988) points out that this was not always the case. McGlone and Wilmshurst (1999) found that dense montane-sub-alpine low conifer forest became established from 7000 years BP at Glendhu (alt. 600m a.s.l), approximately 40km north-west of the Waipori 99-1 site. They did, however, encounter continuous influxes of podocarp pollen from 9600 years BP. This was attributed to long distance dispersal from coastal lowland sources. Afforestation of the Lower Taieri Plain probably began around 10000 years BP and was complete by 9000 years BP. The phytolith record may then be picking up a transition from shrubland to forest, with the pollen record recording the culmination of this afforestation event.

During the early Holocene, sedimentation in the basin was being increasingly influenced by the effects of eustatic sea-level rise. The diatom analyses of Hughes (1999) have proven very useful for assessing the depositional environments during the Holocene. At 10000 years BP sea-level was at -32m (Gibb, 1986). At this time it would not have breached the Lower Taieri Gorge, the aggradational base of which lay at -25m. Freshwater diatoms dominate between 22.25m and 17.20m (Figure 9.4). Brackish water and marine diatoms become increasingly common from 18.40m. Hughes (1999) felt that the sediments between 22.25m and 20.50m were floodplain deposits. From 20.50m there is a change from sand to clays and silts. This change may reflect the loss of gradient experienced by the Taieri River as sea-level began to breach the Lower Taieri Gorge. This may have caused freshwater to flood parts of the floodplain, causing a more substantial body of water to be present on the plain. The appearance of brackish and marine diatoms from 18.40m indicates that a connection existed between the sea and the basin at the time these sediments were deposited. Hughes (1999) infers this to have occurred between 8500 and 7500 years BP, during which time sea-level rose rapidly from -24m to -9m (Gibb, 1986). The culmination of the postglacial marine transgression

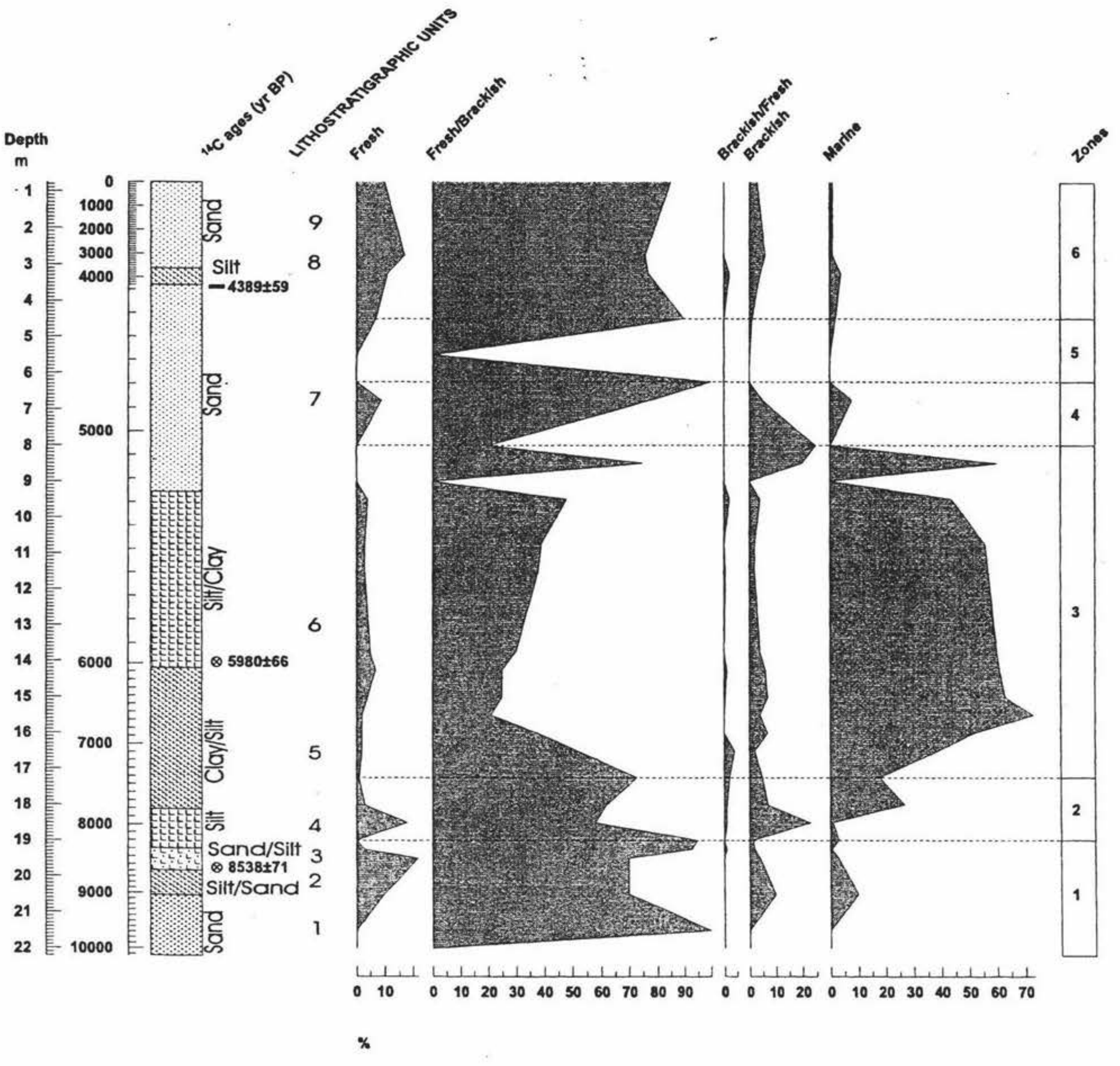


Figure 9.4 Diatoms grouped according to water salinity tolerances during the Holocene (Hughes, 1999).

occurred at 6500 years BP, at which time sea-level reached its maximum extent up the Plain and maximum depth within the basin (Figure 9.5). This is clearly indicated by the dominance of marine diatoms between 17.20m and 8.00m. She notes, however, that there remains a freshwater and brackish component to this assemblage indicating an estuarine type environment. The occurrence of Dinoflagellate cysts between 15.28m and 9.70m supports the suggestion that deep marine waters stood in the basin at this time. Diatom habitat preference does not conclusively support a deep water (planktonic) environment. Diatoms which live predominantly on silt grains (epipelic) are most prolific. Hughes (1999) interpreted this as being indicative of good light penetration

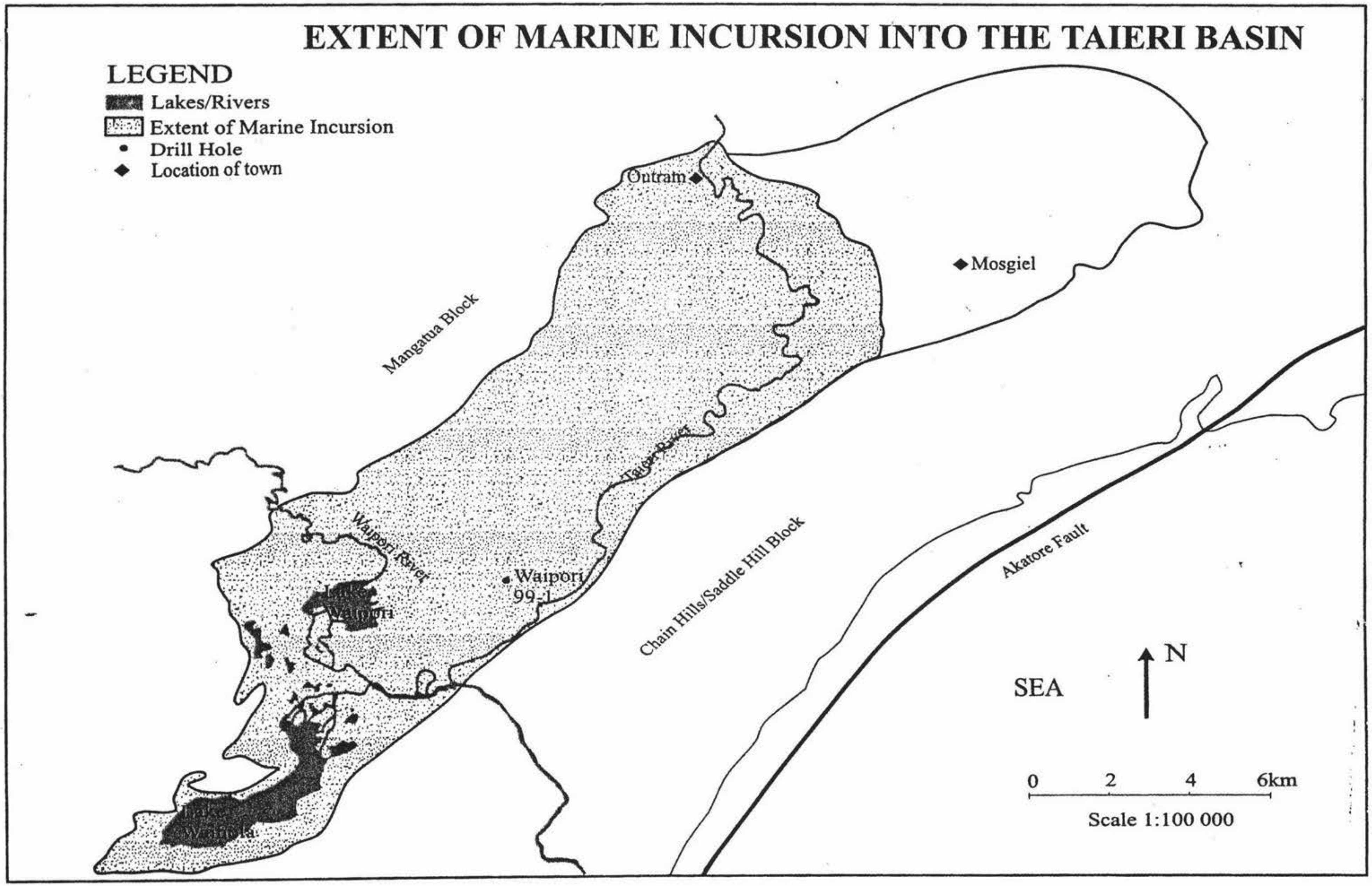


Figure 9.5 The maximum extent of the Holocene marine transgression into the Taieri Basin (from Hughes, 1999).

within the deep body of water, as most diatoms are epipelic. It is likely that this body of water was stratified with fresh water forming a wedge over the denser salt water. Unoxidised minerals and the increase in sulphides between 18 and 9m was interpreted by Billings (1999) as indicating anoxic conditions. A lack of mixing between the freshwater wedge and the basal salt waters would have prevented oxygen reaching the basal layers allowing reducing conditions to develop. Pollen samples throughout these depths contained black opaque precipitates, which in many cases had formed inside the actual grains and spores. This is likely to have been caused by these anoxic conditions.

Zones II (Figure 8.7 a and b) effectively record the palynoflora of the early to mid Holocene. A podocarp-broadleaf forest assemblage covered much of the peripheral area of the basin at this time. *Prumnopitys taxifolia* was the most prominent podocarp in these early forests with *Podocarpus* and *Prumnopitys ferruginea* being common emergents. It is likely that *Prumnopitys taxifolia* quickly colonised the alluvial soils of the plain. *Podocarpus* and *Prumnopitys ferruginea* may have been better represented in areas where the precipitation was greater, such as along the coastal hills and at the foot of the Maungatua Range. *Dacrycarpus dacrydioides* was also prominent and was probably growing in low-lying swampland around the basin. Sharp peaks for both *Podocarpus* and *Prumnopitys ferruginea* at 17.53m maybe related to a briefly wetter climate, though there is no appreciable change in the curve for *Prumnopitys taxifolia*. *Dacrydium cupressinum* pollen appears at low, discontinuous levels in Zone II (and much of Zone III) suggesting that it was not locally present during these times. It is likely that it was migrating up the coast from sea-side refugia at a rate most likely controlled by mid Holocene precipitation changes, and its ability to compete with the already established podocarp trees. The early Holocene restriction of *Dacrydium cupressinum* and the prominence of the drought tolerant *Prumnopitys taxifolia* is well documented in Holocene sites from the southern South Island (refer to Chapter Four). In all cases it is believed that this reflects a drier and probably warmer climate than present and that this was symptomatic of a weak west to south west flow. The findings here concur with such statements. Low influxes of *Fuscospora* pollen suggest that it was once again absent from the region. The nearest known stands of *Fuscospora* beeches are of *Nothofagus fusca* and occur in the Blue Mountains nearly 50km to the west.

A number of broadleaf taxa were present in these podocarp forests. These included *Aristotelia*, members of the Asteraceae family, *Coprosma* spp., *Fuchsia*, *Griselinia*, *Hoheria*, *Muehlenbeckia*, *Myrsine*, *Plagianthus regius*, *Pseudopanax* and *Pseudowintera*. Halocarpus, *Dracophyllum*, and *Phyllocladus* were probably all more common with altitude and with distance inland. *Plagianthus regius* appears to have been the most common small tree in the early forests, but was subsequently in decline. This may reflect increased competition with other canopy species and maybe even with the podocarps themselves. *Pseudowintera* is very common, in contrast with previously discussed warm climate units in the core. As its ecological preferences are wide ranging it is difficult to determine environmental information from this. It is an entomophilous shrub with limited pollen dispersal capabilities. High percentages of its pollen must indicate that it was growing in close proximity to the site, possibly outside the closed forest.

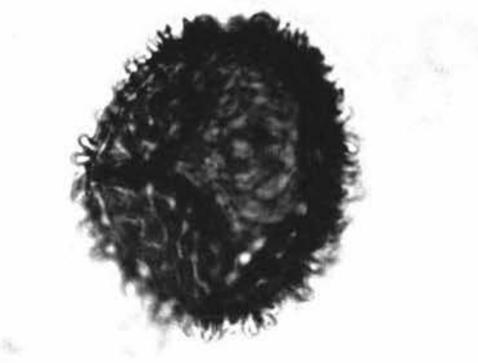


Plate 9.5 An example of a *Lycopodium deuterodensum* spore from the Waipori 99-1 core found at 38.43m.

A reasonably diverse range of herbaceous taxa appear throughout Zone II. Most of these taxa are common to bush margins and stream or lake sides or coastal environments. *Dichondra* and some members of the Apiaceae family are also found in grasslands. Poaceae pollen is present throughout Zone II. This curve probably represents pollen from grasses growing locally in open areas and inwash and long distance dispersal of pollen from the grasslands of the interiors. Tree ferns of the genus *Cyathea* are much more common than those of the genus *Dicksonia*. This is a noteworthy feature of the Holocene palynoflora. In previous warm periods, the two genera are commonly encountered at similar percentages. Ground ferns were probably common in shady gorges and valleys around the basin. The presence of *Lycopodium deuterodensum* (Plate 5) in the core is unusual considering this species is not today found in the South Island. It is commonly found in Kauri forests in Northland. The grains are distinctive and were cross checked with Dr. Mark Large at Massey University. These may have been derived from older tertiary deposits in the basin. *Agathis australis* was once common in the South Island (refer to Chapter Three).

Zone III is characterised by a marked decline in tree pollen. *Prumnopitys taxifolia* is most affected, though most of the podocarp trees undergo some form of decline. Zone III coincides with the culmination of the marine incursion into the basin. This incursion would undoubtedly have drowned the forest that was growing on the Plain. It has been suggested that *Prumnopitys taxifolia* was most common on the exposed alluvium of the plain (mainly to the north). It might therefore be expected that it suffered the most during this flooding event. *Dacrycarpus dacrydioides* appears to have weathered the marine incursion well. This may have related to the opening up of new sites for colonisation due to the locally higher water table and the absence of competition from other podocarp trees which prefer drier ground. A number of short-lived, small tree taxa appear to have proliferated. These include members of the Asteraceae family, *Coprosma* spp., *Dracophyllum*, *Myrsine*, *Plagianthus regius* and *Pseudowintera*. *Griselinia* and *Hoheria*, which were probably common understorey elements in the lowland podocarp forest follow similar trends to the curve of *Prumnopitys taxifolia.* Coastal herbs such as members of the Chenopodiaceae are not represented. Cyperaceae and Restionaceous elements are also poorly represented. *Histiopteris*, a fern which is often found in disturbed areas (Brownsey and Smith-Dodsworth, 1989), has a small peak over two samples in the middle of Zone III. Monolete fern spores appear to have been affected by this marine incursion also. It is difficult to use the same explanation to account for the small decline in *Halocarpus* pollen, when it has been suggested that it was more common at higher altitudes.

The presence of a large peak of charcoal and other black particles in the <50µm range prior to the declines described above may not relate to a fire event. There were no associated particles found in the >50µm range. It may instead relate to the formation of minerals under anoxic conditions. The peaks in the middle of Zone II may be of similar origin. The larger sized opaque particles maybe of organic origin, but be derived from decaying organic material beneath the lagoonal waters. The stabilisation of sea-level within the basin allowed the vegetation to adjust and recover somewhat by the top of Zone III.

Following the stabilisation of sea-level, infilling would have begun. The sedimentation curve shows that this process was very rapid, with the sediments deposited between 14.02m and 3.60m being laid down in the space of around 1600 years (6.9mm/yr). Marine bottom waters lay in the basin until around 5000 years (8.0m) according to Hughes (1999). At this point infilling was sufficient enough to have shoaled the lagoon and allowed fresh river water to mix with the denser saline water. The predominance of brackish water diatoms from 8.0m attests to this. By this time infilling would have brought much of the northern part of the basin above the watertable. The stratigraphy of the core records a break from silts and clays below 9.29m to coarse sands above this depth. Hughes (1999) interprets the fine silts and clays between 18.13m and 9.29m as having been current sorted with coarse sands being washed through the basin, while fine sediments were unloaded. Above 9.29m there was an apparent change in deposition induced by shoaling, so that rapid current sorting in the Taieri River was depositing sands, while the fine sediments were being carried through in suspension.

The sedimentary history of the basin provides the environmental context for interpreting the pollen assemblage of Zone IV. It is likely that progressive infilling from the northern end of the basin to the south saw the succession from wetland vegetation through to *Dacrycarpus dacrydioides* swamp forest and finally *Prumnopitys*-broadleaf forest. This process would have been ongoing. From 5980 years BP ± 70 years, *Dacrydium cupressinum* enters the basin and quickly expands to become the most well-represented podocarp. Because it is a prolific pollen producer and an excellent disperser of pollen its prominence in the diagram may not necessarily indicate that it was the dominant podocarp. But it would have at least been co-dominant with *Prumnopitys taxifolia*. *Prumnopitys taxifolia*, *Prumnopitys ferruginea*, *Podocarpus* and *Dacrycarpus dacrydioides* undergo both relative and absolute declines where *Dacrydium cupressinum* increases at 13.53m. These declines must reflect initial out-competition by *Dacrydium cupressinum*. Conditions must have become suitably wet to allow *Dacrydium cupressinum* to move into the basin. The current distribution of rainfall in the area (Figure 9.6) suggests that conditions were more suitable for it on the coastal Chain Hills, the Maungatua Range and in the north near Swampy Hill. After an initial period of competition the curves for these podocarps show similar trends until the abrupt sediment change at 9.29m. Pollen preservation is poor throughout this sand layer, with counts seldom exceeding 50 grains between 9.29m and 4.33m. The counts shown lack diversity and little emphasis is placed on the abrupt changes presented in the curves of some taxa due to the low pollen concentrations as shown in the absolute diagram (Figure 8.7b).

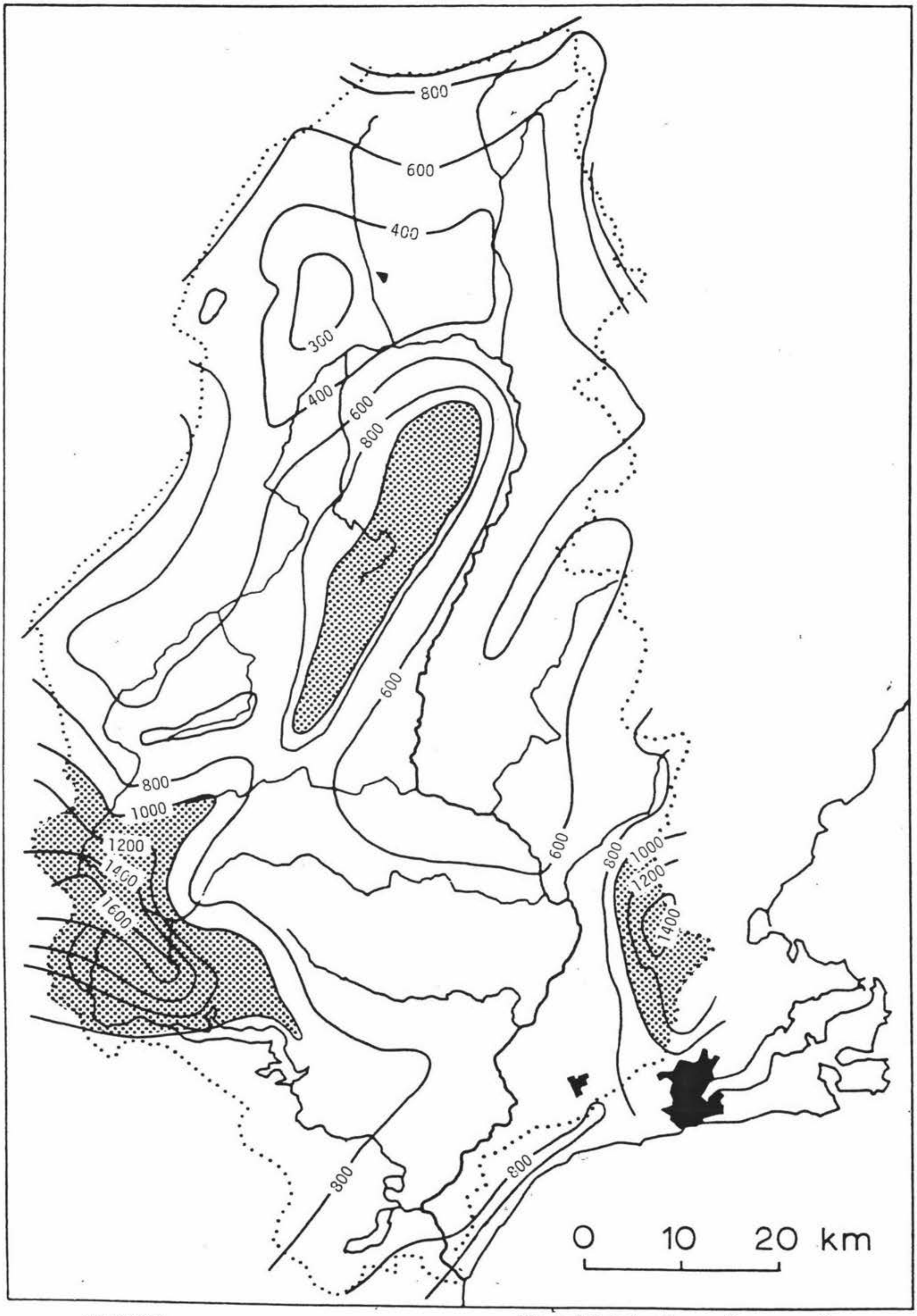


Figure 9.6 Isohyetal map of mean annual precipitation in the Taieri catchment (from Brash and Murray, 1980).

A similar range of shrub and small tree taxa persist in Zone IV. The more reliable absolute diagram shows that *Hoheria* became less common in the area, while *Myrsine*, *Plagianthus* and *Pseudowintera* became more prominent. *Phyllocladus* seems to have become more important in the regional vegetation.

A number of fine grained layers between 4.33m and 2.76m yielded more reliable samples for interpretation. The sample taken at 4.33m shows a forest assemblage similar to that portrayed in the samples taken within the top metre of the fine sediments below 9.29m. A podocarp-broadleaf forest existed around the basin, and probably on the northern plains. *Dacrydium cupressinum* was likely to have been prominent in parts of the basin which received greatest amounts of rainfall. Of the other podocarps, *Prumnopitys taxifolia* was probably the most regionally abundant tree. *Dacrycarpus dacrydioides* was likely to have been growing in the swamplands surrounding the infilling lagoon/lakes which were probably becoming increasingly confined to the southern end of the plains. *Nothofagus menziesii* enters the diagram at this level and is consistently represented until the sample at 0.28m. *Nothofagus menziesii* was expanding in the Glendhu region from 4000 years BP (McGlone and Wilmshurst, 1999). This is not too dissimilar to the radiocarbon date yielded on a shell hash at 3.60m. Given the high rates of sedimentation, the sample at 4.33m may represent a date of around 4500 years BP. *Nothofagus menziesii* was probably spreading into the area from the south-west. From evidence provided at Glendhu, it seems this tree was expanding into low conifer forests which contained *Libocedrus*, *Podocarpus*, *Halocarpus* and *Phyllocladus* at higher altitudes. Pollen evidence in this project does not provide a clear picture of upland vegetation changes, though there does appear to have been a decline in the absolute pollen influx of *Phyllocladus* between 9.55m and 4.33m. There are negligible declines for *Podocarpus* and *Halocarpus*. McGlone and Wilmshurst (1999) argue that although *Nothofagus menziesii* had been present in the general area since 9500 years BP, its expansion at Glendhu and in other parts of southern and south-eastern New Zealand at around 4000 years BP (see Chapter Four) must be related to a regional climatic change. Their explanation relates to an increased south-westerly flow from 7000 years BP. Intensification of this flow toward 2000 years BP brought wetter, cooler winters.

The final sample in Zone IV is characterised by absolute decreases. As these decreases are experienced by all taxa, it probably relates to pollen preservation. A count of 200 was achieved however. The relative diagram shows small increases in *Dacrydium* *cupressinum*, *Podocarpus* and *Prumnopitys taxifolia*. This sample at 3.53m was taken just above a shell hash at 3.60m. Hughes (1999) relates this shell layer to a major storm event in the basin. The fine sediments and the shell hash represent an erosional lag in deposition. Sedimentation appears to have slowed rapidly after the deposition of this shell hash to 0.7mm/yr. This was interpreted by Hughes (1999) to be a reflection of the smaller accommodation space for sediments as infilling neared completion at the southern end of the basin. The concentration of pollen in these upper layers is comparatively low (c.20000 grains per cc) when compared with that in supposedly rapidly deposited units between 14 and 9m (c.60000 grains per cc). This seems anomalous as rapid sedimentation should reduce the pollen concentration It may indeed be a reflection of some real change in the vegetation and its pollen production.

A significant relative and absolute decrease in tree pollen occurs in the sample taken at 3.28m (Zone V). It is unlikely that this decrease is related to the event which deposited the shell hash, as the shell hash lies at a depth below the afore-mentioned sample at 3.53m. It may be related to a supposed 0.6-0.9m increase in sea-level which occurred between 4500 and 3000 years BP. This would have flooded low-lying areas in the basin. *Dacrycarpus dacrydioides* and associated swampland taxa would have borne the full impact of such a sea-level rise. The appearance of Chenopodiaceae pollen at this depth may lend support to this event. However, there is only a small decline in the pollen curve of *Dacrycarpus dacrydioides*. The synchronous declines in *Dacrydium cupressinum*, *Podocarpus*, *Prumnopitys taxifolia*, *Coprosma* and *Halocarpus*, suggests that a more regional disturbance had occurred between the deposition of the sediments at 3.53m and 3.28m. A number of seral taxa appear in this sample. *Coriaria*, *Epilobium* and *Pteridium* are all taxa which commonly colonise disturbed areas. Increases in the curves for Poaceae and Cyperaceae, suggests that the forests had been opened up somewhat. There is a good deal of evidence which suggests that natural fires became more prevalent in the late Holocene (Burrows, 1996; McGlone *et al.*, 1995, McGlone and Wilmshurst, 1999). Most dates for natural fires fall between 5000 and 2000 years BP. Fires were more common in inland areas where they destroyed large blocks of *Halocarpus* and *Phyllocladus* scrubland. Grasslands expanded. As discussed in Chapter Four, the late Holocene climates saw an increase in winter precipitation from southerly frontal systems. McGlone and Moar (1998) suggest drought and fire could have been a feature in areas where summer water deficit could not be quenched by the increased winter rainfall. Fires which began west of the Maungatua Range may have swept east into the basin during a particularly dry summer, destroying significant portions of the podocarp forests. The charcoal record does not show any major influx of charcoal at this depth. An explanation may be that the fire event occurred prior to the time represented at 3.28m. This would allow enough time for small trees and shrubs such as *Hoheria*, *Myrsine* and *Pseudopanax* to colonise cleared areas. The taller podocarp trees would have taken a much longer period of time to re-establish. A finer resolution of samples in this layer may reveal a charcoal peak.

The possibility that this disturbance was not natural, but human induced should not be entirely discounted based on the evidence at hand. Human induced fires are typically recurrent and are evidenced by the maintenance of a seral vegetation. Poaceae pollen and *Pteridium* spores were encountered in the next sample taken at 1.03m. The apparent recovery of tree taxa, particularly *Prumnopitys taxifolia* seems however to refute such a claim. The date provided by the shell hash also pre-dates known Polynesian forest destruction by at least 3000 years. The sample at 1.03m indicates podocarp-broadleaf forest regenerated. *Halocarpus* may have extended its range in areas where *Nothofagus menziesii* was absent. *Dacrydium cupressinum* expands relative to the other podocarps in the uppermost sample at 0.28m. A range of broadleaf taxa become more common, including *Griselinia*, *Hoheria*, *Myrsine*, Myrtaceae - *Kunzea*-type and *Neomyrtus*-type, *Pittosporum* and *Pseudopanax*. These were probably all common elements within the podocarp-forest and scrubland throughout the basin. It is difficult to know where to place this top layer in terms of time. Polynesian clearance is not obvious in the record, though this may relate to the coarse resolution of sampling. European introductions were not obvious in the upper sample either. Hughes (1999) states that the surface of the plain is likely to be older than the present day due to erosion and the draining of the Plain for pasture.

The vegetation changes of the Holocene revealed in this project are placed alongside those of other areas in southern New Zealand in Figure 9.7. The Waipori Holocene sequence is relatively similar to that of McIntyre and McKellar's (1970) site at Swampy Hill. From this it appears afforestation occurred in coastal Otago around 10000 years BP. These early forests were dominated by *Prumnopitys taxifolia*. *Dacrydium cupressinum*

Figure 9.7 (over leaf) Composite diagram showing Holocene vegetation changes around southern New Zealand, including the results of the Waipori 99-1 Holocene section.

Holocene Vegetation Changes in Southern New Zealand

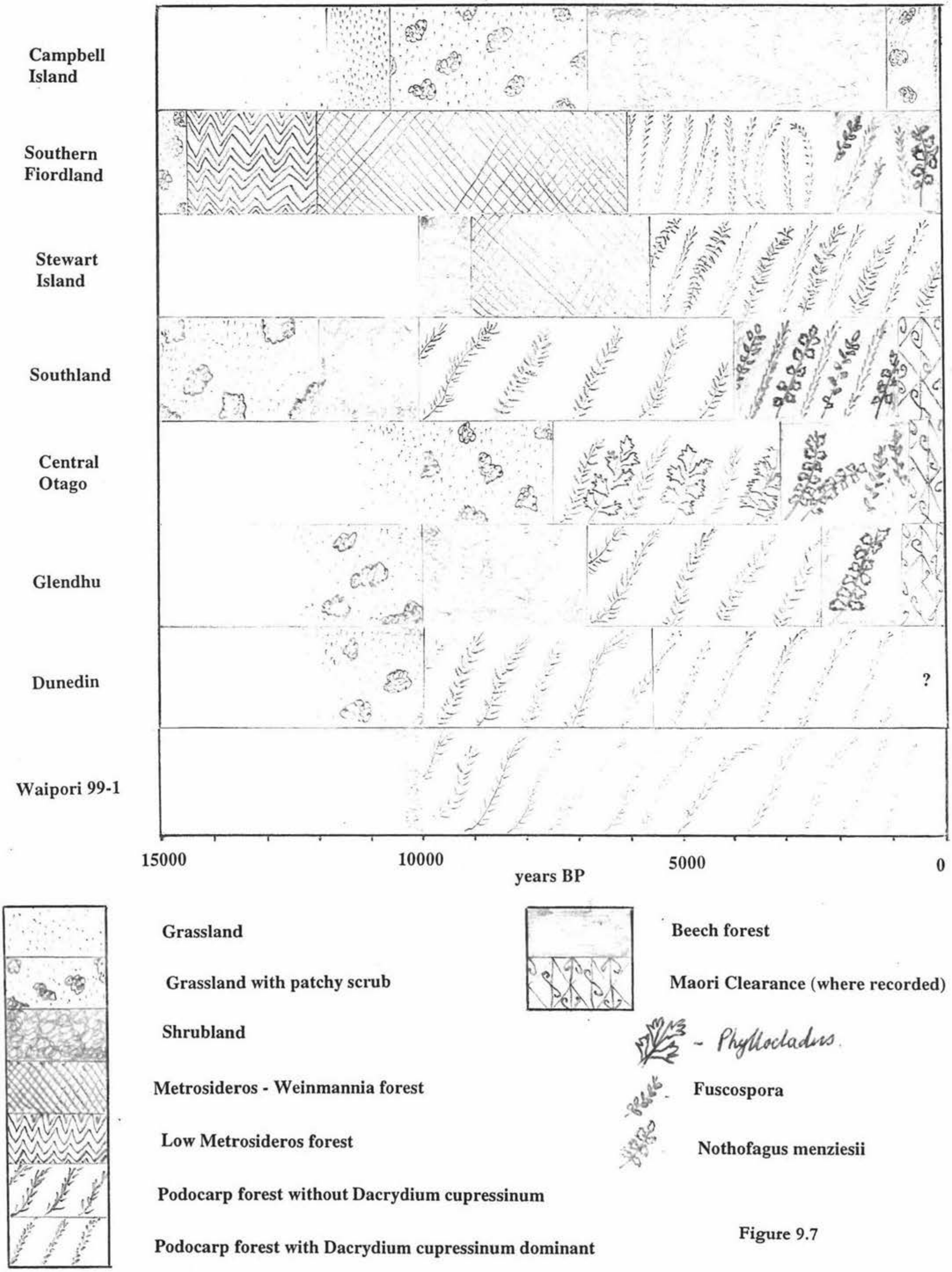


Figure 9.7

expanded into the region around 5500 years BP. This combined date from Waipori and Swampy Hill suggest that *Dacrydium cupressinum* spread in this area relatively earlier than in Southland where it began to expand around 4000 years BP. This may suggest that conditions for the proliferation of *Dacrydium cupressinum* were more favourable along the south eastern seaboard than they were in Southland between 5500 and 4000 years BP. Another possibility is that mid Holocene refugia were few and far between in Southland. The expansion of *Dacrydium cupressinum* on Stewart Island and in southern Fiordland does not support this.

9.6 Core chronology

In conclusion to this discussion, a tentative chronology is proposed for the sediments of the Waipori 99-1 core. The chronology is presented in the flow diagram introduced at the beginning of the chapter (Figure 9.1). This chronology is based on the counting back method. The problems associated with this method have been pointed out previously. It is likely that future dating on the core will help confirm or refute parts of this chronology.

The Holocene section is well constrained and extends from the surface to -22.25m. Below this are c.4m worth of aggradational gravels which overlie a late glacial palaeosol which is suggested here to have formed between 18000 and 11000 years BP. A 9.12m thick sequence of gravels lies between this palaeosol and the next fine layer between 37.42m and 41.05m. This layer contains a warm climate palynoflora. As mentioned above, two dates are proposed for this layer. A radiocarbon date of 31670 ± 600 years was obtained from a piece of in situ wood at 40.80m. This date places these sediments and the palynoflora in the later part of OI stage 3, which extended from 59000 to 24000 years BP. Geologists from Otago University have disputed this date, as it does not fit their models of subsidence in the basin. Their studies suggest that subsidence is driven by uplift on the Titri block, and that there has been a maximum of 10m uplift on this block since OI stage 5. It is their belief that these sediments must be of OI stage 5 or earlier in origin (Litchfield, 2000). If the date is correct, it suggests that either vital pieces of evidence are missing from the uplift story or that movement on the Titri Fault System is not driving subsidence. The latter is considered unlikely given the asymmetric shape of the basin (Litchfield, *pers comm.*). She personally feels that the date is incorrect, and that one date should not be relied upon to constrain this unit. Reports from the Rafter

Radiocarbon Laboratory at IGNS indicate that there was no major contamination from modern carbon sources.

Theoretically the palynoflora of this unit should provide proxy evidence to determine whether it is an interstadial (OI stage 3) deposit, or an interglacial (OI stage 5) deposit, as the two should differ somewhat in their composition. The Waipori 99-1 Holocene sequence should act as a good analogue for other interglacial sequences in the core. The Holocene is characterised by a podocarp-broadleaf forest assemblage. In the early Holocene, *Prumnopitys taxifolia* is the most dominant podocarp tree. *Dacrycarpus dacrydioides*, *Podocarpus*, and *Prumnopitys ferruginea* are all well represented. *Coprosma*, *Halocarpus*, *Phyllocladus*, *Cyathea* and ferns of monolete fern spore affinity feature prominently in the diagram. In the mid to late Holocene, *Dacrydium cupressinum* becomes the dominant podocarp. Total pollen concentrations average around 50000 grains per cc. The fine unit between 40.80m and 37.42m documents a comparatively similar assemblage with *Prumnopitys taxifolia* being the dominant podocarp. The representation of *Dacrycarpus dacrydioides*, *Podocarpus* and *Prumnopitys ferruginea* are all very similar to the Holocene. *Dacrydium cupressinum* is only present in trace levels. *Coprosma* and *Halocarpus* are the most well represented shrub taxa. *Phyllocladus* appears to have been rare during this period. *Cyathea* ferns are well represented along with *Dicksonia*. Monolete fern spores are also common. By most accounts this assemblage appears to be similar to the early Holocene suggesting that it is an interglacial sequence. The absence of *Dacrydium cupressinum* may relate to the fact that the top of this unit was truncated by glacial gravels before it subsided below the baseline of erosion. Therefore if *Dacrydium cupressinum* were to appear late in the sequence, the sediments containing its expansion would have been removed. The probable absence of *Phyllocladus* from the basin is perplexing, but may relate to competition with other alpine shrubs such as *Halocarpus*.

Before it is conclusively stated that this is an interglacial deposit, the possibility that it is an interstadial sequence needs to investigated. It is difficult to suggest what an interstadial palynoflora would look like, when there are no conclusive analogues in the core, or any documented from the south of the South Island. Unfortunately, late Quaternary pollen diagrams are few and far between. A number of diagrams documenting the palynoflora of this period from other parts of New Zealand have been published. From offshore on the Chatham Rise, Heusser and van de Geer (1994) documented several glacial - interglacial cycles from the late Quaternary (refer to Figure

3.4). OI stage 3 is recognised in this diagram as containing comparatively low influxes of podocarp pollen and tree fern spores and greater influxes of *Nothofagus*, *Phyllocladus* and *Coprosma* pollen. The assemblages represented in their study are not directly comparable with terrestrial sites because of the depositional setting, but the general indication is that the podocarps were restricted in OI stage 3. A number of studies from the north-east of the North Island suggest that the period between 57000 and 43000 years BP was warmer than the later part of OI stage 3 (Wright *et al.*, 1995). Studies from the west coast of the South Island suggest that significantly cooler conditions had begun by 30000 years BP (Moar and Suggate, 1973). If the radiocarbon date is correct then it may be possible that this podocarp assemblage represents a glacial refugium. These taxa may have been taking refuge in the Lower Taieri Gorge, spilling out onto the Plain during periods when the climate warmed. The pollen influx data seem to refute this however. Absolute values in this unit average around 120000 grains per cc, which is more than twice that recorded in the Holocene. The pollen evidence suggests that this unit belongs to an interglacial period. OI stage 5 has been proposed.

A cool climate pollen assemblage was noted within a small fine grained unit between 45.19m and 46.88m. It is likely that this came from either a stadial event during an interglacial, or from an interstadial within a glacial period, given that the assemblage is richer in shrub taxa than the presumably full glacial palynoflora recorded at 72m. A small sand layer containing organic material lay between 50.42m and 50.93m. The one sample taken here yielded a low count, but the palynoflora suggested a warm climate. This is problematic, as it is separated from fine units above and below by significant depths of gravel. This small unit could be the remains of a more extensive interglacial unit deposited during a period of tectonic senescence, as mentioned above. It could equally represent a brief, but warm interstadial. The sediment matrix and the resolution of sampling is too poor to state conclusively. Future dating should help place this unit correctly within the Quaternary.

The next fine grained unit extends from 54.78m to 61.50m and is termed the Waipori lacustrine unit. The palynoflora records a cool climate assemblage between 61.50m and 57.62m. It is suggested above that this fine grained unit was deposited during a stadial period of an interglacial. Pollen analyses of the sediments between 57.62m and 54.83m record a warm climate assemblage. *Prumnopitys taxifolia* is dominant, though *Podocarpus* and *Prumnopitys ferruginea* are common. The poor representation of *Dacrycarpus dacrydioides* has been accounted for in the discussion above. *Coprosma* and *Plagianthus regius* are the most common understorey elements, while *Halocarpus* and *Phyllocladus* appear to have been very restricted in contrast with the Holocene. Influxes of monolete fern spores and Poaceae pollen are much higher than in the Holocene or the fine unit between 37.42 and 41.05m. This may reflect a cooler Interglacial phase than those which preceded it. This sequence could represent any range of interglacials earlier than and including OI stage 5, depending on where one places the formerly mentioned layers. If the date at 40.80m is correct and the fine layer is of OI stage 3 origin and the sandy layer at 50m is of no consequence then this layer may represent some part of OI stage 5. Conversely, if the sediments between 41.05m and 37.42m are from OI stage five and there is another interglacial represented in the small sand unit between 50.42 and 50.93m, then these sediments could belong to OI stage 9 or earlier interglacial sequences.

The last warm climate sequence to be recognised in the core is the lignite between 64.35m and 63.63m. On stratigraphic grounds, one could also include the fine grained deposits between 66.61m and 64.35m, though there is no microfossil evidence (due to extremely poor preservation) to link these sediments to a warm period. As discussed above the fact that the lignite must have been deposited in a peat bog, suggests that it is a full interglacial deposit. Pollen analysis agrees with this finding. A *Prumnopitys taxifolia* dominated mixed podocarp-beech forest existed at this time. *Coprosma* and *Halocarpus* were common, but were probably occupying different ecological niches. If *Ascarina lucida* and *Quintinia* were regionally present, then this strongly supports a warm equable climate. Tree ferns seem to have been abundant, along with ground ferns. This assemblage must have been deposited during a very active tectonic period. Over 22m worth of subsidence would be required within the space of an interglacial to bring a peat deposit from the surface below the level required to preserve it in the sedimentary record. Litchfield (2000) found evidence from higher uplifted marine terraces along the coastal range for considerable uplift on the Titri Fault System prior to 128000 years BP. Evidence from an unconformity between two older sets of alluvial fans along the Titri Fault System suggests that there was a major period of deformation during the penultimate interglacial period (OI stage 7 - 186000-245000 years ago), though age constraints on these surfaces are poor. A uranium-thorium date on the lignite was reported as being beyond the range of the technique (i.e. >350000 years). The reliability of this date has been questioned by workers on the core. But from the evidence presented, the lignite could well belong to OI stage 7 or OI stage 9 or possibly some older interglacial. Given the tentative maximum age of 800000 years placed on the palynoflora deposited at 103m, the earliest interglacial that this lignite could have come from is OI stage 19. The latest interglacial would be OI stage 5.

The sequence would read quite nicely if the lignite had been deposited during OI stage 5e, with an intervening stadial and low eustatic sea-level represented by a small gravel pulse, followed by a cool stage 5d assemblage, warming back into a 5c palynoflora between 57.62m and 54.83m. A return to cool stadial conditions and a eustatic low-stand during stage 5b would have enabled the Taieri River to transport gravels across the Lower Taieri, as represented in the 3m gravel sequence above the Waipori lacustrine unit. The thin sandy layer containing organic material may then have represented the brief warm period associated with OI stage 5a. OI stage 4 may be represented in the two samples taken between 45.19 and 46.88m which revealed a shrubland vegetation. The full forest assemblage present in the fine layer between 40.80 and 37.42m could then reflect an anomalously warm late interstadial (OI stage 3) within the last glacial.

This last paragraph highlights how easy it could be to make the data fit a preconceived model. This then emphasises the need to be objective when creating such chronologies. It is tempting to overlook evidence from a number of other disciplines in order to make the data fit ones preconceptions. Without more conclusive dating, speculation and postulation need to be kept on the leash of objectivity. A number of chronological lines have been postulated here, but no particular one is fully endorsed by this project. Until dating can attach these sequences to a Quaternary framework they remain biostratigraphic units subject only to the law of superposition.

Chapter Ten:

CONCLUSION

CONCLUSION

The Waipori 99-1 long core is unique in that it is one of the first cores taken from southern New Zealand to penetrate into Pleistocene aged sediments. As well as providing a record for the mid to late Pleistocene, the core contains an extensive Holocene record. This project looked specifically at the palynology of the core. At the time of writing dating on the core poorly constrained the sediments below the Holocene section. This project suggested a number of chronological lines along which the sediments within the core, and hence the environmental information contained in these sediments may be interpreted (refer to Figure 9.1). Pollen evidence suggests that possibly five, but definitely four distinct warm periods are registered in the sequence. It is considered likely that these all relate to interglacial events. In general glacial periods are registered in the core as thick alluvial gravel deposits. Through the analysis of a number of fine laminations within these gravels the character of the vegetation could be assessed.

Podocarp-broadleaf forests appear to have dominated during these warm periods, with *Prumnopitys taxifolia* being the most consistently common podocarp in the region. *Fuscospora* beeches appear to have once been more common within the area at the time the Waipori lignite was deposited. After this period they seem to have become rare in or absent from the region. *Dacrydium cupressinum* was apparently absent from the region until the mid Holocene. The Holocene record is very similar to that of McIntyre and McKellar's (1970) taken from Swampy Hill. Podocarp-broadleaf forest spread into the basin around 10000 years BP under a drier climatic regime which prevented the spread of *Dacrydium cupressinum*. A change to a wetter, cooler climate allowed *Dacrydium cupressinum* to migrate into the Taieri Basin around 5500 years BP.

A variety of vegetation associations were recorded during periods of cool climate. The main types were shrubland, herbfield, grassland and fernland. These associations were often found concurrently.

A tentative maximum age of 800000 years is suggested for the sediments at 103m, based on the absence of the prolific alpine conifer *Microstrobos* which became extinct at this time. This places all sequences studied above this layer in the mid to late

Quaternary. It is hoped that future dating will help constrain the vegetational, climatic and environmental information presented in this project.

Future work on the core should be aimed at increasing the resolution of samples taken here. The 22m Holocene record provides an excellent opportunity to conduct a detailed study of Holocene forest dynamics. It is suggested that future studies prepare pollen samples and charcoal samples separately, with density separation used for preparing the latter so as to eliminate the error caused by opaque minerals.

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Appendices:

Appendix One:

APPENDIX ONE

Sample depth, lithology and preparation steps

This appendix gives the depths at which all samples were taken and provides information on the sample lithology. Colours are described according to the Munsell soil colour chart. The right hand column details in order, the steps taken in preparing each sample. The codes are as follows:

1	Carbonate removal (HCL)
2	Humic acid removal (KOH)
3	Sand fraction removal (Decanting)
4	Cellulose removal (Acetolysis)
5	Deflocculation (Sodium pyrophostphate)
6	Silica removal (HF)
7	Lignin removal (Oxidation)
8	Fine particle removal (Sieving)

Sample Depth	Sample Lithology	Preparation Steps
0.28m	Soil horizon - 10Y 5/1 greenish grey silt with sand	1,2,3,4,5,6,3,6,8
1.03m	10Y 5/1 olive grey silt with sand	1,2,3,4,3,5,6,3,6,8
3.28m	10YR 5/2 greyish brown silt with sand	1,2,3,4,3,5,6,3,6,8
3.53m	" " "	1,2,3,4,3,5,6,6,8
4.33m	5BG 5/1 greenish grey massive, well sorted sand	1,2,3,4,3,5,6,6,8
5.53m	" " "	1,2,3,4,3,5,6,6,8
6.58m	" " "	1,2,3,4,3,5,6,6,8
7.03m	" " "	1,2,3,4,3,5,6,6,8
8.53m	" " "	1,2,3,4,3,5,6,6,8
9.55m	5GY 4/1 dark olive grey silt with clay	1,2,3,4,5,6,6,8
9.70m	" " "	1,2,3,4,3,5,6,6,8
10.53m	" " "	1,2,3,4,3,5,6,6,8
10.78m	" " "	1,2,3,4,5,6,6,8
11.28m	" " "	1,2,3,4,3,5,6,6,8
11.72m	" " "	1,2,3,4,3,5,6,6,8
13.53m	10GY 4/1 dark greenish grey clay	1,2,3,4,3,5,6,6,8
13.98m	" " "	1,2,3,4,5,6,6,8
14.53m	" " "	1,2,3,4,3,5,6,6,8
14.78m	" " "	1,2,3,4,3,5,6,3,6,8
15.28m	" " "	1,2,3,4,3,5,6,6,8
15.78m	5GY 2.5/1 dark greenish grey massive clay with black flecks	1,2,3,4,3,5,6,6,8
16.28m	" " "	1,2,5,4,6,3,3,6,8
16.78m	" " "	1,2,3,4,3,5,6,6,8
17.28m	" " "	1,2,3,4,3,5,6,3,6,8
17.53m	" " "	1,2,3,4,5,6,6,8
18.03m	" " "	1,2,3,4,3,5,6,3,6,8

18.53m 18.53m cont.	5GY 4/1 dark greenish grey fine and coarse sand	1,2,3,4,3,5,6,3,6,8,7,4,8
19.45m	10Y 3/1 dark greenish grey silt and clay	1,2,3,4,3,5,6,3,6,8,7,4,8
20.09m	5GY 5/1 greenish grey clay	1,2,5,4,6,3,6,3,6,8
20.28m	“ “ “	1,2,3,4,3,5,6,3,6,8
21.33m	5G 4/1 greenish grey massive medium to fine sand	1,2,3,4,3,5,6,3,6,8
21.78m	“ “ “	1,2,3,4,3,5,6,3,6,8
22.23m	“ “ “	1,2,3,4,3,5,6,3,8,6,8
26.53m	5B 5/1 bluish grey clay with silt	1,2,3,4,3,5,6,3,6,8
26.78m	“ “ “	1,2,3,4,3,5,6,3,6,8
27.03m	5BG 4/1 greenish grey silt	1,2,3,4,3,5,6,3,6,8
27.28m	“ “ “	1,2,3,4,3,5,6,3,6,8
27.53m	“ “ “	1,2,3,4,3,5,6,3,6,8
37.53m	10Y 4/1 greenish grey massive clay with dark streaks	1,2,3,4,3,5,6,6,7,4,8
38.18m	“ “ “	1,2,3,4,3,5,6,3,6,8,7,4,8
38.43m	“ “ “	1,2,3,4,3,5,6,3,6,7,4,8
38.60m	“ “ “	1,2,3,4,3,5,6,3,6,7,4,8
38.85m	“ “ “	1,2,5,4,6,3,6,8
39.10m	“ “ “	1,2,3,4,3,5,6,3,6,7,4,8
39.35m	“ “ “	1,2,3,4,3,5,3,6,3,6,8
39.60m	“ “ “	1,2,3,4,3,5,6,3,8,6,7,8
39.76m	“ “ “	1,2,3,4,5,3,6,3,6,8
40.00m	10G 5/1 greenish grey sand	1,2,3,4,5,3,6,3,6,8
40.35m	5GY 4/1 dark olive grey clay	1,2,3,4,5,3,6,3,6,8
40.55m	“ “ “	1,2,3,4,5,3,6,3,6,8
40.63m	“ “ “	1,2,3,4,5,6,3,8,6,8
46.35m	5BG 4/1 dark bluish grey massive fine sand and silt	1,2,3,4,5,3,6,3,6,8
46.50m	“ “ “	1,2,3,4,5,3,6,3,6,8
46.75m	“ “ “	1,2,3,4,5,3,6,3,6,8
50.70m	Sand containing detrital organic material	1,2,3,4,5,3,6,3,6,8
54.83m	10Y 4/1 greenish grey massive silt with black flecking	1,2,3,4,5,3,6,3,6,8
55.08m	“ “ “	1,2,5,4,6,3,6,8
55.32m	“ “ “	1,2,3,4,5,3,6,3,6,8
55.58m	“ “ “	1,2,3,4,5,3,6,3,6,8
55.94m	“ “ “	1,2,3,4,3,5,6,3,6,8
56.20m	“ “ “	1,2,3,4,5,3,6,3,6,8
56.33m	“ “ “	1,2,3,4,5,3,6,3,6,8
56.69m	“ “ “	1,2,3,4,5,3,6,3,6,8
56.90m	“ “ “	1,2,3,4,3,5,6,3,6,8
57.10m	10BG 5/1 greenish grey massive clay with black flecks	1,2,3,4,5,3,6,3,6,8
57.33m	“ “ “	1,2,5,4,6,3,6,8
57.75m	“ “ “	1,2,3,4,5,3,6,3,6,8
58.00m	“ “ “	1,2,3,4,5,3,6,3,6,8
58.75m	“ “ “	1,2,3,4,5,6,3,8,6,8
59.70m	“ “ “	1,2,3,4,3,5,6,3,8,6,8

60.15m	“ “ “	1,2,3,4,5,3,6,3,6,8
60.40m	“ “ “	1,2,3,4,5,3,6,3,6,8
60.90m	“ “ “	1,2,5,4,6,6,8
61.40m	“ “ “	1,2,3,4,3,5,6,8,6,3,6,8
63.65m	10YR 2/1 black lignite	1,2,5,4,5,6,7,4,8
63.70m	“ “ “	1,2,7,4,5,6,8
63.74m	“ “ “	1,2,7,4,5,6,8
63.77m	“ “ “	1,2,4,,6,7,4,8
63.80m	“ “ “	1,2,4,5,6,7,4,8
63.84m	“ “ “	1,2,4,5,6,7,4,8
63.89m	“ “ “	1,2,4,5,6,7,4,8
63.93m	“ “ “	1,2,4,5,6,7,4,8
63.97m	“ “ “	1,2,5,4,6,7,4,8
64.02m	“ “ “	1,2,4,5,6,7,4,8
64.13m	“ “ “	1,2,5,4,6,7,6,4,8
64.23m	“ “ “	1,2,3,4,5,3,6,3,6,8
64.35m	5BG 5/1 bluish grey clay with silt	1,2,3,4,5,3,6,3,6,8
64.85m	5BG 5/1 medium to fine sand	1,2,3,4,5,3,6,3,6,8
65.60m	10G 5/1 greenish grey silt	1,2,5,4,6,3,6,3,6,8
72.22m	10Y 4/1 dark greenish grey fine silt	1,2,3,4,5,3,6,3,6,8
72.32m	“ “ “	1,2,5,4,6,3,6,8
72.42m	“ “ “	1,2,3,4,5,3,6,3,6,8
83.85m	Oxidised 2.5Y 6/4 matrix supported pebble gravel, sandstone and pebbly sandstone with fine sand matrix	1,2,3,4,5,3,6,3,6,8
89.85m	Oxidised 5Y 7/3 pale yellow matrix supported granular and pebbly gravel with fine to medium sand matrix	1,2,3,4,5,3,6,3,6,8
93.70m	Oxidised 2.5Y 5/6 light olive brown matrix supported pebbly gravel with sand and silt matrix	1,2,5,4,6,3,6,8
103.18m	5BG 5/1 greenish grey massive silt	1,2,3,4,3,5,6,3,6,8
103.30m	“ “ “	1,2,3,4,5,3,6,3,6,8
103.40m	“ “ “	1,2,3,4,3,5,6,3,8,6,8
103.50m	“ “ “	1,2,3,4,5,3,6,3,8
103.70m	“ “ “	1,2,3,4,3,5,6,3,8,6,3,6,8
108.75m	5GY 5/1 light greenish grey silt	1,2,3,4,5,3,6,3,6,8
112.50m	5Y 5/6 greenish/bluish grey matrix supported pebbly gravel	1,2,3,4,3,5,6,3,8,6,8
117.85m	Silt within similar unit to that described at 112.50m	1,2,3,4,3,5,6,3,6,8
121.60m	10YR 5/6 yellowish brown finely laminated clay	1,2,3,4,3,5,6,3,8,6,8
121.85m	“ “ “	1,2,3,4,5,3,6,3,6,8
123.10m	5GY 6/1 greenish grey mottled fine sand	1,2,3,4,3,5,6,6,8
126.63m	10Y 7/1 light greenish grey	1,2,3,4,5,6,3,8,6,8

	massive clay	
138.05m	Matrix supported gravel with silt/sand matrix	1,2,3,4,5,3,6,3,6,8

Appendix Two:

Waipori 99-1 Pollen Counts

(cm)	28	103	328	353	433	533	658	703
Lycopodium (Added)	97	32	94	83	47	230	116	204
Dacrycarpus dacrydioides	6	18	6	12	16	0	4	1
Dacrydium cupressinum	28	17	12	54	45	3	18	7
Libocedrus bidwillii	0	0	0	0	0	0	0	0
Metrosideros	0	0	0	0	0	0	0	0
Brassospora	0	0	0	0	0	0	1	0
Fuscospora	0	0	0	0	0	1	1	0
Nothofagus menziesii	0	4	4	5	3	0	0	0
Podocarpus undiff.	4	8	4	15	8	0	1	5
Prumnopitys ferruginea	11	17	6	9	13	1	2	3
Prumnopitys taxifolia	23	30	13	40	24	1	14	10
Aristotelia	0	1	0	0	1	0	0	0
Ascarina lucida	0	0	0	0	0	0	0	0
Asteraceae (Tub.)	3	7	5	4	1	0	0	1
Coprosma	13	13	13	13	18	0	4	6
Coriaria	0	0	4	0	0	0	0	0
Discaria toumatou	0	0	0	0	0	0	0	0
Elaeocarpus	1	0	0	0	0	0	2	0
Epacridaceae - Dracophyllum type	0	1	0	0	0	0	0	0
Ericaceae	0	0	0	0	0	0	0	0
Fuchsia	0	0	0	0	0	0	0	0
Griselinia	5	0	0	0	0	0	0	0
Halocarpus	0	24	11	12	12	1	2	2
Hebe	0	0	0	1	0	0	0	0
Hoheria	4	1	3	0	2	0	1	0
Melicytus	0	0	0	0	0	0	0	0
Muehlenbeckia	0	0	0	0	2	1	0	0
Myrsine	6	0	4	1	1	0	1	0
Myrtaceae - Leptospermum type	1	0	0	0	0	0	0	0
Myrtaceae - Lophomyrtus/Neomyrtus type	2	0	0	0	0	0	0	0
Phyllocladus	4	9	7	6	6	1	2	4
Pittosporum	9	0	0	0	1	0	1	0
Plagianthus regius	0	5	4	4	3	0	0	0
Pseudopanax	11	0	8	0	1	0	0	0
Pseudowintera	1	1	2	0	2	0	0	0
Quintinia	1	0	1	0	0	0	0	0
Apiaceae	0	0	0	0	0	0	1	0
Asteraceae (Lig.)	0	0	0	0	0	0	0	0
Brassicaceae	0	0	1	0	0	0	0	0
Callitriche	0	0	0	0	0	0	0	0
Caryophyllaceae	0	0	0	0	1	0	0	0
Chenopodiaceae	0	0	1	0	0	0	0	0
Convolvulaceae	0	0	0	0	0	0	0	0
Dichondra	0	0	0	0	0	0	0	0
Epilobium	1	0	1	0	0	0	0	0
Gentiana	0	0	0	0	0	0	0	0
Geranium	0	0	0	0	0	0	1	0
Gunnera	0	2	0	1	0	0	0	0
Haloragaceae	0	0	0	1	0	0	0	0
Ileostylus	0	0	0	0	0	0	0	0
Iridiaceae	0	0	0	0	0	0	0	0
Liliaceae	0	0	1	0	0	0	0	0
Montia fontana	0	0	0	0	0	0	0	0
Myosotis	0	0	0	0	0	0	0	0
Plantago	0	0	0	0	0	0	0	0

Waipori 99-1 Pollen Counts

(cm)	28	103	328	353	433	533	658	703
Poaceae	15	7	24	3	1	0	1	1
Ranunculus	0	0	0	0	0	0	0	0
Stellaria	0	0	0	0	0	0	0	0
Wahlenbergia	0	0	0	0	0	0	0	0
Cyathea	7	8	4	8	3	0	0	1
Cyathea smithii	0	0	0	0	0	0	0	0
Cystopteris	0	0	0	1	0	0	0	0
Dicksonia	0	5	0	0	2	0	0	0
Gleichenia	0	1	0	0	0	0	0	0
Histiopteris	0	0	0	1	0	0	0	0
Hymenophyllum	0	0	1	0	2	0	0	0
Leptolepia	0	0	0	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0	0	0	0
Lycopodium fastigiatum	0	3	1	0	0	0	0	0
Lycopodium scariosum	0	0	0	0	0	0	0	0
Lycopodium undiff.	2	0	1	0	0	0	3	0
Lycopodium varium	0	0	0	0	0	0	0	0
Lycopodium volubile	1	1	0	0	0	0	0	0
Monolete fern spore undiff.	15	18	24	16	23	0	5	5
Phymatosorus	1	1	0	0	0	0	0	0
Pteridium	0	2	2	0	0	0	0	0
Trilete fern spore undiff.	4	3	1	4	1	0	0	0
Cyperaceae	18	5	34	0	0	0	0	0
Myriophyllum	0	1	0	0	0	0	0	0
Phormium tenax	0	0	0	0	0	0	0	0
Restionaceae	0	0	1	2	1	0	0	0
Typha orientalis	5	0	3	0	0	0	0	0
Casuarina	0	0	0	0	0	0	0	0
Unknown	6	2	5	0	2	0	0	1
Trees	72	94	45	135	109	6	41	26
Small trees and shrubs	61	62	62	41	50	3	13	13
Herbs	16	9	28	5	2	0	3	1
Ferns and fern allies	30	42	34	30	31	0	8	6
Aquatics	23	6	38	2	1	0	0	0
Unknown	6	2	5	0	2	0	0	1
Total Pollen Count	208	215	212	213	195	9	65	47

Waipori 99-1 Pollen Counts

(cm)	853	955	970	1053	1078	1128	1172	1353
Lycopodium (Added)	156	57	48	48	43	60	30	52
Dacrycarpus dacrydioides	1	6	13	18	10	18	24	17
Dacrydium cupressinum	66	51	38	45	24	22	24	22
Libocedrus bidwillii	0	0	0	0	0	0	0	0
Metrosideros	0	0	0	0	0	0	0	0
Brassospora	0	0	0	0	0	0	0	0
Fuscospora	0	0	0	0	0	0	0	1
Nothofagus menziesii	0	0	0	0	0	0	1	1
Podocarpus undiff.	8	10	9	18	15	4	5	9
Prumnopitys ferruginea	4	13	13	15	12	9	13	11
Prumnopitys taxifolia	6	55	25	32	36	21	22	29
Aristotelia	0	0	1	0	0	2	0	0
Ascarina lucida	0	0	0	0	0	0	0	0
Asteraceae (Tub.)	0	4	6	2	3	3	4	8
Coprosma	3	7	19	14	8	23	19	19
Coriaria	0	0	0	0	0	0	0	0
Discaria toumatou	0	0	0	1	0	0	0	1
Elaeocarpus	0	0	0	0	1	0	0	2
Epacridaceae - Dracophyllum type	0	0	1	1	0	0	1	0
Ericaceae	0	0	0	0	0	0	0	1
Fuchsia	0	0	0	0	0	0	0	0
Griselinia	0	2	0	0	2	0	0	0
Halocarpus	0	16	9	12	12	9	12	11
Hebe	0	0	0	0	0	0	0	0
Hoheria	1	0	0	0	0	0	0	1
Melicytus	0	0	0	0	0	0	0	0
Muehlenbeckia	0	0	0	0	0	0	0	0
Myrsine	0	2	2	0	3	4	3	2
Myrtaceae - Leptospermum type	0	0	0	0	0	0	0	0
Myrtaceae - Lophomyrtus/Neomyrtus type	0	0	0	0	1	0	1	0
Phyllocladus	3	21	6	14	13	21	23	6
Pittosporum	1	0	0	1	2	2	1	1
Plagianthus regius	0	1	2	4	2	5	8	7
Pseudopanax	0	0	2	2	1	0	1	1
Pseudowintera	0	2	6	1	1	7	9	3
Quintinia	0	0	0	0	0	0	0	0
Apiaceae	0	0	1	0	0	0	0	0
Asteraceae (Lig.)	0	0	0	0	0	0	0	0
Brassicaceae	0	0	0	0	0	0	0	0
Callitriche	0	0	0	0	0	0	0	0
Caryophyllaceae	0	0	0	0	0	0	0	1
Chenopodiaceae	0	0	1	0	0	0	0	0
Convolvulaceae	0	0	0	0	0	0	0	0
Dichondra	0	0	0	0	0	0	0	0
Epilobium	0	0	0	0	0	0	0	0
Gentiana	0	0	0	0	0	0	0	0
Geranium	0	0	0	0	0	0	0	0
Gunnera	0	1	0	0	1	1	0	0
Haloragaceae	0	0	0	0	0	0	0	0
Ileostylus	0	0	0	0	0	0	0	0
Iridiaceae	0	0	0	0	0	0	0	0
Liliaceae	0	0	0	0	0	0	0	0
Montia fontana	0	0	0	0	0	0	0	0
Myosotis	0	0	0	0	0	0	0	1
Plantago	0	0	0	0	0	0	0	0

Waipori 99-1 Pollen Counts

(cm)	853	955	970	1053	1078	1128	1172	1353
Poaceae	0	0	1	1	7	2	2	3
Ranunculus	0	0	0	0	0	0	0	0
Stellaria	0	0	0	0	0	0	0	0
Wahlenbergia	0	0	0	0	0	0	0	0
Cyathea	4	13	13	14	16	17	26	31
Cyathea smithii	0	0	0	0	0	0	0	0
Cystopteris	0	1	1	0	0	1	3	2
Dicksonia	0	0	1	1	3	1	2	1
Gleichenia	0	0	1	0	1	0	0	0
Histiopteris	0	0	0	0	0	0	0	1
Hymenophyllum	0	0	0	0	0	0	0	0
Leptolepia	0	0	0	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0	0	0	0
Lycopodium fastigiatum	0	0	1	0	0	0	1	1
Lycopodium scariosum	0	0	0	1	0	0	0	0
Lycopodium undiff.	0	0	0	0	0	0	0	0
Lycopodium varium	0	0	0	0	0	0	0	0
Lycopodium volubile	0	0	1	0	0	0	0	0
Monolete fern spore undiff.	2	15	18	17	32	17	27	29
Phymatosorus	0	0	1	1	0	0	1	0
Pteridium	0	0	0	0	0	0	0	0
Trilete fern spore undiff.	1	3	2	2	1	1	0	1
Cyperaceae	0	3	0	0	3	0	2	0
Myriophyllum	0	0	0	0	0	0	0	0
Phormium tenax	0	0	0	0	0	0	0	0
Restionaceae	2	0	0	0	0	1	0	0
Typha orientalis	0	0	0	0	0	0	0	0
Casuarina	0	0	1	0	0	0	1	0
Unknown	0	0	0	1	0	4	4	7
Trees	85	135	98	128	97	74	89	90
Small trees and shrubs	8	55	54	52	49	76	82	63
Herbs	0	1	3	1	8	3	2	5
Ferns and fern allies	7	32	39	36	53	37	60	66
Aquatics	2	3	0	0	3	1	2	0
Unknown	0	0	1	1	0	4	5	7
Total Pollen Count	102	226	195	218	210	195	240	231

Waipori 99-1 Pollen Counts

(cm)	1398	1453	1478	1528	1578	1628	1678	1728
Lycopodium (Added)	36	82	50	45	53	38	63	77
Dacrycarpus dacrydioides	20	15	15	17	21	14	16	17
Dacrydium cupressinum	7	1	3	2	0	2	1	0
Libocedrus bidwillii	0	0	0	0	0	0	0	0
Metrosideros	0	0	0	0	0	1	0	0
Brassospora	0	0	0	0	0	0	0	0
Fuscospora	0	1	0	0	1	1	0	2
Nothofagus menziesii	0	0	0	0	0	0	0	0
Podocarpus undiff.	9	5	9	12	12	10	11	5
Prumnopitys ferruginea	22	7	11	19	14	14	13	11
Prumnopitys taxifolia	47	14	25	39	32	52	37	38
Aristotelia	0	1	0	0	0	0	7	0
Ascarina lucida	0	0	0	0	0	0	0	0
Asteraceae (Tub.)	4	11	1	3	3	4	3	6
Coprosma	4	26	18	8	14	8	22	15
Coriaria	0	0	0	0	0	0	0	0
Discaria toumatou	0	0	0	0	0	0	0	1
Elaeocarpus	0	0	0	0	0	0	0	0
Epacridaceae - Dracophyllum type	0	4	2	0	0	0	1	4
Ericaceae	0	0	0	0	0	0	0	2
Fuchsia	0	1	0	0	0	0	0	2
Griselinia	3	0	0	2	1	3	0	0
Halocarpus	10	9	7	13	6	17	6	9
Hebe	0	0	0	0	1	0	0	0
Hoheria	4	0	0	2	1	1	1	3
Melicytus	0	0	0	0	1	0	0	0
Muehlenbeckia	0	1	0	0	4	0	0	1
Myrsine	0	3	5	1	3	0	0	0
Myrtaceae - Leptospermum type	0	0	0	0	0	0	0	0
Myrtaceae - Lophomyrtus/Neomyrtus type	0	0	1	0	0	0	0	0
Phyllocladus	16	12	13	8	14	5	11	18
Pittosporum	0	0	0	1	0	0	0	0
Plagianthus regius	0	8	8	2	5	0	2	6
Pseudopanax	1	1	1	0	1	0	0	1
Pseudowintera	4	18	13	15	5	6	16	6
Quintinia	0	0	1	0	1	1	0	0
Apiaceae	0	0	1	1	1	0	0	0
Asteraceae (Lig.)	0	0	0	0	0	0	1	0
Brassicaceae	0	0	0	0	1	3	0	2
Callitriche	0	2	0	0	0	0	0	0
Caryophyllaceae	0	0	0	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0	0	0	0
Convolvulaceae	0	0	0	0	0	0	0	0
Dichondra	0	0	0	0	0	0	2	0
Epilobium	0	0	0	0	0	0	0	0
Gentiana	0	0	0	0	0	0	0	0
Geranium	0	0	0	0	0	0	0	1
Gunnera	0	0	1	0	2	0	1	0
Haloragaceae	0	1	0	0	0	0	1	1
Ileostylus	0	0	0	0	0	0	0	0
Iridiaceae	0	0	0	0	0	0	0	0
Liliaceae	0	0	0	0	0	0	0	0
Montia fontana	0	0	0	0	0	0	0	0
Myosotis	0	0	0	0	0	0	0	0
Plantago	0	0	0	0	0	0	0	0

Waipori 99-1 Pollen Counts

(cm)	1398	1453	1478	1528	1578	1628	1678	1728
Poaceae	4	5	6	5	14	3	4	6
Ranunculus	0	0	0	0	0	0	0	0
Stellaria	0	0	0	0	0	0	0	0
Wahlenbergia	0	0	0	0	0	0	0	0
Cyathea	37	40	38	32	20	21	36	20
Cyathea smithii	0	0	0	0	0	0	0	0
Cystopteris	0	2	3	0	0	0	1	2
Dicksonia	3	1	8	0	6	2	9	1
Gleichenia	1	1	0	0	1	3	0	2
Histiopteris	0	2	3	1	0	1	3	1
Hymenophyllum	0	0	0	0	0	0	0	1
Leptolepia	0	0	0	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0	0	0	0
Lycopodium fastigiatum	0	4	0	0	0	2	1	1
Lycopodium scariosum	0	1	1	0	0	0	0	0
Lycopodium undiff.	0	0	0	0	0	1	0	0
Lycopodium varium	0	0	0	0	0	0	0	0
Lycopodium volubile	0	0	2	0	0	0	2	1
Monolete fern spore undiff.	27	20	21	35	27	38	27	36
Phymatosorus	1	0	2	2	0	1	0	1
Pteridium	0	0	0	0	0	0	0	0
Trilete fern spore undiff.	5	6	3	8	2	5	2	4
Cyperaceae	1	1	1	3	2	3	1	0
Myriophyllum	0	0	0	0	2	0	0	0
Phormium tenax	0	0	0	0	0	0	0	0
Restionaceae	0	1	0	0	5	0	6	4
Typha orientalis	0	0	0	0	0	0	0	0
Casuarina	0	1	0	0	0	0	0	0
Unknown	0	0	0	3	0	0	0	0
Trees	105	43	63	89	80	94	78	73
Small trees and shrubs	46	95	70	55	60	45	69	74
Herbs	4	8	8	6	18	6	9	10
Ferns and fern allies	74	77	81	78	56	74	81	70
Aquatics	1	2	1	3	9	3	7	4
Unknown	0	1	0	3	0	0	0	0
Total Pollen Count	230	226	223	234	223	222	244	231

Waipori 99-1 Pollen Counts

(cm)	1753	1803	1853	1945	2009	2028	2133	2178
Lycopodium (Added)	53	63	36	25	10	162	144	102
Dacrycarpus dacrydioides	16	24	20	21	0	0	0	1
Dacrydium cupressinum	2	0	0	0	0	0	0	0
Libocedrus bidwillii	0	0	0	0	0	0	0	0
Metrosideros	0	0	0	0	0	0	0	0
Brassospora	0	0	0	0	0	0	0	0
Fuscospora	0	0	0	0	0	2	0	0
Nothofagus menziesii	0	0	0	0	0	0	0	1
Podocarpus undiff.	30	6	0	14	1	2	0	0
Prumnopitys ferruginea	27	10	12	17	0	1	0	0
Prumnopitys taxifolia	44	18	35	35	1	1	0	0
Aristotelia	0	0	0	2	0	0	0	0
Ascarina lucida	0	0	0	0	0	0	0	0
Asteraceae (Tub.)	2	5	2	0	0	0	0	0
Coprosma	10	27	13	23	0	0	0	0
Coriaria	0	0	0	0	0	0	0	0
Discaria toumatou	0	0	0	2	0	0	0	0
Elaeocarpus	0	1	0	0	0	0	0	0
Epacridaceae - Dracophyllum type	0	1	0	1	0	0	0	0
Ericaceae	1	1	0	0	0	0	0	0
Fuchsia	0	0	1	0	0	0	0	0
Griselinia	2	0	3	1	0	0	0	0
Halocarpus	25	15	8	16	1	0	0	0
Hebe	0	1	0	0	0	0	0	0
Hoheria	0	3	0	3	0	0	0	0
Melicytus	0	0	0	0	0	0	0	0
Muehlenbeckia	0	3	0	1	0	0	0	0
Myrsine	0	2	0	0	0	0	0	0
Myrtaceae - Leptospermum type	0	2	0	0	0	0	0	0
Myrtaceae - Lophomyrtus/Neomyrtus type	0	0	0	0	0	0	0	0
Phyllocladus	9	16	6	5	0	0	0	0
Pittosporum	3	1	0	0	0	0	0	0
Plagianthus regius	4	10	28	5	0	3	0	0
Pseudopanax	0	1	0	1	0	0	0	0
Pseudowintera	6	11	21	7	0	0	0	1
Quintinia	0	0	0	0	0	0	0	0
Apiaceae	1	0	0	0	0	0	0	0
Asteraceae (Lig.)	0	2	0	0	0	0	0	0
Brassicaceae	0	0	1	0	0	0	0	0
Callitriche	0	0	0	0	0	0	0	0
Caryophyllaceae	0	2	1	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0	0	0	0
Convolvulaceae	0	0	0	0	0	0	0	0
Dichondra	0	0	0	0	0	0	0	0
Epilobium	0	0	0	0	0	0	0	0
Gentiana	0	0	0	0	0	0	0	0
Geranium	0	0	0	0	0	0	0	0
Gunnera	0	0	0	0	0	0	0	0
Haloragaceae	0	0	1	1	0	0	0	0
Ileostylus	0	0	0	0	0	0	0	0
Iridiaceae	0	0	0	0	0	0	0	0
Liliaceae	0	0	0	4	0	0	0	0
Montia fontana	0	0	0	0	0	0	0	0
Myosotis	0	0	0	0	0	0	0	0
Plantago	0	0	1	0	0	0	0	0

Waipori 99-1 Pollen Counts

(cm)	1753	1803	1853	1945	2009	2028	2133	2178
Poaceae	6	5	4	5	1	3	0	0
Ranunculus	0	0	0	0	0	0	0	0
Stellaria	0	0	0	0	0	0	0	0
Wahlenbergia	0	0	0	0	0	0	0	0
Cyathea	26	12	21	14	5	12	0	0
Cyathea smithii	0	0	0	0	0	0	0	0
Cystopteris	1	2	0	0	0	0	0	0
Dicksonia	2	4	4	1	1	7	0	0
Gleichenia	1	0	0	0	0	0	0	0
Histiopteris	2	0	4	1	0	0	0	0
Hymenophyllum	0	0	0	0	0	0	0	0
Leptolepia	0	0	0	0	0	0	0	0
Lycopodium deuterodensum	0	1	1	0	0	0	0	0
Lycopodium fastigiatum	2	2	3	6	0	0	0	0
Lycopodium scariosum	0	0	0	0	0	0	1	0
Lycopodium undiff.	0	0	0	0	0	0	0	0
Lycopodium varium	0	0	0	0	0	0	0	0
Lycopodium volubile	0	2	0	1	1	2	0	0
Monolete fern spore undiff.	19	27	31	26	2	8	2	1
Phymatosorus	0	0	0	0	0	1	0	0
Pteridium	0	0	0	0	0	0	0	0
Trilete fern spore undiff.	4	0	1	3	0	3	0	0
Cyperaceae	2	2	1	17	0	2	0	0
Myriophyllum	0	0	0	0	0	0	0	0
Phormium tenax	0	0	0	1	0	0	0	0
Restionaceae	0	0	0	8	0	0	0	0
Typha orientalis	0	0	0	0	0	0	0	0
Casuarina	0	0	0	0	0	5	0	1
Unknown	0	0	0	0	0	2	0	0
Trees	119	58	67	87	2	6	0	2
Small trees and shrubs	62	100	82	67	1	3	0	1
Herbs	7	9	8	10	1	3	0	0
Ferns and fern allies	57	50	65	52	9	33	3	1
Aquatics	2	2	1	26	0	2	0	0
Unknown	0	0	0	0	0	7	0	1
Total Pollen Count	247	219	223	242	13	54	3	5

Waipori 99-1 Pollen Counts

(cm)	2223	2653	2678	2703	2728	2753	3753	3818
Lycopodium (Added)	10	17	47	176	170	136	36	30
Dacrycarpus dacrydioides	0	0	0	0	1	1	12	43
Dacrydium cupressinum	0	0	0	0	0	0	0	0
Libocedrus bidwillii	0	0	0	0	0	0	0	0
Metrosideros	0	0	0	0	0	0	1	0
Brassospora	0	0	0	0	0	0	1	0
Fuscospora	0	0	0	0	0	0	2	0
Nothofagus menziesii	0	0	0	0	0	0	0	0
Podocarpus undiff.	0	0	0	0	0	3	15	16
Prumnopitys ferruginea	0	3	2	0	0	2	29	24
Prumnopitys taxifolia	1	5	1	1	0	0	57	38
Aristotelia	0	0	0	0	0	0	0	1
Ascarina lucida	0	0	0	0	0	0	0	0
Asteraceae (Tub.)	0	0	1	0	1	0	1	0
Coprosma	0	4	1	1	2	2	10	14
Coriaria	0	0	0	0	0	0	0	0
Discaria toumatou	0	0	0	0	0	0	0	0
Elaeocarpus	0	0	0	0	0	0	1	0
Epacridaceae - Dracophyllum type	0	1	1	0	0	0	0	0
Ericaceae	0	0	0	0	0	0	0	0
Fuchsia	0	0	0	0	0	0	0	0
Griselinia	0	0	0	0	0	0	0	1
Halocarpus	0	0	1	2	0	0	17	4
Hebe	0	0	0	0	0	0	0	0
Hoheria	0	0	0	0	0	0	5	0
Melicytus	0	0	0	0	0	0	0	0
Muehlenbeckia	0	0	0	0	0	0	0	1
Myrsine	0	0	0	0	0	0	0	0
Myrtaceae - Leptospermum type	0	0	0	0	0	0	0	0
Myrtaceae - Lophomyrtus/Neomyrtus type	0	0	0	0	0	0	0	0
Phyllocladus	0	0	0	1	0	0	0	0
Pittosporum	0	0	0	0	0	0	4	0
Plagianthus regius	0	5	18	0	2	3	0	1
Pseudopanax	0	0	0	0	0	0	0	1
Pseudowintera	0	0	0	0	0	0	0	0
Quintinia	0	0	0	0	0	0	0	0
Apiaceae	0	0	0	0	0	0	0	0
Asteraceae (Lig.)	0	0	0	0	0	0	0	0
Brassicaceae	0	0	0	0	0	0	0	0
Callitriche	0	0	0	0	0	0	0	0
Caryophyllaceae	0	0	0	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0	0	0	0
Convolvulaceae	0	0	0	0	0	0	0	0
Dichondra	0	0	0	0	0	0	0	0
Epilobium	0	0	0	0	0	0	0	0
Gentiana	0	1	0	0	0	0	0	0
Geranium	0	0	0	0	0	0	0	0
Gunnera	0	0	0	0	0	0	0	0
Haloragaceae	0	0	0	0	0	0	10	3
Ileostylus	0	0	0	0	0	0	0	0
Iridiaceae	0	0	0	0	0	0	0	0
Liliaceae	0	0	0	0	0	0	0	0
Montia fontana	0	0	0	0	0	0	0	0
Myosotis	0	0	0	0	0	0	0	0
Plantago	0	0	0	0	0	0	0	0

Waipori 99-1 Pollen Counts

(cm)	2223	2653	2678	2703	2728	2753	3753	3818
Poaceae	0	6	6	1	0	1	0	0
Ranunculus	0	0	0	0	0	0	0	0
Stellaria	0	0	0	0	0	0	0	0
Wahlenbergia	0	0	0	0	0	0	0	0
Cyathea	0	60	59	0	1	3	17	17
Cyathea smithii	0	0	0	0	0	0	0	0
Cystopteris	0	6	0	0	0	0	1	8
Dicksonia	0	21	18	0	0	0	7	22
Gleichenia	0	0	0	0	0	0	0	0
Histiopteris	0	0	4	0	0	0	0	4
Hymenophyllum	0	0	0	0	0	0	0	0
Leptolepia	0	0	0	0	0	0	0	0
Lycopodium deuterodensum	0	1	0	0	0	0	0	0
Lycopodium fastigiatum	0	1	0	0	0	0	0	3
Lycopodium scariosum	0	0	2	0	0	0	0	0
Lycopodium undiff.	0	1	0	0	0	0	0	0
Lycopodium varium	0	0	0	0	0	0	0	0
Lycopodium volubile	0	0	2	0	0	0	0	2
Monolete fern spore undiff.	0	26	66	1	1	2	30	12
Phymatosorus	0	4	9	0	0	0	3	0
Pteridium	0	0	0	0	0	0	0	0
Trilete fern spore undiff.	0	37	10	0	0	0	6	8
Cyperaceae	0	4	2	0	0	0	2	0
Myriophyllum	0	0	0	0	0	0	0	0
Phormium tenax	0	1	0	0	0	0	1	0
Restionaceae	0	0	0	0	0	0	0	0
Typha orientalis	0	0	0	0	0	0	0	0
Casuarina	0	0	0	0	0	0	0	0
Unknown	0	0	0	0	0	1	0	0
Trees	1	8	3	1	1	6	117	121
Small trees and shrubs	0	10	22	4	5	5	38	23
Herbs	0	7	6	1	0	1	10	3
Ferns and fern allies	0	157	170	1	2	5	64	76
Aquatics	0	5	2	0	0	0	3	0
Unknown	0	0	0	0	0	1	0	0
Total Pollen Count	1	187	203	7	8	18	232	223

Waipori 99-1 Pollen Counts

(cm)	3843	3860	3910	3935	3960	3976	4000	4035
Lycopodium (Added)	36	23	25	20	15	14	156	222
Dacrycarpus dacrydioides	29	15	19	30	41	45	28	0
Dacrydium cupressinum	1	1	3	4	1	2	1	0
Libocedrus bidwillii	0	0	0	0	0	0	0	0
Metrosideros	0	0	0	1	0	0	0	0
Brassospora	0	0	0	0	0	0	0	1
Fuscospora	0	2	0	2	0	1	1	1
Nothofagus menziesii	0	0	0	1	1	0	0	1
Podocarpus undiff.	9	11	14	14	18	25	14	0
Prumnopitys ferruginea	25	24	34	20	46	23	19	1
Prumnopitys taxifolia	34	17	38	39	67	37	50	0
Aristotelia	0	0	0	0	0	0	0	0
Ascarina lucida	0	0	0	0	0	0	0	1
Asteraceae (Tub.)	2	1	2	1	1	1	1	0
Coprosma	3	7	8	19	4	14	8	0
Coriaria	0	0	0	0	0	0	0	0
Discaria toumatou	0	0	0	0	0	0	0	0
Elaeocarpus	0	0	0	0	1	0	0	0
Epacridaceae - Dracophyllum type	0	0	0	2	1	0	0	0
Ericaceae	0	0	0	0	0	0	0	0
Fuchsia	0	5	1	1	0	2	0	0
Griselinia	0	0	1	0	1	0	0	0
Halocarpus	9	19	9	11	26	6	12	0
Hebe	0	0	0	0	0	0	0	0
Hoheria	0	0	0	0	1	1	0	0
Melicytus	0	0	0	0	0	0	0	0
Muehlenbeckia	0	0	0	1	0	0	5	0
Myrsine	1	1	1	2	0	0	0	0
Myrtaceae - Leptospermum type	0	2	0	0	0	0	0	0
Myrtaceae - Lophomyrtus/Neomyrtus type	1	0	0	0	0	0	0	0
Phyllocladus	0	1	1	1	0	0	1	0
Pittosporum	2	1	1	0	3	0	0	0
Plagianthus regius	1	4	4	1	1	5	2	0
Pseudopanax	0	1	0	0	0	1	1	0
Pseudowintera	0	0	0	0	0	0	0	0
Quintinia	0	0	0	0	0	0	0	0
Apiaceae	0	0	1	0	0	0	0	0
Asteraceae (Lig.)	0	0	0	0	0	0	0	0
Brassicaceae	1	0	0	0	1	0	0	0
Callitriche	0	0	0	0	0	0	0	0
Caryophyllaceae	0	0	0	0	0	1	0	0
Chenopodiaceae	0	0	0	0	0	0	0	0
Convolvulaceae	0	0	0	0	0	0	0	0
Dichondra	0	0	0	0	0	0	0	0
Epilobium	0	0	0	0	0	0	1	0
Gentiana	0	0	0	0	0	0	0	0
Geranium	0	0	0	0	0	0	0	0
Gunnera	0	1	0	0	0	0	1	0
Haloragaceae	3	4	0	41	0	2	0	0
Ileostylus	0	0	0	0	0	0	0	0
Iridiaceae	0	0	0	0	0	0	0	0
Liliaceae	0	0	0	0	0	0	0	0
Montia fontana	0	0	0	0	0	0	0	0
Myosotis	0	0	0	0	0	0	0	0
Plantago	0	0	0	0	0	0	0	0

Waipori 99-1 Pollen Counts

(cm)	3843	3860	3910	3935	3960	3976	4000	4035
Poaceae	2	1	3	3	1	5	0	2
Ranunculus	0	0	0	0	0	0	0	0
Stellaria	0	0	0	0	0	0	0	0
Wahlenbergia	0	0	0	0	0	0	0	0
Cyathea	27	25	21	28	36	13	23	3
Cyathea smithii	0	0	0	1	0	0	1	0
Cystopteris	4	6	8	3	0	2	4	0
Dicksonia	22	26	15	15	15	17	19	3
Gleichenia	2	1	0	1	0	0	0	0
Histiopteris	5	5	1	5	1	4	1	0
Hymenophyllum	0	0	0	0	0	2	0	0
Leptolepia	0	0	0	0	0	0	2	0
Lycopodium deuterodensum	2	1	0	0	0	0	0	0
Lycopodium fastigiatum	2	3	2	0	3	0	1	2
Lycopodium scariosum	0	0	0	1	0	1	1	0
Lycopodium undiff.	0	0	0	0	0	0	0	0
Lycopodium varium	0	0	0	0	0	0	0	0
Lycopodium volubile	0	1	1	1	0	0	0	5
Monolete fern spore undiff.	27	22	18	19	19	38	8	14
Phymatosorus	0	0	0	0	0	0	0	0
Pteridium	0	0	0	0	0	0	0	0
Trilete fern spore undiff.	6	3	6	5	19	6	10	2
Cyperaceae	3	0	1	0	3	9	1	0
Myriophyllum	2	0	0	0	0	1	0	3
Phormium tenax	0	0	0	0	0	2	0	0
Restionaceae	0	0	0	0	0	0	0	0
Typha orientalis	0	0	0	0	0	0	0	0
Casuarina	0	0	2	0	0	0	0	2
Unknown	0	0	2	2	0	0	0	0
Trees	98	70	108	111	174	133	113	4
Small trees and shrubs	19	42	28	39	39	30	30	1
Herbs	6	6	4	44	2	8	2	2
Ferns and fern allies	97	93	72	79	93	83	70	29
Aquatics	5	0	1	0	3	12	1	3
Unknown	0	0	4	2	0	0	0	2
Total Pollen Count	225	211	217	275	311	266	216	41

Waipori 99-1 Pollen Counts

(cm)	4055	4063	4635	4650	4675	5070	5483	5508
Lycopodium (Added)	260	18	254	202	285	73	49	95
Dacrycarpus dacrydioides	0	6	1	0	0	8	0	0
Dacrydium cupressinum	0	0	0	0	0	0	0	0
Libocedrus bidwillii	0	0	0	0	0	0	0	0
Metrosideros	0	1	0	0	0	0	0	0
Brassospora	1	2	0	0	1	0	1	1
Fuscospora	0	1	0	0	1	0	0	1
Nothofagus menziesii	0	0	3	0	0	0	0	0
Podocarpus undiff.	0	31	0	2	0	6	10	6
Prumnopitys ferruginea	1	16	1	0	0	11	23	11
Prumnopitys taxifolia	0	54	0	0	0	20	12	36
Aristotelia	0	0	0	0	0	0	0	0
Ascarina lucida	0	0	0	0	0	0	0	0
Asteraceae (Tub.)	0	1	0	0	0	2	4	6
Coprosma	0	3	0	0	0	20	11	16
Coriaria	0	0	0	0	0	0	0	0
Discaria toumatou	0	0	0	0	0	1	1	0
Elaeocarpus	0	0	0	0	0	2	0	0
Epacridaceae - Dracophyllum type	0	1	0	0	0	0	3	0
Ericaceae	0	0	1	0	0	0	0	0
Fuchsia	0	1	0	0	0	0	0	0
Griselinia	0	4	0	0	0	0	0	1
Halocarpus	0	2	2	2	1	0	2	0
Hebe	0	0	0	0	0	0	0	0
Hoheria	0	0	0	0	0	0	4	1
Melicytus	0	0	0	0	0	0	0	0
Muehlenbeckia	0	0	0	0	0	0	0	0
Myrsine	5	0	3	4	0	0	0	1
Myrtaceae - Leptospermum type	0	0	0	0	0	0	0	0
Myrtaceae - Lophomyrtus/Neomyrtus type	0	3	0	0	0	0	0	0
Phyllocladus	0	0	1	1	1	2	0	0
Pittosporum	0	0	1	0	0	0	2	3
Plagianthus regius	10	5	2	0	0	4	12	3
Pseudopanax	0	0	0	0	1	4	4	0
Pseudowintera	0	0	0	0	0	0	3	0
Quintinia	0	0	0	0	0	0	0	0
Apiaceae	0	0	1	0	2	3	1	0
Asteraceae (Lig.)	0	0	0	0	0	0	0	0
Brassicaceae	0	0	0	0	0	0	0	0
Callitriche	0	0	0	0	0	0	0	3
Caryophyllaceae	0	0	0	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0	0	0	0
Convolvulaceae	0	0	0	0	0	0	0	0
Dichondra	0	0	0	0	0	0	0	0
Epilobium	0	0	0	0	0	1	0	0
Gentiana	0	0	0	0	0	0	0	0
Geranium	0	0	0	0	0	0	0	1
Gunnera	0	1	0	0	0	0	0	0
Haloragaceae	0	0	0	0	0	0	0	1
Ileostylus	0	0	0	0	0	0	0	0
Iridiaceae	0	0	0	0	0	0	0	0
Liliaceae	0	0	0	0	0	0	0	0
Montia fontana	0	0	0	0	0	0	0	0
Myosotis	0	0	0	0	0	0	0	0
Plantago	0	0	0	0	0	1	0	0

Waipori 99-1 Pollen Counts

(cm)	4055	4063	4635	4650	4675	5070	5483	5508
Poaceae	14	3	6	4	1	2	23	23
Ranunculus	0	0	0	0	0	0	0	0
Stellaria	0	0	0	0	0	0	0	0
Wahlenbergia	0	0	0	0	0	0	0	0
Cyathea	29	12	17	36	6	1	23	10
Cyathea smithii	0	0	0	0	0	0	1	0
Cystopteris	0	0	1	1	0	5	4	4
Dicksonia	17	4	24	14	1	0	2	2
Gleichenia	1	0	0	1	0	0	5	0
Histiopteris	0	0	0	0	0	1	0	0
Hymenophyllum	0	0	0	0	0	0	1	0
Leptolepia	0	0	0	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0	0	0	0
Lycopodium fastigiatum	4	0	5	6	0	0	0	1
Lycopodium scariosum	0	1	0	3	0	0	0	0
Lycopodium undiff.	0	0	3	0	0	1	0	0
Lycopodium varium	0	0	0	0	1	0	0	0
Lycopodium volubile	7	0	8	7	1	0	0	0
Monolete fern spore undiff.	84	23	56	73	22	16	48	72
Phymatosorus	0	0	0	2	0	1	2	2
Pteridium	0	0	0	0	0	0	0	0
Trilete fern spore undiff.	22	16	10	15	1	0	5	29
Cyperaceae	1	5	1	1	1	3	4	10
Myriophyllum	1	0	0	1	2	2	3	0
Phormium tenax	0	0	0	0	0	0	0	0
Restionaceae	0	0	0	3	0	0	0	0
Typha orientalis	0	0	0	0	0	0	0	0
Casuarina	0	2	0	0	1	1	0	0
Unknown	0	0	0	0	0	0	3	0
Trees	2	111	5	2	2	45	46	55
Small trees and shrubs	15	20	10	7	3	35	46	31
Herbs	14	4	7	4	3	7	24	28
Ferns and fern allies	164	56	124	158	32	25	91	120
Aquatics	2	5	1	5	3	5	7	10
Unknown	0	2	0	0	1	1	3	0
Total Pollen Count	197	198	147	176	44	118	217	244

Waipori 99-1 Pollen Counts

(cm)	5532	5558	5594	5620	5633	5669	5690	5710
Lycopodium (Added)	37	51	77	55	56	96	54	52
Dacrycarpus dacrydioides	0	0	2	1	0	0	0	0
Dacrydium cupressinum	0	0	0	0	0	0	0	0
Libocedrus bidwillii	0	0	0	0	0	0	0	0
Metrosideros	0	0	0	0	0	0	0	0
Brassospora	0	1	1	0	0	0	0	0
Fuscospora	0	1	0	3	1	0	1	1
Nothofagus menziesii	0	0	0	0	0	0	0	0
Podocarpus undiff.	7	15	4	10	8	2	13	13
Prumnopitys ferruginea	16	21	11	16	23	7	20	22
Prumnopitys taxifolia	13	23	26	8	9	25	14	18
Aristotelia	0	0	0	1	1	0	1	1
Ascarina lucida	0	0	0	0	0	0	0	0
Asteraceae (Tub.)	2	1	8	5	11	3	4	1
Coprosma	16	28	21	21	17	13	39	20
Coriaria	0	0	0	0	1	0	0	0
Discaria toumatou	0	0	0	0	0	0	0	0
Elaeocarpus	0	0	0	0	0	0	0	0
Epacridaceae - Dracophyllum type	0	1	1	3	3	0	2	1
Ericaceae	0	0	0	0	1	0	0	1
Fuchsia	0	0	0	0	0	0	0	0
Griselinia	0	0	3	0	0	6	0	0
Halocarpus	0	0	3	1	1	0	0	0
Hebe	0	0	0	1	0	0	0	0
Hoheria	1	2	3	4	2	4	2	2
Melicytus	0	0	0	0	0	0	0	0
Muehlenbeckia	0	0	0	0	0	0	1	0
Myrsine	0	0	1	1	0	2	2	1
Myrtaceae - Leptospermum type	0	0	0	1	0	0	0	0
Myrtaceae - Lophomyrtus/Neomyrtus type	0	0	1	0	0	0	0	0
Phyllocladus	0	0	0	1	0	0	0	0
Pittosporum	1	1	3	1	0	1	1	0
Plagianthus regius	10	9	7	20	11	15	14	13
Pseudopanax	0	0	0	1	2	0	1	1
Pseudowintera	5	1	0	3	0	0	0	0
Quintinia	0	0	0	0	0	0	0	0
Apiaceae	0	0	0	3	1	0	0	0
Asteraceae (Lig.)	0	1	0	0	0	0	0	0
Brassicaceae	0	0	0	0	0	0	0	0
Callitriche	0	0	0	0	1	2	0	0
Caryophyllaceae	0	0	0	1	0	0	0	0
Chenopodiaceae	0	0	0	0	0	0	0	0
Convolvulaceae	0	0	0	0	0	0	0	0
Dichondra	0	0	0	0	0	0	0	0
Epilobium	0	0	0	0	0	0	0	0
Gentiana	0	0	0	0	0	0	0	0
Geranium	1	0	0	0	0	0	2	0
Gunnera	0	0	1	0	0	0	0	0
Haloragaceae	1	0	0	2	0	0	0	0
Ileostylus	0	0	0	0	0	0	0	0
Iridiaceae	0	0	0	0	0	0	0	0
Liliaceae	0	0	0	0	0	0	0	0
Montia fontana	0	0	0	0	0	0	0	0
Myosotis	0	0	0	0	0	0	0	1
Plantago	0	0	0	0	0	0	0	0

Waipori 99-1 Pollen Counts

(cm)	5532	5558	5594	5620	5633	5669	5690	5710
Poaceae	26	16	12	23	14	13	11	4
Ranunculus	0	0	0	0	0	0	0	0
Stellaria	0	0	0	0	0	0	0	0
Wahlenbergia	0	0	0	0	0	0	0	0
Cyathea	13	18	16	14	16	14	20	14
Cyathea smithii	0	0	0	2	4	0	0	4
Cystopteris	7	2	2	9	1	0	1	5
Dicksonia	14	10	3	9	5	4	8	13
Gleichenia	6	6	5	8	3	3	3	0
Histiopteris	2	0	0	0	0	0	0	2
Hymenophyllum	0	0	0	0	0	0	0	0
Leptolepia	0	0	0	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0	0	0	0
Lycopodium fastigiatum	0	3	2	0	3	0	0	4
Lycopodium scariosum	0	1	0	1	1	0	0	0
Lycopodium undiff.	0	0	1	0	1	0	0	0
Lycopodium varium	0	0	0	1	0	0	0	0
Lycopodium volubile	1	0	0	0	0	1	0	3
Monolete fern spore undiff.	61	71	83	58	34	79	66	83
Phymatosorus	1	4	0	1	1	0	0	1
Pteridium	0	0	0	0	0	0	0	0
Trilete fern spore undiff.	6	6	14	6	6	8	3	2
Cyperaceae	8	7	8	11	9	17	19	30
Myriophyllum	2	0	0	0	0	0	0	0
Phormium tenax	2	0	1	0	1	3	4	7
Restionaceae	0	0	0	1	0	0	0	0
Typha orientalis	0	0	0	0	0	0	0	0
Casuarina	0	1	1	0	0	0	0	0
Unknown	0	0	0	0	0	0	2	0
Trees	36	61	44	38	41	34	48	54
Small trees and shrubs	35	43	51	64	50	44	67	41
Herbs	28	17	13	29	16	15	13	5
Ferns and fern allies	111	121	126	109	75	109	101	131
Aquatics	12	7	9	12	10	20	23	37
Unknown	0	1	1	0	0	0	2	0
Total Pollen Count	222	250	244	252	192	222	254	268

Waipori 99-1 Pollen Counts

(cm)	5733	5775	5800	5875	5970	6015	6045	6090
Lycopodium (Added)	47	169	149	98	197	129	67	26
Dacrycarpus dacrydioides	1	1	0	0	0	1	1	0
Dacrydium cupressinum	0	1	0	0	0	0	0	0
Libocedrus bidwillii	0	0	0	0	0	0	2	0
Metrosideros	0	0	0	0	0	0	0	0
Brassospora	1	0	0	0	1	4	0	1
Fuscospora	0	1	1	0	4	2	2	3
Nothofagus menziesii	0	0	0	0	0	2	0	0
Podocarpus undiff.	1	5	0	2	0	3	4	0
Prumnopitys ferruginea	2	5	0	0	0	0	2	3
Prumnopitys taxifolia	16	3	0	0	0	2	3	3
Aristotelia	0	0	0	0	0	0	0	0
Ascarina lucida	0	0	0	0	0	0	0	0
Asteraceae (Tub.)	2	3	0	1	4	10	10	3
Coprosma	5	2	0	0	5	12	20	16
Coriaria	0	1	0	0	0	0	0	0
Discaria toumatou	0	0	0	0	0	0	1	0
Elaeocarpus	0	0	0	0	2	0	0	5
Epacridaceae - Dracophyllum type	0	0	0	1	1	2	0	1
Ericaceae	0	0	0	0	0	3	1	0
Fuchsia	0	0	0	0	0	0	0	0
Griselinia	3	0	0	0	2	0	0	3
Halocarpus	2	1	0	0	2	1	0	2
Hebe	0	0	0	0	0	0	1	0
Hoheria	4	3	2	6	6	2	3	4
Melicytus	0	0	0	0	0	0	0	0
Muehlenbeckia	0	0	0	0	0	0	2	0
Myrsine	0	1	2	1	3	2	2	2
Myrtaceae - Leptospermum type	0	0	0	0	0	0	0	0
Myrtaceae - Lophomyrtus/Neomyrtus type	0	0	0	0	0	1	0	0
Phyllocladus	0	1	0	0	1	0	0	0
Pittosporum	1	0	0	1	0	0	0	0
Plagianthus regius	12	20	5	0	4	10	15	7
Pseudopanax	0	0	0	0	0	0	1	0
Pseudowintera	0	0	0	0	0	0	0	0
Quintinia	0	0	0	0	0	0	0	0
Apiaceae	0	1	0	0	2	5	0	2
Asteraceae (Lig.)	0	0	0	0	0	4	1	0
Brassicaceae	0	1	0	0	0	0	0	0
Callitriche	0	0	0	1	1	0	0	0
Caryophyllaceae	0	0	0	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0	0	1	0
Convolvulaceae	0	0	0	0	0	0	0	0
Dichondra	0	0	0	0	0	0	0	0
Epilobium	0	0	0	0	0	0	0	0
Gentiana	0	0	0	0	0	0	0	0
Geranium	0	0	0	0	0	0	0	0
Gunnera	0	0	0	0	1	1	2	1
Haloragaceae	0	0	0	1	1	0	0	0
Ileostylus	0	0	0	0	0	0	0	0
Iridiaceae	0	0	0	0	0	0	0	0
Liliaceae	0	0	0	0	0	0	0	0
Montia fontana	0	0	0	0	0	2	0	0
Myosotis	0	0	0	0	0	0	0	0
Plantago	0	0	0	0	0	0	0	0

Waipori 99-1 Pollen Counts

(cm)	5733	5775	5800	5875	5970	6015	6045	6090
Poaceae	9	7	5	5	30	21	38	32
Ranunculus	0	0	0	0	0	0	0	0
Stellaria	0	0	0	0	0	0	1	0
Wahlenbergia	0	0	0	2	0	0	0	0
Cyathea	10	31	11	11	14	8	6	6
Cyathea smithii	0	2	0	0	0	2	2	0
Cystopteris	0	0	0	0	0	7	0	0
Dicksonia	0	11	10	5	3	4	12	1
Gleichenia	0	0	0	0	2	0	0	1
Histiopteris	0	0	0	0	0	0	4	0
Hymenophyllum	0	2	0	0	1	2	3	1
Leptolepia	0	0	0	0	0	0	0	0
Lycopodium deuterodensum	1	0	0	0	0	0	0	3
Lycopodium fastigiatum	3	5	0	0	0	3	7	0
Lycopodium scariosum	0	0	0	0	0	1	0	2
Lycopodium undiff.	0	0	0	0	0	0	0	0
Lycopodium varium	0	1	0	0	0	0	0	0
Lycopodium volubile	0	0	2	0	2	4	0	1
Monolete fern spore undiff.	149	238	193	179	120	82	77	90
Phymatosorus	0	1	1	0	0	1	3	0
Pteridium	0	0	0	0	0	0	0	0
Trilete fern spore undiff.	4	10	1	0	14	2	0	10
Cyperaceae	12	4	6	0	26	39	54	133
Myriophyllum	0	0	0	0	0	1	1	0
Phormium tenax	0	0	0	0	1	0	0	0
Restionaceae	0	0	0	0	0	0	0	0
Typha orientalis	0	0	0	0	0	0	0	0
Casuarina	0	2	0	0	2	1	0	1
Unknown	0	1	0	0	0	0	0	0
Trees	21	16	1	2	5	14	14	10
Small trees and shrubs	29	32	9	10	30	43	56	43
Herbs	9	9	5	9	35	33	43	35
Ferns and fern allies	167	301	218	195	156	116	114	115
Aquatics	12	4	6	0	27	40	55	133
Unknown	0	3	0	0	2	1	0	1
Total Pollen Count	238	365	239	216	255	247	282	337

Waipori 99-1 Pollen Counts

(cm)	6140	6365	6370	6374	6377	6380	6384	6389
Lycopodium (Added)	69	8	25	7	12	15	18	12
Dacrycarpus dacrydioides	0	0	7	9	5	17	4	10
Dacrydium cupressinum	0	0	0	0	0	0	0	0
Libocedrus bidwillii	0	0	0	0	0	0	0	0
Metrosideros	0	0	1	1	0	1	0	1
Brassospora	1	0	0	0	0	0	0	0
Fuscospora	2	6	24	16	23	27	20	25
Nothofagus menziesii	0	0	0	0	0	0	0	0
Podocarpus undiff.	0	0	17	26	11	12	16	20
Prumnopitys ferruginea	0	5	25	33	9	18	18	22
Prumnopitys taxifolia	3	3	28	27	14	16	18	20
Aristotelia	0	1	0	0	0	0	0	0
Ascarina lucida	0	0	0	1	2	1	3	0
Asteraceae (Tub.)	1	0	5	1	1	0	1	0
Coprosma	2	1	8	5	2	0	5	4
Coriaria	0	0	0	0	0	0	0	0
Discaria toumatou	0	0	0	0	0	0	0	0
Elaeocarpus	0	0	0	0	0	0	0	0
Epacridaceae - Dracophyllum type	0	0	0	0	0	0	0	0
Ericaceae	0	0	0	0	0	0	0	0
Fuchsia	0	0	0	0	0	0	0	0
Griselinia	0	0	0	0	2	1	2	0
Halocarpus	1	6	19	19	8	14	0	3
Hebe	0	0	0	0	0	0	0	0
Hoheria	8	0	1	1	1	0	0	0
Melicytus	0	0	0	0	0	0	0	0
Muehlenbeckia	0	0	0	0	0	0	0	0
Myrsine	1	0	0	0	0	2	0	0
Myrtaceae - Leptospermum type	0	0	0	0	0	0	0	0
Myrtaceae - Lophomyrtus/Neomyrtus type	0	4	0	0	0	1	1	0
Phyllocladus	0	1	1	0	0	0	0	0
Pittosporum	1	0	1	0	2	3	2	1
Plagianthus regius	10	0	0	1	0	1	0	0
Pseudopanax	0	0	1	0	0	0	1	0
Pseudowintera	0	0	0	0	0	0	0	0
Quintinia	0	0	1	2	3	0	1	1
Apiaceae	0	1	0	0	0	0	0	0
Asteraceae (Lig.)	2	0	0	0	0	0	0	0
Brassicaceae	0	0	0	0	0	0	0	0
Callitriche	0	2	0	0	0	1	0	0
Caryophyllaceae	0	0	0	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0	0	0	0
Convolvulaceae	0	0	0	0	0	0	0	0
Dichondra	0	0	0	0	0	0	0	0
Epilobium	0	0	0	0	0	0	0	0
Gentiana	0	0	0	0	0	0	0	0
Geranium	0	0	1	0	0	0	0	0
Gunnera	0	0	0	0	0	0	0	0
Haloragaceae	0	0	0	0	1	1	11	0
Ileostylus	0	0	1	1	0	0	0	0
Iridiaceae	0	0	0	0	0	0	0	0
Liliaceae	0	0	0	0	0	0	0	0
Montia fontana	0	0	0	0	0	0	0	0
Myosotis	0	0	0	0	0	0	0	0
Plantago	0	0	0	0	0	0	0	0

Waipori 99-1 Pollen Counts

(cm)	6140	6365	6370	6374	6377	6380	6384	6389
Poaceae	29	7	4	1	2	1	2	0
Ranunculus	0	0	0	0	0	0	0	0
Stellaria	0	0	0	0	0	0	0	0
Wahlenbergia	0	1	0	0	0	0	0	0
Cyathea	11	1	41	23	22	16	24	27
Cyathea smithii	0	0	0	0	0	0	0	0
Cystopteris	0	0	0	0	0	0	0	0
Dicksonia	9	4	32	24	10	6	7	12
Gleichenia	2	0	2	0	0	0	1	0
Histiopteris	0	0	1	2	0	0	0	0
Hymenophyllum	0	0	0	0	0	0	0	0
Leptolepia	0	0	0	0	0	0	0	0
Lycopodium deuterodensum	3	0	0	0	0	0	0	0
Lycopodium fastigiatum	6	0	1	0	0	0	0	0
Lycopodium scariosum	2	0	0	1	1	0	0	0
Lycopodium undiff.	1	0	0	0	0	0	0	0
Lycopodium varium	0	0	0	0	0	0	0	0
Lycopodium volubile	5	0	0	0	1	0	0	0
Monolete fern spore undiff.	99	126	77	178	120	110	79	110
Phymatosorus	0	0	0	2	0	4	0	0
Pteridium	0	0	0	0	0	0	0	0
Trilete fern spore undiff.	11	2	5	2	4	5	2	11
Cyperaceae	21	9	7	12	6	9	17	27
Myriophyllum	0	0	0	0	0	0	0	0
Phormium tenax	0	0	1	0	1	0	0	0
Restionaceae	0	0	3	0	0	0	0	0
Typha orientalis	0	0	0	0	0	0	0	0
Casuarina	2	0	0	0	0	0	0	0
Unknown	0	0	1	1	0	0	0	0
Trees	6	14	102	112	62	91	76	98
Small trees and shrubs	24	13	37	30	21	23	16	9
Herbs	31	11	6	2	3	3	13	0
Ferns and fern allies	149	133	159	232	158	141	113	160
Aquatics	21	9	11	12	7	9	17	27
Unknown	2	0	1	1	0	0	0	0
Total Pollen Count	233	180	316	389	251	267	235	294

Waipori 99-1 Pollen Counts

(cm)	6393	6397	6402	6413	6423	6435	6485	6560
Lycopodium (Added)	20	10	14	10	31	73	76	77
Dacrycarpus dacrydioides	20	20	20	42	11	6	0	0
Dacrydium cupressinum	0	0	0	0	0	0	0	0
Libocedrus bidwillii	0	0	0	0	0	0	0	0
Metrosideros	0	0	0	4	1	0	0	0
Brassospora	0	0	0	0	0	0	0	0
Fuscospora	15	30	15	25	3	2	0	0
Nothofagus menziesii	0	1	0	0	0	1	0	0
Podocarpus undiff.	11	10	14	14	9	8	0	1
Prumnopitys ferruginea	13	8	26	16	0	16	0	0
Prumnopitys taxifolia	20	38	68	37	28	20	0	0
Aristotelia	0	0	0	0	28	0	0	0
Ascarina lucida	2	2	0	1	0	0	0	0
Asteraceae (Tub.)	4	0	0	0	0	0	0	0
Coprosma	0	5	0	15	10	1	0	0
Coriaria	0	0	0	0	0	0	0	0
Discaria toumatou	0	0	0	0	0	0	0	0
Elaeocarpus	0	0	0	0	1	0	0	0
Epacridaceae - Dracophyllum type	0	0	0	0	0	0	0	0
Ericaceae	0	0	0	0	0	0	0	0
Fuchsia	0	0	0	0	0	0	0	0
Griselinia	0	1	0	3	0	0	0	0
Halocarpus	22	14	14	2	1	1	0	0
Hebe	0	0	0	0	0	0	0	0
Hoheria	0	0	0	2	1	5	0	0
Melicytus	0	0	0	0	0	0	0	0
Muehlenbeckia	0	0	0	0	0	0	0	0
Myrsine	1	0	0	1	0	0	0	0
Myrtaceae - Leptospermum type	0	0	0	0	0	0	0	0
Myrtaceae - Lophomyrtus/Neomyrtus type	0	0	0	3	0	0	0	0
Phyllocladus	0	1	3	0	0	0	0	0
Pittosporum	1	1	0	0	0	0	0	0
Plagianthus regius	0	3	1	0	1	3	0	0
Pseudopanax	0	0	0	0	1	0	0	0
Pseudowintera	0	0	0	0	4	5	0	0
Quintinia	0	0	0	0	0	0	0	0
Apiaceae	0	0	0	0	0	0	0	0
Asteraceae (Lig.)	0	0	1	0	0	0	0	0
Brassicaceae	0	0	0	0	0	0	0	0
Callitriche	0	0	0	0	0	0	0	0
Caryophyllaceae	0	0	0	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0	0	0	0
Convolvulaceae	0	0	0	0	0	0	0	0
Dichondra	0	0	0	0	0	0	0	0
Epilobium	0	0	0	0	0	0	0	0
Gentiana	0	0	0	0	0	0	0	0
Geranium	0	0	0	0	0	0	0	0
Gunnera	1	0	0	1	0	0	0	0
Haloragaceae	0	2	1	0	0	0	0	0
Ileostylus	0	0	0	0	0	0	0	0
Iridiaceae	0	1	0	0	0	0	0	0
Liliaceae	0	0	0	0	0	0	0	0
Montia fontana	0	0	0	0	0	0	0	0
Myosotis	0	0	0	0	0	0	0	0
Plantago	0	0	0	0	0	0	0	0

Waipori 99-1 Pollen Counts

(cm)	6393	6397	6402	6413	6423	6435	6485	6560
Poaceae	2	4	3	2	2	2	1	0
Ranunculus	1	0	0	0	0	0	0	0
Stellaria	0	0	0	0	0	0	0	0
Wahlenbergia	0	0	0	0	0	0	0	0
Cyathea	38	43	12	22	65	37	0	0
Cyathea smithii	0	0	0	0	0	1	0	0
Cystopteris	0	0	0	0	1	0	0	0
Dicksonia	15	18	4	3	32	25	0	0
Gleichenia	0	0	0	0	0	0	0	0
Histiopteris	1	1	0	1	0	2	0	0
Hymenophyllum	0	0	0	0	0	0	0	0
Leptolepia	0	0	0	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0	0	0	0
Lycopodium fastigiatum	1	0	0	0	1	1	0	0
Lycopodium scariosum	0	0	0	0	0	0	0	0
Lycopodium undiff.	0	1	0	0	0	0	0	0
Lycopodium varium	0	0	0	0	0	0	0	0
Lycopodium volubile	0	0	0	0	0	0	0	0
Monolete fern spore undiff.	67	33	28	17	8	68	0	1
Phymatosorus	0	1	1	0	13	13	0	0
Pteridium	0	0	0	0	0	0	0	0
Trilete fern spore undiff.	4	6	32	5	0	4	1	0
Cyperaceae	16	48	8	21	2	0	0	28
Myriophyllum	0	0	0	0	0	0	0	0
Phormium tenax	0	0	0	0	0	0	0	0
Restionaceae	0	0	0	0	0	0	0	0
Typha orientalis	0	0	0	0	0	0	0	0
Casuarina	0	0	0	0	0	0	0	0
Unknown	0	3	0	0	0	1	0	0
Trees	79	107	143	138	52	53	0	1
Small trees and shrubs	30	27	18	27	47	15	0	0
Herbs	4	7	5	3	2	2	1	0
Ferns and fern allies	126	103	77	48	120	151	1	1
Aquatics	16	48	8	21	2	0	0	28
Unknown	0	3	0	0	0	1	0	0
Total Pollen Count	255	295	251	237	223	222	2	30

Waipori 99-1 Pollen Counts

(cm)	7222	7232	7242	9370	10330	10340	10350	10370
Lycopodium (Added)	115	47	159	137	32	29	35	365
Dacrycarpus dacrydioides	0	0	0	1	0	0	0	0
Dacrydium cupressinum	0	0	0	0	0	0	0	0
Libocedrus bidwillii	0	0	0	0	3	0	6	0
Metrosideros	0	0	0	0	0	1	0	0
Brassospora	1	0	0	0	0	0	0	0
Fuscospora	0	0	0	1	0	2	0	0
Nothofagus menziesii	0	0	0	0	0	0	0	0
Podocarpus undiff.	3	1	0	1	6	3	2	1
Prumnopitys ferruginea	0	0	0	0	0	0	0	0
Prumnopitys taxifolia	2	0	0	0	2	0	2	0
Aristotelia	0	0	0	0	0	0	0	0
Ascarina lucida	0	0	0	0	0	0	0	0
Asteraceae (Tub.)	8	7	5	0	8	12	9	0
Coprosma	0	1	3	0	23	0	13	0
Coriaria	0	0	0	0	0	1	0	0
Discaria toumatou	0	0	0	0	0	0	0	0
Elaeocarpus	0	0	0	0	1	5	0	0
Epacridaceae - Dracophyllum type	3	0	0	0	1	0	2	0
Ericaceae	0	0	0	0	2	0	0	0
Fuchsia	0	0	0	0	0	0	1	0
Griselinia	0	0	1	0	0	0	0	0
Halocarpus	0	0	0	0	1	2	2	0
Hebe	3	0	1	0	0	0	0	0
Hoheria	0	0	0	0	8	5	11	2
Melicytus	0	0	0	0	0	0	0	0
Muehlenbeckia	0	0	0	0	0	0	1	0
Myrsine	0	0	0	0	2	0	4	0
Myrtaceae - Leptospermum type	0	0	0	0	0	0	0	0
Myrtaceae - Lophomyrtus/Neomyrtus type	0	0	0	0	0	0	0	0
Phyllocladus	0	0	0	0	28	57	42	0
Pittosporum	0	0	0	0	0	3	0	0
Plagianthus regius	0	0	0	0	14	10	7	2
Pseudopanax	4	4	0	0	1	0	2	0
Pseudowintera	0	0	0	0	0	0	0	0
Quintinia	0	0	0	0	0	0	0	0
Apiaceae	2	4	1	0	0	0	1	0
Asteraceae (Lig.)	58	19	37	0	0	1	1	0
Brassicaceae	0	0	0	0	1	0	0	0
Callitriche	0	0	0	0	0	0	0	0
Caryophyllaceae	0	0	5	0	0	2	0	0
Chenopodiaceae	4	5	0	0	0	1	0	0
Convolvulaceae	0	0	1	0	0	0	0	0
Dichondra	0	0	0	0	0	0	0	0
Epilobium	0	0	0	0	0	0	0	0
Gentiana	0	0	0	0	0	0	0	0
Geranium	7	0	0	0	2	0	0	0
Gunnera	0	0	0	0	2	2	1	0
Haloragaceae	0	0	0	0	2	3	3	0
Ileostylus	0	0	0	0	0	0	0	0
Iridiaceae	0	0	0	0	0	0	0	0
Liliaceae	0	0	0	0	0	0	0	0
Montia fontana	0	0	0	0	0	0	0	0
Myosotis	0	0	0	0	0	0	0	0
Plantago	0	0	0	0	0	0	0	0

Waipori 99-1 Pollen Counts

(cm)	7222	7232	7242	9370	10330	10340	10350	10370
Poaceae	114	67	63	8	45	34	55	1
Ranunculus	0	0	0	0	0	5	0	0
Stellaria	3	0	0	0	1	0	0	0
Wahlenbergia	1	0	0	0	0	0	0	0
Cyathea	0	0	0	0	0	0	1	0
Cyathea smithii	0	0	1	0	1	0	0	0
Cystopteris	0	0	0	0	0	0	0	0
Dicksonia	0	0	0	0	4	1	4	0
Gleichenia	0	0	0	0	1	0	0	0
Histiopteris	0	0	0	0	2	0	0	0
Hymenophyllum	0	0	0	0	0	0	0	0
Leptolepia	0	0	0	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0	0	0	0
Lycopodium fastigiatum	2	0	3	0	5	0	3	0
Lycopodium scariosum	0	0	0	0	2	0	0	0
Lycopodium undiff.	0	0	0	0	0	1	2	0
Lycopodium varium	0	0	0	0	0	0	0	0
Lycopodium volubile	0	0	0	0	0	0	4	0
Monolete fern spore undiff.	2	2	3	0	29	37	35	2
Phymatosorus	0	0	0	0	0	0	0	0
Pteridium	0	0	0	0	0	0	0	0
Trilete fern spore undiff.	0	0	1	0	0	4	0	0
Cyperaceae	10	57	10	0	18	15	7	0
Myriophyllum	0	0	0	0	0	0	0	0
Phormium tenax	1	0	0	0	0	0	0	0
Restionaceae	0	0	0	0	0	0	0	0
Typha orientalis	0	0	0	0	0	0	0	0
Casuarina	0	0	0	0	1	0	0	0
Unknown	4	3	1	0	1	2	3	0
Trees	6	1	0	3	11	6	10	1
Small trees and shrubs	18	12	10	0	89	95	94	4
Herbs	189	95	107	8	53	48	61	1
Ferns and fern allies	4	2	8	0	44	43	49	2
Aquatics	11	57	10	0	18	15	7	0
Unknown	4	3	1	0	2	2	3	0
Total Pollen Count	232	170	136	11	217	209	224	8

Waipori 99-1 Pollen Counts

(cm)	10875	11250	11785	12663
Lycopodium (Added)	97	215	285	172
Dacrycarpus dacrydioides	0	1	0	0
Dacrydium cupressinum	0	0	0	0
Libocedrus bidwillii	0	0	0	0
Metrosideros	0	0	0	0
Brassospora	0	0	0	0
Fuscospora	0	0	0	0
Nothofagus menziesii	0	0	0	0
Podocarpus undiff.	0	0	0	1
Prumnopitys ferruginea	0	0	0	0
Prumnopitys taxifolia	0	0	0	0
Aristotelia	0	0	0	0
Ascarina lucida	0	0	0	0
Asteraceae (Tub.)	0	0	0	1
Coprosma	0	0	0	0
Coriaria	0	0	0	0
Discaria toumatou	0	0	0	0
Elaeocarpus	0	0	0	0
Epacridaceae - Dracophyllum type	0	0	0	0
Ericaceae	0	0	0	0
Fuchsia	0	0	0	0
Griselinia	0	0	0	0
Halocarpus	0	0	0	0
Hebe	0	0	0	0
Hoheria	0	0	0	0
Melicytus	0	0	0	0
Muehlenbeckia	0	0	0	0
Myrsine	0	0	0	0
Myrtaceae - Leptospermum type	0	0	0	0
Myrtaceae - Lophomyrtus/Neomyrtus type	0	0	0	0
Phyllocladus	0	0	0	0
Pittosporum	0	0	0	0
Plagianthus regius	0	0	0	0
Pseudopanax	0	0	0	0
Pseudowintera	0	0	0	0
Quintinia	0	0	0	0
Apiaceae	0	0	0	0
Asteraceae (Lig.)	0	0	0	0
Brassicaceae	0	0	0	0
Callitriche	0	0	0	0
Caryophyllaceae	0	0	0	0
Chenopodiaceae	0	0	0	0
Convolvulaceae	0	0	0	0
Dichondra	0	0	0	0
Epilobium	0	0	0	0
Gentiana	0	0	0	0
Geranium	0	0	0	0
Gunnera	0	0	0	0
Haloragaceae	0	0	0	0
Ileostylus	0	0	0	0
Iridiaceae	0	0	0	0
Liliaceae	0	0	0	0
Montia fontana	0	0	0	0
Myosotis	0	0	0	0
Plantago	0	0	0	0

Waipori 99-1 Pollen Counts

(cm)	10875	11250	11785	12663
Poaceae	0	3	2	0
Ranunculus	0	0	0	0
Stellaria	0	0	0	0
Wahlenbergia	0	0	0	0
Cyathea	0	0	0	0
Cyathea smithii	0	0	0	0
Cystopteris	0	0	0	0
Dicksonia	0	0	0	0
Gleichenia	0	0	0	0
Histiopteris	0	0	0	0
Hymenophyllum	0	0	0	0
Leptolepia	0	0	0	0
Lycopodium deuterodensum	0	0	0	0
Lycopodium fastigiatum	0	0	0	0
Lycopodium scariosum	0	0	0	0
Lycopodium undiff.	0	0	0	0
Lycopodium varium	0	0	0	0
Lycopodium volubile	0	0	0	0
Monolete fern spore undiff.	1	3	0	1
Phymatosorus	0	0	0	0
Pteridium	0	0	0	0
Trilete fern spore undiff.	0	0	0	1
Cyperaceae	0	0	0	0
Myriophyllum	0	0	0	0
Phormium tenax	0	0	0	0
Restionaceae	0	0	0	0
Typha orientalis	0	0	0	0
Casuarina	0	0	0	0
Unknown	0	0	0	0
Trees	0	1	0	1
Small trees and shrubs	0	0	0	1
Herbs	0	3	2	0
Ferns and fern allies	1	3	0	2
Aquatics	0	0	0	0
Unknown	0	0	0	0
Total Pollen Count	1	7	2	4

Waipori 99-1 Long Core
Lower Taieri Plain, Otago
Relative and Absolute Pollen Diagrams

Waipori 99-1 Long Core

Lower Taieri Plain, Otago

Relative and Absolute Pollen Diagrams

WAIPORI 99-1 RELATIVE AND ABSOLUTE POLLEN DIAGRAMS

List of Diagrams

* a) denotes relative diagrams and b) denotes absolute diagrams

Lithological Key

▩ - Clay

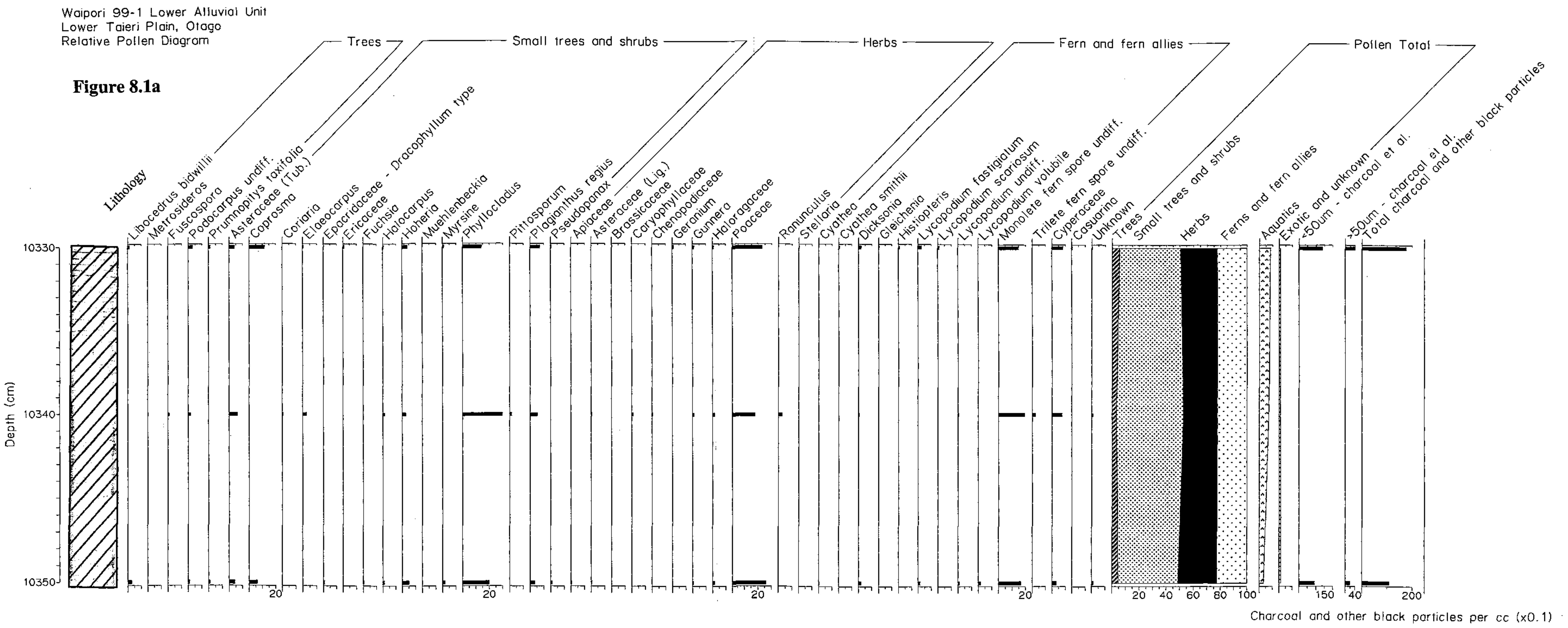
⁙ - Sand

▨ - Silt

▒ - Gravel

▦ - Lignite

Figure 8.1a


Waipori 99-1 Lower Alluvial Unit
Lower Taieri Plain, Otago
Relative Pollen Diagram
Trees
Small trees and shrubs
Herbs
Fern and fern allies
Pollen Total
Lithology
Libocedrus bidwillii
Metrosideros
Fuscospora
Podocarpus undiff.
Prumnopitys taxifolia
Asteraceae (Tub.)
Coprosma
Coriaria
Elaeocarpus
Epacridaceae - Dracophyllum type
Ericaceae
Fuchsia
Halocarpus
Hoheria
Muehlenbeckia
Myrsine
Phyllocladus
Pittosporum
Plagianthus regius
Pseudopanax
Apiaceae
Asteraceae (Lig.)
Brassicaceae
Caryophyllaceae
Chenopodiaceae
Geranium
Gunnera
Haloragaceae
Poaceae
Ranunculus
Stellaria
Cyathea
Cyathea smithii
Dicksonia
Gleichenia
Histiopteris
Lycopodium fastigiatum
Lycopodium scariosum
Lycopodium undiff.
Lycopodium volubile
Monolete fern spore undiff.
Trilete fern spore undiff.
Cyperaceae
Casuarina
Unknown
Trees
Small trees and shrubs
Herbs
Ferns and fern allies
Aquatics
Exotic and unknown
<50um - charcoal et al.
>50um - charcoal et al.
Total charcoal and other black particles
Depth (cm)
10330
10340
10350
20
20
20
20
20
40
60
80
100
150
40
200
Charcoal and other black particles per cc (x0.1)

Waipori 99-1 Lower Alluvial Unit
Lower Taieri Plain, Otago
Absolute Pollen Diagram

Figure 8.1b

Waipori 99-1 Lower Alluvial Unit
Lower Taieri Plain, Otago
Relative Pollen Diagram

Figure 8.2a

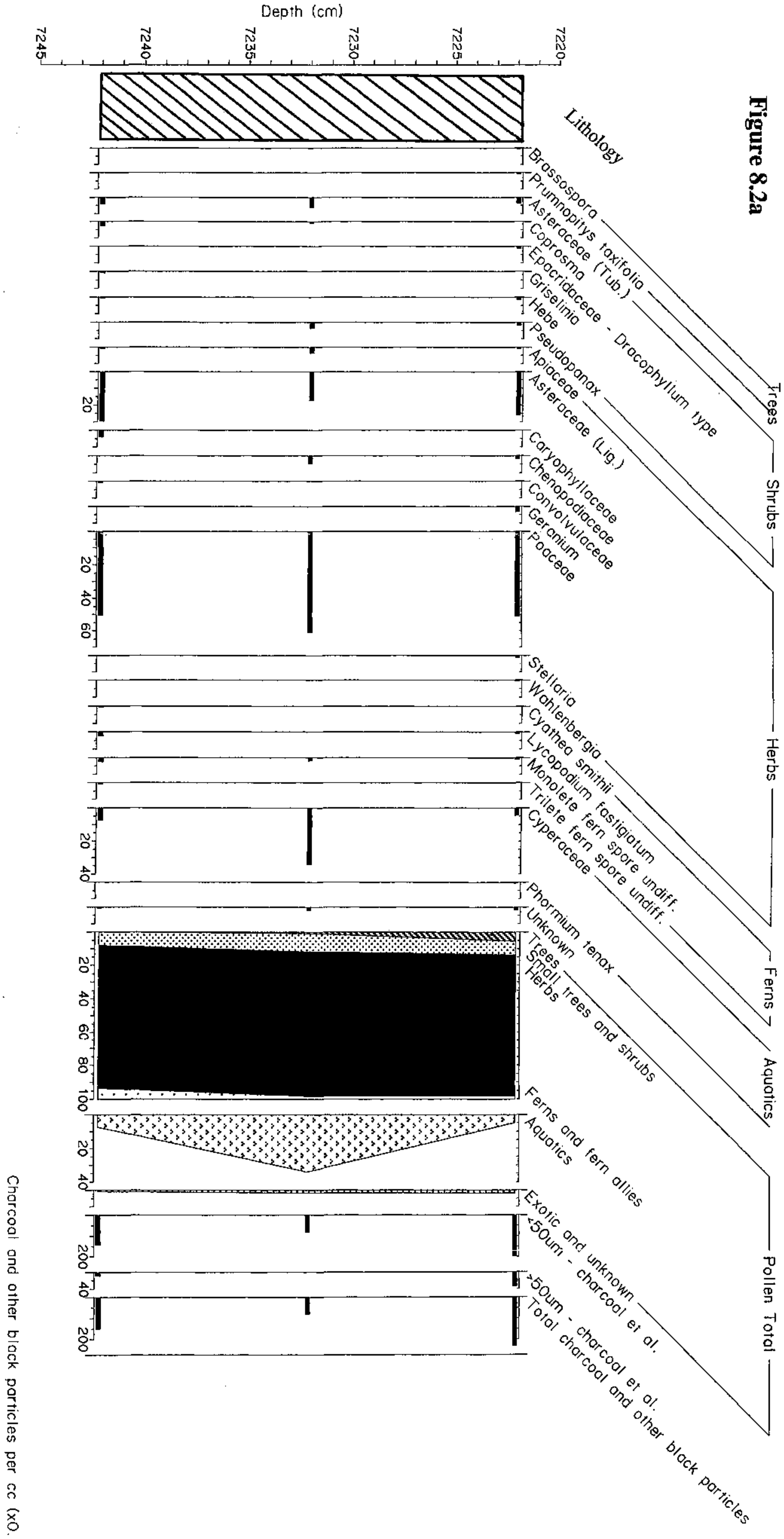
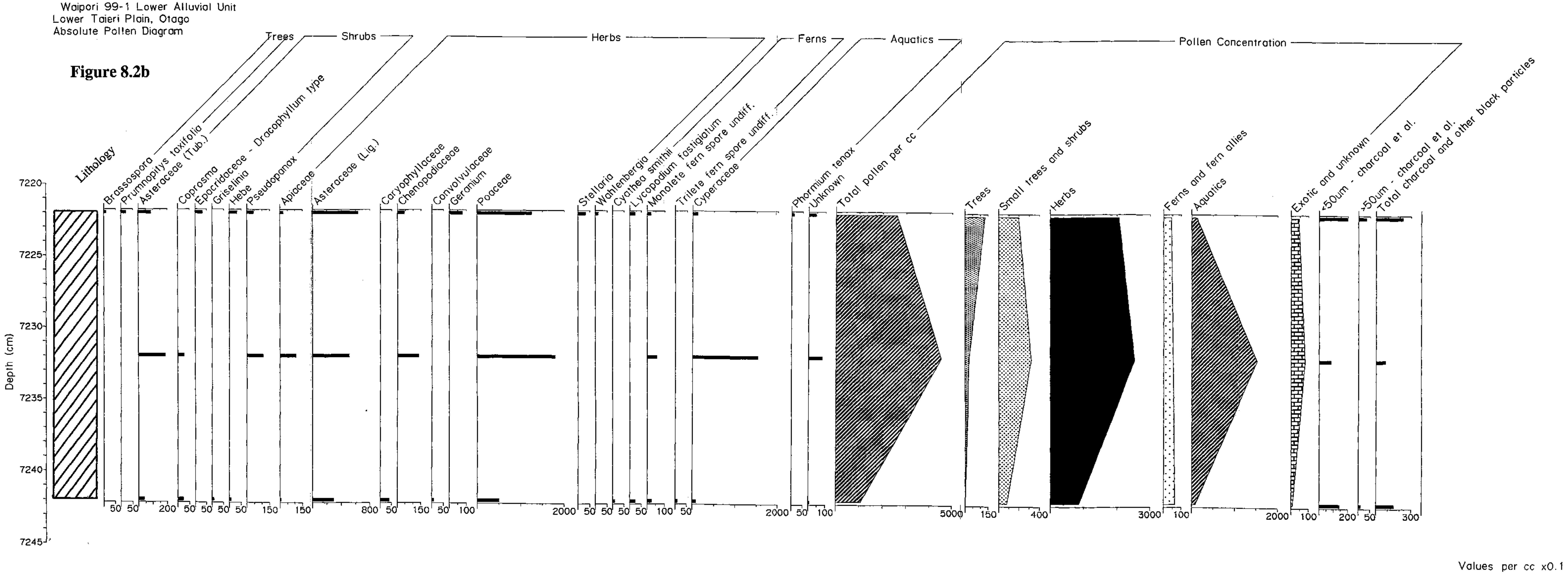
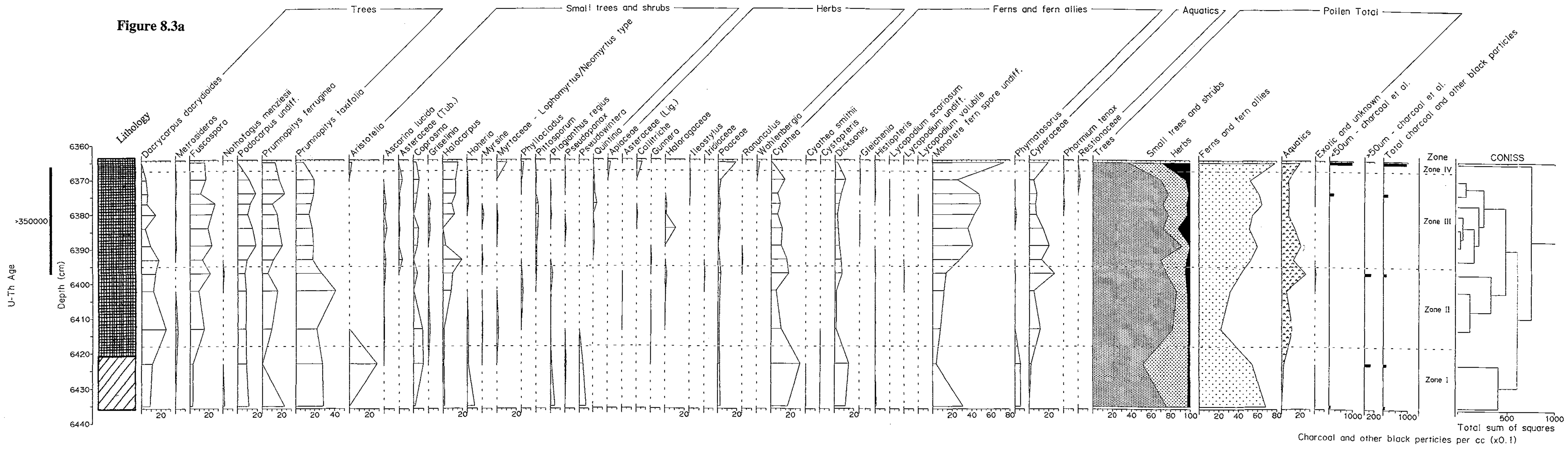


Figure 8.2b


Waipori 99-1 Lower Alluvial Unit
Lower Taieri Plain, Otago
Absolute Pollen Diagram
Trees
Shrubs
Herbs
Ferns
Aquatics
Pollen Concentration
Lithology
Brassospora
Prumnopitys taxifolia
Asteraceae (Tub.)
Coprosma
Epacridaceae - Dracophyllum type
Griselinia
Hebe
Pseudopanax
Apiaceae
Asteraceae (Lig.)
Caryophyllaceae
Chenopodiaceae
Convolvulaceae
Geranium
Poaceae
Stellaria
Wahlenbergia
Cyathea smithii
Lycopodium fastigiatum
Monolete fern spore undiff.
Trilete fern spore undiff.
Cyperaceae
Phormium tenax
Unknown
Total pollen per cc
Trees
Small trees and shrubs
Herbs
Ferns and fern allies
Aquatics
Exotic and unknown
<50um - charcoal et al.
>50um - charcoal et al.
Total charcoal and other black particles
Depth (cm)
7220
7225
7230
7235
7240
7245
50
50
200
50
50
50
50
150
150
800
50
150
50
100
2000
50
50
50
50
100
50
2000
50
100
5000
150
400
3000
100
2000
100
200
50
300
Values per cc x0.1

Waipori 99-1 Lignite Section
Lower Taieri Plain, Otago.
Relative Pollen Diagram

Figure 8.3a



Waipori 99-1 Lignite Section
Lower Waipori Plains, Otago
Absolute Pollen Diagram (values per cc x0.01)

Figure 8.3b

Waipori 99-1 Lacustrine Unit
Lower Taieri Plain, Otago
Realtive Pollen Diagram

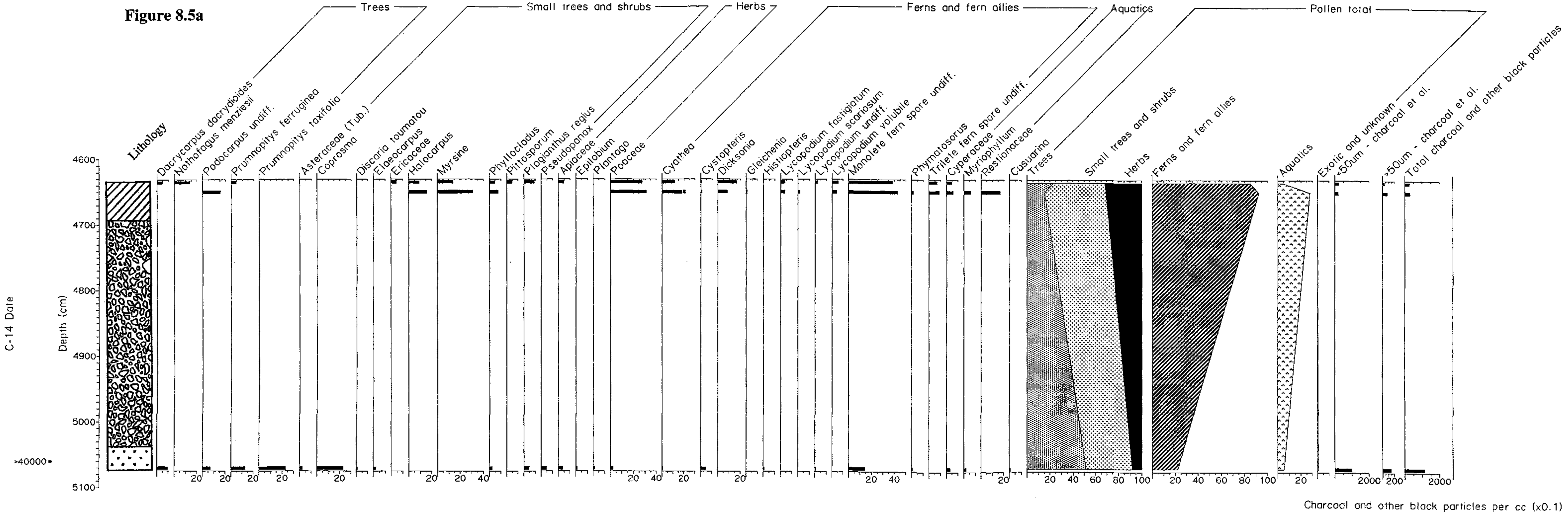
Figure 8.4a

Figure 8.4b


Waipori 99-1 Lacustrine Unit
Lower Taieri Plain, Otago
Absolute Pollen Diagram
(values per cc x 0.05)
Trees
Small trees and shrubs
Herbs
Ferns and fern allies
Aquatics
Pollen Concentration
Lithology
Dacrycarpus dacrydioides
Dacrydium cupressinum
Libocedrus bidwillii
Brassospora
Fuscospora
Nothofagus menziesii
Podocarpus undiff.
Prumnopitys ferruginea
Prumnopitys taxifolia
Aristotelia
Asteraceae (Tub.)
Coprosma
Coriaria
Discaria toumatou
Elaeocarpus
Epacridaceae - Dracophyllum type
Ericaceae
Griselinia
Halocarpus
Hebe
Hoheria
Muehlenbeckia
Myrsine
Myrtaceae - Leptospermum type
Myrtaceae - Lophomyrtus/Neomyrtus type
Phyllocladus
Pittosporum
Plagianthus regius
Pseudopanax
Pseudowintera
Apiaceae
Asteraceae (Lig.)
Brassicaceae
Callitriche
Caryophyllaceae
Chenopodiaceae
Geranium
Gunnera
Haloragaceae
Montia fontana
Myosotis
Poaceae
Stellaria
Wahlenbergia
Cyathea
Cyathea smithii
Cystopteris
Dicksonia
Gleichenia
Histiopteris
Hymenophyllum
Lycopodium deuterodensum
Lycopodium fastigiatum
Lycopodium scariosum
Lycopodium undiff.
Lycopodium varium
Lycopodium volubile
Monolete fern spore undiff.
Phymatosorus
Trilete fern spore undiff.
Cyperaceae
Myriophyllum
Phormium tenax
Restionaceae
Casuarina
Unknown
Total pollen per cc
Trees
Small trees and shrubs
Herbs
Ferns and fern allies
Aquatics
Exotic and unknown
<50um - charcoal et al.
>50um - charcoal et al.
Total charcoal and other black particles
Zone
CONISS
Depth (cm)
5500
5550
5600
5650
5700
5750
5800
5850
5900
5950
6000
6050
6100
6150
Zone III
Zone II
Zone I
2500 5000 7500 10000
Charcoal and other black particles per cc (x0.1)
500 1000 1500
Total sum of squares

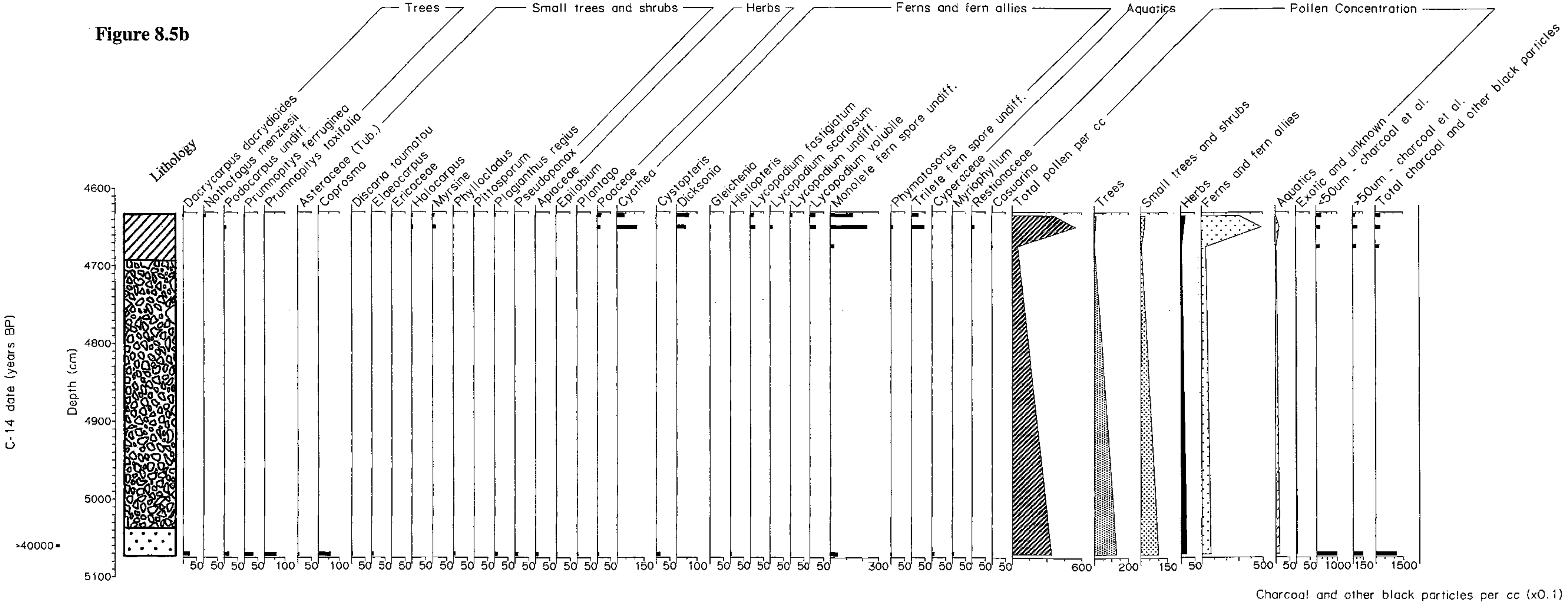
Waipori 99-1 Upper Alluvium -Spot Samples
Lower Taeri Plain, Otago
Relative Pollen Diagram

Figure 8.5a



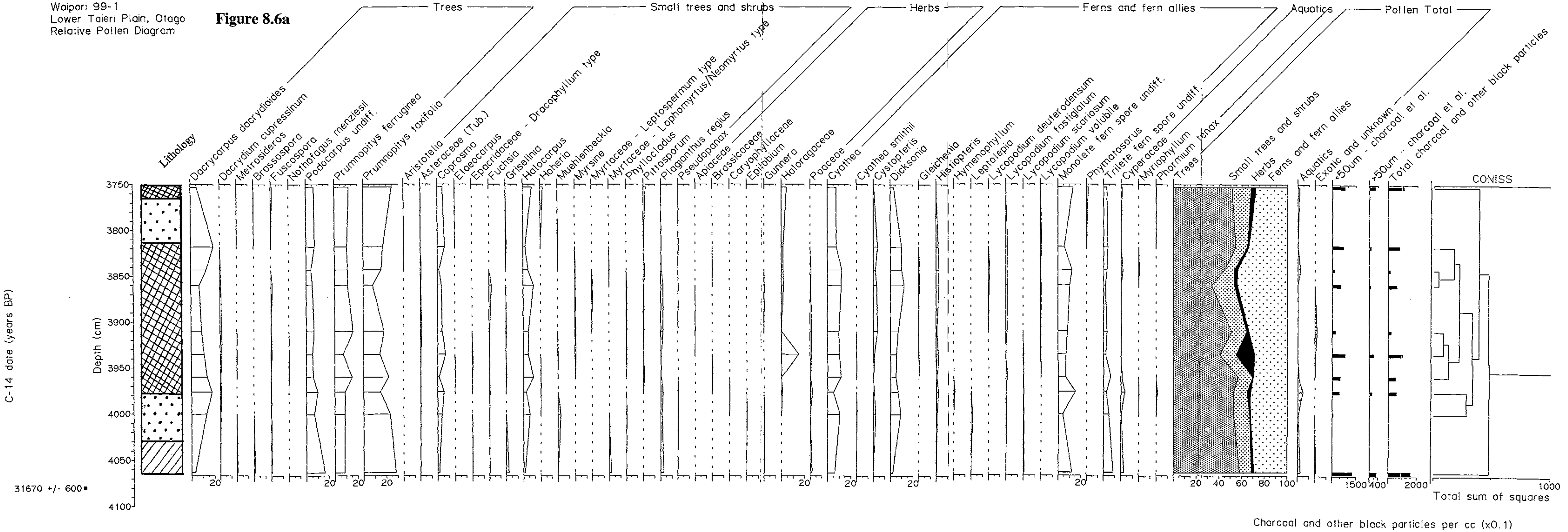
Waipori 99-1 Upper Alluvium Spot Samples
Lower Taieri Plain, Otago,
Absolute Pollen Diagram
(values per cc x0.05)

Figure 8.5b



Waipori 99-1
Lower Taieri Plain, Otago
Relative Pollen Diagram

Figure 8.6a



Waipori 99-1
Lower Taieri Plain, Otago
Absolute Pollen Diagram (values per cc x 0.05)

Figure 8.6b

Figure 8.7a

Waipori 99-1
Lower Taieri Plain, Otago
Holocene and Late Glacial
Relative Pollen Diagram
Trees
Small trees and shrubs
Herbs
Ferns and fern allies
Aquatics
Pollen total
Lithology
Dacrycarpus dacrydioides
Dacrydium cupressinum
Metrosideros
Brassospora
Fuscospora
Nothofagus menziesii
Podocarpus undiff.
Prumnopitys ferruginea
Prumnopitys taxifolia
Aristotelia
Asteraceae (Tub.)
Coprosma
Coriaria
Discaria toumatou
Elaeocarpus
Epacridaceae - Dracophyllum type
Ericaceae
Fuchsia
Griselinia
Halocarpus
Hebe
Hoheria
Melicytus
Muehlenbeckia
Myrsine
Myrtaceae - Leptospermum type
Myrtaceae - Lophomyrtus/Neomyrtus type
Phyllocladus
Pittosporum
Plagianthus regius
Pseudopanax
Pseudowintera
Quintinia
Apiaceae
Asteraceae (Lig.)
Brassicaceae
Callitriche
Caryophyllaceae
Chenopodiaceae
Dichondra
Epilobium
Gentiana
Geranium
Gunnera
Haloragaceae
Liliaceae
Myosotis
Plantago
Poaceae
Cyathea
Cystopteris
Dicksonia
Gleichenia
Histiopteris
Hymenophyllum
Lycopodium deuterodensum
Lycopodium fastigiatum
Lycopodium scariosum
Lycopodium undiff.
Lycopodium volubile
Monolete fern spore undiff.
Phymatosorus
Pteridium
Trilete fern spore undiff.
Cyperaceae
Myriophyllum
Phormium tenax
Restionaceae
Typha orientalis
Casuarina
Unknown
Trees
Small trees and shrubs
Herbs
Ferns and fern allies
Aquatics
Unknown and exotic
Dinoflagellate cysts
<50um - charcoal et al.
>50um - charcoal et al.
Total charcoal and other black particles
Zone
CONISS
Zone V
Zone IV
Zone III
Zone II
Zone I
C-14 date (years BP)
4389 +/- 60-
5980 +/- 70-
8538 +/- 70-
Depth (cm)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
20
20 40 60
20
20
20
20
20
20
20
20 20
20
20
20
20 40
20
20 40
20
20
20
20 40 60 80
20 40 60 80 100
20
2000
8000
600
8000
Dinoflagellate cysts, charcoal and other black particles per cc (x0.1)
1000 2000 3000
Total sum of squares

Figure 8.7b

Waipori 99-1
Lower Taieri Plain, Otago
Late Glacial and Holocene
Absolute Pollen Diagram (values per cc x0.1)