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**LATE HOLOCENE ENVIRONMENTAL
HISTORY OF
NORTHLAND, NEW ZEALAND**

A thesis presented in partial
fulfilment of the requirements for the degree of

Doctor of Philosophy

in Geography

at

Massey University, New Zealand

by

Bernd Striewski

1999

**LATE HOLOCENE ENVIRONMENTAL
HISTORY OF
NORTHLAND, NEW ZEALAND**

Errata

Please note typographical errors have occurred on the following pages:

- p. 96 line 3; for regions read region's
- p. 122 line 6; should read
individual anticyclones than the rest of the country. As a result the prevailing
wind
- p. 122 line 12; for amount read amounts
- p. 122 line 14; for trough read troughs
- p. 125 last line; for (rainfall ≥ 0.1 mm) read (rainfall ≥ 0.1 mm)
- p. 137 last line; for (*Typha latifolia* sp.) read (*Typha latifolia* sp.)
- p. 172 line 20; for (Westland *quintinia*) read (Westland quintinia)
- p. 198 line 24; for Polynesian read Polynesians
- p. 199 line 14; should read
Polynesian colonisation history was marked by rapid decline of the forest
cover.
- p. 222 line 14; for Asterace read Asteracea
- p. 236 line 23; for archeology read archaeology
- p. 249 line 20; for investigation read investigations
- p. 327 line 26; for Cores 1-3 read Cores 2-4
- p. 328 line 1; for core 1 read core 2; line 6 for Core 2 read Core 3; line 9 for Core 3
read Core 4; line 11 for core 2 read core 3
- p. 344 lines 4, 8, 12; for meter read metre

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ABSTRACT

This thesis describes the environmental changes inferred from sedimentological investigations of sediment sequences at three lowland swamp and lake sites of Late Holocene age in Northland, northern North Island. The sites investigated are Wharau Road Swamp (coastal Bay of Islands), Lake Tauanui (inland Bay of Islands) and Lake Taumatawhana (central Aupouri Peninsula).

The purpose of this sediment-based study was to reconstruct aspects of the environmental histories at these localities which would reflect the different environmental changes, natural and anthropogenic, that the sites proper and their drainage basins underwent through the passage of time. Particular emphasis was placed on human-induced environmental changes in order to address the on-going debate over the date of arrival of people in New Zealand. To this end the sediment sequences collected from the drainage basins of the above sites were analysed for a number of sedimentary parameters, including texture, sediment chemistry, mineralogy and organic matter content. In order to distinguish between natural and anthropogenic disturbances the results of these analyses were compared against the results of pollen and charcoal counts performed on the same sediment sequences.

Wherever significant breaks in the sedimentological and palynological record of the sediment sequences were encountered, (bulk) samples were submitted for radiocarbon dating to establish a chronology of environmental changes. At Wharau Road Swamp the radiocarbon chronology was enhanced by the occurrence of one macro-tephra layer within the sediment sequence.

The establishment of a radiocarbon chronology finally allowed one to determine the onset of sedimentologically-palynologically-demonstrated anthropogenic catchment disturbance at the respective localities. At Wharau Road earliest human presence was dated to *ca.* 600 (uncalibrated) years B.P. (about A.D. 1350) and at Lake Taumatawhana at *ca.* 900 (uncalibrated) years B.P. (about A.D. 1050). At Lake Tauanui

sedimentological and palynological evidence for the beginning of human activities provide different dates. While sedimentological data only supported a date of *ca.* 350 (uncalibrated) years B.P. (about A.D. 1600) for the onset of human-induced catchment disturbances, the pollen and charcoal record suggested that anthropogenic deforestation began at *ca.* 1100 years B.P. (about A.D. 850).

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BACKPOCKET:

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Chapter 1

INTRODUCTION

The date for first settlement of New Zealand is not yet fully defined. Although much is known of the archaeology of early settlement of the central and southern regions of New Zealand (e.g. Anderson, 1982; Anderson & McGovern-Wilson, 1990; Caughley, 1988), the colonisation of the north is still a matter of great uncertainty. This is particularly true for Northland, New Zealand's northernmost region. This part of the country has been greatly neglected by archaeological research, despite its obvious potential for research and probable importance in the overall study of the prehistory of New Zealand (e.g. Davidson, 1982; Sutton, 1994). However, over the past two decades this shortcoming has been acknowledged by many workers and the issue became the subject of a lively debate in the archaeological and palaeoenvironmental literature. Adopting different research disciplines and following different lines of investigations the discussion resulted in the establishment of three conflicting hypotheses about the time-depth of human settlement of New Zealand. In essence the dates for first colonisation of New Zealand proposed in these hypotheses span the period from *ca.* 2000 years B.P.¹ (Holdaway, 1996; Sutton, 1987a; *cf.* Sutton, 1987b) to about 800 years B.P. (Anderson, 1991; Higham & Hogg, 1997; McFadgen, 1994; McFadgen *et al.*, 1994; McGlone *et al.*, 1994; *cf.* Newnham *et al.*, 1998; Spriggs & Anderson, 1993). A time span of this order does not allow us to determine with any accuracy the exact point in time at which the first people arrived in the country. The only statement which can be made with any confidence is the fact that human arrival must have occurred some time during this period of about 1200 years bracketed by the above dates. In this situation the commencement of human settlement of New Zealand remains inadequately defined.

¹"years B.P." refers to "radiocarbon years before present (A.D. 1950)", unless noted otherwise. The stated age is based on the (old) Libby half-life of 5568 ± 30 years (e.g. Libby, 1952).

1.1 Aim of research and objective

This thesis aims to address the on-going debate over the date of arrival of people in the country by attempting to more precisely define the exact date and location of initial colonisation of Northland which is believed by some to be the place of first settlement of New Zealand (e.g. *cf.* Bulmer, 1988, 1989; *cf.* Davidson, 1982; Groube, 1968; *cf.* Taylor, 1958). The tools of research employed in this thesis are sedimentological investigations on core material from selected peat and lake sites in Northland which are likely to have been foci of early settlement. The primary objective of this sediment-based study is to reconstruct aspects of the environmental histories of the sites which will reflect the different environmental changes, natural and anthropogenic, the sites proper and their drainage basins underwent through the passage of time. Of these two kinds of environmental changes recorded in the sediments of the sites particular emphasis is placed on human-induced environmental changes. The research conducted is based on the fact that the surroundings of a site subjected to human occupancy undergo palynologically-demonstrated forest destruction associated with geomorphic phenomena such as soil instability resulting in enhanced slope erosion leading to the deposition of colluvium and alluvium in the lower reaches of the affected drainage basins.

In order to detect such human-induced environmental changes in the sedimentary record of a site the collected core material has to fulfil two minimum requirements: firstly, it has to provide a continuous sediment sequence; and secondly, it needs to be old enough to pre-date human occupancy of the site. In view of the timeframe for the possible date of arrival of people in New Zealand as stipulated in the above colonisation hypotheses it is imperative that the sediment records have a minimum time-depth of 2000 years.

Based on these prerequisites three sites, one swamp (Wharau Road Swamp) and two lakes (Lakes Tauanui and Taumatawhana), were investigated for their sedimentary record. The core material collected from these sites provided continuous sediment sequences extending back to the mid-Holocene.

The research conducted on the sediment cores from these sites is part of a three-year (1992-94) "Foundation for Research, Science and Technology" (FRST)-funded programme², entitled: *Identification of the Location and Date of first Maori colonisation of Northland and Auckland using Palynologically and Sedimentologically evidenced environmental change. Part 1: Palaeoecological Investigations.*

It is hoped the results of this research will provide a proxy measure for the date of initial colonisation of Northland and hence provide a means to decide between the above hypotheses of the date of colonisation of New Zealand.

The remainder of this chapter presents an overview of the botanical taxonomic nomenclature used throughout this thesis and the manner in which the thesis after this introductory chapter is organised. The chapters thereafter, Chapters 2-6, describe aspects of the prehistoric exploration and colonisation of the South Pacific region by people (Chapter 2) as well as the physical environment and biota of Northland in particular and the rest of New Zealand in general during the Quaternary period (Chapters 3-6). Introducing the human colonisation history of the South Pacific as well as the physical and biotic environment of New Zealand first was regarded as being necessary in order to "set the scene" for the chapters thereafter. This is because Chapters 2-6 provide three different kinds of information: firstly, an overview of the environmental conditions in Northland and the rest of New Zealand during the pre-human period of the Quaternary; secondly, a description of the human migration patterns in the South Pacific and a discussion of the possible time of arrival of Polynesians in New Zealand; and thirdly, an account of the mode and magnitude of environmental changes during the human era.

Hence, Chapters 2-6 are believed to provide the kind of "background information" necessary to warrant the methodological approach as applied in Chapters 8-10 (Wharau Road Swamp and Lakes Tauanui and Taumatawhana) to address the subject of date and

²The research programme is a joint venture between the School of Global Studies, Geography Programme (formerly Department of Geography), Massey University, Private Bag 11-222, Palmerston North, New Zealand; and the Centre for Archaeological Research, University of Auckland, Private Bag 92019, Auckland, New Zealand. Principal Investigators of the research programme are Professor J R Flenley, Massey University; and Professor D G Sutton, University of Auckland. The programme was funded by FRST-grants FLE 101, FLE 102 and MAU 305.

location of initial colonisation of Northland. The author of the thesis therefore believes that the rationale of this research, more detailed than the one outlined above, and a more comprehensive list of its objectives are better presented after Chapters 2-6, at the beginning of Chapter 7: Research strategy and methodology.

1.2 Taxonomy

The botanical taxonomic nomenclature used throughout this thesis follows the *Flora of New Zealand* (Allan, 1961; Moore & Edgar, 1970; Healy & Edgar, 1980; Webb *et al.*, 1988) and *Standard Common Names for Weeds in New Zealand* (Healy, 1984). Subsequent taxonomic revision and nomenclatural changes (e.g. by Connor & Edgar, 1987; Edgar & Connor, 1978, 1983 and Brownsey *et al.*, 1985) have generally been adopted. Furthermore, *Scientific Names* are given in association with their respective *Common Names* (in Maori and English) only at their first mention. Thereafter only the Scientific Name is being used.

The nomenclature used for the New Zealand fauna, native and introduced, terrestrial, marine and freshwater, follows *The New Zealand Descriptive Animal Dictionary* (Foord, 1990, 1992). The naming of animals at the generic and specific level largely complies with the above procedure adopted for the New Zealand flora.

1.3 Structure of thesis

After this introductory chapter the thesis is structured in the following manner:

Chapter 2 introduces the human colonisation history of the Pacific region. It includes a description of the palaeogeographic setting of the Pacific Basin during the Pleistocene along with the movements of early people from mainland South-East Asia into Island South-East Asia and from there into the island world of Near and Remote Oceania. Particular attention is given to the mode and timing of the colonisation of the islands of

Western and Eastern Polynesia with special emphasis on New Zealand as the last major landmass on earth to be colonised. The chapter concludes with a detailed discussion of the different aspects of the colonisation history of New Zealand.

Chapter 3 deals with the physical environment of New Zealand. It describes the modern geographical setting and physiography of the New Zealand archipelago as a whole and gives a brief outline of the geological and tectonic evolution of the country through the passage of time. The country's main soil groups as well as various aspects of its present-day climate and freshwater resources associated with this geographical and tectono-geological framework are discussed thereafter.

Chapter 4 is principally a continuation of Chapter 3 with special reference to the study area. It introduces Northland and provides details about the modern physical environment of the region. The chapter emphasises certain features of the region's geological and tectonic history, climate, soils and hydrology which distinguish Northland from the remainder of New Zealand.

Chapter 5 is concerned with the biotic environment of all of New Zealand and its Quaternary record. The first half of this chapter discusses the origins, history and composition of the country's indigenous biota and provides a generalised "inventory" of the floral and faunal record. The discussion then continues with a description of the country's present-day main types of indigenous and introduced vegetation. Due to its value as an indicator for environmental disturbances particular emphasis is placed on the indigenous forest cover. The account on this subject includes a description of the structure and different types of indigenous forest, their composition, distribution and change in size during the Late Quaternary. The second half of Chapter 5 focuses on the New Zealand Quaternary and the biotic and environmental changes associated with this period. This part of Chapter 5 includes an outline of the marine and terrestrial record of the New Zealand Quaternary and a chronology of the country's Quaternary glaciations. The palaeoenvironmental conditions and associated vegetation dynamics throughout the "Last Glacial Maximum", the "Late Glacial" and the Holocene, broadly covering the

past 25 ka³, are discussed thereafter. The chapter concludes with an account on the human era and its impact on the environment.

Chapter 6 is closely associated with Chapter 5 as it continues the description of certain aspects of the biotic and physical environment with special reference to Northland. Nevertheless, while Chapter 5 is concerned with a wider range of the various aspects of the New Zealand Quaternary Chapter 6 covers only the climatic variations and vegetational successions in Northland during the past 25 ka.

Chapter 7 describes the research strategy and methodology adopted in this thesis to achieve the above principle aim of more precisely defining the date and location of initial human colonisation of Northland. The chapter outlines in more detail the rationale of the work, the conceptual aspects it is based on and a list of objectives this thesis aims to achieve. It also includes a review of a number of other sedimentology-palynology based studies aiming to detect human activity in the Pacific region. This section is followed by an introduction and description of the methods and materials used in Chapters 8-10 to achieve the above aim.

Chapters 8-10 form the core of this thesis as they present the work done on the sediments collected from Wharau Road Swamp and Lakes Tauanui and Taumatawhana. Each chapter includes an account of the environmental setting of the respective site. It is followed by the description of the stratigraphy of the sediment cores and a radiocarbon chronology of the sedimentation history for the drainage basins of the individual sites. The larger part of these chapters is dedicated to the description, interpretation and discussion of the results obtained from the analyses for the sediment constituents, texture, mineralogy and chemistry of the collected core material. For each site these results are compared with those of pollen and charcoal analyses performed on either the same core material or from adjacent cores from the same sites.

A summary of the conclusions from the sedimentological studies on the core material from the above sites is presented in Chapter 11. The chapter also includes

³"ka" refers to "thousands of years before present".

recommendations for future work following the conceptual (and methodological) approach adopted in this thesis.

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Chapter 2

POLYNESIAN MIGRATION

The exploration of the Pacific region by human groups is an event of the Quaternary period. It begins in the Mid to Late Pleistocene with the movement of the predecessors of modern humans into the westernmost margins of the palaeo-Pacific and finishes in the Late Holocene with the discovery and settlement of the islands of Hawaii, Easter Island and New Zealand which form the cornerstones of the Polynesian triangle. This chapter describes the mode, timing and motives of human migration into this vast area. Owing to the complexity of the subject this chapter has been divided into two major parts: section 2.1 provides a general account of the migration of people throughout Island South-East Asia, Melanesia and Polynesia; section 2.2 deals with the different aspects of human colonisation of the New Zealand archipelago.

2.1 History of colonisation in the Pacific region

Human colonisation of the islands of the Pacific Basin⁴ (see fig. 2.1) spans the period of the Middle to Late Pleistocene and all but the very last part of the Holocene. Including Japan and the Americas, this vast region was the last on earth to be colonised by humans, apart from the Antarctic continent and just a very few isolated islands in other

⁴The **Pacific Basin** is the largest single feature on earth. It is bordered by five continents and occupies a total area of about 180 million km², compared with 24 million km² for the whole of North America and a little less than eight million km² for the Australian continent. From Bering Strait in the north to the Antarctic continent is almost 16,000 km, and from Mindanao Island, Philippines to Panama is more than 17,000 km. The largest structural unit within the Pacific Basin is the Pacific Plate. In the west its margins are formed by the Kermadec-Tonga Trench, Solomon-New Hebrides Trench, Philippine Trench, Mariana Trench, Japan Trench and Kuril Trench; in the north by the Aleutian Trench; and in the east by the North American west coast and the East Pacific Rise which finds its northernmost extent at the height of Mexico. The trenches constitute subduction zones whereas the East Pacific Rise is an area of active sea-floor spreading. Another geological feature of the Pacific Basin is the Andesite Line which coincides closely with the subduction zones. It represents the farthest eastward limit of the continental masses, i.e. the boundary of the continental blocks of Asia and Australia with the Pacific Basin. All of the large islands of the Pacific lie west of the Andesite Line and are continental in type. The smaller islands within the area enclosed by the Andesite Line are oceanic type islands which originated from intraplate volcanism (Badger, 1988; Skinner & Porter, 1987; Strahler & Strahler, 1984; Thomas, 1963).

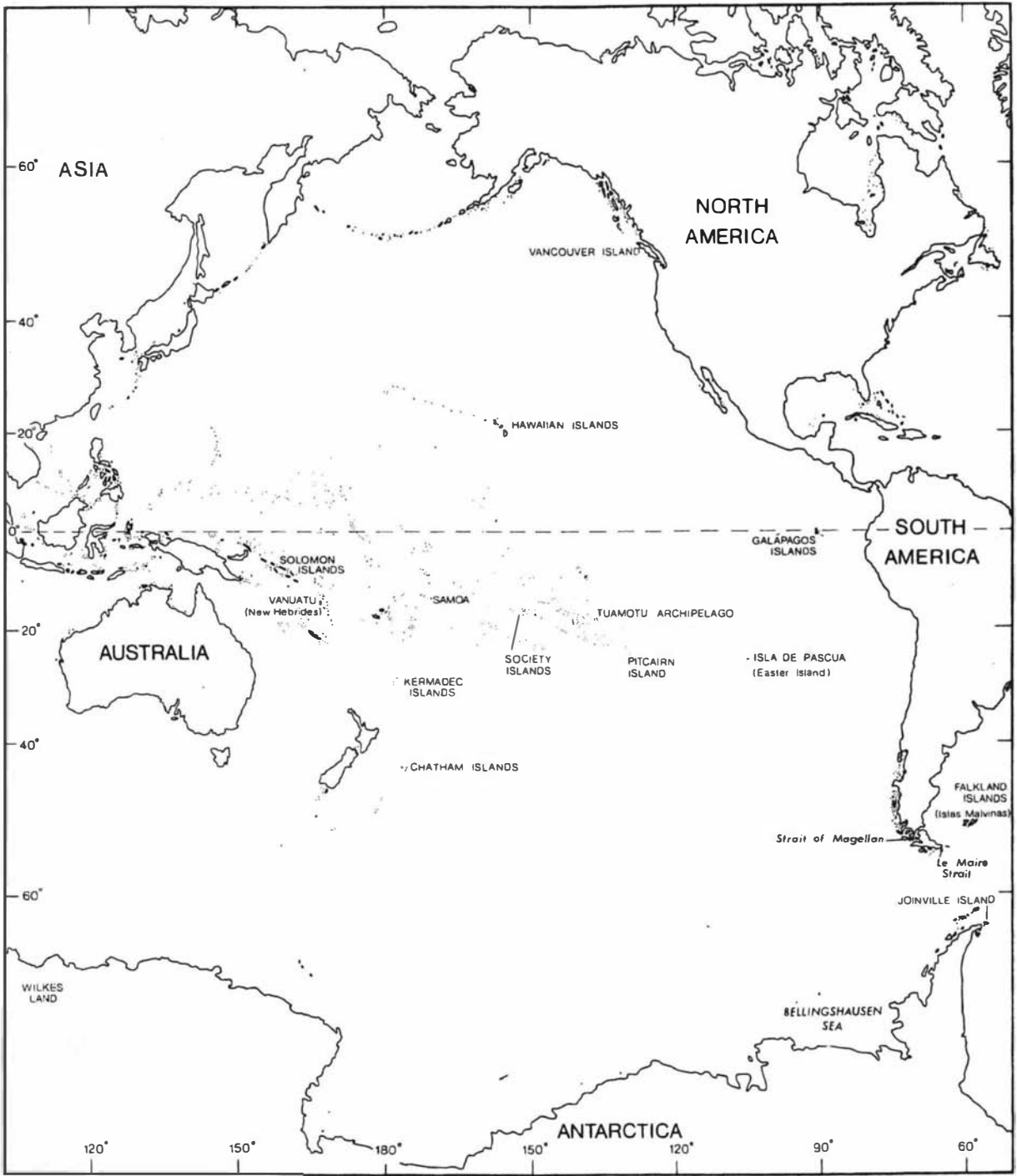


Figure 2.1: The Pacific Basin (Badger, 1988)

oceans which were discovered much later by Europeans.

Unlike the colonisation of Japan and the Americas human expansion into the Pacific Basin was intimately tied to the advances in the technology and management of water transport (Green, 1994). Furthermore, the settlement of this region also involved an adaptation to a variety of different physical and climatic environments. These range from the islands of the continental regions in the western Pacific which are geologically diverse and rich in resources for settlement to the islands on the Pacific Plate east of the Andesite Line (see footnote #4) where basaltic mountains either penetrate the ocean surface to form often large, high volcanic islands or show their presence underwater in the form of usually tiny, low coral islands atop of them with a very restricted range of resources. The climates these environments offer range from tropical in the low latitudes, through sub-tropical and temperate to near sub-Antarctic in the high latitudes (e.g. Irwin, 1992; Thomas, 1963).

2.1.1 The Pacific Basin of the Pleistocene

Due to the indirect effects of the global Pleistocene glaciations the palaeo-geography of the Pacific Basin, in particular of the south-west Pacific, was substantially different from today (see fig. 2.2). During the times of lower sea-level stands those islands of the Pacific Basin closest to the South-East Asian mainland were often physically connected to it. This subcontinental extension of mainland South-East Asia into the Pacific is conventionally referred to as "Sundaland". It comprises Sumatra, Java, Kalimantan (Borneo) and at times Palawan (Philippines) which then became a peninsula, including a number of smaller islands in this region, as well as a large part of the territory now inundated by the South China Sea (Green, 1994).

Furthermore, the continental islands of New Guinea and Tasmania and much of the Arafura Sea floor were joined together with mainland Australia to form the Pleistocene continent of "Sahul". Synonyms for this largest coherent landmass in the south-west Pacific are "Sahuland" or "Greater Australia".

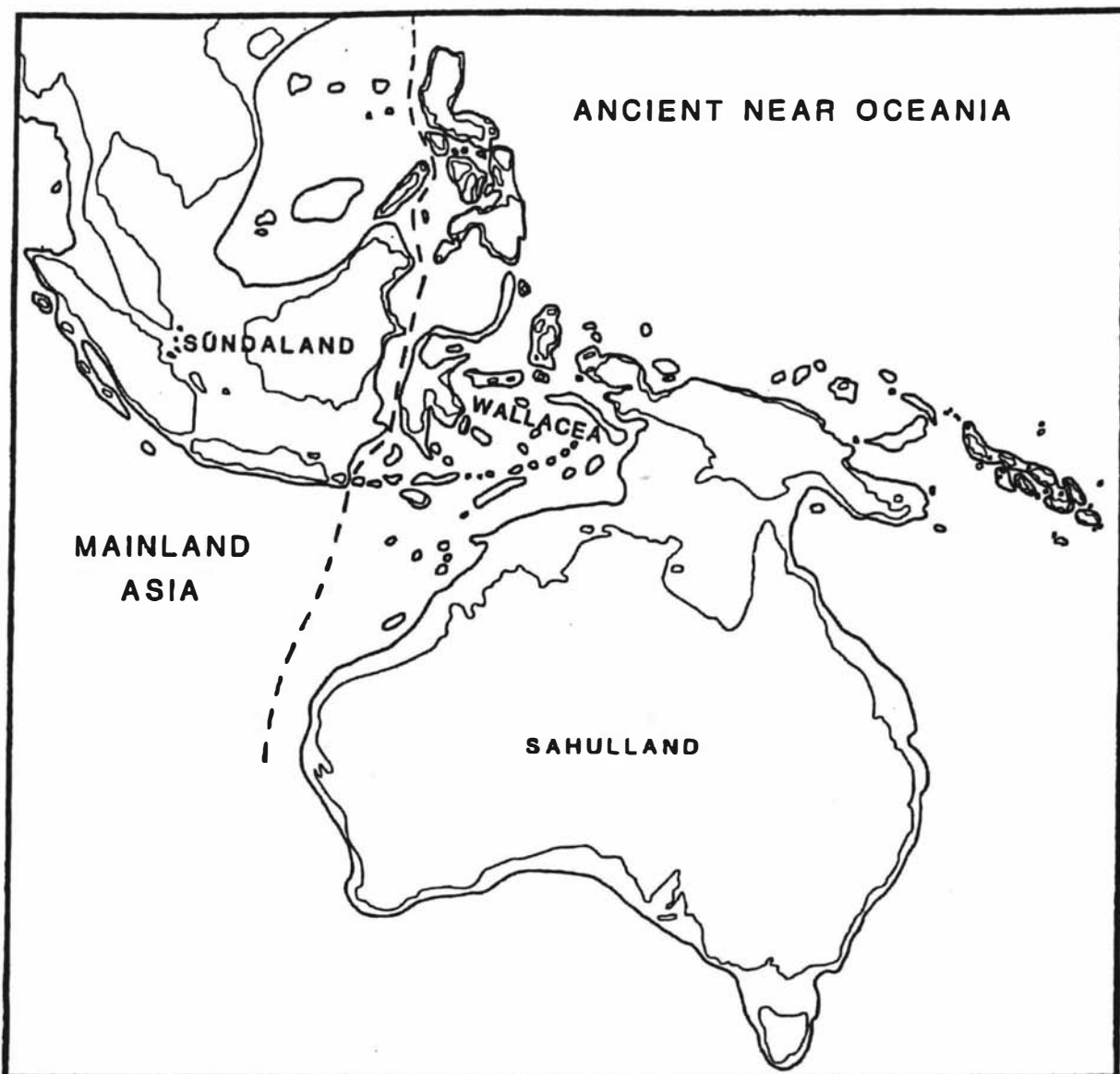


Figure 2.2: Ancient Near Oceania, Sundaland and Sahul with the coastline at a sea-level of -130 m at 53,000 years B.P.; the dashed line signifies the course of Wallace's Line (after Thiel (1987); with modifications by Green (1994).

A third element in this palaeo-geographic setting was "Ancient Near Oceania", an island world comprising the islands of Wallacea, a stretch of open ocean between Sundaland and Sahul, the several expanded islands of the Philippines, the slightly larger islands of the Bismarck Archipelago, as well as the enlarged islands of the Solomon Islands chain which had probably joined to form larger groups of islands such as, Greater Bukida, Greater Gatumbangara, Greater Vellonga and Greater Rendipari (Green, 1994).

The remainder of the Pacific Ocean east and north-east of Ancient Near Oceania and east of Sahul was conventionally referred to as "Remote Oceania", a vast area of hundreds of far-flung relatively small oceanic islands east of the Andesite Line and a few larger continental islands including the New Zealand Archipelago west of it.

However, despite the shifting shorelines, at no time during the Pleistocene and apparently never before was Sundaland ever linked by land to Sahul. Sahul was therefore isolated by water for at least 60 million years, since the dawn of the age of mammals. Consequently the region's mammals are quite primitive in evolutionary terms; marsupials and monotremes which are quite distinct from the more advanced placental mammals of the "Old World" (Africa, Asia and Europe). As humans, including other primates, are placental mammals, the origins of its human inhabitants must be sought outside this region, despite the belief held by many Aboriginal Australians they have always inhabited the continent (Bowdler, 1997).

2.1.2 The earliest human inhabitants

The history of the human settlement of the Pacific Basin begins with the occupation of the easternmost fringes of the south-west Pacific. Owing to the above palaeo-geographic setting Human groups, pre-*sapiens* forms of ancestors classed as *Homo erectus*, travelling on land, were able to occupy the landmass of Sundaland, which is now an island and ocean world (Green, 1994; Irwin, 1992). *Homo erectus* appears to have been the first hominid to spread across the globe with known remains of this species from China ("Peking-Man") and Java ("Java-Man") (Bowdler, 1997). Based on evidence from

Java *Homo erectus* migrated into this region between 0.5 and perhaps 0.9 Ma⁵ ago (Hutterer, 1985). However, the association of these fossils with the presumed chopper-chopping tool industries, or with pebble and flake tool ones, has never been convincingly demonstrated (Green, 1994).

Despite this early occupation of Sundaland by human groups the movement of human populations beyond Sundaland which constituted the first step in the settlement of the Pacific Ocean, was not done until these inhabitants had the ability and technology to cross water barriers. Green (1994) argues that such a movement of populations further into the Pacific did neither depend on their degree of biological development nor the state of their stone-tool technology, but rather on the cultural ability of human breeding populations to cross long stretches of open sea.

The very first geographic boundary these people had to cross on their way out of Sundaland into the island world of Ancient Near Oceania was Wallace's Line⁶, a water barrier separating the two. This crossing was not achieved until new technology in the form of some kind of ocean-going water craft⁷ became available. The exact time of their invention and initial form is not known but a favoured era is the Late Pleistocene, when evidence for sustained exploitation of marine resources first occurs in the archaeological record and people occupy island landmasses accessible only by ocean crossings even during times of lower sea levels (Green, 1994).

2.1.3 The colonisation of Ancient Near Oceania

The, in geological terms, relatively late movement of people into Near Ancient Oceania

⁵"Ma" refers to "millions of years before present".

⁶"Wallace's" or more accurately "Huxley's Line" was a biogeographical barrier to placental mammals of the Sino-Malaysian fauna. It separated one of the richest vertebrate faunas in the world from some of the poorest (Golson, 1971). West of it were predominantly Indo-Malaysian oriental floras and east of it, in varying proportions, impoverished eastern versions of these, mixed with Australo-Papuan elements from the Pacific. With the exception of two larger landmasses, Australia and in the Polynesian region New Zealand, there is a steady decline in the richness of the Indo-Malaysian oriental biota east of Wallace's Line.

⁷The two main types of water-craft being used were bark boats and wood or bamboo rafts. A comprehensive review on these craft is given by Green (1994) and Irwin (1992).

indicates that these first colonisers were fully modern humans, *Homo sapiens sapiens* (Bowdler, 1997; Green, 1994; Irwin, 1992). *Homo erectus* populations of Java were not part of this colonising population as they were probably already extinct by that time (Bowdler, 1997). Furthermore, there is no evidence yet of them having embarked on water crossings beyond Wallace's Line (Irwin, 1992).

Such a colonising population of modern humans poses various questions about their origin and distribution. Altogether two competing hypotheses are invoked to shed light on this issue; the "Population dispersal and replacement" hypothesis and the "population continuity" hypothesis. Bowdler's (1997) and Green's (1994) reviews on the subject provide detailed accounts on these two hypotheses. However, both hypotheses can be summarised as follows: The "Population dispersal and replacement" hypothesis proposes that *Homo erectus* evolved in different parts of the world into regionally distinctive populations of *Homo sapiens* making it simply a matter of time until the appearance of modern humans in this region of the world. The "Population dispersal and replacement hypothesis" suggests that modern humans evolved only once, in Africa, and then spread across the globe, replacing *Homo erectus* populations within the last 100,000 years. In either case, the colonisation of the south-west Pacific must be part of the wider story of Asian prehistory.

Investigations of archaeological sites throughout mainland South-East Asia, Island South-East Asia, Australia and Melanesia revealed evidence of human occupation ranging from 31,000 to 37,000 years B.P. for mainland South-East Asia⁸; 30,000 to 40,000 years B.P. for Island South-East Asia⁹; 30,000 to 40,000 years B.P. for Australia¹⁰ and 28,000 to 40,000 years B.P. for Melanesia¹¹. These dates imply the

⁸Peninsular Thailand (Lang Rong Rien cave): 37,000 years B.P.; peninsular Malaysia (Kota Tampan stone workshop, Perak): 31,000 years B.P. (Bowdler, 1997).

⁹Sarawak [northern Borneo] (Niah Cave): 40,000 years B.P.; Sulawesi (Leang Burung 2 rock shelter): 31,000 years B.P.; Palawan [Philippines] (Tabon cave): 30,000 years B.P. (Bowdler, 1997).

¹⁰Kimberleys (Carpenters Gap 1): 39,000 years B.P.; Cape York Peninsula (Nurrabulgin Cave): 37,000 years B.P.; Perth (Upper Swan): 38,000 years B.P.; Murray-Darling basin (Lake Mungo and associated sites): 37,000 years B.P.; Tasmania (Warreen Cave site): 35,000 years; North-West Cape (Mandu Mandu Creek rock-shelter): 33,000 years B.P. (Bowdler, 1997).

¹¹New Guinea (Huon Peninsula: 40,000 years B.P. and Lachitu rock-shelter: 35,000 years B.P.), New Ireland (Matenkupkum cave site): 33,000 years B.P. and Solomon Islands (Buka): 28,000 year BP (Bowdler, 1997; Irwin, 1992).

continuous presence of fully modern humans throughout Ancient Near Oceania and Sundaland for at least 40,000 years, a period which covers almost the entire Late Pleistocene. The oldest sites in Sahul date to between 30,000 and 40,000 years B.P. and form the basis for the current estimates which suggest that initial landfall leading to the colonisation of Australia was not much earlier than 40,000 years B.P. (Allen, 1989). However, a recent set of thermoluminescent dates from the Malakunanja Cave in Arnhem Land (Northern Territory) suggests that colonisation might have already occurred 50,000 years B.P. (Roberts *et al.*, 1990).

Striking similarity between the archaeological sites from the above regions is an almost complete absence of human skeletal remains bearing evidence of what these initial *sapiens* colonists may have looked like. With the exception of the Australian zone where remains have been recovered, there are no known examples from Melanesia and only very few from South-East Asia, apart from the early pre-*sapiens* Javanese *Homo erectus* examples (Bowdler, 1997; Green, 1992).

Another conspicuous feature is the remarkable similarity of the dates of human occupation throughout the south-west Pacific and Australia. The dates in South-East Asia are no older than in Australasia, they are rather of contemporary age. They suggest that South-East Asia was colonised by modern humans at the same time as Australia, and that colonisation in archaeological terms was rapid once the first ocean crossings were made. Possible evidence for this is a similarity in the stone tool industry over the whole region (Irwin, 1992).

Bowdler (1997) takes up this point to establish the motives for a migration of people into Ancient Near Oceania and Sahul. She argues that the pattern of these dates in geographical space does not suggest colonisation of previously uninhabited regions under duress, due to population pressures and environmental disasters, for example, forcing people to seek new resources. Colonisation due to expansion under duress would leave a clear "gradient of antiquity", with the oldest dates in mainland South-East Asia (including Java and Kalimantan), younger dates would be expected in Sulawesi and other non-continental islands of Island South-East Asia, and even younger dates in

northern Australia for early colonisation, either of contemporary age, or even younger than those in New Guinea, and finally much younger dates in southern Australia and oceanic Melanesia. As the chronology suggests an extremely speedy colonisation rather than a gradual settling and "filling up" of new islands and ecological zones, other motivation must have driven people to voyages of discovery.

The homeland of these people is not known but on the basis of associated artefacts Bowdler (1997) suggests China as the origin of the early colonisers of this region. This is because Chinese Pleistocene artefact assemblages did not change much through time, and the very earliest (up to a million years old) as well as more recent assemblages (up to about 20,000 years B.P.) bear a remarkable resemblance to those of Australasia.

Based on her presented evidence Bowdler (1997) suggests the following colonisation scenario for Ancient Near Oceania and Sahul: modern humans appear to have swept out of southern China at about 40,000 years B.P. (perhaps even 50,000 years ago), embarked on a series of voyages across South-East Asia into uninhabited regions in Australia and Melanesia, as far as the south-eastern end of the Solomon Island chain, but not beyond. There is no indication as to why it occurred at this time and no earlier, but it might be ascribed to the uniquely developed capabilities of *Homo sapiens sapiens*. Culturally these early inhabitants were diverse hunter-gatherers in various habitats (Irwin, 1992; Spriggs, 1997), but there is also evidence for emerging agriculture (a system of drains in swamp margins) at Kuk in the New Guinea Highlands from about 9000 years B.P. (Spriggs, 1997) before the separation of New Guinea from Australia due to rising sea-levels.

Various workers continue the discussion on the human colonisation of Ancient Near Oceania by considering the various navigational aspects of such a migration into uninhabited regions. Birdsell (1977) for example examines possible routes to Sahul on the basis of distance and angle of island target and identifies two sizeable chains of large islands that provided two major potential routes for migration. "Route 1" lies in the north and trends towards the island of New Guinea and "Route 2" is in the south and directed closer to the north-west coast of Australia. Both routes were further broken

down into five likely sub-routes which contained between eight and 17 stages. At no time during the Late Pleistocene with sea-level stands about 40-70 meters below current levels did the length of any of these stages exceed 100 km. They rather ranged from 65 km to perhaps 103 km.

These relatively short stretches of open water between individual islands pose the question of intervisibility between the islands of Wallacea and beyond. Irwin (1992) established that Route 1 of Birdsell's (1977) two major routes offers intervisibility between Sundaland and Sahul all the way, and the islands east and north-east of New Guinea (e.g. Bismarck Archipelago, Manus, Mussau, New Ireland, New Britain, Solomon Islands) were always within intervisibility range (Wickler & Spriggs, 1988). So it appears that during the period of the Late Pleistocene the entire region in between Wallace's Line and the south-eastern end of the Solomon Island chain consisted of relatively narrow ocean gaps, so land was nearly always visible. Irwin (1992) refers to this corridor of large, often intervisible islands, that joins South-East Asia to Melanesia as a "voyaging corridor".

Within this region human expansion as far as the south-eastern end of the Solomon Island chain could relatively easily be achieved with simple water craft technology (Green, 1994). In terms of colonisation this voyaging corridor represented a region of easy Pleistocene island-hopping due to safe sailing conditions and intervisibility of islands. It also acted as a voyaging "nursery" in which maritime technology was able to develop for 50,000 years, and finally it constituted a large safety-net to which the first tentative voyages of deep-ocean exploration into the remote part of the Pacific could return (Irwin, 1992). Birdsell (1977) and Irwin (1992) regard the Pleistocene maritime movement of people within this corridor as the earliest documented voyages in the world.

2.1.4 The migration into Remote Oceania

Beyond the south-eastern end of the Solomon Island chain circumstances gradually

began to change and distances became larger, 350 km and more (Green, 1994), a distance well beyond the range of intervisibility between islands. The ocean gap between the main Solomon Islands and the islands of the Santa Cruz group appears to be the first significant navigational threshold (Irwin, 1992) for early colonists forming the boundary between Ancient Near Oceania and Remote Oceania. Water craft technology and people's navigational and sailing skills at that stage were not advanced enough to traverse this substantially larger gap beyond which islands farther south-east were beyond visibility. Apart from being a navigational threshold to Late Pleistocene hunter-gatherers the south-eastern end of the main Solomon Islands also constituted a major biogeographical boundary (Green, 1994; Spriggs, 1997; Thorne, 1963). According to Spriggs (1997) 30 genera of land birds and 162 genera of seed plants find their eastern limit there. All the land mammals (except bats) which now occur beyond the main Solomon Island chain have been imported by humans once they successfully crossed into Remote Oceania at a much later stage. This cultural as well as biogeographic boundary appears to have made it equally difficult for humans as well as animals and plants to migrate further eastward into Remote Oceania.

However, technological improvement in water craft technology in combination with a more sophisticated sailing and navigation strategy eventually enabled people to cross the boundary into Remote Oceania and to transfer plants and animals on which their livelihood depended across this long-standing biogeographical threshold (Green, 1994). Irwin (1992) suggests that after the complete colonisation of Ancient Near Oceania as far east as the end of the main Solomon Island chain a period of the order of 25,000 years elapsed before people had improved their water craft technology and acquired appropriate sailing and navigational skills to make this crossing successfully.

The colonisation of Remote Oceania was consequently an event of the Late Holocene. By then the sea-level had already risen to its present position (ca. 6000-5000 years B.P.; e.g. Chappell & Shackleton, 1986, fig. 1; Pirazzoli, 1991, plate 44) causing the disruption of Ancient Near Oceania. As a result Australia and New Guinea were no longer joined together (separation after 8000 years B.P.; Spriggs, 1997) and the landmass of Sundaland no longer consisted of islands either joined to each other or to

mainland Asia, leading to the formation of "Island South-East Asia" (after 6000 years B.P.; Green, 1994). The latter comprises Sumatra, Java, Kalimantan, Sulawesi, the Philippines and various smaller islands of the former Wallacea (Green, 1994; Spriggs, 1997). Other islands which emerged from this modern geographic setting include New Guinea, the islands of the Bismarck Archipelago and the Solomon Island chain. Anthropologically this region is defined as Melanesia, conventionally also known as "Modern Near Oceania" (Green, 1994; *cf.* Spriggs, 1997).

2.1.4.1 The Lapita cultural complex

The movement of people into Remote Oceania which began abruptly after 3500 years B.P. is regarded as a burst of sophisticated maritime and Neolithic settlement in the remote Pacific (Irwin, 1992). This deep-sea colonisation of the remote Pacific is associated with the rapid spread of a distinctive archaeological cultural complex, the so-called "Lapita cultural complex" (named after an early find site in New Caledonia [Davidson, 1984]), which originated somewhere in the voyaging corridor. The economy associated with the settlement of Remote Oceania carried its own portable items such as plants and animals, and engaged in long-distance exchange (Irwin, 1992). Such an economy probably gave a colonising population the demographic advantage and ability to settle rapidly across a large area with restricted resources.

The "Lapita cultural complex" has been described as an uncertain and variable archaeological category which is characterised by its high archaeological visibility and its rapid spread from its first appearance in the archaeological record. Another unique feature of this complex is that nowhere else in the world has the settlement of such a vast area been identified with such a clear archaeological signature as Lapita (*cf.* Irwin, 1992). Numerous papers have been published on this subject: explaining theories about its origin, utilising linguistic and biological evidence; the mode of its distribution through mainland and Island South-East Asia and Melanesia; possible reasons for its gradual disappearance through time; quoting the cultural assemblages (e.g. ornaments, water craft, tools, settlement patterns etc.) of this cultural complex; explaining its trade

exchange systems etc. Comprehensive reviews on these and further aspects of the Lapita cultural complex are provided by Green (1994) and Irwin (1992). Within the scope of this chapter only the most relevant aspects of this cultural complex will be mentioned.

The Lapita cultural complex appears abruptly in the archaeological record in the Bismarck Archipelago about 3500 years B.P. and persists in a range of easily recognisable forms for more than a thousand years (Irwin, 1992). So far the exact "homeland" of this cultural complex proved difficult to identify with any accuracy. Workers like Bellwood & Koon (1989) argue for the region of Halmahera (Moluccas) in Island South-East Asia whereas Allen (1984) more generally proposes the Bismarck Archipelago as its homeland. As substantial field work in the Bismarcks has not revealed any evidence for an *in situ* development of the Lapita cultural complex, many workers now adopt a compromise "merger" model which combines elements from both postulated regions (Gosden *et al.*, 1989). Linguistics have often been used in an attempt to determine the origin of Lapita. This is because the spread of the Lapita cultural complex from the Bismarck Archipelago eastward into Remote Oceania seems to be linked to the dispersal of Austronesian languages¹². Austronesian languages spread through Island South-East Asia and Near Oceania during the last 5000 or 6000 years (Irwin, 1992). Their mainly coastal distribution in Near Oceania suggest their introduction into a non-Austronesian region (Spriggs, 1997). Spriggs (1997) argues that the Lapita cultural complex, the most widespread archaeological phenomenon in this region, and Austronesian languages, the most widespread language group in the same area, must surely be linked. The origin of proto-Austronesian may be in the region of South China/Taiwan and its reconstructed vocabulary implies a Neolithic pottery-using society with domesticated animals, houses and sailing canoes. These languages evidently spread from Taiwan through the Philippines to eastern Indonesia along the north coast of New Guinea into the Vitiaz Strait (between New Guinea and New Britain), which is regarded as the homeland for proto-Oceanic¹³ (*cf.* Irwin, 1992;

¹²Austronesian languages cover the Pacific Ocean from Easter Island to East Asia, with an extension as far west as Madagascar. This language family is spoken throughout Polynesia, Micronesia, Melanesia south of the Solomon Islands and much of Island South-East Asia with the exception of Australia. Austronesian languages co-exist with the Papuan language family which is spoken in Papua New Guinea and parts of the Solomon Islands (Davidson, 1984).

¹³Proto-Oceanic forms the group of languages spoken throughout Melanesia, Polynesia and Nuclear Micronesia (Davidson, 1984, fig. 10).

Spriggs, 1997).

Various workers argue against an influence of Lapita from as far west as South-East Asia on the basis of Lapita being a local development, a product of "regional continuity", from pre-Lapita cultures in the Bismarck Archipelago. However, despite all this criticism, the evidence supports the view that Lapita is basically of South-East Asian/Austronesian origin, although some elements were invented and added in the Bismarcks, and some pre-Lapita Melanesian elements were integrated into it (Spriggs, 1997).

As the introduction of pottery with its distinctive ceramic design ("dentate-stamped pottery") was undoubtedly the most conspicuous and probably even most visible feature of Lapita it was initially defined by its pottery (Spriggs, 1997). However, because of further artefacts later associated with it, it is now known to be an entire cultural complex (Irwin, 1992), which includes stone adze forms, ornament types, rectangular stilt houses in sedentary villages as well as introduced domestic animals (e.g. pigs [*Sus scrofa*], dogs [*Canis familiaris*], chickens [*Gallus gallus*] and Pacific/Polynesian rats [*Rattus exulans*]) and various cultigens (e.g. taro [*Colocasia esculenta*], yam [*Dioscorea* spp.] and breadfruit [*Artocarpus altilis*]) (Spriggs, 1997; Davidson, 1984). Green (1979, 1994) further describes Lapita as a culture with maritime, arboricultural and horticultural components, where people fished, kept certain domestic animals, tuberous garden plants and fruit trees, had distinctive sets of pots, stone and shell artefacts and ornaments, and occupied sometimes internally differentiated settlements of up to village size. Furthermore, these people enjoyed a rapid population growth, were effective colonisers, skilful voyagers and, in places, had exchange systems and communications networks over considerable distances.

Archaeologically the most visible evidence of the above exchange and communications network of Lapita was probably the long-distance trade with obsidian. This black volcanic glass, which was valued for its qualities as a cutting tool, has been found in many locations far away from its place of origin. Obsidian from Talasea (north coast of New Britain, Bismarck Archipelago) for example has been found in Lapita sites in the

south-east Solomon Islands and in New Caledonia (Davidson, 1984). However, it has to be borne in mind that the movement of obsidian within Near Oceania is not a feature exclusively pertaining to the Lapita cultural complex. Spriggs (1997) reports pre-Lapita movements of obsidian from Talasea to New Ireland from as early as 20,000 years B.P. with further obsidian finds at Balof Cave (New Ireland) [from 6500 years B.P. onwards], Misisil (west New Britain) [12,000 years B.P.], Matenbek (New Ireland) [19,000-20,000 years B.P.] and Panakiwuk and Balof [7000-8000 years B.P.] (Irwin, 1992). Anyhow, there is no evidence that obsidian was used in the Solomon Islands before the Lapita era (Spriggs, 1997) and obsidian from another source in Lou Island (Admiralty Islands) does not appear in circulation before Lapita times either (Irwin, 1992). The particular fact that Talasea obsidian was already exchanged widely throughout the Bismarck Archipelago long before the advent of the Lapita cultural complex is used as an argument that Lapita is a local development with no need of further migrations into the region from farther west (*cf.* Irwin, 1992; Spriggs, 1997).

However, the technology associated with this cultural complex provided the skills and resources which eventually enabled the early colonists, often referred to as "Lapita-colonists" or "Lapita-people", to colonise Remote Oceania (Spriggs, 1997). Among the improved types of water craft which were imperative to traverse the substantially larger stretches of ocean east of the main Solomon Islands Irwin (1992) mentions the introduction of ocean-going outriggers and double sailing canoes.

Irwin (1992) argues that Lapita is unique in the sense of its unusually broad geographical distribution. It covers the Bismarck Archipelago and Solomon Islands, regions which had already been long-settled, and extends further into the remote Pacific to include the Melanesian islands of Santa Cruz, Vanuatu, New Caledonia and Fiji, as well as West Polynesia (Tonga, Samoa, Futuna and Uvea). In Remote Oceania Lapita approaches an ethnic category as it is associated with the first archaeologically visible settlers of the offshore islands of Melanesia and West Polynesia in an episode of colonisation that was systematic and rational (Irwin, 1992).

Based on the work by Green (1994), Irwin (1992) and Spriggs (1997) the emergence of

the Lapita cultural complex in the Bismarck Archipelago, including the movement of its people from Near Oceania into Remote Oceania, can be summarised as follows. First appearance of Lapita sites is in the Bismarck Archipelago between 3600 and 3500 years B.P. Between 3200 and 3100 years B.P. spread of Lapita settlements south and east through the main Solomon Islands into Remote Oceania with first western Lapita sites in the Reef/Santa Cruz Islands group. Very soon afterwards Lapita sites with their characteristic pottery appeared in Vanuatu and New Caledonia. By 3000 years B.P. Lapita people had moved from northern Vanuatu to Fiji and the islands of West Polynesia. Consequently, the colonisation of Remote Oceania as far east as West Polynesia was a very rapid development which took no more than one or two centuries.

The relatively short time span of 500 years it took Lapita to spread from the Bismarck Archipelago to West Polynesia is taken up by Irwin (1990) to establish motives for people to migrate farther east into Remote Oceania. He argues that such a time span represents as few as 20 human generations, which by world standards, is an extremely fast rate of human expansion. It appears to be unlikely to him that at such a rate of advance people were driven by ecological or demographic pressures, as human populations in Remote Oceania at this time were lower than ever again. Large islands in Vanuatu, New Caledonia and Fiji had the capacity to absorb increasing population numbers, but, if this was the issue, they did not perceptibly slow the rate of expansion. This scenario is very similar to motives of the colonisation of Ancient Near Oceania and Sahul as outlined by Bowdler (1997). Thus other motives must have driven these early colonists to voyages of discovery farther east.

Furthermore, the movement of Lapita and its people eastward brought colonists into previously uninhabited areas. Spriggs (1997) notices that this led to a typical colonisation pattern, consisting of "pioneering" agriculture and rapid extirpation of many birds and other fauna. This pattern reflects a deliberate targeting of pristine fauna while plant and domestic stocks were being established. Furthermore, large-scale clearance for agriculture also caused environmental degradation.

2.1.4.2 Developments in Fiji and West Polynesia

By 1000 B.C. Lapita sites with all the characteristic features of the “Lapita cultural complex” had been established in Fiji and West Polynesia. Davidson (1984) refers to this part of Remote Oceania as a region in which important changes took place, leading from a Melanesian, or more generally Oceanic, material culture to a distinctively Polynesian culture. Until recent discoveries of Lapita pottery in a submerged site in a lagoon in Samoa Tonga was believed to have been the homeland where Lapita colonists became Polynesians (Groube, 1971). With this additional find it seems likely that probably all islands of West Polynesia were rapidly explored and settled once the initial sea crossing to Fiji was achieved. As these islands formed a wider contact sphere in which people maintained a regular contact until historic times it is most likely that such a contact dates from the time of first colonisation about 3000 years ago.

Green's (1994) review on this subject concludes that the homeland of the Polynesians can be placed within the region of West Polynesia where it emerged from the (Eastern) Lapita cultural complex. The distinctive language of these people, their genetics and culture was not brought from elsewhere already fully established. The language rather evolved in this region from a Central Pacific proto-language, ancestral to the modern daughter languages of Fiji, Rotuma and Polynesia. As this language and its people can be associated with the (Eastern) Lapita cultural complex, Polynesians can be regarded as direct descendants of the bearers of the Lapita culture (*cf.* Spriggs, 1997).

During the first 1000 years after its initial colonisation the Fiji-West Polynesian region underwent progressive internal differentiations which led to establishment of an Ancestral Polynesian Society out of the (Eastern) Lapita cultural complex. Basic elements of this new society were already established during the first few centuries B.C. throughout the islands of West Polynesia (*cf.* Green, 1994).

The advent of a characteristic Polynesian society is reflected in conspicuous changes in the associated cultural items such as pottery ware, stone adzes and shell ornaments as

well as in changes in the patterns of settlement¹⁴ and social organisation¹⁵ (Davidson, 1984; Green, 1994). The probably most conspicuous changes occurred to the pottery ware. With the passage of time the initially elaborately decorated Lapita pottery vessels became progressively simpler and were replaced by plainer ware with fewer vessel types (Davidson, 1984; Irwin, 1992). Spriggs (1997) places this development to 2800 years B.P. for Samoa, where it happened rather earlier than in Tonga and Fiji. During the first few centuries A.D. pottery eventually disappeared completely in the islands of West Polynesia (Davidson 1984) and later when Lapita decoration also disappeared in Island Melanesia and Fiji different pottery styles emerged. These new styles did not penetrate as far as Tonga or Samoa (Davidson, 1984); their distribution was limited to the region from Manus (Bismarck Archipelago) to Fiji (Spriggs, 1997). This development can be regarded as the end of the Lapita cultural complex, an event Spriggs (1997) dates to 2500-2000 years B.P.

Green (1994) partially attributes the development of a distinctive Polynesian material culture including its characteristic economic aspects to changes of the physical environment which were encountered east of the Andesite Line. On crossing the Andesite Line early colonists moved away from the larger continental islands such as Fiji into the geologically oceanic part of the Pacific with its volcanic high islands, raised coral and true atolls in which most of Polynesia except New Zealand lies. This new physical environment meant a shift to islands with a much more restricted range of rock types, soils, freshwater resources and ecological niches (also see Thomas, 1963).

The restrictions of the rock material available for making adze kits can be particularly associated with a variety of new forms of these tools as new flaking technologies had to be applied to their production from those materials. Furthermore, the lack of suitable materials for ceramics east of the Andesite Line is also regarded as the cause of the scarcity of pottery in East Polynesia (*cf.* Irwin, 1992). However, this contention is open

¹⁴By A.D. 0 there is evidence in Samoa of people having shifted from initially more coastal settlements to further inland. By then small dispersed hamlets were scattered throughout the islands close to gardens as well as to the sea. Further evidence points to the existence of a marae, as well as small food storage pits, and earth ovens similar to those found throughout Polynesia in more recent times (Davidson, 1984).

¹⁵There is some slight evidence of violence and perhaps even cannibalism among the early settlers of Tonga. Davidson (1984) suggests that the propensity for violence and warfare was spread to all parts of Polynesia from this ancestral homeland.

to dispute as there occurs good pottery clay much further east of the Andesite Line on Easter Island (J R Flenley, pers. comm., 1997)

As to the Polynesian origins, Green (1994) concludes that despite some uncertainties these origins are to be found within the western regions of Polynesia itself with antecedents in the (Eastern) Lapita cultural complex and its associated language and populations. He bases his conclusions on linguistic, biological and archaeological evidence and discards attempts to seek Polynesian origins elsewhere in Asia, the Pacific or even South America. This contention appears to be supported by finds of human remains of definitely Polynesian physical type (Davidson, 1984) in the Lau Islands (eastern part of Fiji) dating from the mid-first millennium B.C.

2.1.4.3 Mode of the exploration of Remote Oceania

The settlement of the remote Pacific east of West Polynesia can not be discussed without addressing fundamentals like the different weather systems early colonisers encountered on their exploratory voyages, their motives for sailing as well as the possibility of multiple voyaging to and multiple settlement of individual archipelagos. These important issues in the settlement of this region will be discussed in more detail below.

The different weather systems in the inhabited part of Remote Oceania include easterly trade wind systems of both hemispheres, the doldrums between, cyclones, the monsoon of the western tropics, sub-tropical variables and westerlies, as well as the movement of high and low pressure systems within them, and the variable seasonal shifts in their latitude (Irwin, 1992).

As for the pattern of settlement in Remote Oceania it is conspicuous that colonisation in the lower latitudes of the tropical Pacific went first against the winds. Despite their difficulties, eastward voyages in the tropics were recorded from early historic times, and the means to do so arise from brief seasonal interruptions in the easterly trade winds

causing westerly winds as well as the ability to tack into the wind. Irwin (1989, 1992) claims that this mode of voyaging was the safest way to sail as going in the direction that is normally upwind one can expect the fastest trip back home if no land farther east can be found. By using this upwind strategy of search and return people could colonise most tropical islands of the Pacific including landfall in South America. However, this strategy did not take people to Hawaii or Micronesia across the wind or New Zealand outside the tropics down the wind. Sailing across and down the winds was only done later when people embarked on exploratory voyages into the higher-latitude margins of East Polynesia. This feature is supported by virtually every radiocarbon date in the remote Pacific.

Irwin (1992) argues that the logic of survival suggests that successful voyages across and down the wind were only done after upwind ones had already been made. Cross- and down-wind voyages outside the tropics could only be made after sufficient experience and skills had been acquired for sailing in these more difficult weather systems.

An often raised question is how far voyages by Polynesians were accidental or deliberate. There are a few points which almost undoubtedly argue for deliberate voyages of colonisation such as the very wide distribution of various domesticated plants and animals within Polynesia as well as the establishment of successful human populations on so many far-flung islands, a feature which cannot have been achieved by fishermen accidentally blown off-course. Davidson (1984) claims that parties of fishermen blown off-course do usually not carry women, pigs, dogs and chickens as well as a variety of cultivated plants. This view is supported by computer simulations of Polynesian voyaging by Levison *et al.* (1973) which demonstrated that uncontrolled drift voyages can explain some of the present distribution of Polynesians, but the chances of making major voyages of colonisation by drift are so negligible that they must have been the result of some kind of directed navigation. The simulation also proved that travelling from West Polynesia to East Polynesia, and from there to Hawaii or New Zealand required some other strategy than uncontrolled drifting.

However, this does not necessarily mean that early voyagers had a particular destination in mind or knew how to get there. They were probably merely attempting to follow a deliberate course, rather than drifting aimlessly. Davidson (1984) takes this subject further and suggests that deliberate voyaging to destinations like Hawaii and New Zealand, makes it unlikely that each of these locations has only been settled once. She suggests that these islands were rather subject to multiple settlement with a steady stream of arrivals of people over time. As for Easter Island the case appears to be different as Davidson (1984) herself claims that this island was settled fairly early and thereafter remained completely isolated. For historic times however, Davidson (1984) claims that deliberate voyages were not undertaken or even considered between West and East Polynesia, or between any other part of Polynesia and Hawaii, New Zealand or Easter Island.

Another important issue in the settlement of the Pacific is return voyages. Irwin (1992) regards return voyages as a natural and conventional part of any maritime settlement which does not make the colonisation of new islands a one-way traffic. This sort of back-communication with the former homeland and the new settlement allowed the reinforcement of new communities and the movement of materials and ideas. He reports on ethnographic evidence for return voyages of up to about 300 miles in areas in Micronesia, Fiji/West Polynesia and in East Polynesia between the Society Islands and the north-western Tuamotu Islands with the exception of marginal East Polynesia.

As the margins of Polynesia were explored links between West and East Polynesia fell away and steeper gradients of isolation and cultural diversification developed where there were effective water gaps. This contention is definitely supported by the cultural divergence of New Zealand from its East Polynesian relatives, given its distance from and the difficulty to return to them. Davidson (1984) also supports this scenario but includes Hawaii into this contact sphere of central East Polynesian islands with its continuing return voyages.

2.1.4.4 The settlement of East Polynesia and its margins

After West Polynesia had already been settled for a substantial period of time and the pre-Polynesian language and Lapita material culture of the original colonisers had gradually changed into distinctively Polynesian forms people embarked on the next west-east crossing into parts of East Polynesia.

Davidson (1984) assumes that on initial colonisation East Polynesia probably underwent the same development like West Polynesia after its settlement. Changes in culture and language took place which later spread throughout the region differentiating it from West Polynesia. Bellwood (1978) refers to the earliest cultural entity of East Polynesia as "Early Eastern Polynesian", commonly also known as "Archaic East Polynesian". Green (1994) points out that the use of these terms proves to be difficult as certain cultural items (e.g. shaped whale-tooth pendants, harpoon points, reel ornaments, and fully tanged adzes) which seem to identify this earliest cultural entity, in fact do not occur among the earliest cultural types in this region but rather appear much later, between A.D. 1000-1200 (Kirch, 1986). So Green (1994) concludes that what is regarded as Archaic or Early East Polynesian culture in fact is only an intermediate stage of cultural development but not the earliest one.

As for the intermediate period of its settlement central East Polynesia is believed to have been part of a broad regional interaction sphere characterised by long-distance voyages involving trade and exchange (Green, 1994). The continuing interaction ensured that new innovations such as the cultural items of the Archaic Eastern Polynesian cultural complex were transferred throughout this central region. Interestingly enough the whole suite of these cultural items is missing in sequences from Hawaii and Easter Island but does occur in New Zealand (Davidson, 1984; Green, 1994).

The exact moment in time when early Polynesians began to settle East Polynesia appears to be difficult to determine with any accuracy as various workers state different periods. Spriggs (1997) states a period from 1600-1300 years B.P. (A.D. 400-700),

whereas Davidson (1984) claims that colonisation of East Polynesia only began after West Polynesia had already been settled for some 1500 to 2000 years which places this event at A.D. 500-1000. Others (e.g. Bellwood, 1978; Davidson, 1979; Finney, 1979; Green, 1979) propose a slightly shorter period of 1000 to 1500 years which dates the beginning of the movement of people into East Polynesia to A.D. 0-500. The latter opinion seems to be the more favoured.

Irwin (1981, 1992) refers to this period of 1000 to 1500 years between the colonisation of West Polynesia and the move into East Polynesia as the "West Polynesian Pause" or "The Long Pause". In the so-called "orthodox model of Polynesian settlement" as proposed by Bellwood (1978), Davidson (1979), Finney, (1979), Green (1979) and Sinoto (1966, 1968, 1979) this time span is regarded as a period during which there was no further colonisation to the east. The above workers argue that such a time span was needed within a West Polynesian homeland to develop in some isolation distinctive features of Polynesian language and culture. As a matter of fact ethnically and culturally all Polynesians show conspicuous similarities which were already noticed by early European voyagers in the South Pacific (e.g. Sir Joseph Banks and Captain James Cook) (*cf.* Irwin, 1992). Furthermore, in terms of physical anthropology all Polynesians form a homogenous and distinctive group in a way which almost defies classification into different physical groups (Davidson, 1984).

The above orthodox model of Polynesian settlement (Sinoto, 1966, 1968, 1979; *cf.* Jennings, 1979) proposes the following colonisation scenario for East Polynesia. At about A.D. 300 the Marquesas were probably the first East Polynesian group to be settled. Thereafter they became a "(primary) dispersal centre" for colonists to Hawaii (settled by A.D. 500), Easter Island (settled by A.D. 400) and the Society Islands (settled by A.D. 600). The Society Islands in turn eventually became a "secondary dispersal centre" for later migrations to Hawaii and New Zealand (settled by A.D. 800). However, it is debated whether there was a second migration from the Society Islands to Hawaii and possibly to New Zealand. Irwin (1981, 1992) contests the validity of this orthodox model on the grounds of this model being based on the interplay of patchy artefact distributions, radiocarbon dates and historical linguistics.

This 1000 to 1500 year long West Polynesian Pause is actually a time span which is based on a gap in the archaeological record between the establishment of settlement in West Polynesia and the appearance of the first sites in East Polynesia which so far appear to have been in the Marquesas. Thus this "gap" in the record is the product of an absence of early sites which pre-date the earliest sites in the Marquesas. Irwin (1981, 1992) regards this pause as an artefact used by prehistorians as a time span needed for the process of diversification, i.e. the transformation from Melanesian Lapita people into distinctively different Polynesian people. In his view it is incomprehensible that Lapita people who had spread rapidly through the western Pacific, apparently without compulsion or stopping before, suddenly went into a "cultural chrysalis" when they reached West Polynesia to emerge after 1000 to 1500 years as Polynesians, only then to be able to move east. What argues for this pause is the fact that the conspicuous ceramic trail of the Lapita cultural complex apparently only went as far east as West Polynesia giving the impression of an abrupt stop in the movement of people farther east. Irwin (1992) uses the following arguments to refute such an abrupt stop: firstly, colonisation could have continued while pottery-making could have stopped. This is known to have happened when manufacturing technology is mismatched with unfamiliar raw materials. This situation was definitely encountered when people moved farther east into the islands of the Pacific Plate with their restricted availability of clays for pottery-making, in particular on atolls. The basaltic high islands apparently did not provide a more favourable environment as Claridge (1984) mentions the worsening quality of raw materials for ceramics on crossing the Andesite Line eastwards.

Secondly, the absence of early sites can be attributed to sampling error. Many archaeological sites in East Polynesia might not have been discovered yet as they may lie buried by erosional deposits or submerged under water. Reasons quoted include the burial of early sites by accelerated alluvial/colluvial deposition following human settlement as well as the possible disappearance of early sites due to active tectonic subsidence in the oceanic region of Polynesia east of the Tonga Trench. Considering these geological facts, there might also be the possibility that Lapita sites extended eastwards of Samoa to the Cook Islands or even beyond, but if so these sites can be expected to be fully submerged.

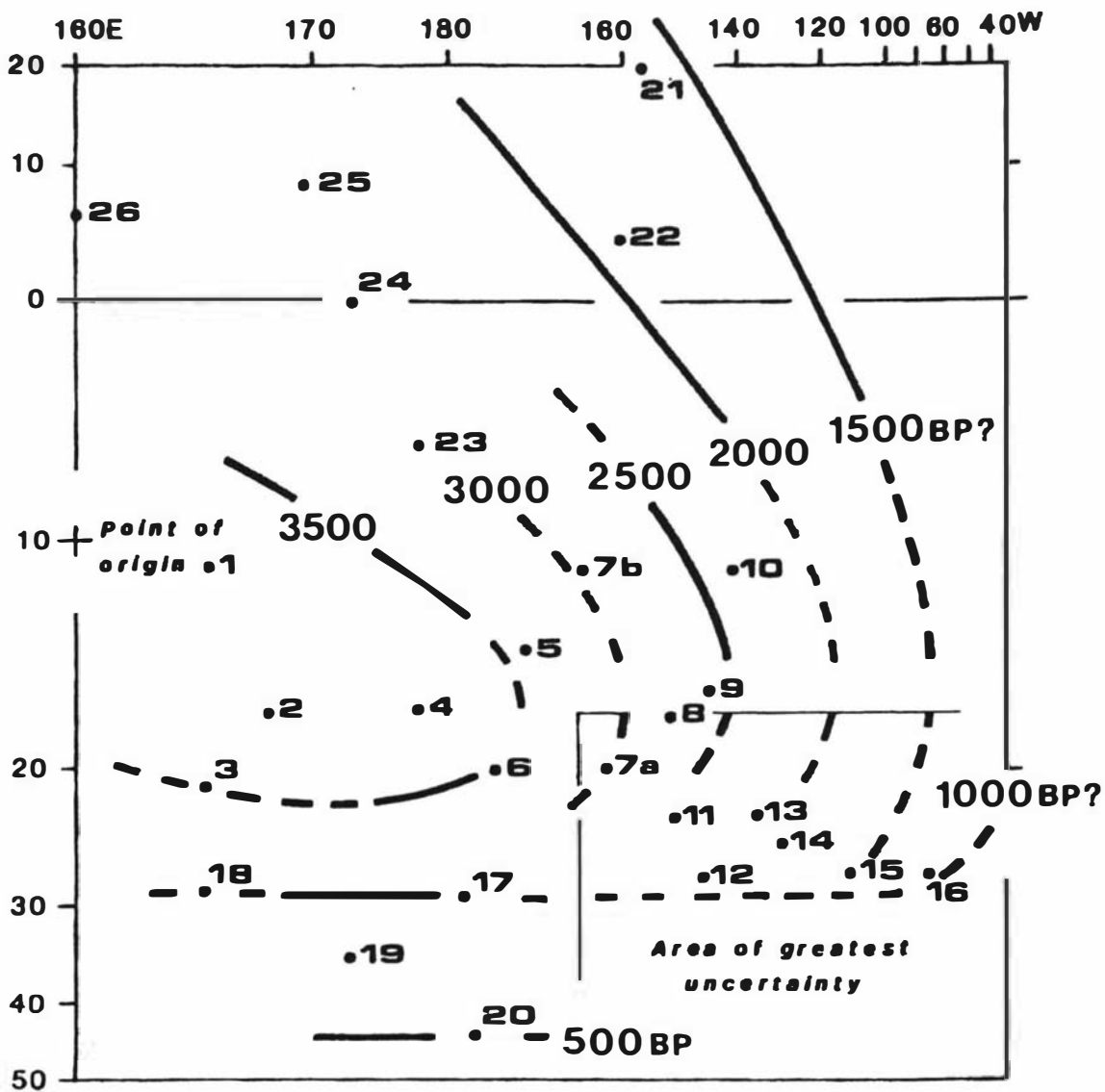
Thirdly, another kind of sampling error might be that not all of the places where sites could be found have been investigated yet.

Apart from the above pause the orthodox model of settlement of Polynesia identifies a second pause. On having settled central East Polynesia, with the Marquesas as a secondary dispersal centre for final migrations to the margins of East Polynesia, people appear to have marked time before exploring the remainder of Polynesia. The reasons given for this pause are much the same as those used to explain the West Polynesian Pause.

Again, Irwin (1989, 1992) doubts such an East Polynesian Pause and rather advocates a "continuous model for the settlement of East Polynesia". He argues that settlement was a continuous process and explains apparent pauses by geographical factors in East Polynesia very different from those encountered in West Polynesia. Firstly, the distances to be covered before making landfall were much greater in East Polynesia, and secondly and even more important, the area of ocean that had to be searched for islands within it was substantially larger. These factors would simply account for more time needed to search the increased space.

To underpin his hypothesis of a continuous settlement uninterrupted by cultural pauses Irwin (1990, 1992) uses a logarithmic projection map, a log/log version of a Mercator projection map, to search for coherence in the pattern of available radiocarbon dates for early settlement (see fig. 2.3). The isochrones of settlement chosen for this model are at regular 500-year intervals.

The conclusions this logarithmic map projection allows can be summarised as follows: firstly, when the geographical positions of the islands of the remote Pacific are plotted logarithmically, the intervals between the isochrones become approximately equal, implying that the colonisation of the area was accelerating at a rate approaching exponential rather than slowing down through time as proposed by many prehistorians. Secondly, near the southern limit of the tropics the isochrones are compressed together, indicating a "high-latitude pause". This feature confirms that higher latitude and late



- | | | |
|------------------|------------------|----------------|
| 1 Santa Cruz | 9 Tuamotu | 18 Norfolk |
| 2 Vanuatu | 10 Marquesas | 19 New Zealand |
| 3 New Caledonia | 11 Austral | 20 Chatham |
| 4 Fiji | 12 Rapa | 21 Hawaii |
| 5 Samoa | 13 Mangareva | 22 Fanning |
| 6 Tonga | 14 Pitcairn | 23 Tuvalu |
| 7a Southern Cook | 15 Easter | 24 Kiribati |
| 7b Northern Cook | 16 South America | 25 Marshall |
| 8 Society | 17 Kermadec | 26 Caroline |

Figure 2.3: Log/log transformation of a Mercator projection map of the Pacific with its point of origin in the eastern Solomon Islands. Island positions are plotted on the transformed grid, and isochrones are based on an early interpretation of available radiocarbon dates for early settlement. Solid lines refer to actual data points whereas dashed lines interpolate between them, offering a qualified prediction of results to come (Irwin, 1992; adapted from Irwin, 1990).

settlement were correlated, most probably because of the differences in accessibility of the islands of marginal East Polynesia due to different wind systems.

Based on figure 2.3 the overall summary of the colonisation scenario for Polynesia could be as follows: colonisation of the first part of central East Polynesia by 500 B.C. On their way from Samoa farther east early colonisers could have made landfall in the Southern Cook Islands first, rather than embarking on long, direct voyages to major island groups even farther east such as the Marquesas. Arrival in the Marquesas by around A.D. 0 and further settlement of the margins of Polynesia during the early centuries of the first millennium A.D., starting with Hawaii around A.D. 400 and Easter Island probably at the same time. Finally settlement of New Zealand by A.D. 1000 from "nearer" Eastern Polynesia, probably the Southern Cook Islands. The Chatham Islands were probably settled last of all.

The above dates of early settlement of individual archipelagos in East Polynesia do not differ substantially from those dates suggested by other workers but propose a rather early colonisation chronology of the region. Other dates for earliest settlement of major island groups are usually older.

For the Marquesas Davidson (1979, 1984), Bellwood (1978), Finney (1979) and Green (1979) propose a date for early settlement of A.D. 300, Kirch (1986) dates this event to the mid-first millennium B.C. and Spriggs & Anderson (1993) and Spriggs (1997) place it into the period of A.D. 300-600.

For the Southern Cook Islands dates for evidence of earliest colonisation range from 1150 B.C. (e.g. Kirch & Ellison, 1994) based on pollen evidence, over A.D. 750-800 (Spriggs, 1997; Spriggs & Anderson, 1993) to A.D. 800-1200 (Irwin, 1992). Latter two periods are both based on archaeological evidence.

For the Society Islands the following dates are stated. A.D. 750-800 (for Tahiti) (Spriggs, 1997; Spriggs & Anderson, 1993); A.D. 800 (Bellwood, 1978; Davidson, 1979; Finney, 1979; Green, 1979) and A.D. 900 (Kirch, 1986).

Opinions on the time of settlement of Hawaii encompass dates from A.D. 400 (Kirch, 1986), through A.D. 600 (Davidson, 1984) and A.D. 650 (Spriggs, 1997; Spriggs & Anderson, 1993) to A.D. 750 (Bellwood, 1978; Davidson, 1979; Finney, 1979; Green, 1979).

Dates proposed for Easter Island are A.D. 400 (Bellwood, 1978; Davidson, 1979; Finney, 1979; Green, 1979; Kirch 1986); A.D. 600 (Davidson, 1984) as well as the end of the first millennium (Spriggs, 1997; Spriggs & Anderson, 1993).

Finally New Zealand, the apparently last major location in East Polynesia to be colonised returns dates of as early as A.D. 0-500 (Sutton, 1987a); A.D. 800 (Bellwood, 1978; Davidson, 1979; Finney, 1979; Green, 1979) as well as the time span from A.D. 800-1200 (Anderson, 1991; Caughley, 1988; Davidson, 1984; Green 1994; Spriggs & Anderson, 1993). An even earlier date of about 2000 years B.P. obtained on bone gelatin from Polynesian/Pacific rats from both main islands of New Zealand is reported suggesting an early, transient, human contact with New Zealand more than 1000 years before settlement (Holdaway, 1996).

The relatively wide range of different dates signifying the earliest settlement of individual archipelagos appears to be best summarised in figure 2.4 which depicts a generalised picture of the colonisation of Island Melanesia and Polynesia.

Various workers (e.g. Davidson, 1984; Irwin, 1992; Spriggs, 1997) also suggest a Polynesian contact with South America. The speculations of the nature of this contact range from occasional one-way voyages of American rafts to Polynesia to two-way Polynesian canoe-trips (*cf.* Irwin, 1992). Irwin (1992) however, supports the view that such a contact was probably achieved by Polynesians in large and fast double-hulled sailing canoes with a crew with great endurance and essentially free to range east with little navigational constraint, but with geographic knowledge of what lay behind them. He places the time of such a Polynesian contact with South America shortly after the settlement of Easter Island and at about the same time as the first discovery of Hawaii. This is because of the greater distance, and also after some experience with cross-wind

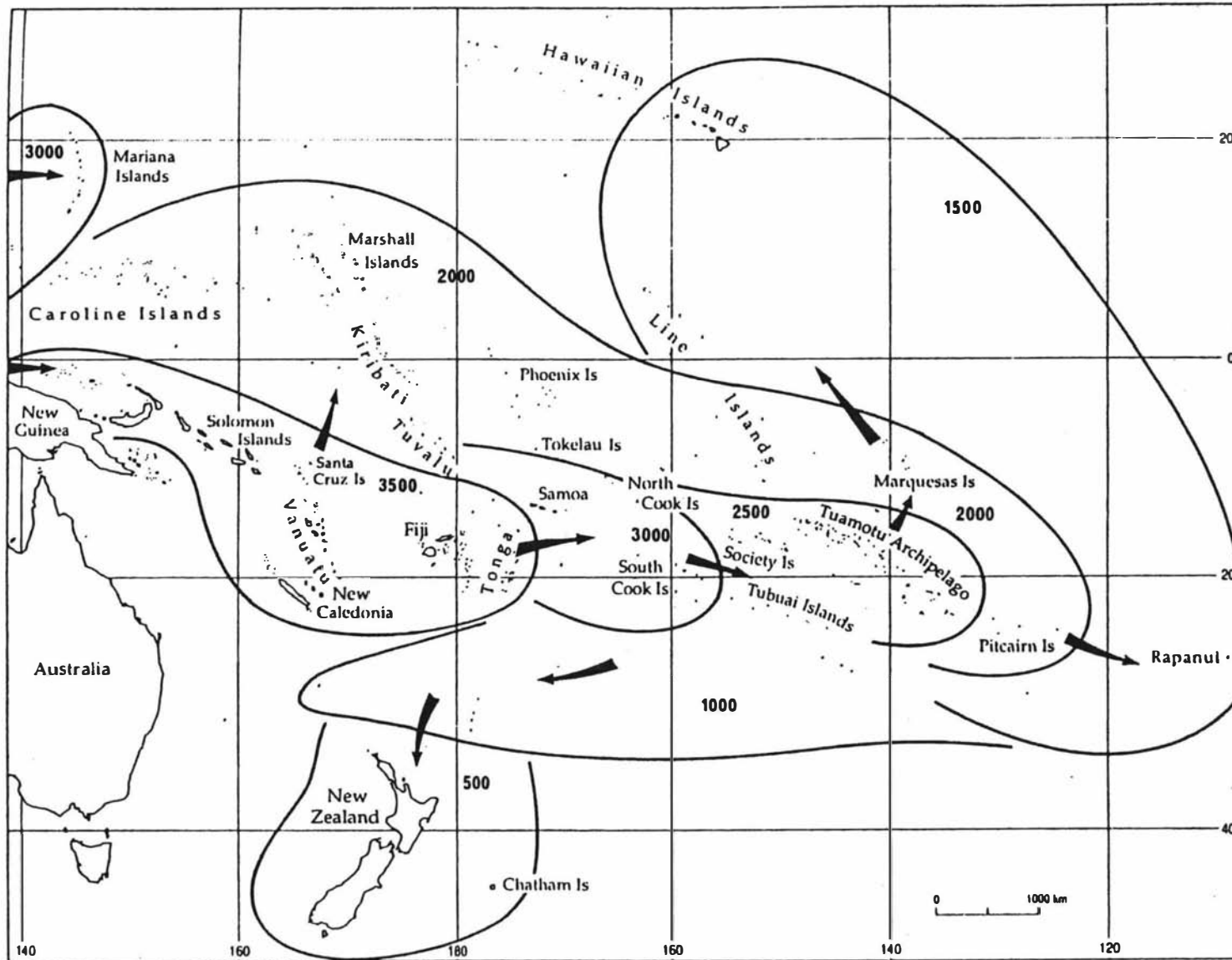


Figure 2.4: Colonisation of Island Melanesia and Polynesia based on archaeological evidence. Dates of settlement expressed in years B.P. (Spriggs, 1997)

passage had been gained. Thus most theories about any extensive American influence in Polynesia, whether in Easter Island or elsewhere have to be discounted (Davidson, 1984; Spriggs, 1997).

However, the most compelling evidence of such a contact is the existence of the South American sweet potato [kumara] (*Ipomoea batatas*) in East Polynesia. Kumara became an extremely important staple food throughout East Polynesia, including Hawaii, Easter Island and New Zealand. Despite its wide distribution in East Polynesia, kumara is believed to have reached West Polynesia and Island Melanesia only much later (Davidson, 1984; Spriggs, 1997). Irwin (1992) rates the relative lack of genetic diversity of this plant in Polynesia as an indicator of the low frequency of contacts with South America.

2.1.5 Summary

The Pacific Basin was the last region on earth to be colonised by people. The history of its colonisation began between 0.5 and 0.9 Ma ago with the movement of pre-*sapiens* hominids into the ancient landmass of Sundaland, the westernmost margin of the (palaeo-) Pacific. Nevertheless, the first step into the Pacific proper was only achieved in the Late Pleistocene when new technology in the form of ocean-going water craft eventually became available. Hence, the spread of human groups into this vast region is inextricably linked with anatomically modern humans, *Homo sapiens sapiens*.

After a series of relatively rapid voyages in technologically simple water craft across Island South-East Asia, into uninhabited regions of Australia and Melanesia first colonists reached the south-eastern end of the Solomon Islands between 50,000-40,000 years B.P. For the next 25,000 years the ocean gap between the main Solomon Islands and the island groups further south formed the next major navigational threshold to further voyages deeper into the Pacific. Movement of people further east only began after 3500 years B.P. and is closely connected with the rapid spread of the distinctive “Lapita cultural complex”. The technology associated with this cultural complex

provided the skills and resources which eventually enabled early colonists to continue their exploratory voyages further eastward.

By 3000 years B.P. Lapita people had reached Fiji and the islands of West Polynesia. Progressive internal differentiations during the first 1000 years after the initial colonisation of this region eventually gave rise to the establishment of an Ancestral Polynesia Society out of the "Lapita cultural complex". These developments also initiated the gradual decline of the "Lapita cultural complex" which disappeared completely around 2500-2000 years B.P. Archaeological evidence suggests that further exploratory voyages out of West Polynesia into East Polynesia and its margins were achieved only after a "pause" of about 1000 to 1500 years at around A.D. 0-500.

The dating of archaeological contexts throughout East Polynesia eventually formed the basis of the "orthodox model of Polynesian settlement" which proposes the following colonisation scenario: settlement of the Marquesas Islands at about A.D. 300 which then became a "dispersal centre" for colonists to Hawaii (settled by A.D. 500), Easter Island (settled by A.D. 400) and the Society Islands (settled by A.D. 600). The Society Islands in turn eventually became a "secondary dispersal centre" for later migrations to Hawaii and New Zealand (settled by A.D. 800).

Reasons for the relatively late colonisation of East Polynesia, in particular its margins, are often attributed to different weather systems outside the remote part of the Pacific which was already inhabited until the beginning of the first millennium. These generally more difficult weather systems would have required sailing strategies across and down the wind to reach locations like Hawaii and New Zealand; these strategies were developed only later. However, doubts about the existence of the above "pause", exclusively based on archaeological evidence, led to the establishment of the "continuous model for the settlement of East Polynesia". This model principally proposes a colonisation of all major East Polynesian island groups earlier than postulated in the orthodox scenario.

By way of summary it can be concluded that the colonisation of the Pacific Basin, in

particular its remote regions, was inextricably linked with the improvement of water craft technology, sailing strategies and navigational skills. These enabled fully modern humans to negotiate two major geographical boundaries: in the Late Pleistocene Wallace's Line at the western margin of the island world of Ancient Near Oceania; and during the Late Holocene a major ocean gap at the southern end of the Solomon Islands chain, forming the boundary between Near and Remote Oceania. Further improvements, in particular the advancement of navigational skills, finally enabled people also to explore the margins of East Polynesia which finally led to the discovery and colonisation of New Zealand, the last major uninhabited landmass in the Pacific.

2.2 Polynesian colonisation of New Zealand

The islands on the margins of East Polynesia (Easter Island, Hawaii and New Zealand) were the last to be colonised. As these islands were either most distant from the source of colonisation in Near Oceania or harder to reach because of the different wind systems they can be expected to have been settled late.

Easter Island, 5000 nautical miles from the source of colonisation of Polynesia in Near Oceania, lies most distant upwind. Hawaii on the other hand is 2000 nautical miles closer to this source but required voyages across the wind to get there. New Zealand in turn constitutes an anomalous example. Geographically it lies closer to islands in Melanesia, Fiji and West Polynesia, than to the nearest part of East Polynesia, from where its first colonisers probably came (also see section 2.1.4.4). It is also much closer to the source of the Lapita cultural complex than any other part of East Polynesia but yet was apparently the last island in Polynesia to be settled.

However, reaching the New Zealand archipelago involved a more complex voyage across the trade winds, through a belt of variables to the latitude of prevailing westerlies. Furthermore, New Zealand is nearly 900 nautical miles farther from the Equator than Hawaii, a feature implying that early explorers had to manage more testing weather conditions in the higher latitudes outside the tropics and find new ways home in

the event of not finding land. Thus unlike the settlement of other islands of Polynesia, navigationally the colonisation of New Zealand was very different (*cf.* Irwin, 1992).

Apart from the obvious difficulties in reaching New Zealand, Irwin (1989, 1992) also offers a number of ways of sailing south. One way is by the northerlies on the leading edge of an advancing front and behind a high, where two systems rotate against each other and the pressure gradient can cause strong winds. This happens regularly throughout the year, sometimes as often as once a week. A canoe utilising these conditions could make a landfall on the east coast of Northland.

Alternatively, because there is a strong north-easterly component in the gales that cross the northern North Island, a canoe caught just north of New Zealand could be blown west of North Cape and, in the moderating westerlies behind a gale, make its landfall on the north-west coast. Landings south of East Cape or Cape Egmont would almost certainly be secondary ones from farther north, even though their impact might be the same. Reason why it is assumed that first canoes came this way is a matter of conjecture but Lewis (1972) mentions that in traditions migrating birds had been noticed. Among these are the long-tailed cuckoo which comes from tropical Polynesia to New Zealand in September, and shearwaters fly south in October. The golden plover goes from Tahiti northward. From these birds people could infer that land lay in a particular direction, although at an unknown distance.

2.2.1 Date of settlement of New Zealand

The date of settlement of New Zealand is certainly one of the most controversial subjects of New Zealand archaeology and it has attracted the attention of numerous workers such as Anderson (1991), Caughley (1988), Davidson (1984), Green (1994), Holdaway (1996), Irwin (1992), Jennings (1979), Kirch (1986), McFadgen (1994), McFadgen *et al.* (1994), McGlone *et al.* (1994), Sutton (1987a,b, 1994a,b) to name only a few as well as their most relevant work on this subject. Altogether the range of dates suggested by these individual workers ranges from A.D. 0-1200 (also see section

2.1.4.4). These dates were derived from radiocarbon dating on either archaeological samples or organic material from pollen cores and sediment columns.

However, before this tool of radiometric dating became available in the mid-1950s the period of initial colonisation was estimated mainly by genealogical means (Anderson, 1989). This method of estimating the initial landfall of people in New Zealand was based on Maori lore implying colonisation was achieved by the East Polynesian ancestors of the New Zealand Maoris who had arrived here in a number of ocean-going canoes which belonged to the so-called “Great Fleet” (e.g. Simmons, 1969).

The date for this initial landfall was derived by multiplying the standard generation length of 20 or 25 years by the number of generations recorded in "whakapapa"¹⁶ from different "iwi"¹⁷. The results aggregated in the period from A.D. 1200-1400 (Anderson, 1989); various workers (e.g. Sinclair, 1991; Simmons, 1969) even date this event to A.D. 1350. Besides, Maori lore also mentioned that people had already arrived in New Zealand before the whakapapa of the occupants of the canoes began. In this context the names of two ancestral navigators, Kupe and Toi, are often mentioned. These two figures of Maori legend are believed to be the founding fathers of New Zealand. Even though there is no traditional warrant for such an assertion the date of Kupe's discovery of New Zealand is placed in A.D. 925 and Toi is believed to have arrived in A.D. 1150 (Dalziel, 1976; Simmons, 1969; Sinclair, 1991).

However, since the use of the radiocarbon dating method in modern archaeology and related environmental disciplines (e.g. sedimentology, palynology, palaeobotany, palaeoecology, etc.) various hypotheses about the period of initial colonisation of New Zealand have been conceived. Anderson (1991) groups them into three major classes designated: “*Early hypothesis*”, “*Orthodox model*” and “*Short prehistory*” (see figure 2.5).

¹⁶“**Whakapapa**”: Maori word for "genealogy".

¹⁷“**Iwi**”: Maori word for "tribe".

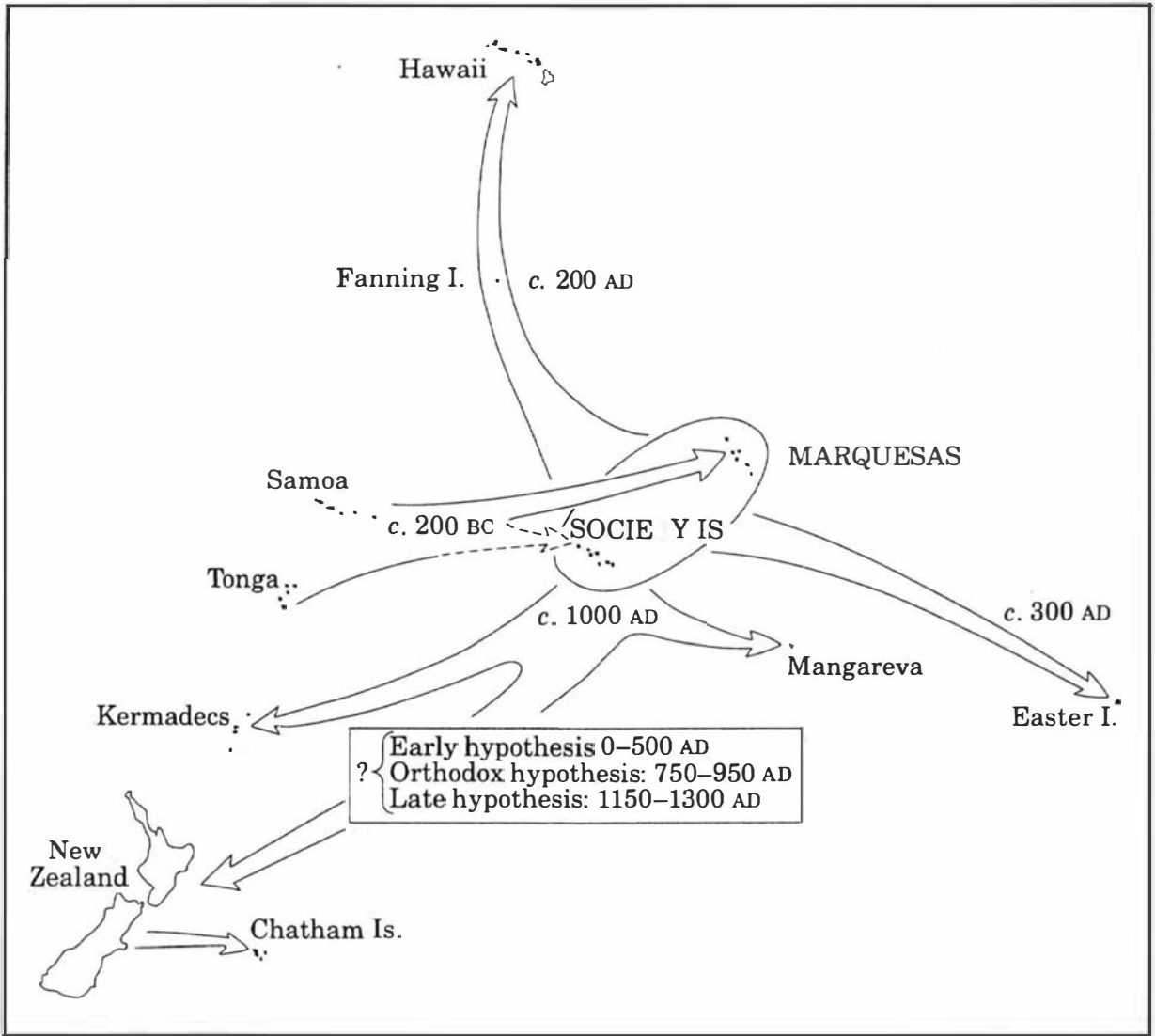


Figure 2.5: Polynesian dispersal patterns and the three hypotheses for the chronology of initial colonisation of New Zealand (Newnham *et al.*, 1998; modified after Anderson, 1991 and Sutton, 1994a).

2.2.1.1 Orthodox model

The undoubtedly oldest of these hypotheses is the *Orthodox model* which encompasses the period from A.D. 800-1000. This model was first used in combination with the absence of East Polynesian "*marae-ahu*"¹⁸ structures in New Zealand (Groube, 1968). Because of this significant difference between New Zealand and other East Polynesian societies, Groube (1968) argued that this *marae-ahu* complex only spread through East Polynesia after the settlement of New Zealand. This event is set to a period before A.D. 1300, and probably well before if the appearance of large fortified sites, so-called *pa*, by A.D. 1500 indicated intensified population pressure. The argument continues that the occurrence of certain rock types from widely-scattered sources throughout New Zealand in earliest settlement sites, the development of local artefact types utilising these stone materials and the existence of an exchange network which distributed them to early sites throughout the country, implies initial settlement several centuries before the earliest-dated sites. The date of first settlement of New Zealand was therefore set at around A.D. 800. Further proponents of this period of time as the date of initial colonisation of New Zealand are Bellwood (1978), Davidson (1984), Green (1975) and Jennings (1979).

2.2.1.2 Early hypothesis

Kirch's (1986) and Irwin's (1981, 1992) reviews of other East Polynesian archaeological sequences gave rise to an even earlier colonisation model, the *Early hypothesis*; a colonisation model which proposes an even earlier colonisation of New Zealand, substantially pre-dating A.D. 800. According to Anderson (1991) no archaeological remains of that antiquity have been recognised yet. The undoubtedly foremost proponent of this colonisation model appears to be Sutton (1987a; also see Sutton, 1987b) who suggests that New Zealand was probably first settled in the period A.D. 0-500. However, much of Sutton's argument for early settlement does not rest on

¹⁸Almost all East Polynesian groups had massive religious edifices either constructed of stone or coral slabs. Examples for this are the *ahu* of Easter Island, the *heiau* of Hawaii and the *marae* of most other areas. As for this New Zealand seemingly constitutes the exception with its simple, and apparently rare shrines and *tuahu*. Furthermore, the New Zealand *marae* of historic times is much more like the *marae* of West Polynesia (Davidson, 1984).

archaeological evidence, but on his reinterpretation of palynological and geomorphological evidence. He argues that very early horticulturally-based societies in the northern North Island might have left archaeological signatures perceptible only in palynological and other evidence of vegetation change, evidence which is readily mistaken as non-cultural. He therefore proposes a cultural influence in some cases of radiocarbon-dated vegetation change which hitherto had been regarded as explicable by natural causes. However, this view is not shared by Enright & Osborne (1988) who argue that Polynesian arrival in New Zealand may substantially pre-date the oldest known archaeological sites, but cannot accept a much earlier date for settlement based on the palynological and geomorphological evidence provided by Sutton (1987a). They conclude that the establishment of an earlier arrival date of people must depend, finally, on the discovery of cultural deposits.

One example of palynological evidence for a pre-A.D. 800 human impact on the environment Sutton (1987a) quotes comes from a study by Chester (1986) on two pollen cores from the Waitangi Forest near the coast in the central Bay of Islands, Northland. Chester reports evidence of human activity beginning at A.D. 550-600. This date was established only by extrapolation from sedimentation rates in the core below a volcanic ash layer identified as Kaharoa ash. Again Enright & Osborne (1988) reject this date of early human-induced environmental change on the ground of the age used for the Kaharoa ash marker horizon. Chester (1986) had assigned an age of 930 ± 70 years B.P. to the Kaharoa Tephra, rendering the onset of the palynologically-evidenced disturbance rather early. However, most workers now use a more recent age of *ca.* 600 cal-B.P. (e.g. Lowe & Hogg, 1992; Lowe *et al.*, 1998) based on a number of more recent radiocarbon determinations.

Another example of very early, but possibly transient, non-permanent, human contact with New Zealand is given by Holdaway (1996). He reports on radiocarbon dates suggesting that the Pacific/Polynesian rat (*Rattus exulans*) was established on both main islands of New Zealand nearly 2000 years ago. *R. exulans* whose distribution ranges from the Andaman Islands off the west coast of South-East Asia, east to Easter Island, and from Hawaii south to Stewart Island in New Zealand, with no evidence in mainland

Australia (Wodzicki & Taylor, 1984) is unlikely to have arrived in New Zealand without human assistance, on, for example, natural rafts. Matisoo-Smith (1994) rather claims that *R. exulans* was exclusively and intentionally transported with proto-Polynesians; its introduction would occur only once by each colonising group; and accidental re-introduction or dispersal of *R. exulans* populations with or without the aid of humans is unlikely. Thus Holdaway (1996) concludes that it is more likely that rats were introduced by transient human visitors, who either left immediately or quickly died out. Reasons for a non-permanent residence of these people could have been the effects of the Taupo eruption at *ca.* 1800 years B.P. Holdaway (pers. comm., 1997) suggests that the magnitude of devastation of the physical and biotic environment of the central North Island as well as the psychological effects this violent eruption most definitely had on early people in the country might have led to an abandonment of the New Zealand archipelago.

2.2.1.3 Short prehistory hypothesis

The previous two colonisation models proposing a rather long period of colonisation of New Zealand are opposed by the *Short prehistory* hypothesis. This hypothesis, embracing the post-A.D. 1200 period, is closely associated with workers like Anderson (1991), McFadgen (1994), McFadgen *et al.* (1994), McGlone *et al.* (1994) and Spriggs & Anderson (1993). In particular Anderson and Spriggs, two proponents of “chronometric hygiene”, argue for later dates for the colonisation of East Polynesia. Their works strongly opposes the efforts of various other workers (e.g. Kirch, 1986; Sutton, 1987a) to push back the claimed dates for early settlements of individual East Polynesian archipelagos. Main argument against a colonisation as early as proposed by Sutton (1987a) is the issue of why people who arrived in New Zealand about two millennia ago, who were mobile by sea and who exploited habitually the sort of coastal resources which leave durable archaeological remains, have been able to live covertly for centuries without leaving traces of their activities at many points along the coast and elsewhere? In particular, were the highly obvious big game such as moas¹⁹

¹⁹ A more comprehensive account of the country's indigenous avian megafauna is provided in section 5.1.2.2.

(Dinornithiformes) and marine mammals, ignored for centuries before hunted enthusiastically in A.D. 1200 or even later (Anderson, 1991). The argument continues that a more rational approach to defining the colonisation period, is to begin from already available evidence, radiocarbon-dated sites, and then to consider how much earlier an arrival date to accommodate other potential evidence of a human presence has to be postulated. To achieve this goal Spriggs & Anderson (1993) re-evaluated all available East Polynesian radiocarbon dates older than 1000 years B.P., for which human association has been claimed by applying a “protocol for acceptance or rejection of dates”. In the light of this a re-evaluated radiocarbon chronology for the New Zealand region (New Zealand, Kermadec Islands and Chatham Islands) the date for initial colonisation now appears to range from A.D. 1000-1200 (Spriggs & Anderson, 1993) to A.D. 1200 (Anderson, 1991).

Another novel approach to date the initial colonisation of New Zealand are navigational considerations. Irwin (1992) argues that the colonisation of New Zealand should fall somewhere in the interval between the settlement of Hawaii and the Chatham Islands. In this scenario Hawaii provides a maximum age and the Chatham Islands a minimum age for the settlement of New Zealand. This is because Hawaii, despite its marginal position, was probably colonised earlier than New Zealand as it was easier to reach. The Chatham Islands on the other hand, the very last island group in all of Polynesia to be settled (Irwin, 1992; Spriggs, 1997) could have only been discovered and colonised from New Zealand. Apart from navigational considerations cultural items found in the Chathams also support this contention (Caughley, 1988; Sutton, 1980). By utilising the orthodox model, if the date of settlement of Hawaii is assumed to be around A.D. 300-400, and with no archaeologically controlled dates older than A.D. 1600 for the Chatham Islands, colonisation of New Zealand could have occurred at a time of A.D. 1000 (*cf.* Irwin, 1992).

2.2.2 Origin of New Zealand Maoris

Less secure than the age of New Zealand’s colonisation is the origin of its founder

population in Polynesia. Davidson (1984), for example, mentions that for forty years it has been firmly established that New Zealand was first settled from Eastern Polynesia but it has never been possible to specify a particular island group. Thus Green (1994) concludes that the discovery of an early Polynesian culture in East Polynesia distinguishable from those of contemporary age in West Polynesia would be an essential step in tracing the origins of the first Polynesian colonisers of New Zealand. This association with East Polynesia is based on assemblages of artefact types [e.g. various forms of tanged adzes, harpoons, whale-tooth pendants and necklace reels (also see section 2.1.4.4)], which also occur in sites dated to A.D. 800-1200 in the Society and Marquesas Islands, but nowhere else in marginal Polynesia or West Polynesia (Green, 1975).

Anderson (1991) also takes up this issue and mentions that prehistoric artefact assemblages which occur in New Zealand but disappear earlier than about A.D. 1200, the date he regards as the beginning of colonisation of New Zealand, elsewhere in East Polynesia, would constitute a secure source of the colonisers of New Zealand. However, no such types have been recognised yet. All that can be identified is a strong similarity between types which occur in some of the earliest-dated New Zealand sites and those in some sites dated very close to A.D. 800-1200.

As the Marquesas currently have the oldest known archaeological sites in East Polynesia they are regarded as the homeland of this region. A rather comprehensive cultural sequence has been developed for this island group which can be roughly subdivided into four major phases (Davidson, 1984). Phase II (A.D. 600-1300) provides the most material for comparison with cultural assemblages in early New Zealand sites. However, suggestions have been made that the Marquesas do not necessarily have to be the homeland of New Zealand Maoris as the earliest settlement may still not have been discovered (Kirch, 1986).

Potential candidates for an even earlier settlement pre-dating that of the Marquesas are the Society and Cook Islands. The Society Islands have been considered as a possible source because of material recovered from the Vaito'otia-Fa'ahia site on Huahine and

the Maupiti burial site, which has conspicuous similarities to New Zealand sites (Irwin, 1992). Furthermore, the Society Islands were also regarded as a secondary dispersal centre in Jennings' (1979) orthodox model of Polynesian settlement. Besides the absence of very early sites could also be attributed to the geomorphological sampling problems of this island group, involving tectonic submergence, coastal aggradation and the deposition of alluvium on coastal plains and into former lagoons (Kirch, 1986).

As for the Cook Islands the Southern Cooks appear to be more significant, as they are more substantial in terms of size than the Northern Cooks which consist of about half a dozen very scattered atolls. Reports of recent excavations in the Southern Cooks support their role as a possible source of New Zealand settlement (e.g. Walter, 1994). This is because of the presence of village-sized communities in the period A.D. 800-1200 in this group; some of them were engaged in offshore communication and trade, a feature which may be significant in view of their relative proximity to New Zealand (*cf.* Irwin, 1992). Irwin (1992) notes that both island groups, the Society as well as the Cook Islands, could have easily been part of this broad regional interaction sphere in central East Polynesia (Green, 1994) [also see section 2.1.4.4], thus providing the first colonists to discover and settle New Zealand.

As for the Southern Cook Islands this view is strongly supported by Walter (1994) who suggests, partially based on linguistic evidence, that this island group is a very likely source for New Zealand's first colonists. However, this view is not supported by Katayama's (1994) work on the biological affinity between the Southern Cook Islanders (Mangaians) and New Zealand Maoris. Katayama's examinations revealed only little evidence of an especially close relationship between these populations. Mangaians seem to be physically more similar to Western Polynesians such as Tongans and Samoans than to New Zealand Maori. Katayama therefore argues for a greater connection of the Cook Islanders to Western Polynesia. This is because the Cook Islands were probably first settled much earlier than usually considered and directly from Tonga and/or Samoa.

2.2.3 Multiple settlement of New Zealand and return voyages

The question has often been raised by prehistorians whether New Zealand was subject to just one or multiple effective colonisations. Davidson (1984) defines an “effective colonisation” as one which introduces significant items of culture or language to an already established society, rather than the arrival of a few people who are either killed or totally absorbed into existing communities. Davidson (1984) herself claims that it is argued that there has been at least one significant settlement from the Society Islands and another from the Marquesas. As the material culture of the Society and Marquesas Islands was indistinguishably similar during the crucial period of colonisation of New Zealand about A.D. 800-1100 it appears to be very difficult to distinguish from which island or islands the first settlers of New Zealand came (Davidson, 1984). She also concedes that these people may well prove to be from the Cook Islands as well.

Further evidence of a multiple settlement of New Zealand by different people appears to be reflected in differences in stone technology, in particular different methods of making adzes as well as stone flakes and blades. As to this there are obviously regional variations at an early date in New Zealand which might be attributable to several separate colonising groups from different home islands which had already developed these individual practices and brought them to New Zealand.

Another proponent of multiple settlement is Sutton (1987a) who proposes that New Zealand was probably colonised repeatedly before *ca.* A.D. 1500. Re-colonisation after that date is unlikely given the evident absence of late prehistoric tropical Polynesian artefact forms in New Zealand and the converse. Davidson (1984) takes a similar course and suggests that a lack of archaeological evidence of a two-way contact with tropical Polynesia is probably indicative of colonists being quite content with the environment they found and remaining in New Zealand once they had reached it. Irwin (1992) supports this contention by arguing that steeper gradients of isolation and cultural diversification developed once the margins of Polynesia had been explored (also see section 2.1.4.2). This feature is definitely reflected in the fact that the large islands including New Zealand were still occupied at European contact, but effectively

marooned from the rest of East Polynesia by then. This isolation accounts for certain characteristics in the subsequent histories of these islands.

Further support for the possibility of a multiple settlement of New Zealand arises from the employment of statistical methods. Utilising stochastic processes to model the colonisation of Polynesia Law (1994) convincingly proves the statistical improbability of single settlement. He concludes that multiple settlements of island groups throughout East Polynesia, including Hawaii, Easter Island and New Zealand, were probably rather the rule than the exception.

Another aspect of the history of human colonisation of New Zealand is the possibility of return voyages. This subject has been taken up by Irwin (1992). Generally acknowledging that return voyages are a natural and conventional part of any maritime settlement, not making the colonisation of new islands a one-way traffic, Irwin (1992) also points out that a return voyage from New Zealand to East Polynesia might have been rather more difficult than an outward one. A voyager intending to return to East Polynesia would have faced rather adverse wind systems. Variables and westerlies could have carried a canoe some way north, but then heading east on a long voyage against the trade winds would have been rather difficult.

Possible stepping-stones on voyages from New Zealand could have been islands to the north, especially the Kermadec Islands (500 nautical miles north-east of New Zealand) and even Norfolk Island (400 nautical miles north-west of New Zealand) which are well visible and close to New Zealand. Even though both islands were abandoned in the last 400-500 years they bear evidence of settlement from East Polynesia over some centuries in which New Zealand played some part (Irwin, 1992). A continuing contact in the form of one-way or two-way voyages after first settlement of New Zealand would explain the presence of New Zealand obsidian artefacts in these island groups (Anderson & McFadgen, 1990). Analyses of obsidian samples by Leach *et al.* (1986) have shown that some of the samples came from Mayor Island, Bay of Plenty, New Zealand, and the suggestion was made that this was prior to A.D. 1400.

2.2.4. Mode of settlement of New Zealand

Colonists to New Zealand brought plants and animals from the tropics to a relatively huge, temperate archipelago, mainly covered in forest and with abundant animal populations without the experience of human predation. Especially in the South Island, East Polynesians arrived in a land for hunting, fishing and gathering (Anderson, 1982). Gardening was probably started by at least one group of immigrants in their very first season, perhaps in a suitable microclimate in the North Island. Because of a climate harsher than that experienced in their East Polynesian home islands the bulk of the species of domesticates did not survive in New Zealand. Among those which would not have lasted are the coconut (*Cocos nucifera*), breadfruit (*Artocarpus altilis*) and banana (*Musa* spp.). Among the animals, pig (*Sus scrofa*) and fowl were absent which is barely surprising in a land that had plenty of marine resources and wildfowl (*cf.* Irwin, 1992).

Various comprehensive models of the mode of the colonisation of New Zealand have been conceived. Irwin's (1992) review on this subject allows the following summary: Caughley's (1988) model proposes a "patterned spread" or "rolling wave" of colonisation that spread both north and south from the north-eastern South Island (near Kaikoura), coinciding with a brief peak in local exploitation of moa and accelerating as it was driven by rising human populations. This model is close to the one suggested by Trotter & McCulloch (1984). Anderson & McGovern-Wilson (1990) point out that this model has nothing to say for the North Island, which lies much nearer to the source of colonists from Polynesia.

Furthermore, Caughley's (1988) model contrasts with a popular model of a fairly rapid coastal settlement, exploration and interaction as proposed by Green (1975), Bellwood (1978) and Davidson (1984). Their model has appeal for the North Island. As New Zealand is such a large archipelago it would have been hit again and again by early colonisers, almost as if for the first time, as colonisers shifted on the coast. The associated archaeological sites should be found near to where a canoe could be beached in shelter and with good access to a range of resources.

At quite an early stage, the activities of early settlers would become archaeologically visible, and sites showing the movement of distinctive industrial stone could signal the presence of their occupants like Lapita pottery did at an earlier stage in other parts of Near and Remote Oceania. Irwin (1992) concludes that present archaeological evidence does not sustain the idea of a long pre-visibility trail to the prehistoric population curve. Furthermore, the conspicuous evidence of bird extinctions at a rather late stage in the New Zealand colonisation history is itself an implicit argument against a “pre-Archaic” New Zealand of an extremely early colonisation.

2.2.5 Summary

The discovery and subsequent colonisation of New Zealand by people during the second half of the Late Holocene finished the long history of exploratory voyages into the vast Pacific Basin which had effectively started when the first modern humans crossed Wallace's Line into the island world of Ancient Near Oceania some time during the Late Pleistocene. Unlike other parts of East Polynesia which lie within the tropics, voyages to New Zealand proved to be more difficult. This is because of New Zealand's extra-tropical position within the South Pacific which necessitated voyages in generally more difficult weather systems. These rather adverse conditions required more advanced sailing strategies and navigational skills which could only be acquired by experimental voyages through the passage of time. This fact is often attributed to the relatively late settlement of the New Zealand archipelago.

However, in spite of the rather late settlement of New Zealand the exact date of arrival of people in the country is rather a matter of dispute. Utilising archaeological and (palaeo-) environmental evidence three different concepts about the date of first colonisation of New Zealand emerged: the Early hypothesis, the Orthodox model and the hypothesis of a Short prehistory. Their respective estimates of the time of human colonisation of New Zealand range from A.D. 0-500 (2000-1500 years B.P.), through A.D. 800-1000 (1200-1000 years B.P.) to post-A.D. 1200 (<800 years B.P.).

Even more contentious than the exact date of arrival of people in the country is the origin of its founder population. Based on archaeological evidence, in particular artefact assemblages, it is assumed that New Zealand was first settled from East Polynesia. As the Marquesas Islands currently have the oldest known archaeological sites in this part of the Pacific they are regarded as a potential source of the early colonists of New Zealand. However, due to the possibility of an even earlier settlement of the Society and Cook Islands, pre-dating that of the Marquesas, these two islands groups might also be potential source areas for exploratory voyages to New Zealand. The case of the Cook Islands as the possible geographical origin of early colonists of New Zealand is further supported by linguistic evidence strongly suggesting the Southern Cook Islands.

Taking into account archaeological and more recently even statistical considerations, the country's prehistoric population of New Zealand rather appears to be the product of multiple than single colonisation by only one group of people from any of the above East Polynesian island groups.

More uncertainty even surrounds the issue of how people settled the New Zealand archipelago once they had made landfall there. Despite various colonisation models, partially based on the timing of the exploitation of the country's natural resources (e.g. the avian megafauna), there appears to be no consensus about a possible pattern of movement of prehistoric people in New Zealand. Altogether the assumptions range from a patterned spread north- and southwards from a starting point near Kaikoura in the South Island to a rapid settlement of coastal areas in both main islands.

Finally, it can be concluded that despite intensive multi-disciplinary research into the subject of the human colonisation of New Zealand, including the exact date of arrival of people, the mode of their spread within both main islands as well as the exact place of first settlement still remains a matter of conjecture.

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Chapter 3

THE NEW ZEALAND PHYSICAL ENVIRONMENT

The New Zealand archipelago consists of about 700 islands with a total land area of 268,000 km², similar in size to that of the British Isles or Japan. The bulk of the New Zealand archipelago (99%) is mainly focused on the three main islands with adjacent smaller islands. This geographical unit is referred to as "mainland New Zealand" which extends about 1600 km from latitudes 34°25'S to 47°20'S. The east-west extent of (mainland) New Zealand is between 100 to 300 km, no place is more than 130 km from the sea, the coastline has a total length of about 15,000 km (see fig. 3.1). Furthermore, the country is very isolated: in a hemisphere centred on New Zealand, the only large continental landmasses, Australia and Antarctica, are at least 1600 km and 2200 km, respectively away. The rest, apart from Indonesia and the islands of the Pacific, is water.

Furthermore, there are also three outlying island groups, with a total area of 1876 km² (see fig. 3.2). They lie far in the subtropical north (Kermadec Islands), east of the South Island (Chatham Islands) and in the subantarctic south (Snares, Bounty, Antipodes, Auckland and Campbell Islands). These extend the latitudinal range of the New Zealand archipelago from 29°15'S to 52°30'S. Although these island groups merely constitute less than one percent of the overall size of the New Zealand archipelago they contribute substantially to the geographical and biological diversity of the country (*cf.* Coulter, 1975; Garnier, 1958; Lowe & Percival, 1993; Lowe, 1994; Maunder, 1971a; Molloy, 1994; Wardle, 1991).

3.1 Geology and tectonic framework

However, the above landmass of on-shore New Zealand constitutes only a minor portion of a substantially larger area of submerged continental crust, termed the "New Zealand subcontinent" or "New Zealand microcontinent". Its size substantially exceeds the extent of the New Zealand continental shelf. Kamp (1986, 1992) defines continental sea-floor

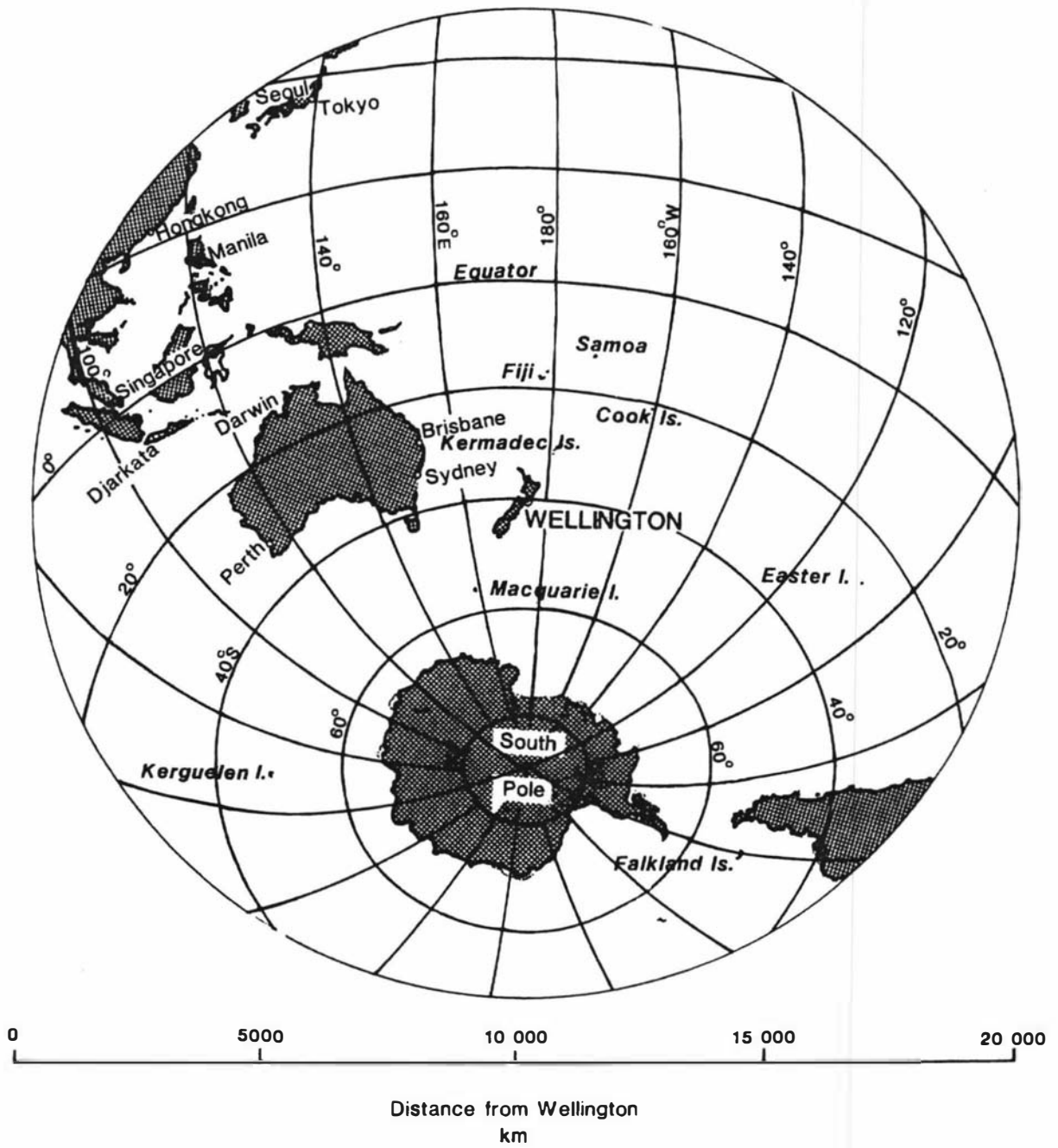


Figure 3.1: Geographical position of New Zealand in the South Pacific with the hemisphere centred on mainland New Zealand (after Wards, 1976; modified by Wardle, 1991).

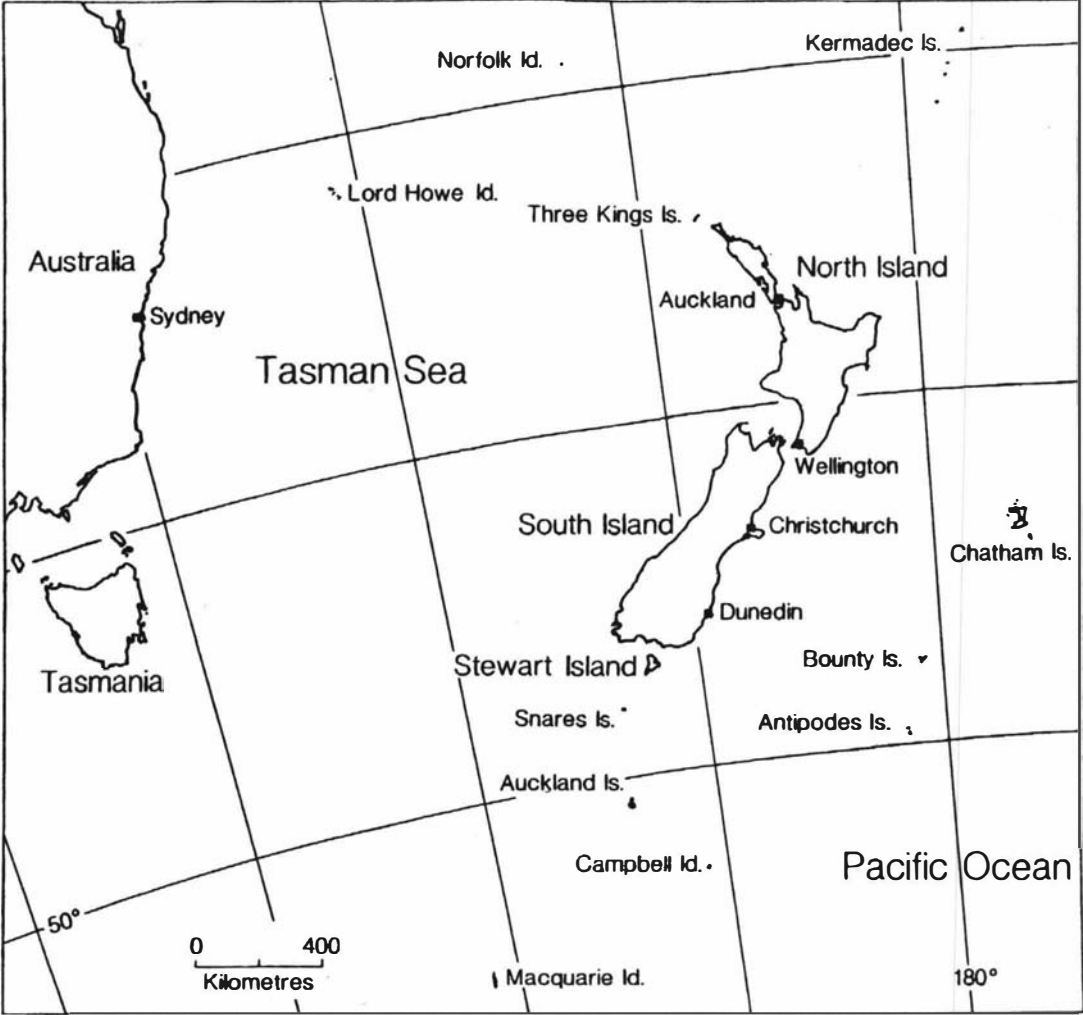


Figure 3.2: Mainland New Zealand with its outlying island groups (McGlone, 1988).

shallower than 2000 meters as the New Zealand subcontinent; Fleming (1975, 1978) even puts this depth to 3000 meters.

Anyhow, in compliance with Kamp's (1986, 1992) bathymetric statement of 2000 meters the New Zealand subcontinent includes the following structural elements comprising thinned continental crust: the modern New Zealand landmass; the Campbell Plateau²⁰; the Chatham Rise²¹; and the Lord Howe Rise²². This greatly generalised picture of the geological and plate tectonic setting of the south-west Pacific with the New Zealand landmass astride the boundary between the Indian-Australian and Pacific Plates, including the submerged parts of the New Zealand subcontinent is summarized in figure 3.3.

Broadly, the following structural elements are present in and around the New Zealand subcontinent: Active spreading ridges on-shore in the Taupo Volcanic Zone and off-shore forming the Havre Trough; convergent plate boundaries south-west of Fiordland in the South Island, forming the Macquarie Trench, and north-east of the North Island, constituting the Hikurangi Trench with its north-eastern extension the Tonga-Kermadec Trench; and strike-slip plate boundary on-shore in the South Island of New Zealand giving rise to the Alpine Fault. The Alpine Fault can be regarded as an on-shore link of the (Hikurangi-) Tonga-Kermadec Trench with the Macquarie Trench.

Had it not been for the active, obliquely converging, boundary between the Indian-Australian and Pacific lithospheric plates, which has evolved over the last 25 Ma, scarcely any part of New Zealand would be above sea-level (Kamp, 1992). This plate boundary, which bisects the NE-SW trending New Zealand archipelago, is marked by active seismicity and volcanic arcs (also see footnote #4), manifesting New Zealand's position as part of the Circum-Pacific Mobile Belt, conventionally known as the "Pacific Ring of

²⁰The **Campbell Plateau** lies south of the South Island. It is a broad undulating submarine surface at water depths ranging from 250 to 1250 m, with several rises covering areas less than 500m below sea-level. Its steep linear slopes on its western (Auckland Island Slope) and eastern (Subantarctic Slope) margins mark the transition of continental to oceanic crust.

²¹The **Chatham Rise** lies east of the South Island and extends for 1400 km east of Christchurch, locating the Chatham Islands at its western end. Water depths are less than 500 m over a width of 100 km across the rise.

²²The **Lord Howe Rise**, including its southern part, the Challenger Plateau lie north of the west coast of New Zealand. The rise is 2000 km long and ranges in width from 250 to 600 km. Its highest peaks are mostly 750 to 1200 m below sea-level, but it rises 2.5 to 3 km above the Tasman Basin.

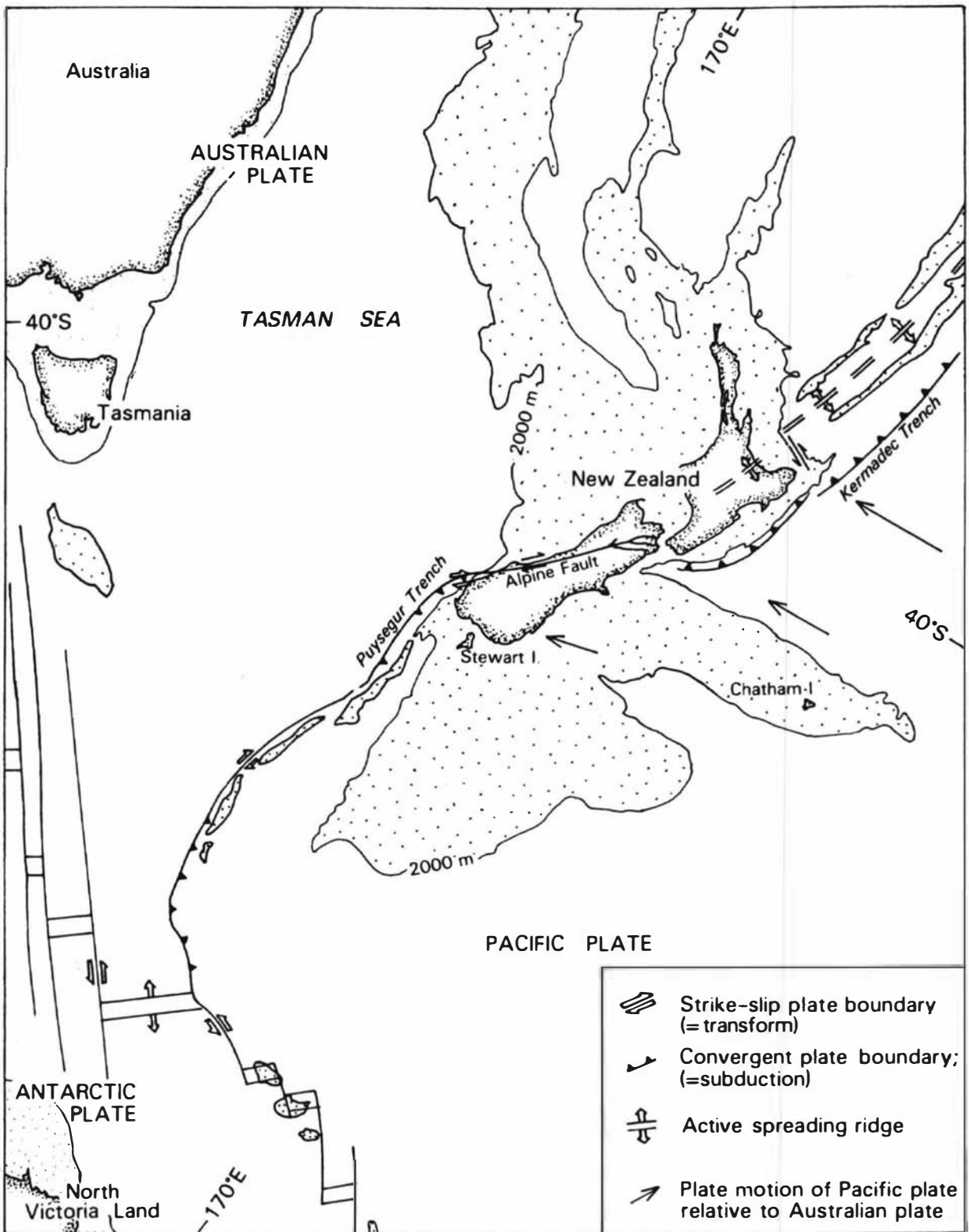


Figure 3.3: Generalised representation of the plate tectonic setting of the south-west Pacific with the New Zealand landmass astride the convergent plate boundary between the Indian-Australian and Pacific Plate. The stippled area surrounded by the 2000 meter contour represents the continental sea-floor constituting the submarine portion of the New Zealand subcontinent, comprising the Campbell Plateau and Chatham Rise on the Pacific Plate and the Lord Howe Rise and its southern extension the Challenger Plateau on the Indian-Australian Plate (after Kamp, 1986).

Fire" (e.g. Lowe & Percival, 1993; Lowe, 1994).

Despite its implications regarding the geological setting of the modern New Zealand landmass the geological evolution of the New Zealand subcontinent will not be discussed in this chapter. A generalised account of the geological history of New Zealand, partially including its marine and terrestrial biota are given by various workers. A few selected references on this topic are: Fleming (1975, 1978); Grant-Mackie (1988); Kamp (1992); Mildenhall (1988); Stevens (1980, 1985); Stevens & Ridge (1988); Suggate & Riddolls (1976); Thorndon (1985). Their accounts include the various stages and processes in the geological evolution of the country such as the various depositional phases in the respective geosynclines off the eastern margin of Gondwanaland; orogenies interspersing the phases of deposition; formation of volcanic arcs in these geosynclines due to subduction of oceanic crust east of them; rifting of the New Zealand subcontinent owing to the opening of the Tasman Sea because of sea-floor spreading; the breaking away of New Zealand from Gondwanaland resulting in the evolution of the unique New Zealand biota; and finally the establishment of the plate boundary between the Indian-Australian and Pacific Plates through the New Zealand landmass from the Miocene onwards.

Nevertheless, due to their far-reaching implications even involving the physical environment of the Northland study area in the far north of the country a brief summary covering the general aspects of the topography and geology, the distribution of soils and the climatic environment of the New Zealand archipelago is given below:

Probably the most conspicuous feature of the main islands of the New Zealand archipelago is its mountainous nature. Around 50% of the country's topography is classed as steep ($>28^\circ$), 20% moderately hilly ($12-28^\circ$), and 30% rolling or flat ($<12^\circ$), with the North Island being more hilly and the South Island dominated by steep lands (Lowe & Percival, 1993; Lowe, 1994; Molloy, 1993). Overall, 60% of the country is higher than 300 meters (Molloy, 1993, 1994; also see fig. 3.4).

The mountainous nature of the New Zealand landscape is undoubtedly best manifested in the NE-SW trending main mountain axis, commonly known as the "axial ranges",

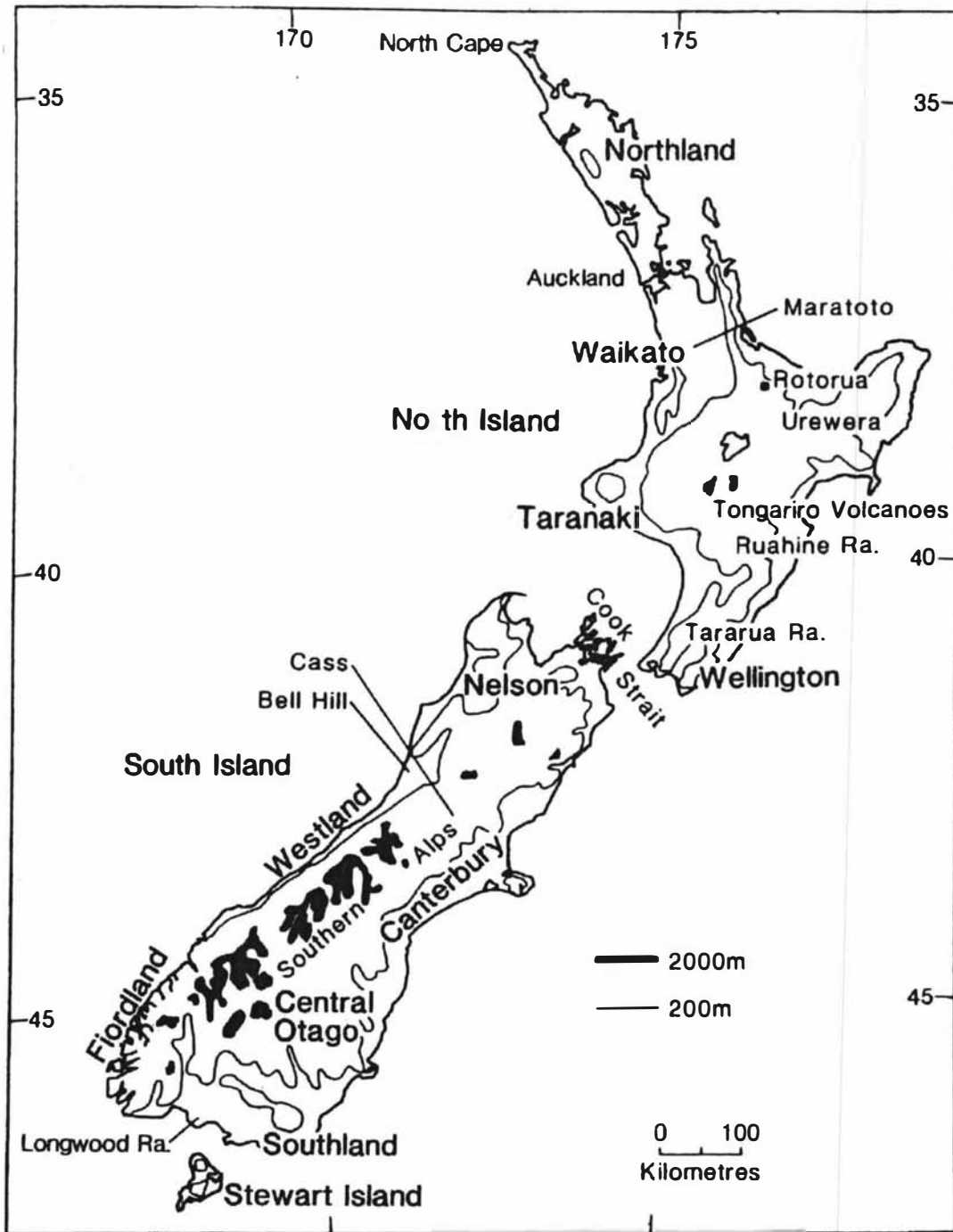


Figure 3.4: Generalised physiography of mainland New Zealand (McGlone, 1988).

extending from Fiordland in the south-west to the Bryant and Richmond ranges in the north of the South Island and from the Cook Strait to the East Cape in the North Island. Constituting structural elements of this axis are the high mountainous Southern Alps in the South Island. They form a continuous barrier over a distance of 750 km. The average elevation of this main divide is over 1500 meters; in the central part of the Southern Alps the mountains even rise between 3000 and 3700 meters above sea-level, with Mount Cook at 3764 meters being the highest elevation in New Zealand. In the North Island the mountain axis continues in the form of the substantially lower, rather hilly Kaimanawa-Raukumara and Ruahine-Tararua ranges. The characteristic feature of this divide is rapid tectonic uplift due to the interactions along the active convergent plate boundary (*cf.* Coulter, 1975; Kamp, 1992; Molloy, 1994; see fig. 3.4).

Much of the geological setting of modern New Zealand is a result of its location astride a convergent plate boundary. The evolution of this plate boundary gave rise to the still ongoing Kaikoura Orogeny with different implications in the main islands.

In the North Island the ocean-continent convergence led to the submersion of the southern part of the North Island giving rise to the formation of marine sedimentary basins. Apart from some smaller areas in the north almost the entire southern third of the North Island was submerged during the early Pliocene. However, in the late Pliocene and Pleistocene continuing tectonism due to subduction along the Hikurangi Trench east of the North Island led to the uplift of the main ranges and the inversion of the marine sequences deposited in the sedimentary basins. Further uplift of the crust occurs in the central and northern North Island. Unlike the south-eastern part of the North Island where uplift is driven by tectonic thickening due to subduction processes, uplift in the central and northern North Island originates from high heat flows and thermal elevation. Volcanism associated with these processes in the central North Island is of Quaternary age. An active volcanic arc of andesite and dacite volcanoes runs from White Island to Mount Ruapehu, a region known as the "Taupo Volcanic Zone". Characteristic features which are associated with this volcanic arc is a backarc region, northwest of the arc, which is characterised by a much-faulted basin-and-range topography including basement rocks and basic and rhyolitic volcanism. Furthermore, large multivent calderas occur immediately north-west

of the active volcanic arc. They are the sources of voluminous rhyolite lava and of pyroclastic deposits in the form of thick sheets of ignimbrites and widely dispersed airfall tephra. In summary it can be concluded that late Cretaceous-Cenozoic rock sequences, including volcanic ones, cover most of the North Island (Kamp, 1992; Lowe & Percival, 1993; Lowe, 1994; Stevens, 1980; see fig. 3.5).

In the South Island, in contrast, the continent-continent convergence across the transcurrent Alpine Fault dominates the tectonic scene, with rapid uplift and dissected relief being the result. Chronology and rate of uplift was not uniform over geological time. It started about 8 Ma ago at the southern end of the Southern Alps and only 5 Ma ago at the northern end (Kamp *et al.*, 1989) with the most rapid rate of uplift of about 10 mm/a in the central part of the Southern Alps (Kamp & Tippett, 1993; Tippett & Kamp, 1993). Consequently the late Cretaceous-early Cenozoic cover rock sequence has largely been removed, and therefore the landforms are developed in indurated pre-Upper Cretaceous basement rocks (Kamp, 1992; Lowe & Percival, 1993; Lowe, 1994; Wardle, 1991; see fig. 3.6).

Of particular significance in the recent geological history were the glaciations and sea-level changes of the Quaternary period. Due to the appropriate physiographic framework such as sufficient elevation and relief and structural features necessary for snow accumulation and the formation of alpine ice caps and major valley glacier systems glaciations had their greatest influence in the South Island (Lowe & Percival, 1993; Lowe, 1994). During the maximum of the last glaciation (*c.* 22-18 ka ago), an almost continuous glacier complex stretched nearly 700 km along the Southern Alps with snowlines lowered around 800 meters below their present positions (Porter, 1975). Glacial deposits such as glacial drift, outwash gravels, and loess were deposited in large quantities in inland basins and on both coastlines, with loess deposits especially abundant on the eastern side of the South Island.

In comparison with the South Island, glaciation in the North Island was minor and its distribution very limited. In the Tararua Ranges cirques and small valley glaciers occurred, and a small ice field is located on the central North Island volcanoes. However, periglacial

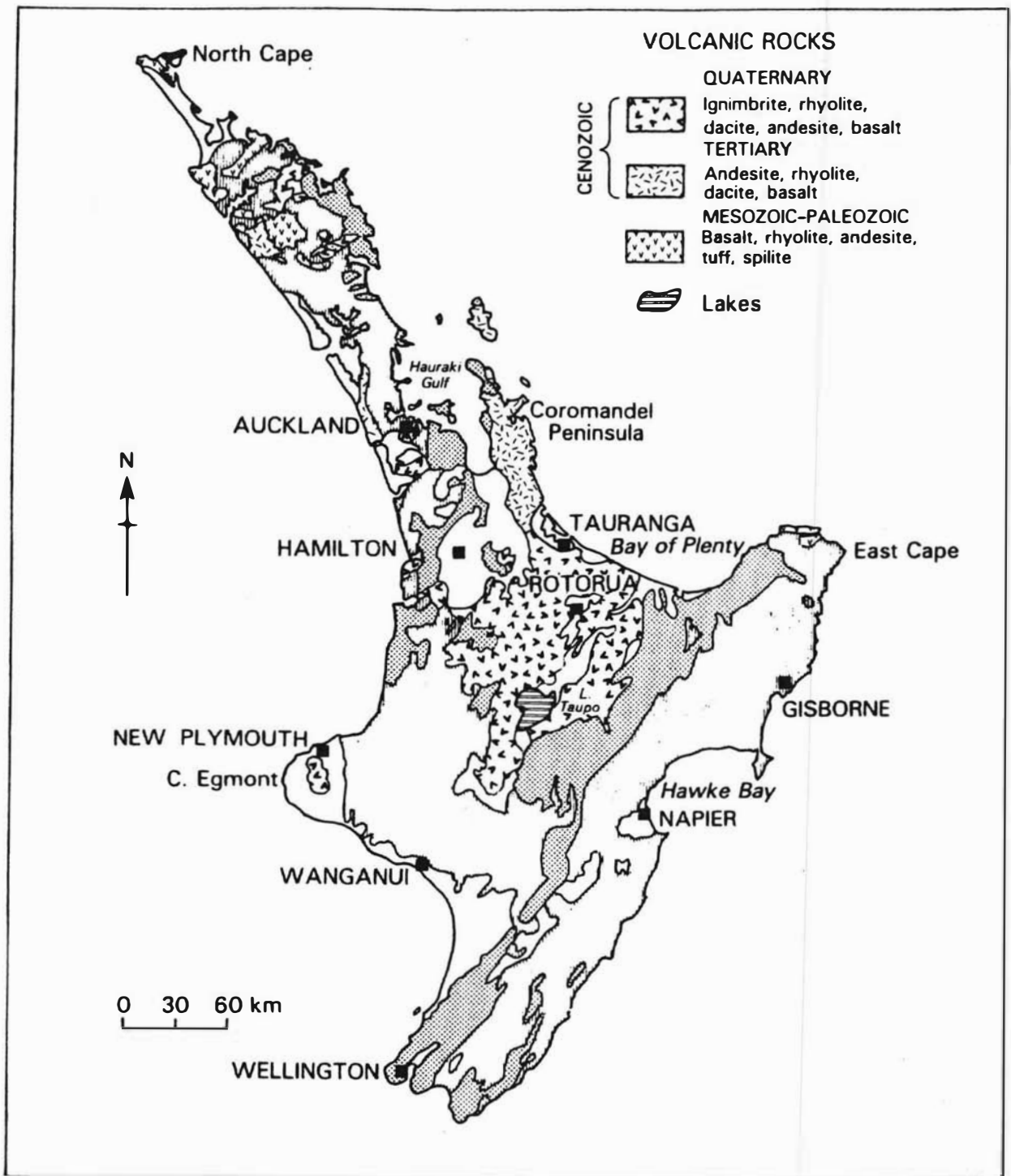


Figure 3.5: Generalised geology of the North Island, New Zealand. The map does not show surficial airfall deposits, particularly tephra, that cover much of the central North Island (Lowe & Green, 1987).

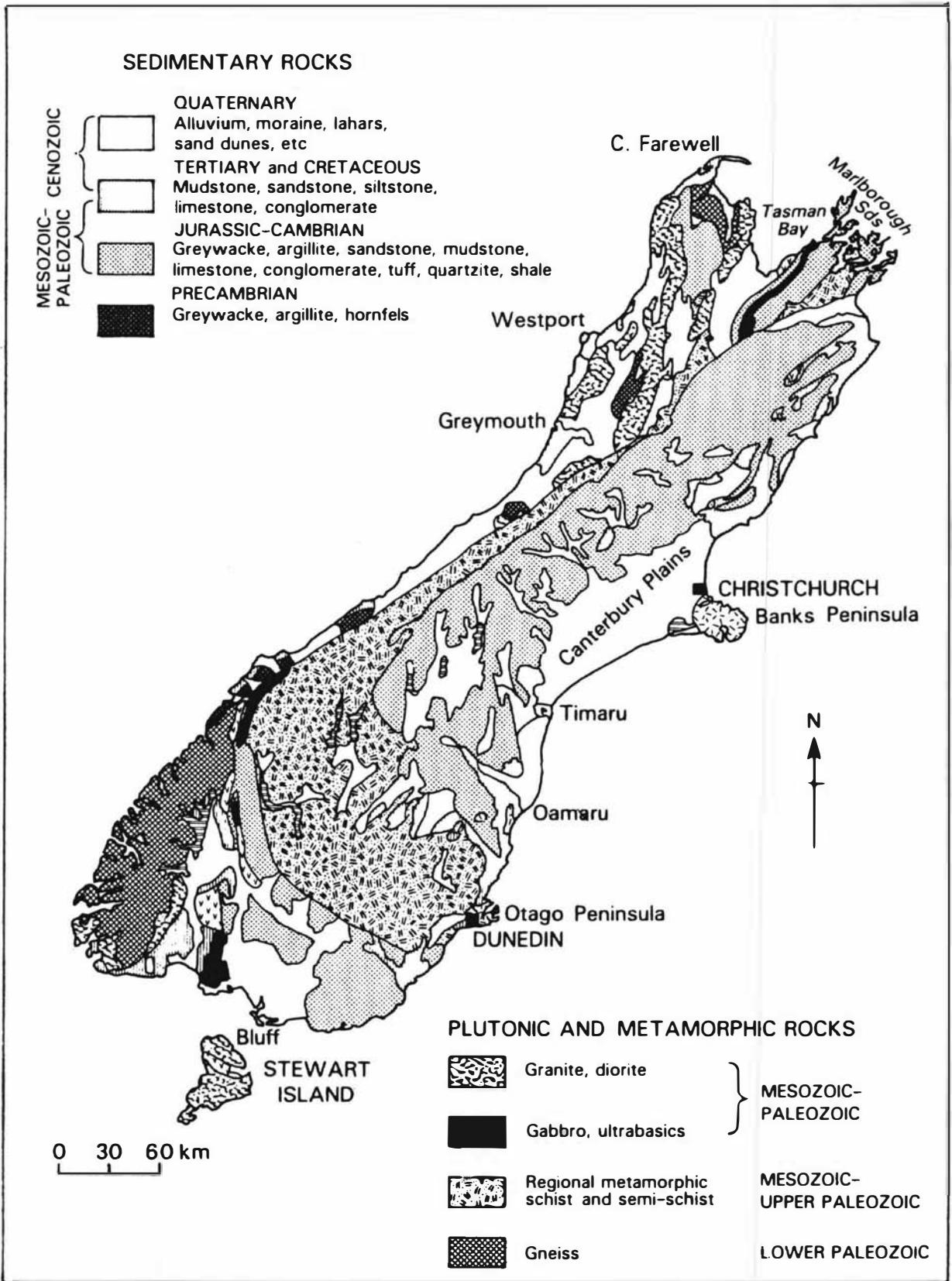


Figure 3.6: Generalised geology of the South Island, New Zealand. The map does not show surficial loess deposits that cover large areas of the eastern South Island (Lowe & Green, 1987).

activity, including severe fluvial and wind erosion at times, prevailed in much of the North Island, with the exception of the Northland peninsula in the far north. Among the airborne deposits loess sheets were laid down in the southern half of the North Island, and in parts of the central North Island tephric loess was deposited at elevations over 400 meters between airfall tephra units during the colder periods (Lowe & Percival, 1993; Lowe, 1994).

The combination of active tectonism, volcanism and high rates of erosion due to generally abundant precipitation and the generally steep topography of the country have produced a dynamic, sharp textured, and youthful landscape with a considerable landform variety. Almost all of the present landscapes are a product of the Quaternary period in particular of the second half of the Pleistocene and the Holocene (Pillans *et al.*, 1992).

3.2 Soils

The soil pattern of the New Zealand landscape is complex, resulting from a wide range of soil-forming factors such as soil parent material, topography, climate, biota, and length of time for soil development (Molloy, 1993; Taylor & Pohlen, 1968a,b). However, in this section no attempt will be made to give a detailed account of the latitudinal and altitudinal distribution of soil groups recognized in the New Zealand landscape. This information is given by Gibbs (1968) and Leamy & Fields (1976). Their accounts list the locations of the major soil groups recognized in the *New Zealand Genetic Soil Classification* [NZGSC] (Pohlen, 1971; Ruscoe, 1975; Taylor, 1948; Taylor & Cox, 1956; Taylor & Pohlen, 1968a,b) including information on the topography, geology and vegetation of these locations. Further references are also made to subjects like soil morphology and pedological processes within these individual soil groups as well as to their actual and potential land use.

However, a very general summary of the distribution of the main soil groups of New Zealand is given by Lowe & Percival (1993) and Lowe (1994) utilising U.S. *Soil Taxonomy* (Soil Survey Staff, 1975). According to that all ten orders of the U.S.

taxonomic classification are represented in New Zealand, but Mollisols and particularly Vertisols are very rare.

The general distribution of New Zealand's main soil groups appears to be best summarized by the 1:1,000,000 scale soil maps of the North (Rijkse & Hewitt, 1995) and South Island (Hewitt, 1995). Both maps incorporate the more recent *New Zealand Soil Classification (Version 3.0)* (NZSC) by Hewitt (1992) which supersedes the above NZGSC. Based on these maps along with Lowe & Percival's (1993) and Lowe's (1994) account on the distribution of the country's main soil groups²³ the following conclusions can be drawn: most New Zealand soils are relatively young owing to the on-going effects of tectonism, volcanism as well as glaciations in the recent geological past of the country. Consequently, most of these soils are of Quaternary age and the bulk of them had formed only since the beginning of the Holocene.

The northern North Island, however, constitutes an exception in this respect. Unlike the rest of New Zealand this part of the country largely escaped the effects of the Pleistocene glaciations. Consequently the soils are old, and in combination with a warm and humid climate formed deeply weathered and clayey profiles. Thus widely distributed in this environment are Ultic Soils (northern yellow-brown earths). Oxidic (northern red and brown loams) and Granular Soils (northern brown granular clays) occur too. Furthermore, Densipan Ultic (northern podzolised yellow-brown earths) and Podzol Soils (northern podzols) which are commonly associated with forest species that produce an acid litter [e.g. *Agathis australis* (kauri) and *Dacrydium cupressinum* (rimu)] are also present. A more detailed account on the soils of the northern North Island, in particular the Northland peninsula, is given in section 4.2.

In the central and western North Island most soils and buried palaeosols have formed within sequences of Quaternary airfall tephra deposits. Most widespread soils are therefore Pumice Soils (yellow-brown pumice soils) in the Volcanic Plateau and Allophanic Soils

²³In spite of the now widely used NZSC, soil designations based on the NZGSC still appear throughout the literature. For the purpose of correlation the main soil groups as recognized in the NZSC at "order" and partially "group" level (see Hewitt, 1992) will therefore also be given in conjunction with their respective NZGSC designations. The latter are stated in brackets.

(central yellow-brown loams) along the western margin of the Volcanic Plateau and in the Taranaki district around Mount Taranaki. Furthermore, a third major soil group in this part of the North Island are Brown Soils (central yellow-brown earths). This soil group which is the most extensive throughout New Zealand is present north-east of the Volcanic Plateau in the Bay of Plenty region and west and south-west of it forming a belt separating the above two areas of Allophanic Soils from each other.

Parts of the southern North Island often experience seasonal moisture deficiencies to varying extents. Apart from Gisborne on the east coast of the central North Island, for the southern North Island Maunder (1971b) recognises small areas of "slight to moderate" summer moisture deficiency near Napier, Palmerston North and Masterton. Soils typically formed under these conditions are Pallic Soils (central yellow-grey earths). They are present in southern Hawke's Bay, Manawatu and Wairarapa. Outside this area of summer dryness Brown Soils (central yellow-brown earths) dominate the southern North Island. They occur east and west of the Wairarapa and south of Hawke's Bay, respectively. Figure 3.7 illustrates the distribution of the above main soil groups in the North Island.

Apart from other environmental factors such as topography the soil patterns of the South Island are substantially influenced by its hydrological regime. Like the southern North Island the eastern South Island, for example, is also characterised by summer moisture deficiency. Those areas affected by "slight to moderate" moisture deficiency are a large area around and south-east of Blenheim, the coastal Canterbury Plains, the Mackenzie Country, and much of North Otago (Maunder, 1971b). These are dominated by Pallic Soils (central and southern yellow-grey earths). The very dry inland basins of Central Otago as well as areas in North Otago in the vicinity of Waimate and Timaru which experience "considerable" moisture deficiency (Maunder, 1971b) even gave rise to the formation of Semiarid Soils (brown grey earths).

The humid and superhumid regions along the west coast of the South Island (Nelson, Westland and Fiordland) constitute the opposite extreme. These environments led to the formation of mainly Podzolic Soils (southern podzol and gley podzols) which in places (e.g. Nelson, northern Westland and Fiordland) are interspersed with Brown Soils (central

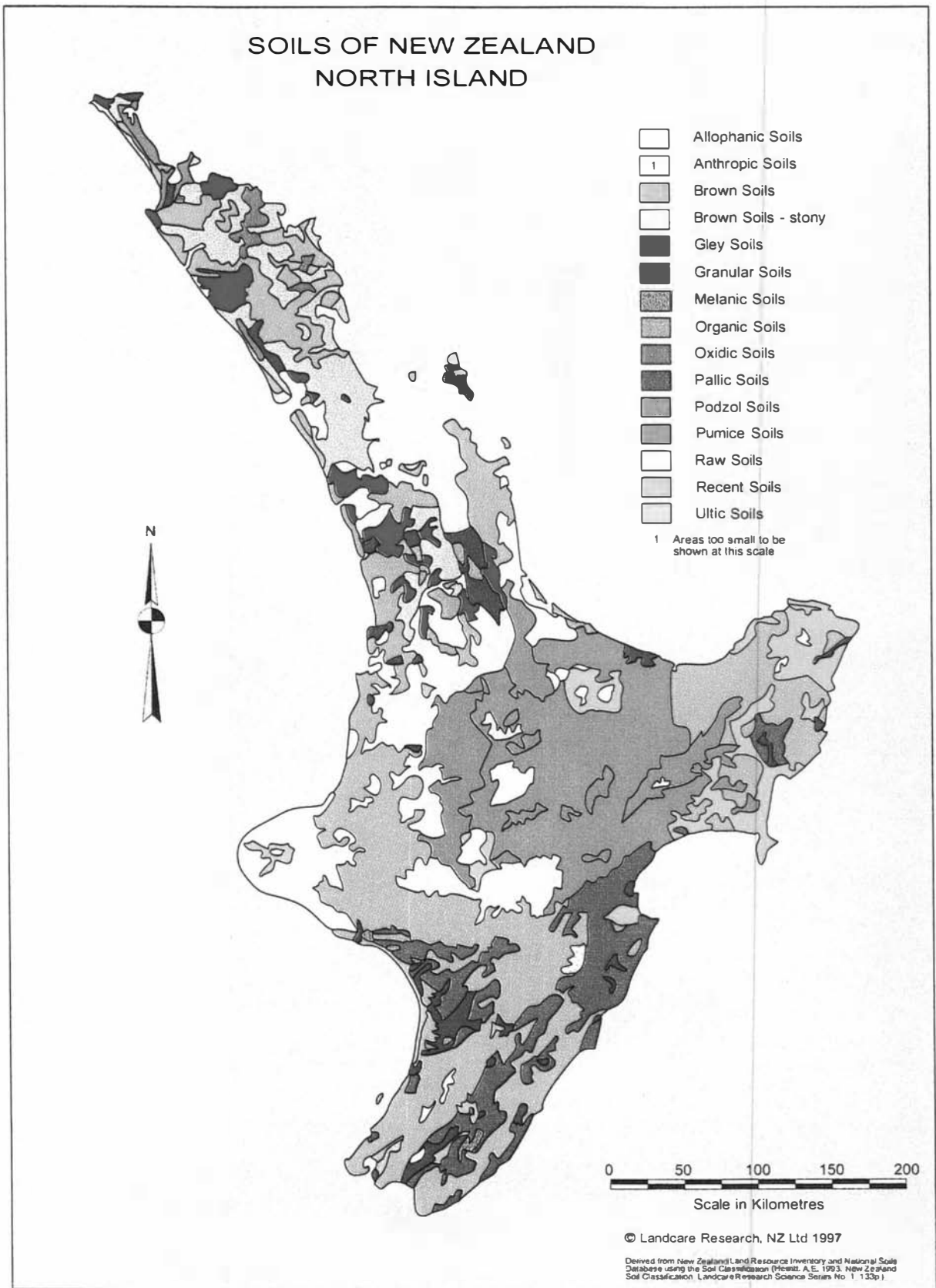


Figure 3.7: Distribution of soils in the North Island as recognized in the NZSC at "soil order" level (Molloy, 1998).

and southern yellow-brown earths).

Other humid parts of the South Island such as the central South Island east of the main divide of the Southern Alps as well as Southland are characterised by the occurrence of Brown Soils (central, high country and southern yellow-brown earths). They constitute the largest main soil group of the South Island.

The smallest main soil group present in the South Island is the group of Raw Soils (alpine bare rock, scree and ice). They comprise weathering products without any substantial horizon differentiation and only occur on the highest peaks along the main divide of the Southern Alps. Figure 3.8 shows the distribution of the main soil groups of the South Island.

3.3 Climate

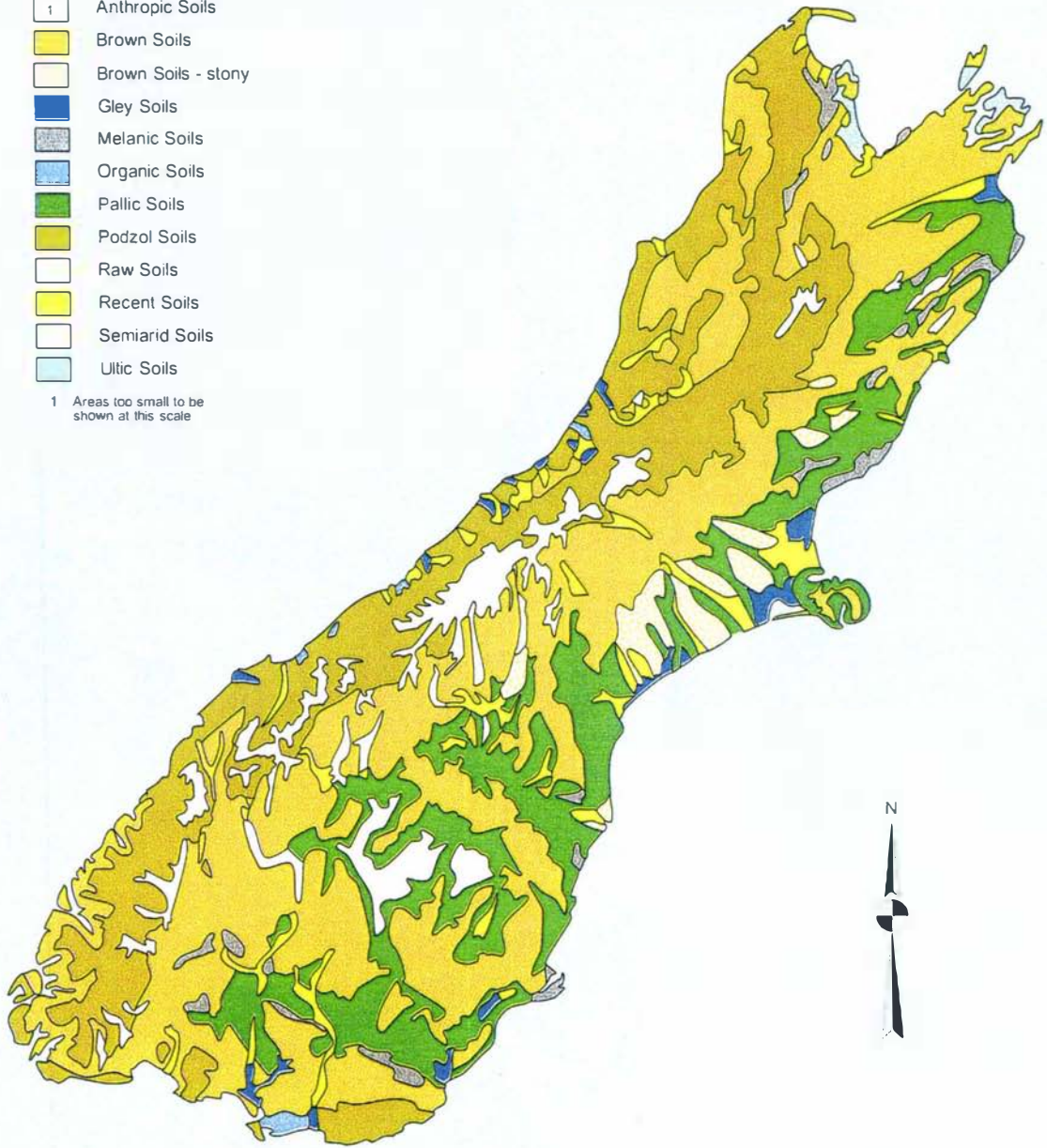
New Zealand is one of few sizeable landmasses south of 35°S. It is situated just poleward of the subtropical convergence zone and lies entirely within the zone of midlatitude westerly winds extending from 70°S to 30°S. Consequently, its climate is very much influenced by this predominant wind flow. The Kermadec Islands, however, constitute an exception to this. Due to their location in the subtropical north they are the only part of the New Zealand territory which is more influenced by south-easterly trade winds.

A conspicuous feature within this Australasian zone of midlatitude westerlies is the absence of a semi-permanent anticyclone, such as that which exists in the subtropical latitudes in the Indian and eastern Pacific Oceans. Instead, there is a continual eastward migration of anticyclones and depressions (cyclones), with their (often) associated cold and warm fronts. They produce much of the highly variable day-to-day weather over New Zealand. The weather patterns associated with the passage of such a system generally range from settled anticyclonic weather with light winds and clear skies to the usually unstable weather conditions of depressions and their associated fronts. The latter are characterised by cloudier conditions and increasing north-westerly winds of a depression and fresh to strong northerly-westerly winds and clouds in combination with moderate, or

SOILS OF NEW ZEALAND SOUTH ISLAND

- 1 Allophanic Soils
- 1 Anthropic Soils
- Brown Soils
- Brown Soils - stony
- Gley Soils
- Melanic Soils
- Organic Soils
- Pallic Soils
- Podzol Soils
- Raw Soils
- Recent Soils
- Semiarid Soils
- Ultic Soils

1 Areas too small to be shown at this scale



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 Derived from New Zealand Land Resource Inventory and National Soils Database using the Soil Classification (Hewitt, A E 1993) New Zealand Soil Classifier: Landcare Research Science Series No 1 (33P 1)

Figure 3.8: Distribution of soils in the South Island as recognized in the NZSC at "soil order" level (Molloy, 1998).

occasionally heavy, rain followed by colder showery conditions of a passing cold front. Often a regular pattern in the progression of these pressure systems and associated fronts prevails. The interval between successive anticyclones, depressions and associated fronts passing over the country is variable but re-occurs at approximately five to 10-day intervals.

Because of the country's isolation in a large area of ocean and because most areas are less than 100 km from the coast New Zealand's climate has a marked maritime character with strong westerly winds. A typical feature which is associated with that is humid conditions as the maritime air arriving from across the Tasman Sea is substantially moisture-saturated. This in turn has a moderating effect on the air temperatures. However, while the country's geographical position determines the general nature of the climate, its orography has a very dominant effect on the variations of the climate and wind flow within the country. The main mountain axes of the North and South Island act as orographic barriers which cause considerable altitudinal and latitudinal disturbances of the prevailing westerly winds. In the South Island, the continuous axial chain of the Southern Alps has a more profound effect leading to sharply differentiated climatic regions. In the North Island on the other hand, the climatic pattern is less strongly differentiated due to the substantially lower altitude of the eastern axial ranges. Nevertheless, due to these orographic disturbances of the wind flow a continuous cloud layer is rarely maintained for any great length of time resulting in low annual cloudiness and high levels of annual sunshine and solar radiation. Furthermore, the distribution of the precipitation pattern is also greatly altered by the orography of the country giving rise to regions which experience extremely high and extremely low annual rainfall, respectively (*cf.* Garnier, 1958; Lowe & Percival, 1993; Maunder, 1971a; Tomlinson, 1976; Wardle, 1991).

Utilising the widely recognized system of climatic classification by Köppen the above climatic features of the country including their orographic alterations classify most of New Zealand as a "warm temperate" *Cfb* climate (Garnier, 1950, 1958). Only four stations throughout New Zealand deviate from this overall picture and classify as *BSk'* (stations Alexandra and Ophir, central Otago), *Cfs* (station Waipiata, central Otago) and *Cfc* climates (station Chateau Tongariro, central North Island) (Garnier, 1950; Maunder, 1971c). However, apart from these four stations a climatic classification by means of the

Köppen system of classification identifies all New Zealand as a *Cfb* climate. Garnier (1950) argues that such a classification of the New Zealand climate is inappropriate as Köppen's scheme of classification does not clearly indicate the climatic differences between the various parts of New Zealand as outlined above. Consequently, other climatic classifications which subdivide New Zealand into climatic regions were devised. They are based on those factors (e.g. individual climatic elements, combination of certain climatic features, etc.) which exert a major influence on the local climate. A summary of the seven most common subdivisions of New Zealand into climatic regions, including the Köppen climatic classification, is given by Maunder (1971c).

However, without focusing on any particular climatic region of New Zealand a general outline of the main climatic elements constituting the New Zealand climate is given below. The information given is mainly obtained from Maunder (1971b) and Tomlinson (1976) and partially from Martyn (1992).

3.3.1 Wind

Because of New Zealand's position within the zone of midlatitude westerly winds the airflow above an altitude of 2000 meters is generally westerly. However, due to the physical nature of the country wind conditions in terms of direction and speed are extremely complicated near the surface. Generally, the prevailing westerly airflow during its passage over the mountainous areas from west to east, turns north-eastwards west of the ranges, and swings back towards the south-east, east of the ranges. Consequently, there is an increase in a south-westerly flow west of the ranges, giving rise to the south-westerlies in Westland. Accordingly, east of the main divide, in particular inland, north-westerly airflows are present, causing the north-westerlies in the inland districts of Otago and Canterbury. Along coastal eastern South Island, however, in such conditions the wind flow is usually north-easterly, mainly because of the funnel effect of Cook Strait, the only substantial gap along the axial ranges (see section 3.1). During the summer south-westerlies are almost as predominant as north-easterlies, mainly due to persistent sea breezes. If the westerly flow is sufficiently strong, Föhn conditions prevail in Canterbury.

Cook Strait, the only substantial gap in the main mountain chain, acts as a natural funnel. During westerly conditions the predominant wind direction through it is nearly always from the north or north-west, whereas strong south-easterly flows dominate in southerly to easterly conditions. North of Taranaki the general air flow is more south-westerly along with a noticeable reduction in windiness during summer months.

Near ground level superimposed on this broad pattern is the presence of sea breezes and Föhn and valley winds. Daytime sea breezes are particularly effective in the lowlands during the warm summer months. They occur especially in the Bay of Plenty, Hawke's Bay, Manawatu and Tasman Bay areas. Föhn and valley winds are only significant in the South Island and Föhn winds have their greatest effect during the winter.

3.3.2 Precipitation

The high moisture content of the maritime air arriving along New Zealand's west coast favours heavy rainfalls. However, its distribution throughout the country is highly uneven owing to the above great differences in altitude and relief of the landscape (see fig 3.9). Due to this the average annual precipitation (1921-1950) throughout New Zealand ranges from as little as 335 mm at Alexandra, Central Otago to as much as 7094 mm at Homer Tunnel, Fiordland. Both locations which represent the wettest and driest areas in the country are in the South Island. Such a spatial distribution of rainfall clearly demonstrates the remarkable control of precipitation by relief in the New Zealand environment. Mountain ranges exposed to westerly or north-westerly winds usually receive annual rainfall that is generally in excess of 2500 mm, and in some areas it even exceeds 10,000 mm. By contrast, in the lee of most mountain ranges precipitation is comparably low, with less than 500 mm in some areas of Central and North Otago. Comparably equally dry regions in the North Island which lie in a similar geographical position include areas of Hawke's Bay, Wairarapa and Manawatu, with an annual rainfall of 700-1000 mm. They constitute the driest areas in the North Island. The remainder of the North Island receives between 800 and 2800 mm annually, with areas in excess of 1500 mm chiefly in Northland (see below; section 4.3.2.2), North Taranaki and around East Cape.

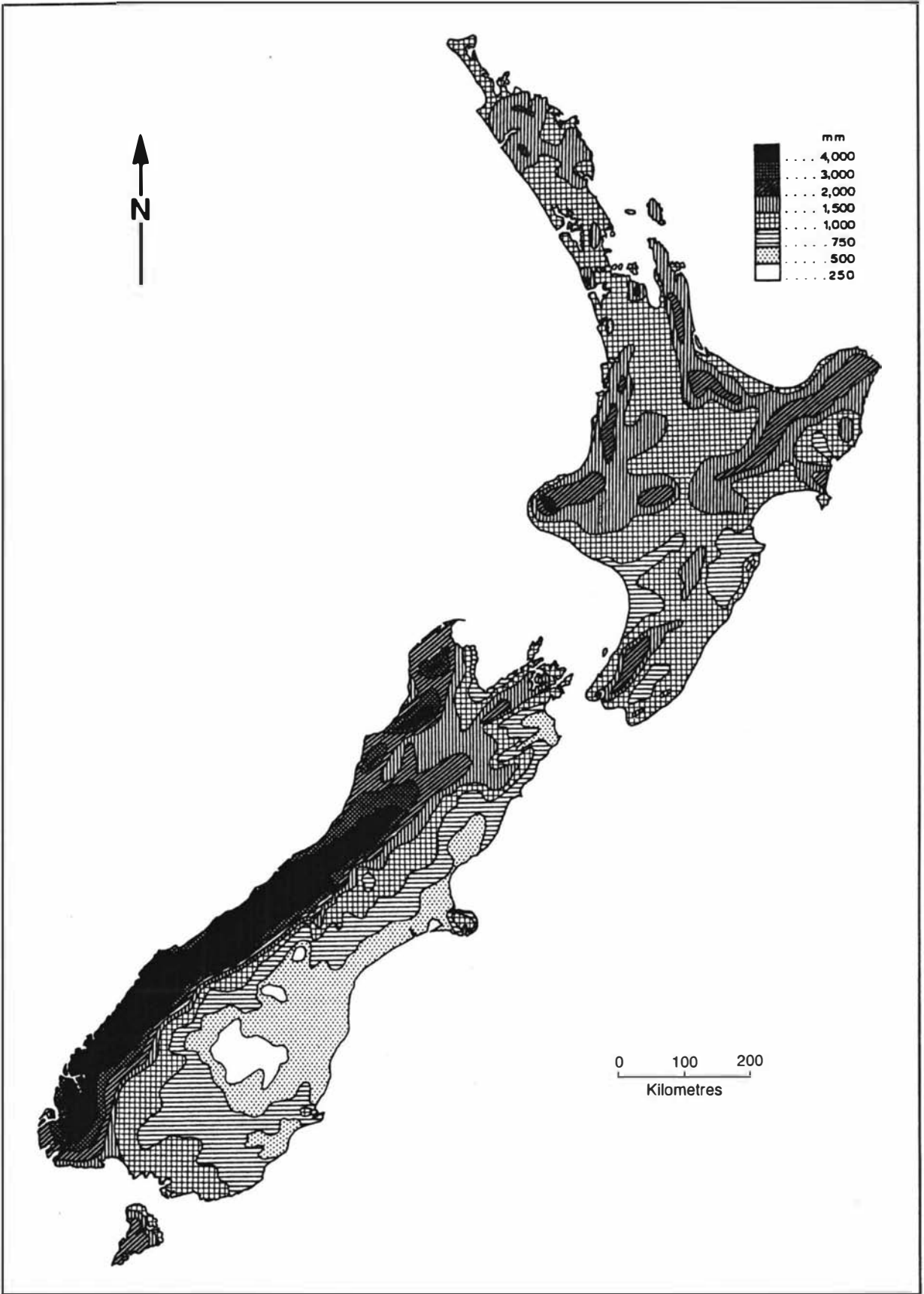


Figure 3.9: Mean annual precipitation (Hosking, 1977).

Nevertheless, the annual amounts of precipitation in the North Island are generally less than in the South Island. Anyhow, both islands display a general west-east rainfall gradient with higher annual precipitation on the west coast. In the North Island this trend is less prominent than in the South Island and a deviation from this general trend occurs in the Gisborne hill country and in the Coromandel Peninsula. These locations receive higher rainfalls than areas west of them mainly due to the effects of their topography on easterly to southerly winds.

Another feature of the average annual precipitation which shows appreciable differences between both islands is its temporal distribution. Over most of the North Island there is precipitation in excess of one millimeter between 100 and 150 days. In the South Island the corresponding figures are of more than 200 days in the Southern Alps, 150 to 200 days on the west coast and between 60 and 100 days west of the main divide over much of Central and North Otago, Canterbury and eastern Marlborough. The remainder of the South Island receives rainfall between 100 and 150 days.

The temporal distribution of the average annual precipitation appears to be very uniform over large portions of the country. Nevertheless, the greatest contrast in seasonal rainfall occurs in the northern North Island, where winter precipitation is almost twice as high as during summer. This predominance of winter rainfall progressively diminishes southwards. In the southern part of the South Island this effect even becomes reversed and more rain falls during the summer. Despite these local differences the average annual precipitation for the whole of New Zealand can be regarded as high and probably exceeds 2000 mm. However, large parts of the country only receive between 600 and 1600 mm.

3.3.3 Temperature

The mean annual temperatures (reduced to mean sea-level) exhibit a north-south gradient. They decrease from 15°C in the far north of the North Island to 12°C around Cook Strait and 9°C in the south of the South Island. The warmest month is January; July is the coldest (see fig. 3.10).

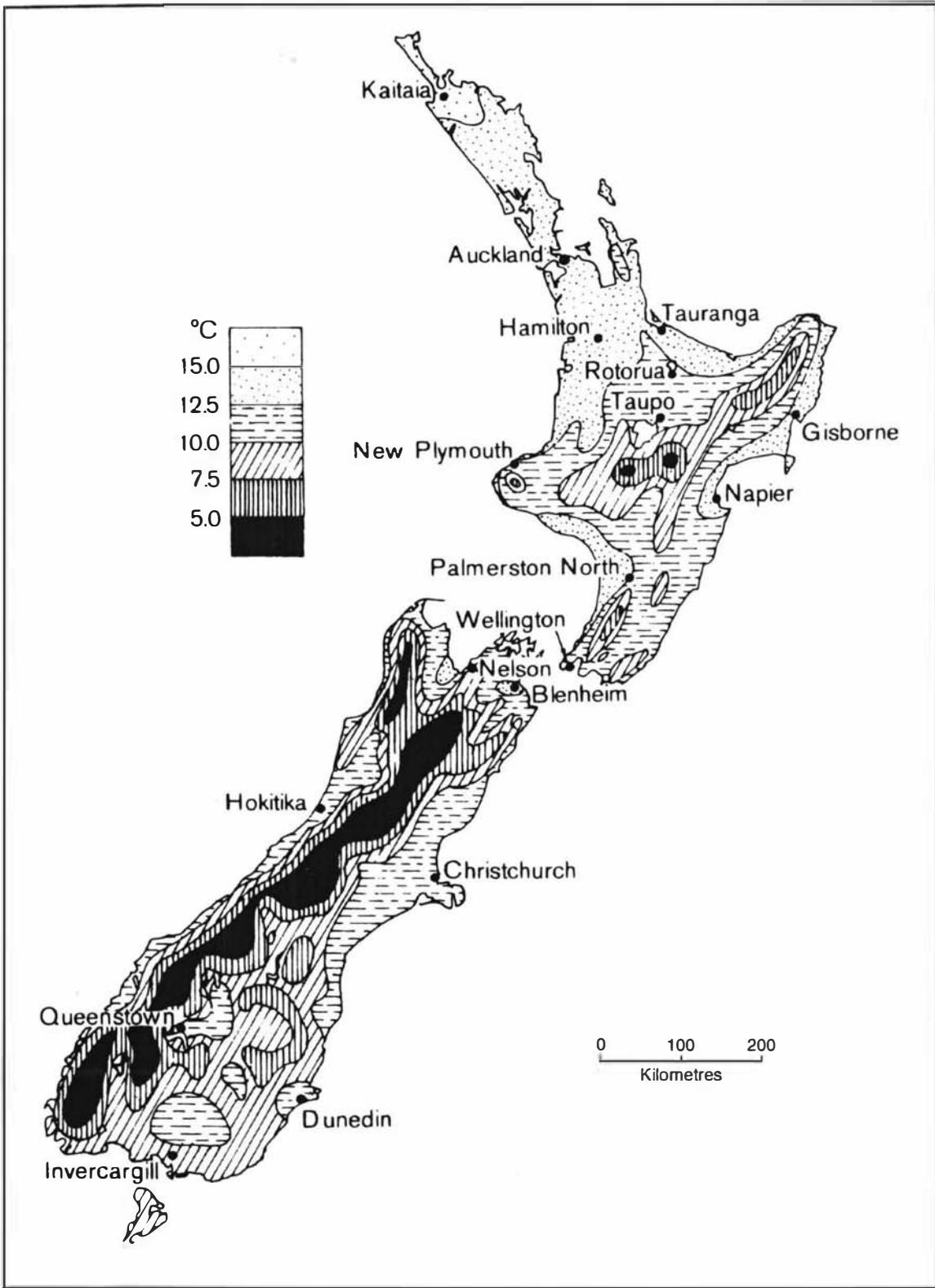


Figure 3.10: Mean annual temperature (Green *et al.*, 1987; after Tomlinson, 1976).

The mean daily maximum temperature (not reduced to sea-level) during January varies from 26°C at Kawerau, Bay of Plenty to 16.5°C at Chateau Tongariro, central North Island - both locations in the North Island. Corresponding temperatures for the South Island lie only 1.5°C below that for Kawerau and the lowest only 1°C higher than that at the Chateau Tongariro.

The mean daily minimum temperature of January (not reduced to sea-level) generally follows the pattern of the mean daily maxima, with higher minimum temperatures in the north and lower ones in the south and in inland areas of both islands. In the northern North Island at Cape Reinga and Mechanics Bay, Auckland, the mean daily minimum is 16°C, the highest in New Zealand. Lowest mean daily minima of 8.5°C and less are encountered in the southern South Island, with Naseby Forest, North Otago, recording the lowest in New Zealand, 6°C.

The mean daily temperature range of January (not reduced to sea-level) clearly reflects the topography of both islands. In the North Island low lying coastal districts in the far north, west and south-west have a relatively small temperature range, whereas in regions on higher ground like in the central North Island and east of the axial ranges, the range of temperature is substantially higher. For example Cape Reinga with a range of 5°C has the smallest diurnal range, compared with 14.5°C in the central region of the North Island (Waiotapu, Wairapukao, Minginui) and about 12°C around Hawkes Bay and Gisborne.

In the South Island the Southern Alps generate a clear east-west gradient with only very minor latitudinal alterations. The Föhn winds which are operational in the inland areas east of the main divide cause a more continental climate which leads to a noticeably higher temperature range than on the west coast. On the west coast the mean daily temperature range lies around 8°C whereas temperature ranges of 14.5°C are encountered in inland areas (Fairlie, Naseby Forest and Earnsclough) east of the main divide. The highest range of 15°C occurs in the Mackenzie Country, South Island, at Tara Hills (Omarama).

The mean daily maxima of July (not reduced to sea-level) show a similar spatial pattern to those of January. The coastal districts of the North Island receive substantially higher

mean daily maximum temperatures than inland areas. The northern North Island (Te Pahi Te Hapuna, Waipapakauri, Kerikeri, all Northland) receives mean daily maxima of 15.5°C as opposed to around 8°C in locations on high ground in the central North Island. In the South Island the mean daily maxima follow the above east-west gradient with temperatures of around 10°C along the bulk of the west coast and around 7°C east of the main divide. The lowest and highest mean daily maxima were encountered at Manorburn Dam in Central Otago (3.5°C) and in Blenheim (13°C), respectively.

The spatial distribution of the mean daily minima (not reduced to sea-level) of July resembles those of January. In the northern North Island the mean daily minima range from 4.5 to 6°C with the highest temperature of 9.5°C at Cape Reinga. With 0°C the lowest mean daily minima of the North Island are reached in the central North Island.

In the South Island the mean daily minima follow the usual east-west gradient. Along the west coast daily minima vary from 2 to 4°C whereas east of the main divide temperatures drop to -2°C, with the lowest mean daily minimum of -5.5°C at Manorburn Dam.

The mean daily temperature range of July (not reduced to sea-level) is almost identical to that of January. In the North Island the smallest diurnal temperature ranges occur in northern New Zealand (about 6 to 8°C) and the largest of about 12°C on higher ground in the central North Island. In the South Island with 8°C the smallest temperature range occurs along the west coast, whereas inland regions east of the main divide experience temperature ranges between 9 and 10°C.

3.4 Hydrology

Despite its relatively small size New Zealand is well-endowed with freshwater resources such as rivers, lakes, and wetlands²⁴. On a national scale rivers occupy approximately 294,600 ha, lakes 339,800 ha, and wetlands 311,300 ha (Scott, 1996). They are generated by high and regular rainfall which ranges between 600 and 1500 mm per year

²⁴**Wetlands** are defined as areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water whose water depth does not exceed six meters at low tide (Scott, 1996).

over most of the country (Duncan, 1992; also see section 3.3.2). These precipitation levels amount the total water resource of the country's rivers alone to about 300 km³/a (Waugh, 1992).

Although high and regular, due to orographic barriers in both Islands the above precipitation levels are not evenly distributed throughout the country (also see section 3.3.2). Extremes in annual precipitation vary from as little as 300 mm in the rainshadow of Central Otago east of the main divide of the Southern Alps to well over 10,000 mm in parts of the West Coast of the South Island. As the mountains in the North Island are lower, annual precipitation is a bit more uniform but in regions east of the Kaimanawa-Raukumara and Ruahine-Tararua ranges (also see section 3.1) still noticeably lower. Consequently, the eastern areas of both islands normally experience dry summers and are subject to seasonal moisture deficits (*cf.* Duncan, 1992; Waugh, 1992; also see section 3.3.2). Average annual rainfall in these drier regions averages around 600 mm (South Island) and 700 mm (North Island), respectively (Duncan, 1987; also see section 3.3.2).

These differences in the spatial ("east-west gradient") as well as temporal distribution ("north-south gradient") of precipitation (see section 3.3.2) are reflected in the hydrology of the country's surface water resources, in particular of rivers. This is because a river's flow regime principally reflects certain climatic elements, particularly precipitation and evapotranspiration, along with other parameters such as geology and vegetation cover of the catchment as well as human activities within the river's catchment. Commonly used indices to describe a river's flow regime include "variation of flows", "monthly flow" and "flow per unit area of catchment" ("specific discharge") (Duncan, 1992). Consequently, due to the complex geology, various climatic regions (see sections 3.1 and 3.3) and differences in vegetation cover throughout both Islands, New Zealand's rivers display a wide range of different flow regimes. They indicate the wide range of different types of rivers the country accommodates.

Duncan (1992) provides some general information about the flow regimes of New Zealand rivers. He argues that the probably best index to describe the variation of flows

of a river is its "coefficient of variation"²⁵ (CV). Values of CV for New Zealand rivers vary from about 0.55 to over 3, with low values indicating stable regimes with only little variation in flow. Based on the CV Duncan (1992) broadly subdivides New Zealand's rivers into four categories²⁶.

The following examples of rivers which fall into any of these categories including stated values for CV are taken from Duncan's (1992) work on the flow regimes of New Zealand rivers: rivers with little variations in flow ($CV < 0.85$) tend to be controlled by large lakes or are mainly spring-fed. Their flow is mainly baseflow, and there are very few small floods. The Buller River ($CV = 0.76$) at Lake Rotoiti in Nelson falls into this category.

Rivers which exhibit CV's from 0.85 to 1.25 tend to drain high rainfall areas. They have a high baseflow, but also frequent and large floods. Typical examples of this category are the rivers of the West Coast of the South Island such as the Ahaura River ($CV = 1.06$).

Rivers with greatest variations in flow ($CV > 3$) are subject to irregular precipitation. They experience long periods of low flow, low base flows, and large infrequent floods of short duration, such as the Whareama River ($CV = 3.37$) in the Wairarapa.

Rivers with CV's in the range from 1.25 to 3 have intermediate characteristics. A typical representative of this category is the Wairoa River ($CV = 2.4$) in Nelson.

Another suitable measure to evaluate the flow regime is the "mean flow" of a river. Of particular interest is the "monthly mean flow" as it describes the month-to-month variations in river flow. Duncan (1992) gives various examples of environmental parameters affecting the mean monthly flow. They include the regional differences in the seasonal distribution of rainfall, including the effect of snow melt during the spring

²⁵The "coefficient of variation of flow" (CV) is the standard deviation of the instantaneous flows (flows at a given instant in time), divided by the mean flow. The calculated figure has no units of measurement and provides a simple index of how variable a river's flow is (Duncan, 1992).

²⁶The four classes for coefficient of variation (CV) by Duncan (1992) are: $CV < 0.85$; $CV = 0.85-1.25$; $CV = 1.25-3$; $CV > 3$.

and summer thaw in the South Island. Further aspects are the effects of the catchment's geology on the discharge of groundwater into rivers, as well as the moderating effects of lake storage on a river's flow pattern.

Insights into specific aspects of a river's flow, e.g. low flow, mean flow or flood flow are gained by determining the "specific discharge"²⁷ of a river. Due to their strong association with the rainfall patterns within the catchment of a river more specific variations of "specific discharge" are derived. Frequently used derivatives are "mean specific discharge", "specific mean annual flood flows" and "specific 2-year return period 7-day low flows" (Duncan, 1992).

The "mean specific discharge" strongly reflects catchment rainfall. For the North Island rivers the range is 8 l/s/km² (equals 290 mm) to 101 l/s/km² (equals 3190 mm) for the Porangahau and Otaki Rivers, respectively. However, most of the catchments yield about 34 l/s/km² (equals 1070 mm) reflecting the relatively even distribution of rainfall over the North Island. The range for the South Island is noticeably wider. The Hakataramea River on the dry Canterbury Plains for example yields as little as 6.7 l/s/km² (equals 210 mm), whereas the Whataroa River on the superhumid West Coast reaches values of 310 l/s/km² (equals 9840 mm) (Duncan, 1992).

The "specific mean annual flood flow" reflects storm rainfall intensities. The highest rates for the North Island are for rivers in the northern part, as they are subject to storms originating from tropical cyclones (see section 4.3.1 and 4.3.2.2). Rivers which fall into this category are the Awanui (Northland), Motu (Bay of Plenty) and Waipaoa Rivers (Hawkes Bay). They have specific mean annual floods of 630, 1140 and 690 l/s/km², respectively (Duncan, 1992). Nevertheless, the bulk of the other North Island rivers have specific flood flows of about 300 l/s/km². With 60 to 70 l/s/km² the Waikato and Tarawera Rivers therefore rather constitute an exception in the North Island. This is because their flood regime is strongly modified by lake and groundwater storage in the

²⁷The "specific discharge", also known as "specific yield" is the flow per unit of catchment area, commonly expressed in litres per second per square kilometer (l/s/km²). It allows to compare directly the flows from different catchments, and can also be converted to depth of runoff in millimeter (mm). A river's discharge can therefore easily be compared with the rainfall within the catchment (Duncan, 1992).

pumice of the central Volcanic Plateau.

A more detailed summary of the above indices of flow regime of sixty of New Zealand's larger or economically more important rivers is given by Duncan (1992). In figures 2.3 and 2.4 he graphically summarizes the various aspects of mean flows and coefficient of variation along with some catchment information for sixty of New Zealand's larger or economically more important rivers. Further data for 96 smaller rivers can be found in Close & Davies-Colley (1990). More substantial information on further aspects of the flow regimes of New Zealand's rivers are provided by McKerchar & Pearson (1989) and Hutchinson (1990). McKerchar & Pearson's (1989) report is about annual maximum floods including related statistics for 343 rivers throughout New Zealand. Hutchinson (1990) on the other hand lists low flow magnitude and frequency from 428 sites nationwide.

Lakes constitute the second large group of New Zealand's freshwater resources. Due to the complex geological history with on-going crustal movements New Zealand has a diverse and dynamic landscape with a variety of different landforms (see section 3.1). These accommodate a wide range of different lake types. As the greater part of these landforms are only of late Pleistocene and Holocene age (see section 3.1) the lake basins formed within them are rather youthful. Another feature associated with the country's complex and dynamic geological and geomorphological evolution is the wide range of basin-forming processes which have occurred in both Islands. Spigel & Viner's (1992) list of lake-forming processes, including the construction of artificially dammed lakes, range from tectonic crustal movements (e.g. faulting, subsidence, uplift) over volcanic activity, glaciation, damming by landslides, river action, wind-blown scour and deposition, dissolution of limestone (karst lakes) to coastal bar formation. Such diversity is almost unmatched elsewhere in the world. In North America and Europe for example glacial action was the major cause of lake basin formation.

The variety and general modes of origin of New Zealand's lakes have been broadly known for some time. Earliest accounts on this subject date from the turn of the century (e.g. Lucas, 1904). Nevertheless, more recent work on general aspects of the origins and

development of lake basins in New Zealand was done by Gage (1975), Lowe & Green (1987), Healy (1975) and partially Spigel & Viner (1992). The subjects covered by these workers range from different aspects of lake morphology (particularly the work by Irwin, 1975a) to the mode of formation and distribution of the different types of lakes formed by the above processes. While Lowe & Green's (1987), Irwin's (1975a) and Spigel & Viner's (1992) work deals with all types of lakes which occur in New Zealand, Gage (1975) and Healy (1975) rather focus on glacial and volcanic lakes, respectively.

Based on their mode of origin lakes are commonly grouped in types of lakes. The probably earliest work of this kind was done by Davis (1882) who adopted a formal classification of the agencies which may produce basins, grouping them as "constructive", "destructive", or "obstructive". Hutchinson (1957) criticizes this kind of classification as it is somewhat artificial and tends to obscure the regional grouping of lakes. He argues that irrespective of the nature of the geological and geomorphological process of basin formation, in general lakes of a certain type will tend to occur in the same regions. The argument continues that glacial lakes, whether formed by destruction or obstruction, will generally be found in the same region, and volcanic lakes, however formed, in other regions.

Based on these points of criticism Hutchinson (1957) compiled the probably most complete classification of lake types comprising 76 types and a number of "subtypes" under eleven main headings²⁸. His classification only takes into account those geological and geomorphological events that actually determine that a basin can hold water.

Attempts by Gage (1975) and Irwin (1975a) to adapt Hutchinson's (1957) classification for New Zealand's glacial and volcanic-tectonic lakes, respectively proved to be inappropriate. Both authors argue that most of the country's glacial and volcanic-

²⁸The eleven **main groups** of Hutchinson's (1957) classification of lake types include: Tectonic basins; lakes associated with volcanic activity; lakes formed by landslides; lakes formed by glacial activity; solution lakes; lakes due to fluvial action; lake basins formed by wind; lakes associated with shorelines; lakes formed by organic accumulation; lakes produced by the complex behaviour of higher organisms; and lakes produced by meteorite impact. As the classification deals with lakes on a world-wide scale some of the types listed do not exist in New Zealand.

tectonic lakes are a product of the combined action of a variety of processes treated separately by Hutchinson (1957). Lowe & Green (1987) put forward that this feature certainly applies to some other lake types as well. Consequently, all classification systems which have been developed for New Zealand lakes take into account this polygenesis by only using a relatively small number of major subdivisions. More recent classifications considering all New Zealand lakes are those by Lowe & Green (1987) and Irwin (1975a,b).

Irwin (1975a,b) recognizes a total of nine main groups of lakes²⁹ which include the majority of the largest and best-known lakes in both Islands. His classification shows that there is a strong correlation between the lake types recognized and their geographical distribution (Irwin, 1975b).

Apart from some modifications Lowe & Green's (1987) classification basically retains the overall features of Irwin's (1975a). Their modified and slightly extended classification contains ten major lake types³⁰ which are also geographically grouped into distinct regions.

As Lowe & Green's (1987) classification of New Zealand lakes appears to be the most recognized it will be used for further references. Based on their classification they summarize the distribution of the different lake types as follows: Volcanic lakes are restricted to the North Island and most are found in the Taupo Volcanic Zone. Glacial lakes on the other hand only occur in the South Island. They appear to be the largest group of lake types in New Zealand. Of the 776 of all New Zealand lakes with a major dimension of ≥ 0.5 kilometre, Irwin (1975b) provides data for and using Lowe & Green's (1987) frequency data (tables 3A and 3B), they constitute 37.5% of all New Zealand and 61.1% of all South Island lakes and mostly occur at altitudes of >600 m.

²⁹The **major lake groups** in New Zealand recognized by Irwin (1975a,b) are: Tectonic basins, formed by earth movement; associated with volcanic activity; formed by glacial activity; formed by landslides; associated with swamps; formed by or associated with rivers; formed by wind; associated with shorelines (bar-type); man-made lakes.

³⁰Lowe & Green's (1987) classification includes the following **main lake groups**: Tectonic basins, formed by earth movement; associated with volcanic activity; formed by glacial activity (includes Antarctic lakes); formed by landslides; in phytogenic basins; formed by or associated with rivers; formed by wind-blown dunes; barrier-bar lakes, associated with shorelines; associated with karst landscapes; and man-made lakes.

The majority of these glacial lakes are small, high country tarns, although the largest South Island lakes are also glacial in origin and occur at lower altitudes. Most of the volcanic lakes are found at altitudes of >275 m on the central Volcanic Plateau, and on the average are larger than the other lake types. The North Island has a predominance of small (<5 km²) wind and river-formed lakes, found mainly at low altitudes (<90 m a.s.l.) along the west coast and in the lower reaches of the major river systems, respectively. Although existing wind-formed lakes are much less common in the South Island than they are in the North Island. Figure 3.11 further summarizes the geographical distribution of the different lake types in New Zealand recognized by Lowe & Green (1987). "Tectonic" and "phytogenic" lake basins which are also recognized in the above classification are not listed. Due to their marked modifications in various ways since their initial formation, they now appear under a different group heading (Green & Lowe, 1987).

3.5 Summary

The New Zealand archipelago is centred on three main islands which occupy a midlatitude position in the south-west Pacific Ocean extending from 34-47°S. The country's active tectonic regime, its recent volcanicity, and the effects of the Pleistocene glaciations, have produced a strongly dissected terrain with a generally youthful landscape with a variety of different landforms. Another unique feature of the islands of New Zealand is their geographical position astride an obliquely converging plate boundary between the Pacific and Indian-Australian plates. In the South Island the plate boundary is marked by the Alpine Fault that continues as the Hikurangi Trench east of the North Island. On-going transformational movements along this boundary gave rise to uplift which created the Southern Alps in the South Island and the axial ranges of the North Island. They both largely account for the high relief characteristics of much of the country, in particular in the South Island, where the highest peaks exceed 3000 meters. The geology of the main axial ranges is rather homogenous. In both islands they consist mainly of upper Palaeozoic and Mesozoic greywackes. The country's oldest rocks occur in the north-west and south-east South Island where mountainous terrain formed in hard, crystalline rocks of

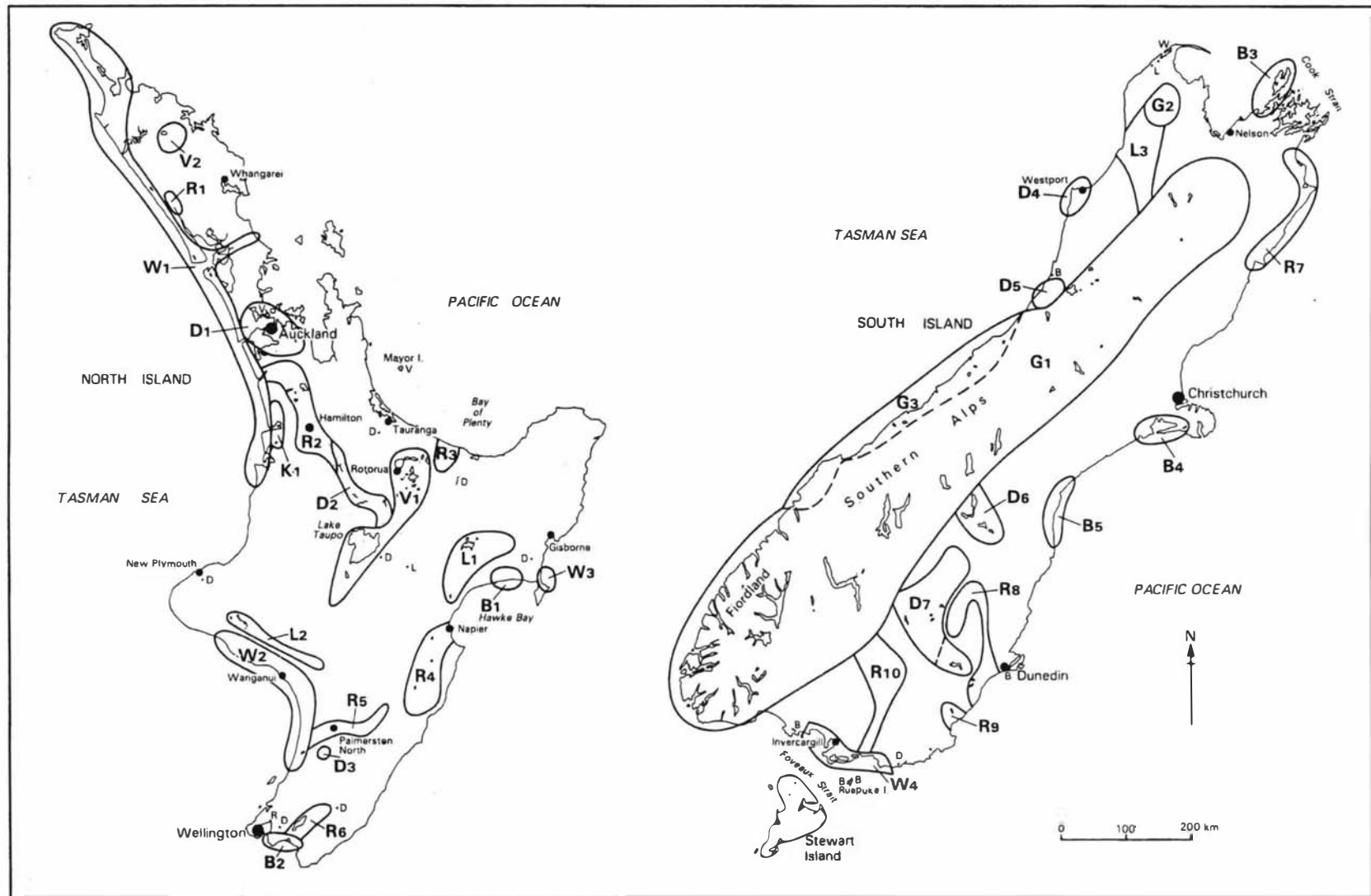


Figure 3.11: Distribution of lake types in New Zealand grouped into distinct districts according to their predominant geological and geomorphological basin-forming process. The letters used indicate the lake type: B (barrier); D (reservoir); G (glacial); K (karst); L (landslide); R (riverine); V (volcanic); and W (sand-dune) (modified after Green & Lowe, 1987).

Precambrian and Palaeozoic age. In the North Island rocks are generally younger, mostly of Cenozoic age which, in particular in the central North Island, are covered by Late Quaternary tephric airfall deposits.

The country's soil pattern is complex and reflects the influence of climatic factors in combination with vegetation, underlying geology, relief and length of time for soil development. Ultic Soils (yellow-brown earths) represent the largest and most extensive soil group. Podzol Soils (podzols) mainly formed under humid conditions and are widespread in Northland, as well as in the western and southern South Island. Pallic Soils (yellow-grey earths) occur in the drier districts of both islands. Soils particularly influenced by the underlying geology, i.e. azonal soils, are mainly found in the central North Island. Oxidic (red brown loams), Granular (brown granular clays) and Pumice Soils (yellow-brown pumice soils) are largely the product of soil development in solid and unconsolidated volcanic materials. However, despite the above complexity of the country's soil pattern the different soil groups share the feature of being relatively young. With the exception of the soils of the Northland region most of them are only of Holocene age.

New Zealand is one of the few sizeable landmasses in the southern hemisphere south of 35°S which lies within the zone of midlatitude westerlies. This zone is characterized by a continual eastward migration of anticyclones and cyclones. The weather patterns associated with this meteorological setting generally range from settled anticyclonic weather with light winds and clear skies to the usually unstable weather conditions of cyclones and their associated fronts. Based on this climatic framework most of mainland New Zealand classifies as a "warm temperate" *Cfb* climate. Generally, most of the country can be classed as cool or warm temperate. The country's main climatic features arise from its oceanic setting and the interaction of westerly airflows with the topographic barrier of SW-NE trending axial ranges. Consequently all climatic elements, in particular precipitation, show a considerable spatial variability. Average annual rainfall appears to be close to 1200 mm but precipitation is highest to the west of the Southern Alps, while to the east marked rainshadows occur. Surface winds from the westerly quarter prevail in all seasons and there is a tendency for these to increase in strength towards southern regions. Furthermore, superimposed on this general pattern is the presence of local winds in both

islands; they include sea breezes and Föhn and valley winds. Due to the orographic disturbances of the airflow a continuous cloud cover rarely exists for any great length of time leading to a high percentage of annual sunshine and solar radiation in most areas. The mean annual temperatures range from about 15.5°C in northern regions to just below 10°C in the south, with seasonal extremes being largely negligible. Even in the coldest areas temperatures rarely fall below -10°C. On the other hand the diurnal temperature range can be large, averaging up to 13.5°C in some localities.

Consequent upon its climatic regime and topography New Zealand is well-endowed with rivers lakes and wetlands. The spatial distribution of these surface water resources, in particular of rivers, clearly reflects the spatial as well as temporal distribution of the country's annual precipitation. The river's flow regime resulting from these climatic conditions, as well as certain geologic and vegetational parameters are expressed in a number of indices (e.g. variation of flows, monthly flow and specific discharge). Lakes constitute the country's second largest group of freshwater resources. Due to the variety of different landscapes New Zealand shows a wide range of different lake types which are rather young. Of the total of 776 lakes in New Zealand with a major dimension of ≥ 0.5 km, volcanic and glacial lakes constitute the largest groups of lakes in the country. While volcanic lakes are restricted to the North Island, glacial lakes on the other hand mainly occur in the South Island. Furthermore, the North Island also has a predominance of small wind and river-formed lakes along its west coast and in the lower reaches of the major river systems.

Due to its geographical position combined with its geological and physiographic setting New Zealand is uniquely situated to record climate-induced environmental changes over geological time. A welter of lake basins of varying dimensions throughout both main islands provide the kind of environmental archives which trap organic and inorganic materials associated with these changes. As for the country's most recent (geological) past as well as historical times these basins also provide a medium to record the effects of human-induced environmental changes.

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Chapter 4

THE PHYSICAL AND BIOTIC ENVIRONMENT OF NORTHLAND

4.1 Geology and physiography

Northland³¹, commonly also known as the Northland Peninsula, comprises New Zealand's northernmost region. It lies between the latitudes 34°S and 36°S and extends from the city of Auckland northwards to North Cape. The peninsula's total length measures about 300 km with a maximum width of less than 100 km across its widest point. Furthermore, no place in Northland is more than 30 km from the coast. This is mainly due to the existence of some inlets penetrating far inland (e.g. Davidson, 1982; Moir *et al.*, 1986; Shaw, 1964; see fig. 4.1).

The peninsula's most distinguishing features from the remainder of New Zealand are probably its orientation and greater distance from the active plate boundary. Unlike the rest of the country with its NE-SW trend, Northland's longitudinal axis exhibits a NW-SE orientation. Furthermore, due to its great distance from the active plate boundary east of the North Island (also see section 3.1) it is a more stable landmass than the rest of the North Island with little recorded seismic activity. There are no active volcanoes either, although volcanic deposits of Mesozoic and Cenozoic age occur throughout Northland. (Ballance & Williams, 1992; Kear & Hay, 1961; Spörli, 1989; Thompson, 1961).

4.1.1 Physiographic framework

Unlike the remainder of New Zealand, physically, Northland is rather unremarkable. There

³¹ Distinguished by a variety of names (e.g. North Auckland) in the past this peninsula has been known for many years as **Northland**. In 1949, however, this definition was finally confirmed by the Geographic Board. Administratively it comprises the local government counties of Otamatea, Hobson, Whangarei, Hokianga, Bay of Islands, Whangaroa and Mangonui (Shaw, 1964; also see fig. 4.2, inset).

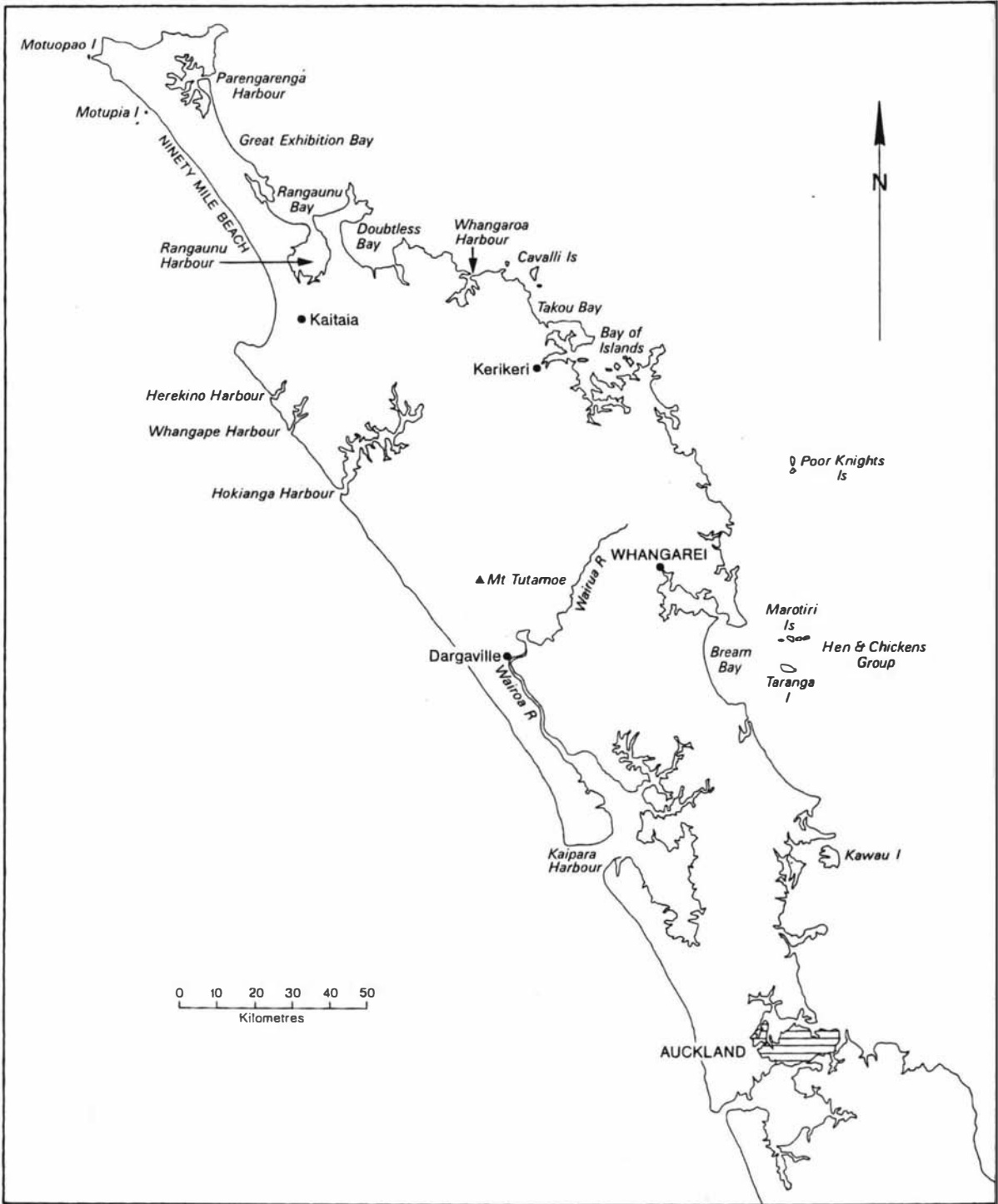


Figure 4.1: Map of Northland including locations mentioned in the text.

are no mountain ranges or isolated peaks of any great height and the peninsula's highest point is constituted in Mt. Tutamoe, about 20 km north of Dargaville, which rises 774 m a.s.l. Northland is characterised by its low relief, with the bulk of the region not exceeding 150 m above sea-level. With the exception of the Wairua and Wairoa Rivers, Northland's rivers are generally short and only have little hydroelectric power potential (Shaw, 1964; also see section 4.4).

Topographically the region's inland landscape is generally subdued and largely classifies as rolling hill country³², with some steeper hills. In many locations this feature is interrupted by many smaller rivers, inlets, and harbours. There are narrow river valleys and limited areas of flat land. The only extensive areas of flat, low-lying land are the Awanui flats, west of Kaitaia; the Ruawai flats, on the eastern banks of the lower Wairoa River; and a small area in the vicinity of Dargaville (Shaw, 1964; Davidson, 1982; Lister, 1976; see fig. 4.2).

The coastline of Northland is probably the region's most distinctive physical feature. It is extremely long in relation to the total area of the peninsula and shows a variety of different landforms. Both coasts, the east and west coast, differ substantially from each other.

The east coast is rugged and deeply indented by many inlets and bays. The largest of them are: Parengarenga Harbour, Great Exhibition Bay, Rangaunu Bay, Rangaunu Harbour, Doubtless Bay, Takou Bay, Bay of Islands and Bream Bay. Of particular value are certain inlets which form the inland extensions of many of the above bays as they act as natural deep-water harbours. The harbours of Whangarei, Bay of Islands, and Whangaroa are the largest of them. Interspersed between these inlets and harbours is the sharply indented coastline along which sandy beaches alternate with rock outcrops forming steep cliffs. Furthermore, there are also many small and fewer larger off-shore islands. The largest of those islands are: Cavalli Islands, Poor Knights Islands, the Hen and Chicken Islands (Marotiri Islands and Taranga Island) and Kawau Island. Another conspicuous feature of the east coast is the occurrence of mangrove swamps in the tidal estuaries and inlets, as well as in the shallower parts of the main harbours (*cf.* Davidson, 1982; Lister, 1976;

³²The slope angle of "Rolling hill country" is defined to range from 3 to 12° (e.g. Molloy, 1993; also see section 3.1).

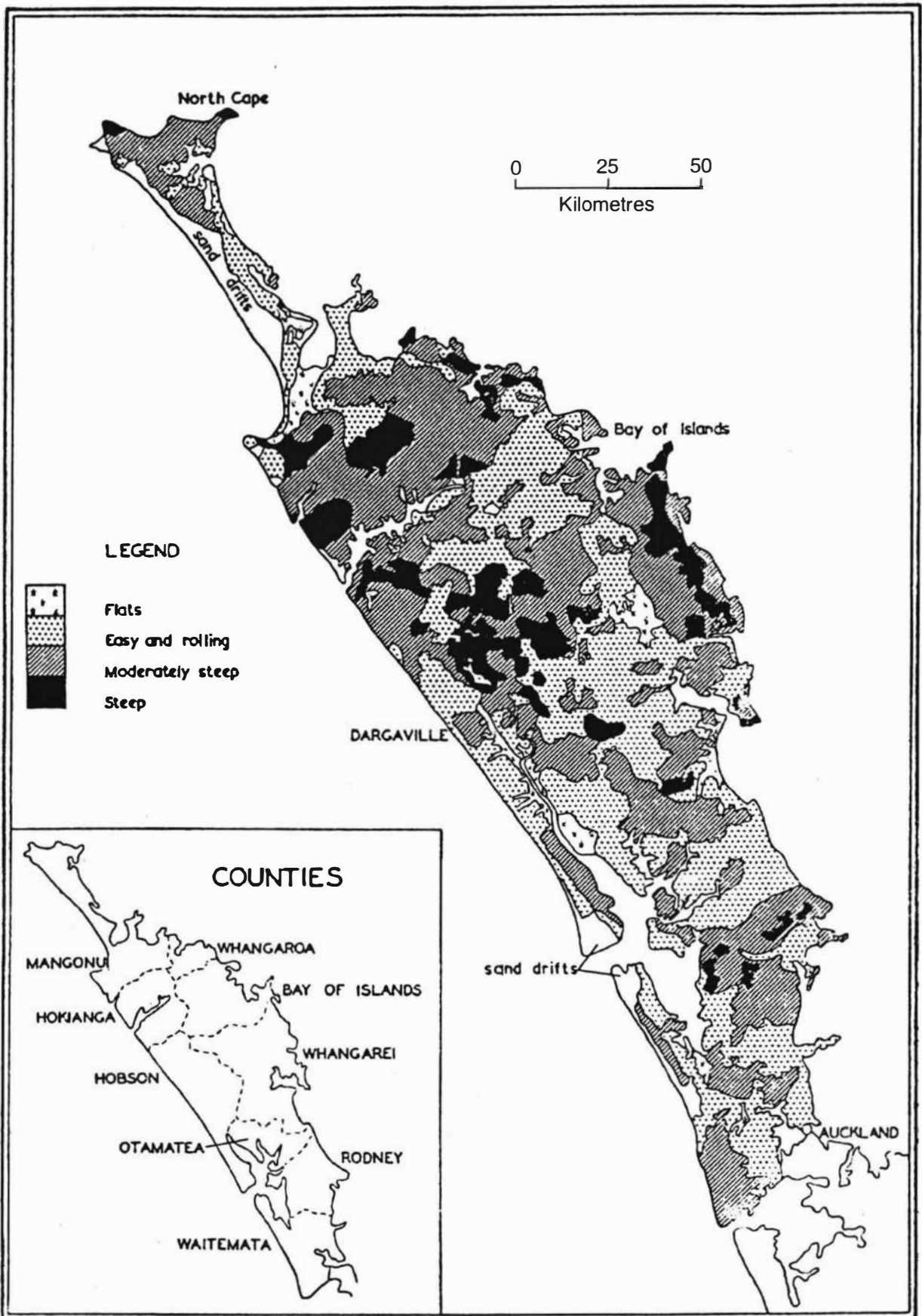


Figure 4.2: Topography of Northland (modified after Taylor & Sutherland, 1953).

Shaw, 1964 Molloy, 1994).

The west coast offers a noticeably different picture. The longshore drift of the Tasman Sea has led to the deposition of sandy material. They produce the characteristic long sandy beaches of Northland trending NW-SE in an almost straight line. Apart from a few volcanic outcrops they stretch almost uninterrupted from Kaipara Harbour in the south to the northern end of Ninety Mile Beach in the Far North. Two tiny volcanic outcrops, Motuopao and Motupia Island at the northern end of the Aupouri Peninsula form the only off-shore islands of the west coast which otherwise is completely devoid of islands. Due to the predominant westerly winds in this part of the southern hemisphere (also see section 3.3.1) extensive sand dune development often accompanied by the encroachment of sand inland is another marked feature in certain parts of the west coast. The homogeneity of the west coast is only interrupted by the occurrence of very few inlets. Unlike the east coast there are only four inlets on the west coast. The two major ones, the Kaipara and Hokianga Harbours, lie in the south; the two minor ones, the Herekino Harbour and Whangape Harbour in the north lie south of Tauroa Point. Although these harbours were invaluable during the last century as a means of access and communication, their use today is very limited due to their shallow depths and the formation of extensive sand bars across the harbour entrances (*cf.* Davidson, 1982; Kear & Hay, 1961; Lister, 1976; Shaw, 1964).

4.1.2 Tectonic architecture

At present, Northland lies some distance away from the active boundary between the Indian-Australian and Pacific Plates and experiences only little geodetic strain. Even though the Northland Peninsula trends NW-SE at right angles to the NE-SE trend of the rest of the New Zealand archipelago its underlying geological structure is believed to be a remnant of the original trend of the country dating from between 80 and 60 Ma ago, when the New Zealand subcontinent rafted away from Australia and Antarctica due to the opening of the Tasman Sea (Ballance & Williams, 1992). Since New Zealand moved into its current position astride the plate boundary in the Miocene (Spörli, 1989), except for the southern South Island, the rest of the country has been rotated to a north-easterly trend due

to shear between the plates. Northland, however, has not rotated, but the eastern North Island has been moved southward and rotated clockwise into its present position during the past few million years (Ballance & Williams, 1992). The present tectonic setting, with the Hikurangi Trough as an active north-west dipping subduction trench east off the central North Island (also see section 3.1), has only prevailed for the past two Ma. Prior to that a different tectonic regime was in place. The nature of the lithospheric plate arrangement during that time, about 25 to two Ma ago, was different from today's and the Tonga-Kermadec sector of the volcanic arc was active in Northland, causing earliest volcanism in this region. Ballance & Williams (1992) suggest that the subduction zone of the Kermadec-Tonga Trench which dipped south-westward at this time formed the north-west trending volcanic arcs in Northland. The associated volcanic rocks of these arcs are commonly known as the "Twin volcanic chains" (e.g. Smith *et al.*, 1989).

The exact nature of the plate arrangement around northern New Zealand at this time as well as its transition to the present regime is still an unsolved problem. Nevertheless, according to Ballance *et al.* (1982) it seems likely that much of the eastern North Island actually lay alongside Northland prior to about two Ma ago, before finally being moved southwards and rotated clockwise to assume its present position. Therefore, Northland can be regarded as a slimmed-down remnant of an old trend, with the 90° arc of the west coast between Taranaki and Cape Reinga following exactly the curvature of the geological structure (Ballance & Williams, 1992). Consequently, apart from these differences in trend Northland rather went through the same basic stages in tectonic evolution since the Late Permian like the remainder of New Zealand (Spörli, 1989). The establishment of New Zealand's current geographical position astride the boundary between the Indian-Australian and Pacific Plate therefore had the same implications for the geological evolution of Northland as for the rest of the country. The gross shape of Northland reflects its gross geological structure and tectonism undoubtedly has a fundamental control on the landforms and their development. Since these large-scale earth movements including their associated volcanicity only began in the Miocene the gross outlines of the present topography of Northland only stem from geological processes of the past 15 to 25 Ma (Ballance & Williams, 1992).

Superimposed on these gross tectonic and resultant topographic features are the geological events of the last two Ma. As Northland largely escaped the immediate influence of the Pleistocene glaciations the regions landforms are much older than anywhere else in New Zealand. In combination with a subtropical climate, with warm humid summers and mild winters (also see section 4.3) a strong weathering regime had fundamental impacts on the region's landform development. This feature is manifested in deeply weathered rocks giving rise to a well worn-down landscape and deeply weathered soils with clay subsoils, usually more than a metre thick. As the region experiences widespread, slow tectonic uplift the resulting combination of moderate to steep slopes and deep clay subsoils cause widespread slope instability leading to an environment particularly favourable to erosion (*cf.* Ballance & Williams, 1992).

4.1.3 Geology

Despite the imprints which geological events and processes during the Late Oligocene to Miocene as well as the Quaternary period left on the modern geomorphology of Northland, the region shared the same basic stages in its tectonic evolution since the Late Permian as the remainder of the country (see above). Spörli (1989) and Brook & Thrasher (1991) subdivide the geological history of Northland and northern Northland respectively into tectono-sedimentary episodes. The geological sketch map of the Northland-Auckland-Coromandel region in figure 4.3 shows the distribution of the rocks deposited during these episodes.

4.1.3.1 Late Palaeozoic to Mid Cretaceous

Spörli's (1989) earliest stage of the geological development of Northland embraces the period from the Late Palaeozoic to Mid Cretaceous. This stage is described as an accretional phase on the margin of Gondwanaland in a sedimentary basin which is commonly known as the New Zealand Geosyncline (e.g. Suggate & Riddolls, 1976). Fault patterns, partially inherited from Cretaceous rifting, divide these earliest rocks of

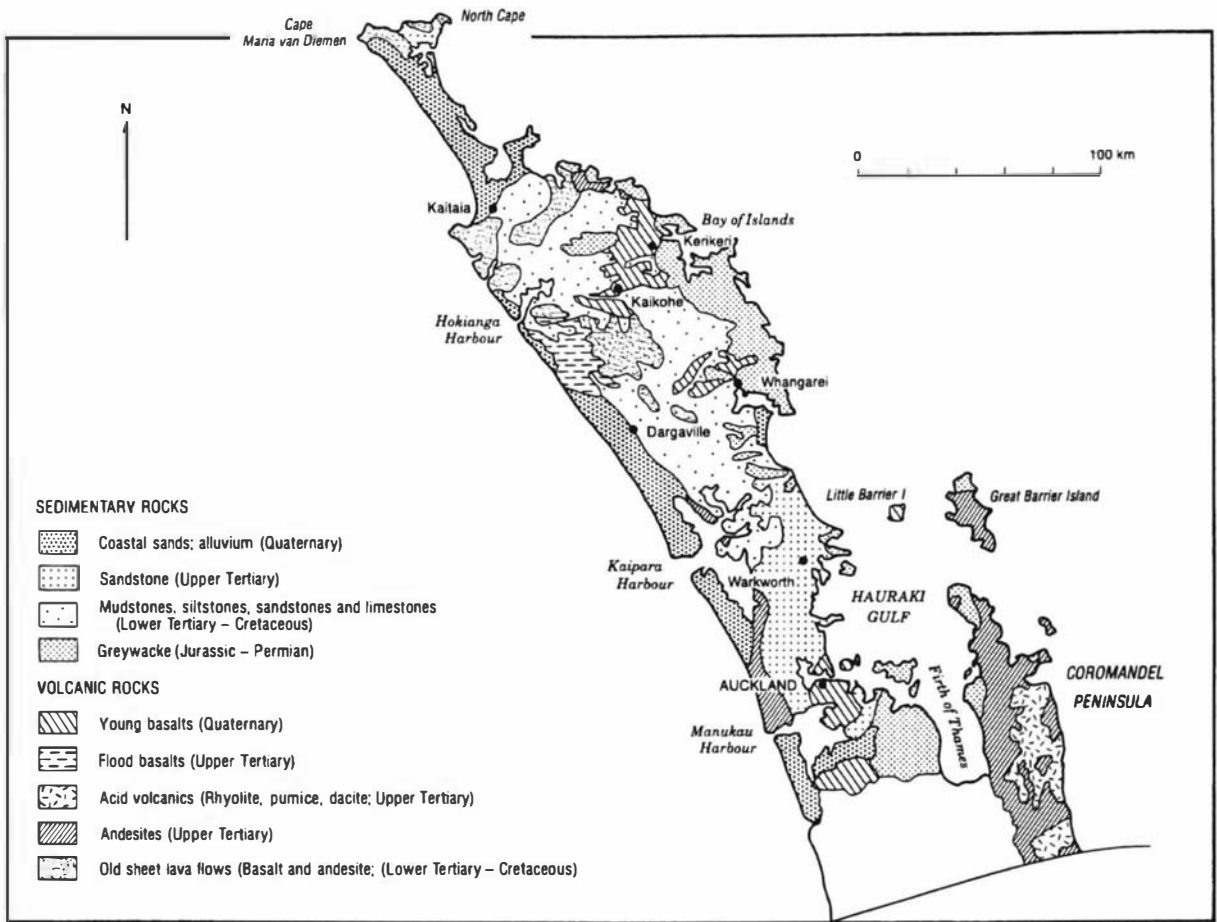


Figure 4.3: Generalised geology of the Northland-Auckland-Coromandel region

Northland into three segments: the Murihiku forearc terrane in the west; the ophiolitic Dun Mountain terrane in central Northland which runs parallel to the west coast; and the Waipapa terrane in the east. The Murihiku terrane and the Dun Mountain terrane are not exposed in Northland; the Murihiku terrane is entirely subsurface and the Dun Mountain terrane can only be detected geophysically (Spörli, 1989). Only the Waipapa terrane or group is exposed in Northland and forms the North Island's oldest rocks.

This belt of basement rocks with a thickness of several kilometers range in age from Permian in the north (Kear & Hay, 1961; Spörli, 1989) to Late Triassic and Early Jurassic (Spörli, 1989; Thompson, 1961) in the south. The group comprises thick complexly folded marine sedimentary rocks, predominantly greywacke and argillite with a broad zone in the central part of this belt containing much chert (Shaw, 1964). In the north these rocks are also intercalated with basic marine volcanics (Kear & Hay, 1961).

The distribution of the Waipapa group rocks along the east coast is quite substantial. The belt stretches from about Whangaroa Harbour southwards to Kawau Island, obscured in places by younger sedimentary and volcanic rocks. Between Whangarei and Bream Tail the belt is broken into fault blocks. Tertiary rocks once continuously covering them now only occupy the down-folded areas. Deep weathering has now reduced most of these rocks to brown clay, but some exposures of fresh rock can still be found in coastal cliffs and quarries. The complex folding and faulting these strata exhibit was probably inherited from the Rangitata Orogeny during the Middle to Late Mesozoic (Shaw, 1964).

Before the onset of major extensional tectonics caused by the rifting of the New Zealand micro-continent away from Gondwanaland (see below) the east coast of the North Island experienced some marine deposition (Spörli, 1989). For the Northland portion of the North Island Brook & Thrasher (1991) date this depositional event to Early Cretaceous times causing marine deposition of clastic sediments and intercalated basaltic volcanics on a north-eastern continental margin. These sequences which now form the Houhora Complex were probably thrust inshore to their present position during compressive tectonic events during the Early to Mid Cretaceous period (Brook & Thrasher, 1991).

4.1.3.2 Late Cretaceous to Oligocene

The following two of Spörli's (1989) tectono-sedimentary episodes of Northland's geological history are mainly marked by tectonic events. The first was the rifting away of the New Zealand micro-continent from Gondwanaland due to the opening of the Tasman Sea during the Late Cretaceous to Palaeocene. This event was preceded and accompanied by extensional faulting which led to thinning of the New Zealand crust to its present anomalous thickness of about 25 km. During this time Northland's characteristic, mostly subrectangular block faults with their NW-SE trending, rift-parallel faults were initiated. Following the Tasman Sea rifting the next tectonic event during the Eocene-Oligocene was the reorientation of rift systems to connect two new areas of sea-floor spreading, the Solander-Emerald trough in the south and the South Fiji Basin in the north.

4.1.3.3 Oligocene to Miocene

The fourth main stage in the geological evolution of Northland was the emergence of a new tectonic regime in Late Oligocene to Miocene times when New Zealand came to lie along the boundary of two convergent lithospheric plates. For New Zealand this tectonic event had two major implications: the establishment of the Alpine Fault in the South Island and the emplacement of the Northland Allochthon with the obduction of the Tangihua Volcanics oceanic crust (see below) in Northland at the end of the Oligocene (Spörli, 1989). The latter was the introduction of a vast sheet of soft marine sediments as well as resistant sea-floor volcanics of Mid Mesozoic to Early Tertiary age (Ballance & Williams, 1992; Kear & Hay, 1961; Shaw, 1964; Thompson, 1961). Ballance & Williams (1992) and Shaw (1964) summarise the marine sediments which had formerly rested against the north-eastern margin of Northland and lapped outwards onto old ocean crust as chiefly soft mudstones, including some resistant sandstones, siliceous claystones, and fine-grained limestones. The sea-floor volcanics are classed by Ballance & Williams (1992) merely as Tangihua Volcanics but also include petrologically similar volcanic rocks of the Wangakea Group (Kear & Hay, 1961; Shaw, 1964). Both the Tangihua and Wangakea Volcanics include resistant lava flows, pillow lavas, dikes, and breccias, mainly of basaltic

composition (Shaw, 1964); their age is described as Late Jurassic to Eocene (Kear & Hay, 1961).

Due to the inception of a new subduction trench along the north-eastern margin of the North Island the Northland region became subject to compressional forces. These forces caused the obduction of off-shore deposits leading to large-scale vertical earth movements. As a result the above deposits, resistant sea-floor volcanics of the Tangihua and Wangakea Group overwhelmed by soft marine sediments, which had formerly rested against the north-eastern margin of Northland were uplifted several kilometers and then gravitationally moved southwards over the Northland landmass. In the process of sliding into place the rocks which are collectively known as the "Northland Allochthon" (*cf.* Ballance & Spörli, 1979) underwent severe deformation which accounts for their substantial folding and faulting. Another unusual feature of the Northland Allochthon was their mode of movement into position. The uplifted sediments did not move as a single mass but rather slid off as successive slices, termed "thrust slices" or "nappes". Consequently, stratigraphically younger nappes from the top of the original sediment pile slid off first and were buried by stratigraphically older material in successive emplacement phases. Thus the nappes deposited in this mode occur in a stratigraphically reverse order, with the youngest deposits in the bottom, and the oldest in the top nappe (Ballance & Williams, 1992). More detailed information on the genesis, distribution, stratigraphy, petrology, chronology and petrology of the Northland Allochthon is given by Ballance & Spörli (1979).

Therefore, the older more resistant volcanic rocks now occur on the surface whereas the younger marine sediments are buried underneath. This feature had far-reaching implications for the development of landforms. The resistant volcanic rocks now form large mountainous masses. Due to the breaking up during the sliding process of the original sheet of rock they now occur in the form of several isolated ranges. They are among Northland's most prominent relief features such as the Tangihua, Mangamuka, Mangakahia, Whirinaki, and some other minor ranges. These steeply sloped and rugged ranges are characterised by rising sharply from the surrounding undulating lowlands with gentle to moderate slopes of soft, less resistant marine sediments of the Northland

Allochthon (Ballance & Williams, 1992; Shaw, 1964).

Another two volcanic units of the Northland Allochthon are the Mount Camel Volcanics and the North Cape Ultramafites. Both units which were dated to Clarence age (Early Cretaceous) exclusively occur in the northern half of Northland (Kear & Hay, 1961). The Mount Camel Volcanics are very similar to the rocks of the Tangihua and Wangakea Volcanics, but include spilitic lavas and keratophyres with interbedded greywackes and argillites. Geomorphologically they appear as the Three King Islands, Mount Camel and also form parts of the Karikari Peninsula as well as the south-eastern part of Doubtless Bay (Shaw, 1964; Kear & Hay, 1961). The North Cape Ultramafites are a group of ultramafic rocks which include varieties of peridotite, serpentine, and gabbro. Their distribution is rather limited as they only occur in two locations in Northland, at North Cape and Cape Kerikeri.

The Northland Allochthon in its entirety extends northward from between the mouth of the Waikato River and Pokeno along the western side of Northland to beyond North Cape. Nevertheless, since its emplacement much of it has been either eroded away or buried by younger deposits. Therefore, it now only outcrops mainly in the north-western part of Northland between Kaipara Harbour and Kaitaia (see fig. 4.3) (Ballance & Williams, 1992).

During the Early Miocene obduction changed into subduction and two volcanic chains were established (Smith *et al.*, 1989), one along the east coast of Northland, the Northland-Coromandel chain, the other along the west coast, the Waitakere chain (Ballance & Williams, 1992; Spörli, 1989).

The Waitakere chain left voluminous deposits of lava, breccia, and conglomerate which extend from the mouth of the Waikato River northward through the Waitakere Hills and Kaipara Harbour to Waipoua Forest (Ballance & Williams, 1992). However, as the Waitakere chain is buried mainly by Quaternary sediments its deposits do not occur at the surface as a continuous chain. They rather outcrop as petrologically different volcanics in two locations: in southern Northland along the eastern shores of the Kaipara Harbour as

the Manukau Breccia and in northern Northland in the region around Waipoua Forest as Waipoua Basalt (Thompson, 1961). According to Thompson (1961) the Manukau Breccia consists of andesitic agglomerate, pumice breccia, flows, pillow lava, and dykes of Oligocene-Miocene age. The Waipoua Basalt is described as a plateau-forming flood basalt which probably includes correlations of the Manukau Breccia. Due to uncertain stratigraphic boundaries the age of this basalt is assumed to range from Miocene to Pliocene.

The Northland-Coromandel chain produced equally voluminous deposits, but in Northland and Auckland they have mostly been eroded away. The only large remaining areas are around Whangaroa Harbour, at Bream Head and on Tauranga (The Hen) Island (Ballance & Williams, 1992). Within the Northland-Coromandel chain these deposits occur as a homogenous group which are classed as Wairakau Andesites (Kear & Hay, 1961; Thompson, 1961). For the area around Whangaroa Harbour Kear & Hay (1961) describe them as andesitic fragmental rocks of Miocene age whereas for southern Northland they are classified as eroded agglomerates, minor flows, and intrusives ranging from quartz andesite to normal andesite including andesitic dykes which in places (e.g. south of Matapouri Bay) intrude the Waipapa Group (see above) (Thompson, 1961).

The landforms formed from these volcanic rocks depends on their petrology. The Wairakau Andesites of the Northland-Coromandel chain and the Manukau Breccia of the Waitakere chain are both andesitic (see above). Ballance & Williams (1992) refers to these rocks as "volcanic breccia" and "conglomerate sheets". Landforms developed in these rocks are characterised by high vertical bluffs with a conspicuous pattern of near-vertical joints in the flat-lying layers of rock. Striking landscapes of high, vertical cliffs developed in these rocks occur in the southern Waitakere Hills, around Whangaroa Harbour, at Whangarei Heads and on Tauranga (The Hen) Island. On the other hand the flood basalts of the Waipoua Basalt of the Waitakere chain (see above) rather form sheets of solid lava. On the northern west coast they form the high south-west sloping tableland of Waipoua Forest (Ballance & Williams, 1992).

Another major geological event during this period was the establishment of the Waitemata

turbidite basin while the Northland Allochthon was still moving (Spörli, 1989). In this basin mainly dark grey sandstones and mudstones deposited during the Late Oligocene (Thompson, 1961) which today cover large areas of southern Northland and Auckland. Due to the relative lack of more resistant volcanics in the sediments deposited in this area a homogeneous well-dissected landscape of moderate slopes developed (Ballance & Williams, 1992). Nevertheless, north of Waiwera the sediments of the Waitemata Group contain a higher proportion of volcanic material such as andesitic grits and deposits from the Manukau Breccia (Thompson, 1961). As these materials are more resistant to erosion the resulting landforms are ridges and cliffs which are substantially higher and steeper than those south of Waiwera. North and north-west of Waiwera the Waitemata Group includes gently dipping beds of sandstone which give rise to steep cliffs, waterfalls, and dip-slope profiles. West of Wellsford they produce a striking bluff-and-ledge topography (Ballance & Williams, 1992).

Other deposits of significant extent from the Eocene-Oligocene are mainly coal measures, greensands, resistant sandstones, and limestones. These sediments are direct or through diagenesis indirect products of marine deposition into the Waitemata Basin (see above). Oldest of these sedimentary rocks are the coal-bearing Kamo Coal Measures of Late Eocene age which also include fireclay, carbonaceous mudstone and sandstone (Shaw, 1964; Thompson, 1961). The once widely distributed coal seams of the Kamo Coal Measures are now mainly confined to the Kamo, Hikurangi, and Kawakawa regions (Shaw, 1961).

In the Early Oligocene, after the deposition of the above sediment, marine deposits of the Motatau Group (Thompson, 1961) were laid down. They chiefly comprise two sorts of limestones: the moderately hard, fine-grained argillaceous limestone, white or grey in colour, showing irregular stratification and fracture, and the coarse crystalline Whangarei limestone, largely composed of foraminifera and broken shell fragments. The former may have accumulated in deep water whereas the latter was probably formed as shell banks in shallow water (Shaw, 1964).

During the Mid Miocene after volcanic activity had ceased on the Waitakere chain, large-

scale vertical earth movements caused a tilting of the Northland region. The western side of Northland was downthrown, while the eastern side was uplifted and broken into tilted blocks along major, steeply inclined faults. Consequently, the rocks in the western portion of Northland became overwhelmed by younger deposits and hence preserved from erosion. In the eastern half of Northland the situation was reverse. Here, the Northland Allochthon forming the caprock was eroded away exposing the greywackes of the underlying Waipapa Group (see above) (*cf.* Ballance & Williams, 1992; Kear & Hay, 1961; Thompson, 1961). Nevertheless, in southern Northland between Whangarei and Brynderwyn the sequences of the Northland Allochthon were only incompletely removed leaving behind north-tilted blocks with steep southward faces and gently northward dipping surfaces.

The landforms developed on exposed greywacke of the Waipapa Group are characterised by their susceptibility to chemical weathering. This feature is reflected in thick clay-rich soils at the surface underlain by a layer of regolith that can exceed 10 metres. As erosional processes do not occur on the unweathered greywacke but on the surficial layers of clay they result in a homogenous landscape of close-set, steep-sided valleys. However, in combination with their tendency to form wide joints in coastal regions greywacke often forms characteristic landforms such as sea caves, and highly irregular intertidal wave-cut platforms and cliffs. The platforms tend to be narrow and the cliffs rounded and usually low (Ballance & Williams, 1992).

4.1.3.4 Pliocene to Late Holocene

The fifth important geological event in Northland was the resumption of volcanic activity in the form of basaltic intraplate volcanism which commenced during the Late Pliocene and continued until the recent geological past (e.g. Kear & Hay, 1961; Smith, 1989; Thompson, 1961; Spörli, 1989). Northland's basaltic volcanicity was initiated by the establishment of a behind-arc rift regime with rhyolitic volcanism in Coromandel. Volcanicity in this region was basically a result of the southward migration of the active volcanic arc towards the subduction trench east of the North Island since the establishment

of a new tectonic regime in the Early Miocene (see above). Each stage of this migration has been marked on the surface by the appearance of volcanic activity as manifested in the volcanic deposits (Wairaku Andesites, Waipoua Basalt and Manukau Breccia) of the twin volcanic chain (see above). Nevertheless, when rhyolitic volcanicity in the Coromandel started in the Late Miocene which continued into the Pliocene it was accompanied by basaltic eruptions in Northland. Due to the above migration of the active volcanic arc the Pliocene-Quaternary volcanism in Northland took the form of shifting fields of intermittent activity (Ballance & Williams, 1992; Spörli, 1989).

Altogether there are four major volcanic fields in Northland of different age. Two of them formed during the Late Pliocene-Early Pleistocene. The remaining two are of Late Pleistocene to Holocene age (Kear & Hay, 1961; Thompson, 1961). The earliest two erupted in the south Auckland region and further north in the Whangarei-Kerikeri district (the "Northland Volcanic Field", e.g. Ashcroft, 1986). The former are scattered on either side of the Waikato River and are commonly known as the "South Auckland Volcanic Field". The latter form the "Horeke Basalts" (name proposed by Mason, 1953) and extend from Whangarei northward to beyond the Bay of Islands, and as far west as Kaikohe. They consist of lava flows which are now forming terraces up to 180 m a.s.l. (Ballance & Williams, 1992; Thompson, 1961).

The second episode of basaltic eruptions of Late Pleistocene to Holocene age formed another two volcanic fields. One occurs in the area which is now occupied by the city of Auckland forming the "Auckland Volcanic Field" and the other once again in the Whangarei-Kerikeri district (Ballance & Williams, 1992). These latest Whangarei-Kerikeri district volcanics are classed as "Taheke Basalts" (name proposed by Mason, 1953) which include both scoria cones and lava flows infilling valley floors (Kear & Hay, 1961; Thompson, 1961).

The Horeke and the Taheke Basalts which both erupted in the Whangarei-Kerikeri district are commonly also known as "Kerikeri Volcanics" or "Kerikeri Volcanic Group" (name proposed by Kear [1961], as used in its extended form by Ferrar [1925] and Hay [1960]). They outcrop over an area of 2500 km² stretching from Maungakaramea, south-west of

Whangarei, 74 km north to Te Ngairi, north-east of Kaeo. Within this region they can be subdivided into three major geographic areas: Whangarei, Puhipuhi and Kaikohe-Bay of Islands (Ashcroft, 1986; Smith & Ashcroft, 1986).

The distinguishing feature of this Pliocene-Quaternary volcanism in Northland is that it was both intermittent and shifting (see above). Eruptions occurred every few hundred or thousand years and each new individual or series of eruptions took place from a new vent. This feature is best reflected in the Auckland Volcanic Field with about 60 separate centres and sporadic volcanic activity ranging from about 160,000 until only 600 years ago which eventually led to the formation of Rangitoto Island (Ballance & Williams, 1992). Figure 4.4 shows the distribution of the Late Pliocene-Quaternary volcanic rocks in the Northland and Auckland regions.

However, the nature of volcanism in Northland can be concluded as follows: with the establishment of the twin volcanic chains during the Early Miocene Northland mainly experienced andesitic and basaltic volcanism. Nevertheless, with the transfer of the volcanic arc from the Coromandel to its present position in the Taupo Volcanic Zone by Pleistocene time, Northland was situated well away from the location of calc-alkaline volcanism (Spörli, 1989). At present it occupies a true behind-arc position ("intra-plate volcanism") which is characterised by volcanic activity ranging in composition from alkali basalt to sub-alkaline and tholeiitic (Cole, 1986; Spörli, 1989).

3.1.3.5 Effects of the Quaternary Glaciations

The sixth and final major event in the geological development of Northland were the indirect effects the Quaternary glaciations had on the peninsula. Since the Pliocene Northland experienced the transport of large volumes of quartzofeldspathic sand (Brook & Thrasher, 1991) along its west coast by nearshore currents and longshore drift. Ballance & Williams (1992) argue that the accumulation and preservation of these extensive sand deposits can probably attributed to the very voluminous volcanic activity in the Taupo Volcanic Zone and Taranaki during the past 2 Ma in combination with a slow regional

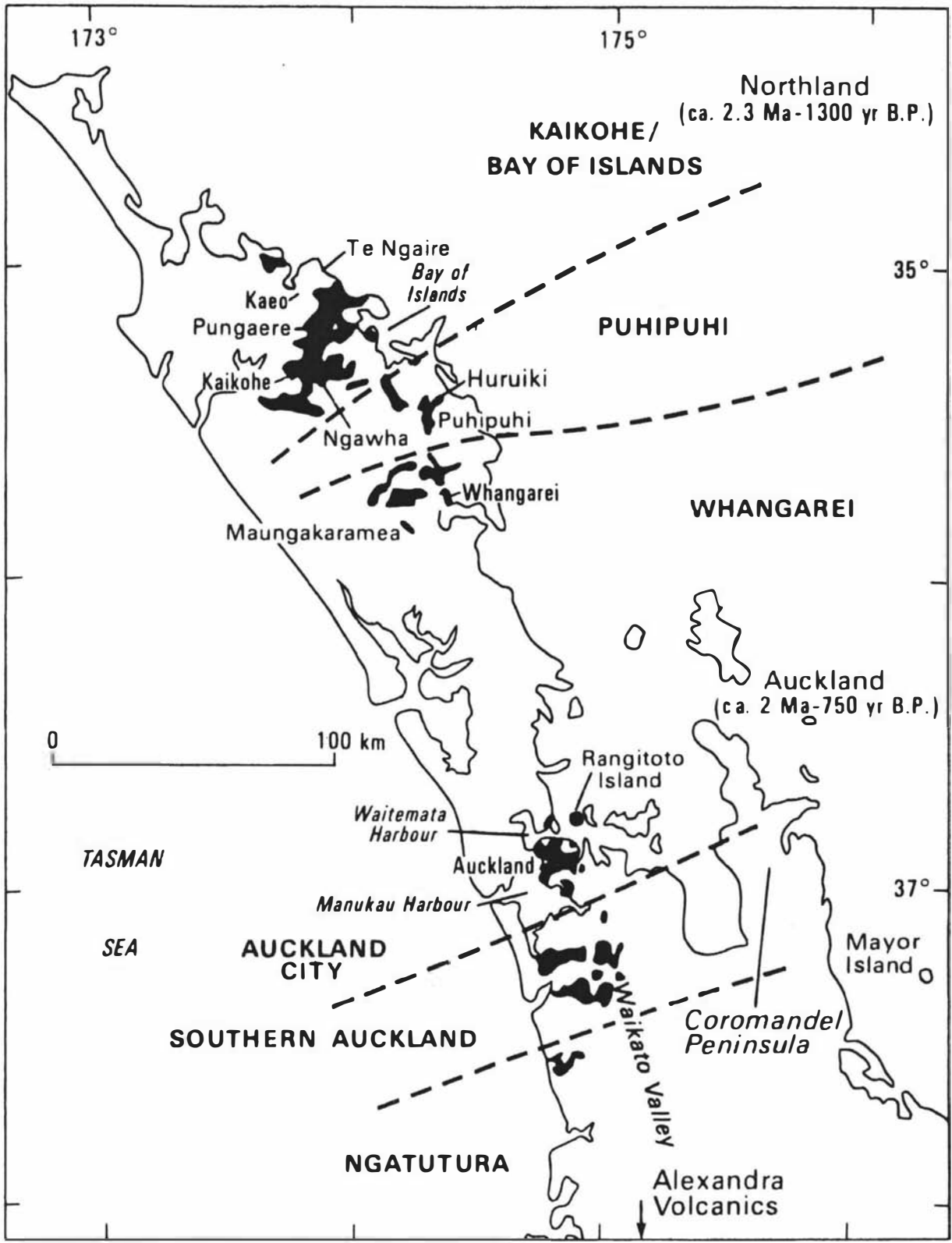


Figure 4.4: Distribution of Late Pliocene-Quaternary volcanic rocks of the Northland Volcanic Field and in the Auckland region. The figures in brackets indicate the age of deposits in individual volcanic regions (modified after Smith, 1989).

uplift.

The deposition of these large volumes of sand was mainly focused on three principal areas: two form the outer barriers of the Manukau and Kaipara Harbours, and the third extends between mainland Northland and the Cape Reinga-North Cape region (see fig. 4.5). The former two have converted open embayments on the west coast into enclosed harbours, while the third is a 85 km long compound tombolo comprising at least four complexes of dunes (e.g. Coster, 1989). The tombolo is commonly known as the Aupouri Peninsula which has linked a number of off-shore islands such as Cape Kerikeri, Mount Camel, Cape Reinga, and North Cape to mainland Northland (Ballance & Williams, 1992).

During the Quaternary glacioeustatic sea-level changes these sand barriers were subject to large-scale morphological processes leading to the widespread development of conspicuous coastal landforms. Immediately associated with those sea-level changes is the formation of marine terraces along many stretches of the coast as well as fluvial terraces inland. The marine terraces, assumed to be of Late Pleistocene age, rise to heights of about 37 m, 12 m, and between 8 and 6 m a.s.l. Other coastal features of Early to Late Pleistocene age are fixed dune complexes and fixed coastal dunes. At Maunganui Bluff they reach heights of about 190 m above sea-level and at Kaipara South Head they range at about 116 m.

Among the Holocene formations are mainly dune deposits. Two main types of dune areas are present: foredunes which run parallel to each other and the coast-line, and fixed dune complexes which consist of large, linked parabolic dunes separated by deflated swampy areas. A third variation, large transverse dunes, is restricted to the present body of shifting sand and partly fixed sand dunes in the immediate vicinity of the coast (*cf.* Shaw, 1964; Kear & Hay, 1961; Thompson, 1961).

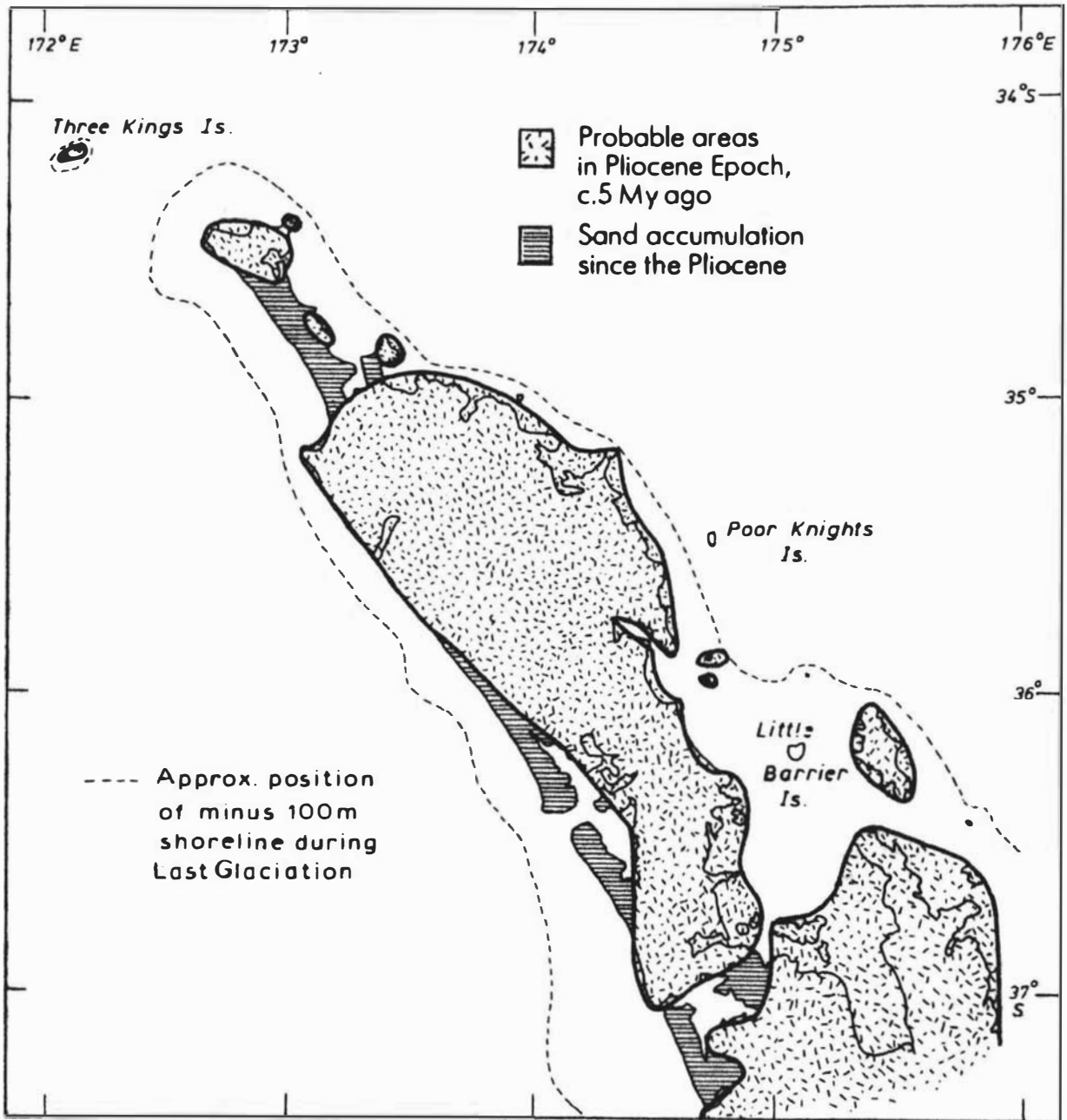


Figure 4.5: Quaternary sand accumulation along the west coast of Northland and between mainland Northland and the Cape Reinga-North Cape region (Ballance & Williams, 1982).

4.1.4 Summary

Although some remains of the Permian to Jurassic landscape can still be identified on exposed greywacke surfaces in Northland, the broad outlines of the modern topography of the region originate from tectonism and volcanism from the Early Miocene. The block-faulted landforms which developed by the end of this period form the basis of the present relief. Pliocene and Pleistocene erosion inland, Pliocene-Pleistocene coastal deposition of large volumes of sand, and Miocene to Holocene volcanicity have resulted in significant local modifications of the landscape, while glacioeustatic sea-level changes superimposed on a general uplift of the region have contributed to the maintenance of a considerable relief inland and to the development of various coastal landforms.

As Northland largely escaped the direct effects of the Quaternary glaciations relatively warm and humid conditions have always prevailed in the region. Consequently, deep chemical weathering of country rock is widespread throughout the peninsula, giving rise to clayey soils and mass movement due to slope instability.

4.2 Soils

The soils in most parts of Northland are the product of the combination of a number of environmental factors rather specific to New Zealand. The most important of them, as summarized by Gibbs (1964), Gibbs *et al.* (1968) and Molloy (1993) and partially already discussed in section 3.2, are as follows: the subdued, rolling topography of the Northland Peninsula (also see section 4.1.1), indicative of the greater age of the landforms; the tectonic quiescence since the Miocene resulting in a long period of uninterrupted soil development (e.g. Fleming, 1962; also see sections 4.1 and 4.1.2); a warm, moist climate (also see section 4.3); the absence of (rejuvenating) direct effects of the Pleistocene glaciations (also see sections 4.1.2, 4.1.3.5 and 5.2.2.1) as well as the lack of more substantial tephra deposits from recent volcanic eruptions in most parts of the region.

The combination of these factors gave rise to soil-forming conditions that are intermediate between the temperate remainder of New Zealand and those of the tropical islands of the south-west Pacific. Hence, the soils of Northland constitute a pedological link between these two regions (Gibbs, 1964; Gibbs *et al.*, 1968; Taylor & Sutherland, 1953).

These conditions have produced a series of soils with a combination of properties which distinguish them from other soils of New Zealand. Although these soils are unusually diverse most of them classify as strongly leached, heavy clays with thin topsoils, low subsoil fertility, and rapid decomposition of organic matter on aeration. Variations from this rather general pattern, in particular in terms of clay content, are determined by soil forming processes, parent material and age. Soils derived from the predominantly sedimentary rocks in the east of the peninsula usually have higher clay contents than those developed on andesitic and basaltic parent material which is more prominent in the central and western parts of Northland (e.g. Gibbs, 1964; Gibbs *et al.*, 1968; Molloy, 1993; Taylor & Sutherland, 1953; also see section 4.1 and fig. 4.3). Nevertheless, despite the general infertility of the Northland soils, there are also localised high fertility soils. Those are mainly associated with more recent parent material such as volcanic, alluvial, and colluvial deposits (e.g. Taylor & Sutherland, 1953).

Another distinctive feature of the soils of the Northland region is the strong correlation between the general composition of the indigenous forest and the degree of soil development. Taylor & Sutherland (1953) suggest that the type of indigenous forest vegetation largely controls the extent of soil leaching under the high and spatially relatively uniform rainfall regime (see section 4.3.2.2) of Northland. In an undisturbed state the distribution of certain species of indigenous forest trees is therefore indicative of the degree of soil leaching.

Despite the rather mosaic forest pattern of Northland which largely qualifies as mixed subtropical rainforest, with considerable areas of *Leptospermum scoparium* (manuka/tea tree) scrub on coastal lowlands and dunes and *Avicennia marina* var. *resinifera*

(manawa/mangrove) in tidal inlets along the coast³³, in relation to soil forming processes only two broad divisions are recognized: hardwoods and conifers (e.g. Gibbs, 1964; Gibbs *et al.*, 1968; Taylor & Sutherland, 1953).

While hardwood vegetation (e.g. *Vitex lucens* [puriri], *Dysoxylum spectabile* [kohehohe], *Beilschmiedia tarairi* [taraire] and *Beilschmiedia tawa* [tawa]) gives rise to mull³⁴ on the forest floor; conifers (e.g. *Podocarpus totara* [totara], *Dacrydium cupressinum*, *Phyllocladus trichomanoides* [tanekaha] and *Agathis australis* on the other hand produce mor³⁵. Under mull-forming trees the typical forest litter comprises a shallow layer of dead leaves which lie directly on the mineral soil. Nutrient recycling is fast due to the rapid decomposition of litter. Consequently the top of the mineral soil is mellow and fertile and is stained brown with humus from the rapidly decomposing litter. The transition to lower horizons is not sharp. Under mor-forming trees the profile is somewhat different. A litter of leaves, twigs and bark decomposes only slowly and forms a markedly acidic humus layer of unincorporated organic material in various stages of decomposition. This layer tends to accumulate on the surface where it is sharply separated from the mineral soil. Humic acids leach from this surface layer and impoverish the mineral soil below of plant nutrients more rapidly than under mull-forming trees. Hence, even under similar rainfall conditions, there is an intensification of strong leaching under mor-forming species, and retardation under mull-forming vegetation (e.g. Gibbs, 1964; Taylor & Sutherland, 1953). This feature is particularly manifested in the strong leaching effect of *Agathis australis* (e.g. Blakemore & Miller, 1968; also see Molloy, 1993 and section 3.2). The soils underlying this conifer are characterised by their high degree of podzolisation (e.g. Ecroyd, 1982) which gained *A. australis* the reputation of being a classic podzolising vegetation (Molloy, 1993). The arguably most conspicuous feature of these so-called "kauri podzols" is their lenticular formation which is restricted to the area directly underneath individual trees of *A. australis*. Due to their morphology and very localised occurrence these podzols are commonly also known as "egg cup podzols" (e.g. Gibbs, 1964; Molloy, 1993).

³³The composition of the indigenous forest cover of Northland and its distribution will be discussed in greater detail in chapter 6.

³⁴**Mull:** Humus-rich mixture of organic and mineral matter (Gibbs, 1980).

³⁵**Mor:** Raw humus (Gibbs, 1980).

In addition to climate and vegetation the soils of Northland also reflect the influence of the underlying geology more clearly than any other part of the country (e.g. Taylor & Sutherland, 1953). One of the earlier soil classifications for Northland based on the underlying geology is given by Taylor & Sutherland (1953). Their rather broad classification recognizes five main classes which are subdivided further into a number of sub-classes. The main classes include:

- "Soils of the 'clay' country";
- "Soils of the sand country";
- "Soils of the 'volcanic' country";
- "Soils of the limestone country"; and
- "Soils of the river flat and swampy country".

Based on the later "New Zealand Genetic Soil Classification" (e.g. Gibbs, 1968; Leamy & Fields, 1976; also see section 3.2) a more detailed tool for the classification of the soils became available. Utilizing this classification Gibbs (1964) and Gibbs *et al.* (1968) recognize eight main soil groups for the Northland region:

- Northern rendzinas;
- Northern yellow-brown earths;
- Northern podzolised yellow-brown earths and podzols;
- Northern brown granular loams and clays;
- Northern red and brown loams;
- Northern yellow-brown sands;
- Northern recent, gley, and organic soils;
- Steepland soils.

The following description of these (main) genetic soil groups is largely based on the work by Gibbs (1964), Gibbs *et al.* (1968) and Leamy & Fieldes (1976) and summarizes the most important characteristics of each individual soil group. Due to the growing importance of the more recent *New Zealand Soil Classification (Version 3.0)* (Hewitt, 1992; also see section 3.2) the equivalent of this more recent soil classification will also

be given for each of the above genetic soil groups.

Generalised representations of the distribution of the main soil groups of Northland as recognized in both of the above soil classification schemes are given in Gibbs *et al.* (1968, fig. 3.1.1), Gibbs (1964, map 3) and Rijkse & Hewitt (1995), respectively; also see figure 3.7.

4.2.1 Northern rendzinas

The northern rendzinas of Northland are heavy soils which are derived from calcareous parent materials. Their distribution is restricted to small areas near the townships of Kaitaia, Kaikohe and Maungaturoto. In the New Zealand Soil Classification (Version 3.0) they qualify as "Rendzic Melanic Soils" (Hewitt, 1992). The pedological properties of this soil group are best represented by the "Arapohue clay" which developed on argillaceous limestone of the rolling hill country in the southern part of Northland (see figures 4.2 and 4.3). The profile of this soil is shallow and characterized by a dark grey granular topsoil rich in montmorillonitic clay with a substantial layer of well decomposed humus derived from a predominantly hardwood-podocarp vegetation. Other characteristics include a very high cation-exchange capacity and base saturation. The thin subsoil consists of a sticky clay which shows a high degree of mottling owing to poor internal drainage. This soil type is found in locations with shallow profiles directly overlying limestone. In deeper profiles the rendzinas occur with other soils in all stages of horizon development including yellow-brown earths and occasionally even podzols. Profile degradation through time due to the chemical alteration of the montmorillonitic clays associated with a drainage deterioration was often also accompanied by vegetational changes from hardwood to podocarp and eventually to kauri forest. Hence, the main problems of the northern rendzinas lie in their physical characteristics. As they are heavy soils with a poor subsoil drainage they are subject to desiccation in summer and become very saturated in winter. In extreme cases this can lead to soil erosion on steeper hills.

4.2.2 Northern yellow-brown earths

The group of yellow-brown earths are widespread throughout New Zealand (see section 3.2). They formed in regions with an annual mean precipitation adequate for plant growth and also sufficient to cause iron compounds to decompose leading to the typical features of soil mottling.

In Northland these (northern) yellow-brown earths ("Ultic Soils"; Hewitt, 1992; also see section 3.2) are extensive on rolling and hilly lands (also see fig. 4.2) and mainly occur between Waipu and Dargaville, between Whangarei and the Bay of Islands, and around the Hokianga Harbour.

They mostly are derived from strongly weathered sedimentary rocks under forest vegetation dominated by mull-forming species. Their profile is characterized by a greyish brown to grey clay loams in the topsoil and yellowish brown compact clays in the subsoil. Other properties, especially soil fertility, vary with the degree of leaching which ranges from weak to strong.

Weakly leached northern yellow-brown earths (e.g. "Puhoi clay") occupy small areas of hill country and are commonly relatively shallow soils over less weathered rock. Due to the more granular structure of their top- and subsoils they are usually well drained although some soils still have a tendency to become waterlogged in wet winter conditions.

Moderately leached northern yellow-brown earths were derived from a variety of different bedrock. The most important of them with their respective parent materials are: "Waiotira clay loam" (from sandstone); "Taumata clay loam" (from calcareous sand- and mudstones); "Omanaia sandy loam and sandy clay loam" (banded sand- and mudstone) and "Omu clay loam" (white siliceous mudstone). They are characterised by brown to greyish brown granular topsoils, and yellowish brown, blocky or nutty subsoils with some prismatic structure in particular in the heavier soils. Drainage of their subsoils ranges from moderate to good.

Strongly leached northern yellow-brown earths commonly develop on parent materials that show red weathering. They are extensive on lower hill slopes and rolling land and

are commonly associated with weakly podzolised yellow-brown earths. This soil group is best represented by the "Whangaripo clay" (from sandstone); the "Marua clay loam" (greywacke); "Rockvale" and "Dairy Flat soils" (calcareous mud- and sandstones); "Aponga" and "Okaka clays" (mudstone); and "Warkworth clay" (sandstone). In contrast to less leached soils, they have a slower drainage, increased amounts of clay and pale grey and brown mottlings, and decreased amounts of plant nutrients in their subsoils. The indigenous vegetation under which they developed was podocarp-hardwood forest with a proportion of *A. australis* higher than on the weakly and moderately leached soils. This feature is believed to have been a contributing factor to the increase in acidity and decrease in base saturation.

4.2.3 Northern podzolised yellow-brown earths and podzols

Northern podzolised yellow-brown earths ("Densipan Ultic Soils"; Hewitt, 1992; also see section 3.2) and podzols ("Podzol Soils"; Hewitt, 1992; also see section 3.2) commonly occur on gently sloping low ridges or lower slopes of rolling land where they derived from deeply weathered sedimentary rocks. Large areas of these soils were formed under forest dominated by mor-forming species (see section 4.2), particularly *A. australis*, which substantially accelerated the leaching process. Those soils which formed under pure *A. australis* stands or forest dominated by this species are commonly also known as "gumlands".

Well developed podzols have thin grey topsoils with little or no structure. They overlie successive horizons of pale grey, black, reddish brown, yellowish brown, and yellow colours. Available plant nutrients are mainly cyclic and are largely retained in the mor horizon. However, where trees were removed the mor horizon oxidised rapidly to expose a surface horizon of very low natural fertility. Another conspicuous feature of these soils is formation of (consolidated) illuvial horizons ("hardpans") of translocated humic materials and precipitated iron and aluminium in the subsoil. In combination with other soil structures these often impervious pans often cause water to accumulate on the surface, or cause seepage bogs to form on hillslopes. Well developed podzols in

Northland contain numerous stumps and gum of *A. australis*. Sporadic occurrences of the above kauri podzols (see section 4.2) are a common feature in areas of yellow-brown earth. In these locations lenticular podzols (egg cup podzols; see section 4.2) developed directly underneath old stumps of *A. australis* indicating the close association with this species.

In Northland weakly, moderately and strongly podzolised soils and podzols commonly occur in complex mosaics.

Weakly and moderately podzolised northern yellow-brown earths have formed on deeply weathered sedimentary rocks under podocarp-kauri forest. Their topsoils are brownish-grey to grey silt loam with weakly developed, very soft, granular aggregates. Subsoils are very firm yellow clay with coarse, blocky aggregates combined into large prisms. The soils are moderately to strongly acid and well leached of bases. Because of their coarse subsoil structure, aeration and moisture contents fluctuate widely. Consequently, pastures or exotic forests are difficult to establish and many areas of these soils are still under scrub. Typical representative of the weakly podzolised yellow-brown earths include the "Rangiora" and "Opaheke clay loams" (from deeply weathered greywacke) and the "Tangitiki sandy loam" (from slightly consolidated sandstone). The properties of the moderately podzolised yellow-brown earths on the other hand are best reflected in the "Waikare clay" (from claystone) and the "Pukenaumu sandy loam" (from dacite and rhyolite).

Strongly podzolised northern yellow-brown earths have developed under mor-forming vegetation. They are very acid and strongly leached of nutrients, with a deep kauri-mor horizon. Both the structure and drainage are poor, and biological activity is very low. Another distinctive feature of all strongly podzolised northern yellow-brown earths are their prominent subsoil clay horizons which in some cases are accompanied by marked accumulations of humus iron and aluminium. The "Wharekohe silt loam" (from clay- and sandstone), the "Hukerenui silt loam" (from sandstone and greywacke), the "Pokapu gravelly loam" (from silicified claystone), and the "Te Kopuru sand" (from slightly consolidated sand) are all strongly podzolised yellow-brown earths.

4.2.4 Northern brown granular clays and loams

Northern brown granular clays and loams ("Granular Soils"; Hewitt, 1992; also see section 3.2) are derived from andesitic rocks and volcanic ash and have formed under forest in regions with a mean precipitation in excess of 1250 mm/a (also see fig. 4.8). They are extensive on hilly land and rolling plateaus ranging in altitude from sea-level to 600 m or more, mainly in the western portion of the Northland Peninsula. Members of this soil type are commonly clay soils with greyish-brown to brown, friable topsoils and brown to yellowish-brown, firm to compact subsoils. The topsoil shows moderately to strongly developed granular and nutty structures which grades into blocky to prismatic structures in the subsoil. Various of their properties (e.g. consistence and natural fertility) vary with the degree of leaching similar to the yellow-brown earths.

Weakly leached brown granular clays and loams (e.g. the "Takitu clay") occupy small areas of mainly hilly terrain. They have developed under mixed forest with a predominance of mull-forming species.

Moderately leached brown granular clays and loams, similar to the "Awapuku clay loam" (from andesitic basalt and andesite), are extensive and formed under mixed hardwood-podocarp forests.

Both weakly and moderately leached soils are commonly associated with the "Te Kie" steepland soils (see below). They are slightly acid and high in exchangeable calcium and magnesium but low in available potassium and phosphorus.

Strongly leached soils of this group (e.g. the "Waimatenui clay" [from andesite] and the "Waitakere clay" [also from andesite]) occupy extensive areas of hilly land, previously covered in mixed podocarp-kauri forest and now mostly cleared for pastoral use. The topsoils are thin, brown to greyish brown, with a well developed nutty structure. The subsoils, when compared with the weakly and moderately leached soils, are duller, more compacted, with a harsher structure, and of greater depth. Commonly these soils have a low natural fertility. Where *A. australis* was the dominant species the soils are very strongly leached, as manifested in the "Tutamoe" (from andesitic basalt), "Rangiuru" and "Aranga clays" and "Tinopai sand". All four soils have an exceedingly low natural fertility, erode readily, and, with the exception of the Tutamoe soils, appear to dry out rapidly.

4.2.5 Northern red and brown loams

The northern red and brown loams ("Oxidic Soils"; Hewitt, 1992; also see section 3.2) derived from basaltic rocks under subtropical forest with precipitation levels of 1250 to 2000 mm/a (also see fig. 4.8). Owing to these environmental parameters this soil group is not very widespread but rather limited to the central part of Northland, in particular in the Bay of Islands district. Both soil types originated from different lithologies. The red loams formed on readily weatherable scoria and scoriaceous rocks and are very limited in their extent. The brown loams on the other hand developed on dense rocks of the basalt flows and are extensive in places. Both soils generally occur in close association and have weathered to clays of low plasticity which comprise aluminium and iron oxides. Despite their extremely high clay content (>50%) the soils are rather friable ("friable clay") and show the structural properties of loams. The topsoils range in colour from red to brown, are very friable, and have a very fine granular structure. Subsoils range from very friable to very firm in consistency, are also red or brown and have fine, nutty or blocky structures. Soil drainage is generally good with a few minor variations: the brown loams have intermittent drainage due to the underlying basalt sheet. Consequently drainage can become impeded to an extent that the soil becomes saturated. The red loams on the other hand freely drain as the scoriaceous parent material allows a good penetration of subsurface water.

For further classification and based on their degree of leaching the northern red and brown loams are also arranged in soil-development sequences.

Weakly leached red loams are commonly derived from basaltic ash and scoria under mull-forming hardwood vegetation. These soils, such as the "Papakauri clay loam" (from basalt scoria) are highly fertile and have excellent properties for biological activity and plant growth. They mainly occur on the sloping sides of volcanic cones.

Moderately leached brown loams (e.g. the "Kiripaka clay loam") formed on scoriaceous basalt under mull-forming hardwood species. They are less friable and granular than red loams, and are slightly lower in natural fertility.

Strongly leached brown loams have developed on basalt under mull-forming mixed, hardwood-podocarp or podocarp-dominant forest. They include the free-draining

"Waiotu soils" on rolling and hilly slopes, and the related "Ruatangata soils" which occupy flat land. Their drainage is usually impeded by the underlying basalt and both soils have a low natural fertility. The most leached soils of the brown loams occur on the gently undulating surface of the older basalt sheets in the Bay of Islands district (also see section 4.1.3.4 and fig. 4.4). They have formed under mixed kauri-podocarp forest, which has been replaced in places by scrub of *Leptospermum scoparium*. They are old soils from strongly weathered basalts which is a poor source of plant nutrients. Hence they are moderately acid and well leached of bases throughout the profile. The subsoils often accommodate a layer of limonite concretions ("ironstone") which in cases of extreme thickness can extend up to the surface. A typical representative of these ironstone soils is the "Okaihau friable clay".

4.2.6 Northern yellow-brown sands

The distribution of the northern yellow-brown sands ("Sandy Recent Soils"; Hewitt, 1992) in Northland is closely associated with the locations of principal Quaternary sedimentary deposits in this region (see section 4.1.3.5 and figures 4.3 and 4.5). Thus, this soil group stretches in an almost continuous strip along the west coast of Northland and across the central part of the Aupouri peninsula from Kaitaia to North Cape. Furthermore they also occupy small inlets on the east coast. These areas consist of (fixed) sand dune complexes with intervening peaty swamps. Following the age gradient of these dune complexes the degree of soil development increases inland. The youngest and therefore least-developed northern yellow-brown sands (e.g. "Pinaki sand") have only a thin surface horizon of humus-stained sand held together by a network of roots which overlie unconsolidated brown sand. To prevent deflation a dense vegetative cover must be maintained on these soils.

Yellow-brown sands of a more advanced age are represented by the "Houhora sand". Sands at this stage of soil development already show a horizon of dark brown sand over yellowish brown loamy sand grading down into yellow sand. These soils are also subject to deflation if the vegetative cover is allowed to decrease.

The oldest yellow-brown earths occur on dunes that have become stabilised for a longer

period (e.g. the "Red Hill soils"). Their topsoils range from sandy loams to sandy clay loams over slightly to moderately compact sandy clay loams grading down into sand. Due to the heavier subsoils these soils have a higher moisture retention than the Pinaki type on loose sand.

4.2.7 Northern recent, gley, and organic soils

The northern recent, gley and organic soils constitute the youngest soil group of Northland. They have formed on flood plains and swamp lands which are often of limited size and occur in isolated locations. In comparison with the other main soil groups of Northland they have an above-average fertility and therefore provide very valuable agricultural land. They have been derived from either alluvial deposits or peat, and their major differences in soil properties are related to the conditions of accumulation of these materials.

The *recent soils from alluvium* ("Fluvial Recent Soils"; Hewitt, 1992) occur in a variety of locations: narrow river flats, low terraces, and fans of most of Northland's main rivers and streams. Due to the high accumulation rate of their alluvial parent materials they have deep profiles which lack a distinctive horizon differentiation. Despite certain variations of the parent material these soils are usually deep, brown, mellow loams with a high natural fertility. Owing to their location, however, they are very subject to flooding and stream erosion.

Gley soils ("Gley Soils"; Hewitt, 1992) are rather a feature of the wider flood plains where drainage is slower so soils become waterlogged for prolonged periods during the year. These conditions eventually lead to the formation of a "gley" horizon in the subsoil which is usually pale grey in appearance with rusty mottlings. In Northland these gley soils are concentrated in a few principal areas: near Kaitaia, along the Wairoa River, near Dargaville and Ruawai and near Waipu. In these locations the Northland gleys are represented by the "Waipu clays", "Wairua clays" and "Kaipara clays".

Organic soils ("Organic Soils"; Hewitt, 1992) have formed in locations where the water table is permanently high and anaerobic conditions led to the accumulation of organic matter. The resulting soils are mostly pure peats or peaty sands such as the "Ruakaka

peaty sand loam and loamy peat" which are common in depressions among sand dunes. Other regions with major occurrences of organic soils include One Tree Point, Waipu and Mangawhai, the areas north of Kaitaia and near Hikurangi, as well as numerous small areas in the sand country south of Dargaville.

The most common pedological features of these organic soils are as follows: most of the peats are characterised by their high acidity. The peaty sands on the other hand show a bleaching of the sand grains. This feature is usually accompanied by the occurrence of a humic hard pan and the presence of gum fragments of *A. australis* throughout the profile.

4.2.8 Steepland soils

Steepland soils occupy isolated ranges of Northland where hard rocks have resisted erosion, or erosion is rapid enough to remove most of the weathered rock. The soils have formed either on andesitic rocks (e.g. the "Te Kie soils"), or on greywacke (e.g. the "Te Ranga soils"). They are characterised by shallow topsoils which are subject to rapid sheet and slip erosion when used as pasture. Most of the steepland soils are still under indigenous forest, with only small areas cleared for farming. Their fertility is moderately high and they are well suited for forestry. Under this use they provide good storage and control of water resources.

4.2.9 Summary

The soils of Northland reflect the influence of climate, vegetation and underlying geology more clearly than those in any other part of New Zealand. Owing to a rather unique combination of environmental factors in this part of the country the resulting soils are rather intermediate between the tropical soils of the south-west Pacific islands and the temperate ones of the remainder of New Zealand. Despite the unusually high diversity among the different main soil groups of Northland but due to their old age most of them display a number of common pedological features which classify them as

strongly leached, heavy clays with thin topsoils, a low subsoil fertility and a rapid decomposition of organic matter on aeration. The only soil group largely deviating from this general pattern is the group of alluvial soils of recent origin which occur along Northland's main watercourses.

4.3 Climate

The proximity of all parts of Northland to the sea in combination with a hilly landscape lying in subtropical latitudes³⁶ gives rise to a climate characterized by warm, humid summers, relatively mild winters, and sufficient annual precipitation (also see section 3.3). Exhibiting these features and utilizing different systems of climatic classification Northland's climate can be classed as follows: In Köppen's widely used classification Northland is recognized as a "warm temperate" *Cfb* climate (see section 3.3). Martyn (1992) on the other hand classifies Northland, like the remainder of the North Island including the northern tip of the South Island, as "subtropical" and refers particularly to the North Island as having a "maritime climate".

Nevertheless, these climatic classification systems are rather inadequate to classify the climate of Northland. Their description of the climate is rather broad and mainly describes the climate of larger areas such as the entire North Island or even all of New Zealand without emphasizing the climatic peculiarities of individual regions (see section 3.3). This point of criticism is particularly true for the classification by Köppen. Such a generalization is largely avoided in Garnier's (1958) and Thornthwaite's (1931) [applied for New Zealand by Garnier (1950)] climatic classifications of New Zealand.

Thornthwaite's (1931) classification is a mathematical system based on precipitation-evapotranspiration (P-E) and temperature-evapotranspiration (T-E) ratios and indices. It subdivides New Zealand's climate into seven major climatic types: three classes of cold climate - taiga (D), tundra (E), and regions of perpetual frost and snow (F), and three precipitation groups - superhumid (A), humid (B), subhumid (C), and semiarid climates

³⁶The **subtropical zones** extend from latitude 25° to 35° N and S. They occupy the position between the tropical and midlatitude zones (Strahler & Strahler, 1984).

(D). Considering minor subdivisions, a total of 17 subtypes can be recognized. Figure 4.6 shows Thornthwaite's (1931) [applied for New Zealand by Garnier (1950)] climatic types for the North Island.

According to that a large part of Northland classifies as humid "BB'r"³⁷ climate. There are only two minor areas of superhumid "AB'r"³⁸ climate; one stretching from Waipoua across the Northland peninsula to the east coast and a second north of the Hokianga Harbour. Both areas constitute higher ground.

Garnier's (1958) classification divides New Zealand into nine climatic regions, based mainly on the combination of westerly, easterly, subtropical, antarctic, inland and altitudinal influences. In this classification Northland, including Auckland, and the lowlands of the Waikato and the Bay of Plenty comprise the climatic region of "Northern New Zealand" which is characterized by a "WTH"³⁹ climate. The southern limit of this climatic region closely follows the southern limit of Thornthwaite's (1931) humid "BB'r" climate in the northern North Island.

4.3.1 Weather systems affecting Northland

The climate of a region is a synthesis of its day-to-day weather which is determined by the atmospheric systems crossing the country and the way in which they are modified by the topography (de Lisle, 1964). A description of the weather systems affecting the whole of New Zealand is already given in section 3.3. Thus the following section merely

³⁷"BB'r" climate indicates a "humid climate dominated by forest vegetation" with a "P-E index of 64-127" (letter "B"); along with a temperature regime classed as "mesothermal" and a "T-E index of 64-127" (letter "B'"); with "adequate moisture at all seasons" (letter "r") (Thornthwaite, 1931).

³⁸"AB'r" climate signifies a "superhumid climate with rain forest as main vegetation" and a "P-E index of ≥ 128 " (letter "A"); in association with a "mesothermal" temperature regime and a "T-E index of 62-127" (letter "B'"); in combination with "adequate moisture at all seasons" (letter "r") (Thornthwaite, 1931).

³⁹Garnier's (1958) subdivision of New Zealand in climatic regions is based on two aspects of the country's climate: the way its climatic elements vary over the land, and the degree to which they express the major controlling factors. The climatic characteristics of each region is expressed by means of a combination of capital letters. For Northland it is "WTH". In detail these letters stand for: **W**: "Westerly" influences are the dominant ones, being expressed particularly in plentiful and reliable rainfall, and relatively small mean annual range of temperature; **T**: subtropical influences are particularly marked in the area from time to time; **H**: a generally homogeneous climatic unit.

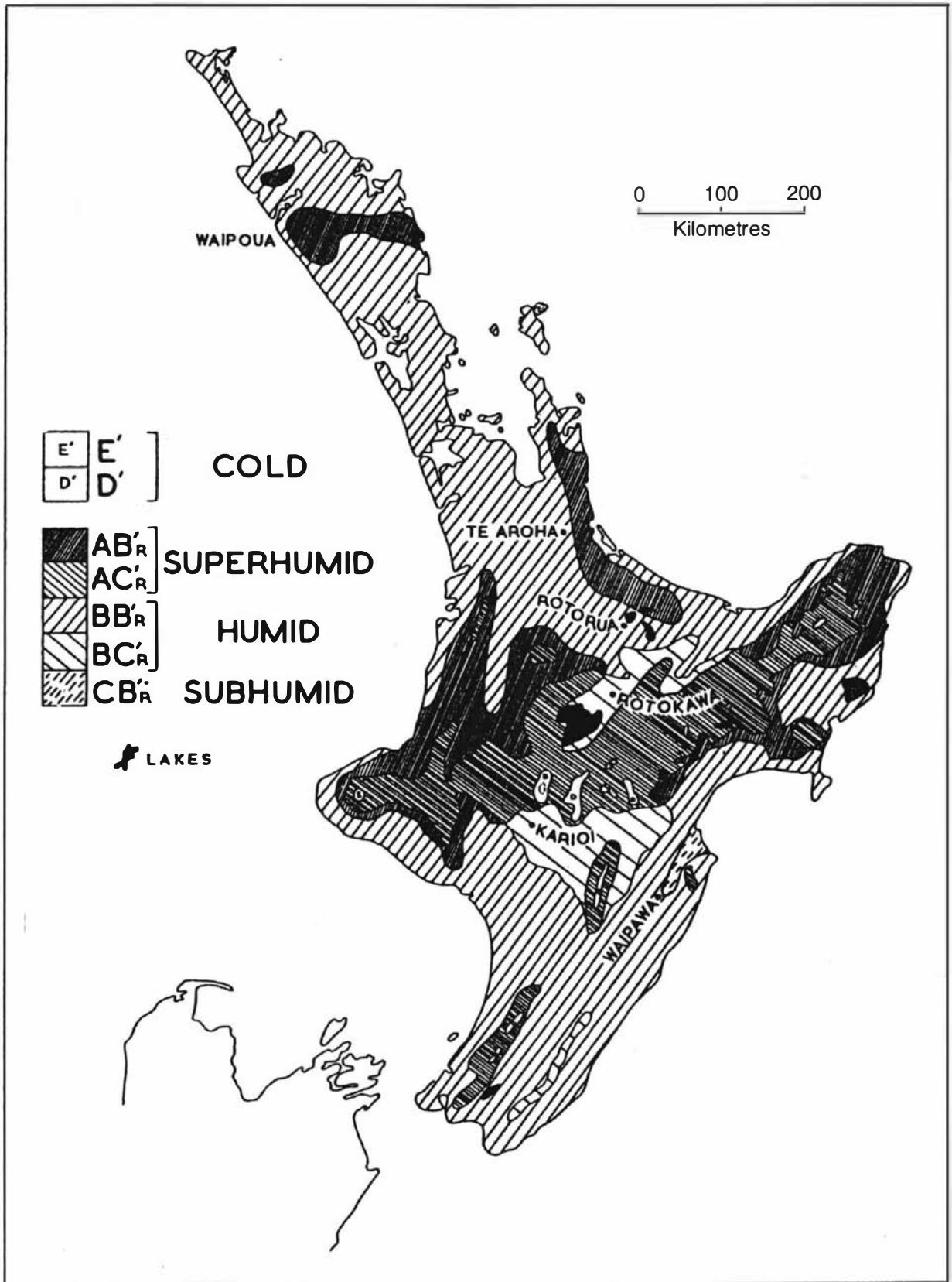


Figure 4.6: Climatic types of the North Island based on Thornthwaite's (1931) classification (Garnier, 1950).

provides a summary of the weather systems affecting Northland and is mainly based on the accounts of Moir *et al.* (1986) and de Lisle (1964).

The weather in Northland is dominated by the migratory anticyclones and intervening troughs of low pressure. As Northland is nearer to the latitude of highest mean pressure than any other part of New Zealand, the region is more often north of the tracks of individual anticyclones than the rest of the country. As a result the two prevailing wind direction over Northland is south-west. The wind blows from the west ahead of an approaching trough when an anticyclone has moved off to the east. As the next anticyclone advances following the passage of the trough the wind tends to blow from the south-east.

During their long passage over warm subtropical waters the north-west winds absorb substantial amount of moisture. Consequently clouds may develop as the air turns southward and is cooled from below by the sea surface. Upward motion associated with the trough then leads to rain. Sometimes subtropical depressions form in these trough in the easterlies and move close to Northland, causing heavy rain.

Also, when anticyclones pass to the north of New Zealand the passage of the following trough is accompanied by a wind change from northwesterly to southwesterly. The cold fronts in such troughs of low pressure are likely to bring less rain to Northland than to areas further south. Nevertheless, the mean annual precipitation is approximately the same as that over most of the northern part of the North Island and more than in many east coast regions south of East Cape.

Subtropical depressions may occur at any time of the year, but develop into major storms more frequently in winter than during other seasons. Tropical cyclones that reach Northland and still retain very low pressures and hurricane force winds are very rare. Anyhow, other storms of tropical origin, which may never have been fully developed tropical cyclones affect Northland about once or twice a year during the period between December and April. They usually bring heavy rain and strong easterly winds.

The above weather systems affecting Northland produce some meteorological situations which give rise to some characteristic weather sequences typical for Northland. Broadly there are about four weather sequences which are representative for Northland. With the exception of tropical cyclones, the following weather sequences may occur at any time of the year:

- Fine weather spells;
- Brief periods of rain;
- Showery weather;
- Periods of heavy rain.

However, these four sequences do by no means exhaust all possible types of situation but represent most of the basic types of which others are merely variations. The sequences may vary in the length of time that the type persists; in the relative intensity of the anticyclones, depressions, and fronts; and in the precise tracks followed by the systems.

The local effects of the daily weather sequences described above generates the local climate of a region. The description of the region's climate is conventionally done by means of climatic elements such as wind, precipitation, temperature, frost, humidity etc. The spatial and temporal variation of some of these elements throughout Northland will be described in more detail below.

4.3.2 Elements of climate in Northland

The following sections on individual elements of climate in Northland are mainly based on the work by Moir *et al.* (1986) and de Lisle (1964). Additional references by workers other than the above will be mentioned appropriately.

4.3.2.1 Wind

The airflow over Northland is predominantly from the south-west (de Lisle, 1975) although topography in some places causes the prevailing wind to be westerly. This is particularly so in winter and spring, but in summer the proportion of winds from the easterly quarter, especially in eastern districts, about equals that from the south-west. This feature arises from the changing location of the high pressure belt, which is further to the south in summer and early autumn than it is in winter and spring. Also, sea breezes contribute to the proportion of easterlies in eastern regions in summer and early autumn. Figure 4.7 summarizes the above situation using mean annual wind frequencies of surface wind directions of five selected stations in Northland.

The wind regime throughout Northland is not homogenous but regionally very different. Exposed coastal areas tend to be very windy, with mean annual wind speeds among the highest in New Zealand. Locations such as Cape Reinga and Mokohinau Island, where wind speeds range around 30 km/h⁴⁰ are representative for such conditions. However, areas that are exposed to most winds but receive some sheltering (e.g. Marsden Point and Kaitaia Airport) typically experience wind speeds of between 15 and 20 km/h. Inland and sheltered areas of Northland are among the least windy in New Zealand, with mean annual wind speeds of around 10 km/h. These conditions are encountered at Kaikohe and Kerikeri Airports.

Spring is usually the windiest season except in exposed locations such as Cape Reinga and Kaitaia Airport where winter tends to be the windiest period. Summer and autumn are the seasons when the highest number of calms occur.

More detailed information on the spatial and temporal distribution of other features of the airflow over Northland such as data on diurnal variations in wind speed, mean monthly wind speed, seasonal proportion of "strong winds"⁴¹, "gale force winds"⁴², and calm conditions, etc. is given by Moir *et al.* (1986).

⁴⁰ 1 km/h equals 0.54 knots or 0.278m/s (Moir *et al.*, 1986).

⁴¹ "Strong winds" are defined as airflows with a mean speed of at least 31km/h (Moir *et al.*, 1986).

⁴² "Gale force winds" are airflows whose mean speed exceeds 63 km/h (Moir *et al.*, 1986).

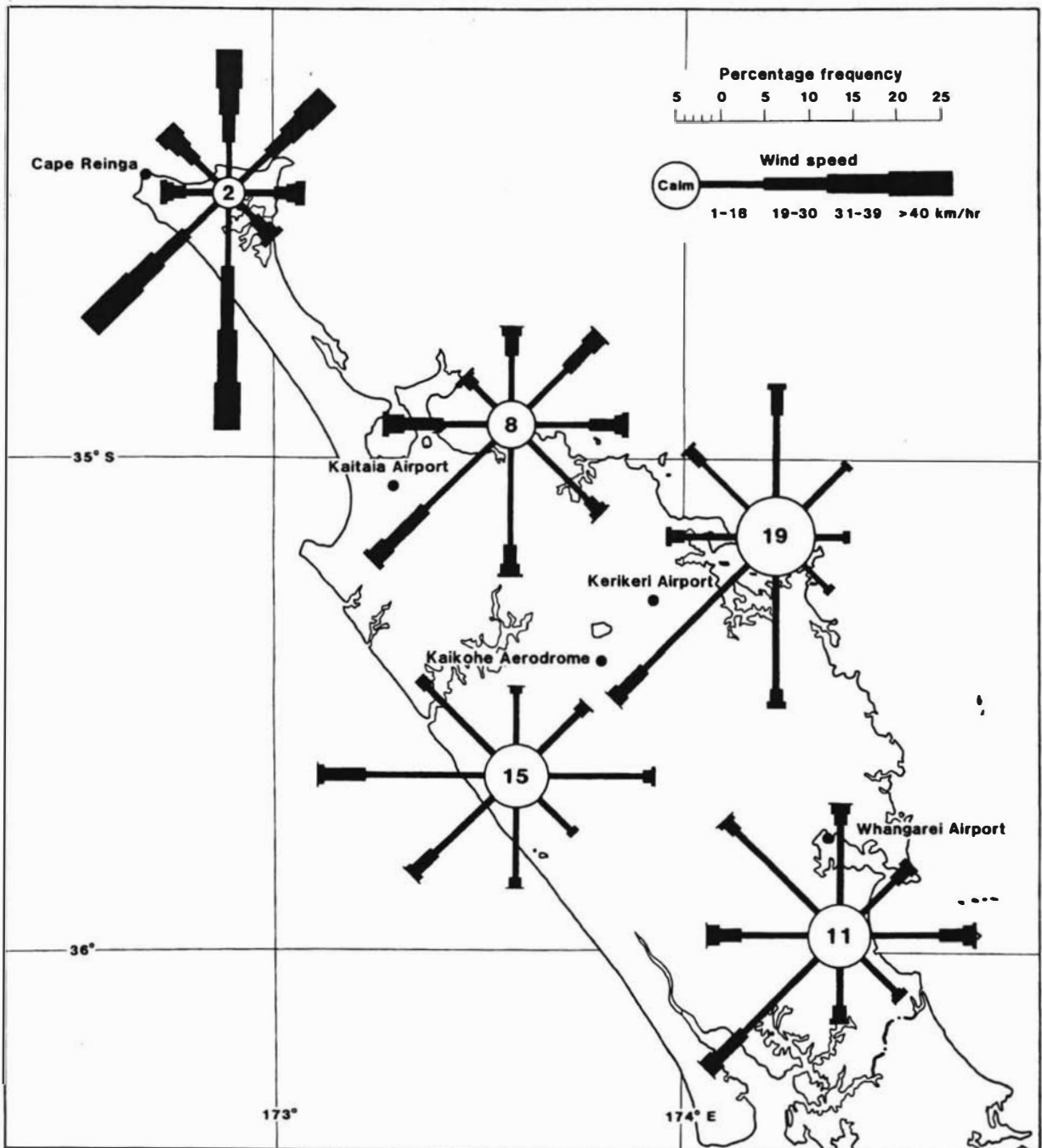


Figure 4.7: Mean annual wind frequencies of surface wind including their speed from five selected stations in Northland based on hourly observations. Locations shown are from north to south: Cape Reinga, Kaitaia Airport, Kerikeri, Kaikohe, and Whangarei Airport (Moir *et al.*, 1986).

Nevertheless, by way of summary it can be concluded that winds in Northland can be strong and gusty⁴³ at times, especially in exposed coastal areas. As expected throughout Northland the well exposed location of Cape Reinga records the highest number of days each year on which gusts exceed 63 km/h and 96 km/h. Although gale force winds can occur in any month they are most frequent between May and August, and especially in July. Maximum gusts recorded in Northland with wind speeds in excess of 150 km/h usually occur in association with the passage of tropical cyclones.

Superimposed on these regional features of the airflow over Northland are local winds such as sea breezes. Sea breezes are common on both coasts during the summer and autumn on days when there is no strong pressure gradient over the region. When there is a marked difference between the sea temperature and the land temperature they may reach 20 to 30 km/h. The diurnal variability of the land-sea temperature difference and interactions with the airflows associated with pressure gradients leads to considerable variation in the daily wind regime. Occasionally the opposing sea breezes from the west and east coast converge inland in a zone marked by a line of cloud and showers. At Kaitaia for example the sea breezes from both coasts can occur at different times of the day.

4.3.2.2 Precipitation

The spatial distribution of rainfall throughout Northland is noticeably governed by the geography of the region. With no place more than 50 km from the sea the Northland peninsula is affected by very moist winds causing abundant rainfall throughout the region. The distribution patterns are also related to the topography, with precipitation ranging from about 1200 mm in low-lying areas to about 2500 mm over some high country between Whangarei and Kaitaia (see figure 4.8).

The rainfall frequency also shows a certain spatial distribution pattern. In the eastern coastal districts the number of annual raindays (rainfall \geq 0.1 mm) is lowest, averaging

⁴³"Gusts" are short-lived but rapid increases in wind speed above the average wind speed.

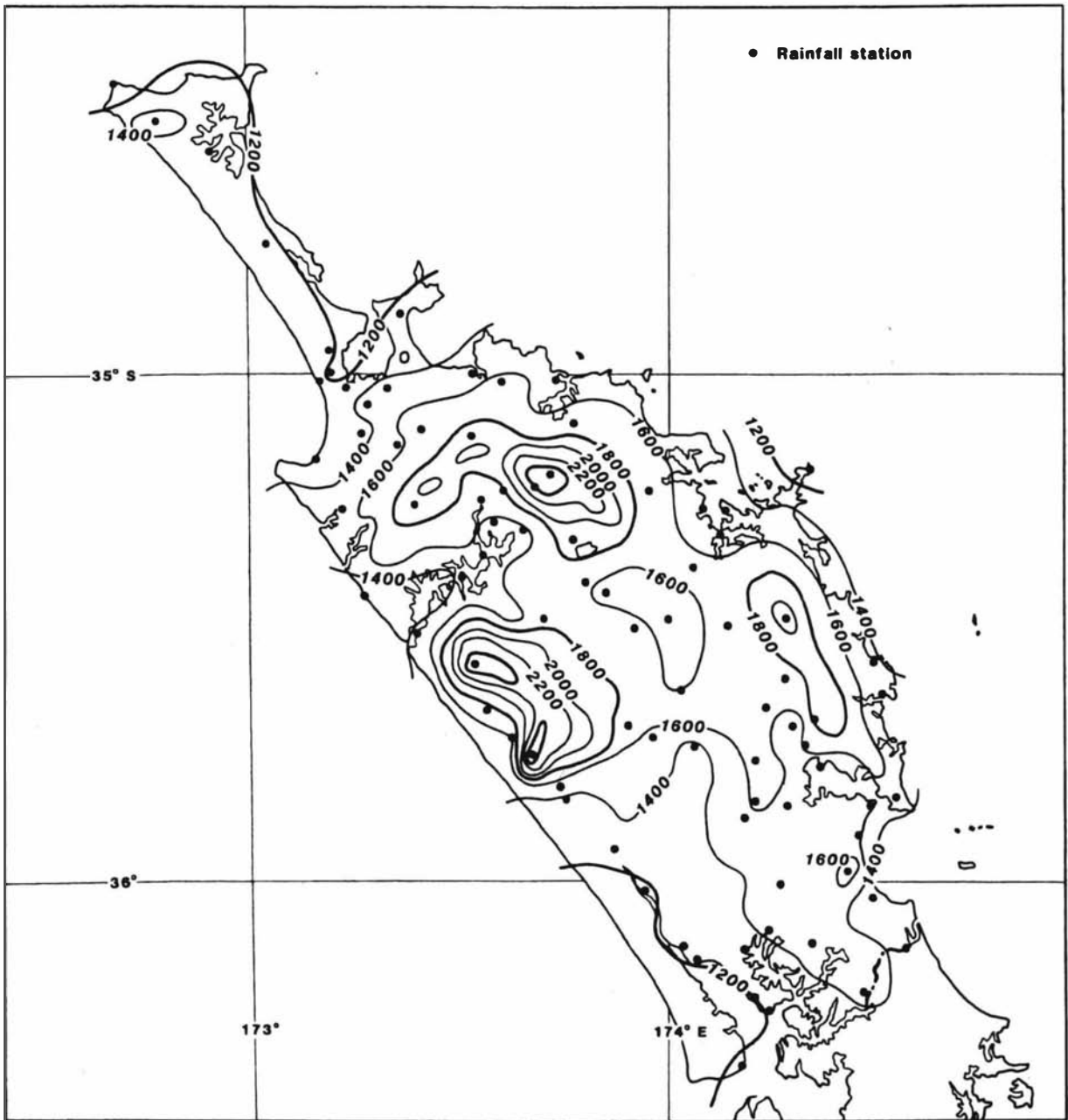


Figure 4.8: Mean annual precipitation in Northland based on 1941-1970 rainfall normals (Moir *et al.*, 1986).

125 to 150, whereas in some western and inland areas their number ranges from 150 to 200, with the highest on the western slopes of the high country.

Furthermore, Northland is also subject to rainfalls of high intensity exceeding 10 mm of precipitation per day. Cape Reinga for example has an annual total of 30 raindays with more than 10 mm of precipitation, Kaitaia Airport 43, Kaikohe 45, Dargaville 38, and Whangarei Airport 39. These 10 mm raindays show the same geographic variability as outlined above. Although the peninsula is so narrow that no rivers of any great length have developed (also see sections 4.1.1 and 4.4.1), these raindays of high intensity are often the cause for flooding. Floods may occur in any month but they are most frequent in winter.

The occurrence of heavy rainfalls is often associated with the passage of depressions of tropical origin over or close to Northland with north-easterly flows between ridges of high pressure to the east and troughs over the Tasman Sea (also see section 4.3.2.1). Intense rainfall events can also occur with thunderstorms. As the total annual precipitation of Northland the spatial distribution of these heavy rainfalls is also clearly influenced by topographic barriers of the peninsula.

The opposite extreme of these heavy rainfalls are periods of low rainfall. By definition periods of 15 days or longer with less than 1 mm of precipitation are referred to as "dry spells" (Moir *et al.* 1986). Dry spells occur occasionally in Northland during the summer and early autumn. There are usually at least one, and frequently two, such periods each year between December and March with an average duration of about 20 days. Nevertheless, the longest dry spell on record lasted 71 days.

Apart from these spatial distribution patterns there is also a marked temporal pattern. The distribution of precipitation shows clear seasonal influences due to the seasonal migration of pressure belts. In summer, the subtropical high-pressure cells are farther south than at other times of the year. This movement displaces the general track of the anticyclones so that they now frequently pass over the North Island. In winter, on the other hand, the high-pressure cells have moved northward, and the whole arrangement

of pressure belts moves with them. Migratory anticyclones (see section 4.3.1) accordingly follow a more northerly track and their centres no longer regularly cross the North Island. In northern New Zealand this general movement of pressure belts causes differences in the precipitation during summer and winter (Garnier, 1958). Figure 4.9 exemplifies these seasonal differences in precipitation.

In Northland these differences are reflected in a clear winter rainfall maximum, while there is a rainfall minimum in summer. From June to August the north and east of the peninsula receives between 35 and 40% of its annual rainfall while the south and west receive about 30 to 35% during these three winter months. Only 18 to 20% of Northland's annual precipitation fall during the three summer months from December to February. Such a degree of seasonal contrast is quite unique throughout New Zealand. Only two other regions of the country, the eastern North Island and inland South Island, exhibit to the same extent such a seasonality in precipitation (Garnier, 1958).

Besides its abundance, another most conspicuous feature of the precipitation regime in Northland is its great monthly and annual variability⁴⁴. For Northland as a whole the average annual variability is about 16%. Figures for selected individual stations throughout Northland are as follows: on the high country west of Whangaruru Harbour the annual variability reaches about 20%, Cape Reinga too has 20%, Waipoua Forest on the west coast 13%, and Whangarei on the east coast 22%. In comparison with the annual rainfall variability for all of New Zealand⁴⁵, which ranges between 10 and 20%, the figure for Northland is rather at the top end.

⁴⁴"Variability" is defined as the average of the differences of the annual totals from the long period (30 years) mean. It is expressed as the "coefficient of variation" which is the ratio of the standard deviation to the mean or percentage of the mean respectively. Accordingly variability is expressed as a percentage (Moir *et al.*, 1986; de Lisle, 1964).

⁴⁵The lowest variabilities throughout New Zealand are found on the west coast of the South Island, a region swept by persistent winds from a westerly quarter. Representative for the low annual rainfall variability of this area is Westport with 11%. Highest variabilities occur in the eastern districts of the North Island. They are a reflection of the irregular occurrence of depressions (Moir *et al.*, 1986; de Lisle, 1964).

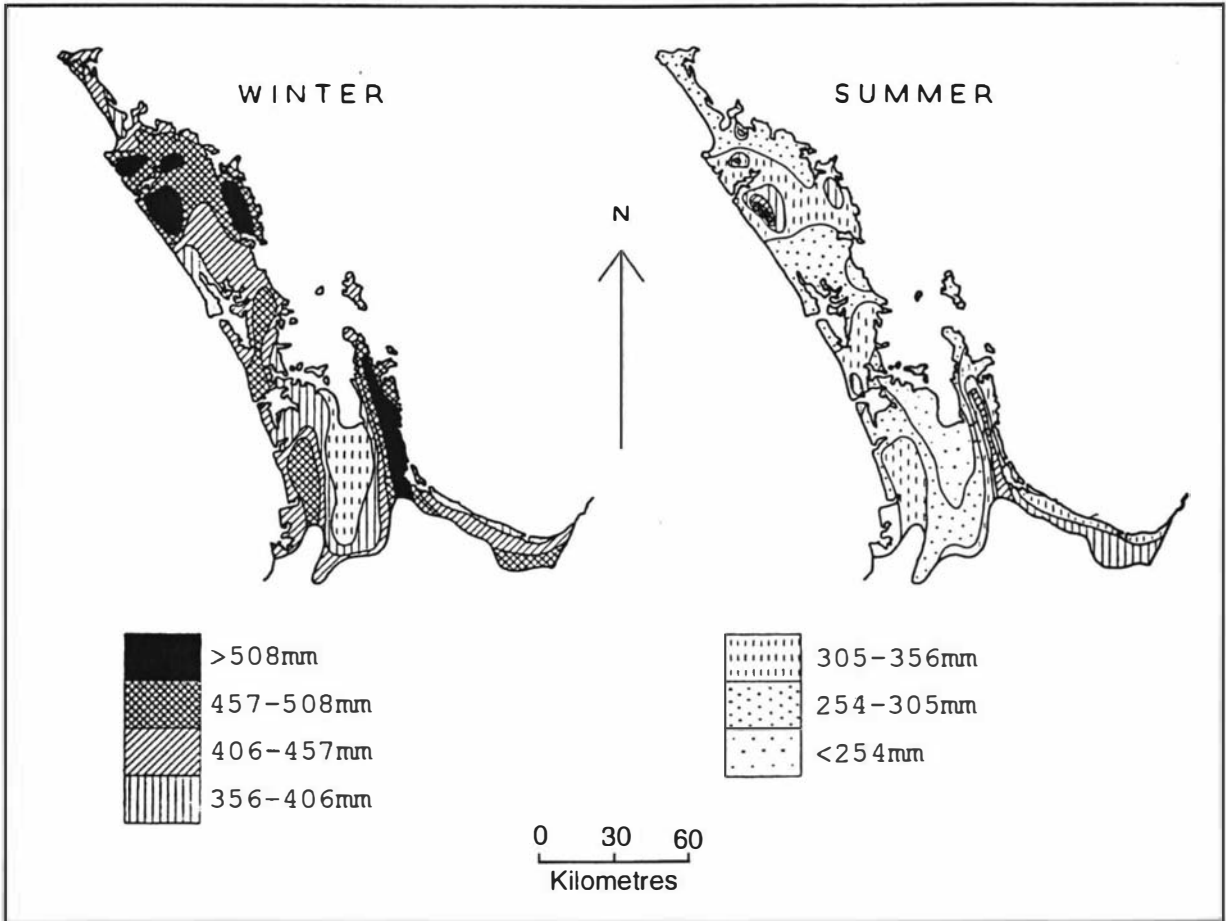


Figure 4.9: Mean distribution of precipitation in northern New Zealand during winter and summer (modified after Garnier, 1958).

4.3.2.3 Temperature

Northland enjoys a mild climate with very few extremes of temperature. Although this feature can mostly be attributed to the relatively low latitudes, the extensive surrounding ocean also has a modifying effect on the temperature of the region.

Like other climatic elements the mean annual (air) temperatures of Northland also exhibit a certain degree of regional variation. In the eastern areas of Northland and the Aupouri Peninsula the mean annual temperatures vary from about 15.5°C to 16.0°C. In western and southern regions the values range from 14°C to 15.5°C. Due to the lack of high mountains in this region (also see section 4.1.1) the influence of elevation on temperature is almost negligible in Northland. Nevertheless, at an environmental lapse rate of 0.6°C/100 m the mean annual temperature at an altitude of about 500m should be close to 12°C, with a mean monthly temperature ranging from about 17°C during January to 10°C during July.

The mean annual temperatures for the southern part of Northland along with those for the region north of the city of Auckland are the highest mean annual temperatures for any part of New Zealand. Although there are other regions in the North Island which have February mean temperatures higher than those found in Northland, no part of the country south of the city of Auckland has higher mean temperatures for July. Figure 4.10 illustrates the pattern of the mean temperature distribution for each season in northern New Zealand.

As reflected in figure 4.10 the mean annual temperature range for Northland is small, averaging 8.5°C which is close to the variation in western districts of both islands. For most east coast districts of New Zealand the annual temperature range is 9.4 to 10.6°C. Inland areas usually show a higher range, with Central Otago reaching a maximum of 13.9°C.

The average daily temperature range is very moderate for Northland. In the Far North the daily range is extremely small. Cape Reinga for example with an annual average of

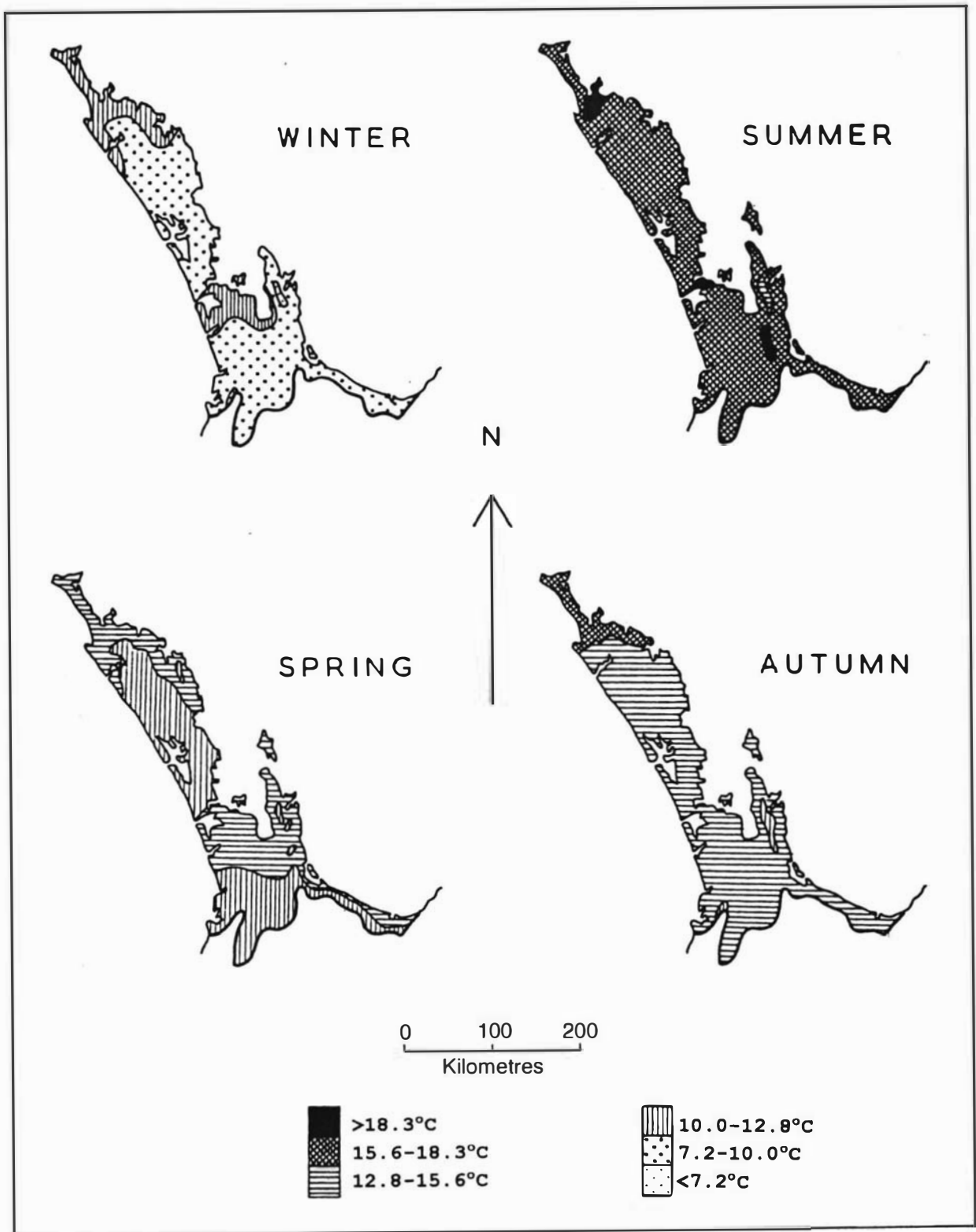


Figure 4.10: Distribution of mean temperatures during each of the four seasons of the year in northern New Zealand (modified after Garnier, 1958).

5.0°C has the smallest for any station in Northland. Largest values are found in sheltered east coast regions, with Glenbervie Forest at 10.1°C having one of the highest ranges in all of Northland.

Diurnal temperature variations throughout Northland are also relatively minor. Available values for Kaitaia for example show a daily range of about 7°C for January and about 4°C for July.

The range of extreme temperatures is also moderate. The highest temperature recorded in Northland was 34.3°C at Kerikeri and the lowest -5.6°C at Glenbervie Forest. By comparison the national extremes lie at 42.4°C and -18.6°C, respectively.

Furthermore, the occurrence of extreme temperatures is also rare. The number of days on which high temperatures have been recorded is not large compared with some inland districts in both islands. The average number of days per year during the period from 1950 to 1959 on which the temperature exceeded 26.7°C ranged from nil at Te Pahi in the Far North, three at Waipoua, four at Glenbervie Forest, five at Kaitaia, nine at Dargaville to 15 at Kerikeri. They compare with up to 40 such days a year in inland Hawkes Bay, and up to 30 in Central Otago.

4.3.2.4 Frosts

Frost is a local phenomenon and its frequency of occurrence can vary widely over very small areas. Areas most likely to be subject to frost are flat areas, from which air is not able to drain away on calm nights, and valleys, where cold air is likely to drift from higher areas. Altogether two different types of frosts are being distinguished: Air frosts and ground frosts. By definition air frosts are frosts with air temperatures, measured by a thermometer 1.3 m above the ground, below 0°C. Ground frosts on the other hand are only recorded when the air temperature at a height of 0.025 m above a clipped grass surface falls below -1°C.

Air frosts are quite rare in most parts of Northland. On the average up to 15 such frosts a year occur in sheltered parts of the peninsula but in most other areas there are fewer than five a year. In detail the figures for a few selected stations are as follows: Locations like Te Pahi station and Te Hapua in the Far North experienced one air frost event on the annual average (period 1931-1973). For other locations further south the figures are nil for Kaitaia (period 1949-1980), one for Kerikeri (period 1945-1973), five for Dargaville (period 1943-1980), and 16.3 for Glenbervie Forest (period 1947-1980). With -5.6°C the latter station even experienced the lowest temperature ever recorded in Northland.

As opposed to air frosts ground frosts can be quite frequent in Northland, especially in sheltered inland areas. In locations like Kerikeri and Glenbervie Forest ground frosts have been recorded on 24.9 (period 1945-1973) and 42.1 days a year (period 1947-1980), respectively. In the remainder of Northland their number is much less, with 5.3 ground frost days a year at Te Pahi station and Te Hapua (period 1931-1973), and 1.7 at Kaitaia Airport (1949-1980). Ground frosts have been recorded in all months except January and February. Nevertheless, many recorded ground frosts are confined to a very shallow layer of air just above the surface and do not seriously affect plant life.

4.3.2.5 Humidity

Due to the proximity of all locations in Northland to the surrounding sea and the lack of any large mountain masses (also see sections 4.1 and 4.1.1), the relative humidity throughout the peninsula is high in all seasons. Relative humidity commonly varies from 70 to 85%. Minimum values are usually reached in the early afternoon when temperatures are highest and maxima often lie between 90 and 100% during clear nights. Despite these rather high figures for relative humidity throughout Northland there appears to be a certain trend. Stations on the western side of the peninsula and those very close to the sea such as Cape Reinga tend to have a slightly higher humidity than those on the east coast or inland.

On the average the diurnal variation is 10 to 15% which is smaller than in many other

parts of New Zealand. Nevertheless, the diurnal variation is greater than the variation from month to month and the difference between mean summer and mean winter humidities.

4.3.2.6 Annual sunshine

Most parts of Northland receive an annual total of about 2000 hours of bright sunshine. This feature is fairly uniform throughout the region and represents about 50% of the possible sunshine that could be recorded in any location. The only areas in Northland which receive noticeably less sunshine are the western flanks of the Tutamoe Ranges on the south-western side of the peninsula. At this high level site (Tutamoe peak 774 m) about 1700 hours of sunshine have been recorded which is about 40% of the possible maximum. For other highland regions of Northland similar sunshine totals are expected.

4.3.2.7 Other elements

Thunderstorms: Although not numerous, thunderstorms are more common in Northland than in most other parts of the North Island. They occur throughout the year but days of thunder are most frequent between May and August when cold, unstable air masses cross the region. Western and central areas have more thunderstorm-days than areas on the eastern part of the peninsula. Their numbers are increasing from 15 a year to 20 in the Tutamoe Ranges. North of Kaitaia and south of Dargaville the number of days of thunder a year is even less. The annual figure there ranges between 10 to 15 such days.

Hailstorms: In Northland hailstorms are rather rare. They only occur on about two days each year, although this figure varies from an average of six days a year at Waipoua Forest to less than once in five years at Aupouri Forest. As with thunderstorms there appears to be a certain temporal distribution pattern with hailstorms. They are most frequently recorded between May and October when 90% of hailstorms in the region occur. They are least likely to occur between January and April.

Tornadoes: On rare occasions tornadoes have occurred in Northland. Nevertheless, tornadoes in New Zealand are much smaller than those which occur in the USA. Their paths are usually of the order of ten to thirty meters in width and between one and five kilometers in length. So far only twelve tornadoes were noted in Northland during the period from 1961 to 1975. However, due to their local and highly transient nature many probably pass unnoticed. Damage caused by tornadoes is occasionally done when they travel through urban areas. One such event was reported in Kaitaia on 6 June 1979. On that occasion a small tornado had developed in the Awanui area during a period of intense frontal activity causing damage in outlying areas of Kaitaia.

4.3.3 Summary

Northland, with its northern location, low elevation and proximity of any part of the peninsula to the sea is characterized by a mild, humid and windy climate. Summers are warm and tend to be mild, while winters experience only a few light frosts each year. Precipitation is commonly abundant throughout the year with sporadic very heavy rainfalls. However, dry spells do also occur, in particular during late summer and early autumn. Most parts of Northland receive about 2000 hours of sunshine per year. Windiness is another important aspect of Northland's climate. It can be very windy in exposed areas and occasionally the region experiences gales, sometimes in association with the passage of depressions of tropical origin.

4.4 Hydrology

4.4.1 Rivers of Northland

The long and narrow Northland Peninsula has no large-scale surface water resources (see fig. 3.10). The rivers of the region are generally short and have an even gradient (also see section 4.3.2.2). Cathcart (1978) attributes this feature to the "morphological maturity" of Northland causing meandering streams with even gradients and slow flow

velocities. The account continues that gradients may be further influenced by lava flows acting as grade control structures. They result in reaches of the river with almost zero grade separated by waterfalls or rapids over the basalt flows. A similar effect on the Kawakawa River has been caused by a series of fault blocks and a large lava flow. In several areas such lava flows have blocked off streams causing large lakes (e.g. Lake Omapere; Healy, 1975; Shaw, 1964) or swamps (e.g. Hikurangi Swamp; Poole, 1983) to form. De Lisle (1964) also notices the drowned valley characteristics of many rivers giving rise to large areas of swamp and low country along their watercourses.

All these features are reflected in Northland's poor hydro-electric power potential (Owen, 1964; also see section 4.1.1). The only operating hydro-electric scheme in the region above 1 Mega Watt (MW) is the 3.2 MW Wairua Falls Station on the Wairua River (see below) (Mills *et al.*, 1990).

Northland's largest rivers are the Wairua and Wairoa River⁴⁶ (Egarr & Egarr, 1981; Owen, 1964) (see fig. 4.11). The Wairua River springs in hilly country north-west of Whangarei. Its headwaters are known as the Waiotu which is joined by a number of other rivers - namely, the Mataroa, Kaiikonui, Kaimamaku, Waiariki and the Whakapara. Where the Wairua and Mangakahia River flow together they form the Wairoa River which at 96 km is Northland's longest river. It forms the northern arm of the Kaipara Harbour and is tidal for most of its length (Egarr & Egarr, 1981). Its catchment drains one third of Northland (Poole, 1983).

Further more general information on individual rivers and catchments in Northland is given by Egarr & Egarr (1981) and the Water and Soil Division, Ministry of Works and Development (1981).

Of the 394 creeks, streams, rivers and estuaries of the North Island Egarr & Egarr (1981) describe 44 rivers and streams of Northland by their location, location of their river mouth and confluence with other rivers, map reference, length, average gradient, recreational use, scenic description, scenic value and recreational value.

⁴⁶The **Wairoa River** is commonly also known as the "Northern Wairoa River" in order to distinguish it from the numerous other Wairoa Rivers throughout New Zealand (Egarr & Egarr, 1981; Owen, 1964).

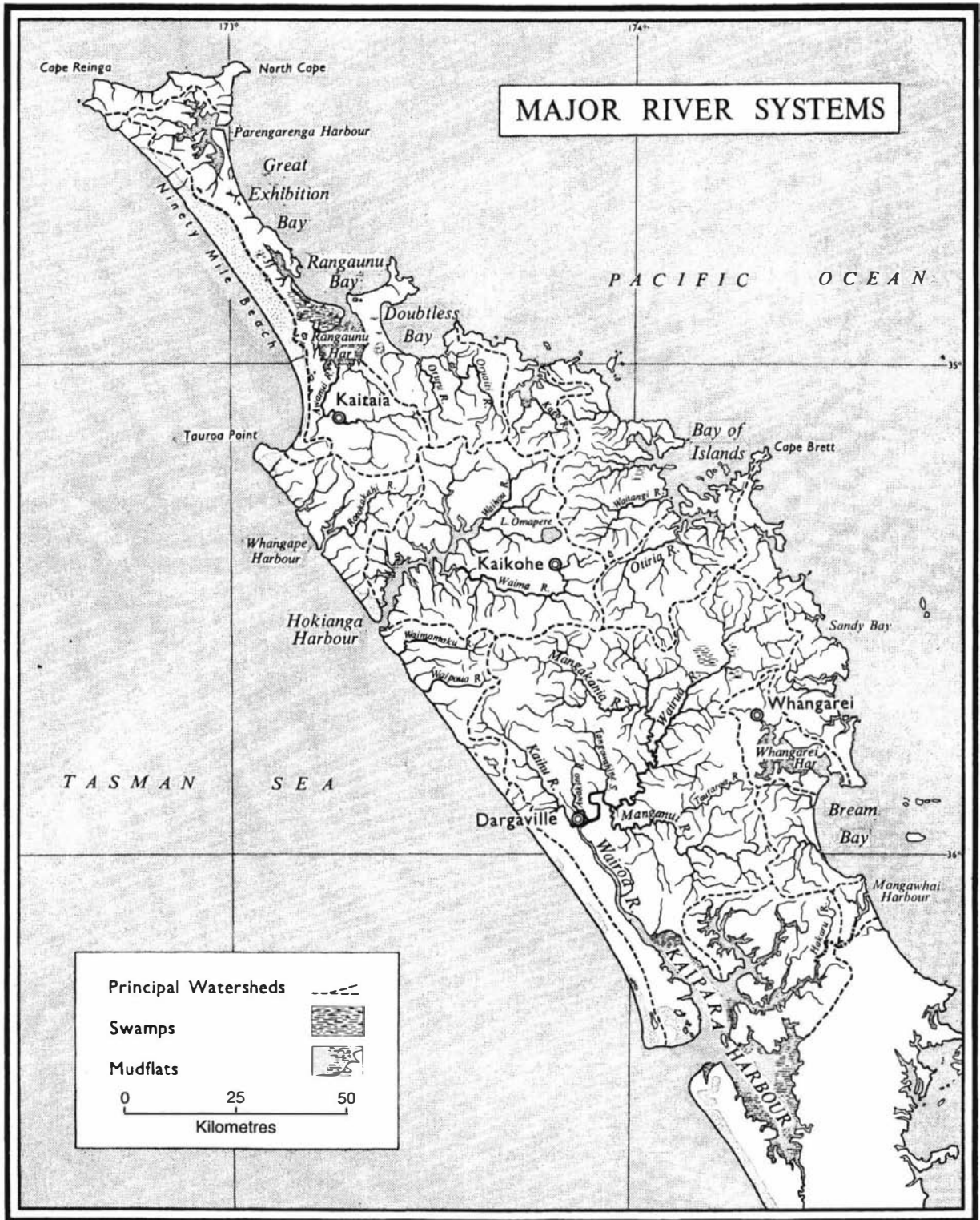


Figure 4.11: Major surface water resources of Northland (Soil Conservation and Rivers Control Council, 1964).

Information and data summaries for 108 catchments for both Islands is provided by the Water and Soil Division, Ministry of Works and Development (1981). The report includes 12 Northland catchments. For each catchment the following information is presented: a map showing the catchment boundaries including its main streams and the location of the stream flow station and rain gauges; a summary of its characteristics (e.g. size, rainfall, altitudinal range, etc.); information concerning the instrumentation, project history and operating agency; and a summary of hydrological data.

Certain aspects of a river's hydrology are a reflection of past and present environmental processes in the physical environment of its catchment. This is particularly true for a river's flow regime and its sediment transport (*cf.* Duncan, 1987). These two aspects are intimately associated with environmental changes, human-induced as well as natural, such as deforestation, slope erosion, and valley alluviation. Therefore, the flow regime, with special emphasis on floods, as well as the sediment transport of Northland's rivers will be discussed in greater detail below.

4.4.1.1 Flow regime

The flow regime of Northland's rivers shows various peculiarities. Certain parameters of their flow regimes are most representative for the greater part of the country or at least the North Island; others differ in many respects from those found in the rest of New Zealand.

The specific mean flow, Q [$l/s/km^2$] (also see section 3.4), of the region's rivers for example is rather representative for the North Island. As Q reflects the prevailing climate (see section 3.4) it is particularly useful in illustrating the general distribution of water resources throughout the country (Duncan, 1987; also see section 3.4). Consequently, the North Island's distinct precipitation peak in winter (see section 3.3.2) is reflected in the flow patterns of its rivers. In this context Northland's Awanui River does not constitute an exception. Along with other typical North Island rivers like the

Mohaka River of Hawkes Bay, the Motu River of the Bay of Plenty, the Waipaoa River of Poverty Bay, the Manuwatu River of the Manawatu, and the Wanganui River of Wanganui, the Awanui River shows a corresponding winter peak in its annual flow patterns (Duncan, 1987; Waugh, 1992). Nevertheless, Duncan (1987) also indicates that this generalization about mean flow patterns of the rivers of Northland rather simplifies the overall picture. This is particularly true for rivers with a substantially larger catchment (e.g. the Wairoa River). Their tributaries may display flow patterns differing from the patterns of the main stem due to spatial differences in precipitation, geology, topography, etc.

Unlike the mean flows the flood flows of Northland's rivers are rather unrepresentative of the rest of New Zealand. Despite the lack of large rivers the region's watercourses are subject to severe flooding and floods can rise to high levels. They can occur in any month but are most frequent in winter (also see section 4.3.2.2). The reason for that is Northland's exceptional combination of a number of environmental factors affecting the rivers flow patterns. In detail these are: high intensity rainfall; small catchments; impervious soils; and steep slope gradients (Cathcart, 1978; de Lisle, 1964; Poole, 1983; also see sections 4.1.1, 4.2 and 4.3.2.2).

The reason for Northland's high intensity rainfalls was already discussed in greater detail in section 4.3.2.2. Another important factor is the catchment size. Even the whole of the Wairoa River catchment which drains a third of Northland (see above) can be affected by a single rain producing storm. Smaller catchments are even more subject to these events as they usually completely fall within low pressure systems. The widespread heavy rain associated with these pressure systems often leads to a rapid concentration of water causing "flash-flood effects" within the catchment (Cathcart, 1978).

Soils impervious to rain further aggravate these flash-flood effects as they enhance overland flow. The reason for their imperviousness can be sought in three pedological features: high clay contents (see sections 3.2 and 4.2), a poor structure and the development of a subsoil pan. High intensity rain falling onto soils exhibiting any of

these features almost entirely drains off as overland flow (Cathcart, 1978). Subsoil pan development is particularly associated with areas which were once covered in kauri forest. These led to the formation of podzolised soils (see section 4.2) which exhibit a very low permeability. Such soil conditions prevent, or at least substantially reduce, the rate at which precipitation is absorbed in the soil. Furthermore, under changed land use these soils, in particular clay soils, are highly subject to erosion leading to an increased inwash of sediments into streams and lakes.

Rapid runoff is further enhanced in combination with steeplands. Although no part of Northland exceeds 790 m above sea-level (see section 4.4.1) there are areas of hillcountry with short and steep slopes falling from 600m above sea-level to almost sea-level within very short distances. As the upper reaches of streams within this rugged hillcountry are on very steep grades very high velocity flows are being reached. They lead to a rapid concentration of water in the affected catchments in the form of the above flash-floods (Cathcart, 1978). In these areas some of the largest floods (>1000 l/s/km²) of the North Island occur (Duncan, 1987).

More recent volcanic rocks of Quaternary age (also see fig.4.3) and other outcrops on higher ground have largely escaped the intensive weathering and did not form impermeable soils. In these areas of more permeable soil cover precipitation more readily recharges the groundwater supplies. Rivers originating from there are usually spring fed and rarely dry up during summer. Floods are also less severe (de Lisle, 1964; *cf.* Poole, 1983).

All the above environmental factors combine to cause rapid rates of runoff throughout the Northland Peninsula, except for those areas dominated by sand dunes (see section 4.1.3.5). This rapid runoff in combination with certain catchment characteristics such as flat flow gradients (see above); undersized channels; tidal influences; and phytogenic blockage results in frequent overflow and ponding (Cathcart, 1978).

Flat flow gradients basically hamper a rapid draining of floodwaters causing a rise in water levels. The effects of the remaining three catchment characteristics on

streamwater runoff are slightly more intricate. Cathcart (1978) describes their cause and effect as follows: Undersized channels are mainly the product of a changed land use. Initially river channels had developed in bush-covered catchments in pre-European periods. These now tend to be inadequate to carry the substantially larger volumes of floodwater draining off the largely grass-covered catchments of post-European land use. Consequently, floodwaters which would have caused flooding every two to three years in a bush-covered catchment now cause flooding several times a year. The problem was further compounded by the draining of marginal swamps (see above), first by gum-diggers and later by farmers, depriving the catchment of any natural storage.

Tidal influences lead to a flooding of marginal swamps along the lower reaches of Northland's rivers. These swamps have formed as a result of the rising sea-level. They created a drowned valley system within which tidal influence occurs some distance inland (see above). The best example appears to be the lower Wairoa River. On each of its tributaries swamps developed where tidal influences cause water to pond and sediment to deposit. These natural ponding areas collect sediment and prevent floodwaters from ponding on land further downstream. Floodwater in these lower reaches often remains ponded between one to two tide cycles.

Phytogenic channel obstruction is another major cause for frequent flooding in the region. However, the increased growth of aquatic weeds triggered by an enhanced input of nutrients due to farming within the catchments is negligible. These weeds do not become a serious problem in streams shaded by evergreen bush. Flooding in many streams in Northland is instead a direct result of willow blockages. Willows were planted along many streams in the region to control bank erosion following the initial clearing of bush from catchments. Owing to a lack of maintenance this erosion control tool has become a problem weed. This is because willows when not properly maintained block the channel and physically retain water. By reducing the stream flow they also lead to the deposition of sediment causing the channel capacity to be permanently reduced in size. Other species obstructing stream flow include Manchurian Ricegrass (*Zizania latifolia*), Giant Bullrush (*Typha latifolia* sp.) and *Glyceria maxima*.

Further statistically-based information about flood flows in Northland can be found in Beable & McKerchar (1982) and McKerchar & Pearson (1989). Their reports deal with flood estimation and flood frequency for different hydrological regions throughout New Zealand.

Based on their statistical analysis of annual flood peaks from 152 recording stations throughout New Zealand Beable & McKerchar (1982) defined nine mean annual flood regions for the estimation of flood size and frequencies. These tend to correspond to lithologic and climatic regions, and a regional equation for flood size, Q , is suggested for each. Data for flood frequency for Northland are provided in the form of a regional frequency curve covering the entire northern North Island. Regional equations and tabled values for flood size on the other hand appear in the same group along with the Auckland region and Coromandel. Furthermore, a summary of flood peak data used in the regional flood frequency analysis is also provided for 21 stations throughout the northern North Island.

However, due to the rather large size of the above hydro-statistical regions the value of the provided information for estimated flood size and frequency for Northland is rather limited. This problem is slightly reduced in the report by McKerchar & Pearson (1989). Using larger data sets and longer records from 343 rivers nationwide they devised a map-based method of estimating mean annual flood flows and 100-year floods. The isolines of their flood flow maps show specific discharge and a flood frequency factor. For the northern North Island (Auckland and Northland) the authors mention the difficulty to obtain a satisfactory set of isolines. However, they conclude that the general trend appears to be an increase in specific discharge from west to east ranging from one to $5 \text{ m}^3/\text{s}/\text{km}^2$. For Northland this statement requires further refinement. There, the marginal regions of both coasts of mainland Northland show specific discharges between one and $3 \text{ m}^3/\text{s}/\text{km}^2$ whereas the central part has around $5 \text{ m}^3/\text{s}/\text{km}^2$. With less than $1 \text{ m}^3/\text{s}/\text{km}^2$ the Aupouri Peninsula as well as the south-western part of mainland Northland have the least flood flow of all of Northland.

Another important parameter of flow regime is low flow. Low flows can have radical

effects on river and stream ecosystems, and the longer the period of low flow, the greater is the effect (Duncan, 1987). Hutchinson (1990) describes the "5-year return period minimum 7-day flow"⁴⁷, "Q57" [l/s], as the probably most useful low flow measure. Dividing Q57 by the catchment area provides values for the "specific 5-year 7-day low flows", "SQ57" [l/s/km²]. By plotting SQ57 against catchment mean precipitation, "R", two parameters which showed strongest correlation, for 356 catchments in both Islands Hutchinson (1990) divided the country into 11 "low flow regions", designated "A" to "K". Northland is covered by low flow regions "A" and "F", with "A" covering all of the Aupouri peninsula, northernmost mainland Northland, and about a third of the eastern part of mainland Northland. Low flow region "F" covers the remainder of Northland, two thirds of the western part of mainland Northland. Based on the slope of "SQ57 vs. R" regression lines both regions show that low flows relative to precipitation inputs are low in these regions, with region "A" having the second lowest values in the country. Nevertheless, all of Northland exhibits a high variability of SQ57 with a wide range in values (Hutchinson, 1990; Waugh, 1970). For the catchments in region "A" SQ57 ranges from 0.2 to 9.3 l/s/km² and for region "F" from 0.01 to 25.8 l/s/km² (Hutchinson, 1990). Waugh (1970) attributes Northland's high variability in low flows to the region's variable geology. In his study of summer low flows in Northland he found that fissured basaltic lava absorbs rainfall and releases it slowly, thus sustaining low flows. Areas with other rock types, e.g., Cretaceous shale and sandstone are less absorbent, and their watercourses have even lower low flows. This feature appears to be particularly true for region "A". Hutchinson (1990) claims that due to the small variation in rainfall SQ57 in this region variability in low flow is mainly related to slope and hydrogeology variables (e.g. infiltration capacity, water storage capacity, and transmissibility). More detailed information on low flow frequency with different return periods for individual catchments in Northland is also given by Hutchinson (1990).

⁴⁷The "5-year return period minimum 7-day flow" (Q57) [l/s] is the minimum mean flow in a consecutive seven-day period which has a probability of 0.2 that flows lower than it will occur in any year (Hutchinson, 1990).

4.4.1.2 Sediment discharge

Changes in land use in particular in association with deforestation are the prime reason for accelerated erosion within a stream's catchment. As the sediment yield of watercourses reflects the erosion rates within the catchment sediment discharge is an important aspect of river hydrology. Reported erosion rates for New Zealand range from as little as 40 t/km²/a to as much as 8000 t/km²/a for catchments of 1000 km² (Thompson & Adams, 1979). In a country the size of New Zealand this is a wide range by world standards.

Of all catchment factors such as annual precipitation, percentage of forest cover, slope gradient and geology, which might be effective in determining the annual sediment yield of a river, precipitation appears to be the most important (Duncan, 1987). This contention is supported by other workers on sediment loads in New Zealand rivers. Thompson & Adams (1979) for example state that erosion, estimated as the mean load per unit of catchment area, is presumed to correlate with rainfall. They conclude that the implied spatial variations in erosion are shown to agree with erosion data from surveyed catchments. Griffiths (1982) explains most of the variance in specific annual suspended sediment yields for 47 basins of the southern North Island with catchment mean rainfall.

Nevertheless, despite comprehensive work on this subject in different parts of New Zealand, e.g. Adams' (1979) work on 40 catchments, Griffiths' (1982) on 47 catchments, both in the central and southern North Island, and Thompson & Adams' (1979) on two hydro-lakes (Roxburgh and Matahina) and 33 catchments on the eastern slopes of the Southern Alps, there is only insufficient data on suspended sediment yields available for Northland. However, based on work by Griffiths & Glasby (1985), Duncan (1987) compiled maps of specific mean annual sediment discharge for both Islands. Accordingly, the specific mean annual sediment discharge of Northland's streams and rivers is rather homogenous throughout the region. The larger part of mainland Northland has sediment yields of 100 to 500 t/km²/a. Merely the entire Aupouri peninsula as well as the southernmost part of mainland Northland including the North Kaipara Peninsula (Pouto Peninsula) have sediment discharge rates of less than 100

t/km²/a. Such relative homogeneity of Northland's sediment discharge reflects the relatively even annual precipitation of the region. The low sediment yield in the northern and southern part of Northland might be best explained with a rapid infiltration of rainfall. This feature most definitely applies to the highly pervious Quaternary deposits of the Aupouri and North Kaipara peninsulas (*cf.* Duncan, 1987).

4.4.2 Lakes of Northland

Using Lowe & Green's (1987) classification scheme for New Zealand lakes (also see section 3.4) there are only lakes of three different types in Northland: Dune lakes; volcanic lakes; and riverine lakes. Of these types the dune lakes constitute by far the most numerous group, followed by the volcanic lakes and finally the riverine lakes (see fig. 4.12).

The maps in fig. 4.12 do not show all the lakes which occur in Northland. They are rather based on Irwin's (1975) checklist of all New Zealand lakes with at least one axis ≥ 0.5 km long. Nevertheless, some general information on a number of lakes with smaller dimensions is also given by Irwin (1975). For some Northland lakes, in particular the larger ones, further referenced information on lake and catchment characteristics, water chemistry and biology can be found in Livingston *et al.* (1986).

4.4.2.1 Wind-blown dune lakes

Northland's most numerous type of lakes, wind-blown dune lakes, are the third most common lake type in New Zealand. They originate by the blocking of valleys or depressions by wind-blown sand deposits. Many dune lakes, often surrounded by marginal peat swamps, occur at the boundaries between the dune belts which run subparallel to the present coastline. As these belts progressively increase in age inland from unstable active frontal dunes on the coast, formed only in most recent historical times, to moderately weathered, stable dunes of Pliocene/Early Pleistocene age reaching

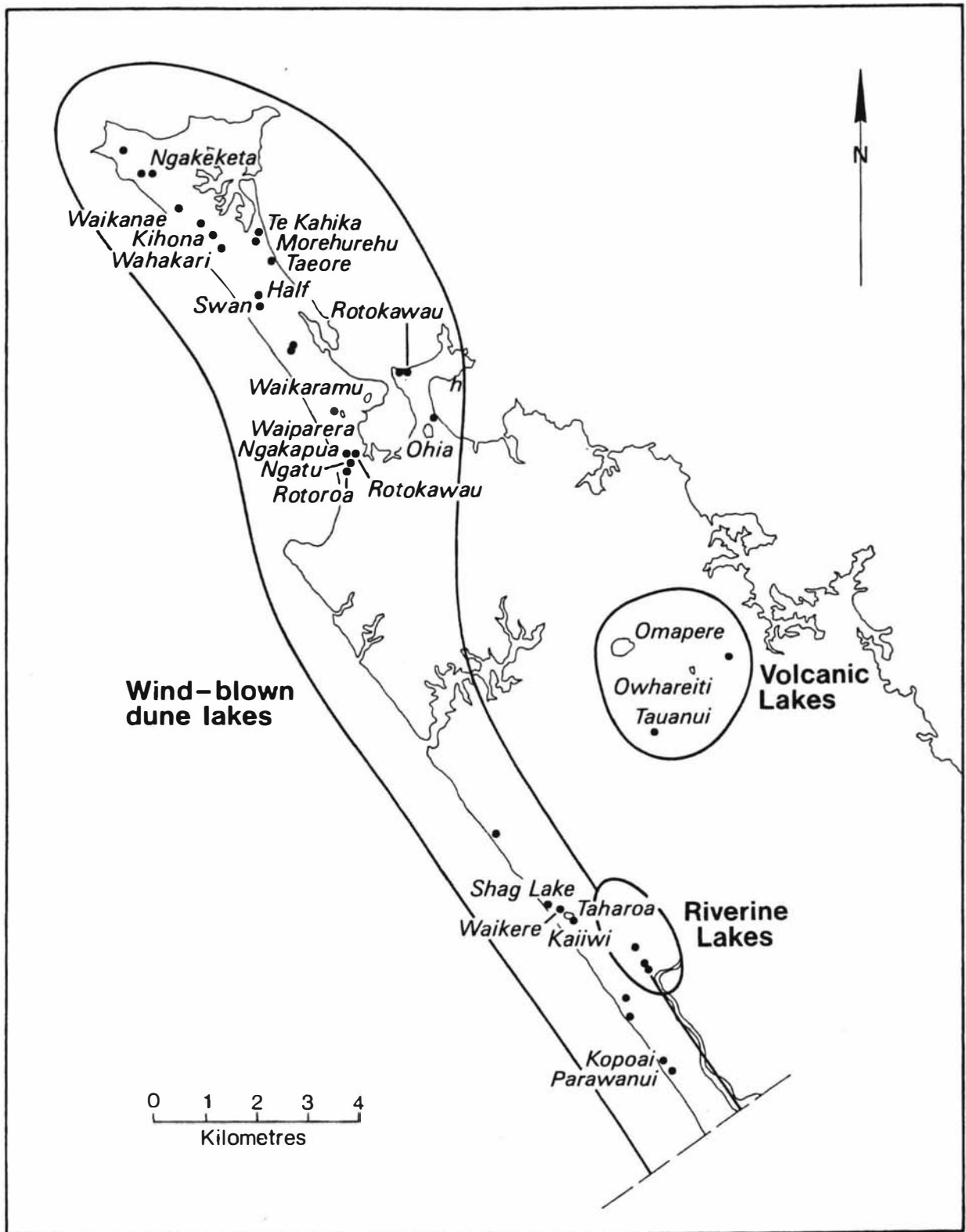


Figure 4.12: Distribution of dune (W), volcanic (V), and riverine (R) lakes with a maximum dimension ≥ 0.5 km in Northland (modified after Green & Lowe, 1987).

heights of 100 to 200 meters (Lowe & Green, 1987). Consequently, dune lakes located in these dune belts show a relatively wide range of ages. Spigel & Viner (1992) summarize their age range from a few hundred years to more than 50,000 years, with ages of 2000 to 3000 years being typical. Further more detailed information including reviews on the mode of formation, age, and type of dune lake (e.g. "barrage lake" or "deflation lake" and their sub-types) of individual dune lakes or groups of dune lakes in Northland and elsewhere along the west coast of the North Island are given by Lowe & Green (1987, 1992).

4.4.2.2 Volcanic lakes

The number of volcanic lakes in Northland is very limited. They all lie in the Kaikohe-Bay of Islands Volcanic District which is dominated by the Horeke and Takeke Basalts of the Kerikeri Volcanic Group of Pliocene/Quaternary age (also see section 4.1.3.4). Of the three major lake basin forming processes for volcanic lakes put forward by Healy (1975) Northland's largest volcanic lakes, Lake Omapere and Owhareiti, seem to have formed from damming by basaltic lava flows from the above volcanics. This view is particularly supported by Lowe & Green (1987, 1992). In their reviews on the formation of Lake Omapere they reveal a rather complex development through its geological history. Tephrochronological analyses of sediment cores from Lake Omapere revealed that the modern lake is very young, having formed *ca.* 1000 years ago, but that earlier transitory lakes existed periodically in the Omapere basin. Palynological analysis on the cores further revealed that the earliest lake deposits may be as old as *ca.* 125,000. This "proto-Lake Omapere" is suspected to have formed through lava damming by flows from the Te Ahuahu volcano, whereas the modern lake possibly formed because of blockage of drainage caused by erosion in the catchment induced by Polynesian deforestation.

4.4.2.3 Riverine lakes

Although riverine lakes are the second most abundant lake type in New Zealand in Northland they constitute only the smallest group. The two most important types of riverine lakes are "oxbow lakes" and "lateral lakes". The former form in abandoned channels, e.g. cut-off meander loops, whereas the latter result from levees blocking the drainage of a main stream's (lateral) tributaries (Lowe & Green, 1987, 1992). In Northland the only riverine lakes occur a few kilometers north-west of Dargaville. Irwin (1975) lists three small ($\leq 0.25 \text{ km}^2$) unnamed oxbow lakes adjacent to the Kaihu River. Lowe & Green (1987, 1992) assign a Late Holocene age to them as they lie on recently active floodplains. Consequently, they may be subject to frequent flooding and sediment infilling.

4.4.3 Wetlands of Northland

Wetlands are numerous throughout Northland covering about two percent of the region (Poole, 1983). Many of them occur along rivers, and around the margins of lakes and estuaries. Left in their natural state most wetlands are either flooded periodically (e.g. estuarine wetlands) due to tidal action or frequently (e.g. riverine wetlands) as a result of flood flows (also see sections 4.3.2.2 and 4.4.1.1).

Nevertheless, despite Northland's abundance of different wetlands there are only five major wetlands in the region regarded as of greatest importance from the viewpoint of nature conservation. Combined in regional groups Scott (1996) lists the following wetlands for Northland: the Aupouri Peninsula wetlands, central part of the Aupouri peninsula; Parengarenga Harbour wetlands, northern end of the Aupouri peninsula; Muriwhenua wetlands, southern end of the Aupouri peninsula; Whangarei Harbour wetlands, adjacent to Whangarei City; and Pouto peninsula (North Kaipara peninsula) wetlands, 45 km south-west of Dargaville. Another two extensive swamplands, the Hikurangi and the Kaitaia Swamp, are described by Poole (1983). The Hikurangi Swamp, north of Whangarei, formed as a result of the damming by a lava flow of a

tributary of the Wairoa River. The Kaitaia Swamp, west of the township of Kaitaia, owes its existence to an abandoned rivercourse. The formation of sand dunes diverted the Awanui River northward to discharge into the Rangaunu Harbour.

4.4.4 Summary

Northland, like the remainder of the country, is well-endowed with rivers, lakes and wetlands. The region's rivers are generally short and have small catchments with steep slope gradients. The different parameters of the river's flow regimes reflect Northland's prevailing climate and physical environment. A winter peak in the annual mean flow patterns indicates the region's predominance in winter rainfall. Flood flows which can rise to high levels and which often occur in the form of flash-floods are almost unmatched elsewhere. These are the result of Northland's unique combination of high intensity rainfalls, small catchments, impervious soils, and steep slope gradients. Low flows on the other hand constitute the other extreme. They are highly variable though extremely low in value. They are believed to reflect the region's variable geology. Despite the uniqueness in flow regime of Northland's rivers their mean annual sediment discharge is rather homogenous throughout the region. With a volume of 100 to 500 t/km²/a for the larger part of Northland it is rather representative for the remainder of the North Island.

In the case of riverine and estuarine wetlands as well as lakes with an in- and out-flows these sediment loads are often deposited within them. Even those lakes and wetlands unaffected by rivers and streams are infilled by sediments through erosion within their catchments. The distribution of Northland's larger lakes (maximum dimension ≥ 0.5 km) is rather uneven. The wind-blown dune lakes only occur throughout the Aupouri Peninsula as well as in a narrow strip along the west coast of mainland Northland. The very limited number of riverine lakes is also concentrated on the west coast in a small area north-west of Dargaville. Only Northland's volcanic lakes constitute an exception. They occur in the Kaikohe-Bay of Islands Volcanic District in the central part of mainland Northland. The region's larger wetlands are equally unevenly distributed.

Three of them lie in the northern part and the remaining four in the southern part of the Northland Peninsula. Despite their irregular distribution throughout the region and different mode of formation these lake and wetland basins act as natural sediment traps. Their sediments archive information about environmental processes within the catchment of the basins. This feature makes them suitable for a variety of palaeolimnological studies.

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Chapter 5

THE BIOTA AND QUATERNARY RECORD OF NEW ZEALAND

5.1 General aspects of the origins, history and composition of the biota of New Zealand

New Zealand is endowed with a biota which is unique in the world and only matched by that of Madagascar. This is because both the New Zealand and Malagasy landmasses accommodate lifeforms of continental evolution in an island-like isolation. For the New Zealand micro-continent this feature is attributed to the combination of four environmental factors: the country's mountainous topography; its extreme isolation from other major landmasses; the maritime temperate climate; and the continental character⁴⁸ of the New Zealand archipelago. Other isolated islands with similar environmental conditions, in particular oceanic island groups, e.g. the Hawaiian and Galápagos Islands, also accommodate some unique biotas, but they differ markedly from New Zealand. Geologically they are much younger and because of their mode of origin they lack a number of typical continental features (see footnote #48). Consequently, their lifeforms could not have evolved *in situ* but must have arrived there by introduction (Molloy, 1994). A common form of species arrival in an island or island group other than through the deliberate introduction by humans is by "sweepstake dispersal"⁴⁹ (Bishop, 1992). However, introduction by sweepstake dispersal was not

⁴⁸Islands and island groups isolated from continental landmasses but accommodating a unique biota with its characteristic features (see below; sections 5.1.1 and 5.1.2) are usually classed as "**oceanic islands**". The New Zealand archipelago generally conforms to this, with the exception that it shows surface features as complex and varied as those found on any continent. New Zealand's **continental character** is particularly manifested in a variety of environmental features ranging from a complex geology, giving rise to different soil types (see sections 3.1 and 3.2), to climatic conditions with moderate temperatures, high levels of precipitation, and drier near-continental areas in the south-east of the South Island (see sections 3.3.2 and 3.3.3). The combination of these features enables the support of a range of different vegetation types, with profuse forest cover of much of the country at altitudes below 1000 meters (see below; sections 5.1.3 and 5.1.4); a network of rivers and a system of lakes of different origin (see section 3.4), ranging from deep glacial lakes to rather shallow wetlands of coastal plains (*cf.* Falla, 1976).

⁴⁹"**Sweepstake dispersal**" is defined as the population of isolated islands by animals and/or plants across sea-barriers. In the case of plants "sweepstake dispersal" can be achieved through the distribution of seeds by wind and birds. With animals sweepstake dispersal mainly occurs among flying birds and insects.

exclusively restricted to oceanic islands and island groups. Certain elements of New Zealand's flora and fauna were also introduced in this manner. Bishop (1992) provides a concise account of floral and faunal introductions from Australia since the disruption of New Zealand from Gondwanaland.

5.1.1 The floral record

The New Zealand landmass is characterized by a long period of geographic isolation which began with its disruption from the Gondwana supercontinent about 80 Ma ago (see section 3.1). Consequently, the indigenous flora of New Zealand displays a low level of biodiversity in species of higher plants (i.e. flowering plants [angiosperms], conifers [gymnosperms], ferns [pteridophytes] and their allies) but shows a high degree of endemism.

The endemism is reflected in many differences in the country's flora from other regions in the world. McGlone (1988) particularly points out the floral differences between New Zealand and the northern temperate zone. Although situated within equivalent latitudes, New Zealand's vascular flora has only few links with that region. Even those families and genera shared with the northern temperate zone are mostly of global distribution. The sharpest contrasts are manifested in the evergreen and perennial character of most New Zealand plants. Unlike the plants in the northern temperate zone annuals and summer-green herbs are rare in New Zealand, and only *ca.* 10 trees and shrubs are fully deciduous. Of those deciduous plants *Plagianthus regius* (manatu/ribbonwood) is the only tall tree; and none of them are dominants in any major vegetation type.

Nevertheless, significant floral differences also exist between New Zealand and its neighbours throughout the South Pacific region. They are most obvious between New Zealand and the oceanic islands and island groups (see above) but also occur between New Zealand and Australia, the nearest continental neighbour. Despite a strong systematic link between both continental landmasses, in particular on a generic level,

Large land animals which require some form of a natural raft (e.g. drifting rafts of vegetation) in order to negotiate sea-barriers are usually not included in this list (*cf.* Bishop, 1992).

most vegetation communities are not at all close (McGlone, 1988). A more detailed account on the floral relationship between Australia and New Zealand is given below.

Statistical information on New Zealand's flora has been provided by various workers (e.g. Godley, 1976; Lowe, 1994; Lowe & Percival, 1993; McGlone, 1988; Molloy, 1994; Wardle, 1991). The following account summarizes the data provided by these workers. The indigenous flora of New Zealand comprises *ca.* 2300 vascular species. This is a small number compared with other countries of similar size and latitude. However, endemism at the specific level is high: *ca.* 85% of the seed plant species and 41% of the fern species. Those native species which are not endemic are predominantly shared with Australia.

At the generic level⁵⁰ the picture is noticeably different. Only 10% of the New Zealand genera are endemic which includes only one genus of fern (*Loxoma*) and 39 genera of flowering plants. With the exception of *Raoulia* with *ca.* 24 species and *Hoheria* with four to five, the diversity of the endemic genera of flowering plants is distinctively low. All of them have only one to three species; 24 genera are even only represented by a single species. Most of those are closely related to larger native genera. Nevertheless, the larger part of the native genera are not endemic and are shared with other regions of the South Pacific; predominantly with Australia, followed by Chile, many Pacific Islands and even regions in South-East Asia. In percentage terms the generic relationships are as follows: Seventy-five percent of New Zealand's seed plants and 85% of the fern genera are shared with Australia. Altogether about 80% of all of New Zealand's higher plant genera are also found in Australia. The equivalent figures for New Zealand genera in Chile are 43% (seed plants) and 40% (ferns), respectively. However, despite the strong generic relationship with Australia, the most distinctive and widespread Australian genera, *Eucalyptus*, *Acacia*, and *Banksia*, do not occur in New Zealand.

The degree of endemism of elements of the New Zealand flora rapidly decreases at

⁵⁰A detailed list of all genera of the indigenous New Zealand flora, including the number of their constituting species is given by Wardle (1991).

higher levels of the botanical classification system. Although 138 native families⁵¹ of higher plants (flowering plants: 109; conifers: 3; ferns and their allies: 26) are recognized in the New Zealand flora none is endemic. Despite the lack of endemic families in New Zealand absence or low representation of distinctive and widespread families of the Australian flora within New Zealand is even more characteristic than at the generic level. Even those families which attain high levels of both diversity and dominance in the Australian floral record, e.g. Myrtaceae, Epacridaceae, Leguminosae, Proteaceae, and Stylidiaceae, are either not represented in New Zealand, or of low diversity, or are represented by different genera.

Nevertheless, the degree of endemism on the specific and generic levels, and the important development of certain genera in New Zealand is considered sufficient to give the New Zealand archipelago the status of a distinct Botanical Region. This region includes the three main Islands, as well as the Kermadec, Chatham, Snares, Antipodes, Auckland, Campbell and Macquarie Islands (also see fig. 3.2). Bearing in mind the latitudinal, from sub-tropical to subantarctic, as well as altitudinal range, particularly in the South Island, this Botanical Region provides environments for a rich variety of different vegetation types.

Another important aspect of New Zealand's flora are those species which are not native. The introduced vascular flora⁵², also referred to as adventive plants, contains 1860 species. The first introductions which arrived with early Polynesians (see also sections 2.1.4.1 and 2.2.4) were largely tropical crop plants. These tropical cultigens could initially only be grown in the warmest parts of the North Island. Later techniques were developed that permitted the cultivation of species like *Ipomoea batatas* (kumara/sweet potato) (also see section 2.1.4.4) at least as far south as Christchurch (Wardle, 1991). The growing influx of permanent settlers from Europe from 1840 onwards resulted in an immense increase in the number of introduced species. More than 1600 species of plants

⁵¹For more information about the native families of the New Zealand flora, including the number of their constituting species see Wardle (1991).

⁵²The largest families of the introduced vascular flora include: Asteraceae (215 species), Poaceae (220), Fabaceae (121), Brassicaceae (74), Caryophyllaceae (54), Lamiaceae (54), Scrophulariaceae (52), and Solanaceae (50). The largest genera are *Juncus* (31 species), *Trifolium* (25), *Rubus* (24), *Carex* (22), *Eucalyptus* (20), *Solanum* (19), *Salix* (16), *Senecio* (16), *Veronica* (16), *Oxalis* (15), *Euphorbia* (14), and *Rosa* (14) (Wardle, 1991).

are assumed to have been introduced since then, mainly comprising crops, grasses, and various species of *Pinus* (Molloy, 1994; Wardle, 1991).

Many of the introduced species became successfully naturalized, and the native versus naturalized status is often uncertain. Altogether about 560 species are now regarded as fully naturalized, with some 240 being more or less common throughout the country. The success of the naturalized flora is largely in habitats created through human interference with the natural environment. Nevertheless, some introduced species also successfully occupied natural habitats, such as flood plains, dunes and lakes, reflecting the low competitiveness of native species in some of these environments.

Low competition from native species in combination with ideal environmental conditions for their proliferation resulted in a rather aggressive spread of some adventive plants. Consequently, more than 80 introduced species are now listed as noxious weeds. The most notorious among them are *Rubus fruticosus* (blackberry); *Cirsium arvense* (Californian thistle); *Senecio jacobaea* (ragwort); and *Rosa rubiginosa* (sweet brier). Other physiognomically prominent species in the north are the widespread *Ulex europaeus* (gorse), *Cytisus scoparius* (broom) and *Hakea sericea* (needlebush). *Lupinus arboreus* (tree lupin) prefers habitats like dunes and alluvial flood plains; and *Ammophila arenaria* is mainly restricted to dunes. The eastern South Island on the other hand is seriously affected by the infestation of *Nassella trichotoma*, a South American tussock grass.

In many places these introduced species have completely changed the landscape and ecology. The deliberate cultivation as well as unintentional release of introduced species into the wild often forced the native flora to retreat to refuges like mountainous terrain, off-shore and outlying islands, and the humid West Coast of the South Island. Some lowland regions, especially the Manawatu, Hawkes Bay, Wairarapa, Waikato, Canterbury, coastal Otago and the Southland Plains, were almost completely transformed to pasturelands by European introductions like *Lolium* spp. (ryegrass), *Dactylis glomerata* (cocksfoot) and *Agrostis capillaris* (browntop).

5.1.2 Fauna

New Zealand's long isolation from the rest of the world also gave rise to an unusual primeval fauna of Gondwanan lineage. This feature is particularly reflected in the absence of cursorial mammals, neither marsupial nor placental, and a lack of snakes. Even despite a few later arrivals from more recent times, mostly from Australia, the country's faunal composition had a distinctively limited variety. Prime reason for that might particularly lie in the ever changing outline of the New Zealand landmass with its continuously changing proportions of emerged and submerged land since its disruption from Gondwanaland (see Stevens, 1980; 1985). Falla (1976) argues that as a consequence of the eastward drifting and physiographically changing New Zealand archipelago only very little, in terms of flora and fauna, could have been brought from the country's original geological location along the western margin of Gondwanaland.

5.1.2.1 Marine and freshwater fauna

Nevertheless, the fossil record is rich in marine life forms, especially invertebrates. Among these the most numerous phylum are the mollusca. They, along with other marine groups, have elements of both tropical and subpolar fauna, with a predominance of cool temperate forms. As a result of the long period of geographical isolation and the varied nature of the long coast line, extending through thirteen degrees of latitude, various endemic species have already developed. The New Zealand faunal record now describes about 2000 indigenous species of mollusca which include various terrestrial forms (see below) (Falla, 1976).

Apart from invertebrates the marine fauna also shows an abundance and high variety of vertebrates. Anderson & McGlone (1992) list 586 genera with 1008 species in New Zealand's ichthyofauna. Half of these taxa are cosmopolitan and found in all the major oceans whereas about one-third of all species are shared with Australia; only one-fifth are endemic. Among these species are various tropical surface fish, including small surface predators like the local barracouta. The largest among these surface fish are

swordfishes, spearfishes, tuna, and surface sharks (Falla, 1976). A more comprehensive summary of the types of fish in New Zealand's inshore waters is given by Anderson & McGlone (1992). As this summary is partially based on taphonomic evidence from prehistoric middens, their description of the country's ichthyofauna is rather only valid for the pre-European Polynesian period (see above). Nevertheless, by any standards the entire pelagic fauna of New Zealand can be rated as rich.

Unlike its marine counterpart the indigenous freshwater ichthyofauna was rather restricted, reflected in a significantly lower species diversity. Altogether it comprised only a few genera with a total of initially 27 native species, most of them small and secretive. Only eels (two species - *Anguilla* spp.), the now rare and probably even extinct grayling (*Prototroctes oxyrhynchus*), and the giant kokopu (*Galaxias argenteus*) exceeded 2kg in body weight (Anderson & McGlone, 1992). These native species occupy all sorts of freshwater habitats but also retain a link with the sea. This is particularly the case with eels and lampreys (*Geotria australis*), but also with the different species of the genus *Galaxias* (Falla, 1976).

Due to the cold sea temperatures marine reptiles do not occur in New Zealand waters any more, but whales of all kinds are well represented, and some of the coastal porpoises are endemic. Altogether 24 species of whales and 21 species of dolphins (Delphinidae) are known to occur in New Zealand waters (Anderson & McGlone, 1992).

Further representatives of marine mammals are the four species of seals (Pinnipedia) which breed in various parts of mainland New Zealand. They are commonly divided into eared (Otariidae) and earless/true seals (Phocidae) (Falla, 1976; Gibb & Flux, 1973).

New Zealand fur seals (*Arctocephalus forsteri*) and sea lions (*Phocarctos hookeri*) are the breeding representatives of the eared seals. Fur seals are the commonest seals in the country which even occur in the North Island. Even though sea lions are endemic to New Zealand they are less frequent in mainland New Zealand; apart from a few

stragglers who make it as far as Stewart Island they mainly occur in high numbers on Auckland and Campbell Islands (Anderson & McGlone, 1992; Falla, 1976; Gibb & Flux, 1973).

Elephant seals (*Mirounga leonina*) and leopard seals (*Hydrurga leptonyx*) represent the earless seals/true seals. Elephant seals have their main breeding grounds on the subantarctic fringe with a few occurrences on the New Zealand mainland. The predatory leopard seal is widely distributed throughout the Southern Oceans and a regular visitor to the Subantarctic Islands. On the New Zealand mainland it straggles as far north as about latitude 40°S (Anderson & McGlone, 1992; Gibb & Flux, 1973).

Including oceanic birds in this list further enhances the country's richness in marine life. Sixty species of albatrosses and petrels alone are represented in New Zealand; twelve of the 18 known species of penguins and a similarly high proportion of marine cormorants also occur in the country. Tropical gannets (boobies) are rare vagrants, but the cool-temperate gannets proper are well established in New Zealand (Falla, 1976).

In view of the abundant marine fauna which has a long association with the physiographically constantly changing New Zealand landmasses, Falla (1976) concludes that the country misses only very few life forms which would have also been adopted to the physical conditions of the marine environment.

5.1.2.2 Terrestrial fauna

The terrestrial fauna on the other hand had to be established from fragmentary beginnings. Falla (1976) argues that in the original separation from Gondwanaland, the departing fragment of the New Zealand landmass either lacked, or subsequently lost, any terrestrial fauna. This feature is reflected in at least three Australian insect families which existed at the time of separation, but are not found in New Zealand. The increasing isolation from neighbouring landmasses even aggravated the situation as the number of terrestrial lifeforms that were able to reach the New Zealand landmass by

dispersal agencies such as air, water or attachment to flying vertebrates, was restricted and selective. Consequently, the terrestrial fauna was impoverished as it lacked diversity.

Falla's (1976) argument continues that due to the continental character of the New Zealand archipelago with its environmental variety and complexity the terrestrial lifeforms of Gondwanan lineage underwent a process of adaptive radiation. Thereby a comparatively limited original stock eventually occupies a variety of vacant ecological niches. This process probably accounts for the high proportion of endemic lifeforms, some of them divergent, from the ancient stock to an extent of being difficult to relate, and others tending to conditions of giantism, or wing reduction or some other modification. To a greater or lesser extent these features are manifested in all classes of the terrestrial fauna, and they are a conspicuous characteristic of the birds.

Hence, the terrestrial native fauna of New Zealand prior to the arrival of humans consisted of a mixture of "archaic" animals of Gondwanan lineage which had already undergone varying degrees of evolutionary changes since the beginning of the country's isolation as well as a few later arrivals from more recent times. Thus, the indigenous pre-human fauna comprised a comprehensive number of different groups of invertebrates and vertebrates. They included various groups of insects, a distinctive avifauna, a restricted herpetofauna, a limited freshwater ichthyofauna, and a few mammals (*cf.* Bishop, 1992; Falla, 1976; Lowe & Percival, 1993; Lowe, 1994; Molloy, 1994; Wardle, 1991).

Among the invertebrates the sub-phylum "Insecta" (insects) undoubtedly represents the numerically largest group. The country's entomological record describes about 10,000 species of insects. Due to their various methods of dispersal Lowe (1973) concedes that this number most probably must also include introduced species.

Of all insect groups beetles, moths and flies had profusely speciated whereas other groups of world-wide significance, such as butterflies, were poorly represented, and there were no social, long-tongued bees (Wardle, 1991). A very characteristic feature of

the native insects is their large size which is often combined with flightlessness as found in all species of beetles. Molloy (1994) suggests that such features are attributes of invertebrates living in cold, windy climates without mammalian predators.

The undoubtedly largest insects are wetas (Stenopelmatidae). These flightless and nocturnal herbivores of the order Orthoptera are represented by more than 70 endemic species. They all share the feature of having rather heavy bodies which, as in *Deinacrida heteracantha*, can attain a body length of 82 millimeters and weight of 71 grams. Wetas are believed to be the most ancient and unchanged Orthoptera with a Gondwanan lineage dating back nearly 200 Ma (Upper Triassic). Due to a lack of mammalian predators wetas presumably fill those ecological niches elsewhere occupied by small rodents (e.g. mice) (Molloy, 1994; Wardle, 1991).

Another distinctive invertebrate with an even older Gondwanan lineage of 550 Ma (Upper Cambrian) is the carnivorous peripatus (*Peripatoides novaezealandiae*) or "velvet worm". Due to an unusual combination of some anatomical characteristics which are shared by Arthropoda and Annelida the peripatus is often regarded as an evolutionary link between these two phyla. Nevertheless, more recent work rather considers it to be an evolutionary "side-branch", evolving from the annelid worms at about the same time as insects. For this reason the peripatus is considered to constitute its own phylum, the Onychophora (Bishop, 1992; Molloy, 1994).

Among the terrestrial Mollusca the New Zealand land snail fauna represents one of the richest in the world; a feature which probably reflects the absence of mammalian predators. Of the more than 1,000 known species of snails in the country the giant *Powelliphanta* snails (Rhytididae) are the largest. These voracious carnivores which can grow up to 100 millimeters in diameter have a Gondwanan lineage older than 100 Ma. Their distribution is mainly delimited to the mountain ranges of the southern North Island and north-west Nelson (Bishop, 1992; Molloy, 1994).

Gondwanan lineage and a high degree of adaptation to the physical environment is also a distinctive characteristic of the terrestrial vertebrate fauna. The former trait is

particularly manifested in the country's herpetofauna which, however, shows a rather restricted species diversity. Unlike neighbouring Australia the New Zealand fauna does not include crocodiles, tortoises and snakes (Falla, 1976). At European contact, the country's herpetofauna comprised only three species of primitive frogs (*Leiopelma* spp.); one rhynchocephalian reptile, the tuatara (*Sphenodon punctatus*); and 41 species of lizards, 17 of them geckos (Gekkonidae) and 24 skinks (Scincidae). In the pre-Polynesian period there had been three additional species of Leiopelmatid frogs as well as a few more species of lizards which since then became extinct (Anderson & McGlone, 1992).

Because of the Gondwanan ancestry of *Leiopelma* the three native species are considered to be the most primitive of all living frogs. Taphonomic evidence of specimens bearing anatomic similarities to *Leiopelma* suggests an age of about 140 Ma (Upper Jurassic) of this species (Bishop, 1992).

With a lineage dating back more than 225 million years (early Mesozoic) *Sphenodon punctatus* is even older. The tuatara is the largest New Zealand reptile, growing to about 0.6 meters long and one kilogram in weight. It is regarded as the sole remaining species from a very early order of reptiles, the Sphenodontida, of which all other members became extinct 60 to 70 Ma ago (late Mesozoic). Despite such ancient lineage *S. punctatus* is assumed to have changed only little from its ancient predecessors (Anderson & McGlone, 1992; Bishop, 1992; Lowe & Percival, 1993; Lowe, 1994).

The country's terrestrial vertebrate fauna was distinctive by its lack of cursorial mammals (see above). Thus mammalian vertebrates were only represented by seals (see above), cetaceans and three species of bats: the long-tailed bat (*Chalinolobus tuberculatus*) and two species of short-tailed bats (*Mystacina*) which even constitute an endemic family. One of the two short-tailed species, *M. robusta*, is even believed to be extinct (Bishop, 1992; Holdaway, 1989; Wardle, 1991). Unlike most other terrestrial vertebrates and invertebrates bats are among the late arrivals in the country long after its separation from Gondwanaland. Bishop (1992) argues that all three species arrived only in New Zealand within the last few million years. *C. tuberculatus* was probably blown

across the Tasman Sea whereas *Mystacina* are assumed to have originated in South America and spread to New Zealand via Antarctica before it became glaciated.

New Zealand's avifauna comprises the major element of the country's land animals. Due to the unusual variety of different species, the group of native birds are the most intriguing terrestrial animals among the indigenous vertebrate fauna. Altogether there were 97 genera (82 of them land birds) with a total of 165 species (125 of them land birds) in the country's pre-human avifauna (Holdaway, 1989). They are usually divided into two categories: those with the power of flight and flightless birds.

The first category includes waterfowl which was abundant, and generally comparable with the avifauna of similar habitats in Australia and further afield (Falla, 1976). Also in this category are the more distinctive forest birds. They include several endemic genera and two endemic families which are predominantly insectivorous, frugivorous or nectar-seeking. Only the various native species of parakeets (*Cyanoramphus*), members of the parrot family (Platycercidae), seem to have been largely seed-eating. Also in this category are two birds which live exclusively in high-mountain terrain, the wren (*Xenicus gilviventris*) and another member of the parrot family (Nestoridae), the kea (*Nestor notabilis*) (Wardle, 1991).

Another peculiarity of the different native birds with the power of flight is that some families which have large species groups elsewhere in the world are only sparsely represented in New Zealand. Owls for example are only represented by two species, kingfishers by one and there are only two species of birds of prey. Even cuckoos which are indigenous in almost every continent only occur as migratory birds in the south-west Pacific. Two species of them winter in New Zealand and are known to be endemic breeders here. Apart from those and some seabirds, the bulk of the annual migrants to New Zealand almost entirely consists of waders or shorebirds from regions near the Arctic Circle. Their preferred habitats in New Zealand are wetlands and estuaries (Falla, 1976).

Furthermore, despite the extinction of various species throughout the geological history

of the country, particularly during historic times (also see section 5.3), native birds with the power of flight even experienced a few new introductions. Apart from deliberate introductions in particular during the post-1840 period, there was also a small number of new arrivals by "sweepstake dispersal" (see section 5.1 and footnote #49) from across the Tasman Sea. Falla (1976) considers that over the past 50 years at least six more species have established themselves in this fashion in New Zealand. The arrival of one of these species, a swallow, even added a new family to the country's fauna.

Flightless birds constitute the second and probably most distinctive category of the country's avifauna. This group of animals represents an evolutionary trend which, apart from having lost the power of flight, is clearly manifested in characteristics like increasing body size and dark plumage (Lowe & Percival, 1993; Lowe, 1994). This category includes the endemic representatives of the ratites⁵³, the kiwis (*Apteryx*) and the moas (Dinornithiformes), rails (*Gallirallus*, *Notornis* and *Aptornis*), a goose (*Cnemiornis*), and a parrot (*Strigops*) (Wardle, 1991). Of those *Cnemiornis*, *Aptornis*, known as the adzebill, and Dinornithiformes are now extinct.

The probably most distinctive group of New Zealand's flightless birds are the ratites. The inclusion of the kiwis in this group of rather large birds (see footnote #53) is mainly due to some structural peculiarities (Falla, 1976). Apart from their small size the kiwis are unusual among living ratites because of their adaptation to life on the forest floor. They are nocturnal and feed on small insects and other invertebrates. Molloy (1994) even ascribes the kiwi characteristics which are usually pertaining to mammals such as the possession of sensory whiskers, acute sense of smell, and external nostrils. Other mammal-like characteristics include dwelling in burrows in the ground as well as the release of an earthy musty scent. It is also assumed that they mark out their territory by means of their strongly scented burrows. Furthermore, the kiwi's body temperature is also lower than that of other birds and closer to that of mammals.

Altogether, the kiwi is represented by several species: The brown kiwis (*Apteryx*

⁵³Ratites constitute a group of flightless birds with Gondwanan lineage. They include the African ostrich, the South American rhea, the Australian emu, the New Guinean cassowary and the Malagasy elephant bird (Bishop, 1992; Falla, 1976; Lowe & Percival, 1993; Lowe, 1994; Molloy, 1994).

australis) which have three sub-species, as well as the great spotted kiwi (*A. haastii*) and the little spotted kiwi (*A. owenii*). The brown kiwis are found throughout the three main Islands, whereas the latter two are restricted to the South Island (Bishop, 1992; Falla, 1976; Lowe & Percival, 1993; Lowe, 1994).

The now extinct moas were herbivores, of which about 12 species existed. They ranged in height from the massive *Dinornis giganteus*, which stood over two meters tall and weighing about 200 kilograms, to smaller species, such as *Megalapteryx didinus*, with a height of about 0.7 meters and a weight of around 20 kilograms. Due to their solid build these birds must have had a profound impact on the vegetation. Depending on the individual species they may have browsed in different habitats and at different levels according to their height. Nevertheless, their preferred habitat appears to have been forests and their margins. There they probably filled niches which in other continents were usually occupied by mammals such as sheep and horses (Bishop, 1992; Lowe & Percival, 1993; Lowe, 1994; Wardle, 1976).

The kakapo is the world's rarest and largest parrot which has evolved a solitary, nocturnal existence. Its abandonment of flight has led to a considerable increase in the kakapo's body height which can be up to 0.65m. The takahe is the largest of New Zealand's remaining flightless birds. This formerly widespread rail is now restricted to parts of Fiordland where it was rediscovered in 1948 after having been presumed extinct for 50 years. Unlike the kakapo and the takahe which are herbivorous the weka is rather an omnivorous bird feeding on a variety of animals (e.g. rats and young seabirds) and vegetable matter (*cf.* Bishop, 1992; Lowe & Percival, 1993; Lowe, 1994; Molloy, 1994).

The reason for the flightlessness of these birds is rather a matter of speculation than being solved. Another point of controversy is when this group of birds eventually became flightless. Bishop (1992) argues that ratites were the first to lose their power of flight even before the disruption of Gondwanaland. As ground-dwelling animals in the cooler parts of the supercontinent their warm-bloodedness and insulating plumage might have provided them with an evolutionary advantage over the then dominant dinosaurs. Nevertheless, recent work has suggested that kiwis are of more recent origin than moas,

their lineage dating back only 40 Ma. If so, it is difficult to explain how the "proto-kiwis" reached the New Zealand archipelago, well isolated from Gondwanaland by then. It is even considered that the kiwi may have originally flown to New Zealand and only then lost its power of flight. This appears to be the case with the kakapo (*Strigops habroptilus*), the takahe (*Notoris mantelli*) and the weka (*Gallirallus australis*). The ancestors of these three species still had the power of flight when they arrived in New Zealand but only later became flightless.

The most plausible reason for the abandonment of the power of flight put forward by Bishop (1992) appears to be the combination of two factors: firstly, the lack of ground-dwelling mammalian predators in the pre-human environment and secondly the plentiful availability of forage on the forest floor, with no other herbivores to contend with. Consequently, their flightlessness enabled these birds to assume the role of herbivores which, according to their size, browsed the vegetation at a variety of levels in a wide range of forest, shrubland and tussock-grassland habitats (*cf.* Molloy, 1994).

5.1.3 Types of vegetation

The New Zealand archipelago with its latitudinal extent, ranging from the subtropical north to the subantarctic south (also see section 3 and fig. 3.2), its wide range of altitudinal zones from warm-temperate to alpine (Wardle, 1991), and its varied landscape which locates habitats ranging from thermal pools to perpetual snows, provides environments for a rich variety of vegetation types.

Earliest work on the vegetation cover of New Zealand and its different vegetation types was done by Cockayne (1928). Other accounts on this subject include later work by Cockayne (1967), Godley's (1975, 1976) description of the native plants of New Zealand with reference to adventive plants as well as Wardle's (1991) work on the vegetation of New Zealand which emphasises vegetation types, habitat classes and environmental gradients and processes that determine them.

However, the country's pre-human vegetative cover appears to be best summarized by describing it as ranging from lowland tussock grassland or shrubland in the drier regions to podocarp-dicotylous forest and *Nothofagus* (southern beech) forest in the more humid locations. Extensive stands of *Agathis australis* forest occurred in the northern North Island, and subalpine grasslands, herbfield, moorland and scrubland at altitudes above 900 m (Ruscoe, 1975).

The more comprehensive post-human vegetation with its adventive plants (also see section 5.1.1) is classified and described by Blaschke *et al.* (1981) and Newsome (1987). Both workers present an analysis of the country's vegetation cover based on vegetation information from the *New Zealand Land Resource Inventory*⁵⁴ (NWASCO 1975-79). As Newsome's (1987) work also involved a number of other sources, its resulting *Vegetative Cover Map of New Zealand* (1:1,000,000) can be regarded as an update of Blaschke's (1981) analysis. Nevertheless, at the broadest level of identification of the components of the country's vegetation cover Blaschke *et al.* (1981) recognized 11 and Newsome (1989) eight vegetation cover groups. The results of Newsome's (1987) classification of the present vegetation cover of New Zealand are summarized in figures 5.1 and 5.2.

Detailed descriptions of the plant communities constituting the above vegetation groups as well as information on their structure and characteristic species and genera are provided by Wardle (1991).

Of all vegetation types of the New Zealand flora the group of indigenous forests appears to reflect best environmental disturbances through the passage of time. This feature is manifested in the steady decline of the native forest cover throughout the Late Holocene. Its proportion of the total land area of New Zealand decreased from 85 to 90% at 3000 yr B.P. (McGlone, 1989) to about 78% at around 1000 yr B.P. (e.g. Kelly, 1980), a point in time which is generally accepted as the date of earliest colonisation of New Zealand by Polynesians (see sections 2.2.1, 2.2.1.1 and fig. 2.5). At the time of European colonisation the native forest cover had already been reduced further to 53% (e.g. Kelly,

⁵⁴The *New Zealand Land Resource Inventory* (NZLRI) is published as a series of Land Resource Inventory Worksheets and accompanying extended legends (NWASCO 1975-79) (Blaschke *et al.*, 1981).

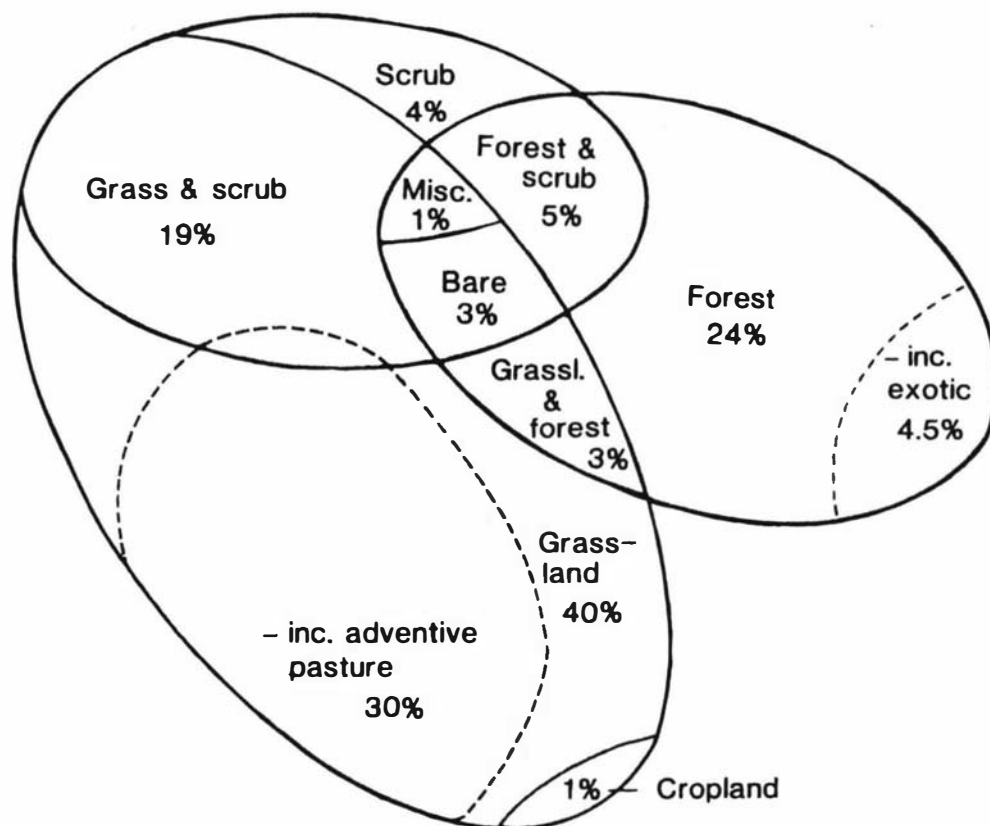


Figure: 5.1: Proportions of the individual cover groups recognized by Newsome (1989) in the present vegetation cover of New Zealand (Wardle, 1991).

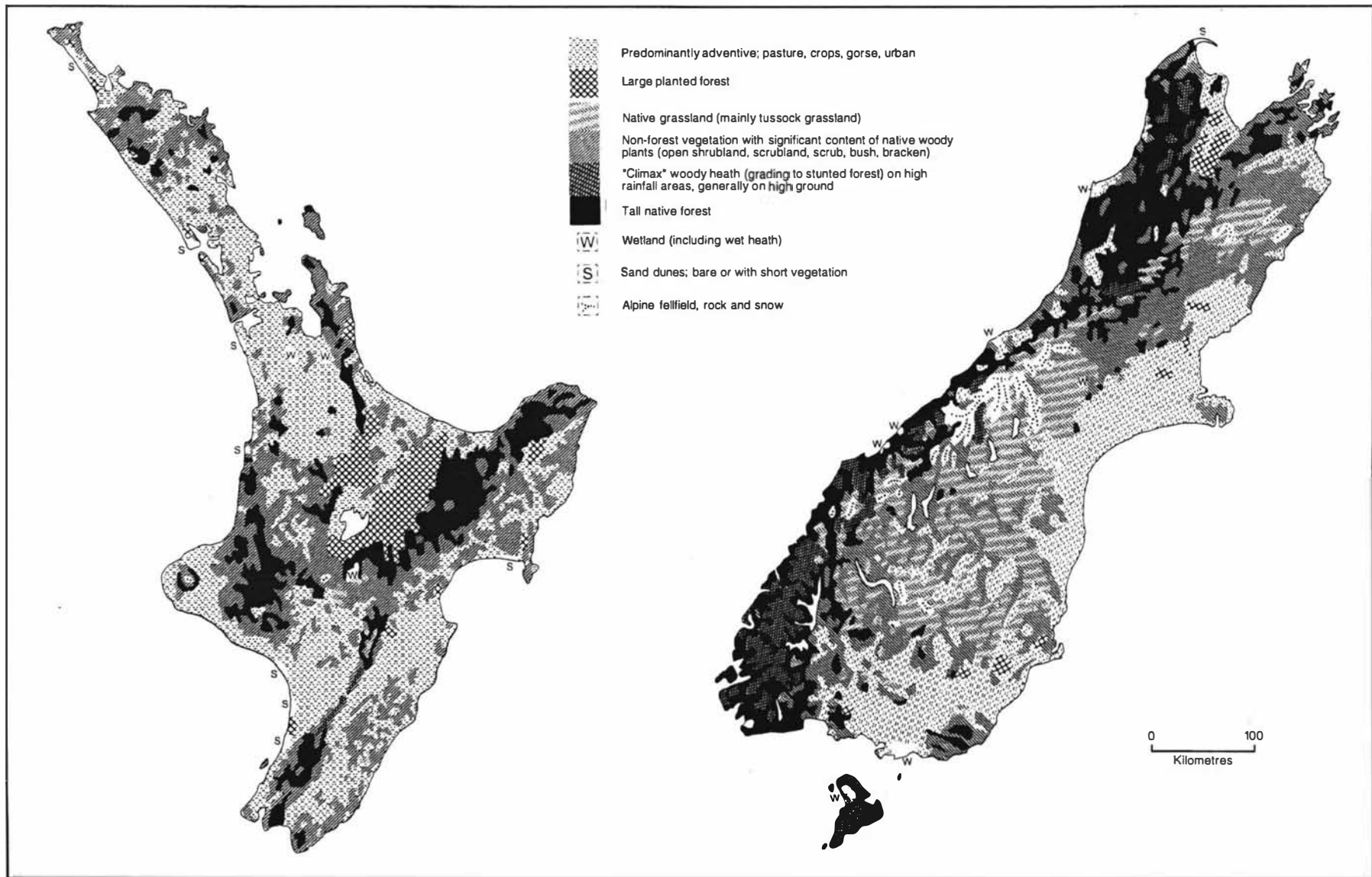


Figure: 5.2: Generalized distribution of the present-day main types of native and adventive vegetation in New Zealand (Wardle, 1991; modified after Newsome, 1987).

1980; Wendelken, 1976) and presently its proportion ranges around 24% (e.g. Kelly, 1980; Newsome, 1987; Wendelken, 1976; also see fig. 5.1).

Because of such obvious significance as an indicator for environmental disturbances the group of indigenous forests will be discussed in greater detail below.

5.1.4 The indigenous forests of New Zealand

As a whole, New Zealand's indigenous forests are distinctively different from those of the Northern Hemisphere and other temperate regions (also see section 5.1.1). In many ways they rather resemble tropical rainforests as they are moist, dense and evergreen with many multi-storied vegetation layers including vines and other plants (e.g. mosses and ferns) growing on trunks and upper branches of trees. Their complex and dense undergrowth comprises lianes, ferns, mosses and lichens (Lowe & Percival, 1993; Lowe, 1994; Salmon, 1980). Other characteristics include a low number of deciduous species (see section 5.1.1) as well as divaricating growth forms with widely angled branches and a tangled growth habit in many shrubs and juvenile trees (e.g. *Sophora microphylla* [kowhai], some *Coprosma* species and juvenile *Dacrycarpus dacrydioides* [kahikatea/white pine]). About 60% of the woody genera produce bird-dispersed fleshy, often brightly-coloured fruits, or fruits with sticky seeds (e.g. *Dacrydium cupressinum* [rimu/red pine], *Dacrycarpus dacrydioides* and *Coprosma*). Nevertheless, the flowers of the trees are generally inconspicuous and lack bright colours. Furthermore, an unusually high proportion (*ca.* 12%, as opposed to only 2% of the British flora) of native species have male and female flowers on separate plants. Finally, the New Zealand forests differ from all others in that they have developed in the absence of herbivorous mammals, although the effect of moa browsing should not be underestimated. Hence, the country's forests bear a closer resemblance to the ancient forests of Gondwanaland than those of any other modern day southern continent (Hackwell, 1983; Lowe & Percival, 1993; Lowe, 1994).

The floristic composition of the country's native forest is dominated by various

combinations of gymnosperms (Gymnospermae) and angiosperms (Angiospermae)⁵⁵. Both classes are represented in rather dissimilar proportions. While the indigenous gymnosperms are represented by a total of three families: Araucariaceae (*Agathis*), Cupressaceae (*Libocedrus*) and Podocarpaceae (*Dacrycarpus*, *Prumnopitys*, *Podocarpus*, *Halocarpus*, *Dacrydium*, *Lepidothamnus*, *Lagarostrobos*, *Phyllocladus*), the number of indigenous families of the evolutionarily more advanced angiosperms amounts to 110 (22 monocotyledons, except Gramineae, and 88 dicotyledons) (Allen, 1961; Moore & Edgar, 1970; Salmon, 1980). However, based on descriptions of the composition of the various indigenous forest types (e.g. Godley, 1976; Halkett, 1991; McGlone, 1988; Salmon, 1980; Wardle, 1991; Wendelken, 1976) only about 12 families of angiosperms significantly contribute to the native forest cover. Of those the most prominent families appear to be Fagaceae, Cunoniaceae, Myrtaceae, Lauraceae, followed by Pittosporaceae, Meliaceae, Proteaceae, Monimiaceae, Epacridaceae, Verbenaceae, Rubiaceae and Palmae.

In their natural distribution, without human interference, the different native forest associations resulting from the combination of these gymnospermous and angiospermous families would occur throughout the main islands, with an altitudinal extent from the sea coast to the subalpine tree limit (Anderson & McGlone, 1992; Wardle, 1991). There are only a few exceptions from this pattern. In the driest eastern districts of the South Island for example the forest cover gives way to more open scrub-light forest associations (Anderson & McGlone, 1992). Further exceptions are grasslands and shrublands which usually occur in locally restricted habitats such as river terraces subject to regular flooding, frost-prone valley floors, steep cliffs, active sand dunes, leached shallow soils, ultramafic soils, and recently disturbed areas which were formerly in forest (McGlone, 1989). Other regions devoid of natural forest are the Waikato/Hauraki Basins where the terrain favoured rapid peat accumulation; parts of the Central Volcanic Plateau where major ash and pumice eruptions regularly destroyed the

⁵⁵In the botanical taxonomy **gymnosperms (Gymnospermae)** and **angiosperms (Angiospermae)** are the two constituting classes of the phylum Spermatophyta. Gymnosperms are cone bearing plants or conifers (pines, spruces, firs, etc.) which are distinguished by the production of ovules and seeds on the leaf surface, not enclosed in an ovary. They are synonymous with the term "softwood". Angiosperms on the other hand are flowering plants whose ovules are enclosed in an ovary. In the New Zealand forest description it is customary to subdivide them further into a *Nothofagus* spp. (southern beech) element and a mixed broadleaved ("hardwood") element. (Hackwell, 1983; Laing, 1964; Newsome, 1987).

forest cover; and in parts of the eastern South Island with its large shifting river channels (Kelly, 1980). Further anomalies in the distribution of the country's higher plants are pointed out and discussed by McGlone (1985), Burrows (1965) and Wardle (1963).

On the main islands the native forests comprise some 48 species of tall and medium-sized trees, and 70 tree species which normally do not exceed 10 meters (Wardle, 1991). Due to their longevity, associated with a massive stature, conifers predominate among the forest trees. Nevertheless, there are only 20 species of conifer, all endemic, of which seven are large trees. The remaining 13 species are of lesser stature and include the *Lepidothamnus laxifolium* (pygmy pine), one of the smallest conifers in the world (Halkett, 1991; Wendelken, 1976). The resulting forest cover incorporating the above species in varying proportions shows a distinct pattern in its distribution. The structural complexity and floristic diversity of the forests diminish with increasing altitude and latitude (e.g. Halkett, 1991; Wardle, 1991). The varying degrees of complexity and diversity eventually allow one to divide the country's different forest associations into two main types: conifer-hardwood forests⁵⁶; and *Nothofagus* forests (e.g. Godley, 1976; Halkett, 1991; McGlone, 1988; Salmon, 1980).

5.1.4.1 Conifer hardwood forests

Conifer-hardwood forests are very diverse and occur throughout the country under all climates but are best developed on warm, fertile, lowland sites (below about 900 meters a.s.l.). Under these conditions conifer-hardwood forests reach their most complex development, comprising tall trees with understoreys of small trees, shrubs and ferns. Bryophytes (mosses and liverworts) and lichens are common, and lianes and epiphytes occur abundantly at all levels within the forest, and often constitute a considerable fraction of the canopy. A typical forest on such sites is multi-storied, comprising up to five canopy layers compared with only three of northern temperate forests.

The tallest of them, the emergent layer, reaches between 30-50 meters in height. The

⁵⁶Synonymous with the term "conifer-hardwood forests" are the designations "conifer-broadleaved forests" and "conifer-broadleaf forests" (e.g. McGlone, 1988; Halkett, 1991).

most common emergents of this layer are tall conifers of the podocarp family (Podocarpaceae): *Dacrydium cupressinum*, *Dacrycarpus dacrydioides* (kahikatea/white pine), *Podocarpus totara* (totara), *Prumnopitys taxifolia* (matai/black pine) and *Prumnopitys ferruginea* (miro/brown pine); and *Agathis australis* (Araucariaceae; kauri). A few angiosperms such as *Metrosideros robusta* (northern rata), *Laurelia novae-zelandiae* (pukatea), and *Knightia excelsa* (rewarewa/New Zealand honeysuckle) also grow tall enough to be included in the emergent layer.

These widely-spaced, large-crowned emergents tower above a lower and more continuous main canopy. This very diverse layer, ranging about 20 meters above the forest floor, is primarily made up of angiosperm trees. The proportion of its typical constituents shows a distinctive geographical distribution pattern. By way of simplification this rather intricate pattern of altering proportions appears to be best summarized by describing *Beilschmiedia tarairi* (taraire) and *Paratrophis banksii* (towai/large-leaved milk tree) as being prevalent in the far north of the North Island. In the central North Island *Beilschmiedia tarairi* is replaced by *Beilschmiedia tawa* (tawa). The latter in turn is replaced by *Weinmannia racemosa* (kamahi) as the commonest tree in the South Island. Among other trees which occur in varying proportions in the main canopy *Vitex lucens* (puriri) and *Nestegis cunninghamii* (black maire), for example, are more common in the North Island than in the South Island. *Metrosideros umbellata* (southern rata) and *Quintinia acutifolia* (Westland *quintinia*), on the other hand, occur throughout both islands, but are particularly abundant on the West Coast of the South Island.

Below the main canopy, at a height between 10-15 meters above the ground, occurs a poorly-defined sub-canopy of small trees and large tree ferns. Many of this highly diverse group of sub-canopy trees have specialized in re-colonizing forest clearings. Common in these spots and along the lighter forest margins are species such as *Melicytus ramiflorus* (mahoe/whiteywood), *Aristotelia serrata* (makomako/wineberry), *Hedycarya arborea* (porokaiwhiri/pigeonwood), *Fuchsia excorticata* (kotukutuku/fuchsia), *Hoheria populnea* (houhere/lacebark) and *Carpodetus serratus* (putaputaweta). Also found in this assemblage is the country's only native palm,

Rhopalostylis sapida (nikau), which has the distinction of being the most southern naturally growing palm in the world. Like the group of small trees, the large tree ferns (*Cyathea* and *Dicksonia*) also prefer lighter spots in the forest cover and therefore are particularly abundant beneath gaps in the main canopy.

The underlying shrub stratum is equally diverse including species of *Alseuosima*, *Aristotelia*, *Coprosma*, *Geniostoma*, *Melicope*, *Melicytus*, *Neomyrtus*, *Pittosporum* and *Pseudopanax*. A common feature of the shrubs in this layer is their divaricating growth form which has been adopted by about 60 different species (e.g. *Plagianthus divaricatus* [salt-marsh ribbonwood], *Sophora prostrata*, and *Coprosma crassifolia*) including a few trees during their juvenile stage. The hypotheses trying to explain such growth forms include anti-moa browsing strategies of the shrubby flora as well as adaptations to extremely arid Pleistocene climatic conditions (*cf.* McGlone & Clarkson, 1993; Wardle, 1963).

The lowermost layer, the ground layer, forms the forest floor. This luxuriant stratum is characterized by a rich variety of plants such as ferns and bryophytes which depend on the relatively stable environmental conditions provided by this habitat (e.g. high soil moisture, subdued light conditions, minor temperature variations etc.). Other, less fragile representatives of the ground layer include herbaceous plants like terrestrial members of the orchid family (Orchidaceae); mat-forming, creeping species of the genera *Nertera* and *Pratia*; various grasses such as *Microlaena avenacea* (bush rice grass) as well as the terrestrial members of the genus *Astelia* (e.g. *A. trinervia* [kauri grass]); and sedges (e.g. *Uncinia uncinata* [kamu/hook grass]) (Bishop; 1992; McGlone, 1988).

A more detailed description of the composition at a specific level of both, lowland and montane conifer-hardwood forests, listing the most important tall and small trees, shrubs, common ground plants and epiphytes, is given by Godley (1976). However, this very diverse and complex forest type shows distinct structural modifications and changes in its floristic composition in relation to the climatic conditions of its location. McGlone (1988) points out marked differences from the above description in cooler

upland sites, wet western and drier eastern districts, and in the warmer far northern North Island. These differences allow a further subdivision of conifer-hardwood forests into three subtypes: *Agathis australis*-podocarp-hardwood forest; podocarp-hardwood forests; and podocarp-hardwood-*Nothofagus* forests⁵⁷ (e.g. Halkett, 1991; Salmon, 1980; Wendelken, 1976). Figures 5.3 and show the distribution of continuous stands of these three principal forest sub-types as well as pure *Nothofagus* forests.

5.1.4.1.1 *Agathis australis*-podocarp-hardwood forests

Agathis australis-podocarp-hardwood forests only occur in the northern North Island, north of latitude 38°S (broadly coincident with the line Raglan-Whakatane) and below 800 meters altitude. They are characterized by a marked change in their floristic composition resulting in very complex and diverse forest assemblages. Typical species which are either endemic to this region or increase markedly there include *Agathis australis*, *Ackama rosaefolia* (makama), *Vitex lucens*, *Phyllocladus trichomanoides*, *Beilschmiedia tarairi*, and *Ixerba brexioides*.

Nevertheless, the most prominent species of this northern region is *Agathis australis*. This largest tree in the country's flora dominates the northern forests but often also forms pure stands. They preferably occur on ridges or, prior to deforestation, on plateaus and in poorly-drained valleys. Common associates of *Agathis australis* are the podocarps (Podocarpaceae) *Dacrydium cupressinum*, *Prumnopitys ferruginea*, *Podocarpus totara* (totara), *Phyllocladus trichomanoides* (tanekaha), *Phyllocladus glaucus* (toatoa), and the hardwoods *Knightia excelsa*, *Beilschmiedia tarairi* and *Ixerba brexioides* (tawari) (McGlone, 1988; Salmon, 1980; Wendelken, 1976).

More southern species such as *Metrosideros umbellata* and *Libocedrus bidwillii* (kaikawaka) are found with *Agathis australis* on the crest of the Coromandel Range, and *Nothofagus truncata* (hard beech/tawhairaunui) and *Metrosideros robusta* occur locally

⁵⁷Synonyms for these subtypes of the conifer-hardwood forest are: "*Agathis australis*-podocarp-broadleaved forest" or "*Agathis australis*-podocarp-broadleaf forest"; "podocarp-broadleaved forest" or "podocarp-broadleaf forest"; and "podocarp-broadleaved-*Nothofagus* forest" or "podocarp-broadleaf-*Nothofagus* forest" (Halkett, 1991; McGlone, 1988).

with *Agathis australis* at lower altitudes (Wendelken, 1976).

Furthermore, *Agathis australis*-podocarp-hardwood forests bear a much closer resemblance to tropical forests than any other forest type in New Zealand. The tropical element is particularly reflected in the profusion of lianes and perching plants such as the conspicuous epiphytes of the genera *Astelia* and *Collosporum*. In coastal areas the tropical nature is emphasized by the occurrence of pure mangrove forests of *Avicennia marina* var. *resinifera* (manawa), which is endemic to the estuaries of Northland (Halkett, 1991).

5.1.4.1.2 Podocarp-hardwood forests

The podocarp-hardwood forests cover most of the western North Island south of latitude 38°S. In the South Island their occurrence is restricted to the Westland region and the coastal fringe of South Canterbury, North and South Otago and eastern Southland. Southernmost extension of this forest type beyond both main Islands is to Stewart Island (see fig. 4.3). In the wetter climates of the North Island and the Westland region these forests are commonly also known as lowland rain forests. Podocarp-hardwood forests are characterized by a predominance of podocarps. They form the emergent layer, whereas the less prominent hardwoods are confined to an understorey. Another conspicuous feature in the floristic composition of this forest type is the absence of *Nothofagus* spp.

In the North Island this forest type is most common on fertile soils such as the recent volcanic soils of the volcanic plateau, alluvial soils and exceptionally fertile hill soils elsewhere. In such sites characteristic tree species are the podocarps matai, totara and kahikatea, and the hardwoods *Elaeocarpus hookerianus* (pokaka) and *Nestegis* spp.: elsewhere these species are rather rare.

In lowland situations below 900 meters most podocarp-hardwood forests have only scattered podocarps, with *Dacrydium cupressinum* the commonest. The hardwood

component in these forests is usually high but very variable due to a distinct distribution pattern of several hardwood species, depending on latitude, altitude and distance from the sea. Nevertheless, despite various local variations (see Halkett, 1991; Wendelken, 1976) the most widespread hardwoods are: *Metrosideros* spp., *Beilschmiedia tawa*, *Elaeocarpus dentatus* (hinau), *Knightia excelsa*, *Laurelia novae-zelandiae*, *Dysoxylum spectabile* (kohehohe) and *Weinmannia racemosa*.

Above 900 meters, in rugged terrain and on boggy ground podocarp-hardwood forests include a wide range of species. The most characteristic are *Prumnopitys ferruginea*, *Podocarpus cunninghamii* (montane totara), *Phyllocladus trichomanoides*, *Phyllocladus glaucus* and *Phyllocladus alpinus* (mountain toatoa), *Libocedrus bidwillii*, *Lagarostrobos colensoi* (silver pine), *Lepidothamnus intermedius* (yellow-silver pine), *Weinmannia racemosa*, *Griselina littoralis* (papauma/broadleaf) and *Quintinia serrata* (tawherowhero).

In the South Island the situation is slightly different. There podocarp-hardwood forests were suppressed or hindered in their full development by the more extensive *Nothofagus* forests. Apart from the absence of some of the main tree species restricted to a more northern distribution such as *Elaeocarpus dentatus*, *Beilschmiedia tarairi*, *Vitex lucens*, *Laurelia novae-zelandiae*, *Dysoxylum spectabile* and *Knightia excelsa*, the southern podocarp-hardwood forests are generally comparable with those in the North Island. However, the southern forests have a noticeably higher proportion of *Metrosideros umbellata*, *Weinmannia racemosa*, *Podocarpus cunninghamii* and *Libocedrus bidwillii* which extend to quite high altitudes in the upland forests.

The podocarp-hardwood forests on Stewart Island are markedly different from those on the North and South Islands. As a whole the forest has a low stature with certain species elsewhere particularly common either occurring in noticeably low numbers (e.g. *Dacrycarpus dacrydioides*, *Prumnopitys ferruginea* and *Elaeocarpus hookerianus*) or even completely missing (e.g. *Podocarpus totara*, *Phyllocladus glaucus* and *Elaeocarpus dentatus*). Altogether only six common tree species occur universally on Stewart Island: *Dacrydium cupressinum*, *Prumnopitys ferruginea*, *Podocarpus*

cunninghamii, *Lepidothamnus intermedius*, *Weinmannia racemosa* and *Metrosideros umbellata* (Halkett, 1991; Wendelken, 1976).

5.1.4.1.3 Podocarp-hardwood-*Nothofagus* forests

Podocarp-hardwood-*Nothofagus* forests are usually dominated by *Nothofagus* trees which form the main canopy. Apart from a few larger podocarps such as *Prumnopitys taxifolia*, *Dacrydium cupressinum* and *Metrosideros* spp., penetrating this canopy, other podocarps and hardwoods are usually restricted to an understorey.

In the North Island most of this forest type occurs below 750 meters in the Taranaki and East Cape districts (see fig. 4.3). The most common *Nothofagus* species in North Taranaki and in the East Cape hinterland west of the Raukumara Range is *N. truncata*; in South Taranaki and east of the Raukumara Range, *N. solandri* var. *solandri* (black beech) dominates. *N. fusca* (red beech/tawhairaunui) or *N. fusca* with *N. menziesii* (silver beech) are abundant above 750 meters on the upper flanks of the main axial ranges and on Mt. Ruapehu. They frequently occur along with *Dacrydium cupressinum*, *Prumnopitys ferruginea* and *Podocarpus cunninghamii*, over understories of *Weinmannia racemosa* and *Griselinia littoralis*. Podocarp-hardwood-forests above 900 meters are rare but occur on parts of the Raukumara, Huiarau and Ruahine ranges and on Mt. Ruapehu. There, increasing with altitude, *Nothofagus fusca*, *N. menziesii* and *N. solandri* var. *cliffortioides* are associated with *Libocedrus bidwillii*, *Phyllocladus alpinus*, and *Griselinia littoralis*.

In the South Island at altitudes below about 650-700 meters podocarp-hardwood-*Nothofagus* forests extend from D'Urville Island southwards including the Marlborough Sounds, Nelson to Golden Bay, and Karamea to Reefton regions (see fig. 4.3). Their composition is generally similar to North Island forests of this type. However, common North Island hardwood species such as *Knightia excelsa* and *Beilschmiedia tawa*, extending only into the Nelson-Marlborough region, and *Metrosideros umbellata* replacing the northern species. As a whole in the South Island *Nothofagus* spp. become

more common and dominant, with *N. menziesii*, and more particularly *Nothofagus solandri* var. *cliffortioides* (mountain beech), extending to the upper tree line, mixed with *Metrosideros umbellata*, *Weinmannia racemosa* and *Libocedrus bidwillii* (Halkett, 1991; Salmon, 1980; Wendelken, 1976).

5.1.4.2 *Nothofagus* forests

Nothofagus forests are very different in structure from typical conifer-hardwood forests. They include the structurally simplest forests in the country. This feature is reflected in *Nothofagus* forests generally being more open, with less undergrowth than podocarp-dominated forests, lower in stature, and floristically less complex. In New Zealand the genus *Nothofagus* (Fagaceae) has four distinct species: *N. solandri*, *N. truncata*, *N. fusca* and *N. menziesii*; with *N. solandri* subdivided into two varieties: *N. s.* var. *solandri*, the lowland to montane black beech, and *N. s.* var. *cliffortioides*, the upland to subalpine mountain beech. Each of these species has slightly different habitat preferences. *N. menziesii* is most typical of subalpine forests in wetter, cooler districts. Both, *N. fusca* and *N. truncata* are less tolerant of those conditions, and *N. fusca* even prefers warm midslope locations. *N. truncata* is even ecologically distinguished by its demand for warm sites, and tolerance of infertile soils. It is the only *Nothofagus* species commonly found north of 38°S (see above).

Nothofagus forests probably constituted the most common forest type before human colonization of the country. As it still occupies extensive tracts of rugged and mountain terrains, *Nothofagus* continues to represent a major element of New Zealand's present-day indigenous forests. It either entirely dominates the forests or occurs in mixtures with other species. Despite the widespread occurrence of *Nothofagus* spp. (see figures 5.3 and 5.4) there are a number of anomalies in their distribution. Despite their occurrence on Mt. Ruapehu, they are absent from Mt. Egmont/Taranaki and between the northern Ruahine and southern Tararua ranges. In the South Island there is also a marked gap in central Westland between the Taramakau and Paringa rivers (also see McGlone, 1985). The absence of *Nothofagus* forests continues on Stewart Island which is completely

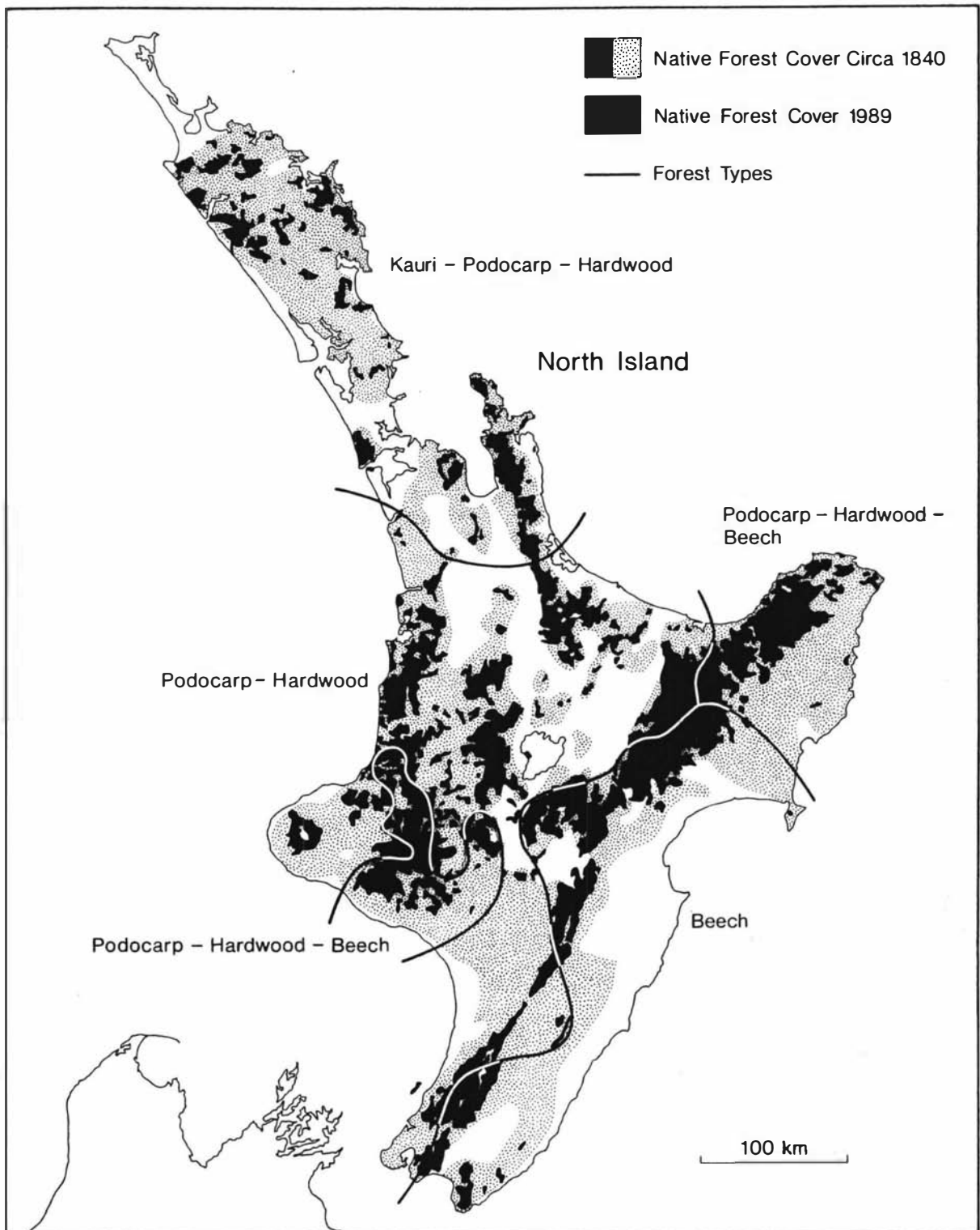


Figure 5.3: The extent of the indigenous forest cover in the North Island prior to European colonization (*ca.* 1840) and present (as of 1989). Solid lines indicate the distribution the predominant forest type (modified after Halkett, 1991).

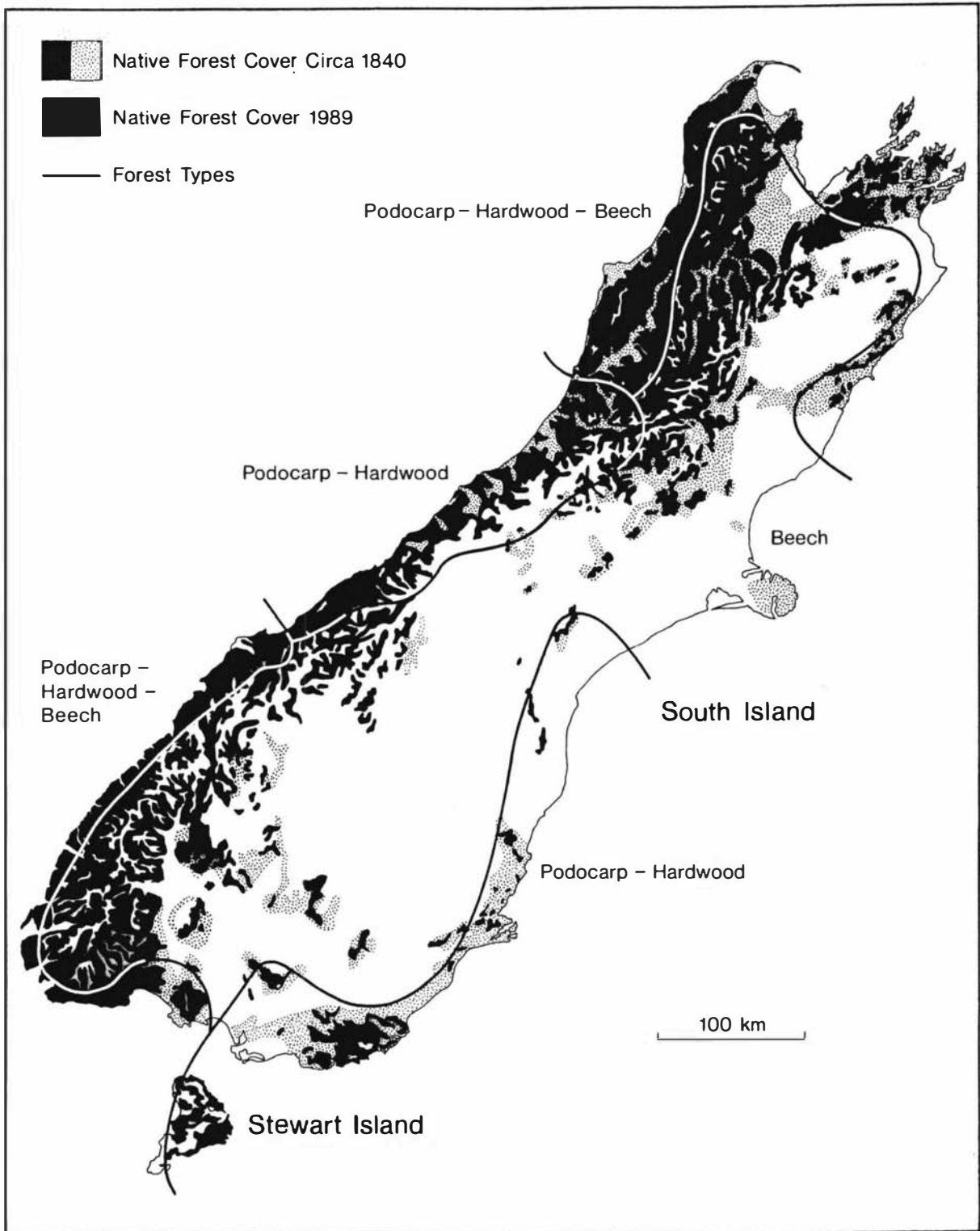


Figure 5.4: The extent of the indigenous forest cover in the South Island prior to European colonization (*ca.* 1840) and present (as of 1989). Solid lines indicate the distribution the predominant forest type (modified after Halkett, 1991).

devoid of *Nothofagus* species.

In the North Island pure *Nothofagus* forests comprise about 40% of the forested area. They mainly occur along the axial ranges, on the highest parts of the Huiarau Range, over most of the Kaweka and Kaimanawa ranges, at the northern end of the Ruahine Range and along the southern crest of the Tararua Range.

In the South Island with a total proportion of more than 80% of the native forest cover *Nothofagus* forests occupy a substantially larger area. They generally extend east of the Main Divide from north-west Nelson to southern Fiordland and Te Waewae Bay in Southland. The climatic conditions encountered in this substantially larger area range from moderate, super-humid in the coastal Fiordland region to cold, semi-arid in the dry, near-continental inland valleys of the eastern Southern Alps (see section 3.3.2).

Such distribution of pure *Nothofagus* forests throughout New Zealand clearly indicates that *Nothofagus* is concentrated in cooler, southern regions, and in uplands, where they form the majority of the tree-lines, rather than in lowlands. These habitats are apparently climatically less favourable for plant growth required by those species constituting other types of conifer-hardwood forests (Halkett, 1991; McGlone, 1988; Salmon, 1980; Wendelken, 1976).

5.2 General aspects of the Quaternary environment of New Zealand

The Quaternary period is well preserved in the physical environment of New Zealand. Altogether the country's Quaternary record covers a wide range of strata including loess, volcanics, marine sediments, and alluvial and glacial deposits. However, the distribution of these deposits is rather uneven; volcanics are principally restricted to the North Island, and glacial deposits mainly to the South Island (also see section 3.1). Marine strata are widely preserved in uplifted basins in the North Island, but rarely occur in the South Island. Loess and alluvial sediments occur throughout both islands, although in the North Island loess is largely restricted to the southern half (Pillans, 1991; also see

fig. 5.5).

5.2.1 Chronology of the New Zealand Quaternary

The time-stratigraphic subdivision of the New Zealand Quaternary has largely been based on either marine biostratigraphy from type sections in the Wanganui Basin in the southern North Island, or terrestrial climatostratigraphy (glacials/interglacials) utilizing glacial deposits in the northern South Island (Pillans, 1991; Suggate, 1965, 1990) (see fig. 5.5). Both schemes resulted in a series of locally defined stages and substages.

The marine stratigraphic sequence of the Wanganui Basin comprises up to 4000 meters of primarily shallow-water strata of Plio/Pleistocene age. Due to tectonic movements the basin margins are now uplifted, and gently dipping strata are exposed on land (Fleming, 1953, 1975; Pillans, 1991). Despite an unconformity between *ca.* 1.45 and 1.0 Ma (Pillans, 1991; Suggate, 1990), creating a gap of almost 0.5 Ma, the Wanganui Basin sediments provide the most complete on-shore record of the Upper and Lower Quaternary of New Zealand (Fleming, 1975). The chronostratigraphy of these marine sequences, considering various recent alterations to the standard New Zealand chronostratigraphic scheme (*cf.* Pillans, 1991), is summarized in table 5.1.

Accordingly, the Plio/Pleistocene boundary, marking the beginning of the Quaternary, as defined at the Vrica stratotype in Italy, and dated at *ca.* 1.63 Ma⁵⁸ (Tauxe *et al.*, 1983), lies near the top of the Nukumaruan Stage in New Zealand. Nevertheless, first faunal evidence of marked cooling in New Zealand Plio/Pleistocene sequences occurs much earlier, at the base of the Nukumaruan Stage *ca.* 2.4 Ma, based on the first incoming of the subantarctic taxa *Chlamys delicatula* (Subantarctic Scallop) and *Jacquinotia edwardsii* (Jacquinot's Spider Crab) to the Wanganui and Wairarapa basins (see fig. 5.5) in the southern North Island (Fleming, 1953, 1975, 1978; Pillans, 1991; Suggate, 1990). This date even correlates perfectly with stratigraphic evidence at "Deep Sea Drilling Project" (DSDP) Site 552A of the first major Northern Hemisphere glacial

⁵⁸The age of the **Pliocene/Pleistocene boundary** was recently reviewed and is now dated to 1.796 Ma ago (quoted by Menzies, 1998:359).

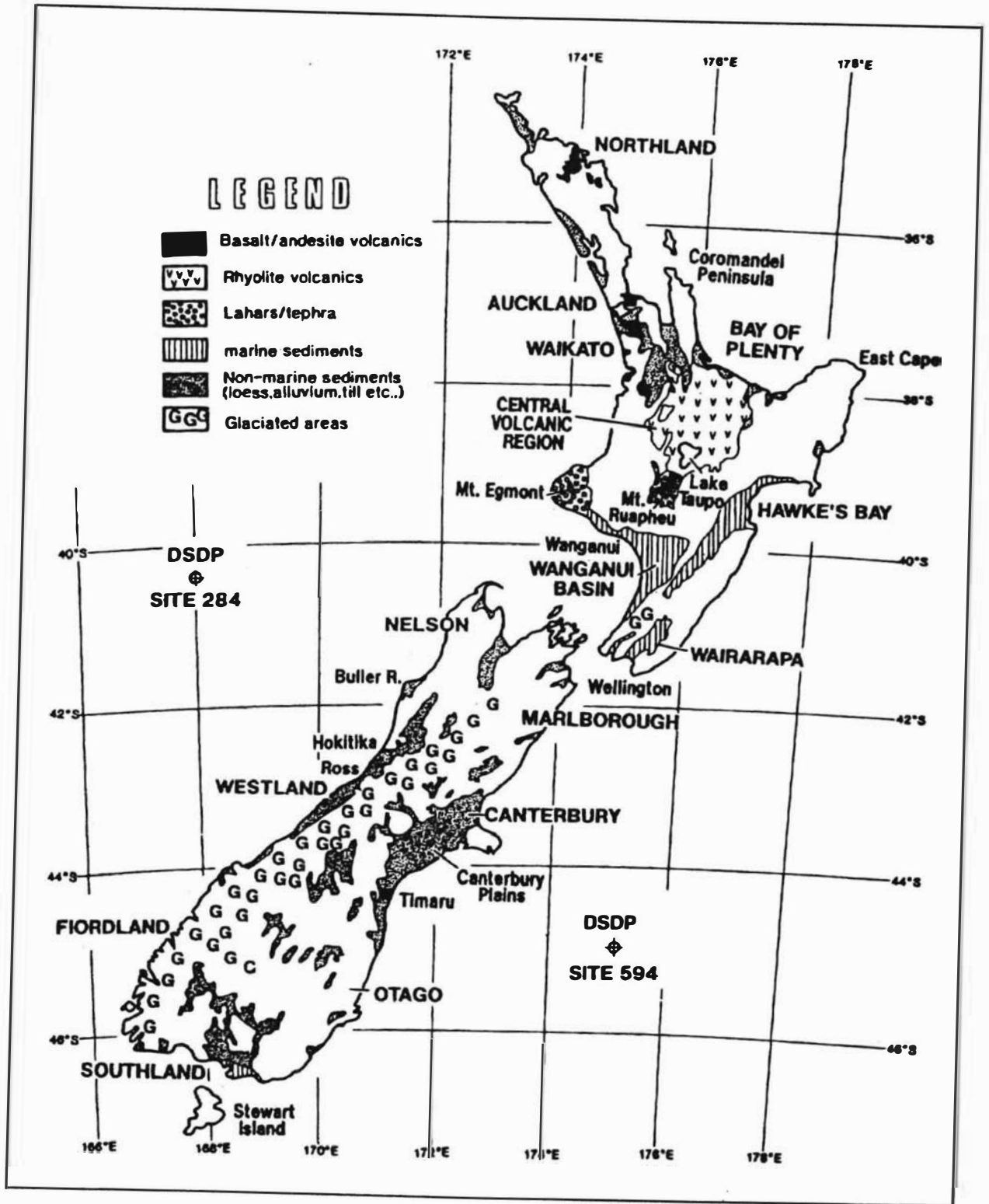


Figure: 5.5: Generalised distribution of Quaternary deposits in New Zealand (Pillans, 1991).

Stage	Age (Ma)	
Haweran	0.35	
Castlecliffian		Quaternary
_____ <i>Unconformity</i> _____	1.0	
Nukumaruan	2.4	
Mangapanian	3.1	Late Pliocene
Waipipian		

Table 5.1: New Zealand Late Pliocene and Quaternary biostratigraphic subdivision with boundaries as defined in the marine sequences in the Wanganui Basin, southern North Island. The unconformity between the Nukumaruan and Castlecliffian stages may represent *ca.* 0.5 Ma (Suggate, 1990).

event, dated at 2.37 Ma (Shackleton *et al.*, 1984). Therefore, for many years the base of the Nukumaruan Stage was recognized as the Plio/Pleistocene boundary in New Zealand (Pillans, 1991).

Unlike the marine sequences of the southern North Island, the record of terrestrial deposits is much more fragmentary and dating is also much less secure. However, the glacial record of the South Island has always been an important tool in the interpretation of the Quaternary history of New Zealand (e.g. Pillans, 1991; Suggate, 1990). Earliest evidence of the country's glaciations appears in the form of glacial deposits near Ross, north Westland, of what has come to be known as the Ross Glaciation. The age of the Ross Glaciation is not certain but by means of correlation with the Wanganui Basin marine sequences (see above) it is inferred to be of Late Pliocene (Waipipian [2.6-2.4 Ma]) age (Suggate, 1990; also see tab. 5.1). However, as a result of the combined effects of erosion and of regional and local tectonic uplift (see section 3.1), there is a substantial unconformity in the glacial record between the onset of the Porika (*ca.* 2.1 Ma) and the Nemona glaciations (*ca.* 0.35 Ma). Consequently, only the last four glaciations which occurred in an environmental setting closely similar to that of the present, generated a physiographic and stratigraphic record for any secure identification. The ones being identified are named Nemona, Waimaunga, Waimea and Otira (Suggate, 1990). However, local evidence of coastal evolution (e.g. formation of marine terraces) associated with interglacial high sea-level stands, extends back about twice as far (see fig. 5.6). Based on the stratigraphic relationships between interglacial marine terraces, and glacial outwash surfaces and moraines in north Westland, Suggate (1985, 1990) has devised a tentative chronology for locally defined glacials and interglacials (*cf.* Suggate, 1965), extending back to Oxygen Isotope Stage 11 (see fig. 5.6). This chronology forms the basis for New Zealand's Quaternary climatic stages.

Furthermore, correlation with isotopic (Oxygen Isotope variations) and lithologic (granulometric variations) records at DSDP Site 594 (see fig. 5.5) could also prove that over the past 0.73 Ma the glaciations of the South Island were in phase (to within 2-3 ka) with major growth phases of the continental ice sheets of the Northern Hemisphere (Nelson *et al.*, 1985). However, post-14 ka glacial fluctuations appear not to be precisely

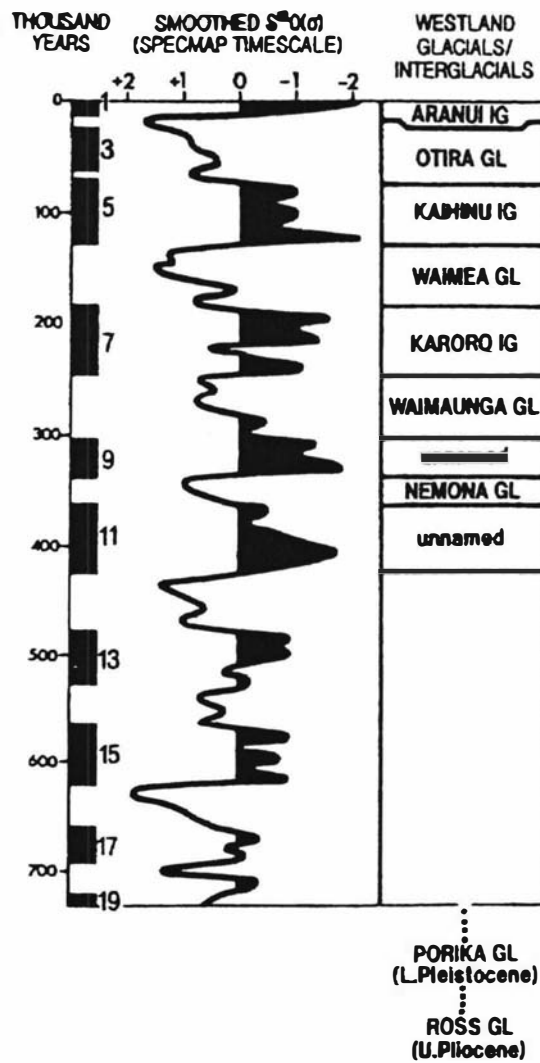


Figure 5.6: Climatostratigraphy of the Quaternary glacial/interglacial sequences based on stratigraphic relationships of terrestrial and marine sequences in north Westland, north-west South Island, correlated with Oxygen Isotope Stages 1-11 (based on Suggate, 1990; modified after Pillans, 1991).

synchronous with those of the Northern Hemisphere (Suggate, 1990). As the marine record at Site 594 is assumed to be free of unconformities, Nelson *et al.* (1985) infer that during that period the South Island has been subject to 12 full glacial and 13 major interglacial episodes (Pillans *et al.*, 1992), which according to Suggate (1990) equal nine full glaciations (Pillans *et al.*, 1992). Figure 5.6 depicts them as even numbered Oxygen Isotope Stages from 18 to 2, with 4 and 2 representing the Otira Glaciation.

5.2.2 Palaeoenvironmental conditions and vegetation during the Late Quaternary

The recurrent glaciations throughout the Pleistocene caused marked changes to the vegetation and landscape. The most significant floristic event was the disappearance of the last remnants of tropical and subtropical taxa at the beginning of the Pleistocene (Mildenhall, 1980). The repeated glacial-interglacial cycles (see fig. 5.6) throughout the Late Pliocene/Pleistocene gave rise to a pattern of cool, and largely deforested periods, alternating with warm, mild episodes during which forest cover was near complete (McGlone, 1985).

Nevertheless, detailed information on palaeoenvironmental conditions throughout the New Zealand Quaternary are principally restricted to the last 25 ka (e.g. Pillans, 1991). The reason for this is two-fold. Firstly, there is a lack of continuous micro- and macro-plant analytical records for vegetational changes extending back beyond the "Last Glacial Maximum"⁵⁹ (McGlone, 1985). Secondly, the lack of secure dating beyond the range of the radiocarbon dating method. Even for radiocarbon dated materials, there are many problems of contamination, and interpretation of ages beyond 30 ka is equivocal (*cf.* Pillans, 1991). Consequently, only the youngest glacial advances of the Otira Glaciation can be dated with any certainty (Suggate, 1990).

Furthermore, apart from the above restrictions, McGlone (1985) argues that the most

⁵⁹The exact length of the "Last Glacial Maximum" (LGM) appears difficult to define. The problem mainly lies in different periods of time allocated to this last stage of the Otira Glaciation. In the terminology used by McGlone (1995) the Last Glacial Maximum dates from 25 to 14 ka. Other sources state periods from 25 to 15 ka (Anderson & McGlone, 1992; McGlone, 1985) and 22 to 14 ka (McGlone, 1988; McGlone *et al.*, 1993).

recent interglacial-glacial cycle, covering the period from the maximum of the Last Interglaciation (Kaihinu Interglacial; Suggate, 1990) at around 120 ka through to the present (see fig. 5.6), is representative for the repetitive climatic and vegetational changes for most of the Quaternary. The following descriptions of the palaeoenvironmental conditions and vegetational changes will therefore be restricted to the Late Pleistocene.

5.2.2.1 The Last Glacial Maximum

New Zealand's Last Glaciation, the Otira Glaciation⁶⁰, was a rather complex geological event, consisting of at least three major interstadials (e.g. McGlone, 1985) and three severe stadials/periods of glacial advances (e.g. Suggate, 1965, 1985, 1990). Based on various local studies McGlone (1985) concludes that forest occupied much of both islands during the interstadials. During the stadials shrubland and grassland communities dominated, and the forest cover was extremely restricted throughout the country. The most recent of these stadials is the Last Glacial Maximum (see footnote #59). This stadial is arguably the palaeoenvironmentally most significant of the Otira Glaciation, as its stratigraphic sequences are better preserved and more accessible than older deposits of previous ones (McGlone, 1985; Pillans, 1991).

The Last Glacial Maximum represents the coldest part of the Otira Glaciation which peaked at *ca.* 18 ka (e.g. CLIMAP Project Members, 1981; also see McGlone, 1985; McGlone *et al.*, 1993). During this period the South Island was extensively glaciated; a

⁶⁰The exact duration of the **Otira Glaciation** is not fully determined. Due to a lack of age controls beyond the range of the radiocarbon dating method the beginning of the Otira Glaciation is rather subject to speculation. Nevertheless, radiocarbon dating has provided some control for later glacial fluctuations of the Otira Glaciation. It allowed to securely date the last major retreat of glaciers, marking the end of the Otira Glaciation and the beginning of the present interglacial, the Aranui Interglacial (Suggate, 1961), at *ca.* 14 ka (Suggate, 1965, 1985, 1990; Suggate and Moar, 1970). The securely established end of the Otira Glaciation and other lines of evidence such as the correlation of the Otira Glaciation with the Last Glaciation of Europe and North America (Fleming, 1975; *cf.* Suggate, 1965, 1990; also see section 4.1.2.1) as well as the likelihood of a stadial around 30 ka and another outside the range of the radiocarbon method (Fleming, 1975) form the basis of the following estimations of the total length of the Otira Glaciation: 70 to 14 ka (Fleming, 1975); ?80 to 14 ka (Fleming, 1978). McGlone (1985) and Stevens (1995) even assume a duration from *ca.* 100 to 10 ka. A detailed revised radiocarbon-based chronology of major advances and retreats of glaciers of the Late Otira Glacial/stadial (Last Glacial Maximum; 22 to 14 ka), is given by Suggate and Moar (1970).

continuous complex of glaciers and ice plateaux about 700 kilometers long and 100 kilometers wide ran along two-thirds of the Southern Alps (Anderson & McGlone, 1992; McGlone, 1988; also see section 3.1). In the North Island glaciation was rather limited and occurred only on Mt. Ruapehu (McArthur & Shepherd, 1990; also see section 3.1), where the only glaciers of the North Island occur today, and in the higher parts of the Tararua Ranges in the form of several cirque and small valley glaciers (Adkin, 1912; Stevens, 1990; also see section 3.1). Off-shore the sea level had dropped to the order of 110 to 120 meters below the present (Pillans *et al.*, 1992), increasing the size of the New Zealand landmass by approximately 50% (e.g. Anderson & McGlone, 1992). Consequently, the three main islands were linked to each other and most islands off the Northland coast, with the exception of Poor Knights Islands, were connected with the mainland (e.g. Fleming, 1978).

Another effect of the cold climate during this period was a significant depression of snowline throughout the country. For the central South Island Soons (1979) estimates an overall lowering of the snow line within the range of 830 to 850 meters below those of the present. These values are consistent with the amount of depression of the "equilibrium line altitude" (ELA) between 750 and 875 meters in the Tasman Valley of the central Southern Alps in the South Island proposed by Porter (1975). Similar figures from the central North Island have been reported by McArthur & Shepherd (1990) for Mt. Ruapehu (ELA depression of 700 to 900 meters) and McGlone & Topping (1983) for Mt. Tongariro (snowline depression of about 800 meters).

Soons (1979) suggests that her postulated depression of snowline of 830 to 850 meters, which appears to be of approximately the right order for other areas of the country, is equivalent to a lowering of mean annual temperatures of 4.5°C. This value agrees with a mean temperature lowering of the order of 4°C to 6°C for the New Zealand region for the period 18 and 15 ka proposed by COHMAP Members (1988). Quantitative estimates of variations of precipitation associated with these temperature changes have not yet been made. However, based on her snowline reconstructions Soons (1979) proposes an increase in precipitation levels during the Last Glacial Maximum, arguing that a lowering of snowline is the result of increased precipitation. However, this association

refutes the above argument of a temperature decrease during the Last Glacial Maximum. Nevertheless, an increase in precipitation, in turn, would be consistent with the postulated increase in westerly wind flow in the South Pacific oceans at 18 ka (COHMAP Members, 1988; Salinger, 1989; also see McGlone, 1985, 1988; McGlone *et al.*, 1993; Anderson & McGlone, 1992). This feature is manifested in the deposition of loess east of the axial ranges in both islands during the Last Glacial Maximum (e.g. McCraw, 1975; also see McCraw, 1975, fig. 1). The deposition of loess, in turn, indicates drier conditions. Due to more contrasting altitudinal positions of the snowline west and east of the Southern Alps during the Last Glacial Maximum (see Soons, 1975, fig. 2) the west-east precipitation gradient may have even been steepened (*cf.* Anderson & McGlone, 1992). Due to the prevailing Föhn effect (see section 3.3.1) which would not have been different from that of the present such feature would even have intensified the aridity of some eastern South Island areas (Soons, 1975). As a whole the climatic conditions during the Last Glacial Maximum can be summarized as having been dominated by cold temperatures, high winds, severe frosts, and droughty conditions (e.g. Alloway *et al.*, 1992; Pillans *et al.*, 1993). However, the latter feature, i.e. more droughty conditions, conflicts with Soons' (1979) proposed increased levels of precipitation during the Last Glacial Maximum.

Furthermore, recent work on the vegetational history of the tropics during the Last Glacial Maximum might disprove the current estimates of a temperature lowering of about 4.5°C for the New Zealand region. Previous evidence from isotope data from foraminifera implied that the tropical oceans had been only 1-2°C cooler at the Last Glacial Maximum (e.g. CLIMAP Members, 1981). However, pollen evidence from montane and lowland areas of South-East Asia and the west Pacific, tropical Latin America and tropical Africa now suggests a temperature depression of *ca.* 5-10°C for these regions (Flenley, 1997, 1998). Such substantially lower temperatures would probably have had far reaching implications for the New Zealand palaeoclimate during the Last Glacial Maximum. Flenley (*pers. comm.*, 1998) argues that cooler temperatures in the tropics during that period would have possibly resulted in a temperature depression of probably around 8°C for the New Zealand region during the Last Glacial Maximum.

Outside the main glaciated areas (see above) geomorphic evidence suggests substantial erosive activity during the Last Glacial Maximum. Both islands, with the notable exception of the Northland Peninsula, were subject to periglacial activity, including severe fluvial and aeolian erosion at times (*cf.* Lowe & Percival, 1993; Lowe, 1994). Nevertheless, it appears that permafrost generally did not occur outside the glaciated areas. McGlone (1988) concludes that permanently frozen ground outside the glaciated areas was probably of extremely limited extent.

Substantial loess sheets were deposited over most of the South Island and the southern half of the North Island (Eden & Furkert, 1988; McCraw, 1975; Milne & Smalley, 1979). In the north-western districts of the North Island loess deposits also occur but with an increasing admixture of volcanic ash (tephric loess) (e.g. Suggate, 1990; also see section 3.1). The loess deposits in the western districts of the South Island are more restricted and shallower than those in the drier south-eastern regions of the South Island (Milne & Smalley, 1979). Other aeolian landforms generated or activated at this time include extensive sand dunes. The most prominent were formed in the south-west North Island (Cowie, 1963; Neall, 1975), in response to a greatly enhanced supply of sand-sized material from upland regions in association with a (probably) drier climate. Furthermore, enhanced erosion in the uplands produced enormous amounts of shattered material which became deposited as alluvial plains, outwash fans, and fluvial terraces in many major river systems of both islands. Fluvial terraces are principally a result of alternating fluvial aggradation and incision due to tectonic uplift. Thus, the most prominent ones occur in areas of rapid uplift (e.g. Pillans, 1991; Suggate, 1990). Figure 5.7 summarizes the above features of the physical environment at the height of the Last Glacial Maximum.

The vegetative cover during the Last Glacial Maximum widely confirms the presence of an open, eroding landscape, almost devoid of trees. Throughout the country, at least south of 37°S, grassland and shrubland communities were dominant in the uplands and over wide areas of lowland. Grassland, and perhaps open herbfield vegetation, was probably most abundant in inland and eastern areas of the South Island. Shrubland was more common in the west and in coastal areas of the South Island and often a dominant

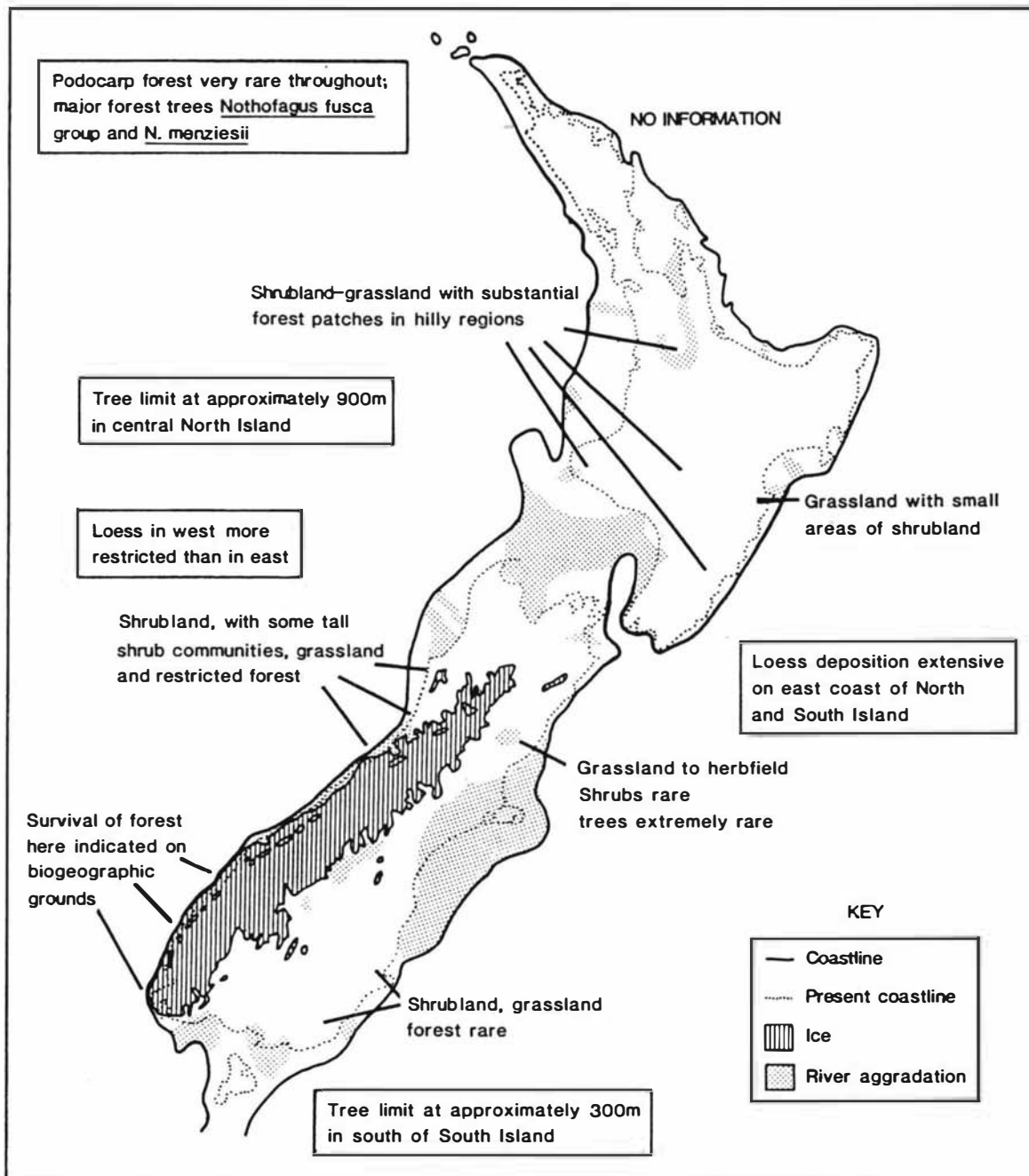


Figure 5.7: New Zealand physical environment at about 18 ka during the height of the Last Glacial Maximum (McGlone, 1988).

component in the North Island. The occurrence of forest during this period was probably exceedingly restricted. Nevertheless, pollen and macrofossil evidence suggests that forest, even though nowhere common, sparsely occurred in small patches in many regions throughout the country. However, in most North Island districts forest was more common than in the South Island. Pollen spectra from selected sites suggest that all trees except *Nothofagus* were rare, and the most abundant tree for most of that period was silver beech. Another frequently recorded taxon is *Libocedrus* along with a low but consistent percentage of podocarp-hardwood forest taxa. Based on this evidence it can be concluded that *Nothofagus* forest, along with extremely small stands of podocarp-hardwood forest, was scattered in isolated sites with a favourable micro-climate. More extensive stands of these types of forest probably existed in the North Island, especially in hilly terrain with a steep topography. These environments were likely to provide small areas of frost-free, north-facing terrain which was more sheltered and less exposed than rolling or flat terrain (Anderson & McGlone, 1992; McGlone, 1985, 1988; McGlone *et al.*, 1993). The only district throughout the country which largely deviated from this pattern was the Northland Peninsula (also see sections 3.2 and 4.1.3.5 and fig. 4.1). Pollen evidence from this region suggests the presence of a mixed *Agathis australis*-podocarp-hardwood forest (also see section 5.1.4.1.1) on the Aupouri Peninsula (*cf.* Newnham, 1990; Newnham *et al.*, 1993; also see below; section 6.1) and *Nothofagus* forest (also see 5.1.4.2) with shrub and grassland associations in mid-Northland, south of the Aupouri Peninsula (Newnham, 1990; also see below; section 6.1). Despite the above shrub and grassland associations, an extensive grassland cover, common for the remainder of the country during the Last Glacial Maximum, probably never occurred in Northland (Dodson *et al.*, 1988). The extent and nature of the above vegetation cover at the Last Glacial Maximum is summarized in figure 5.8.

However, the extremely restricted occurrence of forest outside the Northland peninsula cannot be explained on the basis of cool climates alone. Soon's (1979) proposed depression of annual temperatures of 4.5°C would imply that most of the North Island and the northern South Island below 600 to 700 meters should have been forested during the Last Glacial Maximum. Even in the southern South Island, extensive lowland areas below 300 to 500 meters should have supported forest during that period. Hence,

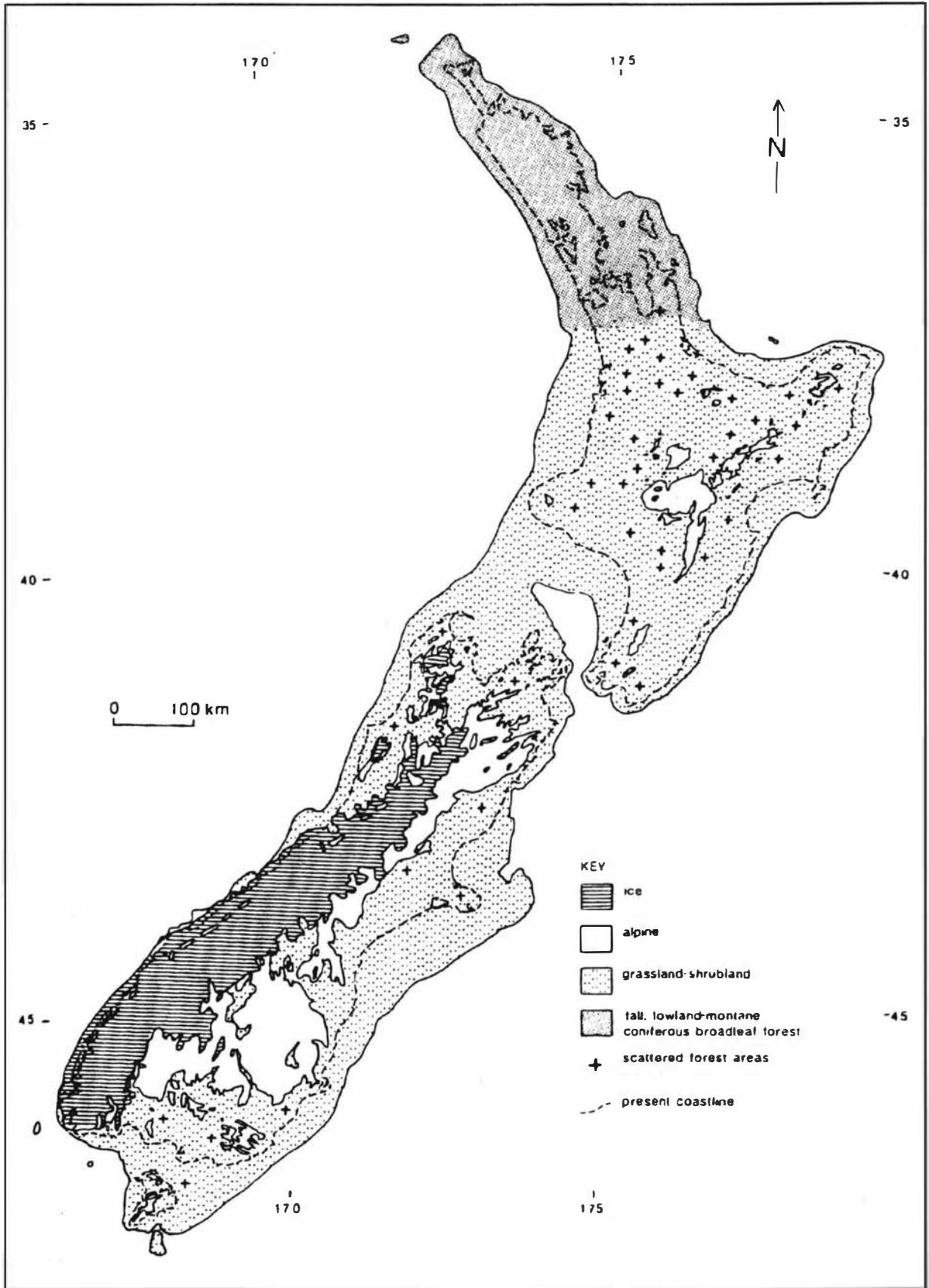


Figure 5.8: Vegetation cover of New Zealand at the height of the Last Glacial Maximum, at around 18 ka (modified after McGlone *et al.*, 1993).

Flenley's (pers. comm., 1998) proposal of a temperature depression of the order of 8°C for the New Zealand region appears to be legitimate (see above). Alternatively, as suggested by Anderson & McGlone (1992), McGlone (1985, 1988) and McGlone *et al.* (1993) other climatic factors could have largely been responsible for establishing and maintaining a near-treeless shrubland and grassland dominated environment. According to the above workers it is probable that a combination of factors, such as the invasion of freezing maritime polar air-masses, causing severe frosts, increased windiness, and episodic drought acted to confine forest to the most sheltered and climatically favoured sites. Fire, consequent upon prolonged drought, has also been considered as a possible factor, but was probably only significant in the eastern districts of the South Island.

5.2.2.2 The Late Glacial

At around 14 ka the climate ameliorated and the glaciers in the South Island rapidly retreated from their extended full-glacial positions (Anderson & McGlone, 1992; McGlone, 1985, 1988; McGlone *et al.*, 1993; Suggate, 1965, 1985, 1990; Suggate & Moar, 1970). This date marks the approximate end of the Late Glacial Maximum and the beginning of the present interglacial interval, commonly known as the Aranui Interglacial (e.g. Suggate, 1990). Thereafter, the physical environment underwent substantial adjustments to the climatic amelioration. By about 12 ka the high levels of erosion on steep slopes and in the uplands of the North Island had ceased. This feature is particularly manifested in near-complete suites of tephra in central and southern North Island montane soil profiles after 12 ka. Loess deposition slowed or ended at about the same time, along with an end of active river aggradation in the North Island due to a reduced supply of erosional debris from upland regions. Furthermore, as a result of the climatic amelioration temperatures rose and at around 12 ka the mean annual temperatures appear to have been within 2°C of their present values (Anderson & McGlone, 1992; McGlone, 1988; McGlone *et al.* 1993).

However, due to distinctive biotic and climatic changes in the New Zealand environment between the retreat of glaciers at the beginning of the Aranui Interglacial

and the onset of major global climatic amelioration marking the beginning of the Holocene (Post Glacial) at *ca.* 10 ka various workers (e.g. McGlone, 1985, 1988; McGlone *et al.*, 1993) commonly refer to the period between 14 and 10 ka as the "Late Glacial". The following chronology of the broad vegetational and climatic changes during the Late Glacial in both islands largely summarizes the work by Anderson & McGlone (1992), McGlone (1985, 1988) and McGlone *et al.* (1993). Detailed descriptions about the floristic composition of the Late Glacial vegetation at a specific and generic level, including special references to various parts of both islands, are provided by McGlone (1988) and partially by McGlone *et al.* (1993).

The beginning of the Late Glacial was marked by a rapid re-afforestation in both lowland and upland sites, in the North Island. During this time podocarp-hardwood forest expanded throughout the North Island with the exception of the south-west sector. By about 12.5 ka continuous forest had spread to the northern half of the south-west sector, except the Wellington region which remained in grassland. At this time nearly 90% of the North Island below the contemporary treeline was forested, but south of 40.5°S forest only occurred in discontinuous patches.

In the South Island noticeable vegetational changes only started at around 12 ka This feature is mainly attributed to the persistence of the extreme climatic conditions of the preceding Last Glacial Maximum. In parts of the wet central and southern portion of the West Coast forest and shrubland had begun to spread, but tall podocarps were still absent. Elsewhere in the South Island shrubland began to replace the previously more abundant grasslands of the full glacial. This transition was finished by about 10 ka.

As a whole the nature of the Late Glacial re-afforestation was very abrupt. In any one region the rate of transformation from open grassland and shrubland to forest vegetation appears to have taken of the order of 300 to 500 years. Hence re-afforestation apparently neither followed any north-south, nor any altitudinal or precipitation gradients. Instead, re-afforestation occurred at about the same time at an individual site as well as throughout extensive regions (e.g. the southern half of the South Island or the southern-central part of the North Island), irrespective of latitude and altitude. Forest re-occupied

upland and lowland sites as well as wetter West Coast districts and drier inland regions at about the same time. Only the extremely arid interior basins of central Otago, which only became re-afforested several thousand years later, deviated from this pattern (Anderson & McGlone, 1992; McGlone, 1985, 1988).

The rapid spread of forest after 14 ka is assumed to have been climate controlled. Frequent extreme weather events during the Last Glacial Maximum, in particular the frequent incursion of cold polar air-masses with its associated weather phenomena (see above), not climatic averages, are attributed to the restriction of forest in micro-climatically favoured isolated environments. With the decreasing intensity of the strong glacial westerly air-flow system at the end of the Otira Glaciation (Stewart & Neal, 1984) these climatic barriers were lifted. Restricted patches of podocarp-hardwood forest immediately responded in the form of rapid expansion from their refugia (Anderson & McGlone, 1992; McGlone, 1985, 1988).

5.2.2.3 The Holocene (Post Glacial - 10 ka to present)

The beginning of the Holocene was marked by a substantial climatic amelioration which led to a substantial vegetation change throughout mainland New Zealand. By 9.5 ka the last pockets of cooler-climate and higher-altitude taxa had disappeared from the lowlands. *Nothofagus menziesii*, *Phyllocladus alpinus* and *Halocarpus bidwillii* which were so extensive in the North Island during the Last Glacial Maximum, had either retreated to very small isolated patches of trees in edaphically or climatically unfavourable sites or regionally become extinct (e.g. in Taranaki). Instead, conifer-hardwood forests extended throughout the country, occupying locations from sea-level to the altitudinal limits of tree growth (McGlone, 1985, 1988). Despite this general change of vegetation to conifer-hardwood dominated forests the regional composition of this forest type usually varied greatly throughout both islands.

In the western and northern North Island for example the number of *Dacrydium cupressinum* increased abruptly and between 10.5 and 9.3 ka it became the dominant

podocarp tree in this region. However, in the east of the North Island *Podocarpus-Prumnopitys* remained dominant. At about the same time a range of other hardwood taxa, including *Metrosideros*, *Ascarina lucida* (hutu), and tree ferns also became common in the North Island (McGlone *et al.*, 1993).

The South Island offered a slightly different picture. Here, the beginning of the Holocene rather marked the re-occupation of the landscape by tall forests (McGlone, 1988). The only noticeable deviation from this general pattern was central Otago which remained dominated by grassland and shrubland for at least another 1500 years. In the wetter districts of the South Island, along the West Coast, *Dacrydium cupressinum* became the predominant tall podocarp tree. Tree ferns, *Ascarina lucida*, *Weinmannia racemosa* and many other hardwood species were also present in these wetter forests from the beginning of the Holocene. In the extreme south-west of the South Island, including Stewart Island, hardwoods, especially *Metrosideros* and *Weinmannia*, and tree ferns continued to dominate until the mid-Holocene, although small numbers of podocarp trees were also present. As a whole the entire re-afforestation of the South Island is believed to have taken of the order of about 1000 years. In the north forest probably spread earlier than in the south (McGlone, 1988; McGlone *et al.*, 1993).

From a biogeographic viewpoint the beginning of the Holocene can generally be regarded as the final phase in the afforestation of New Zealand. By *ca.* 9.5 ka (McGlone, 1988) all the lowlands throughout the country, except for the central south-eastern districts of the South Island (see above), eventually became covered with tall podocarp-hardwood forests. This conspicuously uniform forest type, subdivided into a wet western and dry eastern type, extended throughout both islands. Even some high-altitude subalpine sites usually had some type of low podocarp-hardwood forest or shrubland (McGlone *et al.*, 1993; see Anderson & McGlone, 1992, fig. 8.1C).

Largely deviating from this general pattern were only those types of forest invading the shrubland-grasslands which had persisted during the Late Glacial (see section 5.2.2.2). These forests were characterized by having a sizeable component of *Nothofagus* forming an early type of mixed hardwood-podocarp-*Nothofagus* forests. Notable stands

of this forest type developed in the northern South Island and the southern tip of the North Island. McGlone (1988) notices that all sites which supported this type of forest usually occurred in areas of poor soils and rugged relief; locations which were probably better suited to the expansion of *Nothofagus* spp. than edaphically more favourable sites (see above).

5.2.2.3.1 The Early Holocene (9.5 to 7.5 ka)⁶¹

In many areas of the country the floral composition of the forests and shrublands of the Early Holocene differed substantially from those of the present day. Especially in western and northern regions of New Zealand Early Holocene forests had a higher proportion of a range of hardwood taxa, including, *Metrosideros* spp., *Ascarina lucida*, *Dacrydium cupressinum*, and tree ferns than modern forests (see section 5.2.2.3). These plants are known to be frost-sensitive and favour a climate with minimum fluctuations in temperature and precipitation (McGlone, 1988; McGlone *et al.*, 1993). The proportion of *Nothofagus* on the other hand declined during the Early Holocene. This genus which is known for its tolerance of harsh, exposed environments, generally became restricted to montane and subalpine sites where it still dominates at present (McGlone *et al.*, 1993).

Based on these associations McGlone (1988) infers a reduction in the westerly and southerly windflow over New Zealand, allowing greater incursions of northerly, anticyclonic systems, as well as a higher frequency of easterly to north-easterly winds⁶². The resulting climate for all of New Zealand is assumed to have been generally milder, less frost-prone, and almost certainly less windy (McGlone *et al.*, 1993). The precipitation patterns associated with this climate would have shown a number of east-

⁶¹Due to a series of substantial shifts in composition and structure the Holocene forest cover underwent expansion after *ca.* 7.5 ka. McGlone (1988) divides the Holocene into two parts: the "Early Holocene" from 9.5 to 7.5 ka, and the "Late Holocene" from 7.5 ka to the present.

⁶²The fire history of the eastern South Island obviously supports the contention of a weaker westerly circulation. As there is no evidence for large outbreaks of fire during the Early Holocene McGlone *et al.* (1993) conclude that westerly windflow must have been reduced. Had southern New Zealand been under the influence of strong zonal westerlies during the Early Holocene, the resultant regime of warm, dry Föhn winds east of the Southern Alps would have made devastating outbreaks of fire inevitable.

west and north-south gradients which were rather different from those of the present.

Even the western districts of both islands, for example, are believed to have experienced different precipitation levels. While the weakening of the westerly circulation probably led to lower precipitation levels than at present along the West Coast of the South Island, more frequent northerly winds possibly increased the overall precipitation in the north-western sector of the North Island (McGlone, 1988). An abundance of organic deposits and the prominence of both *Dacrydium cupressinum* and tree ferns as well as a more common occurrence of *Ascarina* spp. in the north-west of the North Island during this period appear to support the contention of a higher precipitation in this region (McGlone, 1988; McGlone *et al.*, 1993).

For the eastern South Island and south-eastern North Island pollen and macrofossil evidence (dominance of *Prumnopitys taxifolia* and *Podocarpus*, with only a small proportion of *Dacrydium cupressinum*) on the other hand suggests that effective precipitation had been low or even lower than at present (McGlone *et al.*, 1993). McGlone & Bathgate (1983) even propose a 30% depression of effective precipitation for the entire south-eastern South Island. A widespread absence of organic deposits throughout the east of both islands during the Early Holocene probably indicates generally lower precipitation levels in these locations (McGlone *et al.*, 1993).

Taking into account the above precipitation gradients McGlone *et al.* (1993) summarize the country's climate during the Early Holocene as follows: summers were probably characteristically cloudy and moist due to a predominance of northerly and easterly winds, whereas winters must have been often calm and anticyclonic, with few deep, vigorous fronts and a weaker overall southerly windflow. These rather mild conditions are generally regarded as the cause of the low occurrence of *Nothofagus* forests (also see section 5.1.4.2) throughout the country during the Early Holocene (see above). Rogers & McGlone (1989) suggest that the mild, cloudy, and moist conditions that may have prevailed throughout the axial mountain chain of both islands were the primary reason that low shrubland was abundant and *Nothofagus* forest scarce.

5.2.2.3.2 The Late Holocene (7.5 ka to present)

The period from 7.5 ka was marked by a series of shifts in composition and structure of the Holocene forest cover. This feature was manifested in the expansion of various hardwood and conifer taxa from apparently pre-existing local sources over wide areas of both islands (McGlone, 1988).

Of all these floristic changes of the Late Holocene the arguably most prominent was the expansion of *Nothofagus* forest. After having reached a low during the Late Glacial, many montane sites throughout the axial ranges experienced a rapid invasion by *Nothofagus* forest. First areas to be invaded by *Nothofagus* forest at the beginning of the Late Holocene were the upland regions in the north-eastern sector of the South Island and the southern North Island. In the latter region this process is still assumed to be incomplete (see section 5.1.4.2) and to continue to the present. However, depending on local environmental conditions (e.g. precipitation levels, soils conditions etc.) *Nothofagus* spread at different rates through most upland sites of both islands over the next few thousand years. By about 2 ka, apart from the above exception, *Nothofagus* had largely supplanted montane podocarp dominant forests and subalpine shrubland which generally had no or only little *Nothofagus* spp. during the Early Holocene. Only few areas such as central Westland (the “beech gap”; McGlone, 1988), the coastal south-eastern districts of the South Island and coastal Taranaki (including Mt. Taranaki) remained *Nothofagus*-free (Anderson & McGlone, 1992; McGlone, 1988; McGlone *et al.*, 1993; Rogers & McGlone, 1989; also see section 5.1.4.2).

Apart from this rather New Zealand-wide floristic change to the native forest cover a number of less prominent, more regional changes also occurred throughout both islands. In central Otago shrubland-grassland communities were replaced by low forest, largely comprising *Prumnopitys taxifolia*, *Podocarpus hallii*, *Phyllocladus alpinus*, and *Nothofagus menziesii*. Merely the very driest inland valleys remained in low shrubland (McGlone, 1988; McGlone *et al.*, 1993).

From *ca.* 7 ka McGlone (1988) and Ogden *et al.* (1992) report an increase in *Agathis*

australis in the northern North Island north of 38°S latitude (also see section 5.1.4.1.1). While there is agreement about the onset of Late Holocene spread of this taxon, its mode of expansion remains a matter of controversy. McGlone (1988) argues that the expansion of *Agathis australis* occurred at about the same time (i.e. ca. 7 ka) throughout the region, indicating a spread from local populations rather than migration from a northern refugium. Ogden *et al.* (1992) on the other hand claim a southward propagation from c. 35°S latitude reaching its current southern limit at c. 38°S latitude by ca. 3 ka. The hypothesis of a southward migration appears to be supported by pollen evidence from various sites in the Waikato lowlands, an area close to 38°S latitude. In all sites *Agathis australis* showed a marked increase at around 3 ka (e.g. McGlone *et al.*, 1984; Newnham *et al.*, 1989).

Other conifer and hardwood taxa which also markedly increased in the northern North Island during this period include *Libocedrus plumosa*, *Phyllocladus trichomanoides*, *Prumnopitys-Podocarpus*, *Knightia excelsa* and *Nestegis* (McGlone *et al.*, 1984; Newnham *et al.*, 1989). Anderson & McGlone (1992) report that in the North Island these taxa (including *Quintinia*) even spread into lowland and montane forests. Some of them also made an appearance in the northern third of the South Island from where they spread down the West Coast.

While these new plant associations were forming a number of taxa of the previous forests were markedly declining at the same time. The most prominent of them were *Dacrydium cupressinum*, *Ascarina lucida* and tree ferns. *Dacrydium cupressinum* and tree ferns gradually declined in many western and northern districts (McGlone, 1988; Anderson & McGlone, 1992). *Ascarina lucida* which used to be an abundant understorey tree in lowland and montane forests throughout the western districts of both islands during the Early Holocene became severely and progressively reduced in quantity. After 1.7 ka its occurrence became restricted to the West Coast of the South Island and a few scattered localities in the northern South Island and the North Island (McGlone & Moar, 1977).

The whole of these vegetational changes during the Late Holocene towards the

country's pre-human vegetation cover are summarized in figure 5.9.

The reasons for these profound transformations of the forest vegetation during the Late Holocene are largely attributed to a radical alteration of broad climatic conditions. Of all climatic elements the decline of strong glacial westerly and southwesterly airflows are believed to have significantly altered the country's precipitation patterns (Anderson & McGlone, 1992; McGlone, 1985, 1988, 1989; McGlone *et al.*, 1993).

Based on the nature of the above vegetational changes McGlone (1989, 1989) proposes a strengthening of atmospheric circulation at around 7 ka. This would have resulted in the intensification of both meridional southerly and zonal westerly windflow which probably significantly accelerated at or after 3 ka.

In the South Island stronger southerly flow primarily caused cooler and wetter conditions in the eastern districts, and cooler, more variable climates in the west. In the North Island the expansion of the southerly circulation would have resulted in generally wetter conditions in the east including the eastern site of the axial ranges. The western districts on the other hand would have received less precipitation with cooler conditions.

The shift to a more southerly circulation is also assumed to have caused a greater variability in the climate. Such greater variability, which is believed to have increased since 3 ka, changed the climatic regime from the one with a low seasonality during the Early Holocene towards the present more seasonal situation. Consequently, summers probably became drier in northern and western locations, whereas winters became wetter with an overall increase in frostiness (McGlone, 1988, 1989; McGlone *et al.*, 1993; Rogers & McGlone, 1989).

The intensification of westerly winds primarily brought droughty conditions to the eastern districts of both islands. However, due to its more mountainous character the South Island was much more affected by the strengthening of westerly flow. Apart from increased disturbance by stronger winds the inland regions east of the main divide became subject to prolonged drought due to stronger Föhn winds (Anderson &

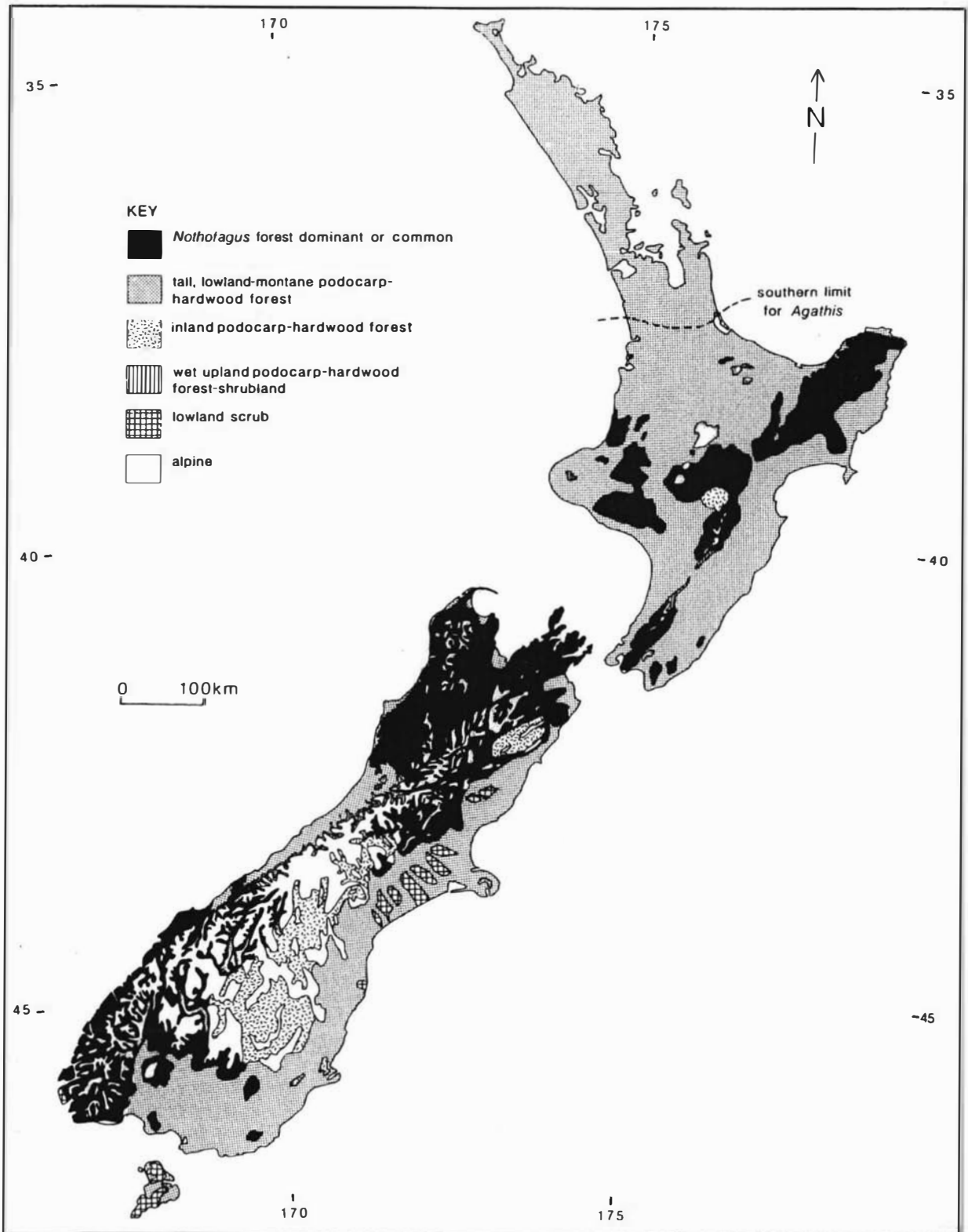


Figure 5.9: Late Holocene vegetation cover of New Zealand at about 3 ka (McGlone *et al.*, 1993; modified after McGlone 1989).

McGlone, 1992; McGlone, 1988, 1989; McGlone *et al.*, 1993).

Stronger Föhn winds are generally attributed to the outbreak of devastating fires in the south-eastern South Island from about 2.5 ka. In view of the controversy of the date of colonization of New Zealand by Polynesians (see section 2.2.1) these fires are regarded as having created the final set of major natural vegetation changes (Anderson & McGlone, 1992; McGlone, 1988; McGlone *et al.*, 1993).

As a whole the climatic change during the Late Holocene can generally be interpreted as a change from a mild, equable Early Holocene climate with occasional disturbance to the forest structure (see section 5.2.2.3.2) to one in which drought, frost and disturbance was common. This trend has been continuous since 7 to 6 ka, but intensified towards the present (McGlone, 1989). In particular the above spread of *Nothofagus* in the uplands appears to indicate a more continental climate and cooler average temperatures.

Physical evidence of a general decline in average temperatures is mainly given in the form of glacial fluctuations in the South Island. Burrows (1979), for example, mentions an increased frequency of glacial advances and retreats during the past 5000 years which followed an interval of limited glacial activity. According to Suggate (1990) there was an intermittent but overall build-up of glaciers east of the main divide in the region of the Mt. Cook National park from about 5 ka until recent centuries. West of the main divide he reports a clustering of dates of glacial advances during the periods from 2.57 to 2.16 ka and from 1.51 to 1.19 ka. Despite such physical evidence of cooler periods but due to variations in the extent and timing of glacial advances in different valley systems it is difficult to infer temperature fluctuations from these glacial records. Secure data on the palaeotemperature of the Late Holocene are only available for the last millennium. For the period from A.D. 1000 to 1900, for example, the fluctuations of the annual mean temperature are believed to have been of the order of $\pm 0.5^{\circ}\text{C}$ (Burrows & Greenland, 1979; Burrows, 1982). Before that period the temperature variations may have been greater as some glacial advances were more extensive than thereafter (Burrows, 1979).

5.3 The human era and its impact on the environment

The undoubtedly most significant event in the environmental history of the country has been the arrival of people in the Late Holocene⁶³. The impact of the activities of the first colonisers can broadly be subdivided into two categories: first, their interference with the native flora and associated geomorphic processes and second, their impact on the indigenous fauna.

5.3.1 Prehistoric anthropogenic forest destruction

Prior to human colonisation of the New Zealand archipelago most of vegetational successions over the past 25 ka have been climate-controlled (see section 5.2.2). With respect to the human era Molloy (1969:60) suggests that "man-made fire has displaced climate as a major controlling factor over wide areas since about A.D. 1000 and could be responsible for some changes reflected in fossil pollen sampled near the surface of peat profiles, especially the so-called reversion of grass pollen."

The strong anthropogenic control of vegetation is unequivocally reflected in the reduction of the country's native forest cover through the passage of time. Prior to Polynesian settlement, approximately 78% of the country was covered in indigenous forest (also see figures 5.3, 5.4 and 5.9). By the time of European colonisation this portion had already been reduced to 53% and presently ranges around 24% (see section 5.1.3 and figures 5.1, 5.3 and 5.4).

Fire was the primary agent of transforming the landscape during Polynesian settlement throughout the Pacific region (e.g. Kirch, 1982). In this respect New Zealand did not constitute an exception as McGlone (1983:23) mentions that "fire was the primary instrument of land management and it was used liberally." (also see McGlone, 1989). Deliberate ignitions by Polynesian were already noticed by early Europeans to the country. In 1896 Walsh reported clearance of the native bush by fire to create paths for

⁶³For a fuller discussion on the date of arrival of people in New Zealand see section 2.2.1.

travel.

However, McGlone (1983) argues that despite the liberal use of fire by Polynesian settlers, not all firing of the forest can be assumed having been deliberate. This is particularly true for forest in the drier regions of the eastern South Island (also see section 3.3.2 and fig. 3.9) where the probability of accidental fire is high. Nevertheless, outside these drier regions one can be sure that forest destruction was deliberate and sustained.

The exact reason for the large-scale Polynesian forest destruction within a relatively short period of time appears to be difficult to explain. This is because there were various economic factors which argued in favour of the retention of forest. The forests were a resource which provided a variety of foods and other products, e.g. edible fruits, large populations of ground and tree-dwelling birds and also a range of construction materials. McGlone (1983) remarks that despite the presence of these forest resources, the Polynesian colonisation history was marked by the a rapid decline of the forest cover. Consequently there must have been "powerful incentives for the destruction of the forest and superior economic uses to which the cleared land could be put." (McGlone, 1983:18). The most important of these incentives McGlone (1983) gives are:

Clearance for bracken: The importance of *Pteridium esculentum* (bracken) as a major staple food in prehistoric New Zealand has been long recognized (e.g. Colenso, 1880; Best, 1942). McGlone (1983) mentions that bracken root was an important Polynesian diet in nearly all localities, in particular those outside the regions where kumara (also see section 2.1.4.4) could easily be cultivated. As bracken fernland is easily suppressed by invading shrubland and forest, favoured areas of *Pteridium esculentum* growth were maintained by repeated burning (e.g. Davidson, 1982; Prickett, 1983; McGlone, 1983, 1989; Taylor, 1958). Thus, the maintenance of bracken fernland by burning would have inevitably led to a spread of fire into adjacent forest (McGlone, 1983).

Clearance of land for cultivation: Taking New Zealand as a whole it appears to be doubtful that this was the major reason for the reduction of the forest cover in

prehistoric times. McGlone (1983) argues that most of the land cleared by Polynesians lies outside the region of intensive horticultural activities. Horticulture was only successful in the northern North Island, in particular Northland, with its milder climate (see section 4.3) as well as in the coastal regions of the central North Island. Polynesian forest destruction for crop planting was therefore only of importance in the climatically favoured north. However, even within the Northland region this kind of forest reduction was limited to those areas which were more suitable for gardening, in particular kumara growing. Taylor (1958) points out that yellow-brown earths (see section 4.2.2), alluvial and colluvial soils (see section 4.2.7) were particularly well suited for this form of horticulture.

Clearance for travel: The extensive movement of Polynesians within and outside their tribal districts required to keep tracks open. These facilitated the movement of people as well as navigation. Preferred areas of forest clearance for tracks were ridges where the forest was less dense and therefore could more readily be burnt (Best, 1942).

Clearance for dwellings, fortifications and security: Although in the most densely populated regions the areas covered by settlements and fortifications was probably not great, the area of land cleared around a settlement or fortifications was often much larger. The reason for that are largely related to the tactics of Maori warfare which was characterized by surprise and ambush. Large-scale forest clearance around a dwelling site would therefore deprive potential enemies of their cover and reduce the possibility of surprise (McGlone, 1983).

Clearance for hunting: The extent to which fire was used as an aid to hunt game, in particular the indigenous mega avifauna (see section 5.1.2.2), appears to be contentious. McGlone (1983) argues that fire was probably not an important aspect in moa hunting, as the moa appears to have declined as rapidly from forests untouched by fire as from those that were cleared. Anderson (1982) rather believes that moa hunting by dog was the most likely hunting method.

Despite the above human endeavours to reduce the forest cover there also seem to have

been climatic constraints. McGlone (1983) notices that there is a broad correlation between the country's mean annual precipitation and the (pre-European) forest cover (see figures 3.9, 5.3 and 5.4). All areas with an average precipitation of less than 600 mm were effectively devoid of forest at the beginning of European settlement, and also almost all parts of both islands with less than 800 mm/a. In the South Island, much of the area with precipitation ranging from 800 to 1200 mm/a was also without forest cover. In the North Island with an annual precipitation between 800 and 1600 mm/a (also see sections 3.3.2 and 4.3.2.2 and figures 3.9 and 4.8), deforestation was concentrated in the regions with rainfall at the lower end of this range. However, there also appear to be a number a regional differences between both islands. The portion of those areas with an annual precipitation between 1000 and 1600 mm which escaped deforestation in the North Island is substantially higher than in equivalent regions in the South Island. This is particularly true for the west of the North Island and Northland (McGlone, 1983).

Based on these climatic patterns McGlone (1983) concludes that beside human activities the single most important factor in forest destruction was precipitation. In areas with an annual precipitation in excess of 1600 mm only limited forest clearance on the most valuable sites was possible. Rainfall in the 800-1600 mm/a interval permitted widespread clearance of forest. However, whether or not an area was cleared depended on a range of local factors, e.g. topography, soils, availability of food resources etc. Therefore, areas which were valued for their agricultural potential were all cleared. Other regions likely to be subject to forest clearance included areas around the larger lakes and rivers as well as the more accessible portions of the coastline.

However, despite the widespread use of fire by people as an agent to transform the landscape, McGlone (1989) claims that there is no secure way to distinguish human ignitions from natural fires which were already significant long before settlement (see section 5.2.2.3.2). Kirch & Ellison (1994:312) reject this view and put forward that "the appearance of substantial and sustained quantities of charcoal particles in alluvial and colluvial sediments, and of microscopic carbon particles in pollen slides, can reasonably taken as a proxy measure of human-induced disturbance within the immediate

catchment area.". Both workers stress the importance of a *sustained* presence of charcoal, because while rare natural fires may have occurred, these will normally produce only short-term peaks in the charcoal record. Such evidence is usually substantially strengthened when matched against other independent palaeoenvironmental information, e.g. palynological evidence of anthropogenic deforestation, geomorphic evidence of increased rates of erosion, (palaeo-) zoological evidence of human-induced faunal extinctions, etc. (Kirch & Ellison, 1994).

McGlone (1983, 1989) takes up this point and offers a number of palynological and geomorphic associations which are regarded to be the most probable indicators of anthropogenic burning of the forest. He argues that destruction of forest by fire often leads to soil instability, followed by erosion of steep slopes and subsequent deposition of inorganic debris in the lower reaches of affected catchments. This feature is usually accompanied by a continuous influx of abundant microscopic charcoal particles into the sediment sequences of affected sites, a decline of arboreal pollen influx and a corresponding upsurge of pollen and spores of non-arboreal vegetation, in particular bracken, shrubs and grasses.

However, Anderson & McGlone (1992) question the validity of the association of a persistent peak of *Pteridium esculentum* (in pollen diagrams) with anthropogenic burning. They argue *P. esculentum* also peaks after natural fire and thus is not indicative of human ignitions. It is true that *P. esculentum* rapidly spreads, in particular in the North Island, after forest clearance (e.g. McKelvey, 1973) but it is also readily suppressed by regenerating forest (Dring, 1965). Its continued presence therefore relies on constant burnoff of the regenerating forest vegetation.

Further support for the above associations is given by Wilmshurst & McGlone (1996). Both have shown that after widespread natural forest destruction (i.e. Taupo eruption around 1850 years B.P.) forest regeneration was rapid and tall forest had redeveloped within 200 years of the eruption, even at sites overwhelmed by the Taupo Ignimbrite. Such evidence appears to strongly justify that *sustained* presence of charcoal in pollen records, coincident with a significant decline of arboreal taxa, unequivocally indicates

anthropogenic forest destruction by fire.

Using these criteria, but disregarding the naturally burnt regions in central Otago (see section 5.2.2.3.2), substantial deforestation can be detected throughout New Zealand. The dates associated with anthropogenic forest clearance on a large scale, depending on the locality, range from 800-500 years B.P., with a peak period at around 600 years B.P. (e.g. Anderson, 1991; Anderson & McGlone, 1992; McGlone, 1983, 1989).

5.3.2 Prehistoric anthropogenic faunal extinctions

It is well established that a major "extinction episode" began around 1000 years B.P. and continues to the present (Holdaway, 1989; McGlone, 1989). Cassels (1984) suggests that the large scale extinction event after 1000 years B.P. was relatively abrupt, and not part of a long decline in populations of species. During that period of time the New Zealand indigenous fauna lost about 40-50% of its avifauna (*ca.* 30 species and subspecies of birds), at least 50% of the frog fauna, and an unknown proportion of the lizard and invertebrate faunas (Cassels, 1984; Holdaway, 1989; also see section 5.1.2.2). Of these faunal losses the notably most significant was the disappearance of the indigenous mega avifauna, in particular the moa (see section 5.1.2.2).

Reasons for the decline and extinction, particularly of the avifauna, have been attributed to a number of factors ranging from climatic deterioration through changes in vegetation, anthropogenic fire, predation by dog and rat to predation by humans (McGlone, 1989). However, Holdaway (1989) largely discounts the possibility of climatic changes and mainly attributes their decline and extinction to human predation and the predation of the introduced Pacific/Polynesian rat (*Rattus exulans*) (see sections 2.1.4.1 and 2.2.1.2) and dogs (*Canis familiaris*) on smaller birds (also see Cassels, 1984). Despite the impossibility of *R. exulans* having preyed directly on birds larger than chickens, Fleming (1969) assumes they might have had an indirect effect on larger birds through predation of their eggs. However, the extinction of mature moas and other large ground-dwelling birds on the other hand was most probably the result of human

predation (e.g. Anderson, 1984; Davidson, 1984; Trotter & McCulloch, 1984).

Other vertebrates which became extinct either through direct or indirect effects of the colonisation of New Zealand by people include a number of terrestrial, marine and freshwater species. Among the small land animals three species of Leiopelmatid frogs (see section 5.1.2.2) became extinct during the prehistoric era, some lizards, Paryphantid land-snails and giant weta became restricted in their range. Anderson & McGlone (1992) assume that the restriction of range of these species reflects refugia from *R. exulans*.

The exploitation of marine mammals (e.g. fur seal, sea lion, leopard seal, elephant seal and cetaceans; see section 5.1.2.1) and the subsequent southward retreat of the seal's breeding colonies during the pre-European era has been reported by Smith (1989).

A review of the over-exploitation of shellfish as well as marine and freshwater fish (also see section 5.1.2.1) is given by Anderson & McGlone (1992).

5.4 Summary

The Quaternary period of New Zealand is well preserved in a variety of terrestrial and marine strata. The time-stratigraphic subdivision of this sedimentary record is mainly based on the marine biostratigraphy of the Wanganui Basin type section as well as glacial deposits and marine terraces in the northern South Island. Glacial activity in the form of extensive ice sheets, typical for the Quaternary period throughout the Northern Hemisphere, was largely restricted to the uplands in the South Island. However, correlation with isotopic and lithologic records at DSDP Site 594 proved that for the past 0.73 Ma these glaciations were in phase with the major growth phases of the continental ice sheets of the Northern Hemisphere. Despite the rather limited extent of the glaciated areas the climatic deterioration associated with these periods of glaciation caused marked changes to the biota and physical environment throughout both islands.

During the Last Glacial Maximum the climatic conditions were characterized by cold temperatures, high winds and severe frosts. Estimates for the lowering of the mean annual temperature range from 4 to 8°C. Such conditions largely reduced the vegetative cover to grassland and shrubland communities throughout the uplands and over wide areas of lowland. Only a few isolated sites with a favourable micro-climate probably supported patches of *Nothofagus* forest, along with extremely small stands of podocarp-hardwood forest. As a result of the combination of a cold climate and an open, almost tree-less landscape, both islands were subject to periglacial activity, including severe fluvial and aeolian erosion. Only the northern North Island, north of latitude 37°S, largely escaped these conditions. Due to more favourable climate conditions throughout the Last Glacial Maximum this region is assumed to have supported podocarp-hardwood forest which was only slightly different from the contemporary forest cover.

The beginning of the Late Glacial was marked by a climatic amelioration. The glaciers in the South Island retreated from their extended full-glacial positions and by about 12 ka the high levels of erosion throughout the North Island had ceased. At about the same time the mean annual temperatures were within 2°C of their present values.

From 14 ka the North Island experienced a rapid re-afforestation by podocarp-hardwood forest, mainly dominated by cool-climate species (e.g. *Nothofagus menziesii* and *Libocedrus*). By about 12.5 ka all of the North Island north of the Wellington region was forested below the contemporary treeline.

Owing to the continuing influence of the strong glacial westerly wind system over the South Island noticeable vegetational changes in this part of the country only started at around 12 ka. Apart from a notably slower rate even the nature of these changes was markedly different from the North Island. Instead of a rapid expansion of podocarp-hardwood forest, shrubland generally began to replace the previously more abundant grasslands of the full glacial. This transition was finished by about 10 ka with forest only occurring in a few sheltered areas in the South Island.

However, despite these regional differences between the North and South Island it can

generally be concluded that mainland New Zealand underwent a relatively progressive afforestation and landscape stabilization reflecting a warming climate. No significant reversals of these overall trends occurred and afforestation throughout both islands was largely complete by *ca.* 9.5 ka (e.g. McGlone, 1995). This fact is of particular significance in relation to the Younger Dryas climatic oscillation which caused substantial cooling in the northern hemisphere, in particular in the North Atlantic region, during the Late Glacial period at around 11-10 ka. For the New Zealand archipelago McGlone (1995) concludes that there is no (unambiguous) vegetational evidence for a cooling event synchronous with the northern hemisphere Younger Dryas.

The beginning of the Holocene generally constituted the final phase in the afforestation of New Zealand. As outlined above by *ca.* 9.5 ka all the lowlands throughout both islands, with the exception of the driest south-eastern districts of the South Island, became covered with podocarp-hardwood forest. However, the climate during this epoch was not uniform but displayed rather contrasting characteristics.

The Early Holocene was characterized by a mild, equable climate with minimum fluctuations in temperature and precipitation. These conditions favoured the spread of frost-sensitive taxa (e.g. *Metrosideros* spp., *Ascarina lucida*, *Dacrydium cupressinum* and tree ferns) which eventually became dominant in the forest cover.

From about 7 ka the atmospheric circulation probably strengthened which intensified the westerly and southerly windflow over New Zealand. These changes resulted in a shift towards a more seasonal climate in which drought, frost and disturbance was common. The vegetation cover responded to these climatic changes with a marked decline of many frost-sensitive taxa which were prominent during the Early Holocene (e.g. *Dacrydium cupressinum*, *Ascarina lucida* and tree ferns). At the same time taxa more tolerant of cooler and windier conditions largely expanded their range. In the North Island *Agathis australis*, *Phyllocladus trichomanoides*, *Libocedrus*, *Nestegis*, *Quintinia* and *Knightia excelsa* among others, spread into lowland and montane forests. This shift in the floristic composition of the Late Holocene forest cover appears to indicate a general decline in average temperatures. An increased frequency of glacial advances and

retreats in the South Island during the past 5000 years largely supports this contention. From about 2.5 ka outbreaks of devastating fire deforested large areas in the south-eastern South Island. These fires are generally regarded as the final set of major natural vegetation changes before the arrival of Polynesians in the country. The climatic conditions at about this time were close to those of the present.

Finally, from 1 ka both islands experienced a substantial decline of their indigenous fauna, in particular the mega avifauna. Based on the abruptness of these faunal extinctions natural causes can be largely ruled out and instead entirely attributed to the either direct or indirect effects of the arrival of people in New Zealand during the most recent part of the Late Holocene.

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Chapter 6

LATE QUATERNARY CLIMATE AND VEGETATION OF NORTHLAND

The climatic and vegetational history since the Last Glacial Maximum is reasonably well documented for most of the country south of latitude 37°S (for a fuller discussion see section 5.2.2). However, for Northland this record is rather incomplete and pollen-based climatic and vegetational studies covering this period are limited to very few sites throughout Northland.

6.1 General aspects of the Last Glacial Maximum to present vegetation and climate

Sites from which sediment sequences were collected include Paramoa and Te Werahi Swamps, near Cape Reinga, northern Aupouri Peninsula (Dodson *et al.*, 1988); Trig Road Swamp and Houhora Tavern Section, near the township of Houhora, central Aupouri Peninsula (Newnham *et al.*, 1993); Otakairangi Swamp, near Whangarei, central mainland Northland (Newnham, 1992); an Early Quaternary pollen profile from the North Kaipara Barrier (Murray & Grant-Mackie, 1989); and fourteen spot samples from lignites interbedded with dune sands along the North Kaipara Barrier from about Maunganui Bluff south to Kaipara Harbour (Mildenhall, 1985; also see fig. 4.1). The time span covered by these samples, based on radiocarbon dating and pollen assemblages, ranges from (probably) the earliest Pleistocene to the Early Holocene.

The pollen records from these sites indicate the following palaeovegetational scenarios: the Cape Reinga region appears to have supported persistent podocarp-hardwood forest (also see section 5.1.4.1.2) for the past 17,000 years. The central Aupouri Peninsula sites bear evidence for mixed podocarp-hardwood forest prior to the Last Glacial Maximum, but the Last Glacial Maximum itself may be missing from the sediment sequences due to possible hiatuses in sedimentation. Furthermore, due to considerable uncertainties with the radiocarbon chronology from these sites, the palaeovegetational information

obtained can only be regarded as tentative.

However, the pollen profile from the Otakairangi Swamp, spanning 30,000 years, provides a rather better record, indicating persistence of diverse podocarp-hardwood forests throughout this period. However, like the sites from the central Aupouri Peninsula, this record is also affected by uncertainties regarding the radiocarbon chronology.

The record from the North Kaipara Barrier indicates a transition from *Agathis australis*-podocarp-hardwood forest (also see section 5.1.4.1.1) to podocarp-hardwood-*Nothofagus* forest (also see section 5.1.4.1.3). Mature *Agathis australis* forests established during the Marahauan Substage (*ca.* 1.6 Ma), a warmer period, were apparently overwhelmed by migrating sand dunes during the following Okehuan Substage (*ca.* 1 Ma). During both substages conditions were wet, probably indicating a climatic cooling of approximately 2°C as inferred from the increase of *Nothofagus* pollen during the Okehuan (Murray & Grant-Mackie, 1985).

Mildenhall's (1985) results suggest cooler conditions due to the presence of a large number of *Nothofagus menziesii* pollen. Similarly symptomatic of cool conditions is the abundance of *Phyllocladus* and wood of *Libocedrus bidwillii* in a number of samples. Nevertheless, all samples containing these two pollen dominants also have taxa consistent with warm, coastal, frost-free, temperate climates. Therefore, local edaphic conditions or wind must be the controlling factor in the dune sands. In view of the uncertainties associated with these results Mildenhall (1985) concludes that (palaeo-) climatic conditions from this part of Northland can only be guessed at as a good regional pollen rain and good sequences are required to determine trends.

Nevertheless, despite the chronological uncertainties of the sequences from the Houhora and Otakairangi sites, the overall trend points to various podocarp-hardwood forest associations throughout the Northland Peninsula at a time during which the remainder of New Zealand only supported vegetation types ranging from incomplete forest cover (predominately *Nothofagus*) to subalpine-type shrub and grassland (see sections 5.2.2.1

and 5.2.2.2). This evidence largely complies with Wardle's (1963, 1988) hypothesis that the Northland region may have acted as an important refugium for warm temperate forest during the Last Glacial Maximum.

Pollen records for Northland only covering the climatic and vegetational changes during the Holocene are equally scarce. So far there is only one reported site, McEwan's Bog, south of Whangarei that provides a ca. 6500 year long sequence (Kershaw & Strickland, 1988). The record indicates that mixed conifer-hardwood forest dominated the region until the beginning of the European era. *Dacrydium cupressinum* was the dominant pollen producer but its proportion gradually decreased relative to *Podocarpus* and *Nothofagus fusca* type, particularly after 4000 years B.P. *Agathis australis* was always present and had its maximum abundance from ca. 3500 years B.P. These vegetational changes suggest that the climate may have been warmer and wetter than today from at least 6500 to about 4000 years B.P. when there is evidence for both lower temperatures and precipitation and perhaps increased seasonality. From ca. 3400 years B.P. the climate became effectively wetter, probably due to a further reduction in temperature.

Consequent upon a number of factors, in particular incomplete pollen records and uncertainties with the radiocarbon chronology of many of these pollen records, it appears that the vegetational and climatic successions since the Last Glacial Maximum for Northland are currently best described by marine sequences from three deep-sea sediment cores (S794, S803 and S804) from the Bay of Plenty, north-east North Island (Wright *et al.*, 1995).

The marine deep-sea cores of Wright *et al.* (1995) record palaeoceanographic and onshore palaeovegetational (and palaeoclimatic) changes of northern New Zealand from isotopic stage 4-3 boundary (≈ 59 ka; also see fig. 5.6) to the present. Pollen evidence from these cores indicates that between 59-43 ka Northland was fully covered by a conifer-hardwood forest in which *A. australis* was dominant. Based on their work on terrestrial sequences from the Northland region (also see above) Newnham (1992), Newnham *et al.* (1993) and Ogden *et al.* (1993) suggest that during this period Northland experienced a somewhat cooler (2-3°C decrease in mean annual

temperatures), moister climatic regime than now. Between 43-12 ka (isotopic stage 3a-2; also see fig. 5.6) *Nothofagus fusca* type forest spread in Northland, while tree-fern-rich conifer-hardwood forest must have become much more restricted. The abundance of *Halocarpus*, *Phyllocladus*, Asteraceae, and grasses (Poaceae) indicate the presence of some open scrub and grassland. However, neither Dodson's *et al.* (1988; also see section 5.2.2.1) nor Newnham's (1992) pollen sequences record any similar flora from their North Cape and Otakairangi sequences, respectively (Wright *et al.*, 1995). In compliance with McGlone *et al.* (1984) Bay of Plenty study for the period 50-28 ka, Wright *et al.* (1995) suggest a decline in temperature of 3-4°C for Northland during the Last Glacial Maximum with drier and frostier conditions. During the later stages of the Last Glacial Maximum *A. australis*, *Dacrydium cupressinum*, and *Cyathea smithii* (soft tree fern/katote) increased sharply, while *Nothofagus fusca* type and *Halocarpus* vanished between 16.5-14.6 ka, followed by a resurgence of the previous *Nothofagus*, *Halocarpus*, Asteraceae, and Poaceae assemblages between 14.6-10 ka. These successions imply an early warming and moistening of the climate followed by the re-establishment of cooler, drier, glacial conditions (Wright *et al.*, 1995). Newnham's (1992) Otakairangi pollen sequence shows a similar *Nothofagus fusca* type/*Halocarpus* interval peaking at around 13 ka.

Isotopic stage 1 (10 ka) begins with an abrupt resurgence of conifer-hardwood taxa and tree ferns. *Dacrydium cupressinum*-dominant, *Ascarina lucida* and tree fern-rich forest became established throughout northern (and western) New Zealand around the beginning of the Holocene as increasingly warm and moist climates began to predominate (McGlone, 1988; Newnham, 1992; Newnham *et al.*, 1989; Wright *et al.*, 1995).

A conspicuous feature of the country's biogeography is the distribution of its flora. McGlone (1985) and Wardle (1963, 1988) describe the occurrence of centres of endemism and disjunction⁶⁴. Accordingly, the northern half of the North Island (north of approximately 39°S; McGlone, 1985, fig. 2; Wardle, 1963, fig. 1; Wardle, 1988, fig. 1) constitutes floristic centres with high proportions of endemic and disjunct species.

⁶⁴For a detailed description of the biogeographic terminology see McGlone (1985:724).

About 95 species are endemic north of 38°S (Wardle, 1991) with the majority of them being woody (ca. 55%) and some 18% are tall trees, including *A. australis*, *Halocarpus kirkii* (monoao), *Beilschmiedia tarairi*, *Caldcluvia rosifolia* (makamaka), *Ixerba brexioides*, *Planchonella costata* (tawapou), *Toronia toru* (toru), *Dracophyllum latifolium* (spiderwood/neinei) and *Phebalium nudum*. The high proportion of endemic woody species in the northern centre contrasts markedly with the type of endemics in the more southerly regions and reflects the greater degree of woodiness of the northern flora as a whole (McGlone, 1985).

6.2 Pre-European vegetation

Based on soil-vegetation relationships (also see section 4.2) and indigenous forest remnants Taylor & Sutherland (1953) reconstructed the pre-European vegetation cover of Northland (see fig. 6.1).

According to Taylor & Sutherland (1953) most of the region was covered with a mosaic of dense podocarp forest, with some areas dominated by *A. australis* or by hardwood trees. Coniferous forest apparently occupied ridge tops and the steeper slopes. Hardwood forest, with a *Beilschmiedia tarairi*-dominant canopy, would probably have occupied much of the more fertile lower slopes and gullies. The wetter flats on the other hand were likely to have been covered largely with *Dacrycarpus dacrydioides* dominated semi-swamp forest.

Prior to the 1840s the native forest cover was dominated by vast tracts of primary northern forest (e.g. Colenso, 1844; Marjoribanks, 1846). However, by the time of large-scale European settlement from A.D. 1840 (also see fig. 5.3) much of the lowlands were occupied by *Leptospermum* and *Pteridium* scrub (Taylor & Sutherland, 1953). McKelvey & Nicholls (1959) report the occurrence of kauri gum in widespread gumlands (also see section 4.2.3) and in soils developed on west coast dunes (also see section 4.2.6). This indicates that these areas formerly supported forest with a prominent *A. australis* element. Taylor & Sutherland (1953) inferred from soil profiles that at least

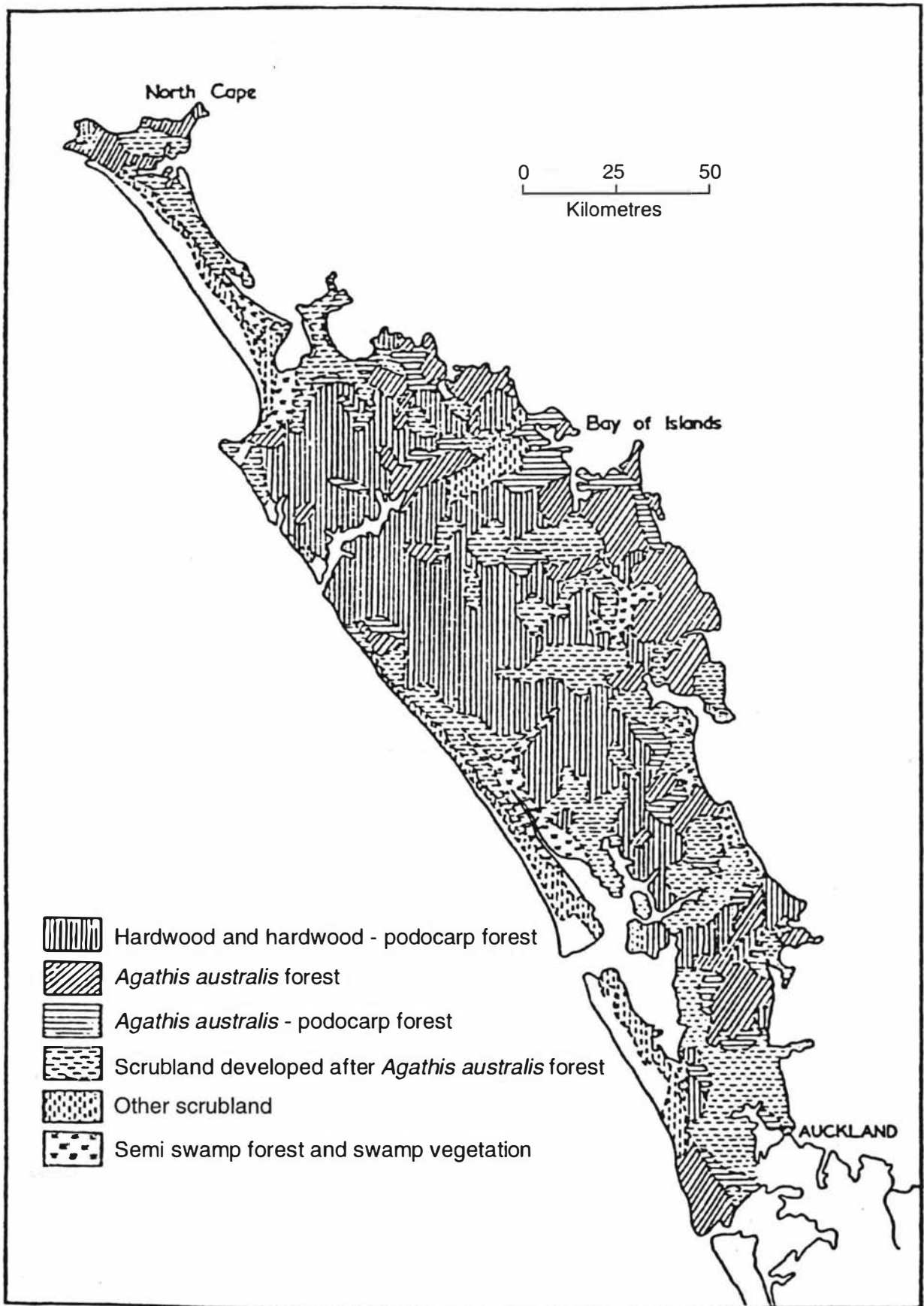


Figure 6.1 Pre-European vegetation of Northland (modified after Taylor & Sutherland, 1953).

some of the gumland areas may naturally have supported a scrub cover; others were probably cleared as the result of early Polynesian activities.

6.3 Present day vegetation

The once unbroken tracts of the pre-European native forest cover have been replaced by scattered forest uplands which are separated by intervening fertile lowlands (also see figures 5.2 and 5.3). Based on Masters' *et al.* (1957) *National Forest Survey of New Zealand, 1955* and McKelvey & Nicholls' (1959) forest type description of the indigenous forest cover of Northland it can be concluded that the present-day indigenous forest remnants are largely consistent with those inferred from Taylor & Sutherland's (1953) pre-European soil-vegetation relationships (see section 6.2 and figures 5.2 and 6.1).

The largest remaining tracts of indigenous forest occur north of Whangarei. These include the Raetea, Herekino, Warawara, Omahuta-Puketi, Waipoua and Russel State Forests (McKelvey & Nicholls, 1959; also see fig. 6.2).

However, smaller but yet significant indigenous forest remnants occur throughout Northland; those in the southern half of the Northland Peninsula are usually smaller than in the north and more scattered (see fig. 6.2). Newnham (1990) argues that these present-day forest remnants mostly occupy steep south-facing slopes at higher altitudes underlain by infertile soils. They are therefore unlikely to represent the full diversity of Northland's pre-human forest cover.

The floristic composition of Northland's indigenous forests includes 20 forest types (McKelvey & Nicholls, 1959). Nevertheless, most of them are podocarp-(broadleaved) hardwood associations⁶⁵ with a prominent element of *A. australis*. According to McKelvey & Nicholls (1959) these forest associations include the following

⁶⁵ **Podocarp-(broadleaved) hardwood forest associations** refer to forest types in which the hardwood element predominately comprises broadleaved angiosperms with only a minor component of *Nothofagus* spp.

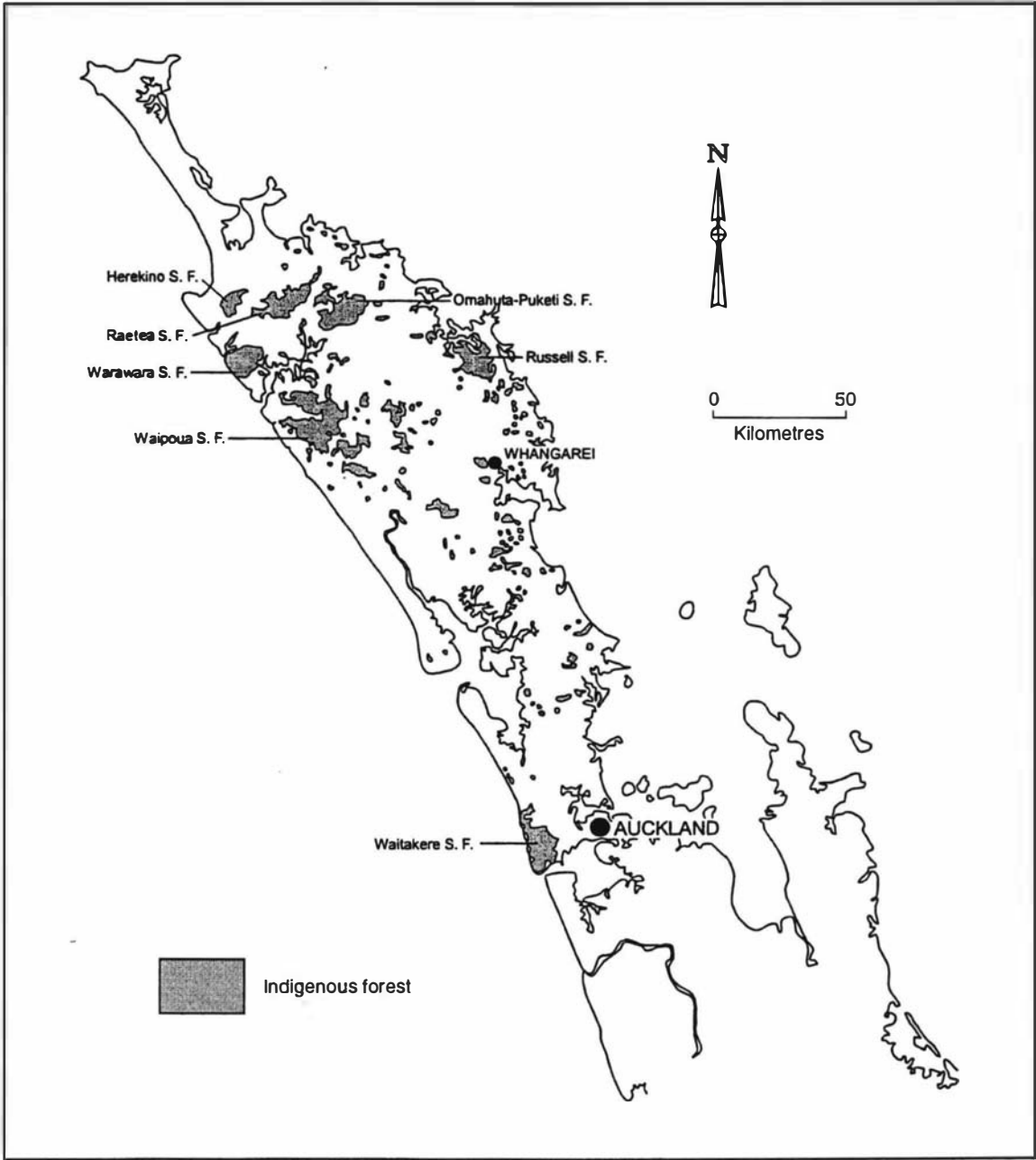


Figure 6.2: Present day indigenous forest cover of Northland (Elliot, 1997; modified after Masters *et al.*, 1957 and McKelvey & Nicholls, 1959).

gymnosperms: *Dacrydium cupressinum*, *Phyllocladus trichomanoides*, *Podocarpus hallii* and *P. totara*. *Halocarpus kirkii* and *Phyllocladus glaucus* may be locally common. Typical angiosperm hardwoods include *Beilschmiedia tarairi*, *B. tawa*, *Dysoxylum spectabile*, *Ixerba brexioides*, *Quintinia serrata* and *Weinmannia silvicola* (tawhero).

The distribution of these floristic associations ranges from areas with leached clay soils (see section 4.2.2) and podzolised sands (see section 4.2.3) to more fertile soils developed over basalt (see section 4.2.5), in alluvial and colluvial deposits (see section 4.2.7). Stands of *A. australis* usually occur on infertile soils (also see sections 4.2 and 4.2.3), mainly confined to ridge tops and steeper slopes (e.g. McKelvey & Nicholls, 1959; Taylor & Sutherland, 1953). A detailed account of the present-day forest composition in Northland in other environmental settings (e.g. swamp margins, valley bottoms, coastal areas etc.) is given by Newnham (1990).

6.4 Summary

Unlike the remainder of New Zealand south of latitude 37°S the vegetational and climatic record of the Northland region is rather incomplete. Sites providing a pollen record extending into the Last Glacial Maximum are few and their radiocarbon chronologies are often affected by a number of uncertainties. Consequently, the vegetational and climatic conditions in Northland during the Last Glacial Maximum are currently best described by marine deep-sea cores from the Bay of Plenty (Wright *et al.*, 1995).

Pollen assemblages from these cores imply a cooler and drier climate in northern New Zealand during the Last Glacial Maximum, in particular between 43-12 ka. The temperatures are believed to have declined between 3-4°C during this period (Wright *et al.*, 1995). However, pollen evidence from terrestrial sequences indicate that throughout the Aupouri Peninsula, *A. australis* remained a common element in the conifer-hardwood association (Odgen *et al.*, 1993), and there is no evidence to suggest that

Nothofagus was part of this most northern assemblage (Dodson *et al.*, 1988; Newnham *et al.*, 1993; Odgen *et al.*, 1993).

It can therefore be concluded that during the Last Glacial Maximum the Aupouri Peninsula largely supported mixed *A. australis*-podocarp-(broadleaved) hardwood forest. The remainder of Northland, south of Kaitaia, on the other hand was largely covered with *Nothofagus* forest, associated with shrub and grassland communities (Newnham, 1990; Newnham *et al.* 1993). Such vegetational cover contrasts conspicuously with the remainder of the country south of latitude 37°S which was largely devoid of forest, except for microclimatically favoured areas where pockets of forest survived. Elsewhere grass- and shrubland communities were common (Anderson & McGlone, 1992; McGlone *et al.*, 1993; also see section 5.2.2.1 and fig. 5.8).

The beginning of the Holocene was marked by an abrupt resurgence of conifer-hardwood taxa and tree ferns throughout the most part of New Zealand. Terrestrial pollen records covering the Holocene indicate that podocarp forest was dominant until European clearance (e.g. Kershaw & Strickland, 1988). The regionally dominant *Nothofagus*-podocarp-hardwood forest eventually became replaced by podocarp-hardwood forest during the early stages of the Holocene (e.g. Newnham, 1990).

The human era was mainly marked by large-scale forest clearance, Polynesian and European alike. During the Polynesian era Northland was mainly covered with a mosaic of dense podocarp forest, with some areas dominated by *A. australis* or by hardwood trees. While coniferous forest apparently occupied ridge tops and steeper slopes, hardwood forest would probably have occupied much of the more fertile lower slopes and gullies. The wetter areas were likely to have supported *Dacrycarpus dacrydioides* dominated semi-swamp forest (Taylor & Sutherland, 1953).

The European era was marked by large-scale forest clearance which, apart from a few smaller occurrences in the south, reduced the indigenous forest cover to a few larger centres north of Whangarei. However, the present-day vegetation of Northland still accommodates 20 different forest types (McKelvey & Nicholls, 1959), most of which

are podocarp-(broadleaved) hardwood associations with a prominent element of *A. australis*.

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Chapter 7

RESEARCH STRATEGY AND METHODOLOGY

The previous chapters, Chapters 2-6, provided rather general information about the timing and patterns of systematic human exploration of the Pacific region during the Late Holocene as well as an overall description of changes of the physical and biotic environment of New Zealand, with special reference to Northland, during the course of the Late Quaternary. It is hoped that these chapters provided the prehistorical and environmental background information which forms the basis of this research. Hence, this chapter describes the rationale of the research presented in this thesis as well as the methods and materials employed to achieve its aims as outlined in section 1.1.

7.1 Rationale of research

This section focuses on the rationale and principal research objectives of this thesis. As the research presented here is inextricably associated with the diverging and apparently irreconcilable concepts about the date of first arrival of people in New Zealand it was deemed to be necessary to begin this section with a brief outline of the history of research into the human settlement of the Pacific and the different hypotheses about the chronology of colonisation of New Zealand which arose from it. Each hypothesis is discussed in detail. The discussion includes a review of arguments corroborating and refuting each respective hypothesis. Thereafter, the conceptual principles of sediment-based environmental investigations are being introduced. This section is followed by a review of other palaeoenvironmental research into the detection of human activities recorded in sediment sequences from sites throughout Polynesia and a few selected locations elsewhere in the world.

7.1.1 Historical background

Research into the human colonisation history of the Pacific region is more than two centuries old. Throughout this time various lines of investigations in various research disciplines have been followed to address this issue. They range from rather inexact analyses and interpretations of ethnographic and historic accounts of traditional navigation methods at the beginning of systematic research into this subject to more sophisticated methods in the recent past involving computer simulations of ancient voyaging routes, experimental voyages by various ocean-going vessels etc. However, of all of these modern tools of research the arguably most important one was the advent of modern archaeological research about 40 years ago (*cf.* Irwin, 1992; also see Chapter 2). More recently this array of modern research disciplines has been further extended by the use of proxy methods utilizing environmental records to shed light on timing of settlement of the Pacific region, in particular East Polynesia. Nevertheless, in spite of the wide range of different scientific disciplines and methodological approaches involved in this research the matter of *how* and even more important *when* the Pacific region was colonised still remains the subject of contentious debate (see Anderson, 1995 and Sutton, 1994).

The first consensus in this often highly speculative debate was reached when absolute age determinations by means of the radiocarbon dating method could be made from the mid-1950s (see section 2.2.1). Sutton (1994a) argues that the availability of this chronometric tool enabled Sinoto in 1966 to develop his (radiocarbon-based) model of the dispersal of the Polynesians which became known as the "orthodox scenario" of the colonisation of Polynesia (also see Sinoto, 1968, 1979; and sections 2.1.4.3 and 2.2.1.1). Outlining certain peculiarities (see section 2.2.1.1) about the country's very early prehistoric period⁶⁶ for New Zealand this orthodox hypothesis of colonisation was first stated in detail by Groube in 1968. Thereafter it became commonly known as the "orthodox model" or "orthodox hypothesis". Based on her assessment of the country's early radiocarbon dates (on archaeological materials) for New Zealand the name of Janet Davidson eventually became closely associated with the orthodox model. She

⁶⁶New Zealand's very early prehistoric period is commonly being referred to as either the "Archaic New Zealand phase", "East Polynesian phase" or even "Early Maori phase" (e.g. Anderson, 1989a, fig. 1).

summarized that first settlement of New Zealand must have occurred around A.D. 800 (Davidson, 1984) or as previously stated within the range of 1200-1000 years B.P. (Davidson, 1981).

This consensus about the colonisation of Polynesia, in particular East Polynesia, was first challenged in 1981 by Irwin's "model of continuous settlement" which contested the existence of the "West Polynesian Pause" or "The Long Pause" (also see section 2.1.4.4) of about 1000 to 1500 years (Irwin 1981, 1992) as proposed in the orthodox model. Instead Irwin (1981, 1992) argued that this pause is an artifact used by prehistorians and that voyaging had always been continuous throughout the era of Polynesian colonisation of the Pacific region (also see section 2.1.4.4). Finally the publication of Kirch's *Rethinking East Polynesian prehistory* in 1986 brought about the collapse of the orthodox model. This paper, in essence, is a serious critique of Sinoto's account of the sequence and chronology of first and subsequent colonisations of the major island groups in Polynesia. Broadly speaking by re-examining the radiocarbon chronology, the chronology of early sites and their artefact assemblages from early sites in East Polynesia (Hawaii and the Marquesas) Kirch (1986) concluded that human settlement for this region was *earlier* than had been proposed in the orthodox model. A review of Kirch's (1986) points of criticism of Sinoto's scenario is given by Sutton (1987a, 1994a).

Since Kirch's effective rebuttal of the orthodox model in 1986, which was widely regarded as the "paradigm" (e.g. Sutton, 1987) of the Polynesian colonisation history until then, there has been a situation which Anderson (1995:110) describes as a "period of considerable uncertainty" about the chronology of human colonisation in Polynesia. He elaborates that there is "no sign of a new consensus forming, except for the common shape of the problem" which he defines as certain assumptions about the colonising behaviour of human groups. These assumptions eventually gave rise to (different) estimations of the "archaeological visibility of colonisation" of human groups and the "representativeness of the radiocarbon record" of their activities. Hence, differing views on these two points eventually and inevitably led to the demand of new conclusions about the commencement of colonisation (see Anderson, 1995).

7.1.2 Concepts of human colonisation in the Pacific

As a consequence two broadly divergent schools of thought about the "archaeological visibility" of a colonising population have recently emerged out of this conceptual framework: One school of thought asserts that colonising populations behave in ways which created an incrementally *rapid* and *distinctive archaeological record*⁶⁷ which is represented by settlement sites of later than orthodox date⁶⁸. This school of thought is commonly known as the "Short prehistory" hypothesis (see section 2.2.1.3) or "Late settlement model". It is based on a high economic efficiency, as reflected in the prominence of horticultural activities, of a sizeable and late (i.e. later than orthodox date [see footnote #68]) colonising population. The substantial landscape degradation usually associated with prehistoric horticultural and agricultural practices is expected to follow, not precede, the (initial) colonisation phase which is believed to only skim the pristine pre-human indigenous resources (Anderson, 1995).

The other school of thought argues that colonising populations behaved in ways which created an incrementally *slow* and *cryptic archaeological record*⁶⁹. Early remains associated with human activity therefore have low probabilities of discovery. Hence, colonisation is unlikely to be recorded archaeologically and consequently must precede the current archaeological record. This model became known as the "Early hypothesis" (see section 2.2.1.2) or "Early settlement model" respectively. It is based on the concept that population growth through time of a group of colonising people eventually leads to an expansion of their economic activities. These, in turn, generate a steadily increasing abundance and variety of remains associated with these activities which eventually move the archaeological evidence of human presence into the visible part of the colonisation spectrum (Anderson, 1995).

⁶⁷ A "**rapid and distinctive archaeological record**" is defined as having a large and fast-growing colonising population with diverse subsistence patterns which is mainly focused on large wild game (Anderson, 1995).

⁶⁸ The term "**orthodox date**" refers to the date of commencement of human colonisation of individual major island groups in Polynesia as proposed in Sinoto's (1966; also see Sinoto 1968, 1979) orthodox scenario. A number of these dates are stated in section 2.1.4.4.

⁶⁹ A "**slow and cryptic archaeological record**" is generated by an initially small colonising population which is characterised by its high degree of mobility and a slow growth rate (Anderson, 1995).

7.1.2.1 Short prehistory

The hypothesis of a Short prehistory of human occupation of the islands of East Polynesia is inextricably linked with the work by Anderson (1991) and Spriggs & Anderson (1993). Utilizing a "protocol for acceptance or rejection of dates" (also see section 2.2.1.3) both workers re-analysed *ca.* 300 archaeological radiocarbon dates from New Zealand (Anderson, 1991), 109 from Hawaii (Spriggs & Anderson, 1993) and 38 from elsewhere in East Polynesia (Spriggs & Anderson, 1993). Based on the re-analysis, the above workers referred to as the application of "chronometric hygiene", of this corpus of dates from early (archaeological) sites (mainly associated with moa-hunting) they postulated that human colonisation of New Zealand and the rest of East Polynesia must have occurred *later* than proposed in the orthodox model. For East Polynesia, excluding New Zealand, Spriggs & Anderson (1993:211) concluded that "there is nothing to demonstrate settlement in East Polynesia earlier than A.D. 300-600, and then only in the Marquesas". From the corpus of radiocarbon dates from New Zealand Anderson (1991:792) inferred that "no reasonably acceptable date ranges extend at 2 SD earlier than the 12th century A.D., and an initial colonization at about that time appears robust in the face of potential objections"; Spriggs & Anderson (1993) proposed that colonisation occurred around A.D. 1000-1200. Other proponents embracing the hypothesis of a late, post-A.D. 1200, date for initial colonisation of New Zealand include McFadgen (1994), McFadgen *et al.* (1994), McGlone *et al.* (1994) and lately Higham & Hogg (1997) and Newnham *et al.* (1998).

Sutton (1994b) seriously questions Anderson's (1991) and Spriggs & Anderson's (1993) late date for colonisation of New Zealand. He argues that Anderson's (1991) corpus of early archaeological radiocarbon dates are disproportionately from sites in the central and southern regions of New Zealand, with only a very small number of dates from within and north of the Hauraki Gulf. Sutton (1994b) continues his argument by outlining that the extremely small number of Anderson's (1991) early dates from northern New Zealand remains a problem for the credibility of the Short prehistory hypothesis. This is because the Northland region and the islands off its east coast have long been considered a likely area of first landfall (e.g. Mitcalfe, 1984; also see section

2.2). Sutton's (1994b) next point of criticism of a Short prehistory is the archaeological visibility (see above) of early settlers. Anderson (1989b, 1991; also see Anderson & McGovern-Wilson, 1990 and McGlone *et al.*, 1994) contends that *first* people in New Zealand are readily seen in the archaeological record of moa-hunting sites. Sutton (1988, 1994b) disputes this arguing that the archaeological visibility of founding populations is dependent on their size, the susceptibility of the landscape to discernible effects of human presence, settlement distribution and the growth rate of the human population.

Based on Brewis' *et al.* (1990) postulated low rate of population growth for precontact (pre-European) Maori of (probably) less than one percent per annum⁷⁰ Sutton (1994b) seriously queries the archaeological visibility of early colonisers. According to Sutton (1994b) it would take at least 350 years for a small founding population of e.g. less than 100 individuals to increase tenfold. It appears questionable whether a total population of 1000 would be archaeologically visible and the remains of their activities already having been identified.

Sutton (1994b) continues his list of points of criticism of a Short prehistory by outlining that to date only a very limited amount of archaeological research has been done on the early period in Northland and other regions of the North Island (also see Davidson, 1982). This would even allow for the possibility of a time-trend in the colonisation of the country from north to south, as yet undetected. Furthermore, the distribution of moa-hunting sites is highly discontinuous, with only relatively few in Northland. In that situation it may be premature to make moa-hunter settlements synonymous with the first arrival of people. A more comprehensive critique of Anderson's (1991) Short prehistory of New Zealand in the light of the archeology, demography and economy of early settlements is given in Sutton (1994b).

7.1.2.2 Early hypothesis

Based on Kirch's (1986) proposition of early human settlement of East Polynesia (see

⁷⁰The exact rate of growth for the precontact (pre-A.D. 1769) Maori population of New Zealand is calculated to 0.875% per annum (Brewis *et al.*, 1990, tab. 9).

above) Sutton (1987) has attempted to extend this concept to New Zealand. In his much noted publication *A paradigmatic shift in Polynesian prehistory: Implications for New Zealand* Sutton (1987a) suggested that New Zealand was probably first settled in the period A.D. 0-500 (also see Sutton, 1994a,b). It is worthy noting that in New Zealand no archaeological remains of that antiquity have been recognized to date. Furthermore, no cultural remains (in the North Island) have yet been found buried *in situ* beneath the Taupo Tephra⁷¹ (*ca.* 1850 years B.P.) or the even younger Kaharoa Tephra⁷² (*ca.* 665 years B.P.) (e.g. Anderson, 1991). Much of Sutton's (1987) argument for an extremely early colonisation rests on McGlone's (1983; also see McGlone 1989) assertion that Polynesian forest destruction by burning may have caused subsequent episodes of soil instability resulting in erosion of steep slopes and the deposition of colluvium and alluvium in the lower reaches of affected catchments.

Sutton's (1987) proposition for an early arrival of people in the country is therefore considered against the palynological and geomorphological evidence that has been used by previous workers, in particular McGlone (1983), to establish or affirm the accepted (orthodox) date of 1200-1000 years B.P. (see above) for first settlement of New Zealand. Sutton's (1994a) major point of criticism is that vegetational disturbances reflected in the pollen spectrum from selected sites have been interpreted as *natural* if they pre-date the orthodox date of colonisation of New Zealand, and *cultural* if they post-date that date. Instead, Sutton (1987, 1994a,b) argues that very early horticulturally-based societies in the far north of the North Island might have left archaeological signatures perceptible only in palynological and geomorphological evidence of environmental change, particularly anthropogenic forest destruction through burning, evidence which is readily confused as non-cultural (also see section 2.2.1.2). Hence, smaller fires preceding the period of substantial and sustained deforestation in New Zealand, commencing at around 800-400 years B.P. depending on the locality (e.g. Anderson, 1991; Anderson & McGlone, 1994; McGlone 1983, 1989; also see section 5.3.1) are highly suggestive of anthropogenic disturbance and should be considered as possibly human-induced [also see Molloy's *et al.* (1963:75-76) review on the *causes of*

⁷¹The **Taupo Tephra** is dated to 1850 ± 10 years B.P. (Froggatt & Lowe, 1990, tab. 1).

⁷²The **Kaharoa Tephra** has been allocated an age of 665 ± 15 years B.P. (Lowe & Hogg, 1992; Lowe *et al.*, 1998).

deforestation]. Sutton (1987) therefore proposes a cultural influence in some cases of radiocarbon dated vegetational changes in the northern North Island which hitherto had been regarded as being the cause of natural events. This view is largely shared by Bulmer (1989) but discarded by McGlone. "He (McGlone) believes that the interpretation of the minor perturbations commonly found at the bases of recent pollen spectra is fraught with ambiguities which can only be resolved through the excavation of cultural deposits." (cited by Sutton, 1987:139; also see Sutton, 1994a).

Anderson & McGlone (1992) generally reject Sutton's (1987) notion of an extremely early colonisation of the country. Their major point of criticism is Sutton's association of fire with human settlement. They argue that New Zealand has a history of fire extending back over millions of years. Even by restricting the application of Sutton's criterion that fire may equal human occupancy to the last glacial-interglacial cycle (also see section 5.2.2) during which modern humans evolved (also see section 2.1.3), one would have to consider the possibility of colonisation of New Zealand many thousand years ago. In this context the fire history of central Otago for example would demand settlement by 2500 years B.P. (also see section 5.2.2.3.2). Anderson & McGlone (1992:217-18) concede that "although this is not impossible, there is not a shred of supporting evidence.". They continue their argument by outlining that "it seems most unlikely that there could have been human settlement for at least 1500 years before the first dated archaeological site, particularly since it apparently affected only the driest area of New Zealand and had no perceptible impact on the avian megafauna (also see section 5.1.2.2) in a region where the earliest known sites are dominated by such remains.". Based on this evidence they assume that only fires after 1000 years B.P. are the result of human activity. Smaller fire disturbances occurring several hundred years before the above period of large-scale deforestation are therefore more likely of having been ignited by lightning-strike, the only effective source of fire in pre-human New Zealand (e.g. McGlone, 1981, 1983, 1989; also see Anderson & McGlone, 1982).

In spite of their general agreement "that Polynesian arrival in New Zealand may substantially predate the oldest known archaeological sites." Enright & Osborne (1988:144; also see section 2.2.1.2) principally join Anderson & McGlone (1992) in

their critique of Sutton's (1987) early date of colonisation. They vigorously contest Sutton's (1987) (re-)interpretation of palynological and geomorphic evidence of Late Holocene environmental changes from various locations mainly in Northland and argue that "several sources used are misinterpreted, and others are interpreted in a way that ignores more reasonable conclusions.". Particularly criticized is Sutton's (1987) assertion, based on palynological evidence provided by Chester (1986), that human activity in the Bay of Islands began at A.D. 550-600 (1400-1350 years B.P.). Enright & Osborne (1988) argue that this date cannot be accepted on the grounds of faults with the time-scale of Chester's (1986) pollen-stratigraphic record. Their criticism mainly surrounds the issue of the extremely old age Chester had assigned to the Kaharoa ash marker horizon from which she inferred the above date of settlement by interpolation (for a fuller discussion see section 2.2.1.2).

Finally, Enright & Osborne (1988:144) leave no doubt about sharing McGlone's (see above) scepticism about the validity of pollen studies to accurately date the arrival of people. In their opinion the "establishment of an earlier arrival date must depend, finally, on discovery of cultural deposits.". They conclude that "if indirect evidence for palynology and geomorphology is to be used as a partial surrogate, then a much more substantive, and unambiguous data set will be required."

Other opponents of anthropogenic influences as a possible cause of Late Holocene vegetational changes, especially forest destruction, and subsequent geomorphic processes pre-dating the orthodox date of colonisation of New Zealand include McFadgen (1985) and Grant (1985). In their work on the depositional and erosional processes of Late Holocene coastal and inland deposits, respectively, both favour cycles⁷³ of climatic change over the past 2000 years as the primary cause for soil

⁷³Both workers divide the Late Holocene stratigraphy of New Zealand into chronostratigraphic units. Grant (1985; also see Grant, 1994) divides the Late Holocene into eight major periods of erosion and alluvial sedimentation. These are: Taupo (1764 years B.P.), Post-Taupo (1600-1500 years B.P.), Pre-Kaharoa (1300-900 years B.P.) Waihirere (680-600 years B.P.) Matawhero (450-330 years B.P.), Wakarara (180-150 years B.P.), Tamaki (A.D. 1870-1900) and Waipawa (A.D. 1950-present). Based on their accumulative deposits and respective soils McFadgen (1985; also see McFadgen 1989, 1994) divides the Late Holocene coastal stratigraphy between Auckland and Dunedin into three chronostratigraphic units: the Tamatean Chronozone (*ca.* 1800-450 years B.P.), the Ohuan Chronozone (*ca.* 450-150 years B.P.), and the Hoatan Chronozone (*ca.* 150 years B.P. to present). These chronozones represent depositional episodes each comprising two phases: a high rate of deposition (unstable phase), followed by a low rate of deposition and soil formation (stable phase).

instability and erosion in coastal and inland regions. In essence, they claim that certain periods during the Late Holocene have been characterised by high frequencies of intense cyclonic rainstorms which induced slipping over large areas. Human agency as a possible cause for these processes has essentially been ruled out by both workers. Grant (1985) even excludes a possible influence of introduced wild animals (e.g. deer and possums) as a contributing factor to soil instability and erosion. Their position of "nature-as-sole-cause", excluding any human influence, has even been reiterated in later work (see Grant, 1994; McFadgen, 1989, 1994). With reference to the above geomorphic processes as indirect evidence for early cultural ignitions their position is as follows:

Grant (1985:109) rejects this hypothesis and instead argues "that burning of vegetation is in the same category as earthquakes as a cause of increased erosion, because it may increase the supply of available material for transport, but it *cannot* contribute directly to sediment transport.". Furthermore, "there is no unquestionable evidence in New Zealand that damage to vegetation by fires has been, and is at present, a primary cause of increased erosion and sedimentation on a major scale.". Anderson & McGlone (1982) and McGlone (1989) partially agree with Grant in that New Zealand has a long history of high *natural* erosion rates largely unassisted by forest clearance through burning. However, this is principally only true for the mountain and hill country of the axial ranges where a soft-rock lithology of often only lightly metamorphosed sandstones and argillites in combination with rapid rates of tectonic uplift and steep slopes frequently promote massive erosion events (O'Loughlin & Pearce, 1982; also see McSaveney & Whitehouse, 1989 and section 3.1). O'Loughlin & Pearce (1982) even suggest that present rates of (natural) slope erosion and subsequent sediment yields may even be subdued compared to rates during the Pleistocene glaciations, in particular during the Last Glacial Maximum (also see section 5.2.2.1). For these regions they therefore suggest that "the real effects of humans and their animals, particularly Europeans, on mountain geomorphic processes and rates require re-evaluation." (1982:78).

However, to dispute Grant's (1985) claims there is ample palynological and geomorphic

evidence from throughout New Zealand for *localised* soil movement after burning:

Molloy's (1977) work in the Cass District, Canterbury has demonstrated quite unequivocally that firing of forest triggered soil instability and erosion. He indicated that many of the erosion features in this area are at least 600 years old and probably resulted from Polynesian and natural fires and from climatic events.

For many sites in Canterbury McSaveney & Whitehouse (1989) report the occurrence of charcoal from forest tree species in the soils which bear characteristics of forest soils. McSaveney & Whitehouse attribute these features to human reduction of the forest cover leading to the mobilisation of slope deposits and subsequent deposition as colluvium. Hence, fire which formed the charcoals eventually led to regolith instabilities which ultimately buried the soils. About three out of four radiocarbon dates from such Canterbury sites where colluvium has buried soils with charcoal at the interface fall into the period 1000-500 years B.P. Based on these associations McSaveney & Whitehouse (1989) further suggest that the frequency of soil disturbance increased almost by one order of magnitude from *ca.* 950 years B.P.

From a peat bog at Porters Pass, inland Canterbury McGlone (1983) reports accelerated infilling from 0.6 mm/a when the site was surrounded by forest, to 1.7 mm/a when the area converted to grassland. Based on the charcoal and pollen record the cause of the (final) forest destruction is believed to be burning at around 765 ± 60 years B.P.

Recent work on estuarine environments has convincingly demonstrated that forest clearance in coastal regions often also led to a substantial increase in sedimentation over the normal erosion⁷⁴ rates. Hume & McGlone's (1986) study on the sedimentation patterns of Lucas Creek, Upper Waitemata Harbour, Auckland showed that net (marine) sedimentation rates varied from less than 1.0 mm/a in pre-Polynesian times⁷⁵ (6500-700

⁷⁴Bennett (1939) defines "**normal erosion**" (or "geological erosion") as loss of soil and detritus from the land that occurs under "natural" environmental conditions. According to Bennett these losses are imperceptibly slow and benign with no net loss of soil when occurring under a vegetation cover of grass and trees. Nevertheless, he recognizes that naturally bare and sparsely vegetated areas, slopes exposed to high levels of precipitation, and water-concentrating depressions erode more rapidly.

⁷⁵Length of the period of the "**pre-Polynesian times**" and "**Polynesian settlement**" as stated by Hume & McGlone (1986).

years B.P.) to 1 mm/a during Polynesian settlement (700-110 years B.P.) to 3 mm/a for European settlement (110 years B.P.-present) and finally decreased to less than 2 mm/a for the present day.

Further examples for localised enhanced soil erosion after forest clearance have been reported from the eastern North Island. There pollen- and sediment-based studies from various lake sites (e.g. Lakes Poukawa, Rotonuiaha, Tutira, Waikopiro and Waikaremoana unambiguously showed increased sedimentation rates into the lake basins following Polynesian forest destruction within the catchments of the sites (Newnham *et al.*, 1998; Page *et al.*, 1997; Wilmshurst, 1997; *cf.* Wilmshurst *et al.*, 1997).

Studies from the western North Island include the work by Blaschke *et al.* (1992) and DeRose *et al.* (1991, 1993). These workers report post-deforestation denudational processes on various steep land hillslopes in Taranaki in historic times, in particular since the early 1900s.

McFadgen (1985), in essence, extends Grant's (1985) view of a non-human influence on their postulated Late Holocene erosional and depositional episodes to coastal environments. He discards sea-level changes and tectonic and volcanic events as explanations for his depositional episodes and instead favours increased frequencies of tropical and extratropical cyclones as a possible cause. McGlone (1989) disputes this notion and indicates that anthropogenic burning of vegetation on unstable substrates such as coastal sand dunes would inevitably have initiated erosional processes. He concludes that "the stratigraphic and chronological evidence of McFadgen (1985) appears to better fit an hypothesis in which coastal sequences were disturbed at various times by a variety of events, some of the most important of which were Polynesians and then Europeans using the fragile dune systems." (1989:122).

However, additional support for the Early hypothesis comes from other indirect, non-archaeological, studies including palaeozoology, palaeodemography and computer simulations of prehistoric exploration of the Pacific. The use of a proxy

palaeozoological tracer of human arrival in New Zealand was adopted by Holdaway (1996) applying AMS radiocarbon dating on subfossil bone collagen of the Pacific/Polynesian rat (*Rattus exulans*) (also see section 2.2.1.2). Holdaway reports radiocarbon ages of up to *ca.* 2000 years B.P. on bone gelatin from *R. exulans* from non-cultural sites in both main islands. These dates imply an early, but yet transient, human contact with New Zealand about 1000 years before the orthodox date (for a fuller discussion see section 2.2.1.2). Nevertheless, the validity of these dates has been challenged by Anderson (1996) who attributes the old age of these dates to a number of factors that could have caused the effect of a high "inbuilt age". These factors range from various aspects of the stratigraphy of the above sampling sites through dietary incorporation of old carbon to unremoved contamination by old carbon from external sources. However, the possibility of dietary influences on rat-bone ages has recently been addressed by Beavan & Sparks (1998). Their analysis of bone gelatin and food items of a modern population of *R. exulans* from Kapiti Island, south-western North Island has shown variations in ^{14}C which could have implications on the validity of Holdaway's (1996) early dates. The variations reported by Beavan & Sparks (1998) could be associated with the diet of the rats. Nevertheless, the controversy surrounding AMS radiocarbon dating of *R. exulans* bones has recently resulted in a lively debate on this issue (see Anderson, 1998; Sparks, 1998; Sparks *et al.*, 1997).

Further proxy evidence substantiating an early date of colonisation is provided by Brewis *et al.* (1990) demographic model of the pre-European Maori population of New Zealand. Utilizing standard demographic algorithms based on a number of parameters⁷⁶ combined with skeletal and comparative evidence of mortality and fertility estimates Brewis' *et al.* (1990) inferred a precontact Maori population growth rate of 0.875% per annum (see footnote #70). However, this growth rate was found to be too *low* to populate New Zealand within the time constraints of the orthodox prehistoric sequence. To explain this conundrum Brewis *et al.* (1990) proposed three alternative interpretations. These include: possible inaccuracies of skeletal evidence for estimations of precontact fertility and mortality; rapid population growth in the earliest part of the

⁷⁶Brewis' *et al.* (1990) prehistoric population model for New Zealand is based on the following (palaeo-) demographic parameters: a (Polynesian) founding population size of 50 and a total Maori population of 150,000, based on Pool's (1977) estimate of 125-175,000, at the time of effective European contact at A.D. 1769.

Polynesian period up to A.D. 1150; as well as the possibility that the prehistoric sequence of New Zealand may have been *longer* than the generally accepted 1000-1200 years.

However, the possibility of inaccuracies for estimations of mortality was largely discarded based on evidence from other Oceanic palaeodemographic research. Furthermore, a possible underestimation of actual levels of prehistoric fertility was also deemed to be unlikely in view of other demographic parameters such as a high mortality rate in females and children. The possibility of a high rate of population growth in the earlier part of the prehistoric sequence followed by a slower rate of growth or even no growth also appears to be highly unlikely. Brewis *et al.* (1990) argue that based on the orthodox date of initial colonisation of New Zealand an annual population growth rate of about 3% between A.D. 850 (orthodox date) and approximately A.D. 1150-1350 would have been required to increase the Maori population to its contact size of about 150,000 (see footnote #76). Brewis *et al.* (1990:354) suggest that "such high initial rates of intrinsic increase would require either extremely low mortality or very high completed fertility values. Both these possibilities are far removed from the current osteological evidence.". Based on these considerations they conclude that "the estimated contact period population of New Zealand could have built up constantly at a lower rate if New Zealand was first settled long before the commonly accepted date of 750-950 A.D." (1990:354). Based on an apparently more acceptable prehistoric population growth rate of less than one percent per annum (also see Sutton, 1994b:249-50) it can be assumed that initial colonisation probably occurred *before* the orthodox date.

A probably more novel approach in the research of the human colonisation history of the Pacific Basin are Irwin's (1992) computer simulations of the prehistoric exploration of the remote Pacific. Despite its novelty these simulations are rather a continuation of Levison's *et al.* (also see section 2.1.4.3) pioneering simulations in this field in 1973 followed by later simulations by Irwin *et al.* (1990). Primary aim of Irwin's (1992) simulations was to provide a means of testing for theoretical propositions about colonisation and to review a range of more specific suggestions about the settlement of particular islands. Simulating voyaging by different sailing methods and strategies, in

different seasons, directions, and for different periods of time Irwin (1992) ran numerous "feasibility trials" with starting points for exploratory voyages from the eastern margin of Melanesia and throughout Western and Central Polynesia. With reference to the exploration of the Polynesian margins (see section 2.2) from these starting points for New Zealand Irwin (1992) suggests that it was accessible from several island groups to the north, including New Caledonia, Fiji, Tonga and the Southern Cook Islands. According to Irwin (1992) New Zealand could be reached from these islands within fairly narrow target arcs. The simulations for voyages from New Caledonia gave best results for July, while Tonga and the Southern Cooks were better in January. Considering the size of the New Zealand archipelago Irwin (1990:169) concludes that "all or any of these southern islands (i.e. Norfolk Island, the Kermadecs and New Zealand) could have been discovered in Lapita times (also see section 2.1.4.1), or at any time since.". Nevertheless, Irwin (1990) concedes that an obvious reason against an early discovery of New Zealand is its geographical position outside the tropics. He argues that "sailing in cooler conditions in a different weather regime may have deterred explorers." (1990:169). As a consequence early navigators might have decided against exploring the southern margins of Polynesia during the first 2000 years of deep-ocean voyaging (also see sections 2.1.4 and 2.1.4.1). This contention is supported by a possibly early discovery of Norfolk Island and the Kermadecs (also see section 2.2.3), 400 and 500 nautical miles, respectively, north of New Zealand. Both lie within the tropics at 29°S which is less than 120 nautical miles south of Easter Island and Rapa which were both occupied. Irwin (1992) argues that a relatively early discovery of New Zealand from the above southern islands is quite plausible as New Caledonia is New Zealand's closest large neighbour. Furthermore, New Zealand also lies closer to West Polynesia and Fiji than it does to the closest part of East Polynesia, the Southern Cook Islands. However, despite the greater distance Irwin's (1992) simulations demonstrated that New Zealand could be reached from the Southern Cooks within about 21 days of sailing.

The possibility of an early colonisation of New Zealand from any of these northern Islands, in particular the Southern Cook Islands, based on computer simulations gains even more plausibility in view of recent anthropogenic and environmental research in

Mangaia Island, Southern Cook Islands. Kirch (1996), Kirch & Ellison (1994) and Kirch *et al.* (1991, 1992) report environmental evidence for human colonisation of the island from *ca.* 2500 years B.P. (Ellison, 1994). Further support comes from Walter (1994) who, partially based on linguistic evidence, suggests that this island group is a very likely source for New Zealand's first colonists (also see section 2.2.2). Comparing material culture from the Cook Islands and New Zealand Davidson (1984; also see section 2.2.2) supports the contention of the Southern Cook Islands as the geographical origin of the first people who discovered and settled New Zealand.

In spite of the relatively late beginning of this lively debate on the timing of colonisation of New Zealand after Kirch's (1986) rebuttal of the orthodox model of the colonisation of East Polynesia the possibility of an early settlement of New Zealand is actually not a novel idea only made possible by modern techniques of research. Rather, the notion of an arrival of people earlier than orthodox date was already foreshadowed by some of Groube's remarks in 1968. With reference to Northland's agricultural potential Groube (1968:143) suggested that there is a "very real possibility that the earliest sites in New Zealand are in North Auckland (Northland; also see section 4.1, footnote #31), the optimum zone for tropical agriculture". Later he mentions that "there is a possibility that an unknown period of partial dependence on agriculture may have preceded the maximum development of the moa-hunting activities" (1968:143). This remark is of particular significance in view of Anderson's (1989b, 1991) assertion that *first* people in New Zealand are readily seen in the archaeology of moa-hunter settlements (see above). The bulk of the *earliest* sites Anderson clearly associates with moa-hunting date to the period 800-700 years B.P. (Anderson, 1989b, Appendix E).

Nevertheless, despite reservations that early colonisers would not have immediately exploited the country's rich avian megafauna (e.g. moas, geese, adzebill; also see section 5.1.2.2), in particular the moa, Groube (1968:144) also concedes that "the possibility of an as yet unexplored early agricultural phase in North Auckland cannot be discounted, but the sites of this phase have not yet been located." These remarks are particularly significant in view of Groube's (1968:144) proposition - based on a number of demographic and socio-economic considerations (i.e. population size, pressure on

natural resources, Maori warfare, construction of fortifications, etc.) - that settlement of New Zealand must have occurred "well before the 10th century A.D." Taking into account the potential of erosional processes to bury and therefore conceal the earliest settlement sites as claimed by Cumberland (1962) for the Canterbury Plains in the South Island Groube (1968:145) considers it "more probable, and certainly more testable, to suggest that in the unexplored far north of the North Island, where already there is an early radiocarbon date from undoubted agricultural activity⁷⁷, the earliest evidence is yet to be discovered". This concept has recently been corroborated by Grant (1994). In his work on periodically recurring major periods of increased erosion, flooding and alluviation and their effects on the country's physical and biotic environment Grant (1994:189) proposes that "the time of first settlement may never be known". This is because the above geomorphic processes will have destroyed earliest habitation sites by either erosion or burial with alluvium. From this he infers that "this is the reason why sites relating to early periods of settlement are difficult to find." (1994:190). The absence of very early sites appears to be rather widespread throughout Polynesia, in particular throughout the smaller oceanic islands. For the Society Islands Kirch (1986; also see section 2.2.2) attributes their absence to similar geomorphic processes including neo-tectonism.

7.1.3 Sediment-based evidence for human-induced environmental disturbance

Taking into account Groube's (1986) assumptions as well as the results from other non-archaeological methods (see above) evidence for initial colonisation appears not only to be restricted to earliest archaeological indications, such as habitation sites and dated artefact-bearing context. Despite repeatedly expressed doubts about the meaningfulness of non-archaeological methods (e.g. Anderson, 1991, 1995, 1996; Spriggs & Anderson, 1993; also see section 7.1.2) it appears more likely that earliest evidence for human presence rather derives from anthropogenic environmental changes, in particular alterations to the forest cover, the use of fire for clearance and their associated geomorphic effects on the landscape.

⁷⁷Groube (1966) claims discovery of a buried taro garden in the Bay of Islands which has been radiocarbon dated to A.D. 800.

Hence, the employment of palaeoenvironmental investigations therefore appears to offer the best methodological approach in determining the approximate timing of initial human colonisation of New Zealand (also see Hunt & Holsten, 1991; Kirch & Ellison, 1994; Sutton, 1987, 1994a,b).

Based on the successful application of palaeoenvironmental investigations into the timing of human colonisation in other parts of Polynesia (see review below; section 7.1.5) the author of this thesis employed sedimentological investigations on sediment cores from selected sites throughout Northland, New Zealand's northernmost region.

The selection of Northland for this study was mainly based on environmental considerations. Various environmental parameters, in particular soils (see section 4.2) and climate (see section 4.3), were similar to those of the source islands of earliest colonists of New Zealand (Bulmer, 1988b; *cf.* Bulmer, 1989; Davidson, 1982, 1984; Sutton, 1994b). This view is strongly supported McFadgen (1994) who indicates that earliest settlement occurred in Northland (and around Cook Strait). Other evidence strongly arguing for Northland as the first region in New Zealand to be colonised was the strong concentration of the country's Polynesian population in the northern North Island at the time of European contact (Davidson, 1982; McGlone, 1983; Newsome, 1987). Furthermore, Maori lore also describes Northland as the place of first landfall in New Zealand for early Polynesian colonists (Mitalfe, 1984; also see section 2.2). To this end sediment cores from a total of 14 different locations throughout Northland were collected (see fig. 7.2 and Appendix I).

Before analyzing these cores basal samples were submitted for radiocarbon dating to eliminate those cores which were too young for the purpose of this research. Sediment cores from those sites which returned radiocarbon ages of more than 2000 years (see section 1.1) were considered for further investigations as described below (see section 7.2). Of those analysed cores from sites with a sedimentary record long enough to pre-date earliest human arrival in New Zealand only three sites, Wharau Road Swamp and Lakes Tauanui and Taumatawhana, bore clear sedimentological (and palynological) evidence of human-induced environmental changes. These three sites are discussed in

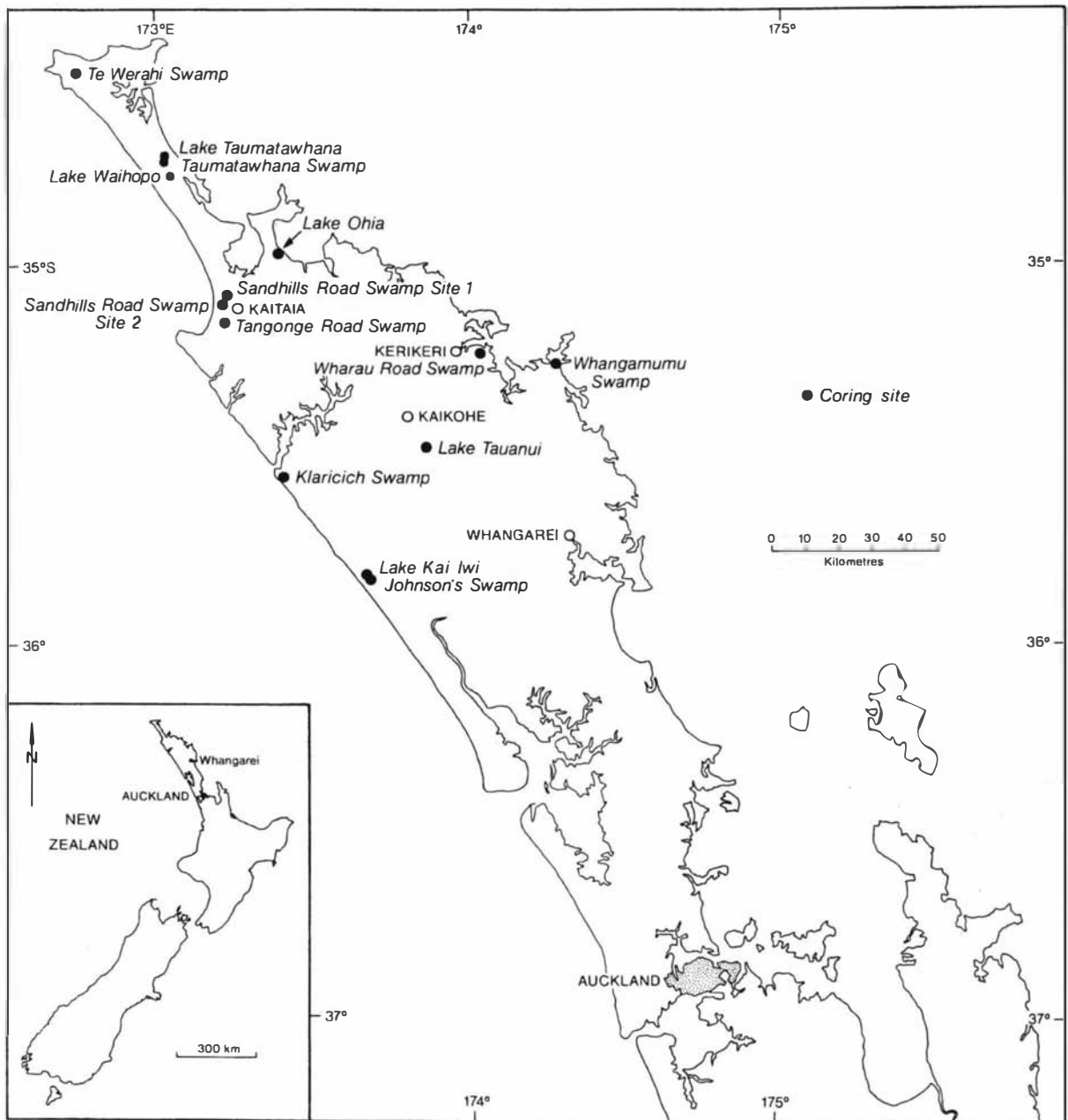


Figure 7.2: Location of coring sites in Northland, New Zealand.

detail in Chapters 8-10.

The conceptual framework upon which the sedimentological investigations of the sediment sequences from these sites is based on the fact that lake and swamps act as "environmental archives". This is because these sediments are the product of the environmental processes, physical, biological, and chemical, that have been operating within the surrounding catchment. As such, they provide a record of the timing and magnitude of environmental change, both natural and anthropogenic. In addition to recording the cumulative effects of environmental change, lake and swamp sediments, given the right condition, can also record event-based effects (Page & Trustrum, 1997). Thus, lake and swamp sediments in their "final" form constitute a function of complex interactions between mechanisms of deposition, re-suspension, chemical and biogenic transformation, exchange with water and organisms and longer-term diagenesis (*cf.* Jenkin *et al.*, 1941; Oldfield, 1977; Page & Trustrum, 1997; *cf.* Pennington, 1981; *cf.* Thomas, 1988). Figure 7.1 exemplifies these processes for lake basins; it emphasizes on the impact of human activities within the lake's catchment on the sedimentary processes on the entire lake-catchment ecosystem.

7.1.4 Principle research objectives

It is the primary aim to deduce an environmental chronology from the sedimentological investigations employed on the sediment sequences from Wharau Road Swamp and Lakes Tauanui and Taumatawhana. It is hoped that the results of these investigation will provide a date of early human presence in Northland, pre-dating the archaeological record of any known cultural site in that region. This thesis therefore ultimately aims to decide between the two conflicting hypotheses of the time of arrival of people in New Zealand.

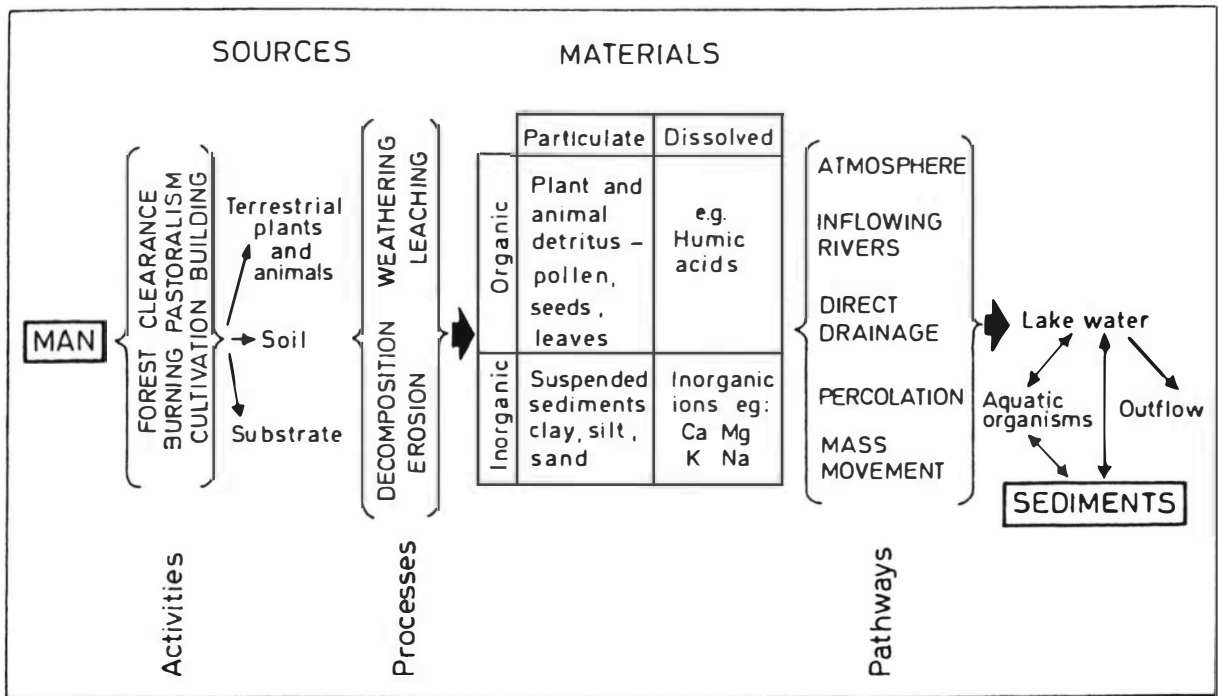


Figure 7.1: Simplified partial model of the interrelationships between lacustrine sedimentation and human activity within a lake drainage basin (Oldfield, 1977).

7.1.5 Review of previous palaeoenvironmental studies

Owing to a number of uncertainties with the archaeological record, sediment-based palaeoenvironmental studies have been widely applied throughout Polynesia in order to determine the time-depth of human presence in individual island groups. Case studies are available from sites throughout the Polynesian Triangle. They include: Easter Island (Flenley, 1979; Flenley & King, 1984; Flenley *et al.*, 1991) which bears evidence of forest destruction associated with the decline of megalithic architecture and the creation of new landscapes by anthropogenic erosion on Aneityum, Vanuatu (Groube, 1975) and Lakeba, Fiji (Hughes *et al.*, 1979).

In some places palynological investigations have been more successful in detecting the earliest signs of human impact than archaeology. In the Southern Cook Islands, for example, the date of earliest known human presence was extended from 500 years B.P. to 2500-1800 years B.P. (Ellison, 1994; Kirch, 1996; Kirch *et al.*, 1991, 1992).

Substantial human inputs to landscape changes reflected in the sediment sequences from small freshwater lakes have also been reported from French Polynesia; they include Tahiti (Parkes *et al.*, 1992) and Mo'orea (Lepofsky *et al.*, 1996).

7.2 Description of methods used

This section describes the research methodology employed in order to achieve the principle aim of this thesis, as stipulated in Chapter 1. The description covers the principal aspects of the selection of suitable sites for palaeoenvironmental studies, methods applied for the collection of sediment cores in the field as well as the variety of analytical procedures employed on the sediment sequences collected from the different localities in Northland.

7.2.1 Site selection

Section 7.2.1 introduces the different criteria applied for the selection of sites for sediment-based palaeoenvironmental studies as well as the suitability of selected sites for these studies.

7.2.1.1 Criteria for site selection

Sites (e.g. lakes and swamps) chosen were those whose stratigraphy was undisturbed by human activities (e.g. gum digging or agriculture). As the research project also involved palynological investigations of the sediment sequences collected (see section 1.1) preference was given to sites with a moderate diameter of about 100 to 500 metres in order to obtain pollen derived from a moderate-sized area (Jacobson & Bradshaw, 1981). Smaller sites would give too local a picture and therefore might miss certain agricultural practices (e.g. shifting cultivation); larger sites on the other hand would give a regional picture but would not resolve the slight impact of low initial Polynesian populations. With respect to lake sites only small enclosed lake basins were chosen for sampling as they receive their pollen predominately from restricted areas (Jacobson & Bradshaw, 1981).

7.2.1.2 Suitability of selected sites

The suitability of sites likely to have recorded sedimentologically-/palynologically-based evidence for human presence in the locality was decided on the basis of four criteria:

- completeness of core material for above investigations (i.e. no hiatus in the sediment sequence);
- proximity to sites of specific ecological factors likely to have appealed to first people who settled Northland (see below);

- proximity of known archaeological sites; and
- sediment sequences of sufficient age (determined by radiocarbon dating [see below; section 7.3.1]) to span the time-depth of human occupancy (also see section 1.1).

The ecological appeal (see second bulletpoint above) of a certain locality can largely be regarded as the product of a number of environmental factors which would have ensured successful colonisation of the area. These factors were taken to be:

- a *climate* that would favour the crops of early settlers (also see sections 2.1.4.4 and 8.2, footnote #84);
- *soils* of sufficient fertility and extent to support a colonising population; and
- accessibility of *natural resources*, both marine and terrestrial.

Areas where these factors co-occurred were likely to have been foci of early settlement. Climate (also see section 4.3) is probably the most important limiting factor given the marginality of tropical root crops (e.g. Yen, 1991) in New Zealand. On the basis of climate, Bulmer (1988a) suggested that the Far North of Northland was the optimal zone for initial settlement of New Zealand. Good garden sites of any substantial size are not widespread throughout Northland, although many smaller areas exist. Substantial areas of volcanic soils (see section 4.2.5), similar to some in Polynesia, can be found in the Waima Valley, Hokianga, in the Kaikohe-Bay of Islands District (also see section 4.1.3.3 and fig. 3.7). The numerous wetlands in Northland (see section 4.4.3), some of which occupy substantial areas, e.g. Hikurangi Swamp, the Kaimaumau Wetlands and the recently drained Te Aupouri swamp country. They would have provided valuable resources in terms of wildlife and taro cultivation. No place in Northland is far from either coast (see section 4.1 and fig. 4.1), and many coastal sites exist which meet the above criteria.

Sites which complied with these environmental requirements, and which provided suitable sediment sequences, were chosen for in-depth sedimentological (and palynological) investigations.

7.2.2 Coring methods

The different sampling sites along with the different types of sediments pertaining to these sites necessitated the use of different (hand-operated) coring equipment. For the collection of lake sediments a modified Vallentyne mud sampler (Walker, 1964) was used. Sediment cores from peat swamps were extracted with either a D-section sampler (Jowsey, 1966), a Hiller peat sampler (West, 1977) or a custom-made 120 mm diameter peat corer.

7.2.3 Collection and description of sediment cores

Sedimentation in lakes and reservoirs does not occur uniformly over their bed, and sediments that have been deposited are sometimes re-suspended, transported to different locations and re-deposited. Most sediment re-suspension and re-deposition mechanisms move sediment gradually downslope into the deeper parts of lakes, a phenomenon known as sediment focusing (Spigel & Viner, 1992). Likens & Davis (1975) and Lehman (1975) describe sediment focusing as differential deposition that results in accumulation of larger amounts of sediment in the deeper parts of lake basins. Thus, the deepest parts of a lake usually provide the best sedimentary record even though Davis *et al.* (1984) demonstrated on Mirror Lake (New Hampshire, USA) that its deepest part was not always the point of sediment focusing throughout the Holocene. Nevertheless, Bonney (1976, 1978) has demonstrated that sediments from the deepest part of a lake best reflect pollen influx. Consequently the deepest part of lakes was always chosen for core collection.

The sediment cores, from lake and swamp sites alike, were collected as one meter long core segments (see section 7.2.2). After recovery from the respective coring equipment each core was examined and described according to the Tröels-Smith (1955) classification system for unconsolidated sediments. Thereafter, cores were transferred into electrical trunking boxes (Flenley, 1992), sealed up and returned to Massey University, Palmerston North, where boxes were stored in a purpose-built refrigerator at

5°C.

7.2.4 X-ray photography

X-ray photography (radiography) was used as a non-destructive core analysis technique. It has been demonstrated by Baker & Friedman (1969) that this method allows detailed sedimentological, stratigraphic and structural analysis of sediment cores without damaging the core box or disturbing the core contents. Furthermore, this method also allows the detection of thin layers of tephra in the sediment cores (Lowe, *et al.*, 1981) which are otherwise barely visible. Dugmore & Newton (1992), for example, used the method to locate very thin, fine-grained tephra of Icelandic origin in Scottish peats. To this end, radiographs (X-ray photos) for all sediment cores were taken in the Radiology Section at the Veterinary Science Clinic at Massey University, Palmerston North. The source-to-film distance (distance between X-ray tube and X-ray film) was chosen in a manner that the scale of the radiographs was almost 1:1, with only some minor distortions towards the margins of the radiographs. However, this problem could largely be reduced by applying a correction factor based on the true lengths of the cores and their apparent length on the X-ray images. As the distortions were not uniform across the entire core the application of a factor did not always provide a depth scale that was in complete agreement with the true length of the cores. However, this problem could be overcome by using distinctive features of the sediment core (e.g. cracks, plant macrofossils etc.) as reference points which were also readily identifiable in the radiographs. Finding the correct times of exposure caused some initial problems. This is because of the varying constituents of the core material from core to core and even within individual cores. Nevertheless, the problem was largely resolved by experimenting with various values of X-ray exposure.

Lake sediments proved to be particularly suitable for X-ray radiography as they consist of relatively fine-grained material which readily reveals its structure and microstructure in the radiographs. However, swamp sediments were less suitable for this method because of their fibrous nature. This is due to the material consisting of a high amount

of rootlets, twigs, fragments of wood etc. at different degrees of decomposition. These materials absorb a large amount of X-ray radiation on their passage through the core obscuring many microstructures present in the inorganic matter present in the core material.

7.2.5 Sampling methodology

Subsampling of the core material for the sedimentological investigations (see below; section 7.2.6) was done on the basis of the radiographs (see section 7.2.4) and field descriptions (see section 7.2.3) of the sediment cores. By adopting this strategy it was ensured that individual (sub-) samples did not extend across stratigraphic boundaries within the sediment sequences.

7.2.6 Laboratory methods

The sedimentology of the collected sediment cores was analysed for sediment texture, sediment mineralogy, sediment chemistry and sediment constituents (e.g. organic matter, inorganic matter and moisture content). These properties were investigated by means of particle size analysis with a particle analyzer ("Sedigraph") for sediment texture, plasma emission spectrometry (Inductively Coupled Plasma-Mass Spectrometry [ICP]) for sediment chemistry, X-ray diffraction (XRD) and differential thermal analysis (DTA) for sediment mineralogy and drying and combustion of sediment material for the determination of sediment constituents.

Prior to these investigations X-ray photography was employed on the intact core material for the study of their structures (including possible core compaction as a result of the coring process) and detection of possible tephra layers (see section 7.2.4). For future reference the core material from a few selected sites (e.g. Lakes Kai Iwi and Waihopo and Klaricich and Te Werahi Swamps [see Appendix I]) were also photographed. The photographs were taken of the freshly exposed surface after splitting

the cores lengthwise.

The following sections (7.2.6.1-5) describe in detail the different sedimentological analyses, including their respective sample pretreatments, employed on the core material from those localities which were chosen for in-depth investigations (see section 7.2.1).

7.2.6.1 Pretreatment of samples

The nature of the sedimentological investigations performed on the core material required a number of physical and chemical pretreatments for sediment disaggregation. They ensured the creation of loose assemblages of grains for the suite of analyses to determine sediment texture and mineralogy (see below; sections 7.2.6.2-3).

All sedimentological investigations, except for the XRD-analysis (see below; section 7.2.6.3), required the same basic sample preparation. This preparation was as follows: the sediment cores stored in electrical trunking boxes at 5°C at field moisture (see section 7.2.3) were subdivided and dried in a fan-forced oven at 40°C overnight. The sample length of the core segments was specific to the material and lithology of the cores as well as the kind of analysis being performed on the material. The sampling interval was kept as short as possible in order to enable as high a temporal resolution of the individual samples as possible.

7.2.6.1.1 Physical disaggregation

Oven-dried (40°C) samples were homogenized by physically breaking up aggregates with a rubber pestle. The disaggregated sample was then dry-sieved on a 2.00 mm mesh to separate coarse (>2.00 mm) and fine (<2.00 mm) sediment (Loveland and Whalley, 1991). Sedimentological analyses were undertaken on the fine fraction (<2.00 mm). After this step no further sample preparation was required for the determination of the sediment constituents. Further chemical pretreatments required for the proper

determination of sediment texture and mineralogy are mentioned below (sections 7.2.6.1.2.1-3).

7.2.6.1.2 Chemical removal of cements and other binding agents

The analysis of sediment texture and mineralogy required the removal of a number of cements and binding agents, including organic matter, iron and aluminium oxides, and oxyhydroxides and carbonates.

7.2.6.1.2.1 Removal of organic matter

The removal of organic matter from samples earmarked for the analysis of sediment texture and mineralogy was achieved by oxidation with a 30% hydrogen peroxide (H_2O_2) solution as recommended by Day (1965). A combined warm/cold oxidation was applied to the samples. For warm oxidation about 50 ml of H_2O_2 was added to about 10 g of sample and taken to 65 to 70°C on a hot plate (Kunze and Dixon, 1986). Depending on the initial organic matter content of the core material a second warm oxidation was applied. After cooling off, the same quantity of H_2O_2 was added again to the sample- H_2O_2 suspension and allowed to work overnight at room temperature. This step was followed by boiling the samples to remove the excess H_2O_2 . The addition of copious amounts of distilled water ensured that the samples were not taken to dryness during this step.

7.2.6.1.2.2 Removal of iron and aluminium oxides and oxyhydroxides

Coatings of iron and aluminium compounds often act as cementing and binding agents in soils and sediments (Gee and Bauder, 1986) and therefore have to be removed to aid sediment disaggregation. Mehra and Jackson (1960) recommend the use of a bicarbonate-buffered sodium dithionite-citrate system for iron oxide removal.

The removal of these compounds could only be performed after the destruction of sediment organic matter (see section 7.2.6.1.2.1) as organic free samples are required for this treatment. The Mehra and Jackson (1960) method, with minor modifications by Kunze and Dixon (1986) and Whitton and Churchman (1987), was used.

Thirty ml of 0.26 M sodium citrate solution $[\text{C}_3\text{H}_4(\text{OH})\cdot(\text{COONa})_3\cdot 2\text{H}_2\text{O}]$ and 5 ml of 1 M sodium bicarbonate solution (NaHCO_3) were added to the organic free sample. The suspension was heated to 80°C in a water bath. When the solution reached this temperature approximately 1 g of solid sodium dithionite ($\text{Na}_2\text{S}_2\text{O}_4$) was added, with constant stirring for one minute, followed by occasionally stirring for a total of 15 minutes. Following the 15-minute digestion period the samples were centrifuged and the supernatant liquid discarded. This step was repeated several times until the supernatant liquid showed no signs of discolouration (by iron and aluminum compounds) any more. Following this samples were rinsed by adding 30 ml of sodium citrate reagent in combination with stirring, heating in the water bath and finally centrifuging to recover the sample.

7.2.6.1.2.3 Removal of carbonates

Carbonates constitute another effective cement which needs to be removed from the sediments prior to the determination of sediment texture and mineralogy. However, preliminary tests with a 10% hydrochloric acid (HCl)-solution (Arbeitsgruppe Bodenkunde, 1982) did not reveal the presence of any substantial quantities of carbonate minerals in the sediments, rendering the removal of carbonates unnecessary.

7.2.6.2 Sediment texture

The sediment texture (i.e. grain-size distribution) of the core material was determined by means of the grain-size of its inorganic constituents. Grain-size is a fundamental property of sedimentary materials that reveals much about their origin and history

(McCave & Syvitski, 1991). Therefore the grain size of a clastic sediment is a measure of the energy of the depositing medium and the energy of the basin of deposition (Reineck & Singh, 1975).

7.2.6.2.1 Grain size scale

The analysis of the sediment texture was performed only on the fine fraction (<2.00 mm; see section 7.2.6.1.1). The grain-size scale, used throughout this thesis to express the sediment texture, is based on the Wentworth size-classes (Wentworth, 1922) as used by Friedman & Sanders (1978). This combination resulted in the following grain-size classes:

very coarse sand:	1000 to 2000 μm ;
coarse sand:	500 to 1000 μm ;
medium sand:	250 to 500 μm ;
fine sand:	125 to 250 μm ;
very fine sand:	62.5 to 125 μm ;
very coarse silt:	31.25 to 62.5 μm ;
coarse silt:	15.63 to 31.25 μm ;
medium silt:	7.81 to 15.63 μm ;
fine silt:	3.91 to 7.81 μm ;
very fine silt:	1.95 to 3.91 μm ;
clay:	<1.95 μm .

The determination of sediment texture of the pretreated sediments (see section 7.2.6.1.1) was carried out by means of two different methods: the silt- (1.95 to 62.5 μm) and clay-fraction (<1.95 μm) was analysed with a "Micromeritics Sedigraph 5100 V3.02" (Micromeritics Instrument Corporation, Norcross, Georgia, USA) particle size analyzer (Micromeritics, 1991). Although the Sedigraph 5100 has an analytical range from 0.18 to 300 μm , only the grain-size distribution of the silt- and clay-fraction were determined with this apparatus. This is because the 62.5 μm division between the silt- and sand-

fraction, close to the boundary where Stoke's settling law breaks down (Coakley & Syvitski, 1991), renders the results for the sand-fraction obtained by the Sedigraph rather unreliable. To this end the sand-fraction (62.5 to 2000 μm) was separated from the bulk sample by wet-sieving, using a nylon mesh, and determined separately. For graphic representation (see Chapters 8-10) both sets of granulometric data (i.e. 1.95-62.5 μm and 62.5-2000 μm) were amalgamated by re-calculating the results to the initial bulk samples, covering the entire fine-fraction (see above).

7.2.6.2.2 Grain-size analysis of the clay- and silt-fraction

For the sedigraph analysis of the silt- and clay-fraction a minimum sample size of approximately 2.5 g (Risberg, 1989) was required. Samples that yielded more than 2.5 g were split down with a sample splitter ("riffle box"). Samples were then dispersed in a 0.5% sodium pyrophosphate ($\text{Na}_4\text{P}_2\text{O}_7 \cdot 10\text{H}_2\text{O}$)-solution (Berezin & Voronin, 1981) at a ratio of 1:20. The dispersal agent was allowed to work overnight. Prior to Sedigraph analysis the sample was agitated with an electric stirrer for about one hour followed by ultrasonic dispersion in a ultrasonic bath for 30 minutes.

7.2.6.2.3 Grain-size analysis of the sand-fraction

Owing to the extremely small sample size of the sand-fraction (average sample weight $\ll 1$ g) this fraction could not be broken down further into its individual sub-fractions (*cf.* Lewis, 1984). Consequently, the entire sand-fraction was regarded as a "bulk-fraction".

7.2.6.3 Sediment mineralogy

The sediment mineralogy was determined by means of XRD, DTA and petrological microscopy. The analyses were carried out at LandCare Research, Palmerston North, and the instruments involved were: a Philips 4 kVa PW 1710 micro-processor-

controlled X-ray diffractometer with a PW 1050/80 goniometer and PW 1775 sample changer; and a DuPont 99 micro-processor controlled DTA instrument. The pretreatment of samples earmarked for the determination of sediment mineralogy was almost identical to the procedures outlined in section 7.2.6.1. It differed only in that samples were not dried at 40°C prior to pretreatment. Instead, samples were pretreated at field-moisture to avoid the collapse of certain clay minerals during the drying process (J Kirkman, pers. comm.).

7.2.6.3.1 X-ray diffraction

The determination of the sediment mineralogy by XRD was performed on the fractions: <2 µm, 2-20 µm, and >20 µm; separation of these fractions was achieved by centrifugation (Whitton & Churchman, 1987).

The material of the <2 µm-fraction was treated with a 1 M KCl and a saturated MgCl₂ in order to saturate them with Mg²⁺-and K⁺-cations. Samples prepared in this fashion were then mounted on clean, dry glass slides (approx. 25 x 25 mm) by using about 1 to 2 ml of the sample suspension. The sample suspension was then allowed to dry in air. After drying X-ray diffractograms were obtained on the samples. The analyses usually revealed representatives of the following four principal clay mineral groups: kaolinite, illite, smectite and chlorite. In order to distinguish smectite minerals from chlorite, where possible overlap occurs (Hardy & Tucker, 1988), the sample needs to be treated with a compound which systematically intercalates itself into the mineral lattice. To this end the Mg²⁺-saturated slides were sprayed with a 10% glycerol in water solution. Glycerol leads to the expansion of some smectites, thus distinguishing them from chlorites. Further treatment involving heating the sample in a furnace, to distinguish the individual clays, as certain clay minerals such as kaolinite and certain chlorites collapse leading to their disappearance in the diffractogram. After the diffractogram for the Mg²⁺-glycerol samples were obtained the slides were heated to 550°C for two hours, cooled and another diffractogram obtained.

XRD analysis on the 2-20 μm - and >20 μm -fraction was performed on unsaturated material. Diffractograms were obtained on oven-dried (105°C) and ground material that was mounted on glass slides, using acetone as a mounting agent.

Quantification of the minerals present in all three fractions was done by means of semi-quantitative analysis according to Whitton & Churchman (1987).

7.2.6.3.2 Differential thermal analysis

DTA analysis was performed only on the <2 μm -fraction to establish quantities of gibbsite and kandite (kaolinite and halloysite) present in the sample. The analyses was performed on dried and ground Mg^{2+} -saturated clays (Whitton & Churchman, 1987).

7.2.6.3.3 Petrological microscopy

Petrological microscopy was employed only on those samples for which the X-ray diffractograms revealed high amounts of X-ray amorphous material (e.g. volcanic glass, plant opal, diatoms etc.). Separation of these materials was achieved by density separation with sodium polytungstate (SPT). The recovered (amorphous) material was mounted on glass slides and examined with a petrographic microscope. The method involved identifying and counting all grains which occurred with several bands distributed across the entire mount (Whitton & Churchman, 1987).

7.2.6.4 Sediment chemistry

The chemistry of the sediment cores was determined by bulk chemical analysis (Engstrom & Wright, 1984).

7.2.6.4.1 Pretreatment of samples for chemical analysis

As the determination of the sediment chemistry had to be performed on liquid digests the required sample preparation involved a series of pretreatments that dissolved and destroyed the inorganic and organic phase of the sediments. This was achieved with a 1:1 concentrated hydrofluoric acid (HF)/concentrated nitric acid (HNO₃)-solution treatment to dissolve the inorganic phase. Further steps included an oxidation of organic residues involving 30% H₂O₂ (see section 7.2.6.1.2.1), followed by an extraction of the elemental constituents from the sample residue with a 2 M HCl-solution (R Brooks, pers. comm.).

7.2.6.4.2 Inductively-coupled plasma spectrometry

Determination of the total element concentration of the samples was performed by means of ICP-analysis (e.g. Crock & Briggs, 1995), carried out by AgResearch (New Zealand Pastoral Agriculture Research Institute Ltd., Grassland Research Centre, Palmerston North, New Zealand). This method allows a total of 23 elements, including Al, As, B, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Se, Si, Sn, Sr and Zn to be determined.

7.2.6.4.3 Classification of elements in main groups

Based on the work by Håkanson & Jansson (1983) and Mackereth (1965, 1966) these elements were further subdivided into the following main groups:

- major elements (Al, K, Mg, Na and Si);
- carbonate elements (Ca and Mg);
- nutrient elements (P);
- mobile elements (Fe, Mn and S);
- heavy metal elements (As, Cd, Co, Cr, Cu, Mo, Ni, Pb, Tn and Zn) and

- "other elements" (B, Se and Sr).

According to Håkanson & Jansson (1983), whose work is based on Nordic environments, major elements make up the largest group (approximately 80%) of the sediment matrix. This group is followed by carbonate elements (approx. 15%), nutrient elements (approx. 10%) and mobile elements (approx. 5%). The combined group of the heavy metal and "other elements" which can also be referred to as "trace elements" constitutes the smallest group. They account for less than 0.1% of all elements in the sediment matrix.

Given the aim of this thesis (see section 1.1) it appears inappropriate to discuss all of these element groups in detail, in particular the group of heavy metal elements. Due to their toxic properties, their presence in sediments is rather indicative of industrial pollution in historic times (e.g. Daoust *et al.*, 1996; Dickson, *et al.*, 1996; Kemp *et al.*, 1977). For the detection of the activities of prehistoric people the interpretation of the groups of major, carbonate, mobile and nutrient elements therefore appears to be much more appropriate. This concept largely follows the approach adopted by other workers who utilized changes in these element groups in sediment sequences from northern Europe to detect environmental disturbances by prehistoric people (e.g. Pennington, 1981; Huttunen *et al.*, 1978; Huttunen & Tolonen, 1977; Digerfeldt, 1972, 1975; Renberg, 1976). Hence, in this thesis the group of heavy metal elements as well as "other elements" will not be considered for further discussion with respect to sedimentologically-evidenced human-induced environmental changes.

7.2.6.5 Sediment constituents

Unconsolidated sediments consists of three phases: inorganic matter which comprises the mineral phase, organic matter and pore fluids/water. They can readily be determined by means of thermal treatment of the bulk sample at different temperatures.

The moisture content of a sample is the ratio of the weight of the moisture in the sample

to the weight of its solid phase. The solid phase usually consists of organic and inorganic/mineral matter. The sediment's moisture content was determined directly by loss in weight after the sample was dried at 105°C until a constant weight was reached. Various workers state drying periods ranging between six (Håkanson and Janson, 1983) and a minimum of 16 hours (Whalley, 1981). However, best results were achieved with drying periods of three days.

Determination of the organic matter content of the samples was achieved by means of loss-on-ignition (LOI). This method quantitatively removes the organic matter from the inorganic material by ignition of the sample at high temperature (Nelson & Sommers, 1982). Sample ignition was performed in a combustion furnace ("Muffel Furnace") by means of "dry combustion". This method involves a combustion of the samples at temperatures between 550 and 600°C (Kretzschmar, 1989) until a colour change to white, grey or red-brown has occurred (Leser, 1977). Best results were obtained with a combustion temperature at 550°C for four and a half hours. After ignition the organic matter content was directly determined by weight difference. Material used for this determination were the moisture-free samples from the preceding water content determination. The use of these samples was necessary as the above combustion temperature not only ignites organic matter but also void substances, in particular pore water. Removal of those substances by sample combustion would result in a much higher weight loss of the bulk sample. This, in turn, would lead to values for organic matter content which are in excess of their true content.

Various workers (e.g. Håkanson and Janson, 1983; Kretzschmar, 1989; Leser, 1977; Nelson & Sommers, 1982) argue that organic matter determination by LOI is a rather inaccurate method as not only organic substances will ignite. Inorganic constituents such as hydrated aluminosilicates and phyllosilicates (in particular clay minerals) would loose structural water, void compounds would evaporate and carbonate minerals would decompose at temperatures of 550°C, thus resulting in weight losses considerably in excess of the actual organic content.

Determination of the organic matter content through weight loss after oxidation (see

section 7.2.6.1.2.1) on parallel samples earmarked for grain-size analysis (see section 7.2.6.2) did not confirm the above contention. Comparison of the results for organic matter content obtained by both methods showed good agreement. On the average these results only differed by about 0.5% from each other with the samples earmarked for particle size analysis usually showing the higher value. The application of a correction factor was therefore considered unnecessary.

7.3 Dating of sediments

To date the onset of sedimentologically-/palynologically-evidenced environmental changes, natural and anthropogenic alike, a chronology had to be established for each sampling site.

7.3.1 Radiocarbon dating of sediments

Owing to the scarcity of identifiable volcanic ash layers in Northland (e.g. Lowe *et al.*, 1998; Newnham *et al.*, 1998; also see Pullar, 1972), radiocarbon dating has generally been the sole means of establishing a chronology. This method is limited by its reliability beyond 30,000 years (e.g. Hogg, 1982).

7.3.1.1 Accelerator Mass Spectrometry dating

The AMS method was chosen for radiometric dating of organic material because of its small sample capability (e.g. Beukens, 1992). The dating was performed on sample sections of 0.05 to 0.06 m length submitted to the Rafter Radiocarbon Laboratory, Institute of Geological and Nuclear Sciences, Lower Hutt, New Zealand. The radiocarbon dates reported in this thesis are conventional radiocarbon ages (Stuiver & Pollach, 1977), i.e., based on the (old) Libby half-life of 5568 ± 30 years (also see footnote #1), with ages expressed in radiocarbon years B.P. ± 1 standard deviation (\pm

1 σ). The counting error includes the statistical uncertainties of the sample, background, and reference standards and, where applicable, errors in estimating $\delta^{13}\text{C}$. Unless otherwise specified, no corrections have been made for secular variations in ^{14}C atmospheric levels.

7.3.1.2 Sources of error in radiocarbon dating

Radiocarbon dating, in particular on bulk organic samples, has been subject to a number of problems, ranging from samples being affected by large "inbuilt errors" as well as the confusion with younger dates due to contamination of dates near the limit of the radiocarbon dating method (e.g. Newnham *et al.*, 1993). Large inbuilt errors in lake sediments have been reported by Pennington *et al.* (1976) due to the inwash of old allochthonous carbon into the lake during the initial stages of forest disturbance. Radiocarbon dates from swamps also bear the risk of contamination due to root penetration of the sediments from above (e.g. Flenley *et al.*, 1991) enabling the movement of soluble humic acids within the sediment column. In their latest work McGlone & Wilmshurst (in press) claim that radiocarbon chronologies from sediments in lakes and swamps are almost always prone to the influx of carbon.

In view of these potential sources of error in radiocarbon dates from lake and swamp sediments it appears to be necessary to utilize other, independent, time-markers to establish a more reliable chronology. In this context tephrochronological markers, if present, could provide a robust age control on any radiocarbon chronology likely to be affected by inbuilt age.

7.3.2 Use of tephra layers for dating

Volcanic airfall deposits from various sources in northern New Zealand (e.g. Taupo Volcanic Zone, Taranaki, Major Island, and the Auckland Volcanic Field) have proven to be useful datable stratigraphic marker beds for a variety of purposes (e.g. Green &

Lowe, 1985; McFadgen, 1981; McGlone & Topping, 1977; Pullar, 1973). However, only few identifiable volcanic ash layers are preserved in Northland, due to the direction of the ash "fallout" and remoteness from the source (see section 7.3.1). Of those sites from which sediment sequences have been collected, only a few had the benefit of tephrochronological markers to support the radiocarbon chronology established for each site. However, those sites which bore tephras were identified by Dr. S Cronin (pers. comm.).

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CHAPTER 8

WHARAU ROAD SWAMP

The Wharau Road Swamp is a near-coastal wetland in the Bay of Islands on the east coast of Northland. The peat swamp is situated at latitude 35°13'31"S and longitude 174°03'20"E (NZMS 260, P05/052635), about 0.5 km south of the Hauparua Inlet, an arm of the Kerikeri Inlet and about 2 km west of Onewhero Bay. The next larger settlement, the township of Kerikeri, lies approximately 8 km west of the swamp. The exact geographical position of the study site is shown in figure 7.2. This chapter describes the physical setting and vegetation of the site and its surrounding as well as the laboratory and field work employed on the sediment cores extracted from the site.

8.1 Physical setting of the region

Sections 8.1.1-1.3 describe the physical setting of the surrounding of the Wharau Road Swamp. The study area described is broadly defined by a line running from the township of Kerikeri south to the settlement of Puketona and from there east to the settlement of Waitangi. On the seaward side the area is bordered by the coastline of the Bay of Islands between Waitangi and Kerikeri.

8.1.1 Geology and physiography

The above area lies in the easternmost portion of the "Kaikohe-Bay of Islands Volcanic District" (see section 4.1.3.4 and fig. 4.4) or "Bay of Islands (Volcanic) Zone" (Hochstetter, 1864). The topography of this part of the Bay of Islands Volcanic Zone is very similar to the remainder of Northland. The landscape is generally subdued and largely classifies as rolling hill country (see section 3.1). However, the larger part of the area, in particular the area adjacent to the coastline, is rather flat and shows slope angles

between 0 and 12° (Department of Lands and Survey, 1980a). The elevation of these (coastal) flat areas ranges from 20 to 40 m a.s.l. Steeper land only occurs further inland. There, a number of ridges have slope angles ranging from 12 to 28° (Department of Lands and Survey, 1980a) and rise in height between 80 and 100 m a.s.l. Only a few isolated peaks in the area exceed 100 m a.s.l.

The area's geology is dominated by two main units: sedimentary rocks of the Waipapa Group and volcanic rocks of the Kerikeri Volcanics (Kear & Hay, 1961; also see section 4.1.3.4). Within the study area both formations of the Kerikeri Volcanics occur, the older Horeke as well as the younger Taheke Basalts (e.g. Kear, 1961; also see section 4.1.3.4). However, as the Horeke Basalts are only of marginal significance due to their peripheral location in the westernmost part of the study area they will not be discussed here in any detail.

The mode and time of formation, lithology and distribution of the Waipapa sedimentary rocks and the Taheke Basalts were already described in more detail in section 4.1.3.1 and 4.1.3.4, respectively. Both units are rather contrasting in age. Ranging in age from Permian to Jurassic the basement-forming sediments of the Waipapa Group constitute the oldest rocks in the entire North Island (Kear & Hay, 1961; Shaw, 1964; Thompson, 1961; also see section 4.1.3.1). The Taheke Basalts on the other hand are very young. These products of Late Quaternary volcanism (see section 4.1.3.4) are among Northland's most recent deposits. In the peninsula's volcanic chronology they even constitute the most youthful volcanic rocks (e.g. Kear & Hay, 1961; Thompson, 1961). Physiographically the Taheke Basalts are distinguished by displaying clear volcanic forms, and occur as (summit) scoria cones surmounting the modern topography associated with lava flows infilling recent valleys (e.g. Ashcroft, 1986; Smith & Ashcroft, 1986; Thompson, 1961). These basalts are distinguished by having originated from a number of volcanic centres throughout the Kaikohe-Bay of Islands Volcanic Centre. Within this region Kear (1961) recognized a total of 11 volcanic centres from which the Taheke Basalts erupted during the course of the Late Quaternary (see fig. 8.1).

In the study area the Taheke Basalts are represented by the "Te Puke Basalt Member"

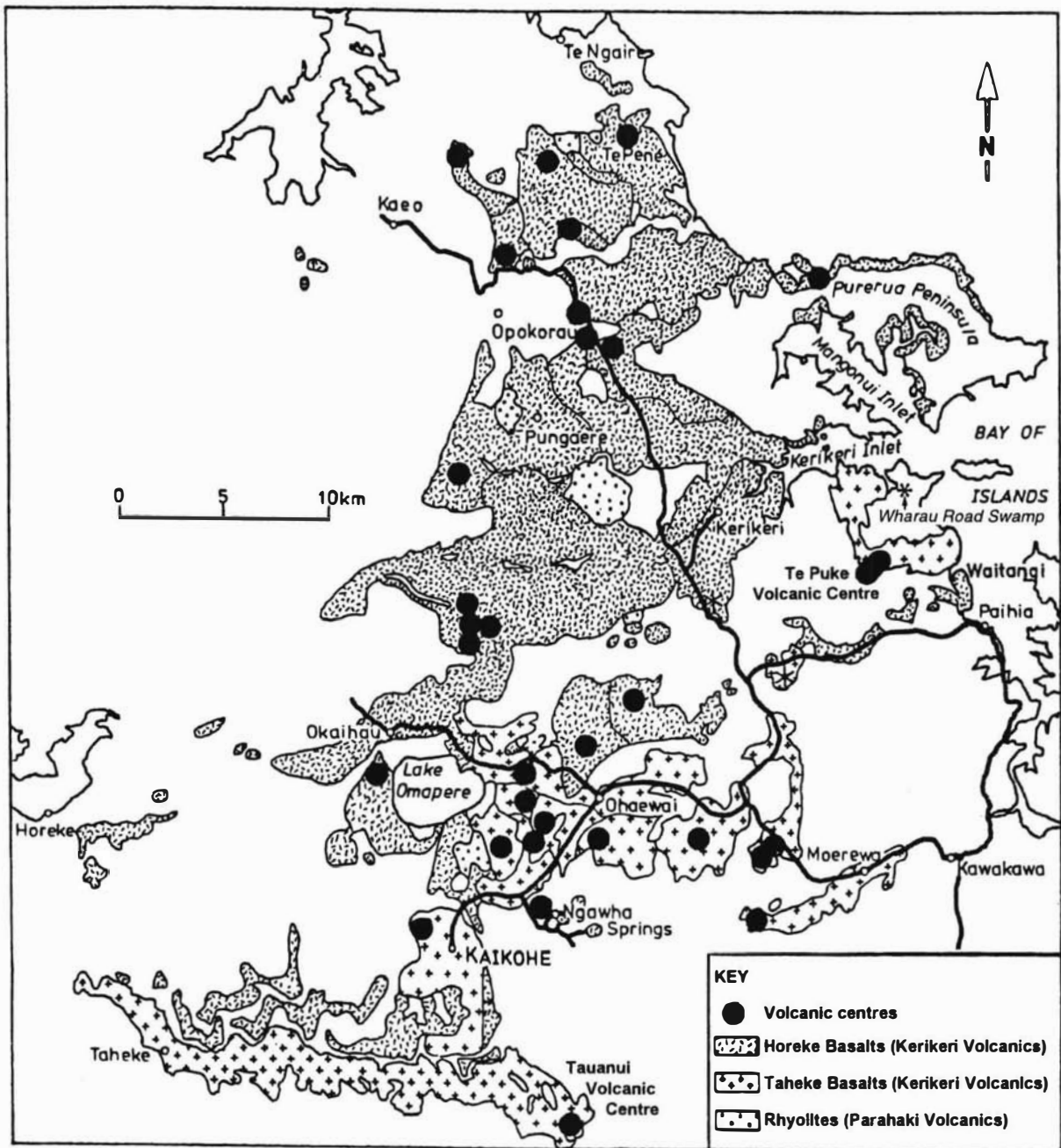


Figure 8.1: Distribution of the Kerikeri basalts (Horeke and Taheke Basalts including their individual volcanic centres) and associated rhyolites of the “Parahake Volcanics” in the Kaikohe-Bay of Islands Volcanic Zone. The Wharau Road Swamp is situated just south of the Kerikeri Inlet (modified after Smith *et al.*, 1986).

from the “Te Puke Volcanic Centre” (Kear, 1961). The Te Puke Volcanic Centre is constituted by Mt. Te Puke (136 m a.s.l.) which Kear (1961) describes as a well-preserved, virtually uneroded scoria cone with multiple vents. In Ashcroft’s (1986) classification scheme for the Kerikeri Volcanics Mt. Te Puke qualifies as a “Type Five” volcanic outcrop whose cone is made up of scoria resulting from Hawaiian-strombolian activity with no phreatic ash known. Two distinct lava flows originate from this volcanic centre; one extending northwards into the Kerikeri Inlet, and the other running eastwards reaching the coast at Onewhero Bay (Kear, 1961; Kear & Hay, 1961; see fig. 8.1).

As many of these lava flows occupy former stream valleys the hydrology of the area usually undergoes substantial alterations. In the Kaikohe area widespread changes to the drainage patterns by lava flows infilling recent stream valleys and thus leading to the displacement and damming of streams have been reported by Muhlheim (1973). The most prominent examples of impeded valley drainage due to the damming by lavas in this region are the formation of Lakes Omapere and Owhareiti (see section 4.4.2.2; also see figures 4.12 and 8.1).

Within the study area the most substantial changes to the valley drainage have been caused by the above northerly lava flow from Mt. Te Puke (Ferrar, 1925; see fig. 8.1). Chester (1986) reports the formation of peat swamps in the Waitangi State Forest due to valley blockage by this lava flow. Valley damming by the same lava flow is also responsible for the formation of the Wharau Road Swamp study site just a few kilometers north-east of the Waitangi State Forest. Based on the morphology of its scoria cone Mt. Te Puke is believed to have formed from a single eruption (Chester, 1986). Consequently, the beginning of drainage impediment in the study area leading to the growth of the swamps in the Waitangi State Forest as well as the Wharau Road Swamp would have been contemporaneous with the formation of Mt. Te Puke.

The problem in determining the date of the onset of the formation of the Wharau Road Swamp lies in the apparent difficulties in establishing the accurate age of the Te Puke Volcanic Centre. While there is no doubt of the Taheke Basalts in their entirety

throughout the Kaikohe-Bay of Islands Volcanic Zone (see above) having formed during the most recent geological past (i.e. Late Pleistocene-Holocene; e.g. Kear, 1961; Kear & Hay, 1961, Shaw, 1964; Thompson, 1961) the exact age of the Te Puke Volcanic Centre and its associated lava flows on the other hand is rather a matter of uncertainty.

Earlier work on this subject mainly focused on the assessment of the relative age of individual members of the Kerikeri Volcanics utilizing a number of geomorphic associations.

In Kear's (1957) scheme on "erosional stages of volcanic cones as indicators of age" Mt. Te Puke would class as a "Volcano Stage" summit cone of Haweran/Holocene age. In a later scheme utilizing four main associations Kear (1961) devised a "chronological order of eruption" for the individual volcanic centres of the Kerikeri Basalts. In this chronology (of the assumed order of eruption) the Mt. Te Puke Volcanic Centre is recognized as the youngest product of Late Quaternary volcanism in the Bay of Islands Volcanic Zone (see Kear, 1961, fig. 3). This feature would even make Mt. Te Puke the youngest volcano in Northland (*cf.* Wellman, 1962).

Based on the stratigraphic position of basalt bombs in a coastal section in Onewhero Bay Wellman (1962) proposes a date of A.D. 200 to 700 for the formation of Mt. Te Puke. As these volcanic bombs were found nowhere else they are believed to be of local origin from Mt. Te Puke. Wellman (1962) describes them as being stratigraphically bracketed by directly overlying (sea-rafted) Loisels Pumice and directly underlying yellow soil apparently of Leigh Pumice age. Later work by Pullar *et al.* (1977) "re-identified" Wellman's (1962) sea-rafted Loisels Pumice as probably sea-rafted Taupo Pumice. Based on these associations it can be concluded that the formation of the Wharau Road Swamp pre-dates the Taupo eruption which is dated to *ca.* 1850 years B.P.⁷⁸ (Froggatt & Lowe, 1990).

The determination of the absolute age of the basalts from Mt. Te Puke by means of the

⁷⁸The Taupo eruption (and its associated tephra) is dated to 1850 ± 10 years B.P. This age represents an error-weighted mean age and pooled error of 41 available dates of Taupo tephra from the "Taupo Volcanic Centre" (Froggatt & Lowe, 1990, tab. 1).

K-Ar methods did not substantially reduce the degree of uncertainty of the accurate age of these deposits and their associated geomorphic effects. Earlier work by Stipp & Thompson (1971) yielded an age of 17 ± 6 ka⁷⁹ for the Taheke Basalts from Mt. Te Puke which was regarded as the youngest date determined on any Northland volcanic deposit.

However, later work by Smith *et al.* (1993) dated the Te Puke basalts by the K-Ar method to 140 ± 60 ka⁸⁰. This substantially older date constitutes a striking contrast to the one obtained by Stipp & Thompson (1971). Stipp & Thompson (1971) suggest that the reason for this extremely old date might mainly lie in the extremely high air correction value (99%) and the real possibility of excess argon exhibited in very young rocks. They conclude that such conditions preclude any real confidence in the indicated age.

Nevertheless, despite such uncertainties regarding the accurate age of the Te Puke basalts there appears to be only little doubt that volcanism in the study area was late. Evidence from relative and absolute dating methods clearly points to a Late Quaternary origin, most probably the Holocene. It also seems very likely that the formation of the Te Puke Volcanic Centre was the last event in a long series of basaltic volcanicity in Northland (see section 4.1.3.4) and marked the end of volcanic activity in this region.

8.1.2 Soils

Like the remainder of Northland (see section 4.2), the soils of the study area reflect the underlying geology as well as the type of indigenous vegetation (see below) very clearly. Based on the *New Zealand Genetic Soil Classification* (see section 3.2) Sutherland *et al.* (1980) recognize five major and two minor “genetic soil groups”⁸¹ within the study area. The major soil groups include “brown loams”, “red loams” (see section 4.2.5),

⁷⁹0.017 ± 0.006 Ma (GA 3168); age determination to ± 1 σ (Stipp & Thompson, 1971, tab. 1).

⁸⁰0.14 ± 0.06 Ma (sample no. 44060) (Smith *et al.*, 1993, tab. 1).

⁸¹A fuller description of the “genetic soil groups” of the Northland Peninsula based on the physiography and parent material of the terrain as well as the pedological subdivision of the mapped soil taxonomic units is given by Cox *et al.* (1983).

“podzolised yellow-brown earths” (see section 4.2.3) and “yellow-brown earths and related steepland soils” (see sections 4.2.2 and 4.2.8). The minor soil groups are represented by “organic soils” and “gley soils” (see section 4.2.7).

The more recent *New Zealand Soil Classification (Version 3.0)* by Hewitt (1992) (see section 3.2) classes these soil groups as “Oxidic soils” (brown and red loams), “Ultic soils” (podzolised yellow-brown earths and yellow-brown earths and related steepland soils), “Organic soils” (organic soils) and “Gley soils” (gley soils). Their (generalised) distribution within the study area is shown by Rijkse & Hewitt (1995). Within the hierarchy of the New Zealand Soil Classification the above classifications only identify the soil order. However, a more detailed classification to “group” and “subgroup” level (see Hewitt, 1992) for some of the above (genetic) soil groups will be given below.

As outlined above these soil groups are closely associated with the underlying geology of the area. The associations are as follows: Brown and red loams derive from the volcanic rocks of the Kerikeri Volcanics (“soils of the ‘volcanic’ country”; Taylor & Sutherland, 1953). Podzolised yellow-brown earths and yellow-brown earths and related steepland soils have developed on the sedimentary rocks of the Waipapa Group (“soils of the ‘clay’ country”; Sutherland & Taylor, 1953). Organic and gley soils (“soils of the ‘river flat’ and ‘swampy’ country”; Sutherland & Taylor, 1953) on the other hand are confined to most recent unconsolidated alluvial deposits (Hay & Kear, 1961; Kermode, 1982; Sutherland *et al.*, 1980). Due to the strong correlation between underlying geology and soil type there is a certain east-west pattern in the geographical distribution of these soil groups within the study area.

Brown loams find their largest extent in the western part of the study area where they constitute the “Kerikeri series” (Sutherland *et al.*, 1980). They have developed on older basalt rocks of the Horeke Basalts derived from the Keri Volcanic Centre (e.g. Hay & Kear, 1961; Kear, 1961; Kermode, 1982; also see section 8.1.1 and fig. 8.1). These loams consist of moderately to strongly leached friable clay (Sutherland *et al.*, 1980) of low natural fertility (Taylor & Sutherland, 1953). They were formed under mixed *Agathis australis*-podocarp forest, which has been replaced in places by scrub of

Leptospermum scoparium (manuka/tea tree) (Gibbs, 1964). The low soil fertility of the brown loams is largely a result of the mor-forming litter from the above conifer forest. The leaching of humic acids from this highly acidic humus layer into the solum leads to a rapid depletion of plant nutrients from the soil (e.g. Gibbs, 1964; also see section 4.2). Hewitt (1992) recognizes the Kerikeri brown loams as “typic orthic oxidic soils”.

Podzolised yellow-brown earths lie east of the region of brown loams where they occupy the central part of the study area. These moderately podzolised soils of the “Hukerenui series” (see section 4.2.3) comprise silt loam with yellow subsoil (Sutherland *et al.*, 1980). They have developed from deeply weathered sedimentary rocks, especially sandstone interbedded with greywacke and argillite, of the Waipapa Group (Gibbs, 1964; Kear & Hay, 1961; Kermode, 1982; also see section 3.2). The New Zealand Soil Classification classes them as “mottled densipan ultic soils” (Hewitt, 1992). Taylor & Sutherland (1953) suggest that this soil type probably formed under forest largely composed of mor-forming species, in particular *Agathis australis*. However, at the time of European colonisation of the area these soils were covered with low scrub and rushes (Juncaceae) but the presence of gum from *Agathis australis* and the remains of roots in the soils indicates that they formerly supported *Agathis australis* forest. Owing to this association podzolised yellow-brown earths (and related soils) are also widely known as “gumlands” (see above; also see section 4.2). Because of the formation of impervious pans and other soil structures there are often drainage problems in these podzolised soils. They range from impounded water on the surface to the formation of bogs (*cf.* Gibbs, 1964).

A combination of podzolised yellow-brown earths and yellow-brown earths and related steepland soils occupy the eastern part of the study area. As the podzolised yellow-brown earths also belong to the Hukerenui series their pedological properties are identical to those already mentioned above. The yellow-brown earths and related steepland soils are represented by the “Rangiora series” (see section 4.2.3) which also derived from deeply weathered sedimentary rocks of the Waipapa Group (see above). Sutherland *et al.* (1980) describes the texture of these strongly leached to weakly podzolised soils as ranging from clay and clay loam to silty clay. In Hewitt’s (1992) soil

taxonomy they are referred to as “mottled albic ultic soils”. They are believed to have developed under forest containing many mor-forming trees (e.g. *Agathis australis* and *Dacrydium cupressinum*) but because of their low fertility, scrub in many places replaced the forest where it had been destroyed by fire (Taylor & Sutherland, 1953).

The lava flows from the Te Puke Volcanic Centre (see section 8.1.1 and fig. 8.1) accommodate the second suite of volcanic soils within the study area. Unlike the brown loams of the Kerikeri series in the western part of the study area these loam soils have developed on substantially younger basalts including limited occurrences of basaltic scoria in the immediate vicinity of the volcanic cones (*cf.* Kermode, 1980). Due to their more recent origin the resultant predominantly brown loams are less leached than those of the Kerikeri series and qualify as “weakly to moderately leached” (Sutherland *et al.*, 1980). With the exception of the scoriaceous section of the easterly lava flow most proximal to the volcanic cones both lava flows accommodate brown loams. These loams of the “Ohaeawai series” consist of silt loam which is commonly bouldery (Sutherland *et al.*, 1980). Red loams of the “Papakauri series” (see section 4.2.5) developed on the above scoriaceous section of the easterly lava flow. They consist of silt loam and are reported to have a better drainage than Ohaeawai soils due to the higher permeability of their scoriaceous parent material (*cf.* Gibbs, 1964; Sutherland *et al.*, 1980).

Another suite of “pure” yellow-brown earths and related stepland soils occupies the south-western and central part of the study area. They are represented by an assemblage of soils of the Rangiora (see above) and “Marua series” (see section 4.2.2). The latter comprises moderately to strongly leached light brown clay loam (Sutherland *et al.*, 1980). As these soils also derived from the sedimentary rocks of the Waipapa Group (see above) their occurrence within the study area is marked by a number of overlaps with the Hukerenui soils (see above). These result in a discontinuous distribution of this soil group in the form of a few larger isolated patches which extend from the south-west of the study area across the Hukerenui soils (see above) eastwards to the Ohaeawai soils of the northerly lava flow from Mt. Te Puke (see above).

Organic and gley soils constitute a minority soil group within the study area. They have

formed on very recent, unconsolidated to very soft alluvial (and partially estuarine) deposits ranging from mud and sand to gravel with minor peat (see Kear & Hay, 1961; Kermode, 1982).

The largest group of organic soils is represented by the “Otakairangi series” which consists of an assemblage of imperfectly to poorly drained peaty clay loam and loamy peat (Sutherland *et al.*, 1980). They form the peaty soils of the swamp system within the Waitangi State Forest (Chester, 1986; Kermode, 1982; also see section 8.1.1) within the central part of the study area. A second suite of organic soils forms part of the coastal fringe in the southern part of Onewhero Bay. This rather small area locates imperfectly to very poorly drained peaty clay loam of the “Otanga series” (Sutherland *et al.*, 1980). Both soil types owe their formation to depressions (Otakairangi soils) or low flats (Otanga soils) where the water table was permanently high and anaerobic conditions led to the accumulation of organic matter (e.g. Gibbs, 1964).

Gley soils represent the smallest soil group within the study area. They form in areas with a poor natural drainage which causes the presence of ground water at or near the surface for prolonged periods throughout the year (e.g. Gibbs, 1964). Within the study area their occurrence is limited to two rather restricted locations. The first lies on an estuarine flat on the southern shore of the Kerikeri Inlet, just east of the Okura River mouth. These gleys of the “Takahiwai series” have developed in predominantly clayey substrate. Due to their immediate vicinity to the Kerikeri Inlet they are classed as “weakly saline” (Sutherland *et al.*, 1980). The second suite of gley soils within the study area has formed within the Wharau Road Swamp study site. Sutherland *et al.* (1980) mapped the sediments forming the swamp as imperfectly to poorly drained clays of the “Waipu series”.

8.1.3. Climate

Within the various climatic classifications devised for the New Zealand environment the study area qualifies as a humid “BB’r” climate in Thornthwaite’s (1931) and as a

“WTH” climate in Garnier’s (1958) classification. Detailed descriptions of the characteristics of these climatic types are provided in section 4.3. Further details on the weather systems associated with the region’s climate and its climatic elements is given in sections 4.3.1 and 4.3.2, respectively.

This section therefore describes only the most relevant climatic elements prevailing in the study area. Their description is based on observations recorded at two meteorological stations in the vicinity of the study area: Kerikeri⁸² and Kerikeri Airport⁸³. These stations were chosen because of their close proximity to the study area. The meteorological data collected in these locations therefore probably represent best the climate of the study area. Unless stated otherwise the description of the following individual climatic elements is largely based on the work by Moir *et al.* (1986). Partial reiterations of statements already made in section 4.3.2. are therefore inevitable.

Wind: As for the remainder of Northland the airflow over the study area shows a marked predominance for south-westerly directions (see fig. 4.7; station Kerikeri Airport). However, despite its coastal location the study area largely receives some sheltering from the surrounding topography from these south-westerlies. The resulting mean annual wind speeds of as little as 10 km/h are among the lowest throughout New Zealand. The windiest season within the region appears to be spring. During this period 47% of the annual total of all strong winds⁸⁴ occur. The calmest seasons are undoubtedly summer and autumn. With a proportion of 31% and 26%, respectively, both seasons record the highest number of calm days of the annual total (all data recorded at Kerikeri Airport, 1964-1966).

Rainfall: Due to the rather low-lying character of its terrain (see section 8.1.1) the study area is among those regions in Northland which receive the lowest mean annual precipitation. The annual precipitation (1941-1970 rainfall normals) within the area

⁸²Geographical position of the meteorological station at Kerikeri: NZMS 260, P05/971632; Lat. 35°14’S, Long. 173°57’E; Alt. 73 m a.s.l. (New Zealand Meteorological Service, 1973).

⁸³Geographical coordinates for the location of the meteorological station at Kerikeri Airport are not available. However, the position of the airport’s Terminal Building is: NZMS 260, P05/938593; Lat. 35°15’59”S, Long. 173°54’04”E; Alt. ≈152 m a.s.l.

⁸⁴Moir *et al.* (1986) defines “strong winds” as airflows with a mean speed of at least 31 km/h.

largely ranges from 1400 to 1600 mm (see fig. 4.8) with 1648 mm/a recorded at Kerikeri (1941-1970) (New Zealand Meteorological Service, 1973). The temporal distribution of the region's rainfall largely complies with the rest of Northland (see section 4.3.2.2; also see fig. 4.9). With 34% of its annual precipitation (1941-1970) falling in the period June to August the region shows a clear winter rainfall maximum. Only 18% of the region's annual precipitation falls during the three summer months from December to February (data recorded at Kerikeri) (New Zealand Meteorological Service, 1973). Figure 8.2 illustrates the region's annual rainfall distribution.

These rainfall events occur on an average number of around 140 raindays⁸⁵. This is a rather low number in comparison with some western and inland areas of Northland (see section 4.3.2.2) which have an annual average of over 200 raindays. The variability (see section 4.3.2.2) of the region's precipitation on the other hand is conspicuously high. With a value of 21% (data recorded at Kerikeri) the region's annual rainfall variability is one of the highest throughout Northland and markedly above the national average of 10 to 20% (see section 4.3.2.2).

Temperature: With an annual mean of 15.1°C (recorded at Kerikeri, 1941-1970 temperature normals) (New Zealand Meteorological Service, 1978) the temperatures of the study area are among the warmest throughout Northland (see section 4.3.2.3). Figure 8.3 summarizes the study area's monthly temperature regime (1945-1973, data recorded at Kerikeri).

As for the remainder of Northland the mean annual temperature range within the study area is reasonably small. With an average of 8.7°C (1941-1970, recorded at Kerikeri) (New Zealand Meteorological Service, 1978) it is close to the peninsula's average of 8.5°C (see section 4.3.2.3). The region's average daily temperature range on the other hand is reasonably high. Averaging 10.2°C (1945-1970, recorded at Kerikeri) (New Zealand Meteorological Service, 1973) it constitutes one of the highest daily temperature fluctuations throughout Northland.

⁸⁵Due to the instrumental limitations of the standard New Zealand Meteorological Service rain gauge a "rainday" is defined as a day on which ≥ 0.1 mm of rain falls (e.g. New Zealand Meteorological Service, 1973).

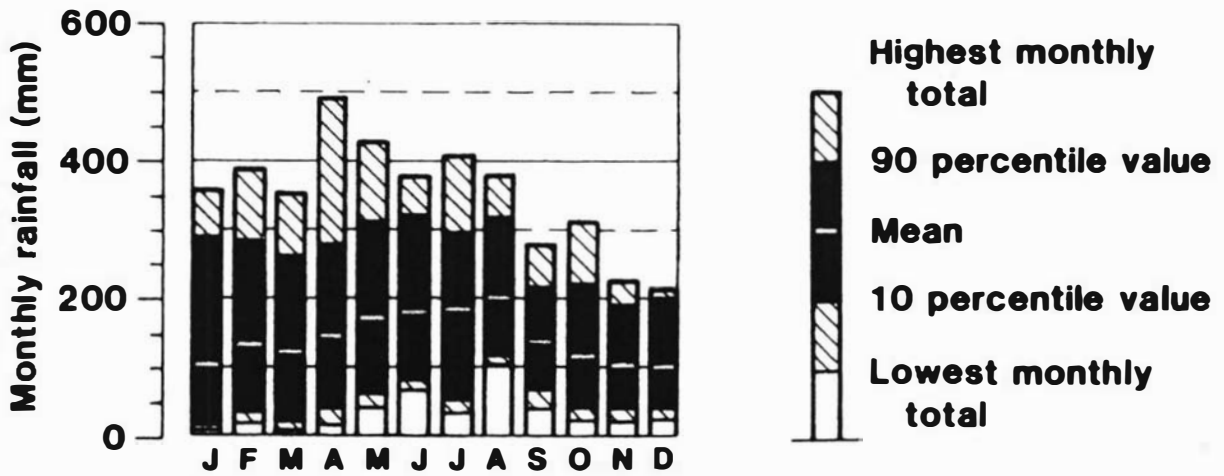


Fig. 8.2: Monthly rainfall normals (1935-1973) for Kerikeri. The mean values for each month are shown along with the 10 and 90 percentile including maximum and minimum recorded values (modified after Moir *et al.*, 1986).

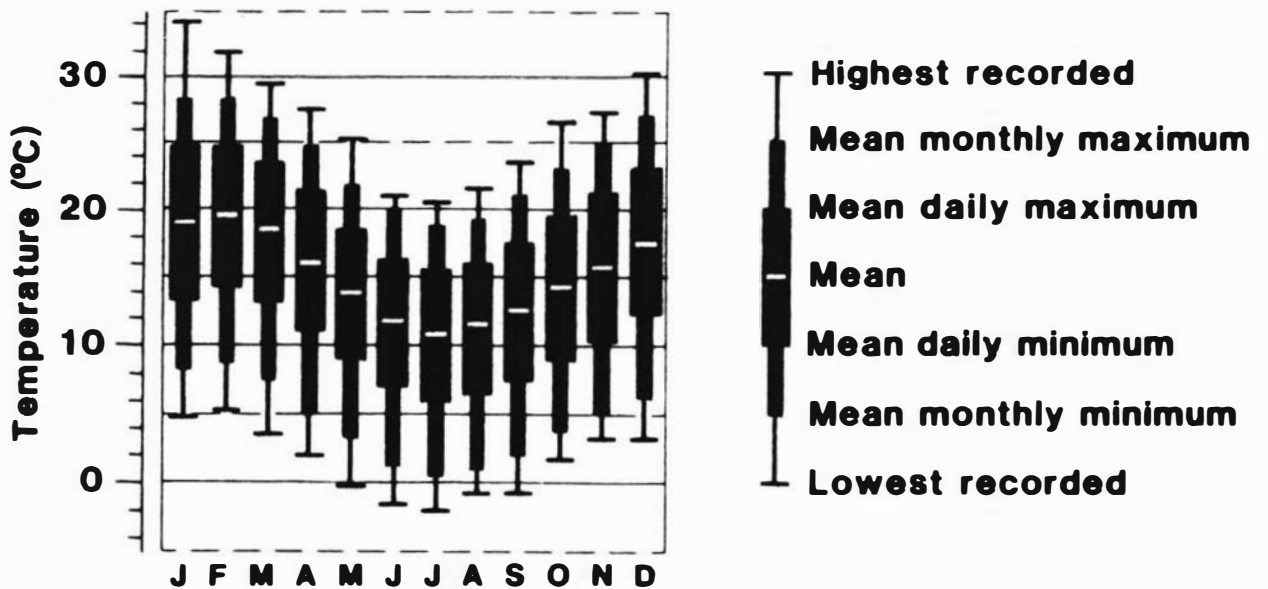


Figure 8.3: Monthly temperature normals (1945-1973) for Kerikeri including highest recorded, mean monthly maximum, mean daily maximum, mean, mean daily minimum, mean monthly minimum and lowest recorded (modified after Moir *et al.*, 1986).

Frost: In compliance with the high mean annual temperatures for all of Northland the region's number of days with frost is rather limited. Altogether there is only a recorded average of 25.7 days (1951-1970, recorded at Kerikeri) of ground frost in the region (New Zealand Meteorological Service, 1973).

Humidity: Due to the proximity to the coast the region's relative humidity is reasonably high. The annual average (1945-1970, recorded daily at 0900 hours at Kerikeri) ranges around 80% (New Zealand Meteorological Service, 1973).

Sunshine: Like most parts of Northland the study area receives a high annual total of bright sunshine. The region's average lies at 2011 hours (1938-1970, recorded at Kerikeri) which equals about 47% of the possible maximum (New Zealand Meteorological Service, 1973).

Altogether the study area's climate can be summarized as having warm humid summers and mild winters. The mean annual precipitation ranges from 1400 to 1600 mm with a pronounced maximum during the winter months. The prevailing winds mainly blow from the south-west which is largely in compliance with the remainder of Northland.

8.2 Vegetation of the region

As in the Bay of Islands region in general the vegetation of the study area is inextricably linked with the colonisation history of the region. Both prehistoric Polynesian colonisation as well as European contact with the region in historic times left their imprints on the area's vegetation.

Although the exact date of first Polynesian colonisation of the Bay of Islands region is not yet fully defined (also see section 2.2.1) archaeological evidence points to a long period of human occupancy of the region. As the area provided ample natural resources⁸⁶ it enabled a large Polynesian population to develop there. Its population was

⁸⁶The Bay of Islands region offered a wide variety of natural resources to early inhabitants. These ranged from suitable sites for building, numerous headlands which could be fortified, fresh water and favourable

mainly concentrated in two areas: all along the coastline, but in particular in the south-east Bay of Islands; and in those inland areas endowed with fertile volcanic soils (see section 8.1.2), especially around Ohaeawai, Kaikohe and Puketone (e.g. Department of Lands and Survey, 1985). A more comprehensive account of the Polynesian settlement patterns, its associated economy and individual archaeological sites in the coastal and inland Bay of Islands is given by Davidson (1982). As the region bears earliest evidence for Polynesian horticulture throughout New Zealand (Davidson, 1982) it can be assumed that clearing of the land started early. The probably clearest evidence of an early form of horticultural activity within the region is given on Moturua Island in the south-east Bay of Islands (e.g. Davidson, 1982; Department of Lands and Survey, 1985). From this location Davidson (1982) reports a series of ditches on a slope in association with garden soils intermixed with cultural layers and charcoal. Radiocarbon dates obtained from the site range from A.D. 1230 ± 100 and A.D. 1420 ± 90 to A.D. 1440 ± 85⁸⁷. Davidson (1982) argues that while the earliest date (obtained from the earliest charcoal layer [“layer 6”]) is unlikely to provide an accurate age of the site the latter two dates (obtained from the [artificial] garden soil [“layer 5”]) are probably more reliable.

It is suggested that this form of horticulture was conducted by means of shifting cultivation which necessitated the expansion into the forest by felling and burning (e.g. Department of Lands and Survey, 1985). As there was only little control of the fire once a blaze had been started large areas of the region probably became severely deforested. In view of the above dates from Moturua Island large-scale deforestation in the region by Polynesians to clear land for extensive cultivation probably dates to soon after A.D. 1400. Forest clearance on a smaller scale had probably already started much earlier. The resultant forest destruction must have been substantial as Davidson (1982) reports extensive deforestation in both the coastal and inland Bay of Islands region at the time of first European contact.

soils [see section 8.1.2] to a climate [see sections 4.3 and 8.1.3] suitable for the cultivation of imported tropical crops [e.g. *Ipomoea batatas* (kumara/sweet potato), *Colocasia antiquorum* (taro), *Cordyline* spp. (e.g. Ti kouka/cabbage tree), *Broussonetia papyrifera* (paper mulberry) and *Dioscorea* spp. (yam)]. The combination of these features made the region an attractive place for Polynesian settlements which was probably unparalleled elsewhere in New Zealand (cf. Davidson, 1982; cf. Department of Lands and Survey, 1984; Esler, 1973).

⁸⁷Statement of radiocarbon dates in compliance with Davidson (1982:18).

European contact with the region began over 200 years ago. It started with the visits of Cook in A.D. 1769 and Marion du Fresne in A.D. 1772. From then on European influences slowly spread. In the early 1800s whaling ships frequently called for supplies. Following the visit of Marsden in A.D. 1814 mission stations were set up. Settlements developed soon after the Bay of Islands became the administrative centre for the developing colony of New Zealand. Some of the earliest crops and vegetables introduced by European settlers to New Zealand were grown there. Land clearing already begun by Polynesians was extended and sheep and cattle introduced. The improvement of agricultural techniques through the passage of time (e.g. use of fertilisers, heavy machinery, better farming methods etc.) led to a large-scale modification of the physical environment of the region. It culminated in an almost complete removal of all native forest that had escaped previous Polynesian deforestation (Department of Lands and Survey, 1985; Esler, 1973).

The following sections (8.2.1-2.3) are an attempt to describe the study area's vegetation and its associated changes through the passage of time; from its pre-human state until the present.

8.2.1 Pre-Polynesian vegetation

The relatively long history of human occupancy and its profound impact on the physical environment of the study area (see above) makes it rather difficult to reconstruct the region's vegetation prior to the arrival of humans. Remnants of former indigenous vegetation within the study area which might give clues to the pre-human vegetation are scarce. The only sizable area of native forest left in the region is the Opuia State Forest (Chester, 1986). The forest proper lies outside the immediate study area, just a few kilometers south of the settlement of Waitangi, inland from the townships of Paihia and Opuia in the coastal Bay of Islands. However, despite its floristic composition of (predominantly) indigenous species the site probably does not reflect the pre-human vegetation of the region. This is because Chester (1986) regards it as a site which consists of mostly emerging secondary growth *Agathis australis*-podocarp-hardwood

forest (see section 4.1.4.1.1). Nevertheless, the site also includes a few large specimen of *Agathis australis*. They are believed to be remnants of the former *Agathis australis* mosaic forest typical of the region's pristine vegetation.

Generally the region's pre-human vegetation is regarded as having consisted of podocarp-hardwood forest (see section 5.1.4.1.2). The podocarps were mainly represented by *Dacrydium cupressinum*, *Dacrycarpus dacrydioides*, *Podocarpus totara*, *Prumnopitys ferruginea* and *Phyllocladus trichomanoides* which formed the forest's emergent layer (see section 5.1.4.1). Dominant species of the hardwood element included *Beilschmiedia tarairi*, *Dysoxylum spectabile* (kohekohe) and *Vitex lucens* which in turn were largely confined to the main canopy below (see section 5.1.4.1). A somewhat tropical element was added to these forests by *Rhopalostylis sapida*, tree ferns, vines and perching plants which formed an integral part of the sub-canopy layer as well as a dense undergrowth in the shrub layer. In places, these species associations were interspersed by *Agathis australis*. In some locations small, pure groves of *A. australis* even formed prominent features of the landscape (*cf.* Department of Lands and Survey, 1985; *cf.* Taylor & Sutherland, 1953).

However, as for the remainder of Northland the study area also shows a strong vegetation-soil-geology relationship (*cf.* Taylor & Sutherland, 1953; also see sections 4.2, 6.2 and 8.1.2). Consequently there was a certain variation in the floristic composition of the above predominantly podocarp-hardwood forest of the region.

The deeply weathered sedimentary rocks of the Waipapa Group with their infertile mainly clayey soils ("soils of the 'clay' country"; see section 8.1.2) supported a variety of forests ranging from mixed (podocarp-hardwood) forests to *Agathis australis*-podocarp forest with *Agathis australis* as a prominent element. While *Agathis australis* and the podocarps were probably more prominent on ridges and steeper slopes, the hardwoods (dominated by *Beilschmiedia tarairi*) probably dominated the lower slopes and gullies (*cf.* Department of Lands and Survey, 1985; Taylor & Sutherland, 1953).

The more fertile basalts soils ("soils of the 'volcanic' country"; see section 8.1.2) of the

Kerikeri Volcanics generally supported mixed (podocarp-hardwood) forests too but pure hardwood forests were more common. The latter were dominated by *Beilschmiedia tarairi* but also contained *Dysoxylum spectabile*, *Vitex lucens* and the podocarp *Podocarpus totara* (cf. Department of Lands and Survey, 1985; cf. Taylor & Sutherland, 1953).

The wetter flats of unconsolidated alluvial deposits (“soils of the ‘river flat’ and ‘swampy’ country”; see section 8.1.2) supported mixed (podocarp-hardwood) forest. Despite the relative homogeneity of this forest type the prevalence of certain edaphic factors led to a number of variations: In areas affected by permanent surface water *Laurelia novae-zelandiae* and the podocarp *Dacrycarpus dacrydioides* became predominant elements and on the coast *Metrosideros excelsa* (pohutukawa), *Corynocarpus laevigatus* (karaka) and *Sophora microphylla* came into prominence (cf. Department of Lands and Survey, 1985; cf. Taylor & Sutherland, 1953).

The coastal fringe was characterized by the occurrence of *Avicennia marina* var. *resinifera* which further upstream were superseded by jointed rush species (Juncaceae). Further inland in freshwater swamps *Typha orientalis* (raupo) and *Phormium tenax* (flax) became the main components of the region’s wetland vegetation (Department of Lands and Survey, 1985).

The occurrence of shrubland was probably very limited at that time, except where forest had regenerated after natural catastrophes (e.g. wildfires), or where forest encroached on swamps. Grassland is even likely not to have existed (Department of Lands and Survey, 1985).

8.2.2 Pre-European vegetation

As anywhere else in New Zealand the arrival of Polynesians in the region caused substantial changes to the area’s vegetation cover. Generally each Polynesian settlement cleared at least enough land for its dwelling houses, living space and plots for

gardening. Horticultural activities often performed in the form of shifting cultivation necessitated the felling and burning of the natural vegetation (see section 8.2.1). This form of clearing caused widespread damage to the mainly podocarp-hardwood forest cover and often only left isolated patches of vegetation undestroyed in the more protected gullies. After abandoning a site forest usually rapidly regenerated but after repeated burning the primary forest did not recover any more. These sites were then colonised by secondary growth mainly comprising shrubland of *Leptospermum scoparium* and *Pteridium esculentum* (rarahu/bracken). Due to the dense nature of this shrubland often further burning was required to clear paths (Department of Lands and Survey, 1985). However, the forest was not always destroyed to make way for gardening. Commonly the forest around settlements was burnt in order to induce the growth of *Pteridium esculentum* whose edible rhizomes were harvested (e.g. Davidson, 1984).

8.2.3 Modern vegetation

Along with the remainder of Northland the region's modern vegetation is largely a product of European deforestation. However, unlike the larger part of Northland forest removal by Europeans started exceptionally early in the region. According to Thode (1983) European forest exploitation in the Bay of Islands began as early as May 1772 when Marion du Fresne called into the bay to fell kauri trees to repair damage to foremasts and bowsprits. During the following decades between 1772 and 1835 the volume of timber, in particular *Agathis australis*, removed through the mast and spar trade increased in volume and then declined. Along with other harbour areas in Northland (e.g. Whangaroa, Hokianga and Kaipara) particularly the near-coastal areas of the Bay of Islands experienced a selective felling of *Agathis australis* during this period. The trade decline in the 1840s with the beginning of organised colonisation of the country by European settlers consequent upon the British decision to annex New Zealand (e.g. Dalziel, 1976). The focus then shifted from masts and spars to building timbers. The period between 1840 and 1910 with its rapid population increase, along with an increased demand for export timber, was generally marked by a vast

exploitation of *Agathis australis* which reached its peak in 1906 (Thode, 1983). As elsewhere throughout Northland by 1910 the once large *Agathis australis* forests no longer existed in the Bay of Islands, having been removed by fire and logging.

With the arrival of European settlers the post-1840 era also experienced a large-scale removal of the forest to provide land for pastoral farming. Along with other regions in Northland the introduction of exotic animals and plants caused further damage to the physical environment which had already been depleted by Polynesian gardening and European logging. However, because of a combination of various factors (e.g. leached soils, geographical isolation of Northland, small size of holdings etc. [see Lister, 1976]) until recently farming has only been partially successful in the Bay of Islands region. In particular the infertile clayey soils developed on the sedimentary rocks of the Waipapa group which are predominant in the study area (see section 8.1.2) did not sustain crops and productive pastures. Consequently, much of the cleared land reverted to shrubland of *Pteridium esculentum* and *Leptospermum scoparium* or became covered in noxious exotic weeds (e.g. *Ulex europaeus*); others developed into secondary (predominantly mixed podocarp-hardwood) forest (cf. Department of Lands and Survey, 1985; cf. Thode, 1983).

To compensate for the losses of indigenous timber resources afforestation in the Northland region with a variety of species, exotic as well as native, started in the early 1900s. In 1903 at Puhipuhi a few unsuccessful attempts were made to establish plantations of *Podocarpus totara* and *Eucalyptus* spp. Later in the late 1920s-early 1930s plantations with a range of *Pinus* species were started at Waitangi (see below) and Waipoua (Thode, 1983).

In view of these modifications to the region's vegetational cover the modern vegetation of the study area can largely be regarded as an artefact of human activity in prehistoric and historic times. This fact is particularly manifested in the kind of *Vegetative Cover Classes* (see section 5.1.3) for the study area. The probably most conspicuous feature of this vegetational survey of the study area as mapped by Newsome (1986) is the almost complete lack of any elements of the region's pristine indigenous vegetation as

described in section 8.2.1. The recognized vegetational cover rather ranges from “orchards or vineyards and pasture” (“C1”) around the township of Kerikeri, “Exotic forest” (“F9”) in the central part of the study area and “Grassland and gorse scrub” (“GS6”) in the north-eastern section of the study area to “Grassland and *Leptospermum* scrub or fern” (“GS2”) in the south-eastern part of the study area. A more detailed picture of the area’s modern vegetation cover is given by the Department of Lands and Survey (1980b).

The largest of these vegetative cover classes is F9 which is represented by the Waitangi State Forest. Owen (1964) describes the forest as a “State exotic forest” covering an area of approximately 2630 ha which equals about half the size of the study area as defined in section 8.1. Established in 1934 it is Northland’s third largest State exotic forest (see Owen, 1964) of which 2000 ha (Chester, 1986) are planted in exotic species. They include *Pinus radiata* (radiata pine), *P. taeda* (loblolly pine) and *P. elliottii* (slash pine) (Owen, 1964). However, the remaining area, particularly the steep gullies, is occupied by small patches of remnant indigenous vegetation (Chester, 1986). Although Chester (1986) is not specific about the kind of forest within these patches of remnant indigenous vegetation based on the predominance of clayey soils in this area (see section 8.1.2) it can be assumed to be either mixed podocarp-hardwood or *Agathis australis*-podocarp forest (see section 8.2.1).

Of the entire study area the modern vegetation in the coastal fringe appears to be least affected by anthropogenic modifications. The coastal mudflats support mangrove swamp (*Avicennia resinifera*) in various locations (Chester, 1986; Fredericksen, 1988); the coastal cliffs on the other hand are dominated by *Metrosideros excelsa* (Chester, 1986).

8.3 Description of the Wharau Road Swamp

Sections 8.3.1-3.3 describe the environmental setting of the catchment of the Wharau Road Swamp and the site itself, the stratigraphy of the sediment cores extracted from the

site as well as the radiocarbon chronology established for one of the cores.

8.3.1 Physiography and vegetation of the site

The exact geographical location of the Wharau Road Swamp has already been described above. The swamp proper covers approximately 17.5 ha and includes an ephemeral lake at its western end (see fig. 8.4). The surrounding hills, comprising a system of ridges and gullies, are of low relief nowhere exceeding 100 m a.s.l. (see plate 8.1). The swamp slopes gently to the west and is enclosed in a valley basin which is partially dammed by the northerly lava flow from the Te Puke Volcanic Centre (see section 8.1.1). Such mode of origin qualifies the Wharau Road Swamp as a topogenous swamp (Elliot *et al.*, 1992, 1997).

The geology of the catchment of the swamp is dominated by two units: Basalts from Mt. Te Puke (see above) which border the site to the north-west and sedimentary rocks of the Waipapa Group which constitute the remainder of the catchment (Kear & Hay, 1961; Kermodé, 1982; also see section 8.1.1).

Due to the area's strong geology-soil relationship (see section 8.1.2) the following soils occur within the swamp's catchment: Ohaeawai soils (brown loams/oxidic soils) in the north-west; Hukerenui soils (podzolised yellow-brown earths/mottled densipan ultic soils) in the north-east; and a combination of Hukerenui and Rangiora soils (yellow-brown earths and related stepland soils/mottled albic ultic soils) in the south-west. The constituting sediments of the swamp itself are recognized as Waipu soils (gley soils) (Sutherland *et al.*, 1980; also see section 8.1.2).

The modern undisturbed vegetation of the swamp is floristically relatively rich. Numerous swamp tolerant shrubs and small trees are present; especially abundant are *Cordyline australis*, *Leptospermum scoparium* and *Coprosma tenuicaulis*. *Typha orientalis* is common, and the sedge *Eleocharis acuta* is widespread. Many small herbs occur as scattered individuals, including *Isachne* spp., an aquatic grass of the Poaceae family. The

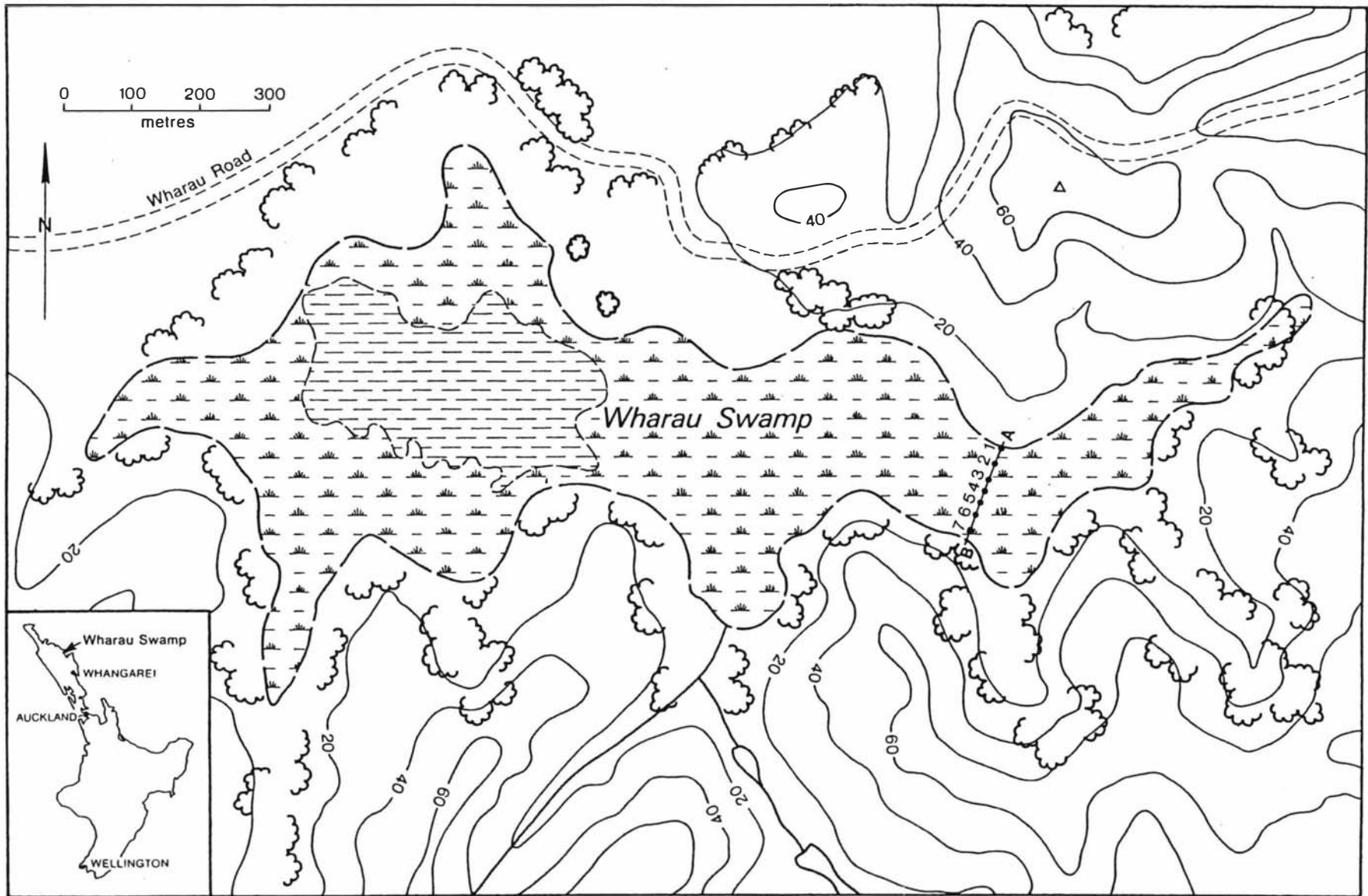


Figure 8.4: Location and physiography of the Wharau Road Swamp. Numerical values are elevations (in meters). A—B indicates the coring transect across the swamp. Numbers 1-7 signify the sediment cores collected along the transect.



Plate 8.1: Wharau Road Swamp, coastal Bay of Islands.

margin of the swamp is fringed in many places by exotic *Acacia* species (Elliot *et al.*, 1992, 1997).

The vegetation within the (dry parts) of the swamp's catchment has largely been removed for farming. The landuse within this part of the catchment as recognized by the Department of Lands and Survey (1980b) includes various combinations of "pastoral farming on sown and developed pasture", "farm woodlots and shelterbelts" and "undeveloped and reverted farmland". The latter mainly supports secondary vegetation of shrubland, chiefly comprising *Leptospermum soperium* and *Ulex europaeus* (*cf.* Elliot *et al.*, 1992, 1997).

8.3.2 Description of sediment cores

Using a D-section sampler (see section 7.2.2) a series of boreholes was made along a transect across the swamp (see fig. 8.4). This transect was chosen because of its relatively undisturbed state. Much of the lower, western parts of the swamp have been drained and cleared for farming (see section 8.3.1). Altogether a total of seven sediment cores were collected from this transect ranging in length from 0.65 m (core 1), 2.50 m (core 2) and 3.00 m (cores 3, 4, 6 and 7) to 4.00 m (core 5) (see Elliot *et al.*, 1992, 1997).

8.3.2.1. Stratigraphy

Of all sediment cores collected core 5 provided the longest sequence of organic deposition (see above). It was therefore chosen for a number of sedimentological analyses (granulometry, mineralogy and organic matter content of the core constituents), pollen analysis as well as to establish a radiocarbon chronology for the site. This core can be divided from top to bottom into six broad stratigraphic units (see fig. 8.5): Loose peaty mud; coarse peat. Organic mud (gyttja); coarse peat, organic mud; and a substratum of sandy clay (also see Elliot *et al.*, 1992, 1997). The following stratigraphic

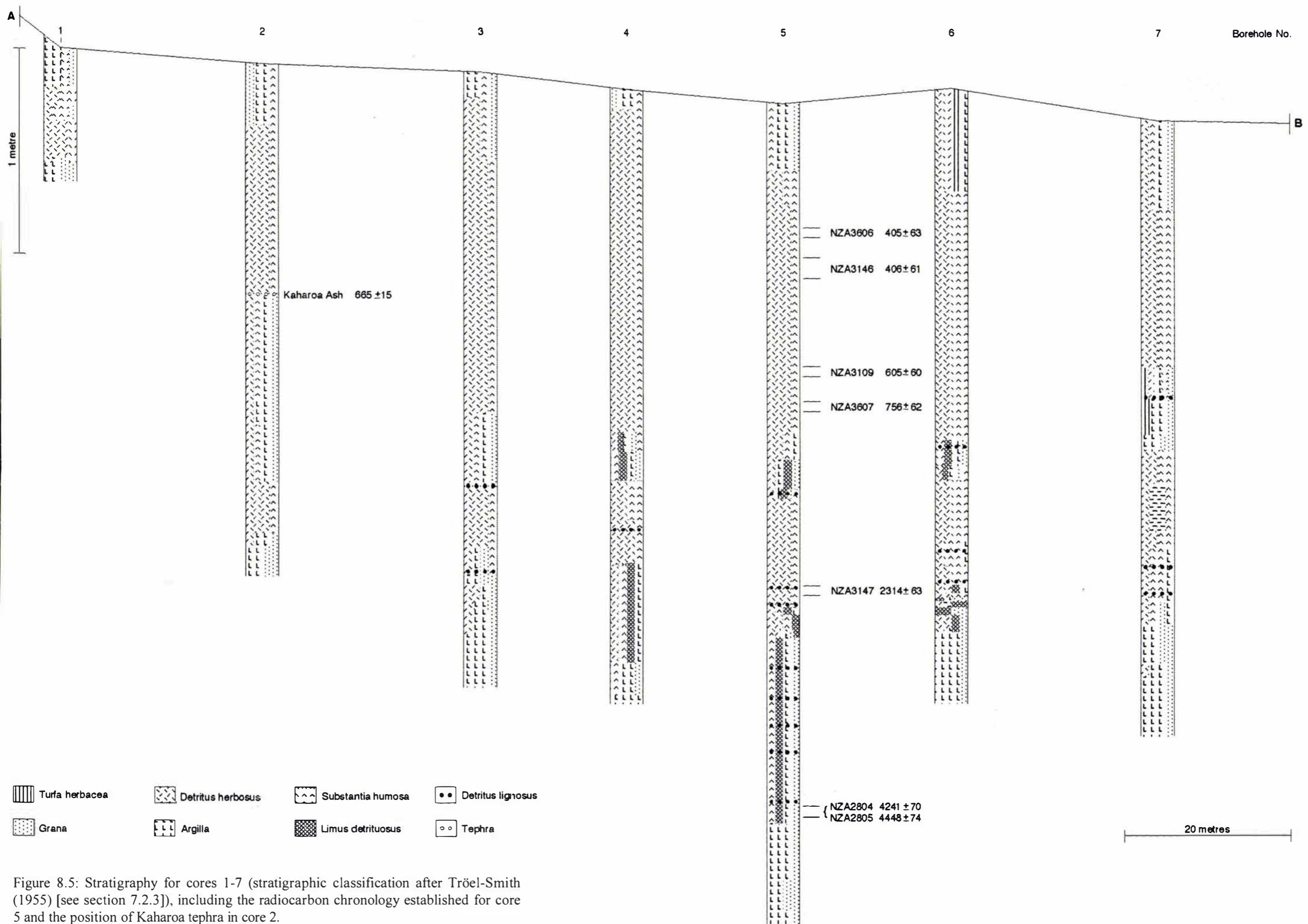


Figure 8.5: Stratigraphy for cores 1-7 (stratigraphic classification after Tröel-Smith (1955) [see section 7.2.3]), including the radiocarbon chronology established for core 5 and the position of Kaharoa tephra in core 2.

descriptions utilize the Tröel-Smith (1955) classification for unconsolidated sediments (see section 7.2.3).

The uppermost unit of core 5 extends to a depth of 0.33 m, the top 0.20 m of which was too loose to be retained in the sampler. This dark brown material was made up of *Argilla*, *Grana* and *Substantia humosa* at a ratio of 2:1:1. The second unit extends to 1.60 m and can be subdivided into two sub-horizons. The uppermost sub-horizon, between 0.33 and 0.50 m, consists of dark brown *Detritus herbosus* and *Substantia humosa* at a ratio of 2:2. The lowermost sub-horizon, between 0.50 and 1.60 m, consists of red-brown *Detritus herbosus* and *Substantia humosa* at a ratio of 3:1. The third unit, between 1.60 and 1.74 m, consists of a brown gyttja made up of *Detritus herbosus*, *Substantia humosa* and *Argilla* in a ratio of 2:1:1. A transition, extending from 1.74 to 1.88 m, includes equal amounts of *Argilla*, *Grana*, *Limus detrituosus* and *Detritus herbosus*. The upper and lower boundaries of this unit are not well defined, and transitions are noted in the field records. From 1.93 to 2.46 m the fourth unit consists of dark brown/black *Detritus herbosus* and *Substantia humosa* at a ratio of 3:1. The fifth unit, extending from 2.46 to 3.51 m, consists of brown *Limus detrituosus*, *Argilla*, *Grana* and *Detritus herbosus* in equal parts. The lowermost unit, from 3.51 m to the base at 4.00 m, comprises *Argilla* and *Grana* at a ratio of 3:1 (see Elliot *et al.*, 1997). A full description of the stratigraphy of all seven sediment cores is provided in Appendix II.1.

8.3.2.2 X-ray radiography

Because of their length cores 3 and 5 (see above) were chosen for X-ray radiography (see section 7.2.4). Despite a complete coverage of both cores the obtained radiographs were only of limited use for detailed sedimentological, stratigraphic and structural analyses of the core material. This is mainly because of the highly organic nature of the core material (see section 8.3.2.1). The occurrence of core constituents such as coarse detritus, rootlets and occasional even peat, in particular in the upper sections of the cores, largely obliterated possible core micro-features such as volcanic ash bands or

laminations of silty/clayey inorganic matter (see section 7.2.4). Therefore, the obtained radiographs were only used to distinguish between predominately organic and inorganic sections of the core. For more detail see radiographs in Appendix V.1 (Wharau Road Swamp, core 3) and V.2 (Wharau Road Swamp, core 5) (radiographs of Appendix V.1 and V.2 lodged at Massey University Library).

8.3.3 Radiocarbon dating

Seven samples were radiocarbon dated by accelerator mass spectrometry (AMS) (see table 8.1; also see section 7.3.1.1).

Depth (m)	Accession No.	^{14}C (years B.P.)	$\delta^{13}\text{C}$ (‰)	Material dated
<i>Wharau Road Swamp</i>				
0.60-0.65	NZA-3607	405 ± 63	-25.67	Litter
0.75-0.80	NZA-3146	406 ± 61	-26.6	Treated peat
1.28-1.33	NZA-3109	605 ± 60	-27.1	Treated peat
1.45-1.50	NZA-3606	756 ± 62	-27.13	Litter
2.35-2.40	NZA-3147	2314 ± 63	-29.8	Treated peat
3.43-3.48	NZA-2804	4241 ± 70	-28.5	Plant fragments
3.43-3.48	NZA-2805	4448 ± 74	-29.2	Humins fraction

Table 8.1: Radiocarbon dating of samples from core 5. The conventional ^{14}C age is expressed in years B.P. ± 1 σ based on old half life after Stuiver & Polach (1977).

Figure 8.6 shows the age-depth relationship of the radiocarbon chronology obtained for core 5. The lowermost and oldest samples was dated for two fractions: a plant fragment fraction which returned a date of 4241 ± 70 years B.P. (NZA-2804), and a humin fraction which returned a date of 4448 ± 74 years B.P. (NZA-2805). These dates are in good agreement, and afford a high degree of confidence in their accuracy. Using an error weighted mean of the two ages provides a chronology for onset of organic deposition beginning *ca.* 4300 years B.P. Initially the rate of sedimentation is relatively slow (*ca.* 0.55 mm/a), but the rate increases sharply after *ca.* 750 years B.P. Because sedimentation is still continuing, the line in figure 8.6 would be expected to pass through the origin, and to be progressively steeper near the origin because the upper sediments are less compacted than lower ones, or the sedimentation increases owing to increased erosion. Based on this assumption, NZA-3146 and -3607 are therefore

probably slightly too old for the expected sedimentation rate. If so, this may be due to inwash of old soil carbon into the swamp during forest clearing (also see section 7.3.1.2). Age estimates for events occurring between dated samples are interpolated from the age-depth curve in figure 8.6. A rhyolitic ash layer was present in core 2 at 1.11-1.13 m. Electron microprobe analysis positively identified the deposit as Kaharoa Tephra (Cronin, pers. comm.). Its stratigraphical position broadly correlates with NZA-3606 (756 ± 62 years B.P.) of core 5 (see Elliot *et al.*, 1997).

8.4 Sedimentology of core material

The sedimentology of the core material extracted from the Wharau Road Swamp was investigated for a number of their physical and chemical properties, including sediment texture, organic matter content, sediment mineralogy and sediment chemistry (also see section 7.2.6). The methods and materials applied for these analyses were already described in detail in section 7.2.6. The following sections (8.4.1-4.4) will therefore report only the results of the above investigations. Due to the nature of the coring equipment (see sections 7.2.2 and 8.3.2) used to collect the sediment cores the quantity of core material available was rather limited. Hence, the above analyses, along with palynological investigations, could not be performed on a single but rather had to be distributed over a number of cores. As a result of these limitations cores 1-3 and 5 were used for the determination of sediment texture and organic matter content, core 7 for sediment mineralogy and core 5 for sediment chemistry.

8.4.1 Sediment texture

Cores 1-3 and 5 were analysed for their sediment texture (see figure 8.7). However, core 5 was only of limited use for this investigation because of the very limited quantity of core material left after the application of chemical and pollen analyses on this core. The remaining material therefore only allowed a basic determination of the ratio of coarse ($>62.5 \mu\text{m}$) to fine ($<62.5 \mu\text{m}$) sediment. The tabled results of the analysis for sediment

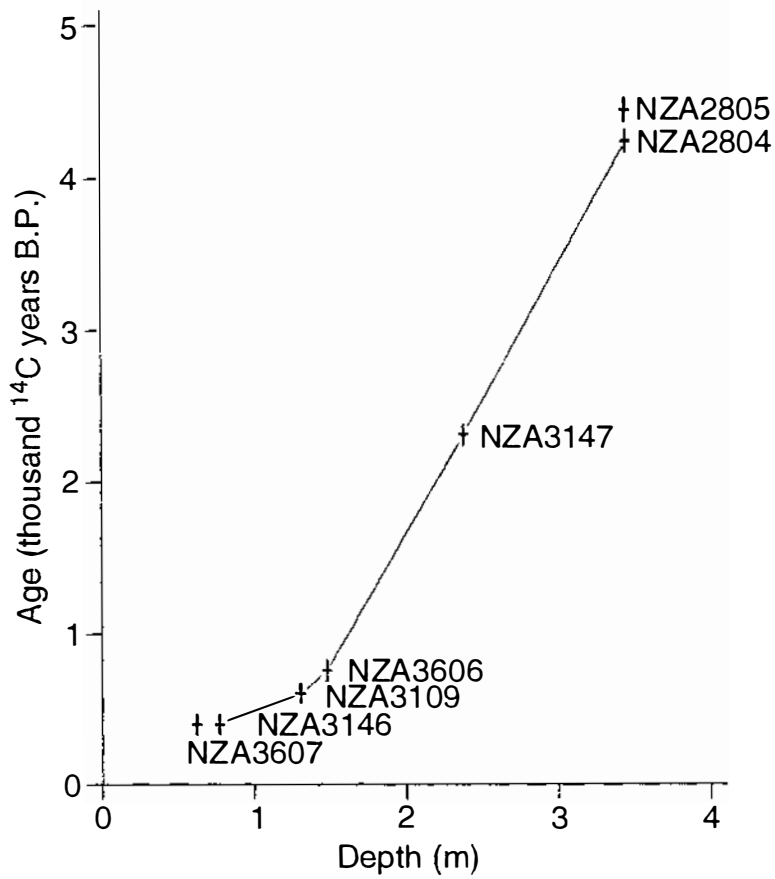
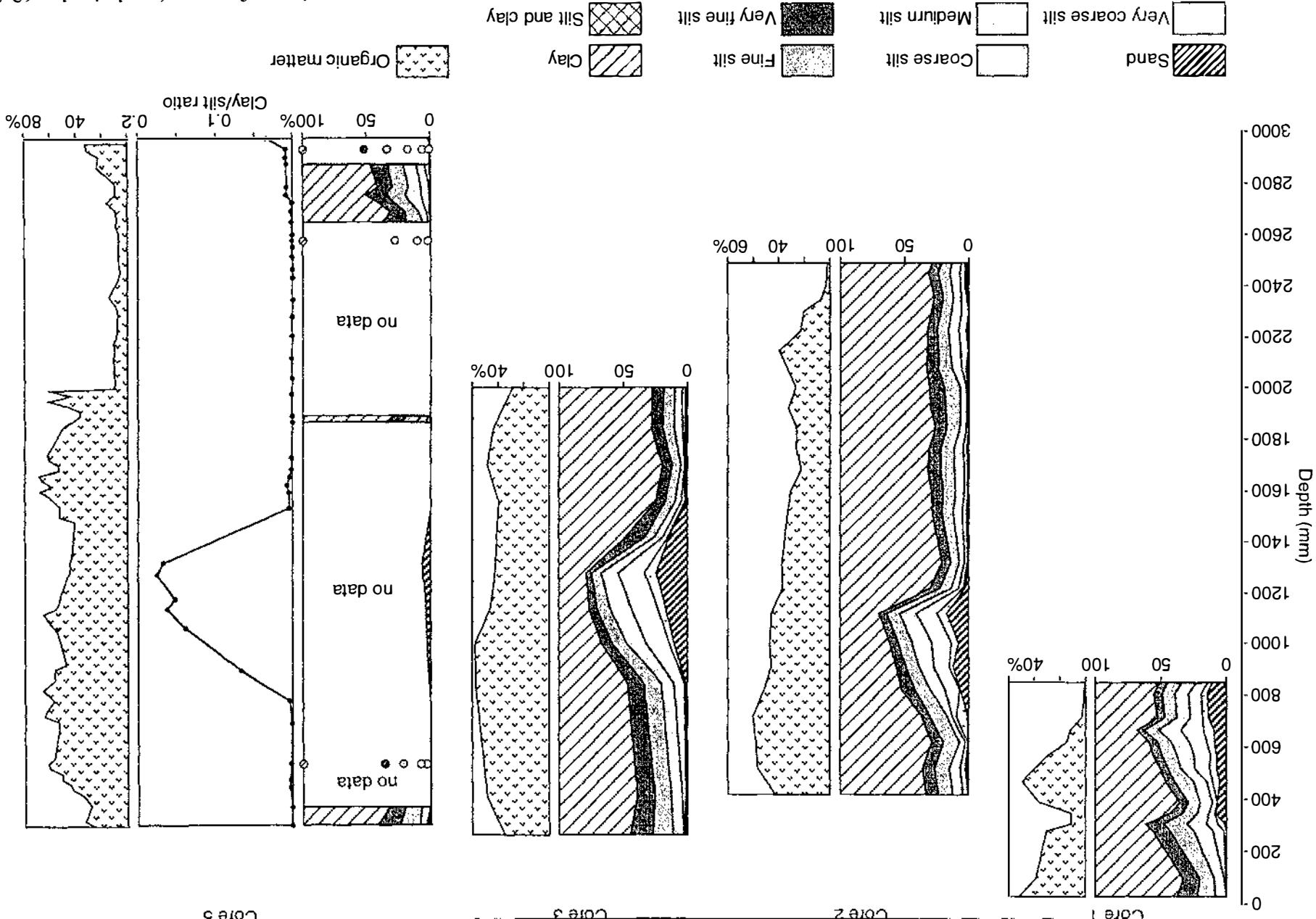


Figure 8.6: Age-depth curve for core 5. The horizontal bars represent the magnitude of statistical counting error on the ¹⁴C dates (2σ); the vertical bars indicate the length of the core segment used.

Figure 8.7: Grain-size classes and organic matter content for cores 1-3 and 5. Core 5 shows only proportions of coarse (sand-sized, >62.5 μm) and fine (clay/silt-sized, <62.5 μm) sediment.



texture from cores 1-3 and 5 are listed in Appendix II.2.

Core 3 with an overall length of 3.00 m was analysed only to a depth of 2.00 m, and core 2 was lacking the first 0.30 m from the top as this section was lost during coring. Despite their different overall length (core 1: 0.65 m, core 2: 0.30-2.50 m; core 3: 3.00 m, analysed to a depth of 2.00 m and core 5: 4.00 m, analysed to a depth of 3.00 m), they all show an almost identical grain-size distribution pattern with depth. Cores 1-3 are characterised by high clay contents (average 50-60%) throughout their total length. This trend is interrupted only by a sudden increase in the sand fraction from values below 1% to up to 15%. This increase occurs at the expense of the clay fraction. The clay fraction is reduced by almost half to an average of 25-30%. In cores 2 and 3 the reduced clay content is located from 1.30 m to 0.72 m and from 1.42 m to 0.84 m, respectively, and in core 1 from the base to 0.28 m.

The content of the finer silt fractions for cores 1 and 2 (i.e. very fine, fine and medium silt; also see section 7.2.6.2) remains largely unaffected by the increase of sand (where sand-sized material is present). However, core 3 shows a strong increase in these fractions (also cumulative values) from 21% (bottom) up to 43% (top). Of the coarse silt fractions (see section 7.2.6.2), initial values of 3% (core 2) and 5% (core 3) were observed which remain quite stable up to 1.30 m and 1.42 m respectively. The total content of these fractions then rises abruptly to a maximum of 24% and 31%, respectively, and then sharply declines from about 0.60 m. Core 1 displays a similar trend. The proportion of coarse to fine sediments in core 5 follows a very similar pattern to the grain-size distribution for cores 2 and 3. A sharp rise in the sand fraction occurs at 1.32 m (sand:clay/silt ratio: ≈ 0.17) and remains elevated until 1.065 m (sand/clay:silt ratio: ≈ 0.14) before declining.

8.4.2 Organic content

Cores 1-3 are all dominated by a high organic matter content with maximum values of 50-60%. In core 1 (see fig. 8.7) the organic matter rises from a low value of 5% at the

base to a peak of 63% at 0.43 m, then declines sharply from 0.39 m to a low of 11% between 0.35 m and 0.31 m. A sharp rise to 24% occurs at 0.28 m, followed by a more gradual increase to 52% at the top. Cores 2 and 3 (see fig. 8.7) show similar trends for their organic content, i.e. steadily increasing organic content from the base upwards, marked only by minor fluctuations in this trend until the surface is approached, where both cores exhibit declines from about 0.40 m (Elliot *et al.*, 1993, 1997). Core 5 offers a slightly different picture. From a maximum of 40% at the base at 3.00 m values gradually decline to an average of 10% between 2.80 and 2.00 m. At 2.00 m there is a sharp increase to approximately 60%. Values remain at this elevated level between 2.00 and 0.54 m. However, a minor decline to values ranging from 41 to 48% occurs between 1.26 and 1.48 m. From 0.54 m the organic matter content steadily decreases from 62% to 6% at 0.2 m. The tabled results of the analysis for organic matter content, including the results for sediment moisture and inorganic matter content, are listed in Appendix II.3.

8.4.3 Sediment mineralogy

XRD analysis (see section 7.2.6.3.1) of mineral species in the clay and silt fraction of core 7 revealed major amounts of halloysite and smectite, and lesser amounts of mica (probably biotite) and vermiculite throughout the core. Trace amounts (<5%) of quartz and feldspar are also present in the silt fraction. The NaF test for allophane (see Fieldes & Perrot, 1966) indicated that small amounts of this short range order mineral are present in the clay fraction. Halloysite and smectite are the dominant clay mineral species, and show a distinct pattern of distribution throughout the core. From the base of the core to a depth of 2.56 m smectite dominated over halloysite. Thereafter to the top of the core, halloysite and smectite were present in approximately equal amounts (Elliot *et al.*, 1993, 1997).

Further XRD analysis on samples from core 5 on the fractions <2 μm , 2-20 μm and >20 μm (Appendix II.4) revealed the following picture: throughout the length of the core the <2 μm -fraction is dominated by four principal mineral fractions: quartz, kandite and

amorphous silica. The values for quartz average around 15%, kandite shows values of around 35% and amorphous silica, including plant opal, diatoms and volcanic glass, shows an average of about 50%. An undoubtedly conspicuous feature of this fraction is the extremely high amount of amorphous silica which assumes maximum values between 0.78 and 1.275 m where it entirely consists of volcanic glass.

The 2-20 μm -fraction reveals a slightly different situation. Here, quartz constitutes the the predominant mineralogical fraction with values averaging about 65%. Kandite has almost entirely disappeared from this fraction and the occurrence of amorphous silica is restricted to the first half of the sediment core between 1.27 m and the sediment surface. Within this range it almost entirely consists of plant opal. A significant amount of volcanic glass (10-60%) only occurs from 1.275 to 0.895 m.

Within the >20 μm -fraction quartz, biogenic silica (e.g. plant opal and diatoms) and volcanic glass are the main constituents of the minerogenic fraction of the core. Quartz predominates from 2.979 to 2.28 m ($\approx 80\%$), at 2.04 m, 1.685 m and from 0.695 m to the sediment surface. In between these intervals, at 2.28 m, 1.89 m and from 1.625 to 0.78 m volcanic glass is the major constituent of the mineral phase, assuming portions of 10%, 15% and 35-90%, respectively.

8.4.4 Sediment chemistry

The results for Al, Ca, Fe, Mg, Mn, Na, S and P (see section 7.2.6.4.3) for core 5 are plotted as a concentration versus depth graph (see fig. 8.8). The entire range of elements obtained from the analysis of the chemical composition of the sediment core is listed in Appendix II.5.

Elements (or cations) such as Al, Ca and Mg show an irregular concentration distribution with depth, without any conspicuous peaks. Fe and P show an increasing tendency from low values at the bottom of the core (Fe approx. 200 mg/g dry matter, and P 25 mg/g dry matter) to comparatively high values at the top of the core (Fe

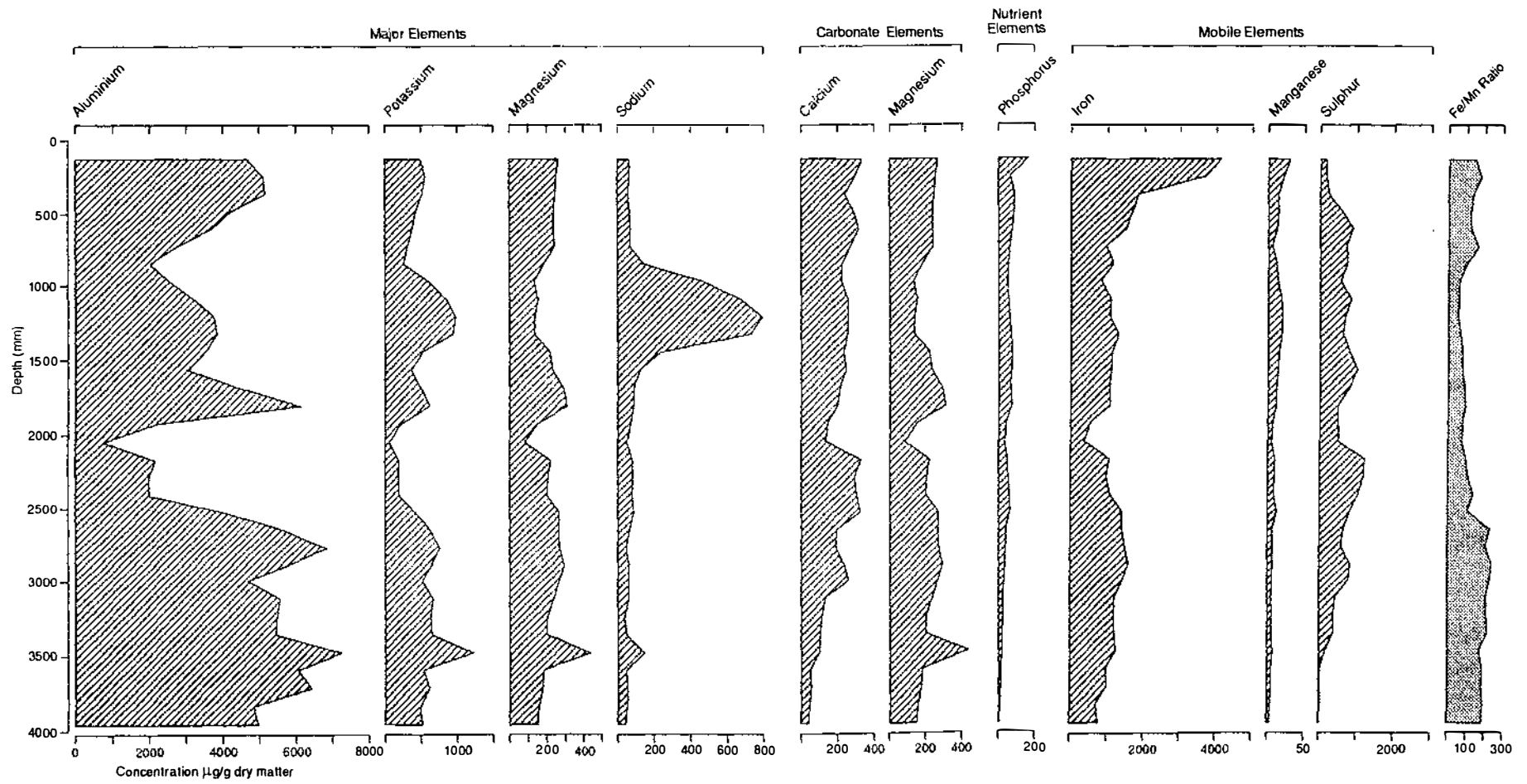


Figure 8.8: Sediment chemistry of core 5. Elements are classed according to their environmental abundance.

approx. 1250 mg/g dry matter, and P 475 mg/g dry matter). Potassium and Na show sharp rises in their concentration from 1.50 m and then decline at about 0.75 m. Manganese follows a similar trend (Elliot *et al.*, 1993, 1997).

8.5 Discussion

8.5.1 Radiocarbon chronology

The regression in figure 8.6 shows an initial rather slow rate of sedimentation (approx. 0.56 mm/a) between NZA-2805/2804 and NZA-3606 was followed by a more rapid rate (2.0 mm/a), especially after NZA-3109 (*ca.* 600 years B.P.). The Kaharoa Tephra found in core 2 at 1.11-1.13 m (see section 8.3.3) has been assigned an age of 665 ± 15 years B.P. (Lowe & Hogg, 1992; Newnham *et al.*, 1998; also see footnote #71). This tephra was not found in core 5, which constitutes the longest core and lies almost in the centre of the transect (see figures 8.4 and 8.5). Such a feature is not unusual as distal tephtras often concentrate in pockets in swamp deposits (see Elliot *et al.*, 1993, 1997). However, its presence in core 2 allows the age of the Kaharoa Tephra to be correlated with changes in the sediment texture in this core (Elliot *et al.*, 1993, 1997).

8.5.2 Sedimentology

The changes in the physical and chemical properties of the sediment cores appear to indicate significant events in the environmental history of the catchment. Stratigraphic evidence for these events is given by the conspicuously altered granulometry of the cores. These changes in grain-size distribution occur in core 1 from the base up to 0.28 m, in core 2 from 1.30 m to 0.72 m, in core 3 from 1.42 m to 0.84 m, and in core 5 from 1.32 m to 0.90 m (see fig. 8.7). These depth ranges appear to give evidence of a period of increased erosion within the catchment as the granulometry shows an abrupt increase in coarse grain-size fractions such as sand, very coarse silt and coarse silt. The reason

for this could be anthropogenic destruction of forest, leading to soil instability which results in erosion and sedimentation (McGlone, 1983, 1989; also see discussion in section 5.3.1). Kirch *et al.* (1992) found similar evidence of erosive events and forest disturbance in the form of clay bands in a lake on Mangaia, Southern Cook Islands. Whether these clay bands resulted from human activity or from natural causes (e.g. tropical cyclones, El Niño events) is unknown. Flenley *et al.* (1991) believe that a unit of silt, sand and gravel in a lake on Easter Island provides evidence for human-induced soil erosion.

The coincidence of changes in grain-size distribution with a reduction in organic matter in the above depth ranges of cores 1, 3 and 5 also supports this contention. This is thought to represent the deforestation which results in an increased inwash of inorganic matter into the swamp site. The assumption is based on the fact that the bulk of the organic input into lake sediments comes from stable organic residues derived from terrestrial soils and vegetation of the catchments, rather than from the degradation of organic matter derived from the water column (Mackereth, 1965, 1966; Oldfield *et al.*, 1985). Utilizing such association the vegetation cover appears to have recovered, which is reflected by an increasing value of organic matter and a decreasing input of coarser sediment particles into the site. Dawson (1990) encountered the same features in lake sediments on Mangaia, Southern Cook Islands, which were interpreted as being indicative of two main periods of catchment erosion. This tendency is clearly evident in cores 1, 3 and 5. Only core 2 does not show any conspicuous reduction in organic matter coincident with an increase in the sand fraction. The decrease in organic matter immediately below the top of cores 2 and 3 suggests a second period of deforestation with the same consequences, namely soil erosion and sedimentation. The decline of organic matter close to the top of the cores indicates that deforestation must have been most recent, and is probably of European origin. The only reason why the reduction in organic matter towards the top of core 2 is not as obvious as in core 3 is the fact that the first 0.30 m of this core are missing. Core 1 is also missing a distinct drop in organic content at the top. The reason for that could be its marginal location within the site. Such locations may receive more growth-promoting nutrients as a result of erosion than those which occupy a more central position (e.g. cores 2 and 3).

Further evidence of a major erosive event in the swamp catchment is provided by the sediment chemistry for core 5. In particular, the elements potassium (K), sodium (Na) and manganese (Mn) support this contention as they show a distinct peak in their concentration profile from 1.50 m to 0.75 m. This depth range corresponds with the depth ranges of core 2 (1.30-0.72 m), core 3 (1.42-0.84 m) and core 5 (1.32-0.90 m), where increased erosion is indicated by changes in their stratigraphy. There is no obvious correspondence between the stratigraphic data of core 1 and the results of the sediment chemistry of core 5. The reason for this is probably the marginal position of core 1, which has experienced a different environmental history. The high concentration levels of K, Na, and Mn within the above range can be attributed to an increased rate of inwash of freshly exposed soil during periods of reduced vegetation cover, which resulted in a reduced weathering rate of country rock and decreased input of mineral matter into the site. These conclusions correspond with the stratigraphic evidence of cores 2, 3 and 5. Indications of a second deforestation event as in cores 2 and 3 (see above) are also evident at the top of core 5, but are not as distinct as in the depth range between 1.50 m and 0.75 m.

The investigations of the clay mineralogy of core 7 reveal an increase in smectite and a decrease in halloysite with depth. As there are no obvious breaks in the mineralogy down the core, this general tendency does not constitute any evidence for an erosive event within the catchment. Rather the relative abundance of smectite in the lower parts of the core reflects poor drainage and an increased level of silica in solution, conducive to the formation of smectite, whereas the formation and persistence of halloysite in the upper parts of the core is a consequence of good drainage (Elliot *et al.*, 1993, 1997).

The high proportion of amorphous silica, in particular volcanic glass, in core 7 clearly indicates that this part of Northland was subject to airborne volcanic ash showers. The probably greatest potential of these microscopic ash layers lies in ability to act as time-marker beds. If positively identified through geochemical "fingerprinting" they could greatly enhance the radiocarbon chronology established for the site (e.g. Newnham *et al.*, 1998; Pilcher, 1996).

8.6 Conclusions

The results from the analysis of sediment texture, sediment chemistry and organic matter content provide strong evidence for a period of increased erosional activity within the catchment of the Wharau Road Swamp. This contention is particularly supported by the radiocarbon chronology of the site which implies a high sedimentation rate, especially after NZA-3109 (*ca.* 600 years B.P.).

Due to the nature of the relationship between sediment texture, sediment chemistry and organic matter content it can be assumed that the postulated erosional activity is a result of forest disturbance within the catchment of the site. The results of pollen analysis performed on core 5 and reported in Elliot *et al.* (1993, 1997) clearly support this view. After NZA-3109 (*ca.* 600 years B.P.) Elliot *et al.* (1993, 1997) observes a major decline in all important tree and shrub elements. This feature is accompanied by a sharp increase in *Pteridium esculentum* along with a substantial rise in the concentration of charcoal particles in the pollen diagram (see fig. 8.9; also see Elliot *et al.*, 1997, fig. 4b). McGlone (1983, 1989; also see section 5.3.1) associates such features with Polynesian deforestation. Chester (1986) also reports evidence of human-induced deforestation from a swamp within the Waitangi State Forest only a few kilometers south-west of the Wharau Road Swamp (see section 8.1.1). However, her signs of early human activity have been dated to between 1400 and 1350 years B.P.

Based on the above evidence from sedimentological analyses and radiocarbon dating of core material it can be concluded that the catchment of the Wharau Road Swamp was subject to deforestation commencing at *ca.* 600 years B.P. Evidence from pollen analysis and charcoal counts allows one to attribute the forest destruction to Polynesian deforestation. This rather late date for Polynesian occupancy of this near-coastal site within the Bay of Islands complies with Anderson's (1991) hypothesis of a *Short prehistory* about the period of colonisation of New Zealand (see section 2.2.1.3). Consequently, there is no evidence from the Wharau Road Swamp to support Chester's (1986) hypothesis of a considerably earlier date of colonisation of this part of the Bay of Islands region.

Wharau Road Swamp, Coastal Bay of Islands, Northland.
 Relative frequency data.
 Analyst: M B Elliot

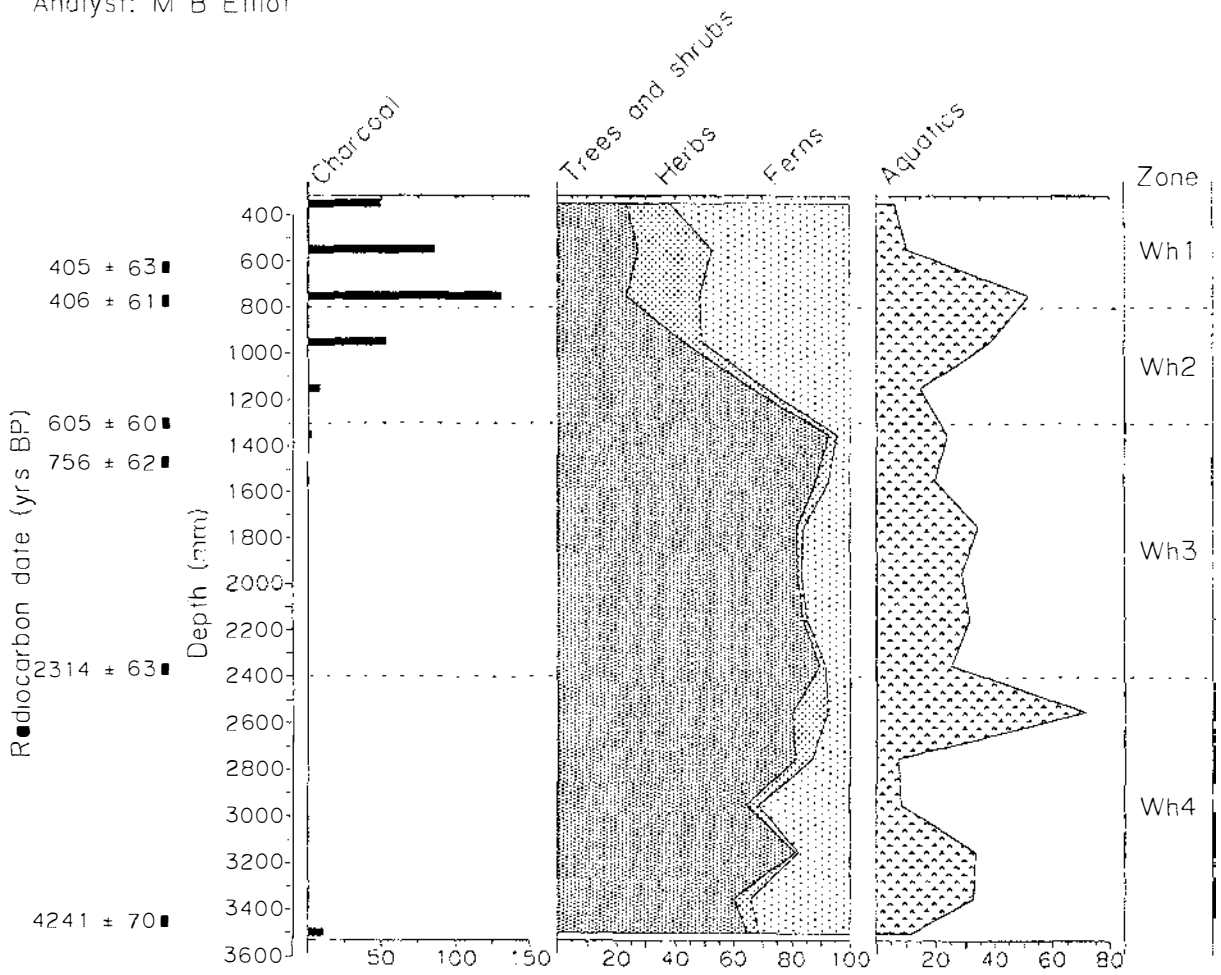


Figure 8.9: Summary pollen diagram (core 5) for Wharau Road Swamp, including its radiocarbon chronology.

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Chapter 9

LAKE TAUANUI

9.1 Description of Lake Tauanui

9.1.1 Physical setting and vegetation of the site

Lake Tauanui is situated in the central Bay of Islands district in Northland (see fig. 7.2) at latitude 35°30'06"S and longitude 175°51'32"E (NZMS 260, PO6/887332); its altitude is about 230 m a.s.l. (see fig. 9.1).

The lake occupies an area of approximately 10 ha but this varies considerably as lake levels fluctuate (see Striewski *et al.*, 1994). A small cone forms an island within the lake and may be connected to the shore at times of low lake levels (see plate 9.1). There are no inflow or outflow streams. Drainage is by seepage at the south-western end.

The lake is part of the Tauanui Volcanic Centre (Kear, 1961) which constitutes the southernmost volcanic centre of the Kerikeri Volcanics (see fig. 8.1) within the Kaikohe-Bay of Islands Volcanic District (also see sections 4.1.3.4 and 8.1.1 and fig. 4.4). The lake largely owes its formation to the eruption of lavas from the Tauanui Cone (351 m a.s.l.) which forms part of the Tauanui Volcanic Centre. The resulting lava flow [Mason's (1953:362) "Third Taheke Flow"] dammed runoff water from the Mangakahia Range and led to the formation of the lake. Thus, Lake Tauanui is not a volcanic lake (also see section 4.4.2.2 and fig. 4.12) in a strict sense, but rather the "by-product" of Late Quaternary volcanism in Northland (also see Irwin, 1975).

The geological setting of Lake Tauanui is therefore dominated by volcanic rocks. The lake proper is set within the "Third Taheke Flow" which forms part of the Taheke

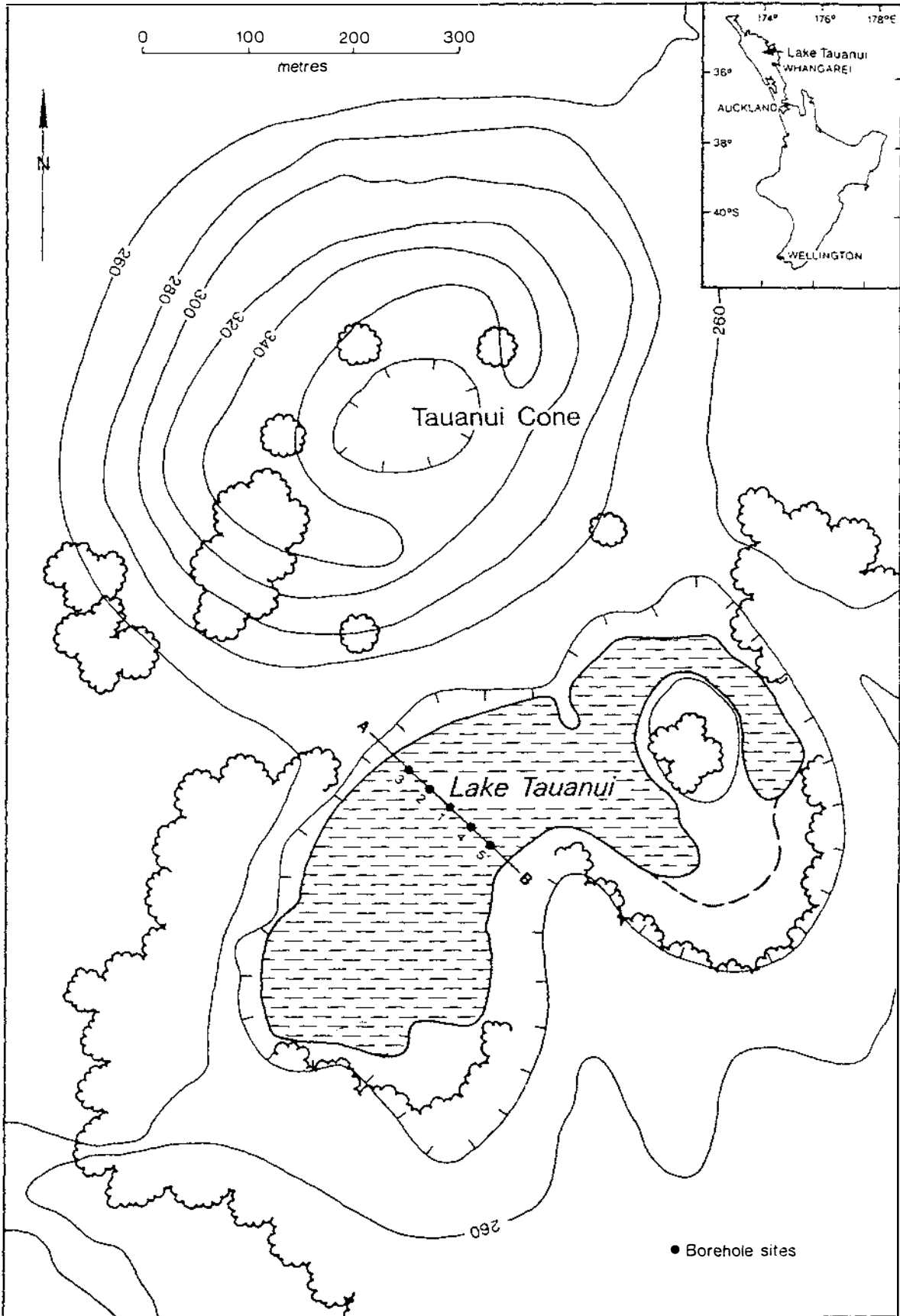


Figure 9.1: Location and physiography of Lake Tauanui. Numerical values are elevations (in meters). A—B indicates the coring transect across the lake. Numbers 1-5 signify the sediment cores collected along the transect.



Plate 9.1: Lake Tauanui, inland Bay of Islands, Northland

Basalts (see fig. 8.1) of Holocene age (Kear & Hay, 1961; also see section 4.1.3.4). The area immediately south of the lake comprises the substantially older Tangihua Volcanics of Late Jurassic to Eocene age (Kear & Hay, 1961; Thompson, 1961; also see section 4.1.3.3).

The exact age of Lake Tauanui is the matter of some uncertainty due to a lack of well established ages of the volcanic units within the Kaikohe-Bay of Islands Volcanic District (*cf.* Stipp & Thompson, 1971). However, by using geologic criteria to assess relative ages, combined with known K/Ar ages from Horeke Basalts, Muhlheim (1973) has assessed the age of Tauanui Cone as *ca.* 5000 years B.P. Radiocarbon dates (NZA 2806, 2807) of 5385 ± 81 and 5439 ± 73 years B.P., respectively, indicate her assessment is reasonable. These radiocarbon dates provide a minimum age for the lake formation as they date the onset of organic deposition. These dates were obtained from a twig fraction (NZA 2806) and a humin fraction (NZA 2807) from a portion of a sediment core retrieved from the lake at a depth of 3.69-3.74 m from the lake bottom. On this basis an age for the lake formation and final eruption of Tauanui of between 5000 and 6000 years B.P. is proposed (Striewski *et al.*, 1994).

The vegetation within the immediate vicinity of the site is characterized by dense bush that extends to the southern margins of the lake. On the northern side, including Tauanui Cone and its flanks, the vegetation is mostly improved pasture with only scattered individual trees, mostly *Beilschmiedia tawa* and *Podocarpus totara*. A dense stand of *Dacrycarpus dacrydioides* is found some 400 m north-east of the lake (Striewski *et al.*, 1994; also see plate 9.1).

The present-day vegetation as described by the Department of Lands and Survey (1980) is characterized by agricultural activities. The larger part of the catchment area is used for pastoral farming and only a small area immediately south of the lake proper still supports natural forest and shrubland as described above (also see fig. 5.2). The vegetational cover of the area during the pre-Polynesian and pre-European period was largely similar to the one described in Chapter 8: Wharau Road Swamp. The appropriate information can therefore be obtained from sections 8.2.1 and 8.2.2, respectively (also

see fig. 6.1).

The soils around Lake Tauanui clearly reflect the underlying geology. Sutherland *et al.* (1980) recognize the following soil groups: weakly to moderately leached brown loams (also see section 4.2.4) of the "Kiripaka series" within the immediate catchment of the lake and weakly to moderately leached red loams (also see section 4.2.5) of the "Papakauri series" on the Tauanui Cone. The area south of Lake Tauanui, coinciding with the Tangihua Volcanics (see above), carries a combination of weakly to moderately leached brown granular loams and clays and related steepland soils (also see section 4.2.4 and 4.2.8) of the "Te Kie series" and moderately to strongly leached yellow-brown earths and related steepland soils (also see sections 4.2.2 and 4.2.8) of the "Tautoro series".

The climate of the area around Lake Tauanui appears to be best described by meteorological data recorded at the Kaikohe Aerodrome Meteorological Station. Accordingly, the most relevant climatic parameters for the region are as follows: the mean annual precipitation (1941-1970) ranges around 1766 mm (also see fig. 4.8), with dry spells occurring in late summer or early autumn (also see fig. 4.9) and the mean annual temperature of the region averages 14.5°C (also see fig. 4.10); the predominant air-flow at Lake Tauanui is from the west (Moir *et al.*, 1986).

9.1.2 Description of sediment cores

From a transect across the deepest part of the lake (see fig. 9.1) a total of five sediment cores was collected using a modified Vallentyne mud sampler (see section 7.2.2).

Due to the stiff nature of the basal mud cores 2-5 did not penetrate the entire lacustrine sediment. Consequently these cores are substantially shorter than the one collected from borehole 1. Altogether the total length of each core ranged from 2.34 m (core 3), 2.37 m (core 5), 2.49 m (core 4) and 3.27 m (core 2) to 4.00 m (core 1) (Striewski *et al.*, 1994).

9.1.2.1 Stratigraphy

A conspicuous feature of all five sediment cores was their almost complete lack of any major stratigraphic features (e.g. laminations, changes in core constituents etc.). Figures 9.2 and 9.3 show the stratigraphy of all five cores collected from the transect (also see Appendix III.1).

This feature is particularly manifested in cores 2-5 which throughout their total length comprise only two parts of *Limus detrituosus* and two parts of *Argilla* (stratigraphic classification after Tröels-Smith (1955) [see section 7.2.3]). Only core 1 displays a slightly more complicated stratigraphy which allows it to be subdivided into four broad stratigraphic units, ranging from the sediment-water interface to 2.93 m, 2.93 m to 2.97 m, 2.97 m to 3.74 m and 3.74 m to the bottom of the core at 4.00 m (see fig. 9.2).

The uppermost stratigraphic unit (sediment-water interface to 2.93 m) of core 1 consisted of soft, dark grey/brown gyttja, comprising two parts of *Argilla* to one part each of *Limus detrituosus* and *Substantia humosa*. The middle unit (2.93 m-2.97 m) consisted of grey clay made up of four parts of *Argilla* with only traces of *Limus detrituosus* and *Substantia humosa*. The boundaries above and below this unit were clearly defined. The lower unit (2.97 m-3.74 m) immediately below can broadly be subdivided into two sub-units: The upper unit from 2.97 m-3.00 m was identical in nature to the sediment above the clay band (see above), although possibly darker in colour. The lower unit from 3.00 m-3.74 m consisted of dark brown gyttja comprising *Limus detrituosus* and *Substantia humosa* at a ratio of 2:2 with only a trace of *Argilla*. Slip marks were observed at 3.40 m and 3.47 m. The bottom unit (3.74 m-4.00 m) on the other hand was characterized by consisting solely of grey clay (*Argilla*) which showed some mottling (Striewski *et al.*, 1994).

9.1.2.2 X-ray radiography

Cores 1-3 were chosen for X-ray radiography. In these cores the following stratigraphic

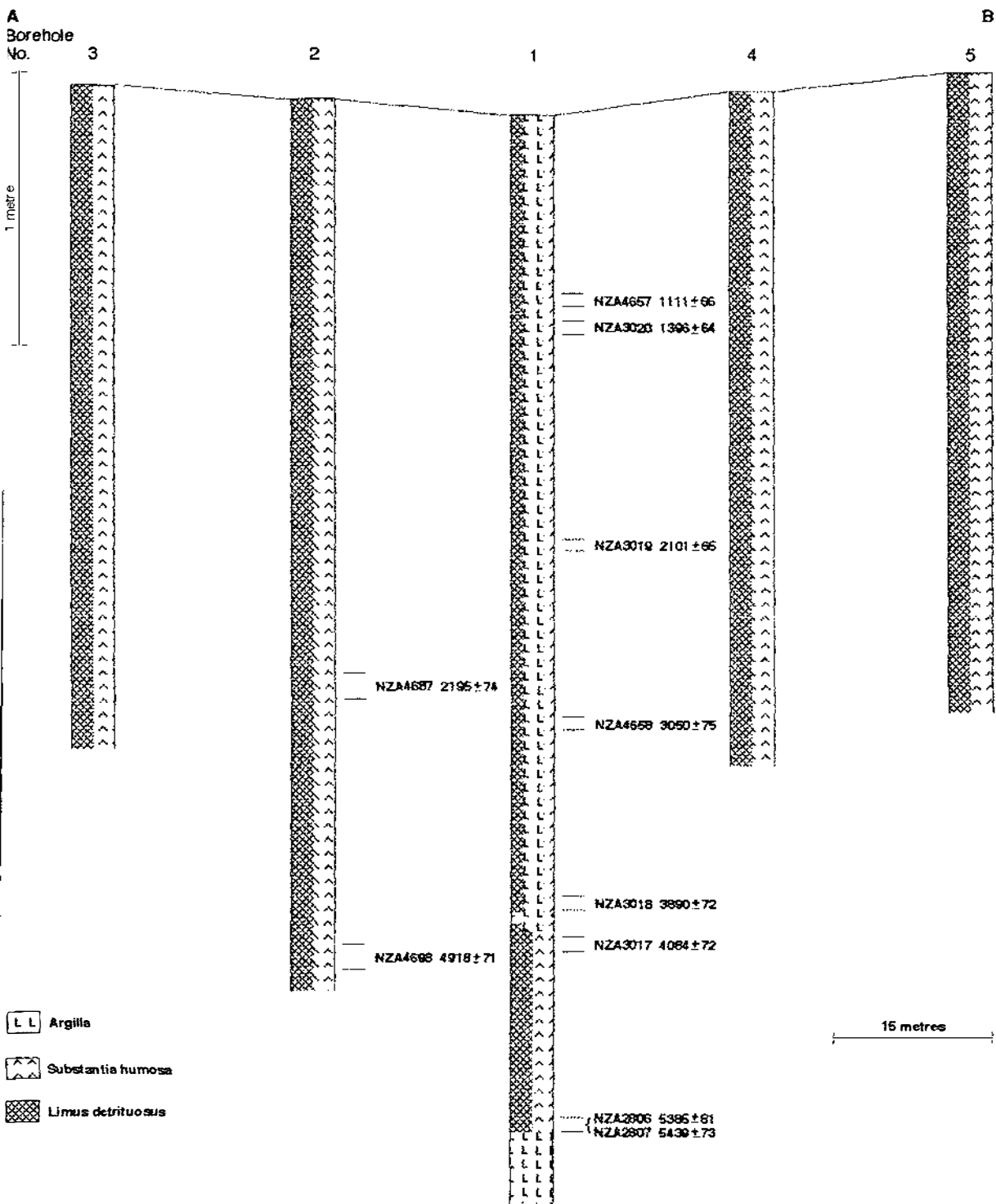


Figure 9.2: Stratigraphy for cores 1-5 (stratigraphic classification after Tröels-Smith (1955) [see section 7.2.3]), including the radiocarbon chronology established for cores 1 and 2.

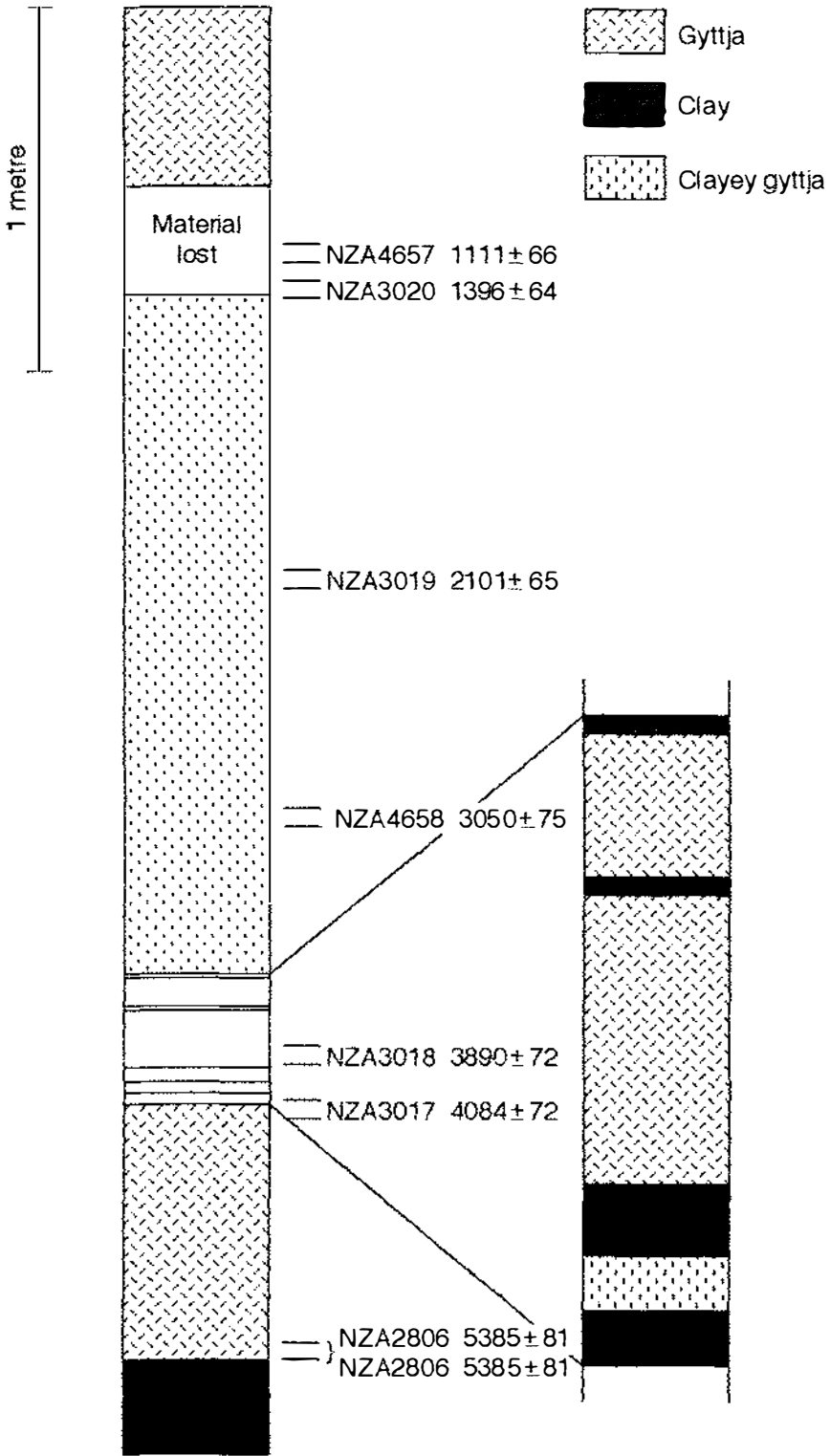


Figure 9.3: Stratigraphy for core 1, including its radiocarbon chronology.

features were encountered: core 1 shows no conspicuous changes throughout its entire length, indicating homogenous core material. There are only a few sections which appear in a lighter shade on the radiographs. These sections occur at the following stratigraphic positions within the core: 1.00-1.05 m, 2.72-2.73 m, 2.75-2.77 m and 2.82-3.00 m. The latter section is markedly lighter than the other ones (see Appendix VI.1 [radiographs of Appendix VI.1 lodged at Massey University Library]).

Core 2 is dominated by dark shades. Features such as laminar structures are not present in the core material. Occasionally the dominating dark shade of the radiographs is interrupted by a few scattered lighter bands and a few lines (see Appendix VI.2 [radiographs of Appendix VI.2 lodged at Massey University Library]).

Core 3 is also characterized by dark shades and an absence of linear features. Only a section from 1.00-1.07 m appears noticeably lighter in shade as opposed to the remainder of the core. Furthermore as in core 2 a few scattered dark lines are occasionally visible throughout the core material (Striewski *et al.*, 1994) (see Appendix VI.3 [radiographs of Appendix VI.3 lodged at Massey University Library]).

9.1.3 Radiocarbon dating

A total of eight samples from core 1 were submitted for radiocarbon dating by AMS (see table 9.1 and fig. 9.3; also see section 7.3.1).

Depth (m)	Accession No.	^{14}C (years B.P.)	$\delta^{13}\text{C}$ (‰)	Material dated
<i>Lake Taumai</i>				
0.65-0.70	NZA-4657	1111 ± 66	-31.63	Treated gyttja
0.75-0.80	NZA-3020	1396 ± 64	-30.80	Treated gyttja
1.55-1.60	NZA-3019	2101 ± 65	-30.90	Treated gyttja
2.21-2.26	NZA-4658	3050 ± 75	-31.14	Treated gyttja
2.87-2.92	NZA-3018	3890 ± 72	-32.12	Treated gyttja
3.02-3.07	NZA-3017	4084 ± 72	-30.76	Treated gyttja
3.69-3.74	NZA-2806	5385 ± 81	-27.40	Twig fraction
3.69-3.74	NZA-2807	5439 ± 73	-28.90	Humin fraction

Table 9.1: Radiocarbon of samples from core 1. The conventional ^{14}C age is expressed in years B.P. ± 1 σ based on old half life after Stuiver & Polach (1977).

The basal sample was dated for two fractions: a twig fraction which returned a date of

5385 ± 81 years B.P. (NZA-2806), and a humin fraction which returned a date of 5439 ± 73 B.P. (NZA-2807). These dates are in good agreement and afford a high degree of confidence in their accuracy. Given that they provide a chronology for the onset of organic deposition in Lake Tauanui which is considered to have formed as a result of the last eruption of Tauanui Cone at *ca.* 5000 years B.P. (see section 9.1.1) the dates (NZA-2806 and -2807) are considered to be correctly emplaced stratigraphically. Figure 9.4 shows the age-depth relationship of the radiocarbon dates from core 1.

9.2 Sedimentology of core material

The description of the sedimentology of the sediment cores extracted from Lake Tauanui will be in compliance with the format of chapter 7. The following sections will therefore be restricted to the reporting of the results from the various analyses of the core material. Detailed descriptions of the methods and materials applied were already reported in chapter 5. Of the five sediment cores collected from Lake Tauanui only cores 1, 2 and 4 (see figures 9.1 and 9.2) were used for the determination of sediment texture, sediment mineralogy and organic matter content.

9.2.1 Sediment texture

Common features of all three cores are the high values of clay-sized material (average content of approximately 85%) throughout their total length (see figures 9.5 and 9.6; also see Appendix III.2).

In all three cores the high clay content is interrupted only by peaks in the proportions of coarse particles. In cores 2 and 4 there is good stratigraphic correlation between the uppermost, coarse particle peaks of the cores as they occur at almost the same depth below the sediment surface. In core 1 the portion of coarse particles, in particular sand-sized material, is almost negligible; average values range between 0.1 and 0.3% throughout the length of the core. The distribution of coarse particle-bearing peaks in

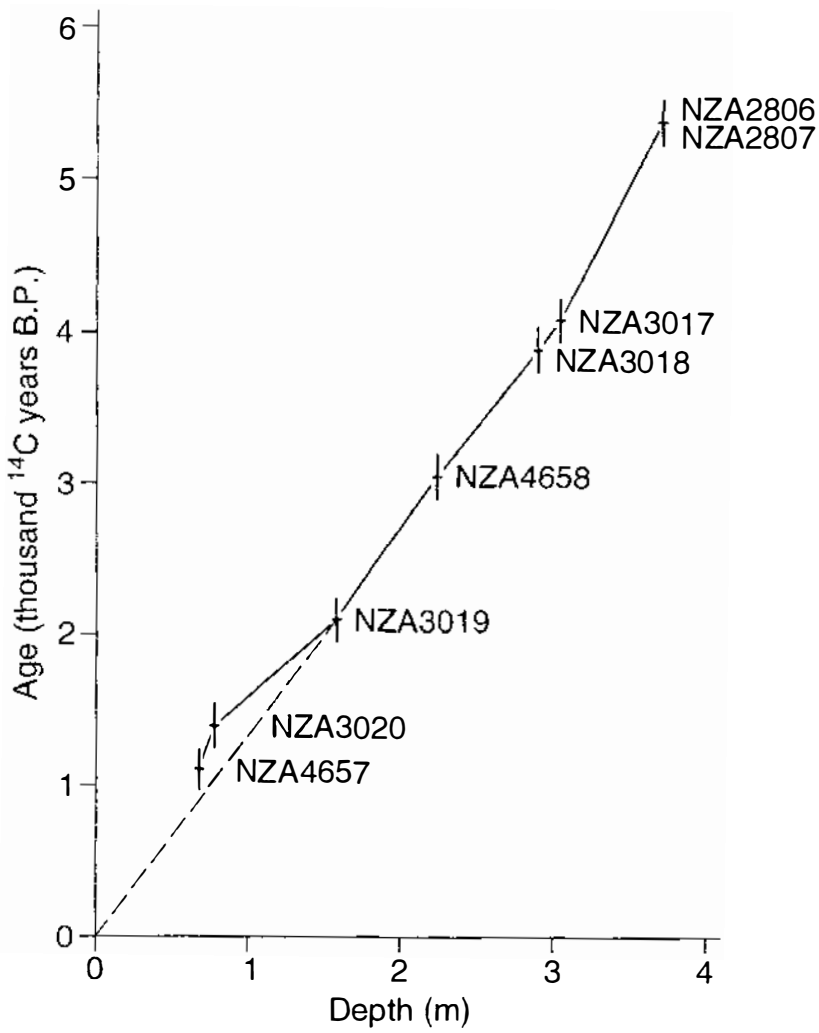


Figure 9.4: Age-depth graph for core 1. The horizontal bars represent the magnitude of statistical counting error on the ¹⁴C dates (2σ); the vertical bars indicate the length of the core segment used.

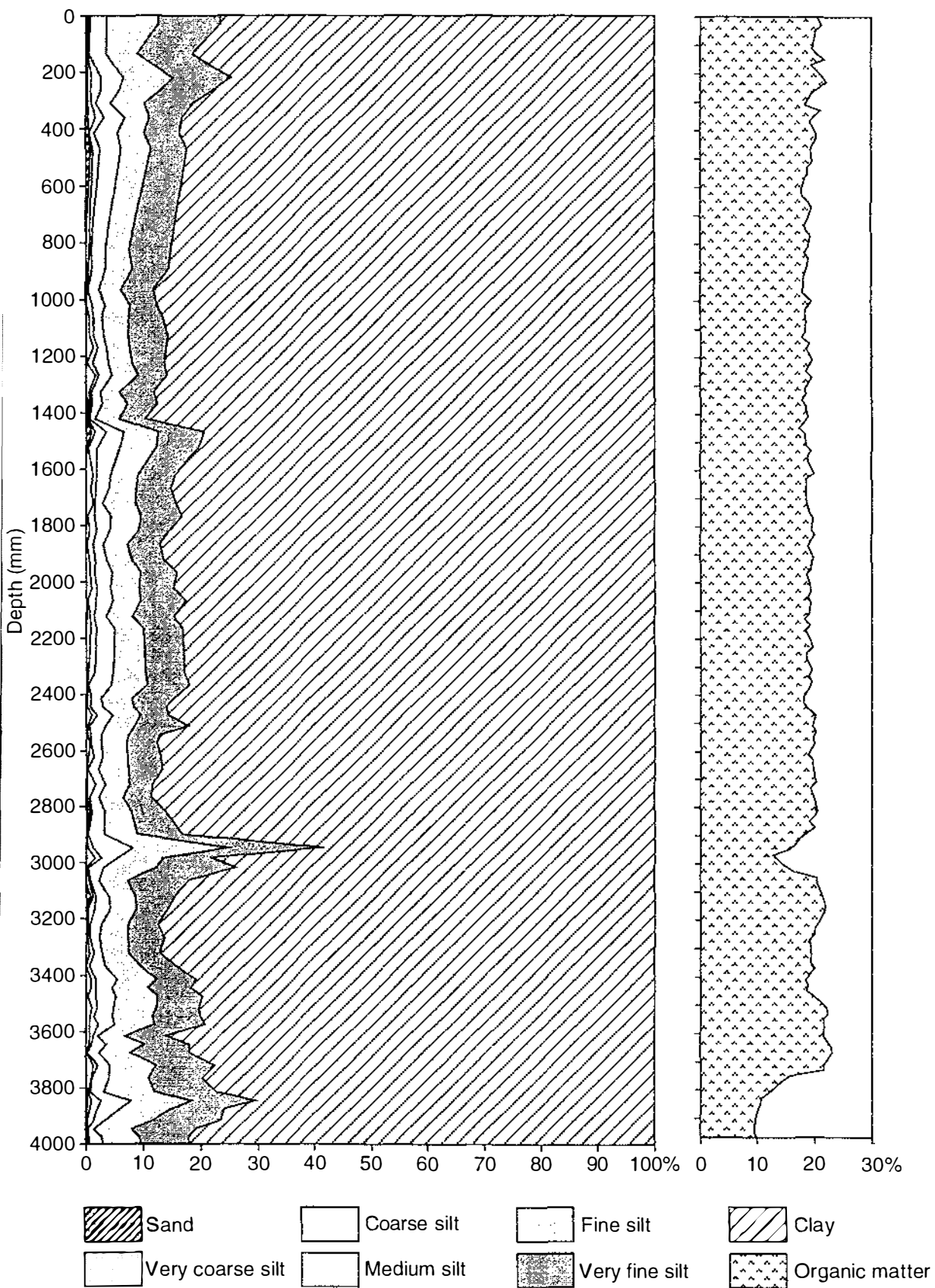


Figure 9.5: Grain-size classes and organic matter content for core 1.

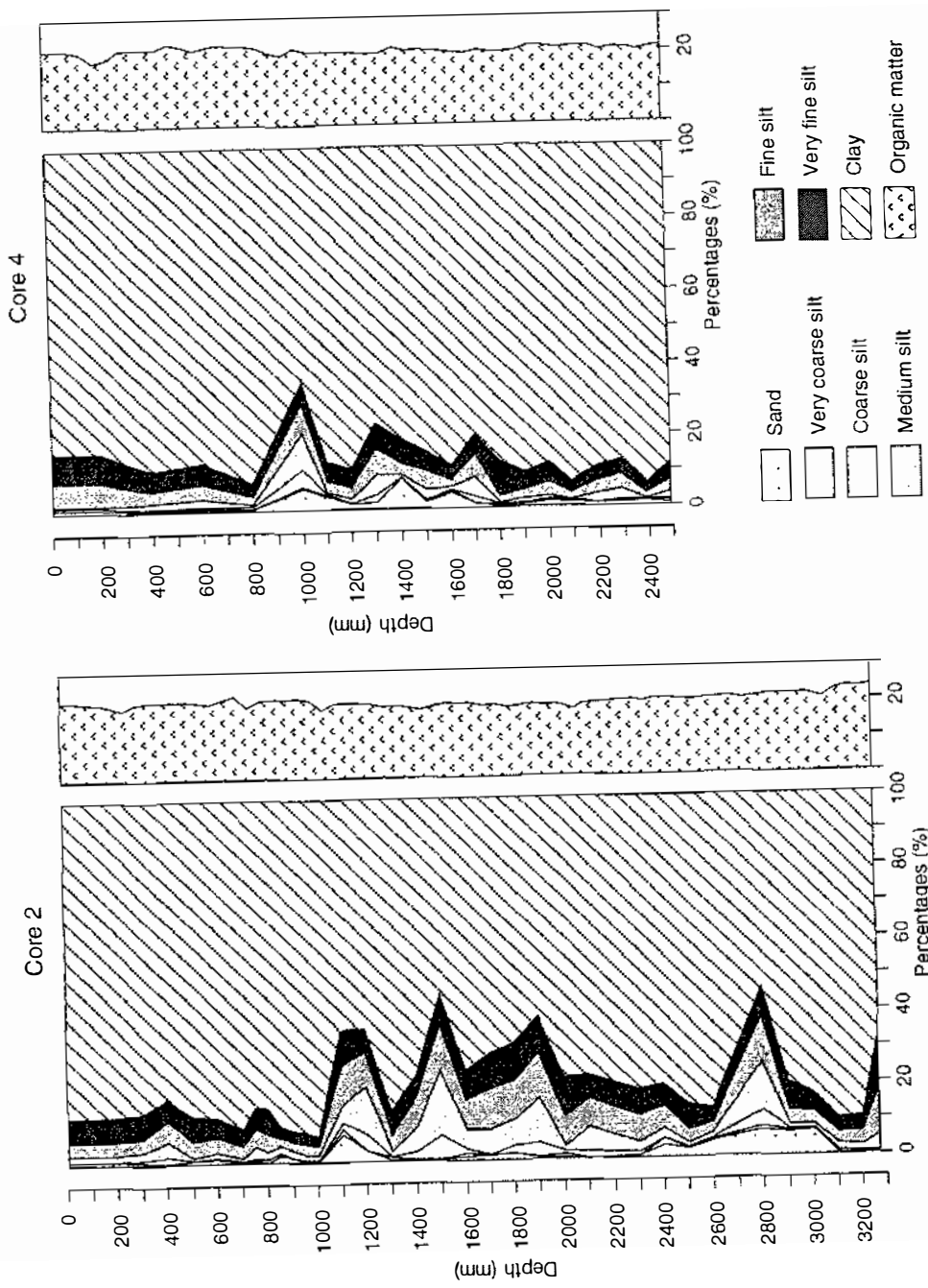


Figure 9.6: Grain-size classes and organic matter content for cores 2 and 4.

cores 2 and 4 is as follows: the lowermost peak occurs only in core 2 at 3.27 m and comprises mainly medium (4.5%), fine (13%) and very fine silt (13.7%). Sand and coarse silt contribute only negligibly. A much larger second peak at 2.80 m also occurs only in core 2. The sand fraction, which increases above 3.10 m, achieves a maximum of 7%. Coarse silt (4.2%), medium silt (13.4%), fine silt (12.7%) and very fine silt (7.6%) also peak at 2.80 m (see fig. 9.6).

A smaller third peak, which is observed in both cores, occurs at 2.40 m and 2.29 m in cores 2 and 4, respectively. This is mainly made up by elevated values of coarse silt (1.4%), medium silt (3.5%), fine silt (5.4%) and very fine silt (5.4%). A fourth larger peak is again common in both cores. In core 2 it occurs at 1.90 m and in core 4 at 1.70 m. The trend is most pronounced in core 2 where the entire silt fraction contributes to the peak except for very coarse silt. Coarse, medium, fine and very fine silt assume the following fractions respectively: 3.8%, 12.4%, 12.5% and 9.8%. Sand does not contribute to this peak, though slightly elevated at 1.80 m. A similar trend is observed in core 4 (see fig. 9.6).

A fifth peak is situated at 1.50 m in core 2 and at 1.30 m in core 4. In core 2 the constituent grain-size fractions are made up of coarse silt (6.6%), medium silt (17.5%), fine silt (12.9%) and very fine silt (8.2%). Sand and very coarse silt have very low values. Core 4 shows a similar pattern though a peak in sand at 1.40 m (8.5%) precedes the main peak in silt fractions (see fig. 9.6).

The uppermost peak is situated at 1.10 m (-1.20 m) and 1.00 m for cores 2 and 4, respectively. In core 2 this peak is characterised by values which are on the average twice as great as those immediately above or below. For sand this peak value is 7.8%, for coarse silt 4.6%, medium silt 12.9%, fine silt 11% and for very fine silt 9.6%. Core 4 has a similar pattern (see fig. 9.6).

Within core 1 the proportion of the individual silt fractions and the clay fraction throughout the length of the core are almost identical to those in cores 2 and 4. The overall silt fraction averages around 15% and displays only peaks at 3.845 m (29%),

from 3.1225 to 2.95 m (26 to 42%), at 1.4675 m (20%) and at 0.22 m (25%) (see fig. 9.5). The sand fraction in core 1 slightly deviates from this pattern. Unlike cores 2 and 4 which show a number of peaks in the sand-fraction, core 1 is characterized by a rather uniform pattern. The generally low portion of sand-sized particles within the range of 0.1 to 0.3% (see above) is only interrupted at 3.1225 m, 1.4675 m and from 0.465 to 0.415 m where values of 0.8%, 1% and $\approx 0.7\%$, respectively, are encountered (see fig. 9.5).

9.2.2 Organic content

The organic matter content in all three cores is characterised by its consistency throughout the total length of the cores (see Appendix III.3). Values range between 20 and 22% (see figures 9.5 and 9.6). Only core 1 shows a distribution slightly different from the ones from cores 2 and 4. Here, the organic matter content shows noticeably low values in two places: the first occurs in the lowermost part of the core where values gradually rise from a minimum of about 10% at 4.00 m to about 22% at 3.73 m. From there values remain reasonably stable to about 3.03 m. From 3.03 to 2.87 m the organic matter content declines substantially, assuming a minimum of about 13% at 2.97 m. Thereafter, from 2.87 m to the sediment surface values return to their previous levels of around 20-22% (see fig. 9.5).

9.2.3 Sediment mineralogy

The sediment mineralogy of the sediment sequences from Lake Tauanui was determined by analyzing samples from selected stratigraphical positions from core 1 and 2 by means of XRD, DTA and petrological microscopy (see section 7.2.6.3).

Samples collected from core 1 were analysed for their mineralogy in the $<2 \mu\text{m}$ -, 2-20 μm - and $>20 \mu\text{m}$ -fractions (see Appendix III.4). Predominant minerals in the $<2 \mu\text{m}$ -fraction are kandite and amorphous silica. Both mineral groups constitute the bulk of the

entire mineral phase of this fraction. Their respective proportions range from about 35 to 55% (kaolinite) and 20 to 50% (amorphous silica). The 2-20 μm -fraction mainly comprises quartz, feldspar, hornblende and amorphous silica. Throughout the length of core 1 their values fluctuate around 15% (quartz), 20% (feldspar), 10% (hornblende) and 55% (amorphous silica). With respect to quartz and feldspar the $>20 \mu\text{m}$ offers a similar picture. Apart from the occurrence of diatoms, plant opal and volcanic glass the proportions of other mineral groups in this fraction is rather negligible. Diatoms and plant opal are present throughout the length of core 1 with proportions ranging from 30 to almost 70% and 10%, respectively; volcanic glass on the other hand occurs only at 1.525 m in a larger quantity (38%).

In core 2 the clay ($<2 \mu\text{m}$) and silt (2-62 μm) fraction was analysed to a depth of 1.90 m below the sediment surface. Results are presented in figure 9.7 for samples from 0.90 m, 1.50 m and 1.90 m below the sediment surface.

All samples revealed a predominance of material with a lattice d-spacing of 0.7 nm ($14^\circ 2\theta$). A spacing of 0.7 nm ($14^\circ 2\theta$) is diagnostic for the first order XRD peak for kaolinite and halloysite (both 1:1 layer-type, non-expanding clay minerals), as well as for the second order XRD peak for smectite, vermiculite and chlorite. The latter are 2:1 layer type clay minerals with a first order d-spacing of approximately 1.4 nm ($7^\circ 2\theta$). Heat treatment resulted in a disappearance of the 0.7 nm ($14^\circ 2\theta$) peak indicating that the constituent mineral was either kaolinite or halloysite. Transmission electron microscope (TEM) examination showed that halloysite is the dominant mineral. Halloysite occurs in three different morphological forms: "tubular halloysite", "curled flake halloysite" and "circular halloysite". The occurrence of the "tubular halloysite" is negligible and the "curled flake halloysite" represents the bulk of the mineral. Circular halloysite was present in minor amounts.

Apart from the halloysite, the XRD diffractograms also show three minor, one moderate and one major XRD peaks representing 1.4 nm ($14^\circ 2\theta$) minerals (smectite/vermiculite/chlorite). The minor peaks occur at 0.10 m, 0.90 m and 1.50 m, the moderate one at 1.70 m and the major one at 1.90 m (see fig. 9.7)

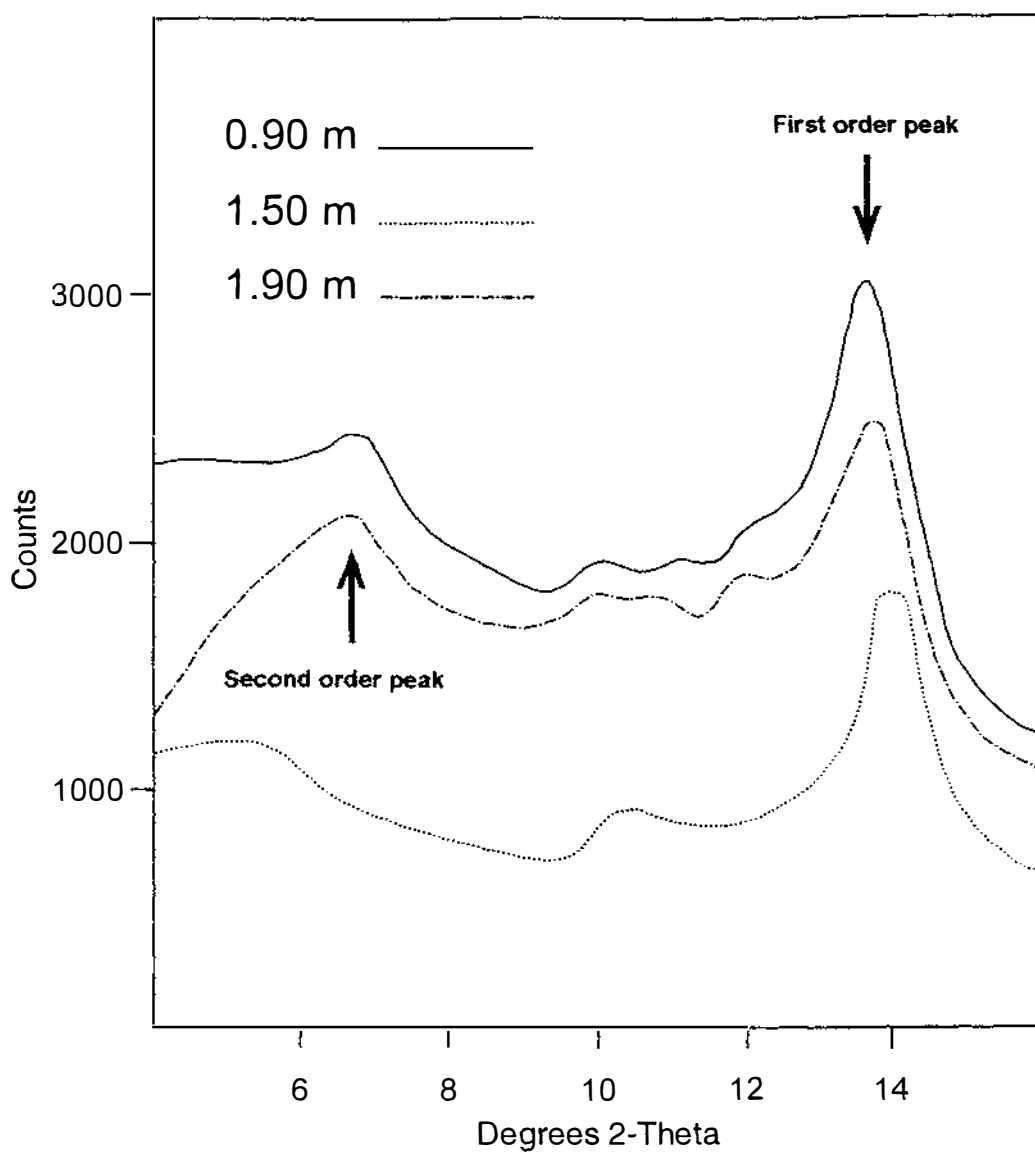


Figure 9.7: X-ray diffractograms from core 2, at 0.90 m, 1.50 m and 1.90 m below the sediment surface. Note first order peaks (halloysite) for 0.90 m, 1.50 m and 1.90 m at $14^{\circ}2\theta$, and second order peak for 1.90 m at $7^{\circ}2\theta$.

The petrologic analysis of the sand fraction revealed a dominance of volcanic glass, minor amounts of quartz, traces of feldspar and some Fe-oxides (probably haematite). The quartz/volcanic glass ratio is about 1:10 and continues throughout the core with a few minor variations.

9.3 Discussion

9.3.1 Radiocarbon chronology

The age-depth relationship in figure 9.4 suggests a slow rate of sedimentation between NZA-2806 and NZA-3017 which was followed by a more rapid rate between NZA-3017 and NZA-3019. The slightly steeper gradient between NZA-3019 and NZA-3020 indicates a noticeable increase in the sedimentation rate after 2101 ± 65 years B.P. Thereafter, a decline in gradient between NZA-3020 and NZA-4657 implies a reduced sedimentation rate. This trend probably continues until the present (see fig. 9.4; extrapolation from NZA-4657) (Striewski *et al.*, 1994; *cf.* Elliot *et al.*, 1998).

9.3.2 Sedimentology

In cores 2 and 4 changes in the environmental history of the catchment of the lake are inferred from shifts in the granulometric composition of the sediment. Changes in grain-size distribution are reflected by a shift from predominantly fine-grained to more coarse grained fractions in core 2 at 1.10 m (-1.20 m), 1.50 m, 1.90 m, 2.40 m, 2.80 m and 3.27 m and in core 4 at 1.00 m, 1.30 m, 1.70 m and 2.29 m.

Reineck & Singh (1975) argue that the grain-size of a clastic sediment is a measure of the energy of the depositing medium, and hence coarse sediment peaks may indicate periods of increased erosion within a lake catchment. However, Binford (1983) describes changes in grain-size distribution from Guatemalan lakes which indicate that

disturbance-induced erosion results in greater influx of very fine inorganic particles (i.e. silt- and clay-sized sediments). At Lake Tauanui the period when human-induced erosion occurs corresponds with a sedimentation characterised by high clay content. Reasons for this could be recurring disturbance of the forest leading to soil instability which in turn results in erosion and sedimentation. Other explanations, such as direct input of volcanic ash, or a shift in lake level, bringing the shoreline closer to the coring site, are also possible. McGlone (1983, 1989; also see discussion in section 5.3.1) describes soil erosion associated with Polynesian deforestation. Kirch *et al.* (1992) report evidence for a major erosive event (either natural or human-induced) in the form of clay bands in a lake on Mangaia, Southern Cook Islands.

Evidence for periods of temporary soil instability, as indicated by changes towards coarser grain-size grades (see above), also appears to be provided by the sediment mineralogy. The results of the XRD analyses from core 2 seem to support the contention that there was an increased period of erosion at 1.10 m (-1.20 m), 1.50 m and 1.90 m. As the XRD record for core 2 ends at 1.90 m the coarse particle-bearing peaks in the sediment texture below that depth can not be discussed here.

The dominant mineral at the above stratigraphic positions is halloysite. The shape of the XRD pattern for this mineral appears to be linked to these phases of increased erosional activity within the lake's catchment. During periods of enhanced erosional activity the peaks in the XRD pattern appear relatively broad and low, whereas they are relatively sharp and higher outside these periods of erosion. This feature is particularly significant as the height and sharpness of a peak in a diffractogram reflects the degree of crystallinity of a mineral (i.e. the higher and sharper the peak the more crystalline the mineral). Based on the appearance of the second order peak of halloysite it seems that the halloysite deposited in the lake during periods of enhanced erosional activity is more amorphous (or less crystalline) than the halloysite laid down during non-erosive events. Nevertheless, irrespective of its degree of crystallinity this mineral is more likely to have been washed into the site than to have formed *in situ* (J Kirkman, pers. comm., 1994).

In core 1 evidence from the analysis of sediment texture and organic matter content also

points to a number of periods of enhanced soil instability within the lake's catchment. However, unlike the textural evidence for periods of enhanced catchment disturbance in cores 2 and 4 which mainly occur in the sand-fraction, the ones in core 1 occur (almost) exclusively in the silt-fraction. Sharp increases in the proportion of silt-sized material occur at 3.845 m, and from 3.1225 to 2.95 m, at 1.4675 m and at 0.22 m (see fig. 9.5). With respect to their stratigraphical position in core 1 these peaks largely overlap with those peaks in the sand- (and silt-) fraction observed in cores 2 and 4.

Furthermore, the more pronounced peaks in the silt-fraction in the lower part of core 1 are also accompanied by substantial breaks in the course of the organic matter content which assume minimum values between 3.73 and 4.00 m and 2.87 and 3.03 m (see fig. 9.5). The peaks in the silt-fraction at 1.4675 m and 0.22 m are not accompanied by any noticeable changes in organic matter content. This feature is consistent with the evidence in cores 2 and 4.

An increase in more coarse-grained inorganic material accompanied by a decline in the organic matter content was also encountered in cores 1-5 at the Wharau Road Swamp and interpreted as evidence for a period of increased erosion within the catchment (for a fuller discussion see section 8.5.2).

The reason for the more fine-grained nature of the inorganic material washed into the lake during periods of enhanced catchment erosion lies mainly in the position of core 1 along the transect from which the sediment cores were collected (see fig. 9.1). While core 1 lies in the centre of the transect and thus only receives the most fine-grained material washed into the lake during periods of enhanced erosional activities; cores 2 and 4 are situated much closer to the shore. They are therefore likely to receive the more coarse-grained particles of the sediment input into the lake.

9.4 Conclusions

The analyses of sediment texture and sediment mineralogy especially from cores 1 and 2

provide evidence of repeated periods of soil instability within the catchment of Lake Tauanui. Based on the oldest radiocarbon dates from this chronology deposition of organic material in the lake which probably formed *ca.* 5500 years B.P. is likely to have started at *ca.* 5400 years B.P. (NZA-2806/2807). Increased quantities of inwashed silt-sized inorganic material accompanied by minimum values of sediment organic matter content strongly suggest that during this period of time the catchment of Lake Tauanui was subject to soil instability leading to accelerated deposition of material into the lake (also see discussion in section 8.5.2). The combination of both features strongly suggests a reduced vegetational cover within the lake's catchment as the cause for these erosional activities (also see discussion in section 8.5.2). This feature is largely supported by pollen analysis performed on core 1 and reported in Striewski *et al.* (1994) and Elliot *et al.* (1998). Accordingly, only few trees or shrubs were present in the pollen source area at the time of the beginning of organic deposition in Lake Tauanui (see fig. 9.8; also see Elliot *et al.*, 1998, fig. 4b).

The remainder of the above sedimentologically-demonstrated erosional events mainly occur in Elliot *et al.* (1998) pollen zone "T2" (3.15 m-1.25 m; *ca.* 4300 years B.P.-*ca.* 1850 years B.P.). This pollen zone is characterised by repeated forest disturbance in the form of oscillating peaks and troughs in the forest taxa throughout. This feature is also reported to have been accompanied by catchment erosion. Elliot *et al.* (1998) regards the forest disturbance as being climate-controlled and ascribes an increased occurrence of summer drought and the effects of cyclones to the marked erosional activity within the catchment. Furthermore, the second silt-bearing peak between 2.95 and 3.1225 m in core 1 is accompanied by a charcoal peak in the pollen diagram at 3.00 m (see fig. 9.8) which is dated to *ca.* 4000 years B.P. Elliot *et al.* (1998:30) attributes this feature to a fire in the lake catchment which "is followed immediately by inwash of clay sediment assumed to be the result of catchment erosion". Hence, there is strong support from sedimentologically- as well as palynologically-based evidence for a period of enhanced catchment erosion as a result of a reduced vegetational cover at around 4000 years B.P.

The third silt-bearing peak at 1.4675 m is accompanied by a general decline in all arboreal taxa (see fig. 9.8) and thus can be assumed to be the result of forest instability.

Lake Tauanui, inland Bay of Islands, Northland.
 Relative frequency data.
 Analyst: M B Elliot

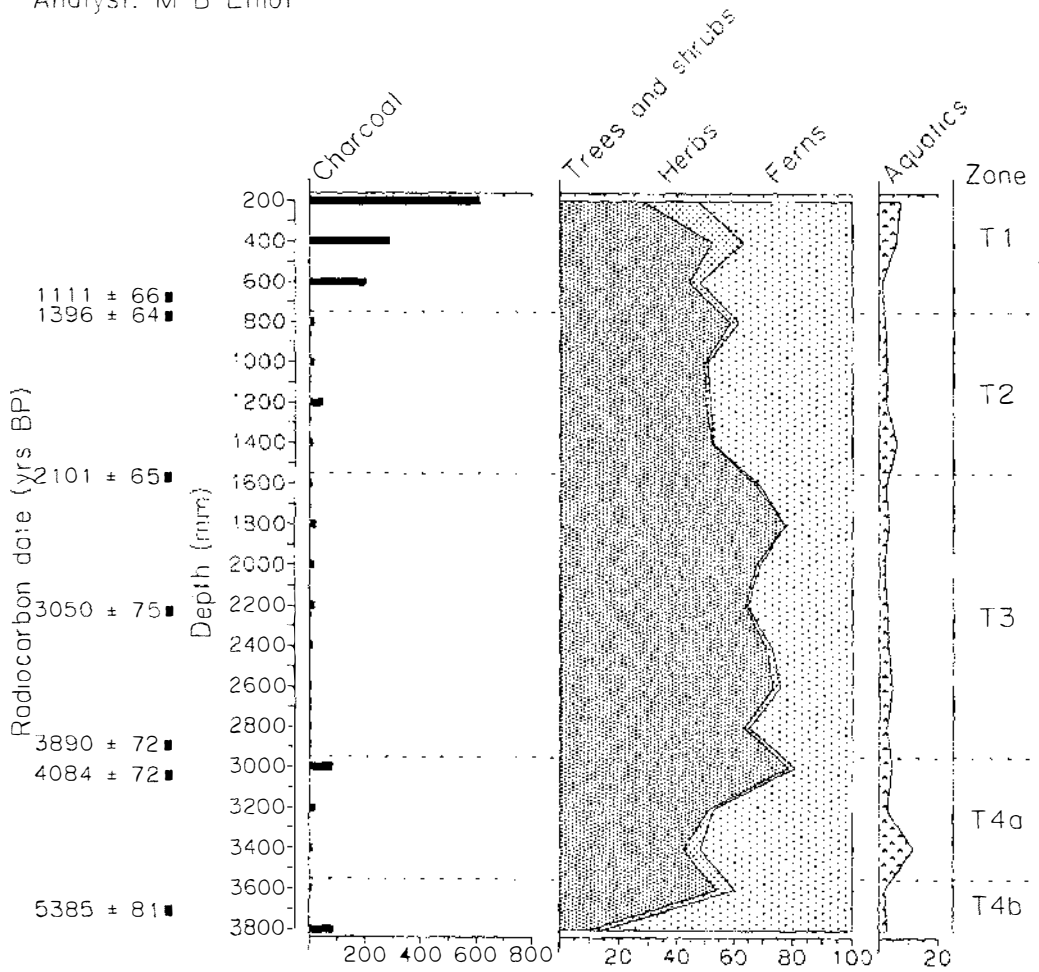


Figure 9.8: Summary pollen diagram (core 1) for Lake Tauanui, including its radiocarbon chronology.

This view is supported by Elliot *et al.* (1998) who describe the pollen record from Lake Tauanui for the period from *ca.* 4300 years B.P.-*ca.* 1850 years B.P. as being characterized by oscillating peaks and troughs in all forest taxa (also see fig. 9.8).

The uppermost silt-bearing peak in core 1 at 0.22 m falls into Elliot *et al.* (1998) pollen zone "T1a" (0.65 m-0.00 m; *ca.* 1100 years B.P.-present) which is characterized by catastrophic forest disturbance. Elliot *et al.* (1998) consider these disturbances to be the result of early Polynesian activity within the catchment and dates their onset to about 1100 years B.P. This date substantially pre-dates the above sedimentological evidence which, through extrapolation⁸⁸ in the radiocarbon chronology, places the onset of this event at *ca.* 350 years B.P.

Based on the above evidence the following conclusion can be drawn: since the beginning of organic deposition into Lake Tauanui about 5400 years B.P. sedimentological evidence suggests that the catchment has been subject to four major periods of enhanced erosional activity. In association with the pollen record of the site the first three of these events can clearly be attributed to natural causes, probably climatically-controlled forest instability. Only the uppermost sedimentologically-evidenced catchment disturbance, dated to 350 years B.P., can clearly be attributed to Polynesian forest clearance in this locality.

The sedimentologically-/palynologically-demonstrated evidence of Polynesian forest disturbance in the uppermost part of core 1 from Lake Tauanui corresponds closely with the evidence for anthropogenic disturbance in the catchment of Wharau Road Swamp (Chapter 8) in the coastal Bay of Islands.

⁸⁸The date for the onset of the sedimentologically-demonstrated catchment disturbance at 0.22 m was determined through extrapolation in the radiocarbon chronology along a line between NZA-3019 and the origin of the age-depth graph (see fig. 9.4).

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Chapter 10

LAKE TAUMATAWHANA

10.1 Description of Lake Taumatawhana

10.1.1 Physiography and vegetation of the site

Lake Taumatawhana is situated in the locality of Onepu in the Aupouri Peninsula about halfway between Houhora and Te Kao on the west of the Far North Road (see figures 7.2 and 10.1) at latitude $34^{\circ}43'15''\text{S}$ and longitude $173^{\circ}01'08''\text{E}$ (NZMS 260, N03/129203). The lake occupies an area somewhat less than 1 ha (see plate 10.1) within a block of land administered by the Department of Conservation within which, adjacent to the lake, is a 9.8 ha parcel designated as a proposed historic reserve (Maingay, 1991). This historic reserve features two well-preserved *pa* sites which overlook the lake on the southern side and an extensive area of early Polynesian gardens to the north (Maingay, 1991) (see fig. 10.1).

The lake lies *ca.* 30 m a.s.l. and formed as part of coastal progradation processes that followed the post-glacial sea-level rise. Prevailing westerly winds and aeolian process led to extensive dune formation and the creation of the Aupouri Peninsula, a large tombolo linking the northern archipelago to mainland Northland (see section 4.1.3.5; also see fig. 10.1). Within this extensive dune system lie numerous small lakes and peat swamps formed in the trailing arms of parabolic dunes and also between such dunes where drainage has been impeded by dune movement. Lake Taumatawhana is one such lake in this system and at its eastern end drains by seepage into a larger peat swamp which lies within a large parabolic dune. Within Green & Lowe's (1987) classification of New Zealand lakes Lake Taumatawhana is recognized as a wind-blown dune lake (see section 4.4.2.1 and fig. 4.1.2). The dunes within which Lake Taumatawhana formed

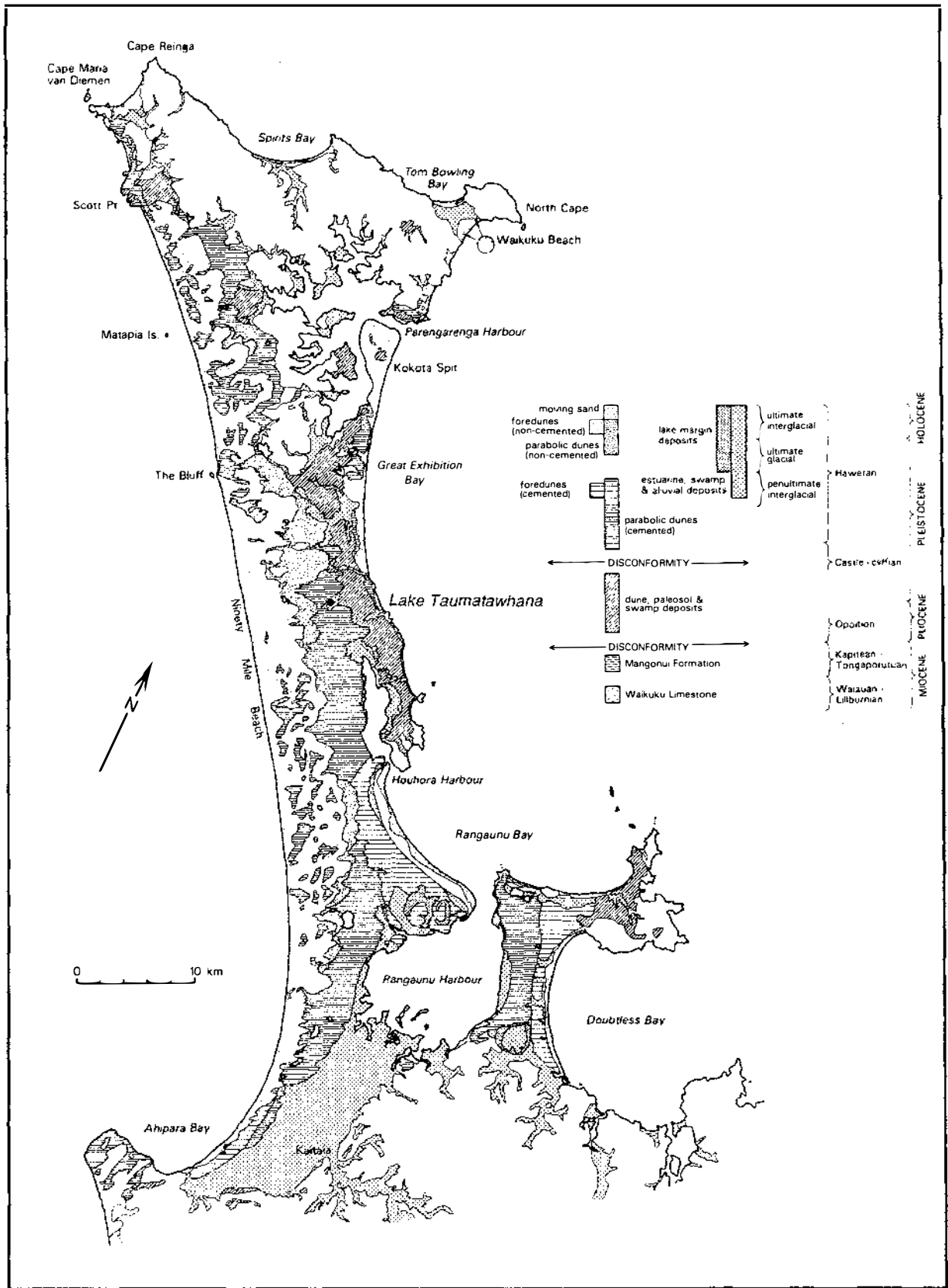


Figure 10.1: Geological setting (Upper Cenozoic) of the Aupouri and Rangiawhia Peninsulas. Lake Taumatawhana lies in the central part of the Aupouri tombolo (modified after Brook & Thrasher, 1991).



Plate 10.1: Lake Taumatawhana, central Aupouri Peninsula, Northland.

are believed to be of Holocene age (see fig. 10.1) and radiocarbon dating of basal sediments for both the lake and adjacent swamp confirms this view having returned ages of 4883 ± 64 yr B.P. (NZA-3486) and 4792 ± 70 yr B.P., respectively (see tab. 10.1) (Elliot *et al.*, 1995; Striewski *et al.*, 1994).

The modern vegetation in the area surrounding the lake consists chiefly of *Leptospermum* scrub with numerous small *Coprosma* and *Pomaderris* shrubs, scattered *Cordyline australis* and exotic wattles (*Acacia* spp.). The margins of the lake, which are in many parts overhung with *Leptospermum*, support a variety of Restionads and Cyperaceae members as well as marginal clumps of *Phormium tenax*, *Typha orientalis* and numerous aquatic species including *Myriophyllum* which extend out into the water body forming a marginal floating mat. The adjacent peat swamp is in part dominated by *Typha orientalis* in the wetter areas, and in part of *Leptospermum* on the outer drier zones. Scattered slumps of *Phormium tenax* are present and also individual *Cordyline australis* trees. *Gleichenia dicarpa* and *Blechnum minus* are common and a number of swamp tolerant forbs persist including various members of the Asteraceae family. Many of the surrounding low hills formed by the sand dunes are vegetated by pasture grasses, the commonest species of which are *Anthoxanthum odoratum* and *Pennisetum clandestinum*. There are several plantations of *Pinus* in the surrounding district, including the extensive Aupouri Forest extending up the West Coast (Elliot *et al.*, 1995; Striewski *et al.*, 1994).

The modern land use, as recognized by the Department of Lands and Survey (1980a), is dominated by pastoral farming to the north, west and south of Lake Taumatawhana. East of the site the landscape is dominated by natural duneland vegetation (also see fig. 5.2).

The soils surrounding Lake Taumatawhana are a combination of Organic soils of the Ruakaka series (see section 4.2.7) and weakly weathered yellow-brown earths of the Pinaki series (see section 4.2.3) (Sutherland *et al.*, 1979).

The climate of the area around Lake Taumatawhana is characterized by a mean annual precipitation of around 1200 mm (1941-1970; see fig. 4.8; also see section 4.3.2.2). The

temperatures range between 16 and 18°C during the summer, and between 10 and 13°C during the winter months (see fig. 4.10; also see section 4.3.2.3). The prevailing winds in this part of Northland mainly blow from the south (see fig. 4.7; also see section 4.3.2.1).

10.1.2 Description of sediment core

Using a modified Vallentyne mud sampler (see section 7.2.2) one sediment core, 4.46 m long, was recovered from 6.5 m of water from the deepest part of the lake (see fig. 10.2) (Elliot *et al.*, 1995; Striewski *et al.*, 1994).

10.1.2.1 Stratigraphy

The stratigraphy of the core is rather simple and can broadly be subdivided into three units: 0.00-4.00 m black gyttja; 4.00-4.46m black gyttja with progressively increasing amounts of sand towards to bottom of the core (Elliot *et al.*, 1995; Striewski *et al.*, 1994) (see fig. 10.3; also see Appendix IV.1).

10.1.2.2 X-ray radiography

Radiographs taken of the core collected from the site cover the entire length of the sediment core.

Unlike the radiographs obtained from the cores from Lake Tauanui (see section 9.1.2.2) the images from Lake Taumatawhana indicated some changes in the granulometry of the core material; furthermore laminar structures also occurred almost throughout the entire length of the core.

Within the first meter (0.00-1.00 m) the radiographs display an extremely light section

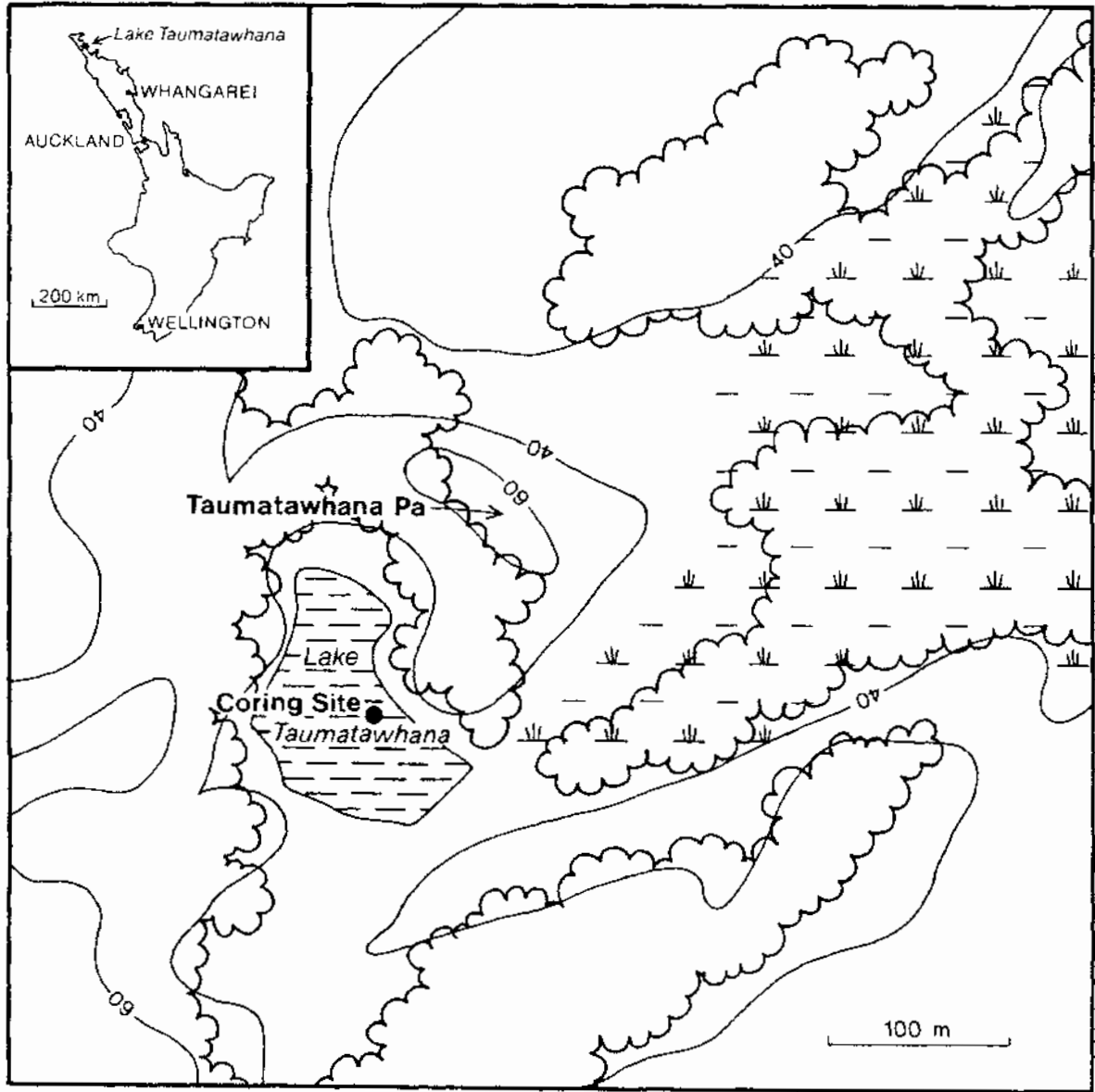


Figure 10.2: Location and physiography of Lake Taumatawhana. Numerical values are elevations (in meters).



Figure 10.3: Stratigraphy of the sediment core from Lake Taumatawhana, including its radiocarbon chronology.

extending from 0.00 m to about 0.37 m. Immediately below, ranging from 0.37 m to 0.44 m lies a section which is characterised by a number of fine laminations averaging about three laminae per 0.01 m core length.

The radiographs of the second meter (1.00-2.00 m) are characterised by predominately light shades (see above). This overall feature is only interrupted by a number of laminations which are chiefly concentrated in three sections ranging from: 1.39-1.41 m, 1.87-1.91 m and 1.97-1.98 m.

This feature is repeated in the third meter (2.00-3.00 m) where a few fine laminae occur between 2.61-2.625 m, 2.765-2.805 m and 2.86-2.93 m.

Within the fourth meter (3.00-4.00 m) laminae are also encountered between 3.13 m and 4.00 m. Within this range they are rather irregularly distributed. Their appearance is not uniform but shows some variations. From 3.13 m to 3.65 m the laminae are almost inconspicuous and lie relatively far apart which results in only a few laminae per 0.10 m core length. However between 3.65 m and 3.83 m they are well defined and occur at a rate of about 12 laminae per 0.01 m. From 3.83 m towards the bottom of this section their appearance becomes less well-defined and they gradually phase out.

This trend continues into the bottommost section of the core (4.00-4.46 m) which is devoid of any laminations and is almost uniform in appearance. For more detail see radiographs in Appendix VII.1 (radiographs of Appendix VII.1 lodged at Massey Library).

10.1.3 Radiocarbon dating

Seven samples from the lake and an additional sample from the adjacent swamp (see section 10.1.1) were radiocarbon dated by AMS (see tab. 10.1 and fig. 10.4). The material dated was bulk sediment obtained from 0.05-0.06 m-length core segments. No dateable plant macrofossils were present.

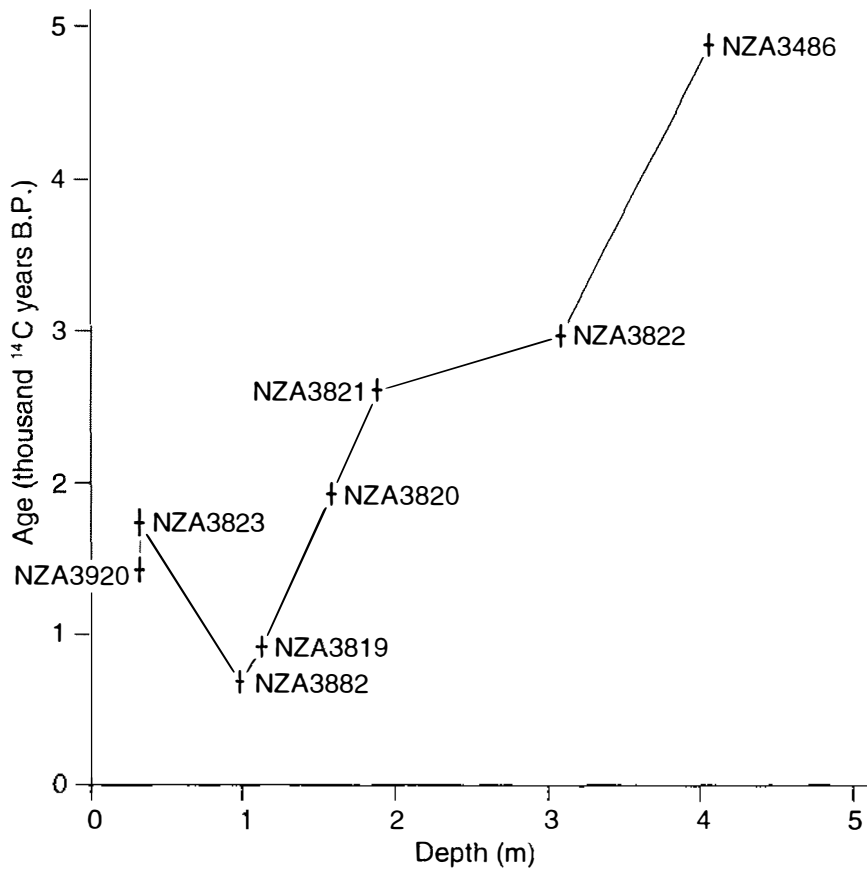


Figure 10.4: Age-depth graph for Lake Taumatawhana. The horizontal bars represent the magnitude of statistical counting error on the ¹⁴C dates (2σ); the vertical bars indicate the length of the core segment used.

Depth (m)	Accession No.	^{14}C (years B.P.)	$\delta^{13}\text{C}$ (‰)	Material dated
<i>Lake Taumatawhana</i>				
0.29-0.34	NZA-3920	1434 ± 77	-29.34	Treated gyttja
0.29-0.34	NZA-3823	1741 ± 83	-29.97	Treated gyttja
0.96-1.00	NZA-3882	686 ± 72	-27.11	Treated gyttja
1.10-1.16	NZA-3819	913 ± 65	-28.24	Treated gyttja
1.56-1.61	NZA-3820	1928 ± 68	-28.84	Treated gyttja
1.86-1.91	NZA-3821	2612 ± 72	-29.51	Treated gyttja
3.06-3.11	NZA-3822	2976 ± 67	-29.41	Treated gyttja
4.05-4.10	NZA-3486	4883 ± 68	-32.14	Treated gyttja
<i>Taumatawhana Swamp</i>				
2.35-2.40	NZA-2808	4792 ± 70	-25.3	Twigs

Table 10.1: Radiocarbon dates of samples from the Lake Taumatawhana sediment core.

The basal samples from the lake and swamp sediments returned ages of 4883 ± 68 yr B.P. (NZA-3486) and 4792 ± 70 yr B.P. (NZA-2808), respectively.

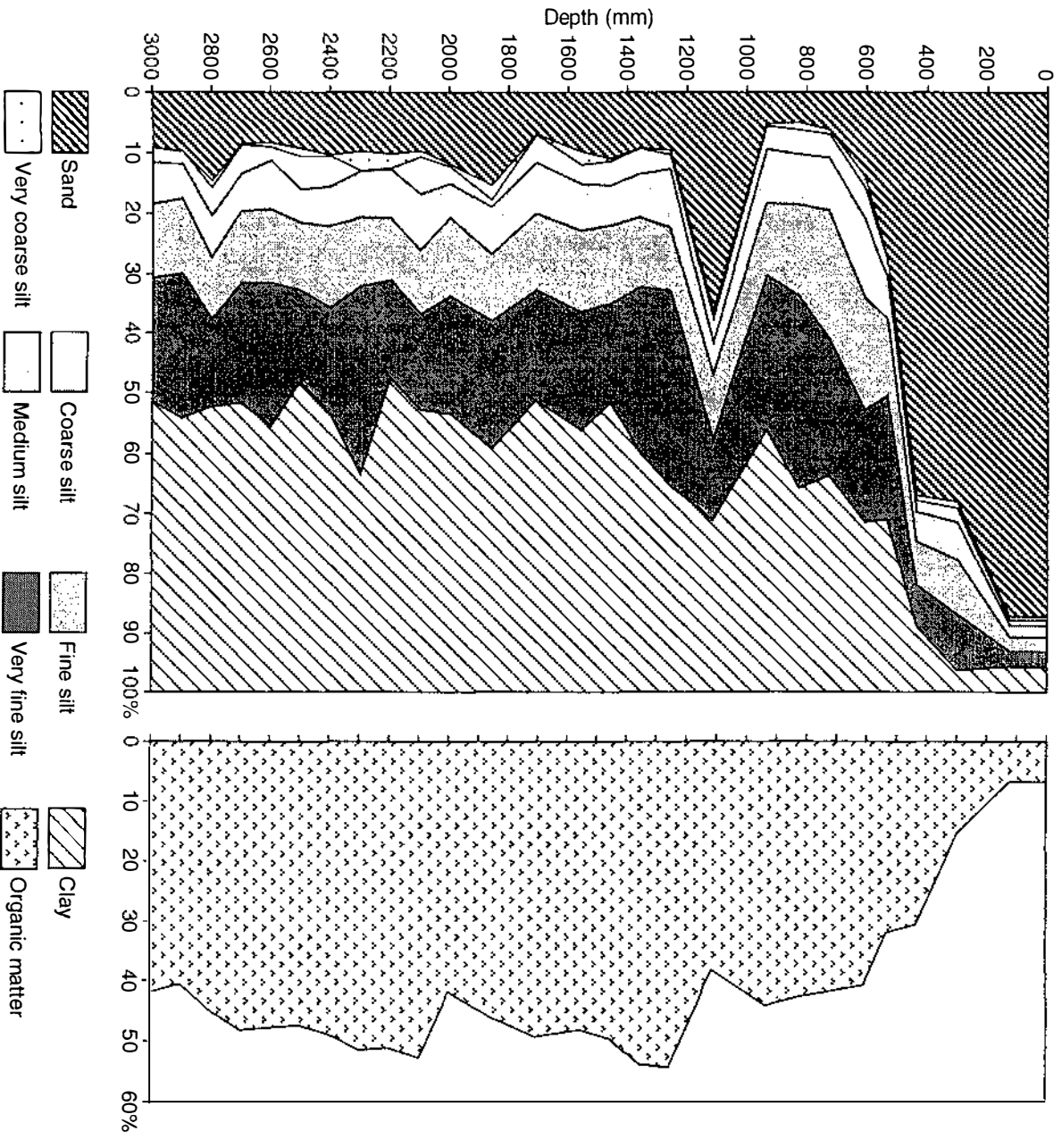
10.2 Sedimentology of core material

In compliance with chapters 8 and 9 the description of the sedimentology of the sediment core recovered from Lake Taumatawhana will be restricted to the reporting of the results from the sedimentological analyses of the core material.

10.2.1 Sediment texture

The sediment texture of the core is characterised by two peaks in the sand fraction (see fig. 10.5; also see Appendix IV.2).

The first peak (35%) occurs at 1.12 m. Prior to this, the sand content is consistently low, averaging 10%. The second peak occurs between 0.61 m and the sediment surface, with an initial value of 14% at 0.61 m, which increases sharply to 27.2% at 0.54 m and achieves a maximum value of 87.2% between 0.13 m and the sediment surface. Low



values for clay fractions are coincident with these peaks in the sand fractions. Between 0.53 m and 0.13 m, clay fraction values range from 29% to 4.3% compared with an average value of 46% for the remainder of the core. Other grain-size fractions remain almost entirely unaffected throughout the core.

10.2.2 Organic content

Typically, the organic matter content is *ca.* 50% (by dry weight) throughout the core (see fig. 10.5). However, a sharp decrease occurs from 0.61 m to the sediment surface (0.00 m) where the organic content is only 6.5%. Lower-than-average values are also noted between 1.12 m and 0.61 m (39.3%), and also at 3.00 m and 2.00 m (also see Appendix IV.3).

10.2.3 Sediment mineralogy

The inorganic portion is characterized by only three minerals throughout the core: quartz, feldspar and a mineral that is amorphous to X-ray radiation. In the X-ray diffractograms, quartz is identified by its 1st- and 2nd-order peaks at $24^{\circ}2\theta$ (= 0.43 nm) and $31^{\circ}2\theta$ (= 0.33 nm), respectively, and feldspar is indicated by its 1st-order peaks at $33^{\circ}2\theta$ (= 0.31 nm) (see fig. 10.6).

The amorphous material, which is most probably amorphous silica gel (J Kirkman, pers. comm. 1995), is indicated by a "hump" in the X-ray diffractogram. The apex of this hump lies in the vicinity of $26^{\circ}2\theta$ (see fig. 10.6). Most of the core appears to consist of this material, as its X-ray diffractogram shows a distinct trend with depth. The exception to this trend occurs in the uppermost section of the core from 0.40 m to 0.00 m, where there is almost no amorphous material. Here the dominant minerals are quartz and feldspar (peaks at $24^{\circ}2\theta$, $31^{\circ}2\theta$ and $33^{\circ}2\theta$, see fig. 10.6) coincident with extremely low values in the clay fraction (clay content between 0.30 m and 0.00 m of 3.6% to 4.3%, see fig. 10.5). Apart from these three minerals, no other minerals were detected in the X-

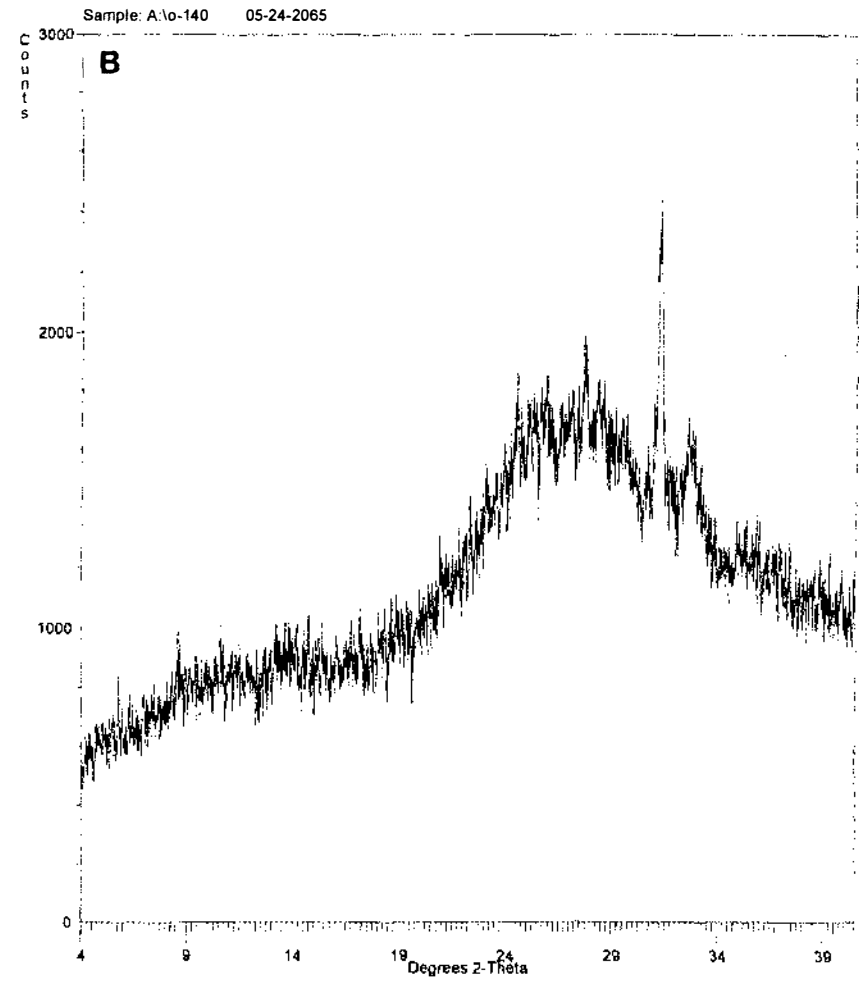
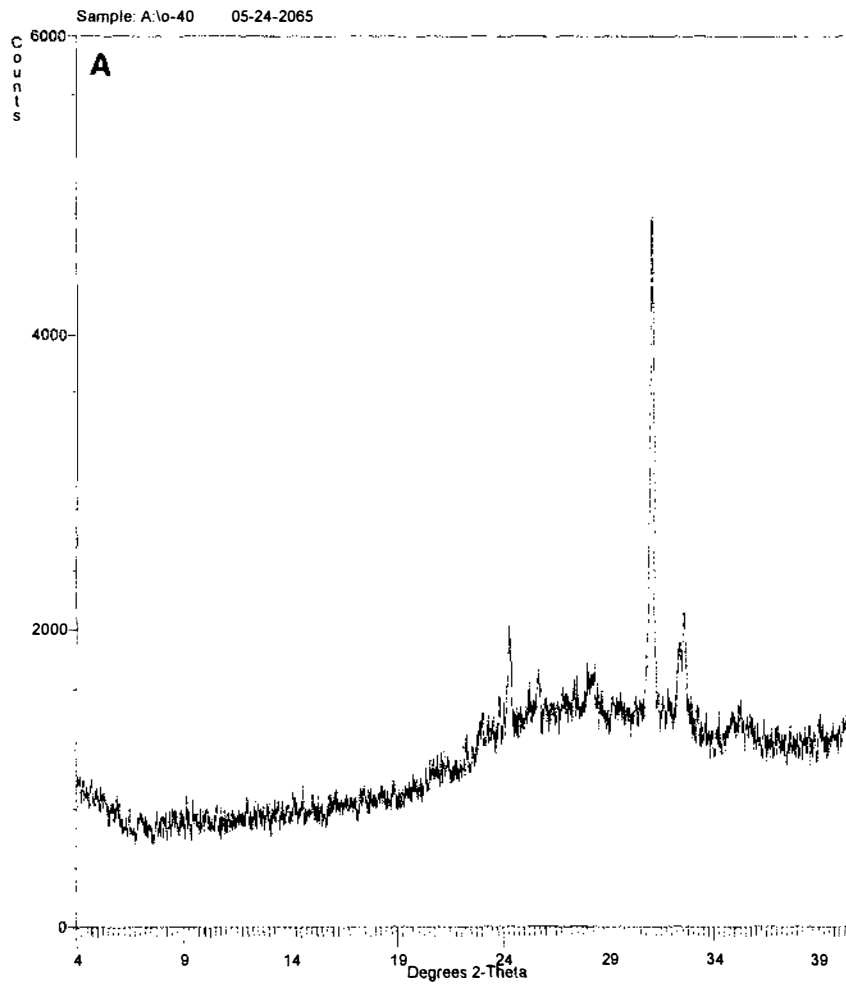


Figure 10.6: X-ray diffractograms for sediment mineralogy on the Lake Taumatawhana sediment core at 0.40 m (A) and 1.40 m (B) below the sediment surface.

ray diffractograms despite the relatively high clay content of the core material (see fig. 10.5). The clay content decreases steadily from 36.3% to 12.9% with a concurrent decrease in the amount of amorphous material reflected in a steady decline hump in the X-ray diffractogram. Further minor fluctuations in the clay content (see fig. 10.5) are reflected in the X-ray diffractogram for amorphous material. Microscopic investigations, by point counting, of the sand fraction also revealed an apparent dominance of quartz. The shape of these grains ranges from angular to well-rounded. Apart from quartz, a few minor iron oxides (probably hematite or magnetite) were also noted. There were also a few feldspars, but in contrast to the silt- and clay fraction, their abundance were extremely low; plagioclase feldspars were totally absent.

10.2.4 Sediment chemistry

In accordance with Håkanson & Jansson (1983) the results of the sediment analysis by means of ICP (see section 7.2.6.4.2) were grouped in major, carbonate, nutrient and mobile elements (see section 7.2.6.4.3). Figure 10.7 shows the concentration profiles of the representatives of these groups between 2.99 m depth and the sediment surface (also see Appendix IV.4).

The group of major elements are characterised by the uniformity of their distribution pattern. All members of this group show consistently low "background" concentrations (Al: $\approx 817 \mu\text{g/g}$, K: $\approx 73 \mu\text{g/g}$, Mg: $\approx 80 \mu\text{g/g}$, Na: $\approx 108 \mu\text{g/g}$, Si: $\approx 37 \mu\text{g/g}$) from 2.99 m upwards to a depth of 0.75 m. On moving further upwards the concentration values of all five elements noticeably increase and then sharply rise from 0.58 m to assume their respective maximum values at 0.17 m depth (Al: $3161 \mu\text{g/g}$, Na: $651 \mu\text{g/g}$, Si: $520 \mu\text{g/g}$) and at the sediment surface (Mg: $149 \mu\text{g/g}$, K: $457 \mu\text{g/g}$). Although magnesium largely follows this trend the magnitude of its increase in concentration from 0.58 m upwards is less pronounced.

Calcium and magnesium constitute the group of carbonate elements (see section 7.2.6.4.3). As magnesium, which also belongs to the group of major elements, was also

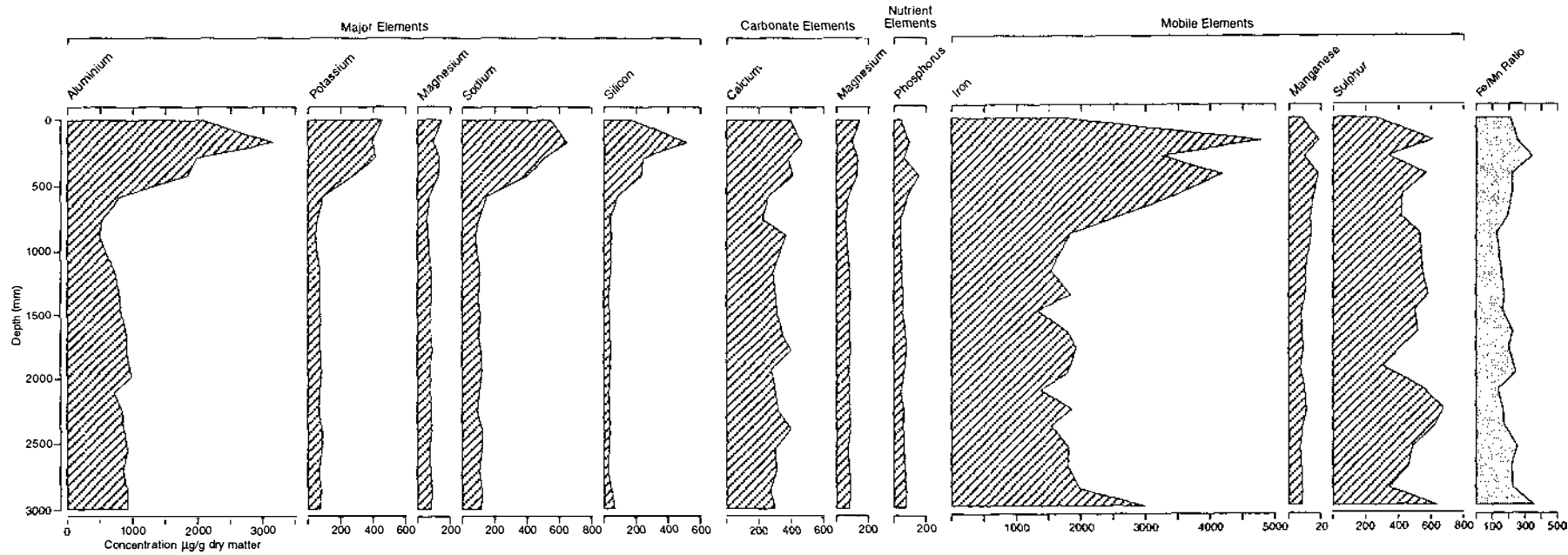


Figure 10.7: Sediment chemistry for Lake Taumatawhana. Elements are classed according to their environmental abundance.

discussed above only the concentration profile of calcium will be described here. Calcium is characterised by a rather irregular concentration profile with several peaks throughout the core's length. Despite the "zigzag" shape of its course the profile of calcium can broadly be subdivided into two sections: 2.99 m to 0.75 m and 0.75 m to the sediment surface. In the bottom section peaks are registered at 0.875 m (369 $\mu\text{g/g}$), 1.785 m (399 $\mu\text{g/g}$) and 2.385 m (398 $\mu\text{g/g}$). At the boundary between both sections at 0.75 m values then drop to an absolute minimum (221 $\mu\text{g/g}$). From there the concentration profile follows the trend exhibited by the major elements with further major peaks at 0.17 m (469 $\mu\text{g/g}$) and 0.42 m (412 $\mu\text{g/g}$).

Of the nutrient elements, only phosphorus can be analysed by ICP (see section 7.2.6.4.3). The record for phosphorus generally complies with that for the major elements. From the base at 2.99 m upwards to 0.75 m values are very uniform broadly ranging from 44 to 80 $\mu\text{g/g}$ with maxima and minima at 1.785 m (80.4 $\mu\text{g/g}$), 2.99 m (79.3 $\mu\text{g/g}$) and 0.75 m (44.4 $\mu\text{g/g}$) and 2.105 m (44.2 $\mu\text{g/g}$), respectively. From 0.75 m upwards the concentration of phosphorus rises and declines in the same fashion as for the major and carbonate elements peaking at 0.17 m (96.4 $\mu\text{g/g}$) and 0.42 m (156.6 $\mu\text{g/g}$).

Of the mobile elements, the concentration profiles of both iron and manganese largely correlate with the trends exhibited by the major elements. The profile for iron exhibits consistently low values in the bottom and middle sections. Apart from a major peak at 2.99 m (2971 $\mu\text{g/g}$) values merely fluctuate between *ca.* 1330 $\mu\text{g/g}$ to 1980 $\mu\text{g/g}$ from 2.86 m to 0.875 m depth. Between 0.875 m and the sediment surface values sharply rise, forming major peaks at 0.17 m (4767 $\mu\text{g/g}$) and 0.42 m (4194 $\mu\text{g/g}$).

The record for manganese largely coincides with the trend for iron. Between 2.99 m and 1.17 m depth levels are consistently low, ranging from *ca.* 7 $\mu\text{g/g}$ to 11 $\mu\text{g/g}$, which, on moving upwards, abruptly increase with peaks at 0.17 m (18.7 $\mu\text{g/g}$) and 0.42 m ($\mu\text{g/g}$).

Due to the largely corresponding trends of the concentration profiles of both iron and manganese the Fe:Mn ratio remains rather consistent throughout the length of the core.

Values merely range from about 150 to 250. Minor peaks only occur at the bottom (2.99 m, 356) and at the top (0.29 m, 343) of the core where values for iron are over-proportionally higher than those for manganese.

Sulphur which also belongs to the group of mobile elements behaves somewhat differently. Unlike any of the elements previously discussed the concentration profile of sulphur does not show any clear trend with depth. However, the rather irregular distribution pattern of sulphur exhibits a few peaks which occur at 0.17 m (614 µg/g), 0.42 m (574 µg/g), 1.36 m (583 µg/g), 2.255 m (678 µg/g) and 2.99 m (636 µg/g). Substantial declines are registered between 0.58 m and 0.75 m (\approx 420 µg/g), at 1.93 m (307 µg/g) and 2.86 m (347 µg/g).

10.3 Discussion

10.3.1 Radiocarbon chronology

Based on the two basal samples from the lake (NZA-3486) and the swamp (NZA-2808) the sediment record broadly spans the past 5000 years. The formation of the lake proper as a result of dune activity and drainage impedance due to the attainment of the sea-level close to the present level probably already began *ca.* 5500 yr B.P. (Elliot *et al.*, 1995).

Altogether, the lake's radiocarbon chronology displays two features which can be associated with periods of high sedimentation rates within the catchment. The first of these features is the "inverse" chronology caused by the uppermost two dates (NZA-3823 and -3920). As both dates are substantially older than the following two dates (NZA-3882 and -3819) from further down the core they appear to have been contaminated by older carbon. In view of their uppermost position in the stratigraphic record this process is likely to have occurred in historic times. European forest clearance within the lake's catchment in order to establish farmland probably caused extensive erosion which led to the inwash of old soil carbon into the lake sediments (*cf.*

Pennington *et al.*, 1976). Apart from sedimentological evidence (see below) this hypothesis is also strongly supported by pollen analysis (see fig. 10.8) done on the core and reported by Elliot *et al.* (1995). The stratigraphic position of these two anomalous dates coincides with the boundary between Elliot's *et al.* (1995) pollen zones "Ta 1b"⁸⁹ and "Ta 1a"⁹⁰ at 0.30 m. For pollen zone Ta 1a Elliot *et al.* (1995) reports the appearance of introduced species which strongly suggest post-European land use changes (including associated geomorphic processes) within the lake's catchment. Further support for the contention of a contamination of the uppermost, more recent, lake sediments with old soil carbon from the catchment is given by the course with depth of the $\delta^{13}\text{C}$ values of the available ^{14}C dates. Those $\delta^{13}\text{C}$ values of NZA-3882 and -3819 are dissimilar to those immediately below, but similar to those from substantially older material from further down the core (see tab. 10.1).

The second marked feature of the site's radiocarbon chronology is the conspicuous break in gradient in the age-depth graph between NZA-3822 and -3821. The gradient between these two dates is noticeably lower than elsewhere in the chronology. This feature indicates a high sedimentation rate during the period bracketed by these two dates. However, neither the results from sedimentological nor from palynological analyses provide evidence for increased deposition of material into the lake for the period bracketed by these two dates.

With reference to the inverse chronology caused by NZA-3823 and -3920 recent work by Higham & Lowe (1998) is worthy of mentioning here. These workers raise the possibility of the two lower radiocarbon dates, NZA-3882 and -3819 (see table 10.1), also being contaminated by older carbon. In view of the possible sources of error in radiocarbon dating (see discussion in section 7.3.1.2) the author of this thesis concurs with this. Consequently, NZA-3882 and NZA-3819 have to be treated as maximum ages only and the true ages of NZA-3882 and NZA-3819 might therefore be somewhat younger.

⁸⁹Ta 1b (1.12-0.30 m depth; *ca.* 900 B.P.-250(?) B.P.) (Elliot *et al.*, 1995).

⁹⁰Ta 1a (0.30-0.00 m depth; *ca.* 250(?) B.P.-present) (Elliot *et al.*, 1995).

Lake Taumatawhana, central Aupouri Peninsula, Northland.
 Relative Frequency data.
 Analyst: M B Elliot

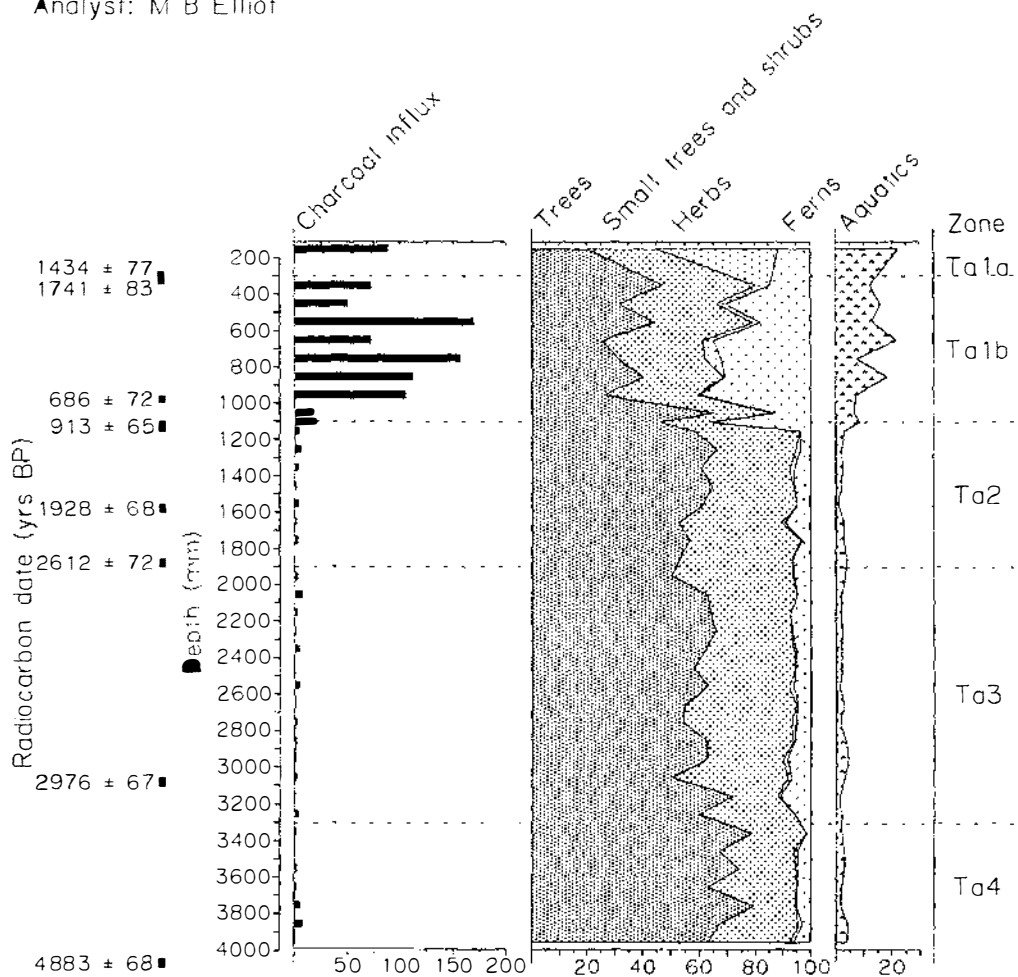


Figure 10.8: Summary pollen diagram for Lake Taumatawhana, including its radiocarbon chronology.

10.3.2 Sedimentology

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

The hypothesis of two periods of increased erosion between 1.12 m depth and the sediment surface is also supported by pollen data from this core (see Elliot *et al.*, 1995). Both predominately sand-sized particle-bearing peaks are covered by pollen zones Ta 1b and Ta 1a (see above). The lowermost peak at 1.12 m even coincides with the boundary between pollen zones "Ta 2" and Ta 1b which is dated to *ca.* 900 yr B.P. (NZA-3819). From this boundary upwards towards the sediment surface a few significant changes occur in the pollen record: All arboreal taxa decline and both the curves for *Pteridium esculentum* and charcoal influx sharply increase in tandem (see Elliot *et al.*, 1995, fig. 3). The combination of these three factors has now generally been accepted as evidence for Polynesian deforestation (see McGlone, 1983, 1989; also see section 5.3.1 and 8.6).

The same features along with the above sedimentological evidence were also observed in the sediment core from the Wharau Road Swamp site and were attributed to Polynesian forest clearance within the swamp's catchment (see section 8.6).

This contention is also strongly supported by the coincidence of changes in the grain-size distribution with an abrupt reduction in organic matter content at 1.12 m and between 0.61 m and the sediment surface. This feature is also thought to represent two distinct phases of deforestation. This is because a decline in organic matter content of the lake sediments signifies a reduced inwash of organic matter into the lake as a result of a reduced vegetative cover due to forest removal.

The same combination of changes in granulometry and organic matter content was also

observed in the sediment cores from the Wharau Road Swamp (see section 8.5.2) and from Lake Tiriara in Mangaia, Southern Cook Islands (see Dawson, 1990; also see section 8.5.2).

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

The chemical stratigraphy of the Taumatawhana core can be best explained if the sediment core is regarded as a suite of soils derived from the lake catchment. The composition of the residues finally reaching the lake bed can then be interpreted in terms of erosional activity within the catchment rather than in terms of changing rates of biological productivity either within the catchment or in the lake itself (Mackereth, 1966). The chemical composition of the sediments in general does not appear to be subject to alterations due to in-lake processes, although some elements are more or less susceptible to post-depositional modifications or pre-depositional leaching processes within the soils of the catchment, especially phosphorus, sulphur, iron, manganese, calcium (and various heavy metal elements) (Mackereth, 1966). As these representatives of the groups of carbonate, nutrient and mobile elements (see section 7.2.6.4.3) have no firm association with the mineral phase of the sedimentary material removed from the catchment and eventually deposited in the lake their concentration profiles down the core do not necessarily reflect erosive processes within the catchment. The distribution of these elements within the lake sediments rather depends on two parameters: redox-conditions within the lake catchment which control leaching processes (Mn and Fe), and limnological conditions within the lake (e.g. biological productivity) which affect elemental precipitation (P, S and some heavy metal elements) (see Mackereth, 1965, 1966).

The group of major elements (see section 7.2.6.4.3) on the other hand shows a strong association with the mineral phase of the products of catchment erosion. This association renders them an important indicator for the erosional history of the catchment. This characteristic particularly applies to sodium and potassium which are clearly associated with the mineral fraction of the sediment rather than with the organic phase (Mackereth, 1965, 1966). In their concentration profiles both elements show noticeably increasing values from 0.75 m which then sharply rise from 0.58 m to the sediment surface. The strong relationship between the mineral content of the sediment and the Na-K concentration implies that these features are directly proportional to the intensity of erosion within the catchment at the time of sediment deposition in the lake. Thus, the extremely high concentration levels of sodium and potassium immediately below the sediment surface even suggest a period of substantial erosive activity within the catchment which continues into the present.

This contention is also strongly supported by the chemical stratigraphy of the remaining members of the group of major elements, aluminium, magnesium and silicon. Their overall concentration profiles are almost identical to those of sodium and potassium. Only aluminium and magnesium deviate slightly from this pattern. Unlike the other elements of this group aluminium shows a few minor fluctuations in concentration between 2.99 m and 0.75 m; and magnesium on the other hand displays only an insignificant concentration peak between 0.75 m and the sediment surface.

In addition to direct erosional removal of these elements from the catchment the processes of removal by leaching from the mineral matter of the soils are also operational within the catchment. Through leaching elements become mobilized, enter the water body of the lake in solution and become deposited through the process of precipitation. This process is most effective during periods of low erosional activity when the soils within the catchment are least disturbed by physical removal of material. However, as element transfer by leaching from the catchment into the lake is less efficient than erosional removal periods of low erosional intensity are characterised by sediments with low element concentrations (*cf.* Mackereth, 1965, 1966). Such conditions prevail throughout the Taumatawhana core below 0.75 m. Thus, the

consistently low element concentrations of aluminium, magnesium, silicon and particularly potassium and sodium between 2.99 m and 0.75 m indicate extremely stable environmental conditions manifested by little soil erosion associated with maximum leaching of the soils in the catchment.

Another noticeable feature of the sediment chemistry of the site is the complete lack of high concentration values of all major elements in the vicinity of the second coarse particle bearing peak at 1.12 m. However, this feature is less a geochemical phenomenon than an artefact of the sub-sampling scheme of the sediment core. The above lack rather reflects the fact that no samples were taken from near the stratigraphical position of this rather isolated and in its stratigraphical extent also restricted coarse particle peak.

On the basis of the chemical stratigraphy of the major elements alone the environmental history of Lake Taumatawhana can be divided into two distinct periods: A period a relatively stable conditions with low rates of erosional activity as reflected in low concentrations of all major elements in the sediments between 2.99 m and 0.75 m. This phase is followed by a change from stable to unstable conditions reflected by high rates of erosion and high concentrations of all major elements from 0.75 m to the sediment surface.

Despite their generally rather loose association with erosional processes within the catchment of the site (see above) some representatives of the groups of carbonate, nutrient and mobile elements exhibit a number of features which allow one to draw a few general conclusions about the environmental history of Lake Taumatawhana.

The group of carbonate elements is represented by magnesium and calcium. As magnesium also belongs to the group of major elements (see section 7.2.6.4.3) it was already discussed above. According to Mackereth (1965, 1966) calcium is not that clearly associated with the mineral phase of the products of erosion but more readily removed from the catchment by leaching. Its lack of pronounced high and low concentration values throughout the core therefore implies that the process of calcium

leaching in the catchment operated very effectively throughout the environmental history of Lake Taumatawhana. Nevertheless, slightly higher concentration values immediately between 0.75 m and the sediment surface also comply with the postulated period of intensive catchment erosion. The more elevated values appear to suggest that removal of material from the catchment was evidently effective enough to render the process of calcium leaching insignificant. Fluctuations in the calcium concentration from 2.99 m to 0.75 m may be interpreted as minor climatic shifts which successively favoured and impaired the process of calcium leaching without causing any large-scale erosion in the catchment.

The mode of deposition of the members of the group of mobile elements is similar but not entirely identical. Migration of iron and manganese from the catchment into the lake is either by physical removal of sedimentary material or by direct solution from the soils. Both processes are largely controlled by the redox conditions within the catchment (see above). Sulphur on the other hand mainly appears to enter the lake sediments through biological pathways. Incorporated into planktonic algae and diatoms sulphur is known to enter lake sediments through various microbial processes (e.g. Mackereth, 1965, 1966; Mortimer, 1941, 1942).

Within the sediments of Lake Taumatawhana iron and manganese appear to have been deposited mainly by erosional removal from the catchment rather than by leaching. This contention is vastly supported by the near constancy of the iron:manganese ratio throughout the core. Removal by leaching can only be achieved when iron and manganese are reduced. This is because both elements are almost insoluble in their oxidised state (Mackereth, 1965, 1966). As manganese is more readily reduced than iron any transfer by reduction of these elements in mobile manganous and ferrous forms would have led to a substantial disturbance of the iron:manganese ratio. Hence, the near constancy of that ratio throughout the core strongly suggests that redox conditions in the soils of the catchment of Lake Taumatawhana have never been such as to facilitate the transfer of iron and manganese into the lake by leaching in ionic form.

The concept of an erosional transfer of both elements throughout the environmental

history of Lake Taumatawhana is further supported by the course of their concentration profiles. Both elements, in particular iron, form peaks between 0.75 m and the sediment surface. Based on the assumption of physical removal of both elements from the catchment this feature clearly suggests a period of increased erosional activity in the recent past.

The concentration profile of sulphur largely deviates from that of iron and manganese. Its course is rather irregular and closely follows the trend of that for calcium. This feature appears to be best explained by the highly biophile nature of sulphur (see above) rendering its distribution down the core subject to the biological regime of the lake and its drainage basin (Mackereth, 1965, 1966). The rather irregular concentration profile is therefore likely to reflect the fluctuations in biological activity within Lake Taumatawhana and its catchment. This contention is supported by Mackereth's (1966) argument that the sedimentation of sulphur is probably not controlled by the sulphate content of the lake water but only by the biological activity within the lake. For the environmental history of Lake Taumatawhana these features allow the following conclusions: firstly, the biological processes leading to the sedimentation of sulphur obviously operated rather independent of erosional activity; secondly, sedimentation of sulphur by organic precipitation always constituted the predominant mode of sulphur deposition into the lake.

The group of nutrient elements is represented by phosphorus (see section 7.2.6.4.3). Despite the highly biophile character of phosphorus (see above) its concentration profile closely corresponds with that of manganese and also follows the trend of that for iron. Mackereth (1966) explains such close correlation by the very low solubility of phosphorus in the presence of precipitating oxidised forms of iron and manganese.

Based on this association the concentration profile for phosphorus is therefore more likely to reflect the environmental history of the site rather than biological in-lake processes. The elevated concentration levels of phosphorus in the upper part of the core therefore also bear strong evidence for ongoing processes of intensive catchment erosion that started in the recent past.

10.4 Conclusion

Sedimentological analyses of a sediment core from Lake Taumatawhana, covering the past 3 ka, indicate that this site has been subject to substantial environmental changes in the recent past. The nature of sedimentological changes down the core allows one to subdivide the environmental history of Lake Taumatawhana into two main periods: a period of stable environmental conditions which was followed by a period of marked catchment disturbance.

Based on the time-depth of sedimentological analyses employed on the sediment core stable environmental conditions within the catchment prevailed from at least 3000 yr B.P. until about 900 yr B.P. During this period predominantly fine-grained inorganic material, interspersed with high amounts of organic material, was deposited into the lake. Low concentration levels of almost all elements indicate leaching processes within the catchment of the lake. The combination of these features appears to indicate "low-energy" catchment conditions with only little soil erosion due to a largely unbroken vegetative cover within the catchment of the site. Palynological investigations of the core material appear to corroborate this hypothesis. Pollen assemblages covering this section of the core show a dominance of arboreal taxa, mostly conifer-hardwood elements (Elliot *et al.*, 1995).

A few marked changes of some sedimentological parameters signify the onset of catchment disturbance from *ca.* 900 yr B.P. Significant shifts in the granulometric composition and organic matter content of the core material indicate the beginning of substantial soil erosion probably triggered by severe disturbances to the vegetative cover of the catchment. Pollen and charcoal data from this part of the sediment core support the contention of substantial vegetational changes within the catchment of Lake Taumatawhana and identify Polynesian deforestation as the cause.

Thereafter, environmental conditions appear to have returned to pre-900 yr B.P. conditions for a brief period. From *ca.* 900 yr B.P. to *ca.* 550(?) yr B.P.⁹¹ changes in the

⁹¹Due to the contamination of radiocarbon dates NZA-3823 and -3920 (see section 10.3.1) no dates younger than *ca.* 700 yr B.P. (NZA-3882) are available for the upper part of the radiocarbon chronology

granulometric composition of organic matter content of the core material indicate a decline in erosional activity within the catchment. However, such changes, implying a slight recovery of the vegetative cover within the catchment, are not supported by pollen and charcoal data.

This rather short-lived period of sedimentologically evidenced environmental stability is preceded by another period of erosional activity after *ca.* 550(?) yr B.P. From this point in time the mode of change of all sedimentological parameters indicates a gradual increase in erosional activity which abruptly rises from *ca.* 400(?) yr B.P. and continues into the present. Based on the magnitude of changes in granulometric composition, organic matter content and sediment chemistry of the core material the catchment of Lake Taumatawhana underwent its most significant environmental changes during that period. In combination with pollen and charcoal data these changes are clearly associated with large-scale anthropogenic deforestation of the catchment, leading to soil instability followed by intensive soil erosion and deposition of material in the lake.

With regard to the colonisation history of Northland it can be concluded that the nature of changes in the sedimentological and palynological record for Lake Taumatawhana provides a strong argument for human-induced catchment disturbance from *ca.* 900 yr B.P. This somewhat early date throws doubt on the hypothesis of a *Short prehistory* of New Zealand (see sections 2.2.1 and 7.1.2.1) which strongly proposes a Polynesian colonisation of the country during the post-A.D. 1200 period. However, in view of Higham & Lowe's (1998) criticism of the validity of the date of *ca.* 900 years B.P. (see discussion in section 10.1) the timing of human presence in this locality might be subject to revision.

for Lake Taumatawhana. Nevertheless, tentative dating of sedimentologically evidenced environmental changes predating NZA-3882 were derived by interpolation from a line extrapolated from NZA-3882 to the origin of the age-depth graph (see fig. 10.4).

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Chapter 11

SUMMARY AND CONCLUSIONS

The results and conclusions drawn from Chapters 8-10 are summarized below. The first heading summarizes the results of the sedimentological investigations employed on the sediment cores collected from Wharau Road Swamp and Lakes Tauanui and Taumatawhana. These details are followed by a discussion about the possible implications of the results from the individual sites for the colonisation history of the far north of New Zealand. Thirdly, it will be summarized in how far the research objectives of this thesis have been met. Finally, recommendations will be made for future work following the conceptual and methodological approach adopted in this thesis.

11.1 Summary of results

This section summarizes the results of the sedimentologically-evidenced environmental history of the drainage basins of Wharau Road Swamp and Lakes Tauanui and Taumatawhana. The results are reported in conjunction with palynological evidence for catchment disturbance from the same sites.

Wharau Road Swamp: The results of the sediment analyses and high sedimentation rates (inferred from the radiocarbon chronology of the site) provide strong evidence for a period of increased erosional activity within the site's drainage basin after *ca.* 600 years B.P. The nature of sedimentological, geochemical as well as palynological changes in the sediment sequence clearly indicates that the above erosional activity is the result of forest destruction by Polynesians.

Lake Tauanui: Sedimentological analyses from cores 1 and 2 strongly suggest repeated periods of soil instability within the lake's catchment from the beginning of sedimentation into the lake from *ca.* 5400 years B.P. This feature largely coincides with

pollen evidence from core 1, indicating repeated (climate-controlled) forest disturbance from *ca.* 5400 to 1100 years B.P. The final period of enhanced erosional activity is indicated in the uppermost part of the sediment sequence from core 1. Extrapolation in the radiocarbon chronology places the onset of this event around 350 years B.P. Pollen evidence for increased catchment disturbance substantially pre-dates the onset of the sedimentologically demonstrated catchment erosion. Pollen data rather suggest catastrophic forest disturbances, attributed to Polynesian deforestation, after *ca.* 1100 years B.P.

Lake Taumatawhana: The lake's environmental history can broadly be subdivided into two main periods: a period of stable environmental conditions which was followed by a period of marked catchment disturbance. The former period spans the time from at least 3000 years B.P. until *ca.* 900 years B.P. Palynological evidence largely supports this view. At around 900 years B.P. marked shifts of a number of sedimentological parameters signify the onset of catchment disturbance. Pollen and charcoal data attribute these disturbances to substantial vegetational changes within the lake's catchment and identify Polynesian deforestation as the cause. From *ca.* 900 years B.P. until about 550 years B.P. sedimentological evidence indicates a decline in erosional activity within the catchment. However, pollen and charcoal data do not support this contention. After *ca.* 550 years B.P. the mode of change of all relevant sedimentological parameters indicates a gradual resumption of erosional activity within the lake's drainage basin which abruptly rises from *ca.* 400 years B.P. and continues into the present. Based on the magnitude of the sedimentological changes the catchment of Lake Taumatawhana underwent its most significant environmental changes during that period. Palynological evidence clearly attributes these disturbances to large-scale anthropogenic deforestation of the catchment.

11.2 Discussion

The sediment sequences from Wharau Road Swamp and Lakes Tauanui and Taumatawhana bear clear evidence of significant erosional activity within their respective drainage basins. Based on McGlone's (1983, 1989) associations for evidence of Polynesian deforestation (for a full discussion see section 5.3) these events are unequivocally the result of soil instability subsequent upon anthropogenic forest clearance. The onset of these human-induced erosional events were dated to *ca.* 600 years B.P. (about A.D. 1350) at Wharau Road Swamp and *ca.* 900 years B.P. (about A.D. 1050) at Lake Taumatawhana.

At Lake Tauanui evidence for anthropogenic catchment disturbance is less pronounced than at Wharau Road Swamp and Lake Taumatawhana. Despite the co-occurrence of McGlone's (1983, 1989) sedimentological-palynological indicators of Polynesian forest clearance in the upper part of core 1 the exact onset of erosional activity can only be determined by extrapolation in the radiocarbon chronology. This procedure places the beginning of anthropogenic catchment instability at *ca.* 350 years B.P. (about A.D. 1600) which is substantially later than the pollen-derived date for human-induced forest disturbance of *ca.* 1100 years B.P.

In view of other evidence for early human occupation of Northland the sedimentologically-based evidence for anthropogenic catchment disturbance at Wharau Road Swamp and Lakes Tauanui and Taumatawhana compare as follows:

Both Wharau Road Swamp and Lake Taumatawhana pre-date current pollen- (and partially other sediment-) based evidence for earliest Polynesian deforestation from other localities in Northland. Chester's (1986)⁹² Jack's Lake pollen sequence from the coastal Bay of Islands dates the onset of Polynesian deforestation to 520 years B.P.; Enright's *et al.* (1988) soil erosional and charcoal evidence of (possibly) Polynesian burning in the Ponaki wetland, just south of North Cape, ranges from 200 to 300 years

⁹²Chester's (1986) pollen-based evidence for forest clearance from her Waitangi I and II pollen records dated to 1400-1350 years B.P. was not considered here due to uncertainties with the time-scale of the stratigraphic record (for a fuller discussion see section 7.1.2.2).

B.P.; and McGlone & Barber's (n.d.; quoted in McGlone *et al.*, 1994) place Polynesian deforestation at Motutangi Swamp, southern Aupouri Peninsula, at around 450 years B.P.

Lake Tauanui also pre-dates earliest pollen evidence for human activities at Jack's Lake and Motutangi Swamp but does not indicate anthropogenic disturbances substantially older than those from the Ponaki wetland.

With respect to other environmental studies in Northland it can be concluded that Wharau Road Swamp and Lake Taumatawhana bear *earliest* proxy evidence for human colonisation of Northland. Only the date for the onset of human activities from Lake Tauanui does not provide a substantially early date. Instead, it is almost synchronous with the onset of anthropogenic burning at Ponaki wetland.

Comparing the dates for the beginning of human occupation at Wharau Road Swamp and Lakes Tauanui and Taumatawhana with earliest dates from cultural contexts throughout archaeological sites in Northland a markedly different picture emerges. The currently oldest archaeological dates of (initial) human occupation in Northland are from the Aupouri Peninsula and range in age from 600 to 700 years B.P. (Anderson & Wallace, 1993; Coster, 1989). Sedimentological evidence for the onset of human activities at Wharau Road Swamp also falls into that period and the date from Lake Tauanui even substantially post-dates the earliest archaeological dates. Only the date from Lake Taumatawhana pre-dates the currently available archaeological evidence for the settlement of Northland by about 200 to 300 years.

With respect to the colonisation history of Northland the following conclusions can be drawn:

Evidence from *Wharau Road Swamp* only pre-dates other palaeoenvironmental evidence for human colonisation from other parts of the Northland region. Archaeological evidence for initial settlement is either synchronous with the date of earliest anthropogenic disturbance from Wharau Road or even pre-dates that event.

Lake Tauanui offers a rather late date for the onset of earliest human-induced environmental changes in that location. Apart from one location in the far north of Northland, its date of the beginning of anthropogenic catchment disturbance is rather pre-dated by archaeological as well as palaeoenvironmental proxy evidence from other sites in Northland.

Lake Taumatawhana provides a substantially older date than Wharau Road Swamp and Lake Tauanui. By employing McGlone's (1983, 1989) associations for evidence of Polynesian deforestation this site bears clear evidence for human activity within the lake's catchment at *ca.* 900 years B.P. This date substantially pre-dates any other environmental as well as archaeological evidence for earliest settlement in Northland. Hence, this site offers the earliest evidence for the presence of humans in Northland. For the colonisation history of Northland the date from Lake Taumatawhana therefore implies that people were already present in this part of New Zealand about 200 to 300 years prior to the oldest (accepted) archaeological dates from cultural contexts. However, Higham & Lowe's (1998) criticism of the validity of this date of 900 years B.P. (see discussion in sections 10.3.1 and 10.4) might necessitate a reconsideration of the timing of human presence in this locality.

11.3 Conclusions

Sedimentological analysis of sediment texture, sediment chemistry and organic matter content have shown marked shifts in the sediment sequences collected from Wharau Road Swamp and Lakes Tauanui and Taumatawhana. The nature of these shifts were clearly diagnostic of periods of enhanced environmental instability within the catchments of the respective sites. In combination with pollen and charcoal analysis on the same core material, utilizing McGlone's (1983, 1989) associations for evidence of Polynesian deforestation, these periods of environmental instability could clearly be attributed to Polynesian deforestation within the catchments of these sites. The evidence presented in this thesis implies that parts of Northland were probably settled and

deforested earlier than indicated by currently available archaeological and other environmental proxy evidence.

With respect to the principal research objectives of this thesis as stipulated in section 7.1.4 the following conclusions can be drawn:

Firstly, the sedimentological analyses employed on the sediment sequences from Wharau Road and Lakes Tauanui and Taumatawhana successfully established a radiocarbon-based chronology of the environmental history of the respective localities.

Secondly, the radiocarbon-dated sedimentologically-evidenced onset of human presence at Wharau Road Swamp and Lakes Tauanui and Taumatawhana were not successful in deciding between the three conflicting hypotheses about the time-depth of human settlement of New Zealand. The dates of the beginning of human presence at Wharau Road Swamp and Lake Tauanui rather comply with the hypothesis of a Short prehistory which places the date of colonisation of New Zealand in the post-A.D. 1200 period. The sedimentological evidence for human presence at Lake Taumatawhana on the other hand is in accord with the Orthodox model which embraces the time span from A.D. 800 to 1000 as the most likely period for the arrival of people in New Zealand. Thus, the sedimentological evidence from Wharau Road Swamp and Lakes Tauanui and Taumatawhana did not assist in resolving the ongoing debate over the date of human colonisation of New Zealand.

11.4 Recommendations

The issue of *when* and *where* first colonisation occurred in Northland, and indeed New Zealand, can not be expected to be resolved on the basis of sedimentological investigations on sediment sequences from only three locations studied here. While various lines of evidence point to an early settlement of Northland, pre-dating settlement elsewhere in New Zealand, the issue is undoubtedly worthy of further research utilizing

human-induced environmental disturbances as a proxy measure for human presence in a locality.

In view of the substantially higher sedimentation rates in lakes, providing a noticeably better temporal resolution than sequences from swamps and bogs, further work on lacustrine sediment sequences is suggested. In Northland the potential for further lake-sediment based studies is outstanding as the region accommodates no less than 46 lakes (see Irwin, 1975) whose dimensions are in compliance with the requirements for sampling sites outlined in section 7.2.1.2. Most of these lakes are wind-blown dune lakes which are situated on the west coast of mainland Northland and on the Aupouri Peninsula (see section 4.4.2.1 and fig. 4.12).

The correct interpretation of palaeoenvironmental processes principally depends on the reliability of the chronology obtained for a sediment sequence. As in this study, most lake-sediment based chronologies were established by radiocarbon dating of individual bulk samples from the sediment sequence. The resulting bulk radiocarbon ages are often subject to uncertainties due to sample contamination by either younger or older carbon (also see sections 7.3.1.2 and 9.3.1). This problem can be addressed by directly radiocarbon dating (AMS method) sufficient quantities of pollen grains from individual taxa extracted from collected sediment sequences (e.g. Prior *et al.*, 1997; Prior, 1998). Radiocarbon chronologies established in this fashion are largely devoid of the above effects. In view of Higham & Lowe's (1998) criticism of the date of *ca.* 900 years B.P. from Lake Taumatawhana (see section 11.3) this method is likely to have the potential to obtain unambiguous chronologies on sequences from lake and swamp deposits.

The reliability of radiocarbon chronologies based on conventional bulk ages can also be verified through the presence of volcanic airfall deposits in the sediment sequences. Due to the remoteness of Northland from the source of Late Quaternary tephra deposits only few identifiable macro-tephras are preserved in the sediments in this part of the country (also see section 7.3.2). The application of micro-tephra analysis would therefore provide an invaluable tool in supporting any chronology of any palaeoenvironmental study site in Northland and any other region of the country outside the immediate

"fallout" range of Late Quaternary macro-tephras (e.g. Newnham *et al.*, 1998; Pilcher & Hall, 1996).

Another approach to obtain (rather) unequivocal chronologies is the employment of palaeomagnetic dating techniques. Within the context of lake-sediment based environmental research particular potential lies in the study of secular variation in magnetic inclination and declination. Once calibrated these records provide consistent and detailed information about the chronology of lacustrine sedimentation which make them an ideal tool for the detection of periods of increased catchment erosion (e.g. Oldfield *et al.*, 1978; Turner & Thompson, 1979). As the application of this method yields the best results on lake sediments which are predominately fine-grained and moderately rich in magnetic minerals (e.g. Oldfield, 1981) sediment sequences from drainage basins within the Northland Volcanic Field (see fig. 4.4) would probably provide ideal sampling sites for palaeoenvironmental studies.

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APPENDIX I

This appendix lists the different swamp and lake sites in Northland (see fig. 7.1) from which sediment cores were collected for the study of sedimentologically-palynologically-evidenced human-induced environmental disturbances. The individual study sites are as follows:

Lake Tauanui, near Kaikohe (NZMS 260, P06/887332)

This is an inland site which is adjacent to two pa sites and within a volcanic field. The lake itself is at the foot of a dormant volcanic cone. A total of five cores were collected across a transect; the longest core yielded four metres of gyttja (organic lake mud). An impenetrable base prevented any deeper sampling (see Chapter 9).

Wharau Road Swamp, coastal Bay of Islands (NZMS 260, P05/052635)

This coastal site provided a total of seven cores which were collected across a transect (see Chapter 8).

Taumatawhana Swamp, central Aupouri Peninsula (NZMS 260, N03/129203)

This site is adjacent to a twin pa site and extensive areas of early Maori gardens. The site is within easy reach of both east and west coasts. A 2.3 m core was recovered from the swamp, consisting of peat and gyttja. From 1.04 to 1.63 m depth alternating layers of clay/sand and organic matter were observed with possible charcoal particles.

Whangamumum Swamp, coastal Bay of Islands (NZMS 260, Q05/267596)

This coastal site lies on the eastern side of the Bay of Islands. Along a transect a total of five sediment cores were collected; the deepest of these cores yielded 2.33 m of sediment before an impenetrable base prevented further sampling.

Lake Ohia, Rangiwahia Peninsula (NZMS 260, O04/444911)

The lake proper is now dry and has previously supported *Agathis australis* forest as evidenced by many stumps and partially buried logs. A total of 2.77 m of sediment were

recovered from this site consisting of 2.62 m of black peat, the remainder comprising chiefly sand which rendered further sampling impossible.

Sandhills Road (site 1) Swamp, near Awanui (NZMS 260, O04/308822)

This is a marginal swamp site (now drained) just west of Awanui and adjacent to Late Pleistocene/Holocene sand dunes on the northern side. Three and a half meters of dark brown peat were recovered from the site.

Sandhills Road (site 2) Swamp, near Kaitaia (NZMS 260, O04/299766)

A transect running East-West across the middle of the swamp was made consisting of five boreholes at intervals of 342 m apart. The longest core from the centre of the swamp yielded 6.5 m of mainly dark brown peat.

Tangonge Road Swamp, half way between Kaitaia and Ahipara (NZMS 260, O04/302734)

This site lies near the southern margin of a swamp which infills the Kaitaia Basin. Four and a half meters of peat and peaty clay were recovered; an impenetrable base prevented deeper sampling.

Klaricich Swamp, near Omapere (NZMS 260, O06/459271)

This narrow (30 meters wide) raupo (*Typha*) swamp is situated on farmland just south of South Head, Hokianga Harbour. The swamp appears to have formed as a result of erosional processes that occurred following deforestation causing the narrow valley drainage to become impounded. The deepest of the five cores collected from this site provided 3.67 m of peaty, detrital mud. Coring was terminated at this depth owing to an impenetrable base of grey sandy clay.

Lake Taumatawhana, central Aupouri Peninsula (NZMS 260, N03/129203)

The lake lies within a dune-field and drainage is by seepage into Taumatawhana Swamp (see above). From the deepest spot of the lake just over four meters of gyttja (organic mud) were collected before an impenetrable base of coarse sand prevented further sampling (see Chapter 10).

Lake Kai Iwi (NZMA 260, O07/697984)

This is a coastal site within the Taharoa domain which is a 538 ha recreation reserve containing three freshwater lakes: Lake Waikere, Lake Taharoa and Lake Kai Iwi, known as the Kai Iwi Lakes which also include Shag Lake. Shag Lake lies outside the Taharoa domain approximately 4.5 km northwest of Lake Kai Iwi. The surface level of Lake Kai Iwi is approximately 70 m above sea level (m a.s.l.) and the lake lies about 2.5 km from the Tasman Sea. To the south Lake Kai Iwi is overlooked by the remains of a *pa* site. Further evidence of Maori occupancy of the area is manifested by burial grounds at the east and west shore of Lake Taharoa (Kaipara District Council, 1987). Two cores were recovered from this site; core 1 was collected from a water depth of 11.85 m and core 2 from a depth of 9.00 m. Core 1 yielded 5.24 m of gyttja (organic mud), sandy gyttja and organic sand. An impenetrable base prevented deeper sampling. Furthermore the stratigraphy of this core revealed volcanic ash layers at 3.60 m, 3.75-3.98 m, 4.05-4.066 m, 4.113-4.17 m, 4.452-4.492 m and 4.536-4.588 m. Core 2 only yielded 2 m of gyttja of various consistency. Coring was terminated at this depth due to an impenetrable base. Volcanic ash layers were not discovered in this core.

Johnson's Swamp, near Lake Kai Iwi (NZMS 260, P07/702978)

This site was chosen for its proximity to Lake Kai Iwi (see above). Both site are overlooked by the remains of a *pa* site and lie in the vicinity of Maori burial grounds. One core was collected from the southeastern end of this site yielding a total of 3.52 m of peat at various stages of decomposition and gyttja with a few intercalated bands of sandy silt/clay were collected before an impenetrable base rendered further coring impossible. As in the Lake Kai Iwi site volcanic ash was also present in this core. A thick beige coloured tephra layer was found between 3.29 and 3.385 m.

Lake Waihopo, central Aupouri Peninsula (NZMS 260, N03/148162)

This is an inland site which is within easy reach of both east and west coasts. In this place the Aupouri Peninsula has a maximum width of only 11 km. One core was recovered from the deepest part of this lake. The core was collected from a water depth of 2.72 m and yielded 4.30 m of sandy gyttja, gyttja and sand including a few pure sand and clay bands intercalated into the core at various depths.

Te Werahi Swamps, south-east of Cape Reinga (NZMS 260, M02/N02/865458)

This site is a coastal wetland on the west coast in the far north of the Aupouri Peninsula. The Te Werahi wetland is a large and complex system covering 422 ha within a large catchment of 3365 ha. The site does not occur as a single unit but can be subdivided into three reaches which are designated upper, middle and lower reaches. They are connected by sandy braided stream channels which are maintained by the flow of the Te Werahi Stream that drains into the Tasman Sea at Te Werahi Beach at the northwestern edge of this wetland. The entire system bears strong evidence of Polynesian occupancy which is reflected in a high number of *pa* sites. In particular the upper reaches are overlooked by a number of *pa* sites which occur as single, twin and triple sites. One core was recovered from the middle reaches about 650 m east of the remains of a single *pa* site. The core site was located on a floating mat of living raupo vegetation with a thickness of 0.18 m. The stratigraphy of this mat revealed some coarse detrital mud with living rootlets at the top that progressively graded into finer material at a more advanced stage of decomposition towards the bottom. Below this mat was a column of water which extended to a depth of 2.23 m. From 2.23 to 2.82 m a sediment layer consisting of dark grey sandy clay with rootlets that gradually graded into light brown sandy clay. Further coring was impossible owing to the impenetrable sandy clay.

APPENDIX II.1

Stratigraphy of sediment cores

Location: Wharau Road Swamp	Altitude:	Map Ref.: NZMS 260, P05/052635
Date: 27.05.1992	Core No.: 1	Corer Used: D-section

DEPTH [m]	DESCRIPTION	N ¹	St ²	E ³	S ⁴	H ⁵	COMPONENTS
0.00-0.19	Gap						
0.19-0.28	Dark brown detritus, mud, living rootlets	3-4	1	0-1	1	1-2	Dh2, Sh2
0.28-0.35	As above with inwashed coarse sediment	3-4	2	1	1-2	1-2	Dh1, Sh2, Gs1
0.35-0.50	Dark brown coarse detritus, mud, (living roots	3-4	1	1-2	2	2	Dh3, Sh1
0.50-0.53	As above	3-4	1	1-2	2	2	Dh3, Sh1
0.53-0.56	Transition						
0.56-0.65	Dark brown clay with some organic matter, ?charcoal, fine rootlets	3	2	1	2	1	Ag2, Ga2, Sh+
0.65	Termination						

¹N: Nigror; ²St: Stratificatio; ³E: Elasticitas; ⁴S: Siccitas; ⁵H: Humicitas

APPENDIX II.1

Stratigraphy of sediment cores

Location: Wharau Road Swamp	Altitude:	Map Ref.: NZMS 260, P05/052635
Date: 27.05.1992	Core No.: 2	Corer Used: D-section

DEPTH [m]	DESCRIPTION	N ¹	St ²	E ³	S ⁴	H ⁵	COMPONENTS
0.00-0.30	Fell out						
0.30-0.56	Dark brown coarse detritus, mud, living rootlets	3-4	1	2	1-2	1	Dh3, Sh1
0.56-0.80	As above	3-4	1	2	1-2	1	Dh3, Sh1
0.80-1.00	As above but redder	3-4	1	2	1-2	1	Dh3, Sh1
1.00-1.11	As above	3-4	1	2	1-2	1	Dh3, Sh1
1.11-1.13	Tephra layer						
1.13-1.28	Transition						
1.28-1.50	Brown gyttja and silt with coarse detritus, ?charcoal	3	2	1	2	2	Dh1, Sh1, Ag1, Gs
1.50-1.64	As above	3	2	1	2	2	Dh1, Sh1, Ag1, Gs
1.64-1.76	Pale brown mud, ?charcoal, inwashed mud-clay	2-3	2	1-2	2	1-2	Ag2, Ga1, Dh1, Sh
1.76-2.00	Brown gyttja, with fine detritus, ?charcoal	3	2	1	2	2	Dh1, Sh1, Ag1, G
2.00-2.04	Transition						
2.04-2.29	Coarse detritus, peat	3-4	1	0-1	1-2	2	Dh3, Sh1, Ag2, Ga
2.29-2.35	Brown clay/gyttja in detritus	3	2	1	2	2	Dh1, Ag2, Ga1
2.35-2.50	Clay pale brown->blue grey, charcoal	1-2	3	0	2	-	Ag2, Ga2
2.50	Termination						

¹N: Nigror; ²St: Stratificatio; ³E: Elasticitas; ⁴S: Siccitas; ⁵H: Humicitas

APPENDIX II.1

Stratigraphy of sediment cores

Location: Wharau Road Swamp	Altitude:	Map Ref.: NZMS 260, P05/052635
Date: 27.05.1992	Core No.: 3	Corer Used: D-section

DEPTH [m]	DESCRIPTION	N ¹	St ²	E ³	S ⁴	H ⁵	COMPONENT S
0.00-0.12	Lost						
0.12-0.42	Loose fresh peaty mud	3-4	-	-	0	0-1	?h3, Sh1, Ga
0.42-0.50	Coarse, detritus peat	3-4	0	0-1	1	2	Dh3, Sh1
0.50-0.78	As above, with living rootlets	3-4	0	0-1	1	2	Dh3, Sh1
0.78-1.00	As above but redder	3-4	1	0-1	1	2	Dh3, Sh1
1.00-1.18	As above	3-4	1	0-1	1	2	Dh3, Sh1
1.18-1.50	As above, but less dark	3-4	1	2	1-2	1	Dh3, Sh1
1.50-1.66	As above	3	1	1	1	1-2	Dh3, Sh1
1.66-1.70	Transition						
1.70-2.00	Brown gyttja with silt, ?charcoal	3	2	1	2	2	Dh1, Sh1, Gal, Ag1
2.00-2.03	?Tephra						
2.03-2.31	Brown coarse detritus peat	3	0	1-2	2	2	Dh3, Sh1
2.31-2.45	Transition, with timber (@2.42-2.45) and at 2.44-2.45. ?charcoal						
2.45-2.50	Brown inwashed clay silt, soft	2-3	2	0-1	1	-	Ag2, Ga2
2.50-2.57	Soft detritus mid-gyttja, ?charcoal	3	1	0-1	1-2	1-2	Dh2, Ag1, Gal
2.57-2.62	Transition						
2.62-2.74	Brown clay, ?charcoal, fine detritus	3	2	0-1	1	1	Dh1, Ag2, Gal
2.74-3.00	Pale brown/cream clay	1-2	1	0-1	1-2	-	Ag3, Gal
3.00	Terminated. Impenetrable						

¹N: Nigror; ²St: Stratificatio; ³E: Elasticitas; ⁴S: Siccitas; ⁵H: Humicitas

APPENDIX II.1

Stratigraphy of sediment cores

Location: Wharau Road Swamp	Altitude:	Map Ref.: NZMS 260, P05/052635
Date: 27.05.1992	Core No.: 4	Corer Used: D-section

DEPTH [m]	DESCRIPTION	N ¹	St ²	E ³	S ⁴	H ⁵	COMPONENTS
0.00-0.10	Lost						
0.10-0.39	Loose fresh peaty mud	3-4	-	-	0	0-1	Dh3, Sh1, G
0.39-0.50	Coarse detritus peat						
0.50-0.90	As above						
0.90-1.00	As above, slightly redder						
1.00-1.38	As above						
1.38-1.50	As above less red	3	1-2	0-1	1-2	2	Dh3, Sh1
1.50-1.67	As above	3	1-2	0-1	1-2	2	Dh3, Sh1
1.67-1.77	Transition						
1.77-1.91	Soft brown gyttja	3	1-2	0-1	1	2	Ag2, Ga1, Sh1, Th+1
1.91-2.00	Soft brown detritus mud with rootlets	3-4	1	0-1	1	2	Dh2, Sh2, Ag+
2.00-2.06	As above	3-4	1	0-1	1	2	Dh2, Sh2, Ag+
2.06-2.10	Transition						
2.10-2.31	Coarse detritus peat, timber 2.13-2.17	3-4	1	2	2	2	Dh3, Sh1, D1+
2.31-2.32	Transition						
2.32-2.50	Brown gyttja with coarse detritus and charcoal	3	2	1-2	2	2	Dh1, Ag1, Sh1, Th+, Ld1
2.50-2.80	As above. Wood at 2.52-2.54	3	2	1-2	2	2	Dh1, Ag1, Sh1, Th+, Ld1
2.80-2.96	As above with clay pods	3	2-3	1-2	2	1-2	Ag2, Ga1, Sh1, Dh+
2.96-3.00	Pale brown clay	2	0-1	0-1	3	-	Ag2, Ga1, Sh1, Dh+
3.00	Termination						

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APPENDIX II.1

Stratigraphy of sediment cores

Location: Wharau Road Swamp	Altitude:	Map Ref.: NZMS 260, P05/052635
Date: 27.05.1992	Core No.: 5	Corer Used: D-section

DEPTH [m]	DESCRIPTION	N ¹	St ²	E ³	S ⁴	H ⁵	COMPONENTS
0.00-0.20	Loose brown mud	3	-	-	0	2	Ag2, Gal, Sh1
0.20-0.33	Dark brown soft mud with living rootlets	3-4	0	0	0-1	2	Ag2, Gal, Sh1, Th+
0.33-0.50	Dark brown peat with rootlets	3-4	0-1	0-1	1	2	Dh2, Sh2, Ga+
0.50-1.00	Coarse detritus peat with living rootlets	3-4	0-1	0-1	1	2	Dh3, Sh1, Th+
1.00-1.50	As above only redder. Timber 1.35-1.37	3-4	0-1	0-1	1	2	Dh3, Sh1, Th+
1.50-1.60	As above	3-4	0-1	0-1	1	2	Dh3, Sh1, Th+
1.60-1.74	Brown gyttja with coarse red detritus	3-4	1-2	1-2	2	2	Dh2, Sh1, Ag1, Ga+
1.74-1.88	Brown gyttja with detritus	3	2	0-1	2	2	Ag1, Gal, Dh1, Th1
1.88-1.93	Transition. Timber 1.91						
1.93-2.00	Dark brown/black peat	4	2	1-2	2	2	Dh3, Sh1
2.00-2.46	As above. Timber 2.36-237/2.44-2.46	4	2	1-2	2	2	Dh3, Sh1
2.46-2.50	Dark brown gyttja with detritus	3-4	2	1	2	2	Ag2, Sh1, Dh1, Ga+
2.50-2.57	Red brown detritus/gyttja	3-4	2	2	2	2	Dh2, Ag1, Sh1, Ga+
2.57-2.61	Transition						
2.61-3.00	Brown gyttja with charcoal; timber 2.68-2.69, 2.75-2.76, 2.90-2.91	3	2	1-2	2	2	Ag1, Gal, Sh1, D?, Ld1
3.00-3.49	As above. Timber 3.16 and 3.40	3	2	1-2	2	2	Ag1, Gal, Sh1, D?, Ld1
3.49-3.50	As above with blue grey clay flecks	3	2	1-2	2	2	Ag1, Gal, Sh1, D?, Ld1
3.00-3.03	Contamination ??? Timber 3.03-3.04						
3.50-3.51	As above with sand	2-3	2	1-2	2	0-1	Ag2, Gal, Sh1
3.51-3.52	Coarse sand, timber??	2-3	-	0	1-2	0	Gs2, Ag1, Gal, Dl+
3.52-3.78	Pale brown clay	2	2	1-2	2	0	Ag3, Gal, Dh+
3.78-3.94	Pale brown sandy clay	1-2	1	0-1	1-2	0	Ag2, Gs2, Ga+
3.94-4.00	Pale brown clay	2	2	1-2	2	0	Ag3, Gal, Dh+
4.00	Terminated						

¹N: Nigror; ²St: Stratificatio; ³E: Elasticitas; ⁴S: Siccitas; ⁵H: Humicitas

APPENDIX II.1

Stratigraphy of sediment cores

Location: Wharau Road Swamp	Altitude:	Map Ref.: NZMS 260, P05/052635
Date: 27.05.1992	Core No.: 6	Corer Used: D-section

DEPTH [m]	DESCRIPTION	N ¹	St ²	E ³	S ⁴	H ⁵	COMPONENTS
0.00-0.18	Soft fresh detritus mud	3-4	0	0	0-1	1	Dh1, Sh1, Ag1, Th1
0.18-0.30	Sample lost						
0.30-0.50	Soft dark brown/black detritus mud	3-4	0	0	0-1	1	Dh1, Sh1, Ag1, Th1
0.50-0.68	Black peaty mud. Living rootlets	4	1	0-1	1	2	Dh2, Sh2, Th+
0.68-1.00	As above only reddish	4	1	0-1	1	2	Dh2, Sh2, Th+
1.00-1.18	As above	4	1	0-1	1	2	Dh2, Sh2, Th+
1.18-1.50	Dark red brown peat	3-4	1	0-1	1-2	2	Dh2, Sh2, Th+
1.50-1.71	As above	3-4	1	0-1	1-2	2	Dh2, Sh2, Th+
1.71-1.84	Brown gyttja rootlets with timber at 1.74-1.76	3	2	0-1	1-2	2	Ag1, Ga1, Sh1, Dh+, Dl+, Th+, Ld1
1.84-1.91	Transition						
1.91-2.00	Soft dark brown peaty mud	3-4	1	0	1	2	Dh2, Sh2, Ag+
2.00-2.20	As above		1-2	1	2	2	Dh2, Sh2, Ag+
2.20-2.33	Dark brown peaty mud. Timber 2.25-2.26	3-4	2	0-1	1-2	2	Dh1, Sh2, Ag1, Dl+
2.33-2.42	Dark brown peat. Timber 2.40-2.41	3-4	1-2	1-2	2	2	Dh2, Sh2, Ag+, Dl+
2.42-2.46	Brown gyttja with detritus	3	2	1	2	2	Ag1, Sh1, Dh1, Ga+, Ld1
2.46-2.48	Dark brown peat	3-4	1	1	2	2	Dh2, Sh2
2.48-2.50	Brown gyttja	3	2	1	2	2	Ag2, Ga2, Dh+, Ag+
2.50-2.53	Brown gyttja with detritus and timber	3	0-1	0	0-1	1-2	Dl1, Dh1, Ag2, Ga+
2.53-2.57	Brown gyttja	3	2	0-1	1-2	2	Ld2, Ga2, Dh+, Ag+
2.57-2.63	Peaty mud (gyttja??)	3	1	0-1	1-2	2	Ag1, Ga1, Dh2, Sh+, Ld2
2.63-2.65	Transition						
2.65-3.00	Brown clay merging to pale creamy clay at base (with charcoal??)						Ag3, Ga1
3.00	Terminated						

¹N: Nigror; ²St: Stratificatio; ³E: Elasticitas; ⁴S: Siccitas; ⁵H: Humicitas

APPENDIX II.1

Stratigraphy of sediment cores

Location: Wharau Road Swamp	Altitude:	Map Ref.: NZMS 260, P05/052635
Date: 27.05.1992	Core No.: 7	Corer Used: D-section

DEPTH [m]	DESCRIPTION	N ¹	St ²	E ³	S ⁴	H ⁵	COMPONENTS
0.00-0.03	Lost						
0.03-0.18	Soft brown detritus mud living rootlets	3	1	0	0-1	1	Dh1, Sh1, Ag1, Gal, Th+
0.18-0.28	Brown muddy detritus living roots	3	1	1	1	1	Dh1, Sh1, Ag1, Gal, Th+
0.28-0.34	Transition						
0.34-0.43	Black peaty mud with living roots	4	1	0-1	1-2	1-2	Dh1, Sh1, Ag1, Gal, Th1
0.43-0.50	Black peat	4	1	2-3	2	2	Dh2, Sh2
0.50-0.60	As above	4	1	2	2	2	Dh2, Sh2
0.60-0.75	Transition						
0.75-1.00	As above, black peat but reddish	3-4		2			Dh2, Sh2
1.00-1.20	Dark red brown peat	3-4	1	2	2	2	Dh2, Sh2
1.20-1.35	Transition. Timber 1.34-1.35						
1.35-1.50	Brown detrital mud, rootlets; charcoal??	3	2	0-1	1-2	2	Ag2, Gal, Th1, Dh
1.50-1.53	As above	3	2	0-1	1-2	2	Ag2, Gal, Th1, Dh
1.53-1.60	Brown mud (clay inwashed)	2-3	2	1	2	0-1	Ag2, Ga2
1.60-1.61	Transition						
1.61-1.77	Dark brown peat	3-4	1	1	1-2	2	Dh2, Sh2
1.77-2.00	Soft woody dark brown peat	3-4	0	0-1	1	2	DI2, Dh1, Sh1
2.00-2.08	Dark brown woody peat. Timber 2.04-	3-4	1	1-2	2	2	Dh2, Sh2, DI+
2.08-2.17	Transition						
2.17-2.35	Fine brown detrital peat. Timber 2.17-	3-4	1-2	1	2	2	Dh1, Sh2, Ag1, DI+
2.35-2.46	Transition						
2.46-2.50	Inwashed clay? with fine detritus	2-3	2	1	1-2	0-1	Ag2, Ga2, Dh+
2.50-2.56	Inwashed clay? with charcoal?	2-3	2	1-2	2	0-1	Ag2, Ga2, Dh+
2.56-2.71	Transition detrital peat/clay pods						(Dh1, Ag2, Gal)
2.71-3.00	Pale creamy brown clay (with chacoal?)	1-2	0-1	0-1	2-3	-	Ag3, Gal
3.00	Terminated						

¹N: Nigro; ²St: Stratificatio; ³E: Elasticitas; ⁴S: Siccitas; ⁵H: Humicitas

Appendix II.2: Sediment texture

Sand-fraction unsieved

Site: Wharau Road Swamp (core 1)

Endresult (individual subfractions)								
Total frequency data								
Sample #	Depth	Sand	Very coarse silt	Coarse silt	Medium silt	Fine silt	Very fine silt	Clay
		>62.50 μm	62.50 μm	31.25 μm	15.63 μm	7.81 μm	3.91 μm	<1.95 μm
	[m]	[freq mass %]	[freq mass %]	[freq mass %]	[freq mass %]	[freq mass %]	[freq mass %]	[freq mass %]
1	0.03	0.0	0.0	0.0	8.3	14.0	15.1	62.6
2	0.1	0.0	0.5	1.4	7.5	11.3	12.7	66.6
3	0.28	0.0	2.0	8.5	14.3	18.4	13.0	43.8
4	0.31	1.7	5.3	8.6	14.9	17.5	14.0	38.0
5	0.35	8.1	0.5	4.4	9.3	11.3	9.5	56.9
6	0.39	7.1	0.0	3.8	9.4	9.0	6.4	64.3
7	0.47	5.2	5.6	4.4	10.1	14.7	6.9	53.1
8	0.52	7.4	5.4	11.5	10.9	9.4	6.2	49.2
9	0.57	7.6	4.6	12.8	13.0	11.4	6.6	44.0
10	0.62	9.5	5.5	13.7	13.6	10.2	6.9	40.6
11	0.67	9.4	8.2	17.3	16.7	11.3	5.4	31.7
12	0.715	13.8	4.5	9.8	10.0	9.3	5.7	46.9
13	0.805	14.9	4.6	9.8	10.1	9.8	6.5	44.3
14	0.85	10.8	3.2	9.4	11.0	10.9	6.0	48.7

Appendix II.2: Sediment texture

Sand-fraction unsieved

Site: Wharau Road Swamp (core 2)

Endresult (individual subfractions)								
Total frequency data								
Sample #	Depth	Sand	Very coarse silt	Coarse silt	Medium silt	Fine silt	Very fine silt	Clay
		>62.50 um	62.50 um	31.25 um	15.63 um	7.81 um	3.91 um	<1.95 um
	[m]	[freq mass %]	[freq mass %]	[freq mass %]	[freq mass %]	[freq mass %]	[freq mass %]	[freq mass %]
1	0.42	0.4	0.1	4.0	7.7	11.4	9.7	66.8
2	0.52	0.9	1.5	4.0	8.5	11.7	9.3	64.2
3	0.62	0.4	0.4	2.1	4.4	12.3	9.7	70.8
4	0.72	1.2	8.4	3.2	4.3	13.4	6.4	63.0
5	0.82	6.3	0.7	11.4	11.5	11.8	10.5	47.8
6	0.91	12.1	3.1	12.3	11.4	10.2	7.6	43.3
7	1	7.9	5.2	15.5	15.1	11.0	6.7	38.6
8	1.12	17.1	7.5	16.0	12.9	10.1	6.2	30.3
9	1.22	2.6	1.4	3.9	5.7	8.8	7.7	70.0
10	1.32	0.1	0.7	2.4	4.1	6.6	7.1	79.0
11	1.52	0.8	1.0	3.2	7.2	9.0	7.8	71.1
12	1.6	0.2	0.5	2.7	6.9	9.4	9.4	70.9
13	1.68	0.0	1.1	2.5	7.8	10.6	10.4	67.5
14	1.76	0.2	1.3	2.9	7.2	10.4	9.1	68.9
15	1.84	0.1	0.1	2.0	5.1	9.9	8.8	74.1
16	1.92	0.0	0.8	0.5	5.1	11.7	11.7	70.1
17	2	0.0	1.1	0.9	4.8	12.5	11.5	69.3
18	2.075	0.8	1.2	3.6	7.2	10.9	9.5	66.8
19	2.15	0.0	0.5	6.1	7.9	9.1	9.0	67.2
20	2.225	0.4	1.7	5.7	8.1	9.2	7.5	67.3
21	2.3	0.4	0.0	5.3	7.8	8.7	7.3	70.4
22	2.35	0.6	0.7	4.9	6.1	8.1	7.2	72.3
23	2.4	1.3	1.8	3.0	6.7	8.3	7.6	71.3
24	2.45	1.0	1.6	4.6	7.6	9.2	7.4	68.6
25	2.49	1.6	1.3	2.9	7.3	7.9	7.7	71.2

Appendix II.3: Sediment texture

Sand fraction unsieved

Site: Wharau Road Swamp (core 3)

Endresult (individual subfractions)								
Total frequency data								
Sample #	Depth	Sand	Very coarse silt	Coarse silt	Medium silt	Fine silt	Very fine silt	Clay
		>62.50 um	62.50 um	31.25 um	15.63 um	7.81 um	3.91 um	<1.95 um
	[m]	[freq mass %]	[freq mass %]	[freq mass %]	[freq mass %]	[freq mass %]	[freq mass %]	[freq mass %]
1	0.265	1.5	0.6	0.5	8.4	16.3	17.5	55.2
2	0.41	0.4	0.6	2.8	8.6	12.9	13.7	61.0
3	0.845	1.2	1.1	8.1	9.9	13.7	13.0	53.2
4	1	10.3	3.7	18.2	15.4	11.5	8.2	32.8
5	1.14	16.7	6.1	21.0	16.7	10.1	6.3	23.2
6	1.28	24.4	9.0	20.6	13.3	7.3	4.4	21.1
7	1.42	14.3	0.7	3.9	6.2	7.7	15.6	51.7
8	1.56	0.3	1.3	2.9	4.9	7.8	7.5	75.2
9	1.7	0.5	1.5	0.0	3.1	6.7	7.6	80.6
10	1.84	0.5	1.4	2.1	6.4	8.6	9.3	71.6
11	2	0.6	0.6	2.6	5.9	8.8	9.0	72.5

Appendix 11.2: Sediment texture

[Sand fraction unsieved]

Site: Wharau Road Swamp (core 5)

Total frequency data								
Sample #	Depth	Sand	Very coarse silt	Coarse silt	Medium silt	Fine silt	Very fine silt	Clay
	[m]	>62.5 um [corrected freq mass %]	62.5 um [corrected freq mass %]	31.25 um [corrected freq mass %]	15.60 um [corrected freq mass %]	7.81 um [corrected freq mass %]	3.91 um [corrected freq mass %]	1.95 um [corrected freq mass %]
1	0.305	0.0	1.9	1.0	5.4	15.5	17.4	58.8
2	0.375	0.0	0.4	0.4	6.4	12.6	12.5	67.7
3	0.45	0.2	no data	no data	no data	no data	no data	no data
4	0.48	0.1	no data	no data	no data	no data	no data	no data
5	0.54	0.1	3.0	0.2	4.5	14.0	14.1	64.2
6	0.695	0.0	no data	no data	no data	no data	no data	no data
7	0.78	0.1	no data	no data	no data	no data	no data	no data
8	0.895	2.0	no data	no data	no data	no data	no data	no data
9	1.065	3.5	no data	no data	no data	no data	no data	no data
10	1.14	3.6	no data	no data	no data	no data	no data	no data
11	1.18	4.2	no data	no data	no data	no data	no data	no data
12	1.275	6.0	no data	no data	no data	no data	no data	no data
13	1.32	6.8	no data	no data	no data	no data	no data	no data
14	1.535	0.1	no data	no data	no data	no data	no data	no data
15	1.595	0.1	no data	no data	no data	no data	no data	no data
16	1.625	0.1	no data	no data	no data	no data	no data	no data
17	1.655	0.0	no data	no data	no data	no data	no data	no data
18	1.685	0.1	no data	no data	no data	no data	no data	no data
19	1.73	0.0	no data	no data	no data	no data	no data	no data
20	1.8675	0.0	0.9	2.9	7.7	12.9	11.5	64.2
21	1.8925	0.0	0.7	1.2	5.4	11.2	10.0	71.6
22	1.978	0.0	no data	no data	no data	no data	no data	no data
23	2.04	0.0	no data	no data	no data	no data	no data	no data
24	2.1225	0.0	no data	no data	no data	no data	no data	no data
25	2.21	0.0	no data	no data	no data	no data	no data	no data
26	2.285	0.0	no data	no data	no data	no data	no data	no data
27	2.3525	0.0	no data	no data	no data	no data	no data	no data
28	2.4375	0.0	no data	no data	no data	no data	no data	no data
29	2.47	0.0	no data	no data	no data	no data	no data	no data
30	2.5195	0.0	no data	no data	no data	no data	no data	no data
31	2.557	0.0	no data	no data	no data	no data	no data	no data
32	2.5825	0.0	0.1	0.1	2.0	8.2	17.5	72.1
33	2.605	0.0	no data	no data	no data	no data	no data	no data
34	2.655	0.1	0.0	2.1	4.4	13.1	17.5	62.8
35	2.695	0.1	1.0	2.1	6.1	10.5	11.6	68.6
36	2.73	0.2	0.2	5.5	9.6	13.2	11.8	59.6
37	2.7605	0.5	0.4	6.3	12.4	14.9	15.8	49.6
38	2.791	0.5	0.8	6.2	9.7	12.9	11.6	58.4
39	2.8785	0.4	3.7	6.8	10.2	12.2	13.5	53.3
40	2.903	0.5	no data	no data	no data	no data	no data	no data
41	2.9365	0.4	0.6	5.3	11.5	16.1	18.1	48.1
42	2.979	1.5	no data	no data	no data	no data	no data	no data

Coarse fraction:fine fraction ratio				
Sand:clay/silt ratio				
Sample #	Depth	Total sand fraction <62.5um	Total clay/silt fraction >62.5 um	Sand:clay/silt ratio
	[m]	[gr.]	[gr.]	
1	0.305	0.0007	1.8370	0.0004
2	0.375	0.0007	2.5105	0.0003
3	0.45	0.0031	0.9095	0.0034
4	0.48	0.0021	0.7898	0.0027
5	0.54	0.0024	0.9359	0.0026
6	0.695	0.0008	0.9748	0.0008
7	0.78	0.0021	0.5432	0.0039
8	0.895	0.0484	0.6683	0.0675
9	1.065	0.0275	0.1690	0.1399
10	1.14	0.0193	0.0993	0.1627
11	1.18	0.0765	0.4240	0.1528
12	1.275	0.0778	0.3652	0.1756
13	1.32	0.2293	1.1370	0.1678
14	1.535	0.0006	0.1232	0.0048
15	1.595	0.0007	0.1425	0.0049
16	1.625	0.0011	0.1452	0.0075
17	1.655	0.0007	0.1688	0.0041
18	1.685	0.0016	0.7326	0.0022
19	1.73	0.0007	0.6500	0.0011
20	1.8675	0.0007	1.8933	0.0004
21	1.8925	0.0024	4.6667	0.0005
22	1.978	0.0007	0.4461	0.0016
23	2.04	0.0001	0.3167	0.0003
24	2.1225	0.0005	0.4326	0.0012
25	2.21	0.0001	0.5333	0.0002
26	2.285	0.0002	0.4606	0.0004
27	2.3525	0.0000	0.0034	0.0000
28	2.4375	0.0000	0.0802	0.0000
29	2.47	0.0002	1.5506	0.0001
30	2.5195	0.0005	0.5312	0.0009
31	2.557	0.0000	1.6855	0.0000
32	2.5825	0.0009	1.5641	0.0006
33	2.605	0.0007	1.3376	0.0005
34	2.655	0.0023	1.0923	0.0021
35	2.695	0.0039	1.9019	0.0020
36	2.73	0.0031	1.0317	0.0030
37	2.7605	0.0161	1.8686	0.0085
38	2.791	0.0179	2.2788	0.0078
39	2.8785	0.0079	0.9599	0.0082
40	2.903	0.0106	1.1396	0.0092
41	2.9365	0.0139	1.5539	0.0089
42	2.979	0.0531	1.4790	0.0347

Appendix II.3: Sediment constituents

Site: Wharau Road Swamp (core 1)

Depth [m]	Soil moisture [%]	Organic matter [%]	Inorganic matter [%]
0.28	7.8	23.8	68.3
0.29	6.7	17.4	75.9
0.31	12.0	11.7	76.4
0.35	14.7	14.6	70.7
0.43	7.6	63.4	29.0
0.52	9.8	37.3	52.9
0.57	22.3	26.6	51.0
0.62	3.4	19.0	77.6
0.67	2.8	14.8	82.4
0.715	2.5	8.2	89.4
0.76	1.4	7.2	91.4
0.85	1.6	4.9	93.6

Appendix II.3: Sediment constituents

Site: Wharau Road Swamp (core 2)

Depth [m]	Soil moisture [%]	Organic matter [%]	Inorganic matter [%]
0.42	15.2	42.4	42.4
0.52	64.9	22.2	13.0
0.62	no data	no data	no data
0.72	7.9	61.6	30.5
0.82	no data	no data	no data
0.91	13.1	44.2	42.7
1	6.3	47.9	45.8
1.12	no data	no data	no data
1.22	no data	no data	no data
1.32	6.7	42.1	51.2
1.42	5.2	34.7	60.0
1.52	37.5	27.3	35.1
1.6	33.8	25.1	41.2
1.68	4.0	28.9	67.0
1.76	46.9	ERR	53.1
1.84	5.1	32.0	62.9
1.92	5.9	36.8	57.3
2	5.0	32.2	62.8
2.15	8.1	42.7	49.2
2.3	5.5	26.3	68.2
2.35	16.1	12.1	71.8
2.4	5.2	9.7	85.1
2.45	4.9	8.8	86.3
2.49	3.5	8.9	87.6

Appendix II.3: Sediment constituents

Site: Wharau Road Swamp (core 3)

Depth [m]	Soil moisture [%]	Organic matter [%]	Inorganic matter [%]
0.265	7.3	34.6	58.0
0.41	8.5	48.4	43.1
0.7	11.4	57.5	31.1
0.845	9.9	57.9	32.2
1	9.4	45.9	44.7
1.14	10.9	42.1	46.9
1.28	9.9	40.8	49.3
1.42	36.3	39.2	24.5
1.56	10.1	48.3	41.6
1.7	9.3	43.5	47.2
1.84	21.2	28.4	50.3
2	7.5	32.3	60.2
2.05	6.3	37.8	55.9
2.19	8.5	53.5	38.1
2.33	7.5	42.8	49.7
2.47	5.7	27.7	66.6
2.61	5.2	27.5	67.4
2.66	5.1	15.5	79.4
2.71	5.8	12.4	81.8
2.76	4.3	7.4	88.3
2.81	16.7	6.0	77.3
2.86	4.7	6.7	88.6
2.91	4.5	6.8	88.7
3	4.6	6.4	89.1

Appendix II.3: Sediment constituents

Site: Wharau Road Swamp (core 5)

Depth [m]	Soil moisture [%]	Organic matter [%]	Inorganic matter [%]
0.2	6.7	25.8	67.5
0.22	6.6	27.6	65.8
0.24	7.4	27.3	65.3
0.28	5.9	24.5	69.6
0.3	5.0	25.0	70.0
0.32	5.7	32.8	61.5
0.34	7.0	31.9	61.1
0.36	6.5	30.1	63.4
0.38	6.0	28.4	65.6
0.4	6.5	31.4	62.1
0.42	7.1	34.9	58.1
0.44	8.3	42.8	48.9
0.46	7.3	44.8	47.9
0.48	8.0	50.9	41.1
0.5	8.1	50.9	41.0
0.52	9.2	60.3	30.5
0.54	8.5	61.9	29.6
0.56	7.6	57.4	35.0
0.68	8.2	53.2	38.6
0.7	8.9	53.5	37.6
0.72	9.6	64.7	25.7
0.74	10.3	63.5	26.3
0.76	10.1	62.2	27.7
0.78	9.9	57.3	32.8
0.8	10.0	61.3	28.7
0.82	9.3	66.0	24.8
0.86	9.5	56.7	33.8
0.88	9.5	57.2	33.2
0.9	6.8	56.7	36.5
0.92	7.5	47.7	44.8
1.05	8.6	54.8	36.6
1.08	8.0	60.2	31.8
1.12	9.1	65.4	25.5
1.14	7.2	56.3	36.4
1.16	8.0	54.0	38.0
1.18	7.5	53.2	39.3
1.2	7.7	52.1	40.2
1.26	6.7	47.6	45.7
1.28	6.9	45.3	47.8
1.3	6.5	44.8	48.7
1.32	7.8	45.0	47.3
1.34	6.1	43.9	50.0
1.48	6.3	41.1	52.6
1.5	7.2	53.0	39.9
1.52	7.7	53.1	39.1
1.54	8.3	52.9	38.8
1.58	10.7	60.9	28.4
1.6	9.7	68.2	22.1
1.62	9.7	58.9	31.4
1.64	10.5	66.5	23.0
1.66	11.7	69.0	19.3
1.68	10.8	53.5	35.6
1.7	9.9	53.8	36.3
1.72	9.5	60.9	29.6
1.74	10.3	62.4	27.3
1.85	8.8	50.2	41.0
1.87	8.3	42.3	49.5
1.89	6.8	37.1	56.1
1.91	7.5	37.0	55.5
1.93	8.6	47.1	44.3
1.95	10.6	61.4	27.9
1.97	8.4	44.9	46.7
1.99	10.3	59.3	30.4
2	86.6	10.0	3.4

Depth [m]	Soil moisture [%]	Organic matter [%]	Inorganic matter [%]
2.03	87.2	9.7	3.2
2.06	87.6	10.3	2.1
2.09	86.8	10.2	3.0
2.12	85.6	10.8	3.6
2.15	86.2	9.9	3.9
2.18	86.5	10.8	2.7
2.21	89.0	8.3	2.7
2.24	88.6	8.0	3.4
2.27	89.4	7.8	2.8
2.3	88.8	7.6	3.6
2.33	86.3	9.5	4.1
2.36	82.4	14.3	3.3
2.43	88.3	7.1	4.7
2.46	84.6	5.9	9.4
2.49	84.2	6.9	8.9
2.52	84.3	7.1	8.5
2.55	81.3	6.7	12.0
2.58	81.8	6.8	11.4
2.61	76.1	6.7	17.2
2.64	69.9	9.3	20.8
2.67	72.7	8.1	19.2
2.7	72.2	9.5	18.4
2.73	68.0	16.4	15.6
2.76	65.9	10.0	24.0
2.79	64.7	9.6	25.6
2.806	66.2	10.1	23.7
2.866	26.4	23.9	49.7
2.9	25.9	22.9	51.2
2.93	25.0	31.5	43.5
2.96	18.2	32.8	49.0
2.99	11.1	30.7	58.2
3	27.0	41.1	31.9
3.03	24.5	32.7	42.9
3.06	20.1	18.0	61.9
3.09	28.0	11.6	60.4
3.12	57.0	6.8	36.2
3.15	58.1	7.4	34.5
3.18	57.4	6.9	35.6
3.21	58.1	7.1	34.8
3.24	60.6	6.4	33.0
3.27	56.7	6.1	37.1
3.3	58.3	5.7	35.9
3.33	59.2	5.7	35.1
3.37	60.3	7.5	32.2
3.4	60.2	5.9	33.9
3.43	55.9	5.1	39.0
3.46	35.1	6.8	58.1
3.48	30.1	5.7	64.2
3.53	21.6	8.2	70.3
3.56	23.2	5.8	71.1
3.59	23.2	5.1	71.7
3.62	22.5	5.4	72.1
3.65	23.9	5.2	71.0
3.68	21.8	5.0	73.2
3.71	21.1	5.2	73.7
3.74	20.9	5.0	74.1
3.77	17.8	4.8	77.4
3.8	15.4	4.8	79.9
3.83	13.0	4.7	82.3
3.86	13.0	4.5	82.5
3.89	12.0	4.3	83.7
3.92	12.0	4.6	83.4
3.95	18.3	5.1	76.5
3.98	16.7	5.1	78.2
4	15.3	4.9	79.7

Appendix II.4

Sediment mineralogy: Wharau Road Swamp (core 5). (<2µm fraction)

Depth (m)	Q ¹	F ²	Kand ³	Am ⁴ SiO ₂	M ⁹	Smec ¹⁰	M-Smec ¹¹	Ver ¹²
0.305	32	0	52	PO 20	7	0	7	2
0.46	20	0	45		6	0	5	4
0.695	20	0	55		9	6	10	0
0.78	15	0	37	Vg ⁵ 48				
0.895	13	0	28	Vg ⁵ 59				
1.14	8	1.2	-	Vg ⁵ 90				
1.275	12	1.7	22	Vg ⁵ 65				
1.535	11	0	36	PO ⁶ 53				
1.625	12	1.0	41	?46				
1.685	10	0	58	Po	10	8	14	0
1.8925	15	0	50	POVg ⁷ 35				
2.04	8	0	49	PO43				
2.28	11	0	35	D ⁸ 54				
2.47	7	0	30	D63				
2.5825	7	1	34	D58				
2.7605	11	0	52	D37				
2.903	12	0	41	D47				
2.979	13	1.5	43	D42				

(Proportions expressed in weight percent)

Key for appendices II.4 and III.4

- ¹Quartz
- ²Feldspar
- ³Kandite
- ⁴Amorphous silica
- ⁵Volcanic glass
- ⁶Plant opal
- ⁷Plant opal + volcanic glass
- ⁸Diatoms
- ⁹Mica
- ¹⁰Smectite
- ¹¹Mica-smectite
- ¹²Vermiculite
- ¹³Cristobalite
- ¹⁴Gibbsite
- ¹⁵Hornblende
- ¹⁶Mica-Vermiculite
- ¹⁷Zeolite
- ¹⁸Magnetite/Ilmenite

Wharau Road Swamp (core 5). (2-20 μ m fraction)

Depth (m)	Q	F	Kand	Crist ¹³	Vg	PO	Diatoms
0.305	90	0	0	1		15	
0.46	56	0	0	0		40	
0.695	82	0	8	0		20	
0.78	45	0	0	0	?	60	?
0.895	32	1.6	0	0	10-20	45	
1.14	8	5	0	2.6		?	
1.275	20	3.5	0	1.5	60	20	
1.535	35	2.2	0	0	?	50-60	
1.625	37	1.4	0	0	-	-	
1.685	60	1.2	0	0			
1.8925	38	0	0	0			
2.04	34	0	15	0			
2.28	24		9	0			
2.47	4	0	0	0			
2.5825	15	0	0	0			
2.7605	70	1.2	0	0			
2.903	75	1.1	0	0			
2.979	52	0.8	0	0			

(Proportions expressed in weight percent)

Wharau Road Swamp (core 5). (>20µm fraction)

Depth (m)	Q	F	Bio SiO ₂	Vg	Vg	PO	Diatoms
0.305	60	0.9	40	0		0	
0.46	30	0	70	0		0	
0.695	65	1	30	5			
0.78	13	2	25	60			
0.895	8	2	30	60			
1.14	6	4		90			0
1.275	5	5		90			0
1.535	25	0	40	35			
1.625	40	0	25	35			
1.685	60	0	40	0		0	
1.8925	65	1	20	15			
2.04	70	1	30	0		0	
2.28	40	0	50	10			
2.47	15	0	85	0		0	
2.5825	70	1	30	0		0	
2.7605	85	1	15	0		0	
2.903	95	1	5	0		0	
2.979	95	1.4	5	0		0	

(Proportions expressed in weight percent)

Appendix II.5: Inductively Coupled Plasma Mass Spectrometry (ICP) analysis

Site: Wharau Road Swamp (core 5)

Sample #	Depth [m]	Element concentration ("sample values") expressed in ug/g dry matter																							
		Al	As	B	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	P	Pb	S	Se	Si	Sn	Sr	Zn	Fe/Mn ratio
blank		22.2	0.09	0.06	1.0	0.009	0.02	0.07	0.09	9.5	4.4	0.56	0.07	0.009	33.1	0.03	34.83	0.09	2.5	0.17	0.0	0.03	0.008	0.12	
1	0.13	4681	1.37	1.66	335	0.082	0.80	0.38	0.91	4131	495	263	29.0	0.082	66	0.60	164.9	0.91	140	2.55	0.0	0.51	4.35	2.24	143
2	0.25	5121	1.84	4.15	297	0.167	1.21	1.16	1.49	3729	566	252	21.0	0.342	67	0.84	67.0	2.55	166	5.09	0.0	0.84	3.85	2.69	178
3	0.37	5172	1.22	2.11	243	0.078	0.85	1.41	0.96	1870	526	247	13.9	0.078	60	0.57	92.2	0.78	245	2.96	0.0	0.40	3.30	2.40	135
4	0.49	4191	1.15	2.23	290	0.079	0.69	1.08	1.06	1683	432	237	14.0	0.079	67	0.67	86.8	1.41	588	2.91	0.0	0.41	3.96	2.35	120
5	0.61	3715	1.41	1.35	316	0.079	0.69	1.07	1.14	1521	387	237	12.2	0.167	73	0.76	77.7	1.50	886	3.34	0.0	0.49	4.21	1.72	124
6	0.73	2768	1.31	1.60	274	0.166	0.68	1.06	1.48	967	327	244	5.9	0.253	72	1.27	65.4	2.27	721	4.01	0.0	0.49	4.61	3.10	165
7	0.85	2023	1.24	0.82	225	0.080	0.60	0.55	0.62	1168	270	185	11.4	0.168	144	0.59	55.5	1.33	732	2.39	0.0	0.41	3.62	0.94	102
8	0.97	2550	0.81	1.99	222	0.081	0.43	0.47	0.72	839	612	135	13.3	0.081	467	0.50	52.7	1.79	569	2.06	0.0	0.32	3.39	1.31	63
9	1.09	3241	1.82	1.41	255	0.078	0.50	0.62	0.87	1093	855	154	18.2	0.165	670	0.66	55.4	6.33	848	2.34	0.0	0.40	3.90	1.35	60
13	1.21	3780	1.26	1.46	259	0.081	0.52	0.56	0.81	1076	982	138	19.7	0.081	792	0.68	62.0	5.92	679	2.61	0.0	0.41	3.67	2.12	55
10	1.33	3858	1.39	1.50	255	0.078	0.50	0.54	0.87	1319	950	137	19.0	0.078	731	0.66	70.2	5.03	622	2.34	0.0	0.31	3.72	2.05	69
11	1.45	3543	1.38	1.31	232	0.083	0.71	0.94	1.47	1133	526	219	14.6	0.174	237	0.88	73.9	6.86	802	3.39	0.0	0.42	4.11	3.35	78
12	1.57	3080	1.21	1.33	247	0.091	0.68	0.92	1.60	1124	373	233	13.8	0.190	125	1.06	74.5	6.18	1012	3.21	0.0	0.46	4.66	9.42	81
14	1.69	4475	0.82	3.02	212	0.082	0.71	1.38	1.73	1060	503	290	11.7	0.082	90	0.78	65.8	2.63	804	1.91	0.0	0.24	4.43	4.14	90
15	1.81	6122	1.13	1.51	200	0.079	0.86	1.94	1.57	1082	624	309	11.3	0.079	90	0.93	74.3	1.31	486	1.92	0.0	0.14	4.27	4.59	96
16	1.93	2195	0.96	0.57	146	0.096	0.40	0.98	1.49	537	227	153	6.8	0.096	72	0.49	44.0	2.01	502	1.93	0.0	0.18	3.14	1.56	79
19	2.05	760	0.98	0.26	130	0.098	0.09	0.14	0.77	366	62	83	4.8	0.098	49	0.29	31.6	0.98	501	1.97	0.0	0.18	2.57	4.92	77
20	2.17	2190	0.89	1.40	330	0.089	0.47	0.61	1.18	1072	205	224	10.6	0.089	85	0.94	49.9	0.89	1225	1.77	0.0	0.16	6.33	7.97	101
17	2.29	1988	0.87	1.67	292	0.087	0.46	0.80	1.07	972	193	206	8.8	0.087	82	1.02	53.7	0.87	1181	1.75	0.0	0.16	5.38	3.92	111
18	2.41	2004	0.90	1.12	304	0.090	0.38	0.52	1.29	1082	202	201	7.8	0.090	81	1.05	60.6	0.90	1060	1.79	0.0	0.16	5.40	2.24	139
21	2.53	4109	0.89	1.60	327	0.089	0.57	1.11	0.99	1410	436	269	12.7	0.089	91	0.65	66.0	0.89	830	1.78	0.0	0.16	4.89	1.84	111
22	2.65	5696	0.96	1.68	195	0.078	1.03	1.85	1.83	1411	632	265	6.1	0.078	62	1.27	40.1	0.78	642	1.57	0.0	0.14	3.74	8.59	231
23	2.77	6834	0.82	1.20	189	0.082	0.98	2.28	1.99	1499	763	270	7.2	0.082	47	1.32	40.1	0.82	594	1.63	0.0	0.15	3.79	9.81	207
24	2.89	5791	0.84	2.29	234	0.075	1.07	1.78	1.84	1601	650	293	6.7	0.075	60	1.31	34.8	0.75	828	1.50	0.0	0.13	4.69	9.94	238
25	3	4692	0.78	2.28	259	0.078	1.02	1.40	2.34	1446	524	268	6.3	0.078	60	1.35	32.8	1.04	795	1.56	0.0	0.14	4.85	9.41	231
26	3.12	5576	0.80	2.42	132	0.080	0.87	1.88	1.33	1229	668	238	5.9	0.080	60	1.11	23.5	0.80	440	1.77	0.0	0.14	2.91	8.10	210
27	3.24	5481	0.95	1.85	112	0.078	0.94	2.10	1.47	1187	637	203	5.7	0.078	36	1.18	23.2	0.78	383	2.51	0.0	0.23	2.42	8.02	210
28	3.36	5444	1.09	1.12	103	0.076	1.08	1.95	4.04	1220	653	202	5.6	0.076	47	1.14	20.8	0.84	389	2.52	0.0	0.22	2.27	8.05	219
29	3.48	7249	2.55	14.69	102	0.255	1.30	2.56	1.76	1255	1221	437	7.3	0.255	146	1.55	20.5	2.55	171	5.36	0.0	0.49	2.89	6.99	172
30	3.6	6054	1.04	4.69	50	0.078	0.93	2.17	0.86	983	531	181	5.2	0.078	45	0.74	12.6	1.73	24	3.71	0.0	0.40	1.11	2.21	189
31	3.72	6431	1.25	1.72	55	0.080	0.96	2.34	1.43	1016	620	178	5.5	0.080	54	0.77	13.3	0.80	22	2.86	0.0	0.23	1.24	1.93	186
32	3.84	4828	1.43	1.55	44	0.081	0.79	1.81	0.72	696	487	156	3.7	0.081	51	0.77	7.2	1.61	22	3.31	0.0	0.41	1.15	1.84	189
33	3.96	4971	1.08	1.28	44	0.081	0.79	1.90	0.72	797	516	152	4.2	0.081	44	0.77	9.1	1.80	25	3.41	0.0	0.41	1.07	2.39	188

APPENDIX III.1

Stratigraphy of sediment cores

Location: Lake Tauanui	Altitude: 230m a.s.l.	Map Ref.: NZMS 260, P06/887332
Date: 09.01.1992	Core No.: 1	Corer Used: Modified Vallentyne mud sampler

DEPTH [m]	DESCRIPTION	N ¹	St ²	E ³	S ⁴	H ⁵	COMPONENTS
0.00-0.14	Very soft dark grey brown clay gyttja	3	0	0	0	2	Ld1, Sh1, Ag
0.14-1.00	Soft dark grey brown clay-gyttja, firmer	3	1	0	1	2	Ld1, Sh1, Ag1
1.00-2.00	As above	3	1	0	1	2	Ld1, Sh1, Ag
2.00-2.93	As above, dryer below	3		1	2	2	
2.93-2.97	Grey clay	2	2	1	2	-	Ag4, Sh, Ld
2.97-3.00	As 2.00-2.93, ? darker	3		1	2	2	Ld1, Sh1, Ag
3.00-3.74	Dark brown gyttja, slip marks, ?faults at 3.40 and 3.47	3-4	2	1	2	2	Ld2, Sh2, Ag+
3.74-3.87	Grey clay, some iron staining	2	0	0	2-3	-	Ag4
3.87-4.00	As above	2	0	0	2-3	-	Ag4
4.00	Terminated. Impenetrable base						

¹N: Nigro; ²St: Stratificatio; ³E: Elasticitas; ⁴S: Siccitas; ⁵H: Humicitas

APPENDIX III.1

Stratigraphy of sediment cores

Location: Lake Tauanui	Altitude: 230m a.s.l.	Map Ref.: NZMS 260, P06/887332
Date: 23.01.1993	Core No.: 2	Corer Used: Modified Vallentyne mud sampler

DEPTH [m]	DESCRIPTION	N ¹	St ²	E ³	S ⁴	H ⁵	COMPONENTS
0.00-0.50	Very soft dark grey/brown gyttja	3	0	0	1	2	Ld1, Sh2
0.50-1.00	Less soft gel mud	3	0	0	2	2	Ld2, Sh2, Ga+
1.00-2.00	As above	3	0	0	2	2	Ld2, Sh2, Ga+
2.00-3.00	As above	3	0	0	2-3	2	Ld2, Sh2, Ga+
3.00-3.28	Dark grey gyttja	3	0	0	3	2	Ld2, Sh2, Gh+
3.28	Terminated						

¹N: Nigro; ²St: Stratificatio; ³E: Elasticitas; ⁴S: Siccitas; ⁵H: Humicitas

APPENDIX III.1

Stratigraphy of sediment cores

Location: Lake Tauanui	Altitude: 230m a.s.l.	Map Ref.: NZMS 260, P06/887332
Date: 24.01.1993	Core No.: 3	Corer Used: Modified Vallentyne mud sampler

DEPTH [m]	DESCRIPTION	N ¹	St ²	E ³	S ⁴	H ⁵	COMPONENTS
0.00-0.27	Very soft dark/brown gyttja	2-3	0	0	0-1	2	Ld2, Sh2, Ga+
0.27-0.49	Soft dark grey/brown gyttja	2-3	0	0	1	2	Ld2, Sh2, Ga+
0.49-1.00	Less soft gel mud; ? sand	3	0	0	1-2	2	Ld2, Sh2, Ga+, Gs+
1.00-2.00	Grey brown gyttja	3	0	0	2	2	Ld2, Sh2, Gh+
2.00-2.44	As above	3	0	0	2	2	Ld2, Sh2, Gh+
2.44	Terminated						

¹N: Nigro; ²St: Stratificatio; ³E: Elasticitas; ⁴S: Siccitas; ⁵H: Humicitas

APPENDIX III.1

Stratigraphy of sediment cores

Location: Lake Tauanui	Altitude: 230m a.s.l.	Map Ref.: NZMS 260, P06/887332
Date: 23.01.1993	Core No.: 4	Corer Used: Modified Vallentyne mud sampler

DEPTH [m]	DESCRIPTION	N ¹	St ²	E ³	S ⁴	H ⁵	COMPONENTS
0.00-0.30	Very soft dark brown gyttja	2-3	0	0	0-1	2	Ld2, Sh2, Ga+
0.30-0.66	Soft dark grey/brown gyttja	2-3	0	0	1	2	Ld2, Sh2, Ga+
0.66-1.00	Less soft gel mud; ?sand, ?charcoal	3	0	0	1-2	2	Ld2, Sh2, Ga+, Gs
1.00-2.00	As above	3	0	0	1-2	2	Ld2, Sh2, Ga+, Gs
2.00-2.48	As above; ?charcoal	3	0	0	1-2	2	Ld2, Sh2, Ag+
2.48	Terminated						

¹N: Nigro; ²St: Stratificatio; ³E: Elasticitas; ⁴S: Siccitas; ⁵H: Humicitas

APPENDIX III.1

Stratigraphy of sediment cores

Location: Lake Tauanui	Altitude: 230m a.s.l.	Map Ref.: NZMS 260, P06/887332
Date: 29.01.1993	Core No.: 5	Corer Used: Modified Vallentyne mud sampler

DEPTH [m]	DESCRIPTION	N ¹	St ²	E ³	S ⁴	H ⁵	COMPONENTS
0.00-0.20	Loose soft dark grey brown gyttja	3-4	0	0	0-1	2	Ld2, Sh2
0.20-0.98	Dark brown gyttja, ?charcoal	3-4	0	0	1	2	Ld2, Sh2, Ga
0.98-1.00	Grey brown gyttja?, trace of sand,	3-4	0	0	1-2	2	Ld2, Sh2, Ga+, Gs+
1.00-2.00	As with 0.20-0.98m with charcoal	3-4	0	0	1-2	2	Ld2, Sh2, Ga+, Gs+
2.00-2.35	As with 0.20-0.98m with charcoal	3-4	0	0	1-2	2	Ld2, Sh2, Ga+, Gs+
2.35	Terminated						

¹N: Nigro; ²St: Stratificatio; ³E: Elasticitas; ⁴S: Siccitas; ⁵H: Humicitas

Appendix III.2: Sediment texture

[Sand fraction unsieved]

Site: Lake Tauanui (core 1)

Endresult (individual subfractions)

Total cumulative data								
Sample #	Depth	Sand	Very coarse silt	Coarse silt	Medium silt	Fine silt	Very fine silt	Clay
		>62.50 um	62.50 um	31.25 um	15.63 um	7.81 um	3.91 um	1.95 um
	[m]	[cum mass %]	[cum mass %]	[cum mass %]	[cum mass %]	[cum mass %]	[cum mass %]	[cum mass %]
0	0	100.0	99.7	99.6	99.3	96.4	87.4	76.8
1	0.03	100.0	99.7	99.6	99.3	96.4	87.4	76.8
2	0.135	100.0	99.7	99.5	99.4	96.4	90.9	81.4
3	0.22	100.0	99.7	99.0	97.3	93.4	85.1	74.9
4	0.265	100.0	99.7	99.2	97.4	94.2	87.2	78.2
5	0.31	100.0	99.6	99.0	98.3	95.7	89.8	81.3
6	0.36	100.0	99.5	98.3	96.7	93.2	89.0	83.4
7	0.415	100.0	99.4	99.4	98.5	94.4	89.7	83.6
8	0.465	100.0	99.2	98.8	97.6	93.9	88.7	82.5
9	0.825	100.0	100.0	99.4	99.0	96.6	92.4	85.2
10	0.89	100.0	99.9	99.5	98.9	96.6	91.8	85.6
11	0.965	100.0	99.9	99.7	99.5	97.6	93.8	88.1
12	1.02	100.0	99.9	99.8	98.8	96.6	92.2	87.5
13	1.06	100.0	99.9	99.4	98.7	97.2	92.5	86.6
14	1.125	100.0	99.9	99.4	98.7	97.0	92.7	85.7
15	1.17	100.0	100.0	98.7	97.9	96.4	92.3	86.0
16	1.2225	100.0	99.9	99.8	98.8	96.1	91.9	86.3
17	1.2675	100.0	100.0	98.3	97.7	95.5	90.8	85.7
18	1.325	100.0	99.9	99.4	98.9	97.3	94.0	88.0
19	1.37	100.0	99.6	99.3	98.9	97.2	92.8	87.6
20	1.4225	100.0	99.8	99.6	99.4	98.4	94.2	89.6
21	1.4675	100.0	99.0	98.4	96.5	93.4	87.4	79.5
22	1.525	100.0	99.8	99.5	98.1	94.1	87.9	80.6
24	1.6225	100.0	100.0	98.7	98.1	95.6	90.9	84.5
25	1.6675	100.0	100.0	99.2	98.3	96.0	91.2	85.3
26	1.7225	100.0	100.0	98.7	98.4	97.1	91.2	84.4
27	1.7675	100.0	100.0	99.7	98.5	95.6	90.4	83.4
28	1.8225	100.0	100.0	99.3	98.1	95.8	90.8	85.6
29	1.8675	100.0	100.0	99.7	98.7	96.9	92.7	86.9
30	1.9225	100.0	100.0	99.3	98.3	96.3	91.8	86.3
31	1.9675	100.0	99.9	99.3	98.5	95.4	90.5	84.2
32	2.0225	100.0	99.9	99.0	98.1	95.8	90.8	84.9
33	2.0675	100.0	100.0	99.7	98.3	95.3	90.5	82.6
34	2.1225	100.0	99.7	99.2	98.5	96.4	91.8	84.6
35	2.1675	100.0	100.0	99.1	98.1	94.9	89.9	83.1
38	2.3225	100.0	100.0	99.6	98.5	95.3	89.6	82.8
39	2.3675	100.0	99.9	99.8	99.6	95.6	89.3	82.0
40	2.415	100.0	100.0	99.7	99.0	97.3	91.9	84.6
41	2.445	100.0	100.0	99.7	99.2	97.0	91.6	86.0
42	2.475	100.0	100.0	98.9	98.0	95.3	90.5	85.5
43	2.515	100.0	100.0	99.7	99.4	96.6	91.5	82.1
44	2.545	100.0	99.9	99.7	99.2	97.3	92.6	87.2
45	2.575	100.0	100.0	99.3	99.1	97.3	92.9	87.6
46	2.6225	100.0	100.0	99.5	98.6	97.1	92.8	86.9
47	2.6675	100.0	100.0	99.9	99.7	97.8	92.6	86.7
48	2.7225	100.0	100.0	99.7	98.3	96.6	92.3	88.3
49	2.7675	100.0	100.0	99.7	99.3	97.7	93.4	88.4
50	2.8175	100.0	99.7	99.3	98.9	96.7	92.1	86.2
52	2.9	100.0	100.0	99.9	99.6	96.8	91.1	83.3
53	2.95	100.0	100.0	99.6	98.7	91.8	75.4	58.3
54	2.985	100.0	99.9	98.4	97.3	94.5	86.5	78.0
55	3.02	100.0	100.0	99.9	99.5	96.9	87.7	73.9
56	3.065	100.0	100.0	99.4	99.2	97.7	92.7	82.0
57	3.1225	100.0	99.2	98.8	98.3	96.1	91.4	84.7
58	3.1675	100.0	100.0	99.7	98.5	95.8	91.2	85.8
59	3.2225	100.0	99.9	99.6	99.3	97.4	92.8	87.5
60	3.2675	100.0	99.9	99.7	99.3	97.7	92.7	86.3
61	3.3225	100.0	100.0	99.3	98.5	97.1	92.4	86.9
62	3.3675	100.0	100.0	99.9	99.3	96.6	90.5	84.3
63	3.415	100.0	99.9	99.1	98.3	94.5	87.6	80.8
64	3.445	100.0	99.9	99.1	98.3	95.5	89.1	81.6
65	3.475	100.0	99.9	99.6	98.3	94.8	87.5	79.7
66	3.515	100.0	99.9	98.9	98.0	95.1	87.7	80.3
67	3.545	100.0	99.9	99.4	98.7	95.5	88.5	80.2
68	3.575	100.0	99.9	99.4	97.9	95.1	88.1	79.3
69	3.615	100.0	99.8	99.3	98.7	97.9	93.2	86.0
70	3.645	100.0	99.9	99.4	98.9	96.5	89.7	82.0
71	3.675	100.0	100.0	99.8	99.6	97.6	92.2	81.9
72	3.72	100.0	99.9	98.7	97.9	95.8	87.9	77.6
73	3.765	100.0	99.8	99.0	99.0	96.1	89.0	79.7
74	3.815	100.0	99.8	99.5	99.2	96.8	88.0	77.3
75	3.845	100.0	99.6	99.0	97.3	92.3	81.7	70.5
76	3.875	100.0	99.8	99.3	98.0	94.1	85.4	75.9
77	3.915	100.0	99.9	99.6	98.5	96.6	88.0	76.2
78	3.945	100.0	99.9	99.6	99.5	98.5	91.8	80.8
79	3.975	100.0	99.9	99.7	99.4	97.1	90.5	82.0
80	4	100.0	99.9	99.7	99.4	97.1	90.5	82.0

Appendix III.3: Sediment constituents
 Site: Lake Tauanui (core 1)

Depth [m]	Soil moisture [%]	Organic matter [%]	Inorganic matter [%]	Depth [m]	Soil moisture [%]	Organic matter [%]	Inorganic matter [%]	Depth [m]	Soil moisture [%]	Organic matter [%]	Inorganic matter [%]
0	9.7	18.5	71.8	1.57	13.5	16.5	70.1	3.13	14.1	18.5	67.4
0.03	8.0	19.6	72.4	1.59	13.7	15.9	70.4	3.15	14.1	18.8	67.1
0.05	7.9	18.6	73.4	1.61	12.6	17.4	69.9	3.17	13.6	18.7	67.7
0.07	8.9	18.4	72.7	1.63	13.2	16.1	70.7	3.19	3.0	16.1	80.9
0.09	8.2	17.8	74.0	1.65	13.5	16.2	70.3	3.21	12.5	18.2	69.4
0.11	7.4	18.3	74.3	1.67	13.1	16.2	70.7	3.23	12.9	17.5	69.6
0.13	8.5	18.8	72.7	1.69	3.9	14.6	81.5	3.25	12.9	17.4	69.7
0.15	8.4	20.0	71.6	1.71	12.8	16.3	70.9	3.27	13.0	16.7	70.3
0.17	9.4	17.8	72.8	1.73	12.8	16.4	70.7	3.29	3.7	14.7	81.6
0.19	2.6	15.8	81.6	1.75	12.8	16.7	70.5	3.31	13.7	16.8	69.4
0.21	8.9	19.5	71.6	1.77	12.6	17.3	70.1	3.33	14.1	16.7	69.2
0.23	9.8	19.9	70.3	1.79	4.3	13.8	81.9	3.35	13.8	16.7	69.5
0.25	10.6	18.6	70.8	1.81	13.2	16.9	69.9	3.37	14.0	17.3	68.7
0.27	11.4	17.4	71.2	1.83	12.8	17.5	69.6	3.39	3.5	15.3	81.2
0.29	3.3	14.8	81.8	1.85	12.4	17.0	70.5	3.41	12.7	16.2	71.1
0.31	9.6	16.6	73.7	1.87	12.4	16.7	71.0	3.43	12.5	16.6	70.9
0.33	10.2	18.8	71.0	1.89	4.8	15.0	80.2	3.45	12.5	16.3	71.2
0.35	10.4	17.8	71.8	1.91	12.1	17.5	70.4	3.47	12.8	17.4	69.8
0.37	10.2	17.4	72.5	1.93	11.9	17.1	70.9	3.49	2.8	16.3	80.9
0.39	3.5	16.3	80.2	1.95	12.7	16.9	70.3	3.51	12.5	19.3	68.2
0.41	10.2	18.3	71.5	1.97	11.4	16.6	72.0	3.53	12.5	19.5	67.9
0.43	10.4	18.2	71.4	1.99	4.5	13.9	81.6	3.55	12.4	18.8	68.8
0.45	11.0	17.6	71.4	2	27.2	14.0	58.8	3.57	11.9	19.0	69.1
0.47	10.5	17.4	72.2	2.03	26.9	14.2	58.9	3.59	3.5	16.3	80.1
0.49	3.7	15.5	80.8	2.05	25.4	14.1	60.4	3.61	11.6	19.1	69.3
0.51	11.3	17.5	71.2	2.07	25.0	14.5	60.5	3.63	11.4	19.9	68.7
0.53	11.0	16.7	72.2	2.09	4.3	14.3	81.3	3.65	11.1	20.4	68.5
0.55	10.5	16.9	72.5	2.11	24.0	14.5	61.5	3.67	10.6	20.7	68.8
0.57	10.9	16.3	72.8	2.13	24.9	13.8	61.3	3.69	3.4	17.4	79.2
0.59	4.1	13.8	82.2	2.15	25.4	14.4	60.2	3.71	8.8	19.7	71.5
0.61	11.2	15.8	72.9	2.17	25.9	13.8	60.3	3.73	8.5	19.8	71.7
0.63	11.4	16.0	72.6	2.19	4.3	14.9	80.8	3.75	8.5	14.4	77.1
0.65	11.5	16.8	71.7	2.21	25.3	14.6	60.1	3.77	8.1	13.2	78.7
0.67	11.8	17.4	70.8	2.23	27.8	14.2	58.0	3.79	3.6	10.4	86.1
0.69	4.3	14.5	81.1	2.25	28.5	13.3	58.2	3.81	7.4	11.3	81.4
0.71	11.3	16.8	71.8	2.27	31.5	12.8	55.6	3.83	7.4	10.0	82.7
0.73	10.7	16.5	72.8	2.29	32.7	12.7	54.6	3.85	6.8	9.9	83.3
0.75	10.9	16.7	72.4	2.31	39.0	11.9	49.0	3.87	6.8	9.5	83.6
0.77	10.9	17.2	71.9	2.33	42.7	10.9	46.4	3.89	3.6	9.4	87.0
0.79	4.5	14.1	81.5	2.35	42.6	11.2	46.2	3.91	6.9	9.1	83.9
0.81	10.2	17.0	72.8	2.37	46.2	10.4	43.4	3.93	6.9	9.1	84.0
0.83	10.3	16.5	73.2	2.39	3.4	14.2	82.3	3.95	7.0	9.0	84.1
0.85	10.2	17.0	72.8	2.41	44.4	10.1	45.5	3.97	7.5	9.1	83.4
0.87	10.4	16.9	72.7	2.43	39.5	11.0	49.5	3.99	3.7	9.7	86.6
0.89	4.7	13.5	81.8	2.45	46.3	10.3	43.4				
0.91	10.6	16.3	73.0	2.47	44.5	11.2	44.2				
0.93	10.5	16.2	73.3	2.49	4.6	15.2	80.1				
0.95	10.1	16.3	73.5	2.51	40.9	11.7	47.4				
0.97	9.9	16.3	73.7	2.53	39.0	12.4	48.7				
0.99	3.8	13.8	82.5	2.55	37.9	12.3	49.8				
1	13.4	17.1	69.6	2.57	34.8	13.1	52.2				
1.03	12.6	16.3	71.1	2.59	4.8	14.8	80.4				
1.05	12.5	16.2	71.3	2.61	29.3	13.4	57.3				
1.07	12.3	16.3	71.4	2.63	27.5	14.4	58.1				
1.09	4.4	13.8	81.8	2.65	25.5	14.7	59.7				
1.11	12.7	16.1	71.2	2.67	25.1	14.9	60.0				
1.13	12.7	15.6	71.7	2.69	4.2	14.2	81.5				
1.15	12.6	16.7	70.7	2.71	23.1	15.6	61.3				
1.17	13.0	16.3	70.7	2.73	22.1	15.1	62.7				
1.19	4.2	15.6	80.2	2.75	20.7	15.7	63.6				
1.21	13.1	17.1	69.8	2.77	20.1	16.1	63.8				
1.23	12.3	16.7	70.9	2.79	4.5	15.2	80.3				
1.25	13.2	16.2	70.5	2.81	18.6	16.7	64.7				
1.27	13.9	17.0	69.1	2.83	18.1	16.5	65.4				
1.29	3.6	14.8	81.6	2.85	17.6	15.7	66.7				
1.31	14.5	15.8	69.7	2.87	16.6	16.8	66.6				
1.33	15.1	15.9	69.0	2.89	4.1	14.0	81.9				
1.35	15.0	15.2	69.7	2.91	13.6	15.2	71.2				
1.37	15.4	15.6	68.9	2.93	12.6	14.7	72.7				
1.39	4.3	13.9	81.7	2.95	11.4	13.8	74.8				
1.41	16.3	15.8	67.8	2.97	8.6	11.7	79.7				
1.43	16.4	15.2	68.4	2.99	3.7	14.4	81.9				
1.45	14.3	14.9	70.8	3	11.0	12.7	76.3				
1.47	13.7	15.9	70.5	3.03	12.1	14.6	73.2				
1.49	12.6	16.1	71.4	3.05	14.2	17.5	68.3				
1.51	13.6	16.1	70.3	3.07	14.2	17.6	68.2				
1.53	14.2	16.6	69.2	3.09	4.5	15.8	79.7				
1.55	14.0	16.2	69.8	3.11	14.1	18.3	67.7				

Appendix III.3: Sediment constituents

Site: Lake Tauanui (core 2)

Depth [m]	Soil moisture [%]	Organic matter [%]	Inorganic matter [%]
0	5.8	21.9	72.2
0.1	5.8	21.9	72.2
0.175	6.3	21.2	72.5
0.25	5.7	19.7	74.6
0.3	5.9	21.4	72.8
0.35	6.0	21.8	72.3
0.4	6.4	21.7	72.0
0.45	6.4	21.7	72.0
0.5	6.1	21.8	72.1
0.55	6.1	21.4	72.5
0.6	6.4	21.0	72.6
0.65	6.6	22.2	71.3
0.7	6.5	23.2	70.4
0.75	6.3	19.9	73.9
0.8	6.2	19.9	74.0
0.85	6.3	21.9	71.8
0.9	6.4	22.0	71.5
0.95	6.5	22.3	71.2
1	6.1	21.6	72.2
1.05	6.4	19.0	74.6
1.1	7.5	20.8	71.6
1.15	7.8	20.6	71.6
1.2	7.3	20.7	72.1
1.25	7.1	20.4	72.5
1.3	7.0	19.7	73.3
1.35	7.1	19.9	73.0
1.4	7.1	19.4	73.5
1.45	7.6	18.8	73.6
1.5	7.7	19.8	72.5
1.55	7.5	20.6	72.0
1.6	7.3	20.3	72.4
1.65	7.3	20.4	72.3
1.7	7.6	19.5	72.9
1.75	7.3	19.9	72.7
1.8	6.9	19.3	73.8
1.85	6.8	19.4	73.8
1.9	7.1	19.9	73.1
1.95	7.4	19.6	73.1
2	7.1	19.8	73.1
2.075	7.0	19.4	73.5
2.1	7.0	19.7	73.3
2.15	7.0	20.2	72.9
2.25	6.8	20.6	72.5
2.3	6.7	20.9	72.4
2.35	6.5	20.2	73.2
2.4	6.6	21.1	72.3
2.45	6.2	20.9	72.9
2.5	6.3	20.6	73.1
2.55	6.6	20.5	72.9
2.6	6.2	20.8	73.0
2.65	6.5	21.0	72.5
2.7	6.8	21.2	72.1
2.75	6.6	20.4	73.0
2.8	6.4	21.1	72.5
2.85	6.8	21.7	71.5
2.9	11.8	21.6	66.7
2.95	6.7	21.6	71.8
3	6.5	21.7	71.8
3.07	7.6	20.5	71.9
3.12	7.8	22.7	69.5
3.17	7.8	23.6	68.6
3.22	7.9	23.1	69.0
3.27	7.6	23.7	68.7

Appendix III.3: Sediment constituents

Site: Lake Taunui (core 4)

Depth [m]	Soil moisture [%]	Organic matter [%]	Inorganic matter [%]
0	8.2	21.5	70.3
0.05	8.2	21.5	70.3
0.1	8.3	21.5	70.3
0.15	7.5	20.6	71.9
0.2	7.0	18.2	74.8
0.25	7.2	19.0	73.8
0.3	7.5	21.6	70.9
0.35	8.7	21.8	69.4
0.4	9.1	21.5	69.5
0.45	9.0	21.6	69.4
0.5	9.3	23.0	67.7
0.55	9.2	22.3	68.5
0.6	8.8	21.2	70.0
0.65	8.9	22.1	69.0
0.7	9.0	22.8	68.2
0.75	9.0	22.2	68.8
0.8	9.3	22.2	68.5
0.85	9.4	21.6	68.9
0.9	9.3	20.3	70.3
0.95	9.9	19.5	70.6
1	10.9	21.4	67.7
1.05	9.9	20.5	69.6
1.1	10.1	20.4	69.5
1.15	10.4	20.2	69.4
1.2	9.8	20.1	70.1
1.25	10.0	20.0	70.1
1.3	9.7	19.7	70.7
1.35	10.1	19.8	70.1
1.4	10.3	21.4	68.3
1.45	10.1	20.6	69.4
1.5	10.1	20.7	69.2
1.55	10.4	20.7	68.8
1.6	10.6	20.3	69.1
1.65	10.1	19.9	70.0
1.7	9.6	19.7	70.7
1.75	10.1	20.5	69.5
1.8	10.2	19.8	70.0
1.85	9.5	19.9	70.6
1.9	9.4	20.0	70.6
1.95	9.5	21.3	69.2
2	10.1	21.3	68.6
2.05	9.7	20.8	69.4
2.09	10.0	20.8	69.2
2.19	9.5	21.3	69.2
2.24	9.3	20.1	70.6
2.29	9.3	20.8	69.9
2.34	9.5	20.9	69.5
2.39	9.3	20.0	70.7
2.44	9.7	20.7	69.6
2.49	9.8	21.2	69.0

Appendix III.4

Sediment mineralogy: Lake Tauanui site (core 1). (<2 μ m fraction)

Depth (m)	Q	F	Kand	Gib ¹⁴	HB ¹⁵	Ver	M	M-Ver ¹⁶	Smec	Am SiO ₂	M-Smec ¹⁷	Zeo
0.03	2	5	47	0.6	8	5	2	2	0	28	0	
0.135	2	4	36	0.7	6	5	1	2	2	41	0	
0.22	2	2	40	0.7	5	5	0	2	0	43	0	
0.31	3	5	35	0.5	8	5	0	0	2	39	2	
0.415	2	3	47	0.6	6	6	0	2	0	33	0	
0.825	2	2	37	0.6	5	7	0	0	0	46	0	
0.965	2	2	40	0.5	6	5	0	0	0	44	0	
1.06	1	2	35	0.6	5	5	1	2	0	49	0	
1.125	1	2	40	0.6	4	5	2	0	0	45	0	
1.2225	1	2	45	0.6	5	6	0	2	2	36	0	
1.325	1	2	40	0.6	4	6	0	1	2	43	0	
1.4225	2	3	30	0.5	5	4	0	2	1	52	0	
1.525	2	3	45	0.6	6	6	0	2	0	35	0	
1.57	3	2	36	0.4	6	4	0	0	0	48	0	
1.6675	2	2	35	0.6	3	6	0	0	0	51	0	
1.7675	2	3	43	0.7	6	5	0	2	2	33	0	
1.8675	2	3	46	0.7	5	6	0	0	0	37	0	
1.9675	2	3	43	0.6	5	5	0	0	0	41	0	
2.0675	2	3	45	0.5	8	7	0	2	2	30	0	
2.1675	2	3	47	0.5	7	6	0	0	2	32	0	
2.275	3	3	40	0.6	9	5	1	0	0	38	0	
2.3675	2	3	48	0.5	8	8	0	0	2	24	0	4
2.445	3	4	48	0.5	8	7	0	0	2	24	0	3
2.515	2	3	45	0.5	7	9	0	0	2	28	0	3
2.575	1	3	45	0.6	6	7	0	0	1	34	0	2
2.6675	2	4	45	0.5	10	7	0	0	1	28	0	2
2.7675	2	4	52	0.5	10	12	2	0	0	14	0	3
2.9	2	4	44	0.5	10	7	3	0	1	27	0	1
2.95	1	5	44	0.2	24	5	2	0	0	14	0	4
2.985	2	4	48	0.3	13	7	0	0	2	23	0	0
3.02	2	4	43	0.3	15	8	0	0	0	25	0	2
3.065	2	4	40	0.6	10	10	0	0	0	33	0	0
3.2675	2	5	56	0.4	7	11	1	3	0	12	0	2
3.3675	2	5	54	0.4	10	11	1	2	0	12	0	2
3.515	3	4	52	0.5	13	13	3	0	2	6	0	3
3.675	2	4	52	0.5	12	6	2	0	2	16	0	3
3.72	3	5	55	0.4	12	5	0	0	0	15	0	4
3.765	3	5	52	0.4	11	5	2	0	0	18	0	3
3.815	4	6	55	0.4	12	6	0	0	0	12	0	4
3.845	4	6	52	0.4	12	4	2	0	0	15	0	4
3.915	3	5	50	0.3	12	6	0	0	0	18	0	5
3.945	4	6	55	0.2	10	4	0	0	0	17	0	3
3.975	2	4	52	0.3	10	8	0	0	0	20	0	3

(Proportions expressed in weight percent)

Lake Tauanui site (core 1). (2-20 μ m fraction)

Depth (m)	Q	F	Kand	Gib	HB	Ver	M	M-Ver	Smec	Am SiO ₂	M-Smec	Zeo
0.03	15	19	10		10					33		3
0.135	14	18	6		9					50		4
0.22	10	21	<5		6					55		3
0.31	12	20	<5		8					50		5
0.415	10	15			7					60		2
0.825	13	15			8					60		0
0.965	16	14			7					56		2
1.06	10	11			7					64		3
1.125	10	13			7					63		2
1.2225	10	13			9					63		0
1.325	11	14			7					63		0
1.4225	10	15			8					62		0
1.525	10	12	6		9					60		2
1.57	10	14			9					60		3
1.6675	14	14			7					60		0
1.7675	10	14			7					64		0
1.8675	16	15			10					50		3
1.9675	16	19			10					50		0
2.0675	12	14			10					56		3
2.1675	16	16	6		12					47		3
2.275	16	17	6		12					46		3
2.3675	17	15			9					52		2
2.445	20	17			12					43		3
2.515	21	16	5		11					45		2
2.575	15	15			10					53		2
2.6675	15	17	5		14					44		5
2.7675	15	17			13					46		6
2.9	12	16	15		18					33		6
2.95	7	11	20		23					30		9
2.985	11	14	15		17					37		6
3.02	12	14	12		17					40		5
3.065	13	17	6		12					48		4
3.2675	16	17	6		13					44		4
3.3675	16	16	5		14					44		5
3.515	17	17	<5		14					42		5
3.675	20	16	5		12					44		3
3.72	21	18	6		14					37		4
3.765	23	18	5		14					36		4
3.815	24	19	5		12					35		5
3.845	24	20	5		11					35		5
3.915	25	20	13		11					26		5
3.945	22	17	12		12					33		4
3.975	24	20	12		11					30		4

(Proportions expressed in weight percent)

Lake Tauanui site (core 1). (>20µm fraction)

Depth (m)	Q	F	Optical QF	Diatom	Vg	Mag/Il ¹⁸	Other	PO
0.03	13	14						
0.135	13	16	20	30	5	10	22	13
0.22	16	22						
0.31	7	16						
0.415	3	6	17	45	15	5	10	8
0.825	5	6						
0.965	5	5						
1.06	6	8						
1.125	5	7	20	53	5	9	6	7
1.2225	4	6	13	68	0	7	7	5
1.325	5	7	24	50	4	9	5	8
1.4225	6	8						
1.525	7	9	14	25	38	7	11	5
1.57	-	-						
1.6675	5	7	24	55	0	6	6	9
1.7675	10	11						
1.8675	6	8	16	54	0	8	5	17
1.9675	8	10	22	40	0	12	14	12
2.0675	5	8						
2.1675	6	9	16	50	0	12	16	6
2.275	5	8						
2.3675	8	9	22	24	0	24	24	6
2.445	9	8						
2.515	10	7	23	40	0	14	16	7
2.575	7	6						
2.6675	12	10						
2.7675	12	10						
2.9	8	11						
2.95	6	9	14	8	0	25	50	3
2.985	7	11						
3.02	6	10						
3.065	8	8						
3.2675	8	8	15	33	0	24	20	8
3.3675	9	12						
3.515	13	13	18	27	0	18	25	12
3.675	12	15						
3.72	24	16						
3.765	20	15						
3.815	24	18						
3.845	14	17						
3.915	24	14	22	8	0	37	28	5
3.945	22	12						
3.975	24	13	35	5	0	28	20	12

(Proportions expressed in weight percent)

APPENDIX IV.I

Stratigraphy of sediment cores

Location: Lake Taumatawhana	Altitude:	Map Ref. NZMS 260, NO3/129203
Date: 25.5.1992	Core No.: 2	Corer Used: Modified Vallentyne mud sampler

DEPTH [m]	DESCRIPTION	N ¹	St ²	E ³	S ⁴	H ⁵	COMPONENTS
0.00-0.30	Loose black gyttja	4	0	0	0	2	Ld2, Sh2, Ga+
0.30-1.00	Black gyttja	4	1	1	1-2	2	Ld1, Sh2, Ga+
1.00-2.00	Black gyttja	4	1	1	2	2	Ld2, Sh2, Ga+
2.00-3.00	Black gyttja	4	1	1	2	2	Ld2, Sh2, Ga+
3.00-3.90	Black gyttja	4	1	1	2	2	Ld2, Sh2, Ga+
3.90-4.00	Black gyttja (in sand)	4	1	1	2	2	Ld2, Sh2, Ga+
4.00-4.11	Black gyttja (in sand)	4	1	1	2	2	Gs+
4.11-4.25	Black gyttja (in sand)	4	1	1	2	2	Ld1, Sh2, Gsl
4.25-4.42	Sand						Ga4
4.42-4.46	Timber						T14, Gs+
4.46	Terminated						

¹N: Nigro; ²St: Stratificatio; ³E: Elasticitas; ⁴S: Siccitas; ⁵H: Humicitas

Appendix IV.2: Sediment texture
[Sandfraction unsieved]

Site: Lake Taumatawhana

Endresult (individual subfractions)								
Total frequency data								
Sample #	Depth	Sand	Very coarse silt	Coarse silt	Medium silt	Fine silt	Very fine silt	Clay
		>62.50 um	62.50 um	31.25 um	15.63 um	7.81 um	3.91 um	1.95 um
	[m]	[freq mass %]	[freq mass %]	[freq mass %]	[freq mass %]	[freq mass %]	[freq mass %]	[freq mass %]
0	0	87.2	0.6	0.9	2.0	2.5	2.6	4.3
1	0.125	87.2	0.6	0.9	2.0	2.5	2.6	4.3
2	0.3	67.9	1.1	2.3	6.3	9.2	9.7	3.6
3	0.435	66.9	0.9	1.9	4.9	7.3	7.0	11.1
4	0.535	27.2	0.1	3.2	7.0	13.0	20.4	29.0
5	0.61	14.0	1.8	5.1	13.2	18.7	18.5	28.7
6	0.73	6.2	0.7	4.0	8.6	21.5	22.7	36.3
7	0.83	5.0	1.2	4.1	8.3	15.1	32.0	34.3
8	0.94	5.3	0.3	3.8	8.9	12.0	25.8	44.0
9	1.115	36.3	1.1	4.3	5.2	10.8	13.4	28.9
10	1.26	9.6	0.8	2.3	9.7	10.4	32.5	34.6
11	1.36	9.1	0.1	4.2	7.2	11.6	27.6	40.1
12	1.46	11.0	0.4	4.0	6.6	12.9	16.8	48.2
13	1.56	9.8	2.2	3.1	7.7	13.6	19.7	43.9
14	1.71	6.9	0.1	4.6	8.4	12.7	18.6	48.8
15	1.86	15.4	2.3	1.2	7.8	11.2	21.3	40.9
16	2	11.9	0.4	2.8	5.6	13.0	19.8	46.4
17	2.1	9.7	1.0	6.1	9.2	10.7	16.1	47.1
18	2.2	10.2	2.4	0.1	8.1	10.3	16.5	52.4
19	2.3	9.8	3.2	0.1	7.6	11.4	31.4	36.5
20	2.4	10.4	0.2	5.0	6.5	13.6	17.9	46.4
21	2.5	9.3	1.3	5.4	5.5	11.3	15.4	51.8
22	2.6	8.3	0.7	2.3	8.0	12.2	24.0	44.4
23	2.7	8.4	0.3	4.8	6.2	11.8	20.2	48.3
24	2.8	14.7	1.1	4.6	6.8	10.4	14.8	47.7
25	2.9	9.7	0.1	2.1	5.7	12.4	24.2	45.8
26	3	9.2	0.0	2.4	6.9	12.2	20.7	48.7

Appendix IV.3: Sediment constituents

Site: Lake Taumatawhana

Depth [m]	Soil moisture [%]	Organic matter [%]	Inorganic matter [%]
0	2.5	6.8	90.7
0.125	2.5	6.8	90.7
0.3	5.4	15.5	79.0
0.38	6.0	19.1	75.0
0.435	9.3	30.6	60.1
0.535	9.4	32.0	58.6
0.61	11.9	40.9	47.1
0.73	11.9	42.0	46.2
0.83	10.9	42.9	46.2
0.94	11.2	44.2	44.6
1.115	9.1	38.3	52.5
1.26	12.1	54.3	33.6
1.36	12.5	53.9	33.6
1.46	12.6	49.6	37.8
1.56	12.5	48.3	39.2
1.71	12.9	49.4	37.7
1.86	12.4	46.2	41.5
2	12.4	41.9	45.7
2.1	12.6	52.9	34.5
2.2	12.4	51.2	36.4
2.3	12.7	51.5	35.8
2.4	12.4	49.0	38.6
2.5	11.9	47.5	40.6
2.6	12.6	47.9	39.5
2.7	12.5	48.3	39.2
2.8	12.2	45.1	42.7
2.9	11.7	40.6	47.7
3	12.0	42.0	46.0

Appendix IV.4: Inductively Coupled Plasma Mass Spectrometry (ICP)

Site: Lake Taumatawhana

Sample #	Depth [m]	Element concentration ("sample values") expressed in ug/g dry matter																					Fe/Mn ratio		
		Al	As	B	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	P	Pb	S	Se	Si	Sn		Sr	Zn
blank		1.4	0.00	0.20	7.8	0.014	0.02	0.00	0.03	386.0	1.6	2.21	3.28	0.000	12.3	0.00	0.61	0.14	26.8	0.21	2.9	0.00	0.029	0.21	
37	0	2050	0.86	0.82	396	0.025	0.32	0.46	2.96	1719	457	149	8.1	0.039	549	0.37	45.0	4.26	251	0.96	176.3	0.12	8.62	4.34	212
38	0.17	3161	1.03	0.76	469	0.116	0.54	0.89	4.85	4767	396	99	18.7	0.103	651	0.42	96.4	4.67	614	2.88	519.8	0.31	12.76	4.60	255
39	0.29	1971	1.18	0.75	381	0.104	0.37	0.12	1.94	3258	411	133	9.5	0.118	509	0.33	62.4	2.93	337	3.33	239.9	0.38	8.56	2.70	343
40	0.42	1839	1.18	0.48	412	0.104	0.21	0.12	0.33	4194	275	129	18.7	0.118	399	0.24	156.6	2.22	574	3.32	234.5	0.35	8.30	2.22	224
41	0.58	808	1.12	0.29	257	0.098	0.20	0.11	0.31	3488	93	75	15.7	0.112	150	0.22	84.5	2.10	423	3.14	85.2	0.34	4.45	1.65	222
42	0.75	532	4.03	0.59	221	0.025	0.10	2.77	0.27	2556	58	57	13.3	0.332	99	5.06	44.4	1.28	417	0.97	38.2	0.14	3.61	4.21	192
43	0.875	495	4.55	1.52	369	0.023	0.16	3.21	0.42	1847	47	67	14.3	0.373	82	5.45	44.9	1.20	533	0.91	49.4	0.19	4.08	2.17	130
44	1.17	726	3.96	1.32	284	0.024	0.18	2.90	1.19	1536	72	81	10.1	0.313	107	4.73	46.7	1.38	544	0.93	41.4	0.14	4.16	2.76	153
45	1.36	810	4.97	1.22	307	0.025	0.18	3.00	0.38	1849	72	89	10.5	0.331	100	5.05	58.6	1.28	583	0.97	29.9	0.14	4.63	5.70	176
46	1.485	828	4.45	1.18	311	0.024	0.19	3.15	0.37	1326	77	80	8.0	0.338	110	5.07	53.1	1.16	502	0.94	36.3	0.15	4.19	2.09	166
47	1.66	906	5.06	1.25	346	0.026	0.20	3.29	0.41	1815	70	80	8.0	0.338	99	5.14	71.7	1.71	520	0.99	35.7	0.16	4.47	2.92	228
48	1.785	914	4.73	1.23	399	0.023	0.23	3.30	0.36	1933	75	92	9.5	0.353	117	5.18	80.4	0.76	419	0.91	46.7	0.16	4.77	3.76	204
49	1.93	982	4.70	1.03	278	0.024	0.26	3.16	0.39	1795	85	79	7.3	0.331	122	5.00	67.1	1.94	307	0.94	38.7	0.13	4.21	4.02	247
50	2.105	716	4.04	1.05	301	0.022	0.17	2.94	2.32	1376	70	79	10.0	0.309	102	4.78	44.2	2.06	559	0.89	28.4	0.11	4.09	2.73	137
51	2.255	852	5.14	1.24	321	0.024	0.22	3.18	0.57	1871	69	89	11.2	0.333	95	5.14	63.7	1.14	678	0.92	39.5	0.14	4.66	4.93	166
52	2.385	861	4.91	1.23	398	0.025	0.16	3.01	0.57	1542	86	87	8.8	0.317	122	4.83	57.3	1.05	627	0.97	38.4	0.13	4.73	3.19	176
53	2.55	924	5.06	1.16	297	0.024	0.18	3.17	0.51	1812	86	74	7.1	0.332	119	5.21	63.6	1.82	488	0.92	32.7	0.14	4.43	2.28	254
54	2.7	863	4.98	1.06	313	0.021	0.20	3.23	0.44	1801	71	83	8.2	0.337	106	4.98	70.3	0.84	463	0.84	28.0	0.14	4.39	4.77	219
55	2.86	922	4.72	0.98	269	0.023	0.27	3.39	0.38	1982	79	88	8.7	0.362	122	5.46	76.1	3.40	347	0.89	48.1	0.15	4.25	5.69	229
56	2.99	921	7.57	0.99	300	0.021	0.34	3.36	0.61	2971	74	81	8.4	0.400	114	5.54	79.3	2.45	636	0.84	67.2	0.24	3.97	3.78	356