Vegetational and climatic changes during the last 40,000 years at Burraga Swamp, Barrington Tops, NSW

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Publication Date:
2001

DOI:
https://doi.org/10.26190/unsworks/20047

VEGETATIONAL AND CLIMATIC CHANGES DURING THE LAST 40,000 YEAR AT BURRAGA SWAMP, BARRINGTON TOPS, NSW

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Thesis submitted for the degree of Master of Science
in the School of Biological Science,
University of NSW

July, 2001

ACKNOWLEDGEMENTS

I am greatly indebted to my supervisor, Dr Helene Martin, who has taught me a tremendous amount and provided me with unstinting assistance over many years. Without her encouragement, this thesis would not have been completed.

My family: John, Naomi, Tamara, deserve my enormous gratitude for their patience, encouragement and emotional support. John helped me with coring and data collecting. John and Naomi wrote the computer programme for Mossiman's equation and John and Tamara greatly assisted with proof reading.

The Joyce W. Vickery Fund of the Linnean Society of NSW provided a grant which was used to fund the work required to obtain the second core. An AINSE grant paid for the ^{14}C dating of eight dates. The School of Chemistry, UNSW, dated three of the samples, free of charge.

Many thanks to Jim Neale of the Research School of Pacific and Asian Studies, Division of Archaeology and Natural History, ANU, who extracted the second core. Many thanks also to Mr Tony Robbie and Ms. Iona Maher without whose assistance that task could not have been completed.

I would like to thank a number of people who have contributed their expertise in various ways. Mrs Karen Wilson of the National Herbarium of NSW, Royal Botanic Gardens, Sydney, identified the seeds in the sediments. A/Professor Gerald Nanson organised X-ray diffraction of many clay samples and Dr John Tibby examined samples for their diatom content. I had valuable comments from many people: Dr Geoff Hope, A/Professor Paul Adam, Dr Scott Mooney, Professor John Roberts, Mr Chris Myers, Dr Ewen Lawson. I am grateful for the assistance of Mrs Jan De Nardi (School of Biological Science). I am also grateful to Mrs Dorothy Yu for her assistance with the use of equipment and facilities made available by the School of Geography and thank Mrs Robyn Murphy who made it possible for me to use the facilities of the UNSW Life Sciences Photography Unit. I also wish to thank the Forestry Commission and National Parks of NSW, who have permitted this research to be conducted.

ABSTRACT

Burraga Swamp is a small enclosed basin at 985 m altitude in Barrington Tops, in the Eastern Highlands of New South Wales, Australia. It lies in the midst of a *Nothofagus moorei* cool temperate rainforest, which is at its southern limits here. The swamp is close to the boundaries between temperate rainforest, subtropical rainforest, sclerophyll forest and sub-alpine formations and may be a sensitive recorder of past changes in the vegetation.

The palynology and the sediments have been studied to a depth of 6.5 metres and were dated with eleven ^{14}C dates. The base of the sediment is about 40,000 years old.

The results showed the following:

From 40,000-30,000 years BP, Burraga was a lake with a very slow rate of deposition of fine grained sediments and flourishing aquatic/swamp vegetation. The dryland vegetation was an open or sparsely treed grassland/herbfield. From 30,000-21,000 years BP, the dryland vegetation remained much the same, but the aquatic vegetation disappeared. From 21,000-17,000 years BP, sandy sediments were deposited at an accelerated rate in a relatively shallow lake, culminating in a layer of gravelly sand. The vegetation was a treeless grassland between about 21,000 and 15,000 years BP. After 17,000 years BP, the rate of sediment accumulation slowed and after 15,000 years, some mesic elements appeared. *Dicksonia antarctica* became prominent between about 13,000 and 12,000 years BP and *Nothofagus* was consistently present after about 11,500 years BP. Peat deposition started about 6,500 years BP. By 6,000 years BP the cool temperate rainforest was fully developed, remaining on the site until the present.

These changes suggest that the climate at 40,000 years BP was drier than the present, becoming drier and reaching maximum aridity about 17,000 years BP, when temperatures were also at their lowest. Subsequently, the temperature increased and around 15,000 years BP the climate became wetter. Maximum moistures and temperatures were reached between about 9,000 and 5,000 years BP. The climate then varied until it reached the present.

Burraga extends the record of treeless vegetation over most of southeastern Australia, during the last glacial maximum, to more northerly localities than previously known.

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Chapter 1 INTRODUCTION

1.1 THE QUATERNARY PERIOD

“Climatic change was the hallmark of the Quaternary........the climatic fluctuations of the Quaternary were unprecedented in terms of the speed and amplitude of global temperature oscillations” (Williams et al., 1998, p. 244), occurring in "sudden jumps rather than incremental changes" (Adams et al., 1999, abstract).

Estimates of the beginning of the Quaternary Period ranges from about 3.5 to about 1.6 million years ago. The assessment of the onset is based on geological and biostratigraphic evidence and is controversial (Shackleton et al., 1984; Lowe and Walker, 1987; Williams et al., 1998). The "historical precedent", a stratigraphic boundary, has been defined at 1.6 million years, but if the onset of the glacial / interglacial cycles is used to define the boundary, the boundary would be placed at 2.4 million years ago (Shackleton et al., 1984).

The Quaternary Period is divided into two epochs: the Pleistocene, from the beginning of the Quaternary to 10,000 or 11,000 years ago and the Holocene, from 10,000 or 11,000 years ago to the present (Martinson et al., 1987; Hope, 1994). The Quaternary is distinguished by the cyclic changes of the earth's ice extent. The cycles consisted of maximum ice cover (glacial stage) and minimum ice cover (interglacial stage). Each of the maximum and minimum stages lasted for about 10% of each cycle (Hope, 1994). Secondary climatic fluctuations are evident within the cycles and are called stadials and interstadials. For the early part of the Pleistocene, the climate cycled between glacial and interglacial, every 41,000 years. Then, 100,000 year cycles began (Hodell and Venz, 1992; Adams et al., 1999; Bernhard, 1999).

At 1.42 million years ago, an interhemispheric climatic link began between the polar oceans and a close correlation developed between the Southern and the North Atlantic Oceans (Hodell and Venz, 1992). The climatic changes in the Antarctic and Southern Ocean lead those in Greenland and precede the onset of the northern hemispheric glaciation (Hodell and Venz, 1992; Petit et al., 1999). During the period 47,000 to 23,000 years ago, the lead time was about 1,000 to 2,500 years (Blunier et al., 1998). The Vostok ice core data strongly suggest that the Southern Ocean plays a significant role in controlling the long-term changes of atmospheric CO_2, which together with atmospheric CH_4 are correlated with the Antarctic air temperature (Petit et al., 1999).

The Vostok ice cores indicate both similarities and differences between successive interglacials (Petit et al., 1999). The current interglacial, the Holocene, is following a similar pattern to that of the last interglacial (Nanson et al., 1992), but the sea level is lower (Hope, 1994). The deuterium record of the ice core revealed that the Holocene is , "by far, the longest stable warm period recorded in Antarctica during the past 420 kyr" (Petit et al., 1999, p.434). Our present patterns in climate and landscapes were set during the Pleistocene. The Holocene represents life as at present (Hope, 1994).

1.2 DATING

Quaternary studies depend on dating to establish an independent time frame. Each absolute dating technique has inherent strengths and weaknesses and is more suitable for particular materials.

Radiocarbon dating relies on the constant rate of decay of the isotope ^{14}C to ^{14}N. ^{14}C is incorporated into living matter in the proportions that it occurs in the atmosphere and decays after death at the constant rate. The amount of ^{14}C remaining in a fossil is a measure of the time since death. The half life of ^{14}C is 5,730 years, limiting the valid dating of materials up to about 35,000 years old. Radiocarbon dating is the most common form of dating used in palynology.

Uranium series dating is based on the measurement of isotopes of U, Th, Pa, which are members of the uranium decay series. Uranium is incorporated into living organisms, usually marine, at the isotope ratio existing when alive. Decay at a constant rate occurs after death. This method can date material older than that dated with the ^{14}C method. For example, the ^{230}Th / ^{234}U can provide ages to 250,000 years. The technique is used on materials found in marine systems and has yielded useful chronologies of fossil coral reefs (Chappell, 1978).

Potassium-Argon technique is based on the decay of ^{40}K / ^{40}Ar, with a half life of 1.2×10^{10} years. The method can be used across the whole range of geologic time on volcanic and igneous rocks. When the precise stratigraphic relationship of igneous material and pollen bearing sediments are clear, the potassium - argon method may be used to date the polleniferous sediments. Studies which correlate the K-Ar and palaeomagnetic reversals, are particularly useful. This joint analysis has contributed to chronological studies in the Quaternary, by enabling correlations to be made between different stratigraphies (eg loess and marine sequences) which could otherwise not have been dated (Chappell, 1978). Palaeomagnetic reversals occur when north becomes south and vice versa, hence can be used to establish world-wide correlation of Quaternary events and of correlating the marine and terrestrial records (Lowe and Walker, 1987).

Thermoluminescence (TL) and Optically Stimulated Luminescence (OSL) dating techniques of quantifying the luminescence from quartz grains are used in dating archaeological materials, meteorites, lunar material, suitable deep-sea sediments and loess deposits. The emitted luminescence has a half-life of 10^9 years or more (Aitken, 1985).

A high resolution chronostratigraphic framework (Fig. 1.2) based on a well dated oxygen-isotope stratigraphy (Martinson et al., 1987) is used for subdividing and correlating Quaternary time. The subdivisions, stable isotope stages, may be correlated with Quaternary climate change (Martinson et al., 1987; Murray-Wallace, 1994).

Geomorphological events usually react more rapidly than does vegetation, to changes in the environment. Thus, sediments are more sensitive recorders of environmental changes, than is vegetation. Two factors which delay the response of vegetation to climatic change, are the life span of trees (generally accepted to be about 200 years) and the time it takes seedlings to reach maturity before flowering. However, it has been shown that vegetation response near ecotones, may be sensitive recorders of past climatic changes (McKenzie and Kershaw, 2000) and may be as short as decades (Peteet, 2000). Recent studies in Norway and Switzerland have demonstrated the sensitivity of angiosperms to rapid temperature changes (Birks and Ammann, 2000). Since the dating techniques such as thermoluminescence and small scale ^{14}C and U/Th dating are providing more refined data, geomorphological studies are used more widely (Lees, 1992; Colhoun, 1991).

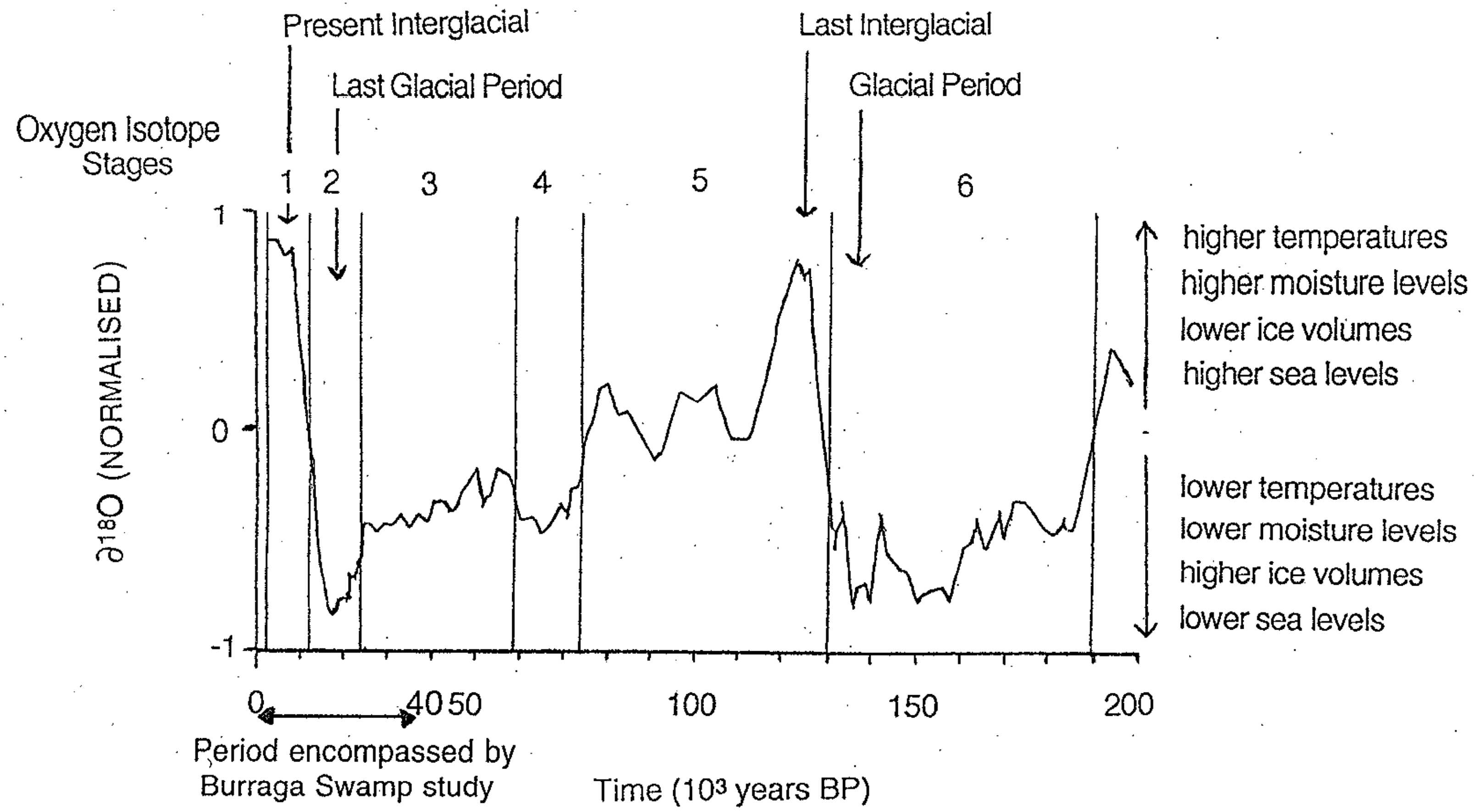


Figure 1.2 High resolution chronostatic framework

1.3 CLIMATIC CHANGE DURING THE QUATERNARY IN EASTERN AUSTRALIA

For Eastern Australian sites mentioned in the text, see Figure 1.4.

1.3.1 TEMPERATURE

In Australia, terrestrial climate changes have been deduced from a wide range of Quaternary studies. Changes in the Tasmanian and Snowy Mountains snowlines and periglacial phenomena have indicated temperature changes (Galloway, 1965; Colhoun, 1980; Markgraf et al., 1992). Australia had experienced only minimal ice cover during successive Quaternary glacial maxima, but glacial temperatures and precipitation were significantly reduced and vegetation changes were apparent. A decrease in temperature is indicated by a lowering in the treeline. The treeline during the last glacial maximum in the Barrington Tops is estimated to have been at an altitude of 1,200 m (Galloway, 1965).

In the Kosciuszko region, there were three glacial advances between about 35,000 and 15,000 years ago, with one of the glaciations at 21,000 to 18,000 years BP (Barrows et al., 2000). The climatic fluctuations which influenced these glacial advances were likely to have affected the Barrington Tops region which experienced only periglacial activity (the disruption of stable surfaces seen in the solifluction / mass-wasting deposits which would have been caused by the colder conditions [Clark et al., 1998]) during the last glacial maximum (Galloway, 1965). Slope deposits of solifluctional origin down to about 900 metres, were common in the Southeastern Highlands of NSW (Galloway, 1965) and snowlines may have been depressed to 800 metres in southeastern Australia (Markgraf et al., 1992). The extent of the fossil periglacial evidence suggests, that during the last glaciation, summers were comparable to current winters (Galloway, 1965). In the Snowy Mountains, the highest mean summer temperature may have been at least 9˚C lower (Galloway, 1965; Barrows et al., 2000) and in Tasmania about 5˚C (Galloway, 1965) / 5.7 - 6.5˚C lower (Colhoun, 2000) than today, while generally throughout eastern Australia the temperature depression may have been between 4˚C and 7˚C (Colhoun, 1991). Amino acid racemization from emu egg shells shows that much of Central Australia was also 9˚C lower than today. Cooling started about 45,000 years ago and the glacial period did not end until 16,000 years ago (Miller et al., 1997).

About 15,000 to 14,000 years ago, ice began to retreat on the Snowy Mountains in NSW. Temperature rose slowly to about 1.5˚C less than present. Deglaciation, although not constant, was completed by 9,000 years BP (Bowler et al., 1976). In Tasmania where an abrupt increase in temperature of 5-6˚C between 14,000 and 12,000 years BP is inferred (Colhoun, 2000), deglaciation was well advanced by about 11,500 years BP and completed by about 9,000 years BP. The Bass Strait land bridge was flooded by rising sea level between about 13,500 and 12,000 years BP (Macphail, 1979) and by 9,000 years BP the ocean around southeastern Australia was warmer (Markgraf et al., 1992).

1.3.2 MOISTURE / WIND / DUST

Fluctuations in lake levels result from changes in precipitation and/or evaporation, hence may be used to decipher past climates. Lakes can be filled by fluvial activity, which can be isolated events, occurring over short periods of time with occasional heavy precipitation in dry circumstances, or in areas of little vegetation, enabling large runoff amounts to occur. During at least part of the lacustral period (from 50,000 to 30,000 years BP) in north Queensland and Tasmania (Pulbeena Swamp), dry conditions are interpreted from the pollen data (Chappell, 1991). This is a feasable situation, since despite lower precipitation but due to reduced temperature and evaporation, increased runoff from slopes and the maintenance of local lake levels could have occurred. Thus, in regions close to catchment sources, eg. Lake Frome in South Australia around 12,000 years BP (Harrison, 1989), lake levels were high, suggesting pluvial conditions, while in areas distal to catchment sources, arid conditions prevailed (Bowler, 2000).

At Lake George in the southern tablelands of NSW and at Lake Wangoom, in southwestern plains of Victoria, lake levels were high at about 50,000 to 45,000 years BP (oxygen isotope stage 3; although at Lake Wangoom U/Th dating indicates 95,000 years, oxygen isotope stage 5b, [Harle et al., 1999]), indicating warm and wet conditions; then became much lower between 40,000 and 35,000 years BP with increasing salinity, indicating lower moisture levels. Lake levels continued to fall until 27,000 years BP (Edney et al., 1990). A review of numerous lake studies by Harrison (1993) indicates there was a moist interval between 30,000 and 24,000 years BP, with a drying trend after 26,000 years BP. During the glacial maximum, the lakes were generally low. Around 15,000 years

BP, freshwater was registered at Lake Wangoom (Edney et al., 1990), Willandra Lakes (Bowler et al., 1976) and at Lake George (Singh and Geissler, 1985): hence a generally wetter period is recorded between 15,000 and 13,000 years BP. By 12,000 years BP, lake levels were low nearly everywhere. After 11,000 years BP, there was a gradual increase in the number of high and intermediate level lakes (Harrison, 1993). Generally, highest lake levels were reached around 6,000 years BP (Chappell, 1991).

Gravels of the Cranbrook Terrace were deposited on a braided plain by flood events which ended about 45,000 years BP. They indicate a wetter period which has been called the 'Cranbrook Pluvial' (Nanson and Young, 1988). Deep lakes of this time may have been filled by the same pluvial (Nanson and Young, 1988; Edney et al., 1990).

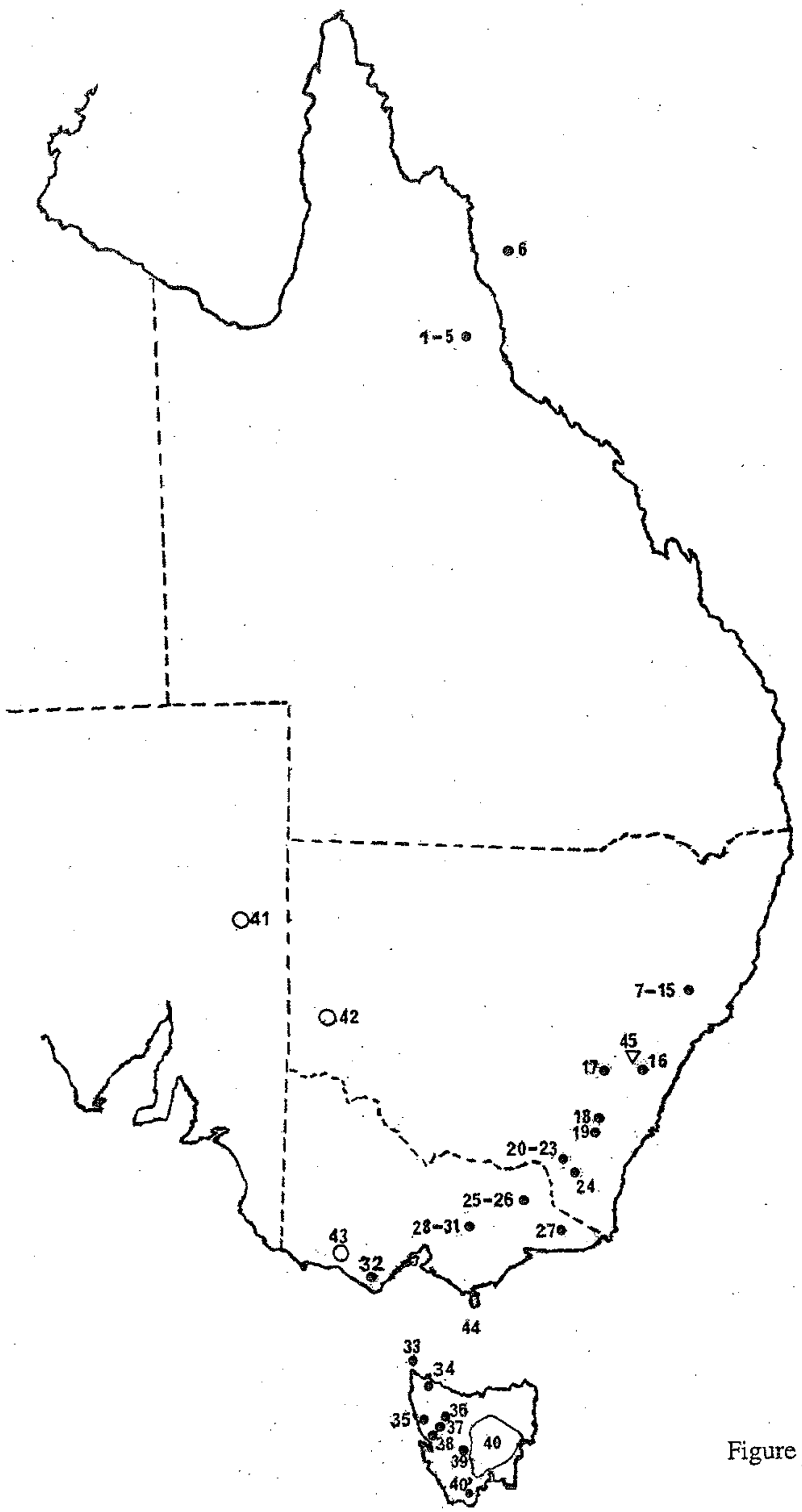
One proxy of past aridity is the amount and frequency of aeolian dust. Particle size analysis of the dust in deep-sea sediments indicates that winds over southern Australia need not have been stronger during the last glacial than those during the Holocene, but that wind erosion may have been greater (Hesse et al., 2000). Wind erosion may be caused by lack of plant cover over the soil or low moisture level in the soil (Hesse, pers. comm.). However, it has been suggested that increased dune-building activity which was at its height between 20,000 and 15,000 years BP, indicates stronger winds (Chappell, 1991). Evidence also suggests that there were stronger westerly winds over a greater area than at present (as far north as 31˚S), but further north the predominant winds were south easterly (Thom et al., 1994; Hesse, 1994).

1.3.3 CARBON DIOXIDE LEVELS

Palaeovegetational changes are routinely assessed for temperature and precipitation on the basis of today's ecological tolerances. However, it has been shown from ice cores that the CO_2 of the atmosphere in glacial phases was about 30 - 50% lower than during interglacials (Barnola et al., 1987; Adams et al., 1999; Moore et al., 2000; Stephens and Keeling, 2000). The lower levels of CO_2 in the atmosphere would stress the vegetation and reduce tree growth (Watts et al., 2000) and favour C4 grasslands (Levis et al., 1999) and shrublands (Adams et al.,1999; Kershaw and Whitlock, 2000). Hence the reduced tree cover and increased grasslands, interpreted from the palaeovegetation studies, may have been partly the result of the lower CO_2 in the atmosphere and not entirely due to aridity.

1.3.4 SUMMARY

In attempting to correlate these Quaternary studies, difficulties arise because of specific local factors in the different south-eastern geographic areas; uncertainty about the relation between precipitation/evaporation and ground water hydrology on lake water levels; the possible effect of meltwater on stream patterns and associated hydrological features within the adjacent plains; dating, particularly at the lower end of the ^{14}C range; the possible impact of Aboriginal burning; interrupted sediment and fossil accumulation (Williams et al., 1991; Harle et al., 1999). Despite these difficulties, general trends are apparent. In summary it would appear that the last interstadial from about 60,000 to 24,000 years BP (oxygen isotope stage 3) was generally cool and wet but was drier than the interglacial period (Harle, 1997; Harle et al., 1999) at 125,000 to 115,000 years BP. After about 24,000 years BP the temperatures decreased and aridity increased, leading up to the height of the last glacial maximum at about 18,000 years ago, during which time for most regions, precipitation is estimated to have been lower by up to 50% of present values (Galloway, 1965; Colhoun, 1991). Between 17,000 and 16,000 years BP conditions of major drying and regional fall in water tables existed (Bowler et al., 1976). Records show that in the tropics the glacials were drier than the interglacials (Kershaw and Whitlock, 2000). The aridity may be critical (Kershaw and Nanson, 1993) and even a cold adapted flora responds to increased available moisture (Kershaw et al., 1986). Rainforests may have survived the glacial phases in "refugia" (Dodson, 1994; McKenzie, 1997; McKenzie and Kershaw, 2000). Aridity was most intense from 18,000 to 15,000 years BP, when temperatures were increasing, after which the climate became warm and wet again and conditions generally similar to the present were reached about 6,000 years ago (Chappell, 1991; Colhoun, 1991; Harrison, 1993; Kershaw and Nanson, 1993). After about 5,000 years BP, cooler, drier conditions followed (Colhoun, 1993). Changes in temperature and moisture do not appear to have been synchronous or of equal intensity over the Australian continent (Nanson et al., 1992; Kershaw et al., 1993). For example, it is suggested that: aridity spread from the Australian centre to the coast as the glacial period strengthened (Nanson et al., 1992), the wettest phases did not correspond with the full interglacials and the driest with the peak of the glacial (Kershaw et al., 1993) and the coldness of the last glacial varied in intensity, as mentioned earlier (Galloway, 1965; Colhoun, 1991).



LEGEND

1 - 5	Atherton Tablelands (Kershaw 1970, 1971, 1975, 1976, 1985, 1994)
6	ODP Site 820 (Kershaw et al., 1993, 1994)
7 - 15	Barrington Tops (Galloway, 1965; Dodson et al., 1986; Dodson, 1987; Dodson et al., 1994)
16	Penrith Lakes Swamp (Chalson, 1991)
17	Mountain Lagoon (Robbie, 1998)
18	Breadalbane Basin and Wet Lagoon (Dodson, 1986)
19	Lake George (Singh and Geissler, 1985)
20 - 23	Snowy Mountains, Kosciuszko region, Southeastern Highlands of NSW (Galloway, 1965; Barrows, 2000; Raine, 1974; Bowler et al., 1976; Martin, 1986; Martin, 1999)
24	Bega Swamp (Hope et al., 2000)
25 -26	Bunyip Bog (Binder, 1978; Binder and Kershaw, 1978) and Crystal Bog (Williams, 1978)
27	Delegate River (Ladd, 1979a)
28 - 31	Southcentral Highlands Victoria (McKenzie, 1997)
32	Wyelangta (McKenzie and Kershaw, 2000)
33	Cave Bay Cave (Hope, 1978)
34	Pulbeena Swamp (Colhoun, 1978; Colhoun et al., 1982)
35	Pieman Dam (Colhoun, 1980)
36	Tullabardine Dam (Colhoun and van de Geer, 1986)
37	Lake Selina (Colhoun et al., 1999)
38	Henty Bridge (Colhoun, 1985)
39	Tarraleah (Macphail, 1984)
40	Southern Tasmanian study (Colhoun, 1978; Macphail, 1979; Markgraf et al., 1986).
40'	Adamsons Peak (Macphail, 1979)
41	Lake Frome (Harrison, 1989)
42	Willandra Lakes (Bowler et al., 1976)
43	Lake Wangoom (Edney et al., 1990; Harle et al., 1999)
44	Bass Strait (Macphail, 1979)
45	Cranbrook Terrace (Nanson and Young, 1988)

Figure 1.4 Map showing locations of sites mentioned in the text. Included are the references for the studies.
Sites 1 - 40 are discussed in Section 1.4

1.4 VEGETATION HISTORIES THROUGH PALYNOLOGICAL STUDIES OF EASTERN AUSTRALIA AND CLIMATIC INTERPRETATIONS

See Map 1.4 for sites mentioned in the text.

This review encompasses the history of rainforest in northeast Queensland and Tasmania, montane and alpine vegetation in the Eastern Australian Highlands: all environments found in the Barrington Tops today. The trends of changes in the vegetation and inferred climates are then compared, paying particular attention to the last 45,000 years, the time span most relevant to this study. There are many sites with Holocene records, but the further back in time, the fewer the sites with these older records.

1.4.1 NORTHEAST QUEENSLAND

Sites studied: Atherton Tablelands

1. Lynch's Crater: an explosion type volcanic crater, about 760 m altitude, with small inlet and outlet streams. The swamp is 45 m below the rim of the crater. Part of the humid tropics of northeast Queensland which contain the most extensive continuous tropical rainforest (complex mesophyll vine forest) in Australia. The palynological record at Lynch's Crater is considered to cover the last two glacial - interglacial cycles and is the longest record: 200,000 - 210,000 years BP (Kershaw 1976, 1985, 1994).

2. Bromfield Swamp: an explosion crater, about 800 m altitude, from which water drains from an outlet on the east side. The swamp, which is 500 m in diameter, 45 m below the rim of the crater, is surrounded by tropical rainforest where natural vegetation survives. Oldest date, about 10,600 years BP (Kershaw, 1975).

3. Lake Euramoo: a double explosion crater, about 730 m altitude, with no inflow or outflow channels. The lake is about 365 m by 230 m, 25 m below the rim, very near the present western limit of tropical rainforest. Oldest date, about 10,000 years BP (Kershaw, 1970, 1971).

4. Quincan Crater: an explosion crater, at about 850 m altitude, with no inflow or outflow channels. The catchment area is small. Within the crater there is an almost circular swamp 260 m in diameter, 60 m below the rim. Natural vegetation is tropical rainforest, but little now exists. Oldest date, about 7,200 years BP (Kershaw, 1971, 1975).

5. Strenekoff's Crater: an enclosed volcanic crater about 6 km east of Lynch's Crater, in tropical rainforest. Oldest date, about 38,000 years BP, but possibly covering same time frame as Lynch's Crater (Kershaw, 1985, 1994; Kershaw et al., 1991a).

Offshore site:

6. ODP Site 820: a marine core from the Great Barrier Reef, 80 km offshore on the continental slope, under 280 m of water. Oldest estimated, date, 1.5 Myr years BP (Kershaw et al., 1993; Kershaw, 1994).

History of the vegetation

Complex notophyll / mesophyll vine forest, which is the most mesic rainforest consisting mainly of rainforest angiosperms, occupies the site today. This type of vegetation is found when oxygen isotope temperatures were high, that is, during the last interstadial, 86,000 to 78,000 years BP, at the time of the Last Interglacial, 126,000 to 115,000 years BP and during the interstadial 190,000 to 179,000 years BP. Between these times of the complex notophyll / mesophyll vine forest, viz. 179,000 to 165,000 years BP and 115,000 to 86,000 years BP, there was a reduction of rainforest angiosperms with an increased amount of sclerophyll and rainforest gymnosperms, forming complex / simple notophyll vine forests. Between 165,000 and 126,000 years BP, just prior to the Last Interglacial period, the oxygen isotope temperatures were at their lowest, designating a glacial period. The vegetation was an araucarian microphyll / notophyll vine forest. Following the last interstadial, 86,000 to 78,000 years BP, the sclerophyll vegetation gradually increased (with a slight reversion between 63,000 and 50,000 years BP) (Kershaw, 1985) in a lead up to the Last Glacial period, 26,000 to 10,000 years BP, when at Lynch's and Strenekoff's Craters, the vegetation was a sclerophyll woodland, which is the driest type of vegetation found in the region today (Kershaw et al., 1991a). There is thus a cyclic pattern in the vegetation, but the vegetation of the last glacial period did not return to that of the preceding glacial period, but was drier.

The offshore location of the ODP Site 820 would have collected pollen from the coast or river discharge and is thus different from the Tablelands' sites. Between 1.5 million years and 120,000 years ago, rainforest gymnosperms were the major group and there were relatively few rainforest angiosperms and a moderate amount of sclerophyll taxa. From the Last Interglacial, 120,000 years ago, to the present, Araucariaceae almost disappeared and mangroves increased greatly (Kershaw, 1994).

The time of transition from sclerophyll of the last glacial period to 'warm temperate rainforest', was variable across the Atherton Tablelands. At Lynch's Crater the change occurred about 10,000 years ago. The rainforest angiosperms increased and rapidly reached their peak by about 8,500 years BP (Kershaw, 1976). At Bromfield Swamp, the sclerophyll changed to rainforest between about 9,500 and 8,400 years BP, becoming established by 8,500 years BP (Kershaw, 1975). At Lake Euramoo rainforest was invading the sclerophyll around 7,600 years BP (Kershaw, 1970) and at Quincan Crater, at about 7,250 years BP, rainforest being established at about 6,500 years BP (Kershaw, 1971).

At all of the four northeast Queensland Tableland sites (Lynch's Crater, Bromfield Swamp, Lake Euramoo and Quincan Crater), the rainforests had reached their maximum extent by 6,500/5,500 years BP. At Quincan Crater, the rainforest changed from the warm temperate to a subtropical, changing to a dry subtropical type at about 2,000 years BP, after which there was a partial readvance of the sclerophyll vegetation at all four sites.

History of the climate

The nature of the vegetation at Lynch's Crater indicates that during the rainforest angiosperm phases (interglacial and interstadials), precipitation and possibly temperature were higher than today. During the intervals of 179,000 to 165,000 years BP and 115,000 to about 96,000 years BP, precipitation dropped to levels similar to the present and temperatures were about 2˚C lower than present. During the glacial period of 165,000 to 126,000 years BP and from 78,000 years BP onwards, the precipitation had dropped to about half of present (to about 1000 mm to 1250 mm). Temperature decreased by about 2˚C to 4˚C (to about 16˚C to 18˚C) (Kershaw, 1985). Precipitation dropped even further after 38,000 years BP and was at its lowest during this period, particularly between about 15,000 and 12,000 years BP, the time of the Last Glacial period, when the swamp dried. Temperature may have been very much lower than present. During the maximum rainforest stage, 6,500/5,500 years BP, the annual rainfall increased to almost double that of today on the Atherton Tablelands. The presence of some hygrophyllous taxa at Bromfield Swamp, absent from Lake Euramoo and Quincan Crater, suggests that the effective precipitation was higher around Bromfield Swamp than at the other sites. Between about 6,000 and 3,750 years BP, mean annual temperatures had risen at Bromfield Swamp, but not to the levels of those at Quincan Crater (Kershaw, 1975). At Bromfield Swamp, precipitation levels seemed to have reduced to those of today, by about 3,000 years BP. The increase in sclerophyll by about 2,000 years BP was possibly due to a reduced precipitation (Kershaw, 1975).

1.4.2 BARRINGTON TOPS, NSW

Sites studies

Barrington Tops: a basalt-capped plateau massif, east of the Great Escarpment of eastern Australia (for description, see Section 2.1). Eight swamps have been studied on the plateau (for locations, see Fig. 2.1c).

7. Butchers Swamp: swamp contains drainage channel, about 1,230 m altitude in the northwest, surrounded by a mixed open forest. Has some stands of *Nothofagus moorei* within 1-2 km. Oldest date is 11,280 years BP (Dodson et al., 1986; Dodson, 1987).

8. Horse Swamp: swamp contains drainage channel, about 1,250 m altitude in the northwest, surrounded by open *Eucalyptus* forest. Isolated stands of *Nothofagus moorei* rainforest occur in sheltered parts of catchment. Oldest date is 11,020 years BP (Dodson et al., 1986; Dodson, 1987).

9. Boggy Swamp: swamp contains drainage channel, about 1,160 m altitude in the north, surrounded by open *Eucalyptus* forest. Pockets of *Nothofagus moorei* rainforest occur in protected areas around the swamp. Oldest date is 9,210 years BP (Dodson et al., 1986; Dodson, 1987).

10. Polblue Swamp: swamp is about 1,430 m altitude in the centre of the plateau, surrounded by open *Eucalyptus* forest. Oldest date is 5,400 years BP (Dodson et al., 1986; Dodson, 1987).

11. Top Swamp: swamp is about 1,530 m altitude in the centre, surrounded by *Eucalyptus pauciflora* open forest woodland. Oldest date is about 3,300 years BP (Dodson et al, 1986; Dodson, 1987).

12. Black Swamp: swamp is about 1,450 m altitude in the southeast, surrounded by *Eucalyptus* open forest and is 1 km from extensive *Nothofagus moorei* stands. Oldest date is 8,600 years BP (Dodson et al, 1986; Dodson, 1987).

13. Killer Bog: swamp contains drainage channel, about 1,260 m altitude in the southeast, surrounded by extensive areas of *Nothofagus moorei* rainforest. Oldest date is 8,230 years BP (Dodson et al, 1986; Dodson, 1987).

14. Sapphire Swamp: swamp contains drainage channel, about 1,260 m altitude in the southeast, surrounded by open *Eucalyptus* forest and has small pockets of *Nothofagus moorei* rainforest within catchment. Oldest date is 230 years BP (Dodson et al, 1986; Dodson, 1987).

15. Burraga Swamp: the swamp of this thesis. Work was also carried out by Dodson

(Dodson et al., 1994). Discussion on this swamp can be found in Chapter 5.

History of the vegetation

The eight swamps studied on the Barrington Tops Plateau formed at varying times during the last 12,000 years. The analysis of the eight sites indicates that local factors were responsible for the local vegetation in the past. Regional changes should not be based only on a single site, but may be identified by collating the results from all the sites (Dodson, et al., 1986).

Before 11,000 years BP, Butchers Swamp and Horse Swamp, were surrounded by open grassy eucalypt forests or woodland with much Asteraceae (Tubuliflorae), becoming more closed at around 11,000 years BP. At Butchers Swamp, the vegetation was then fairly stable until around 1,600 years BP, after which it opened slightly. At Horse Swamp between about 7,300 and 1,600 years BP, *Eucalyptus* and Poaceae were much reduced and *Dicksonia* was abundant. Following the *Dicksonia* peak, the present open forest type was established with cool temperate rainforest present in the area.

Between about 10,000 and 8,500 years BP, the vegetation at Boggy Swamp was a wet eucalypt open forest with a well-developed shrub layer and some *Nothofagus moorei* in the vicinity (Dodson et al., 1986). At 8,500 years BP, *N. moorei* was also present at Black Swamp and Killer Bog. At Killer Bog, the *Nothofagus* percentages were at their maximum, equivalent to the present (Dodson et al., 1986). Maximum *Nothofagus* values were reached at both Boggy and Black Swamps by about 6,000 years BP, the cool temperate rainforest reaching greatest expansion there between 6,000 and 3,500 years BP. The forest then contracted and the eucalypt formations increased (Dodson et al., 1986).

Around 5,400 years BP, a wet eucalypt formation surrounded Polblue Swamp. Then at about 3,500 years BP the forest opened up, a subalpine grassland appeared and the vegetation on the swamp surface became drier (Dodson et al., 1986).

From about 1,500/1,000 years BP, *Nothofagus* increased around the sheltered areas of the more northeasterly sites, Top Swamp and Horse Swamp, with a presence around Polblue. Generally in the west of the plateau, there were small expansions of wet eucalypt forests with a decline in snow grass understorey (Dodson et al, 1986). In the last 230 years there has been no change in forest composition around Sapphire Swamp.

Once deposition began in the basins, sedimentation rates were very slow, increasing greatly within the last 2,600 years (Dodson et al., 1986; Dodson, 1987). Peat began to form at varying times (see Fig. 5.2 this thesis) between about 8,500 and recently at Clive Swamp (Dodson et al., 1986; Dodson, 1987).

History of the climate

Between about 11,000 and 10,750 years ago, cold or periglacial conditions may have existed. Increase in effective precipitation occurred between 8,500 and 5,500 years BP, with temperature and summer rain-bearing winds from the south and east increasing (Dodson et al., 1986). Then conditions became cooler and drier by about 3,500/3,000 years BP (Dodson, 1987). There is evidence at Black and Top Swamps, that at about 2,000 years BP, there was a rise in the watertable and wetter conditions occurred. Between around 1,000/500 years BP, there may have been a small warming with increase in precipitation or cloudiness (Dodson, 1987).

1.4.3 BLUE MOUNTAINS, NSW:

Sites Studied

16. Penrith Lakes Swamp: swamp up to 19 m altitude, at the foot of the Blue Mountains, in a dry sclerophyll forest. Oldest date is 34,000 years (Chalson, 1991).

17. Mountain Lagoon: a swampy lagoon, 540 m altitude, in the eastern Blue Mountains, natural vegetation is a tall open forest. Oldest date is 18,660 years (Robbie, 1998).

History of the Vegetation

At Penrith Lakes at the foot of the Blue Mountains, NSW, between 34,000 and 32,000 years BP there was was a closed eucalypt forest. Then grasslands expanded between 22,000 and 15,000 years BP (Chalson, 1991). At Mountain Lagoon, tree species declined and grasses and herbs increased in the period leading up to 18,000 years BP. The tree cover then returned around 8,000 years BP and the swamp developed from 6,000 years BP. At about 5,000 years BP a slight increase in herbs, grasses and Myrtaceae occurred (Robbie, 1998).

History of the climate

Between 22,000 and 15,000 years ago, conditions possibly became drier (Chalson, 1991; Robbie, 1998). Then, there was a trend to wetter conditions between 11,000 and 8,000 years BP, stabilising until 6,500 years ago and then fluctuating moisture occurred until 5,500 years BP (Chalson, 1991) becoming drier again at about 5,000 years ago (Robbie, 1998).

1.4.4 SOUTHERN TABLELANDS, NSW:

Sites Studied

18. Breadalbane Basin and **Wet Lagoon**: 700 m above sea level in the headwaters of the Lachlan River. They are hydrologically independent from each other. Breadalbane Basin is 25 km and Wet Lagoon is 18 km north of Lake George. Oldest date is 9,300 years BP (Dodson, 1986).

19. Lake George: lake, 674 m above sea level, about 40 km northeast of Canberra. A tectonic basin with a drainage along its meridion. Today, the lake is 25 km in length and 11 km at its widest point, in *Eucalyptus* forest and woodland. Oldest date is 37,800 years BP and estimated to 730,000 years BP (Singh and Geissler, 1985).

History of the vegetation

At Lake George, between about 50,000 and 40,000 years BP, cool temperate rainforest existed, giving way to *Casuarina* and *Eucalyptus* dominated vegetation between about 37,000 to 23,000 years BP. Some cool temperate rainforest taxa were present between 28,000 and 23,000 years BP. The trees then disappeared completely and non-wooded herbfield and grassland occupied the site until about 16,000 years BP. A period of transition from a non-wooded vegetation to a cool temperate forest occurred during the interval of about 16,000 to 10,200 years BP. Then a cool temperate rainforest vegetated the site until about 7,700 years BP after which all cool temperate taxa disappeared and the vegetation became a savannah woodland. From about 6,000 years BP, an eucalypt-dominated dry sclerophyll forest similar to the present, became established (Singh and Geissler, 1985).

Near Goulburn, at Breadalbane Basin and Wet Lagoon, from 9,300 years BP the vegetation remained an eucalypt woodland or open forest with grassland understorey (Dodson, 1986).

History of the climate

On the Southern Tablelands, cool-temperate climatic conditions existed around 28,000 years BP. Between about 21,000 and 15,000 years BP, conditions were cooler, drier and probably windier than today. At about 15,000 years BP, temperatures increased and the driest climates were experienced until 11,500 years BP. However, the greater aridity may have been caused by increasing temperatures rather than continued decrease in precipitation (Kershaw et al., 1991b). The Goulburn sites indicate that the climatic changes which led to the changes in the water levels during the last 9,300 years, were not sufficiently large to cause any significant vegetational change (Dodson, 1986).

1.4.5 SOUTHERN HIGHLANDS OF NSW

Sites studied: Snowy Mountains

20-22. Twynam Cirque; Pound's Creek and Club Lake: cirques around 1,950 m above sea level in alpine vegetation. Oldest date is about 16,500 years BP (Raine, 1974; Bowler et al., 1976; Martin, 1986).

23. Digger's Creek Bog: shrubby subalpine peat bog, 1,690 m above sea level, little below local altitudinal tree-line, in snowgum woodland. Oldest date is 10,000 years BP (Martin, 1999).

Eastern escarpment

24. Bega Swamp: in a tall eucalypt forest, 1,080 m above sea level, on the crest of the eastern escarpment, on a granitic plateau, 30 km east of Nimmitabel. Oldest date is 13,500 years BP (Hope et al., 2000).

History of the Vegetation

The highest elevations were probably an alpine desert until about 16,500 years BP when a short alpine herbfield developed. At about 13,000 years BP, a tall herbfield and bog community developed, lasting for varying lengths of time in the Highlands. At Twynam Cirque the community persisted until about 9,000 years BP (Raine, 1974; Bowler et al.,1976), at Pound's Creek and Club Lake cirques until about 10,600 years BP (Martin, 1986) and at Digger's Creek Bog until 8,500 years BP (Martin, 1999). At Bega Swamp, the vegetation was dominated by shrubby daisy - grass steppe at 13,500 years BP and gave way to a low eucalypt woodland by about 11,800 years BP. Between 11,500 and 10,800 years BP, the vegetation was a herbfield, abruptly changing to a eucalypt forest.

Between 9,400 and 9,000 years BP, there was a transition to tall eucalypt forest, with wet forest elements present mainly between 10,200 and 7,700 years BP, but surviving through to about 2,200 years BP (Hope et al., 2000). At Twynam Cirque, between 3,800 and 1,700 years BP, the hygrophilous vegetation reached minimum values (Bowler et al.,1976). The Digger's Creek and Club Lake sites register a depression of the altitudinal tree-line at about 4,000 years BP (Martin, 1999). At Bega Swamp, however, the closed forest phase ended at 3,900 years BP with the core of the "wet phase" continuing until 3,300 years BP and wet elements are represented until around 2,200 years BP (Hope et al., 2000).

History of the climate

In the higher regions, amelioration of the climate is evidenced by the reduction of seasonal snow cover by about 13,000 years ago and the termination of alpine conditions by 11,800 years BP at Bega Swamp. However, at Bega Swamp, the climate had reverted to less favourable conditions between 11,500 to 10,800 years BP. Climatic conditions then improved until about 4,000/3,800 years BP at Twynam Cirque, Digger's Creek and Club Lake, when the climate began to deteriorate. The climate was most severe between about 3,000 to 2,000 years BP at Digger's Creek and Club Lake (Martin, 1999) and lasted until about 1,700 years BP at Twynam Cirque (Bowler et al.,1976). At Bega Swamp wet conditions began to decline at about 3,300 years BP and dry conditions began only after about 2,200 years BP (Hope et al., 2000).

1.4.6 NORTHEAST HIGHLANDS, VICTORIA

Sites Studied

25. Bunyip Bog: 1,330 m altitude bog, about 280 m by about 147 m, in a eucalypt woodland, on Bunyip Creek, at Mt. Buffalo. Oldest date is 10,250 years BP (Binder, 1978; Binder and Kershaw, 1978).

26. Crystal Bog: 1,350 m altitude bog, in sub-alpine woodland, heath, tussock grass vegetation, on Buffalo Plateau. ^{14}C dates are not provided (Williams, 1978).

27. Delegate River: a *Sphagnum* bog, 900 m altitude, close to Delegate River, surrounded by tall open forest or open forest dominated by *Eucalyptus* species. Oldest date is 12,000 years BP (Ladd, 1979a).

History of the Vegetation

At Delegate River, alpine herbfield or grassland was present about 12,000 years ago (Ladd, 1979a) and similarly at Bunyip Bog before 10,250 years BP (Binder, 1978; Binder and Kershaw, 1978). At about 10,250 years BP wet sclerophyll forests developed on Mt Buffalo plateau, remaining fairly constant until 2,000 years BP (Binder, 1978; Williams, 1978). A layered open eucalyptus forest, similar to that which occupies the area now, began to surround the swamp at Delegate River at about 10,000 years BP, the transition being completed by about 8,000 years BP. The treeline had thus risen by about 10,000 years BP (Ladd, 1979a). The growth of Bunyip Bog swamp increased after 2,000 years BP and the wet sclerophyll forest retreated to lower altitudes (Binder, 1978; Williams, 1978).

History of the climate

Before 10,000 years BP, the climate was cooler becoming mild between 10,000 and 2,000 years BP. After 2,000 years BP, there was a decrease in temperature, which in turn may have been responsible for an increase in effective precipitation, a climatic change undetectable at Delegate River (Binder, 1978; Binder and Kershaw, 1978; Ladd, 1979a).

1.4.7 SOUTH-CENTRAL HIGHLANDS, VICTORIA

Sites studied

There are four sites between altitudes of 930 m and 1440 m in the southern-most subalpine habitats on the mainland. The surrounding vegetation varies from subalpine to riverine in wet sclerophyll forest with *Nothofagus cunninghamii* closeby.

28. Lake Mountain: subalpine open bog, about 400 m by 700 m, 1,440 m altitude, surrounded by *Eucalyptus pauciflora* woodland forest and *Nothofagus cunninghamii* occurs in close proximity. Oldest date is 6,550 years (McKenzie, 1997).

29. Storm Creek: subalpine open bog, about 200 m by 1,000 m, 1,177 m altitude, contains drainage stream, surrounded by wet sclerophyll forest and *Nothofagus cunninghamii* occurs in close proximity. Oldest date is 17,350 years (McKenzie, 1997).

30. Tom Burns: subalpine open bog, about 200 m by 1,000 m, 1,075 m altitude, contains drainage creek, surrounded by wet sclerophyll forest and *Nothofagus cunninghamii* occurs in close proximity. Oldest date is 31,500 years (McKenzie, 1997).

31. Snobs Creek: riverine bog, 930 m altitude, surrounded by wet sclerophyll forest with

Nothofagus cunninghamii occurring, in coppice form, on the site. Oldest date is 11,450 years (McKenzie, 1997).

History of the Vegetation

From around 32,000 to 13,000 years BP, a mosaic of alpine feldmark, herbfield and heathland vegetated the Tom Burns site. At 32,000 years BP the treeline was well below its present position, the wet sclerophyll moving upslope between 31,500 and 26,500 years BP (McKenzie, 1997). "Between about 17,000 and 13,500 years BP, alpine communities reached their greatest extent and much of the central Highlands was treeless" (McKenzie, 1997, abstract). At Storm Creek, very low values of *Nothofagus* were continually registered from 17,000 years BP, indicating that the area may have been a glacial refuge for *Nothofagus* (McKenzie, 1997).

At around 12,000 years BP, the treeline was below 930 m as indicated by the presence of alpine communities with low quantities of *Eucalyptus* and *Nothofagus* at Snobs Creek. Then woody vegetation (wet sclerophyll forests and small areas of *Nothofagus*) invaded along an altitudinal gradient, beginning at about 10,700 years BP at 930 m altitude and between 8,900 and 7,500 years BP at 1,000 m. Then, from about 8,500 to 4,000 years BP, alpine taxa disappeared from all but the highest sites, and wet sclerophyll and *Nothofagus* reached their maximum extent. *Nothofagus* spread into montane forests and possible subalpine heaths, spreading beyond its present range between about 7,000 and 4,000 years BP. From then on to the present, the cool temperate rainforest retracted. *Leptospermum* increased at some sites and some of the alpine taxa disappeared (McKenzie, 1997).

History of the climate

Around 32,000 years BP summer temperatures were lower than present. Between 31,500 and 26,500 years BP, there may have been slight increases in temperature and effective precipitation. It appears that the temperatures were lowest at Tom Burns and Snobs Creek between 17,000 and 13,500 years BP. There were probably increases in temperature and effective precipitation from about 12,000 years BP, with further increases in temperature and effective precipitation between about 8,500 to 4,000 years BP. From then on to the present, the conditions became drier and warmer (McKenzie, 1997).

1.4.8 SOUTHWESTERN HIGHLANDS, VICTORIA

Site Studied

32. Wyelangta: on alluvial flat, 450 m altitude, about 100 m from Arkins Creek, in a cool temperate rainforest patch surrounded by tall open eucalypt forest of the Otway Region. An outlier of the southeastern highlands. Oldest date is 40,300 years BP (uncorrected date) (McKenzie and Kershaw, 2000) .

History of the Vegetation

At Wyelangta, overall, cool temperate *Nothofagus cunninghamii* rainforest with some Tasmanian taxa, eg. *Phyllocladus*, existed from before 40,300 years ago (probably representing the early part of Oxygen Isotope Stage 3, or older) until the present. Cool temperate rainforest pollen values decreased and were replaced by alpine-subalpine herbaceous and heath swamp / cold grassy woodland-open forest assemblage. *Nothofagus* and sclerophyll forest still survived in the vicinity as did *Gunnera* and species of *Lycopodium* now absent from the Otway Ranges but common in Tasmania. Then, a re-expansion of tall open forest was followed by cool temperate rainforest from 5,000 years BP to the present. *Phyllocladus*, present in the early forest phase, did not return in this later cool temperate forest phase (McKenzie and Kershaw, 2000). The Wyelangta site shows a geologically recent biogeographic link of the mainland to Tasmania (McKenzie and Kershaw, 2000).

History of the climate

Temperatures were about 6˚C cooler and conditions were drier, but there were areas devoid of water stress. There were thus "areas sheltered from extremes of temperature, water stress, and protected from fire ..(which)..were the most likely to provide long-term 'refugia' for rainforest taxa" (McKenzie and Kershaw, 2000, p.191). Thus the Wyelangta area may have been a glacial refuge site for *Nothofagus cunninghamii* (McKenzie and Kershaw, 2000).

1.4.9 TASMANIA

Sites Studied

33. Cave Bay Cave: eastern shore of Hunter Island, off northwest coast of Tasmania, cave floor sediments, 15 m above sea level. Nearby vegetation is shrubland. Oldest age is 22,750 years BP (Hope, 1978).

34. Pulbeena Swamp: about 4 km from the northwest coast, a groundwater controlled swamp, about 30 m altitude, about 1.7 km^2. Potentially, natural vegetation is temperate rainforest, but scrub rainforest, wet sclerophyll forest and swamp-forest dominate. Oldest date is 55,200 years BP (Colhoun, 1978; Colhoun et al., 1982).

35. Pieman Dam: a western river backswamp deposit, about 50 m elevation, within a mountainous, temperate and heath covered catchment. Oldest date is 54,000 years BP (Colhoun, 1980).

36. Tullabardine Dam: western swamp, 230 m altitude, in a temperate rainforest. Oldest date is 43,800 years BP (Colhoun and van de Geer, 1986).

37. Lake Selina: West Coast Range lake, 516 m altitude, within *Nothofagus cunninghamii* cool temperate rainforest. Oldest date is 52,160 years (Colhoun et al., 1999).

38. Henty Bridge: lowlands of central west, small lake basin 200 m east of Henty Bridge, 115 m above sea level, in temperate rainforest. Oldest date is 34,600 years BP (Colhoun, 1985).

39. Tarraleah: southwestern margin of Central Plateau, a small closed depression, about 440 m elevation, about 8m by 18 m, formed between the top of an ancient landslip and the defaced hillside. This area had been formerly glaciated and is now covered by rainforest. Oldest age is 9,080 years BP (Macphail, 1984).

40. Southern Tasmanian study: across the range of the current bioclimates in Southern Tasmania, ten mountain sites, all enclosed basins with continuous pollen sequences, ranging from 442 m to 1,158 m altitudes. The sites on Mt. Field (Southern Central Tasmania) are: Beatties Tarn, 990 m a.s.l.; Eagle Tarn, 1,033 m a.s.l.; Tarn Shelf, 1,158 m a.s.l. The other sites are: Unnamed Cirque, Adamsons Peak, far Southeast coast, 960 m a.s.l.; Lake Vera, Frenchmans Cap, 560 m a.s.l.; Brown Marsh, Southern Central Plateau, 750 m a.s.l.; Lake Tiberias, Midlands, 442 m a.s.l.; Ooze Lake, Southern Ranges, 880 m a.s.l. (Colhoun, 1978; Macphail, 1979; Markgraf et al., 1986).

History of the vegetation

Prior to about 50,000 years BP, the western areas (Pulbeena Swamp, Pieman Dam and Lake Selina), were vegetated by rainforest. Then until about 25,000 years BP, the vegetation at Pulbeena Swamp, Pieman Dam, Lake Selina and Tullabardine Dam was basically subalpine trees, shrubs and heath, or herbaceous taxa, (with additional alpine grassland at Lake Selina). There were traces of rainforest species around the sites, in a primarily nonarboreal landscape, while at the Cave Bay Cave site, diverse mesophytic taxa existed (Colhoun, 1978; Hope, 1978; Colhoun, 1980; Colhoun et al., 1982; Colhoun et al., 1999). In southern Tasmania, eucalypt forest / woodland vegetated the Adamsons Peak area (Macphail, 1979).

Then, after 25,000 years BP the vegetation opened up. The north western areas became open grasslands or Asteraceae shrub steppes, attaining maximum development at Cave Bay cave after 20,850 years BP (Hope, 1978; Colhoun et al., 1982; Colhoun, 1985; Colhoun and van de Geer, 1986), while Henty Valley in the central west became progressively more alpine by 20,000 years BP (Colhoun, 1985). The south west of Tasmania was vegetated by a steppe with marshes or shallow lakes (Markgraf, et al., 1986).

Around 14,000 years BP, shrub and tree taxa, including *Nothofagus cunninghamii*, began to increase at Lake Selina and Tullabardine Dam where, after 11,000 years BP the current lowland temperate rainforest was developing (Colhoun and van de Geer, 1986; Colhoun et al., 1999) and Pulbeena Swamp's vegetation changed to a largely wet sclerophyll *Eucalyptus* forest (Colhoun et al., 1982; Colhoun, 1985). At Tarraleah, sclerophyllous taxa dominated prior to 9,125 years BP (Macphail, 1984). From 12,000 years BP onwards, at some south western locations, rainforest taxa including *N. cunninghamii*, infiltrated the sub-alpine communities, culminating in the spread of *Nothofagus* around 9,700/9,500 years BP (Macphail, 1979; Macphail, 1984; Markgraf, et al., 1986). Since 11,500 years BP, short term isolated vegetational shifts are interpreted from the pollen data across Southern Tasmania (Macphail, 1979).

At Pulbeena Swamp, the wet sclerophyll *Eucalyptus* forest reached its maximum development between 8,000 and 6,000 years BP (Colhoun, 1978). At the southern Tasmanian sites, such as Mt. Field and Adamsons Peak, *Nothofagus cunninghamii* occurred outside its current range (including currently alpine areas) reaching its maximum boundary by 7,800 years BP (Macphail, 1979). At Tarraleah, from about 8,900 to about

6,925 years BP there were changes from dry sclerophyll vegetation to wet sclerophyll; with rainforest elements infiltrating the sclerophyll between about 8,900 and 8,325 years BP (Macphail, 1984).

Between 6,000 and 5,000 years BP, the reduced, modern rainforest distribution in the western region, was established (Markgraf, et al., 1986) and in the south by 6,000 years BP rainforests opened up and closed-scrub retreated making way for the current alpine vegetation (Macphail,1979). From 5,000 years BP, four of the sites on the west and east of Mt. Field show changes into discrete environmental groups, with varying proportions of rainforest taxa (Markgraf et al., 1986).

History of the climate

Prior to 50,000 years BP, Tasmania's climate was moist. Around 45,000 years BP conditions may have been somewhat cooler and drier (Colhoun, 1978; Colhoun, 1980). The height of aridity was achieved at some time between 28,000/25,000 years BP and 19,000/14,000 years BP and temperature had decreased by 5˚C (Colhoun, 1985). By 11,000 years BP the precipitation was 50% less than today, producing summer droughts (Colhoun et al., 1982). An abrupt and rapid increase in temperature of about 6˚C occurred after 14,000 years BP, with a possible temporary reversal (Macphail, 1979; Colhoun, 2000). By 12,000 years BP, seasonal moisture stress still existed, as indicated by diatom data. Precipitation may have been lower than today (Markgraf et al., 1986) and short term climatic oscillations may have existed (Macphail, 1979). Then, an island-wide increase in effective precipitation occurred between 11,500 and 9,500 years BP (Macphail,1979) and the climate became relatively warm and moist (Colhoun et al., 1982). Maximum moisture regime with precipitation higher than today and increased temperatures were achieved between about 8,500 and 7,500 years BP and lasted until 6,000 years BP (Macphail, 1979; Macphail, 1984; Markgraf et al., 1986). Then precipitation fell between 6,000 and 5,000 years BP and may have been lower than today and similar to that between 12,000 and 11,000 years BP (Markgraf et al., 1986). From 5,000 years BP, the climate has become increasingly harsh, producing more droughts and frosts (Macphail, 1979).

Generally in Western Tasmania, the vegetation during the last Interglacial / Glacial cycle, varied primarily in response to temperature changes (Colhoun et al., 1999).

1.4.10 GENERAL SUMMARY OF THE HISTORY OF EASTERN AUSTRALIAN VEGETATION AND CLIMATIC INTERPRETATIONS

The different regional vegetations showed similar trends, reflecting similar climatic changes over the time reviewed. In most places the vegetation was wooded, 50,000 to 40,000 years ago, though probably unlike the present.

Vegetation types in eastern Australia around 45,000 years ago, indicate that temperatures and moisture were somewhat lower than at present.

Then gradually, the wooded vegetation was replaced by more open vegetation, indicating drier and cooler climates. Grasslands/shrublands suggest the lowest levels of temperature between about 25,000 and 17,000 / 14,000 years ago. Moisture levels were at their lowest between about 25,000 and 12,000 years BP. During this period, most of southeastern Australia was treeless.

The change in Northeast Queensland, however, was from a rainforest (at various times throughout the Quaternary) to dry sclerophyll forest (at 26,000 years BP).

In eastern Australia aridity continued long after temperatures began to rise. Vegetation in some localities began to recover with increase in temperature, but full recovery to the wettest vegetation types only occurred once moisture levels finally stabilised after about 10,000 years ago.

Although the climatic threshholds varied for the vegetation in different locations, vegetation shifts at all sites signify that the climate had become warmer and wetter by at least 10,000 years BP and the maximum was reached by around 8,000 to 6,000 years ago.

Around 5,000 to 3,000 years BP vegetation became drier, implying that the climate became somewhat cooler and drier. Conditions then improved in most places, but the moist vegetation characteristic of the time just prior to 5,000 years BP, was not replaced. Thus, although climatic conditions again improved after 5,000 years BP, they were slightly cooler and drier than before that time.

Chapter 2 ENVIRONMENT OF BARRINGTON TOPS

2.1 GEOLOGY AND GEOMORPHOLOGY

Barringtops Tops is a basalt-capped plateau massif, which lies east of the Great Escarpment of eastern Australia. The Escarpment had retreated from the east leaving the Barrington Tops Plateau as an isolated residual (Pain, 1983). Barrington Tops is the southern most part of the Northern (New England) Tablelands. This plateau system forms part of the Eastern Highlands of New South Wales. Barrington Tops separates the river basins of the Hunter and Manning River systems (Figs 2.1a and 2.1b).

Evidence suggests that the geomorphic sequence of events in the area have been, the occurrence of erosional levelling of the Palaeozoic sediments, followed by volcanism about 50 Ma ago, covering much of the area with basalt, uplift and then scarp retreat and erosion of the basalts faster than of the underlying Palaeozoic rocks (Pain, 1983).

The Barrington Tops massif is largely Permian granite which had been folded and faulted into the steeply dipping Carboniferous and Devonian sediments underlying the area (Dodson and Myers, 1986). The outcrops of Permian granite on the Plateau, at elevations up to 1,580 m, are rounded hills and convex slopes. Basalts overlie Palaeozoic sediments at altitudes between 600 m and 900 m. At the contact between the basalt and the underlying rock, benches are present. These step-and terrace sequences are one ofthe most striking small scale topographic features of the Barrington Tops landscape. The post-basaltic erosion has cut valleys up to 1,000 m deep through the basalt and into the underlying Palaeozoic rocks and produced ridges and V-valley landforms with steep, straight valley slopes, narrow ridges and narrow valley floors. This erosion has also produced the scarp edges ofthe Barrington Tops Plateau (Pain, 1983; Figs 2.1b, 2.1b (i) and 2.1b (ii)).

The plateau surface is gently undulating between 1,000 and 1,550 m altitude. Although the slopes to the north are gentle, the southern and western sloping regions are steep. Above about 600m altitude, the slopes are basalt, granite or colluvium.The lower altitude slopes are mainly Carboniferous and Devonian sedimentary rocks. On the western side of Barrington Tops Plateau, the basalt is covered with a greater thickness of colluvium than is the less weathered Paleaozoic rocks. Landslides are common on basalt slopes, while surface wash seems to be the main process on Palaeozoic areas (Pain, 1983).

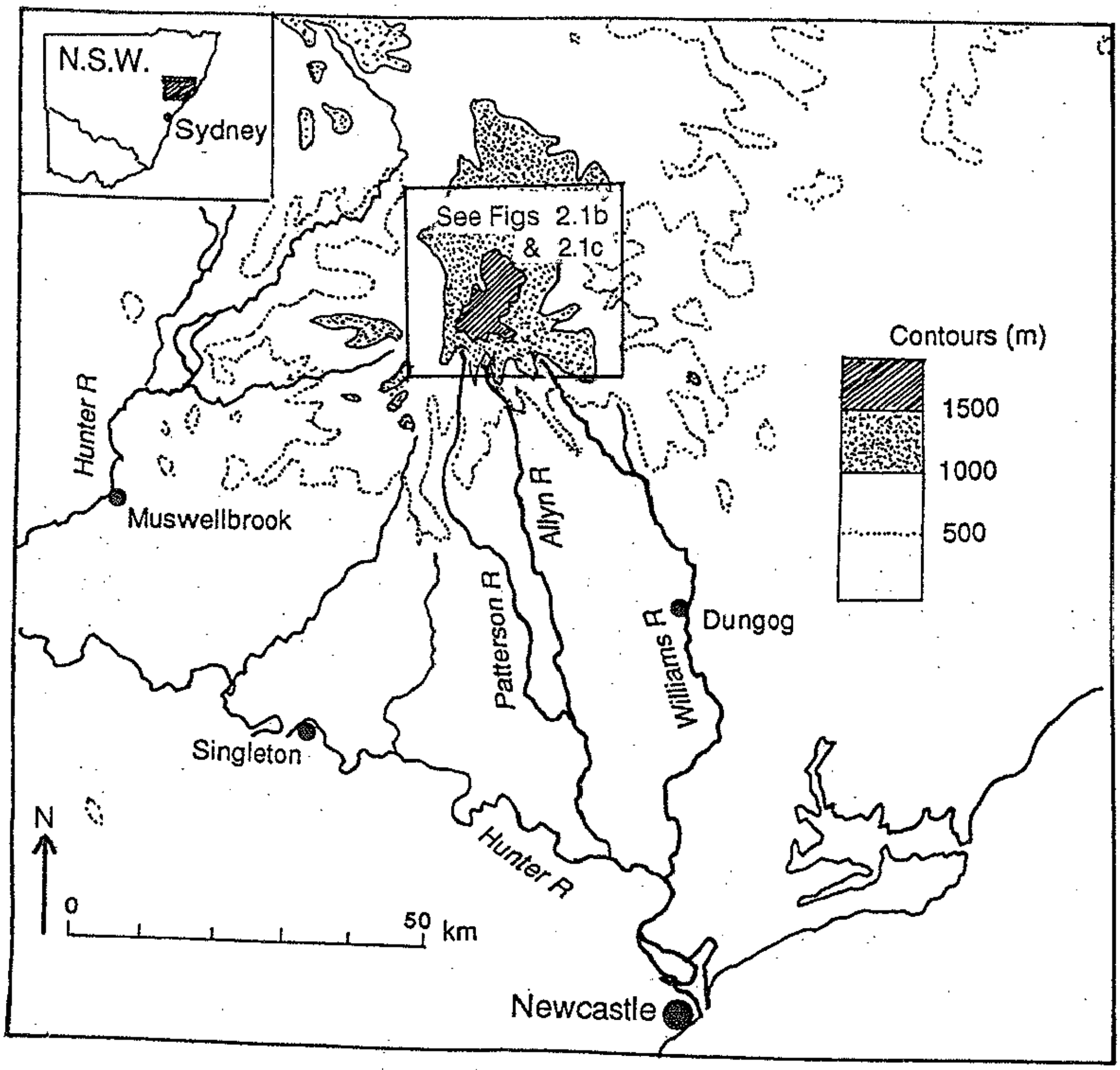


Figure 2.1a Location of Barrington Tops.

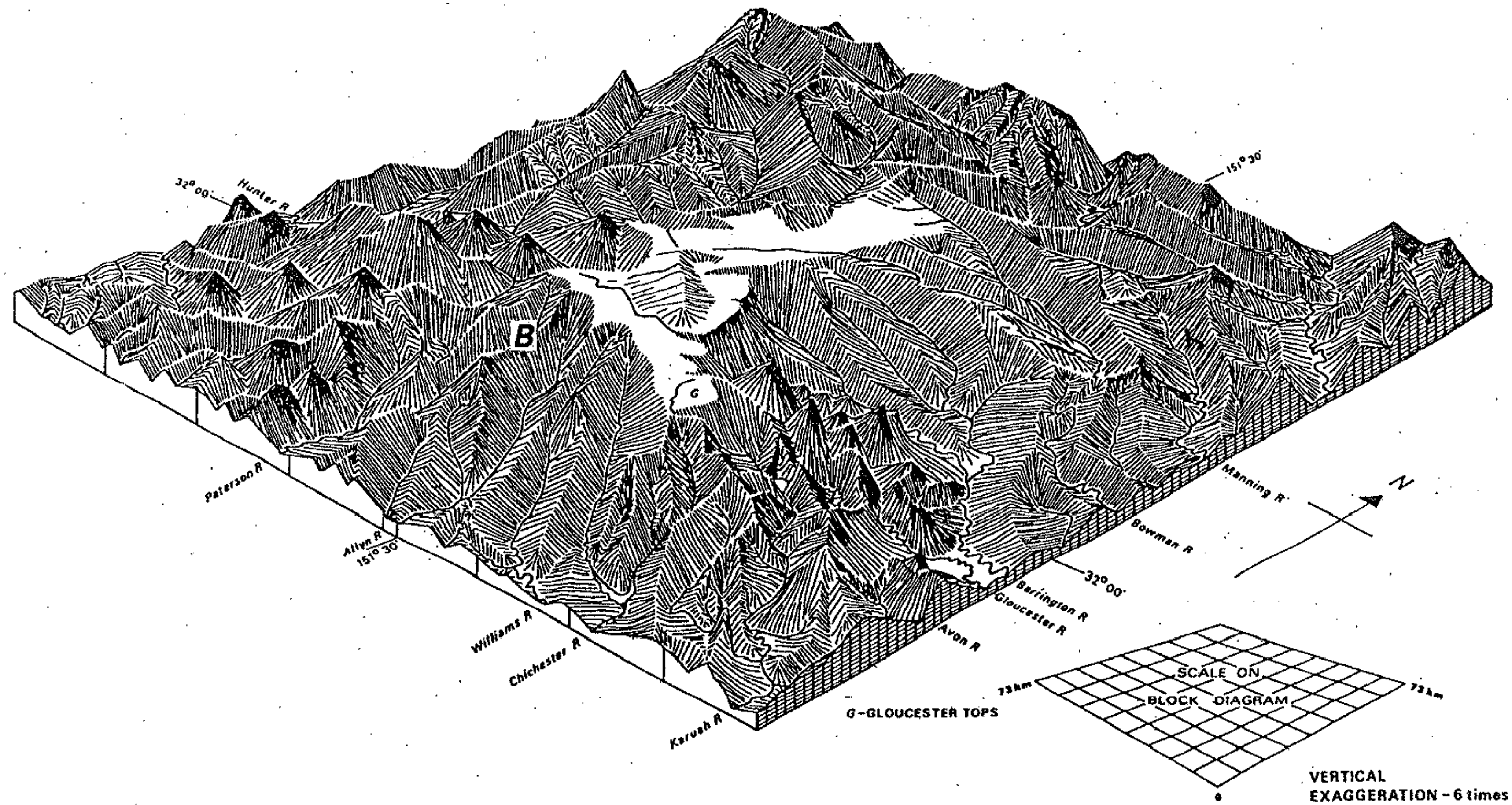


Figure 2.1b Block diagram of the Barrington Tops area (Adapted from Bowden and Turner, 1976). For location of this area, see Figure 2.1a. ***B*** indicates the location of Burraga Swamp.

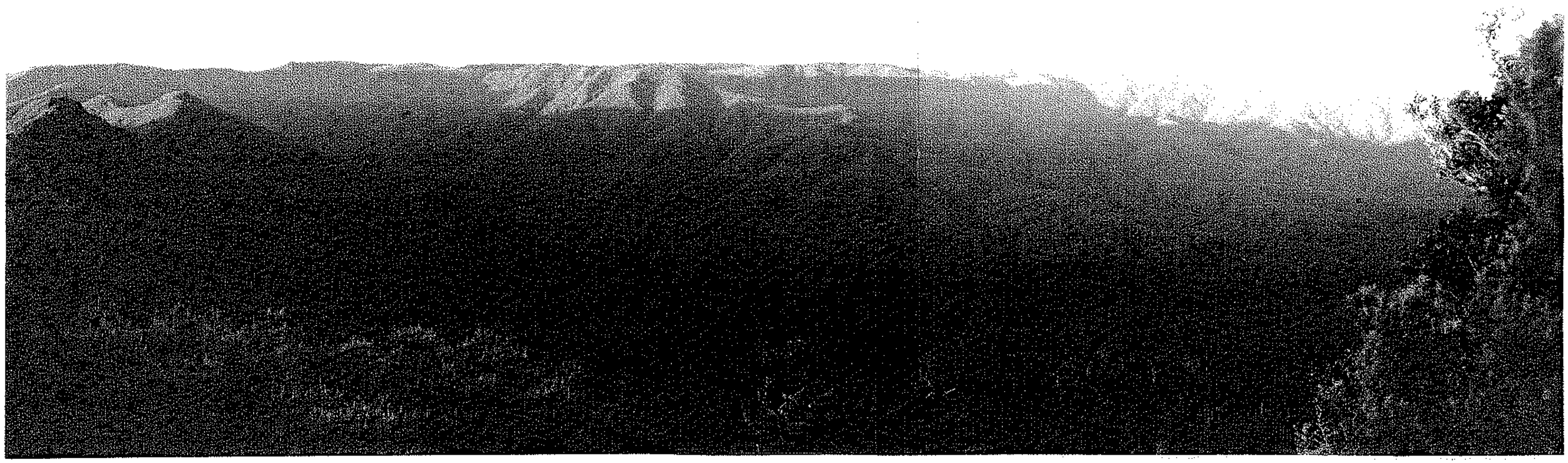


Figure 2.1b (i) View to the northeast onto Barrington Tops Ranges from Allyn Lookout.

Figure 2.1b (ii) View to the southwest into the Hunter Valley from Allyn Lookout.

The main soils on the plateau surface are strongly leached brown-yellow transitional alpine humus and well structured, permeable reddish krasnozems. In granite areas there are highly leached and light- coloured sandy loams. The soils of the slopes and benches of the plateau, which are largely colluvial material, are red to yellow and also highly leached. The soils of the lower slopes are yellow podzols (Dodson and Myers, 1986).

The plateau (see Fig. 2.1c) has a number of slow flowing streams with swamps of Late Pleistocene to Holocene age. These swamps contain saturated moor peats on clay and weathered parent material. The streams flow over the escarpment to lower altitudes, forming river valleys (Dodson and Myers, 1986). The major, radial, drainage lines in the Barrington Tops area, seem to follow the former basalt cone of the Barrington volcano. Outside the volcano, the river patterns tend to follow the structure of the Palaeozoic rocks (Pain, 1983).

The Mount Allyn Range is one of the ridges leading from the southern scarps of the plateau. Burraga Swamp is on the Mount Allyn Range, (32°06’00” S,151°25’07” E), at 985.5 m altitude in the Patterson River valley (Fig. 2.1b). It is a small oval shaped, enclosed basin, just under 1 hectare in area. It is not known how the basin formed, but a landslip seems the most likely explanation (Hope pers. comm.; Roberts pers.comm.). The sediments entering Burraga Swamp come almost entirely from weathered basalts (Roberts, pers. comm.). These come from Mt. Lumeah, a remnant basaltic area to the north east of Burraga Swamp. Large boulders occur on this side of the swamp and fragments of basalt are strewn throughout the forest surrounding the swamp.The forests on the southern and western edges, slope up gently, while the northern and north-eastern sides present a steep rise up to the high cliff of Mt Lumeah (Figs 2.1d and 2.1d(i)).

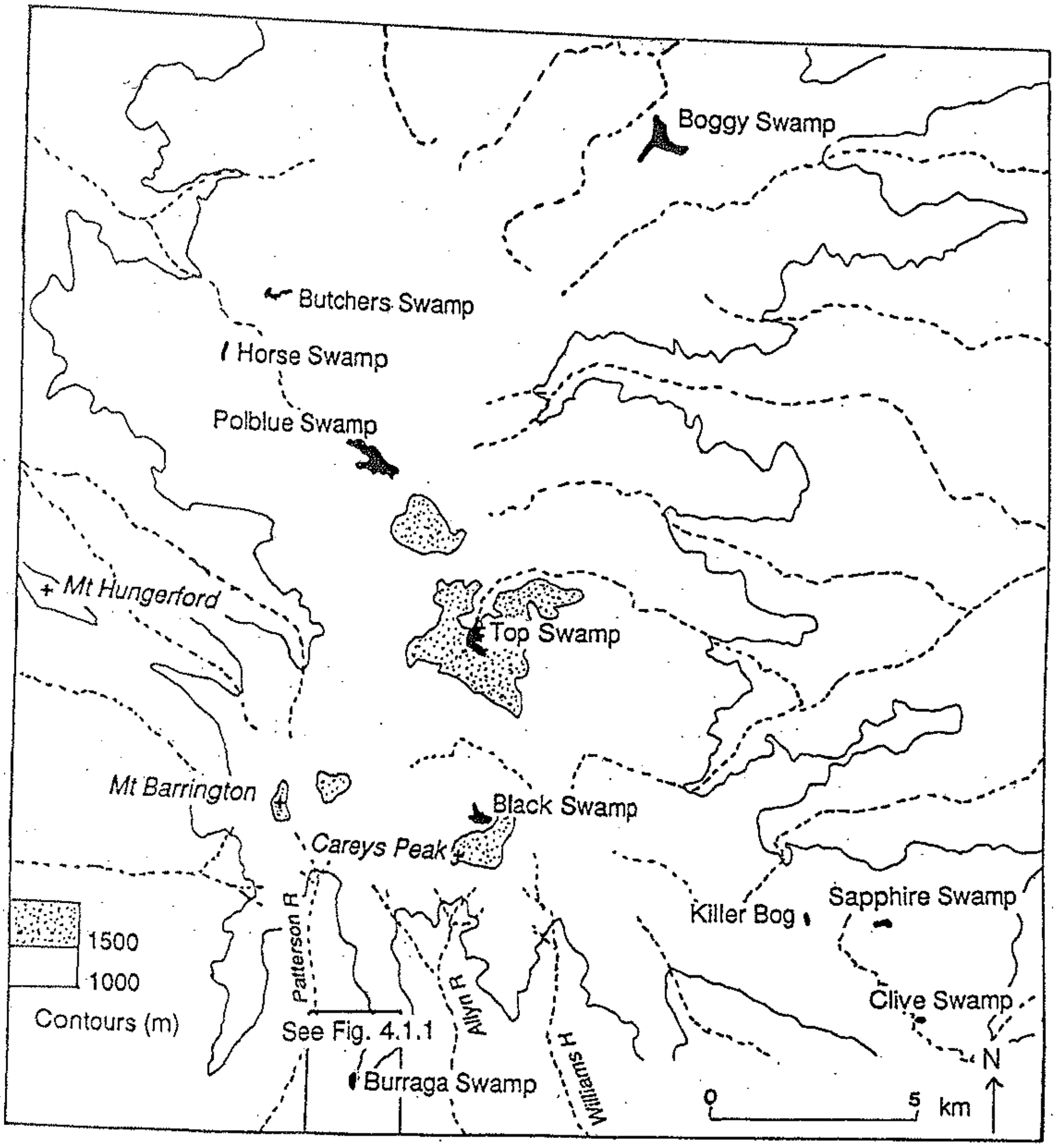


Figure 2.1c Barrington Tops Plateau showing streams and swamps (adapted from Dodson, 1987).
Position of Burraga Swamp is included.

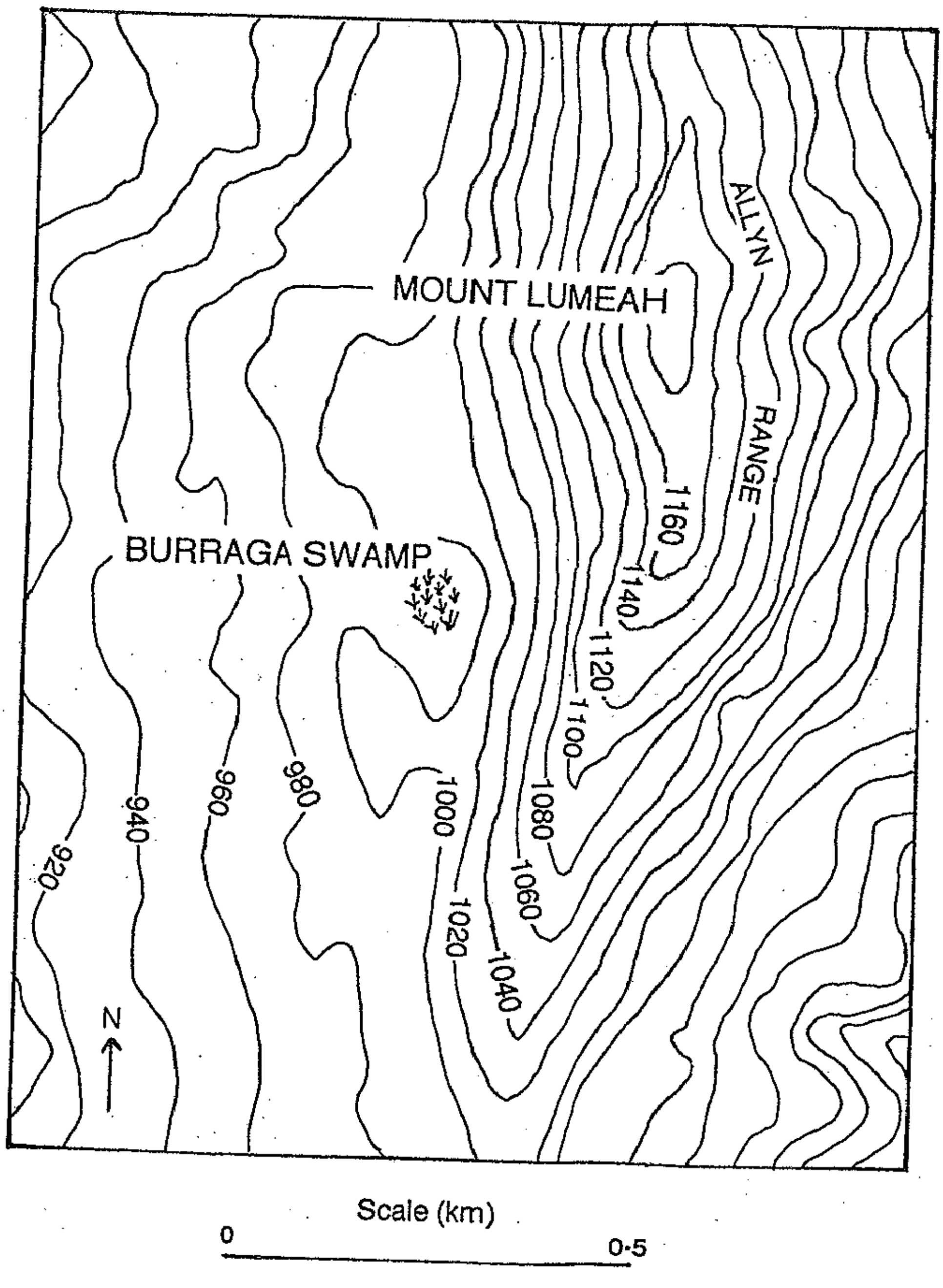


Figure 2.1d Contour map showing the relationship of Burraga Swamp to the slopes of Mt Lumeah.

Figure 2.1d (i) Mt Lumeah behind Burraga Swamp.
Cool temperate rainforest covers the side of the mountain.

2.2 CLIMATE

The plateau experiences a temperate to subalpine climate. The region receives both summer rain from the north and winter rain from the south, although in any one year, either climate type may predominate. There is a strong rainfall gradient over the region which receives mean rainfall values of over 2000 mm / year in the south-east of the area and 750 mm / year in the north-west (Turner, 1981) (Fig. 2.2). In general, the plateau surface receives over 2000 mm / year, with snowfalls most winters. The plateau is often cloud- covered.

Frosts can occur at any time and mists and fogs are common particularly in favourable topographic regions such as hollows. On the plateau, mean winter temperatures vary from -2°C to 9-10°C while mean summer variations are from 8-9°C to 22-23°C. At the base of the plateau, the maximum temperatures are 5-6°C higher.

The lower altitudes where Burraga Swamp is situated, experience less extreme climates than the plateau. The Burraga Swamp area receives desiccating hot north-west winds during the period November to January and cooler west to south-west winds in August to September.

Chichester Dam (Hunter District Water Board) is the nearest meterological station to Burraga Swamp. The climate averages for the last 58 years (taken from the Bureau of Meteorology 2001 website) is provided in Table 2.2.

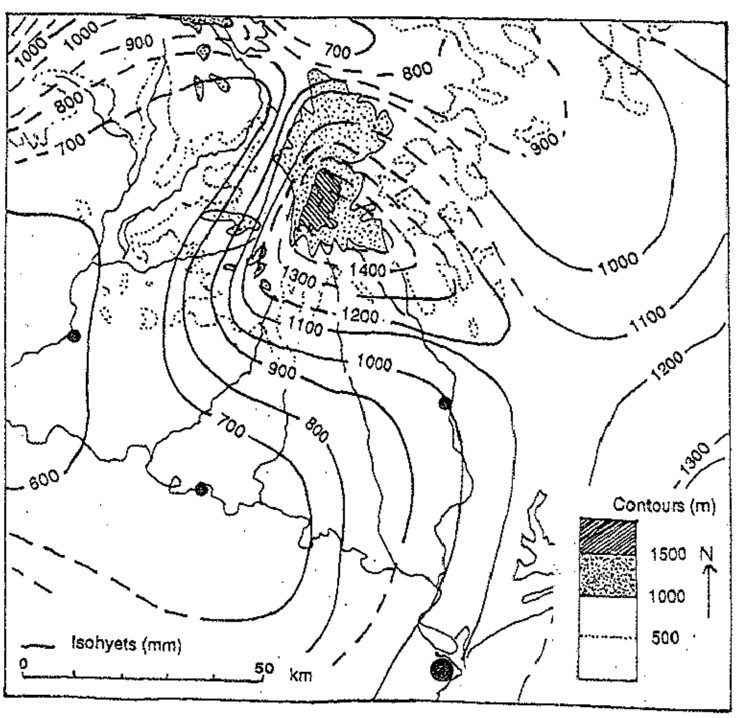


Figure 2.2 Reconstructed isohyets from Turner (1981). Broken lines signify uncertainty.

CLIMATE AVERAGES - long term mean values of weather data

061151 CHICHESTER DAM HUNTER WATER CORPORATION Commenced: 1942 Last record: 2000
Latitude: 32.24 S Longitude: 151.68 E Elevation: 194.0 m State: NSW

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN	No. Yrs	%age comp
Mean Daily Max Temp (deg C)	26.2	24.9	23.3	20.2	17.4	14.2	13.7	15.5	19.1	21.4	24.1	26.6	20.5	18.6	99
Mean Daily Min Temp (deg C)	16.7	16.7	16.2	12.7	9.7	7.0	6.2	6.9	9.8	12.1	14.9	17.2	12.1	13.3	71
Mean Rainfall (mm)	180.1	178.0	172.3	98.1	94.6	106.6	54.1	62.3	63.8	94.0	95.1	125.4	1324.5	57.8	99
Median (Decile 5) Rainfall (mm)	149.8	138.6	132.3	74.5	75.3	78.3	39.6	34.9	53.8	74.3	92.4	108.3	1300.8	55	
Decile 9 Rainfall (mm)	348.4	359.3	329.1	207.5	215.3	220.1	111.1	157.8	138.7	188.0	163.9	255.1	1818.0	55	
Decile 1 Rainfall (mm)	60.4	53.6	43.7	16.0	17.4	25.8	9.9	5.8	8.2	9.2	24.9	26.6	876.3	55	
Mean no. of Raindays	12.5	12.9	13.1	9.9	10.7	11.0	9.2	8.5	8.7	10.3	10.5	11.0	128.3	57.6	98
Highest Monthly Rainfall (mm)	635.2	523.9	666.2	482.7	330.0	526.5	209.6	391.8	181.6	401.7	227.2	390.5		57.8	99
Lowest Monthly Rainfall (mm)	9.9	23.4	0.8	1.0	1.3	7.6	0.0	2.4	0.6	0.0	10.4	0.0		57.8	99
Highest Recorded Daily Rain (mm)	261.6	176.0	240.0	219.2	126.0	110.5	116.8	91.7	120.0	194.3	104.0	137.7	261.6	57.9	99
Mean no. of Clear Days	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	98
Mean no. of Cloudy Days	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	98
Mean Daily Evaporation (mm)	4.4	3.9	3.0	2.3	1.5	1.1	1.3	1.9	2.7	3.5	4.1	5.0	2.9	15.8	60

Table 2.2 Climate averages for Barrington region (August, 2000).

2.3 VEGETATION

The main types of vegetation over Barrington Tops are cool temperate (sub-Antarctic) and sub-tropical rainforests, eucalypt formations. On the plateau itself, sub-alpine communities, grasslands and swamps occur (Fraser and Vickery 1937, 1938, 1939; Forestry Commission of N.S.W. 1983; Dodson and Myers, 1986). The cool temperate and subtropical rainforests are found in similar habitats but the subtropical rainforests occur at lower altitudes (Dolman, 1982). The boundary between subtropical and cool temperate rainforest around the sides of the plateau, occurs at about 900 m (Turner, 1981). where the cool temperate rainforest includes some subtropical rainforest elements with a scattering of eucalypts and sclerophyll forest elements in the rainforest shrub layer (Poole, 1987).

2.3.1 Cool Temperate Rainforest

The cool temperate rainforest " is best developed between 900 and 1200 m but also occurs between 700 and 1550 m, where shelter is afforded along creek beds or folds in the spurs of the plateau" (Dodson and Myers, 1986, p. 296). At the higher elevations on colder, steeper sides or on poorer soils, the communities have fewer species. In these habitats the *Nothofagus* is frequently multistemmed and much smaller, but can still form closed-canopy stands (Poole, 1987).

2.3.2 Mixed subtropical rainforest

Subtropical rainforest occurs mainly on the southern and eastern flanks of Barrington Plateau at altitudes up to about 450 m. Elements of the vegetation type occur to 900 m in protected gullies and soakage areas (Dodson and Myers, 1986). These rainforest communities have a mixed floristic composition, with generally no single dominant species. Characteristic features include strangler figs, palms, large woody vines, epiphytes and stem buttressing.

2.3.3 Eucalypt forest

Eucalypt forest canopies are dominated by *Eucalyptus* species. There are a number of *Eucalyptus* associations, all containing three main strata: tree, shrub and ground flora (Fraser and Vickery, 1939), with relatively open canopies. In the Barrington Tops district, both dry and wet sclerophyll forests are represented, extending from the valley floors onto the Plateau. The forest "comprises a number of well marked, altitude-delimited communities which grade into each other so that the forest forms a continuous whole" (Fraser and Vickery, 1939, p. 1).

2.3.4 Vegetation on the Plateau

Above about 900 m, there is an open forest of *Eucalyptus obliqua* - *E. viminalis*. Between 1,100 m and 1,300 m, *E. fastigata* - dominated open forest occurs, with a well developed shrub layer. Above 1,300 m, there is an *E. pauciflora* - dominated open forest. The understorey is dominated by *Poa sieberana* grassland, maybe some sub-alpine small shrubs and herbs (Dodson and Myers, 1986). Low-lying areas where cold drainage occurs are the coldest in the region and are dominated by *Baeckia utilis* and *Epacris paludosa* along creek banks while areas of poor drainage and swamps are covered by *Sphagnum* hummock-hollow communities or Cyperaceae-Restionaceae sedgeland. Better drained areas are dominated by *Poa sieberana* grassland (Dodson and Myers, 1986; Dodson et al., 1986).

Chapter 3 METHODS AND TECHNIQUES

3.1 VEGETATION SURVEYS

The forest vegetation within 100 metres surrounding the swamp, was examined qualitatively. All species were identified. The regional vegetation was taken from the Boonabilla Management Area Forestry Commission map, 1983.

The swamp vegetation was mapped by visual estimation of the percentage cover of the dominant plant species in one square metre plots. Estimation was assisted by a chart for "visual percentage estimation". All species found on the swamp were identified.

The author citation of all plant names may be found in Harden (1990-1993). Voucher specimens of all species identified have been kept in the UNSW Herbarium.

3.2 MODERN POLLEN SAMPLING

For the assessment of modern pollen deposition, samples of moss polsters and topsoil were collected from each vegetation unit on the swamp and in the forest. Figure 4.1.2 designates the positions of the surface samples studied.

For comparison with Burraga Swamp, Polblue Swamp, within subalpine eucalypt forest, about 15 km north and 500 m higher on the plateau surface, was sampled. Only the results from surface samples are used in this current study.

3.3 THE SEDIMENTS

A Hiller corer was used to extract eleven cores along two transects across the swamp. One transect was from east to west, the other from north to south. In the field, the sediments were described using the Troels-Smith method (Birks and Birks, 1980). The cores were searched for macrofossils such as seeds, charcoal and remnants of leaves and wood. The longest core, 6 metres, was used for pollen analysis. Sampling was done every 10 cm all the way down to the base of the core (Sweller and Martin, 1997), but only the peat section was used during interpretation in this thesis.

Phenol crystals were added to the samples to arrest bacterial action and stored in a cold room at 4°C.

3.3.1 ^{14}C DATING

For ^{14}C Dating, samples were taken from a hole as close as possible, to the pollen analysis core. A soil sampling corer was used. Three samples were ^{14}C dated in the then Radiocarbon Laboratory, UNSW. There was insufficient carbon in the clays to allow dating by conventional carbon methods. Another core, 6.5 metres, close to the original, was extracted with a Livingstone corer (Fig. 3.3.1(i)), for the AMS (Accelerator Mass Spectrometry) dating of the clays. A total of eight samples were sent to ANSTO (Australian Nuclear Science & Technology Organisation) laboratories for AMS radiocarbon dating.

3.3.2 SEDIMENT DESCRIPTION

The mineral section of the second core was analysed for the pollen / spore content and during interpretation used in conjunction with the results of the peat analysis from the first core.

The sediments of the second core were described in detail. The colours of the sediments were described using the Munsell Color Chart (1954) and the cores were sliced longitudinally and photographed in the Photographic Unit of the School of Biological Science. Further examination involved the following techniques.

3.3.2.1 QUANTITATIVE DETERMINATION OF SEDIMENT PARTICLE SIZE

From selected sections of the core, sediment samples of about 2 cm^3, were air dried. The dry material was gently crushed to totally separate the particles. The unconsolidated material was then sorted by a vibrator sieve, shaking for 10 minutes. Sieve sizes used were 2.0 mm, 1.7 mm, 0.5 mm, 63 µm, 45 µm. The dry sieved fractions were weighed and the % by weight of the total was calculated. The final fractions noted were: gravels (more than 2.0 mm), coarse sand (0.5 - 2.0 mm), fine sand (63 µm - 0.5 mm), silt and clay- fine fraction (less than 63 µm).

Some samples, upon air drying, became too hard to disaggregate, even with hammering. These dry samples were placed in water, dissolved and wet sieved. The fractions were then air dried and weighed.

3.3.2.2 ORGANIC / INORGANIC CONTENT

The organic / inorganic content was estimated by loss-on-ignition (combusting dry samples) (Bengtsson and Enell, 1986).

The dehydrated sediments, in lidded crucibles, were ignited at 550°C in a *Thermolyne 62700* furnace for 2 hours. The inorganic and organic contents were then calculated using the following formula:

$$\%\ \text{Inorganic content} = \frac{\text{weight of residue after ignition}}{\text{weight of dry sample}} \times 100$$

$$\%\ \text{Organic content} = 100 - \%\ \text{inorganic content}$$

3.3.2.3 HUMICITY

Humicity is the measure of the amount of humic acid in the sediment. The test for humicity was carried out on the supernatant of the hydroxide digestion during pollen extraction. The test was the depth of browness of a piece of filter paper dipped into the supernatant. The results were recorded on a 5 point scale.

3.3.2.4 CHARCOAL

Quantity of charcoal was estimated on the slides prepared for pollen. The results are given on a three point scale.

3.3.2.5 MACROFOSSIL STUDIES

From the core collected with the Hiller corer, selected sections were treated with 7% nitric acid for two days. By this time, seeds, leaves and pieces of wood had floated to the surface and were removed. Following a water wash, they were placed into 80% alcohol. Only seeds were identifiable.

Selected sections of the Livingstone core, were extracted and the volume determined by the displacement of water method (Birks and Birks, 1980). The material was dispersed in water and washed through a coarse sieve. The easily visible macrofossils were removed and the remaining residue was inspected with a binocular microscope and the macrofossils were removed with forceps and a fine brush. The material to be retained was initially stored in water to completely clean the specimens. After a few days, the water was decanted and replaced by 95% alcohol. The material was stored in the cold room. Microscopic examination was carried out on the stored material.

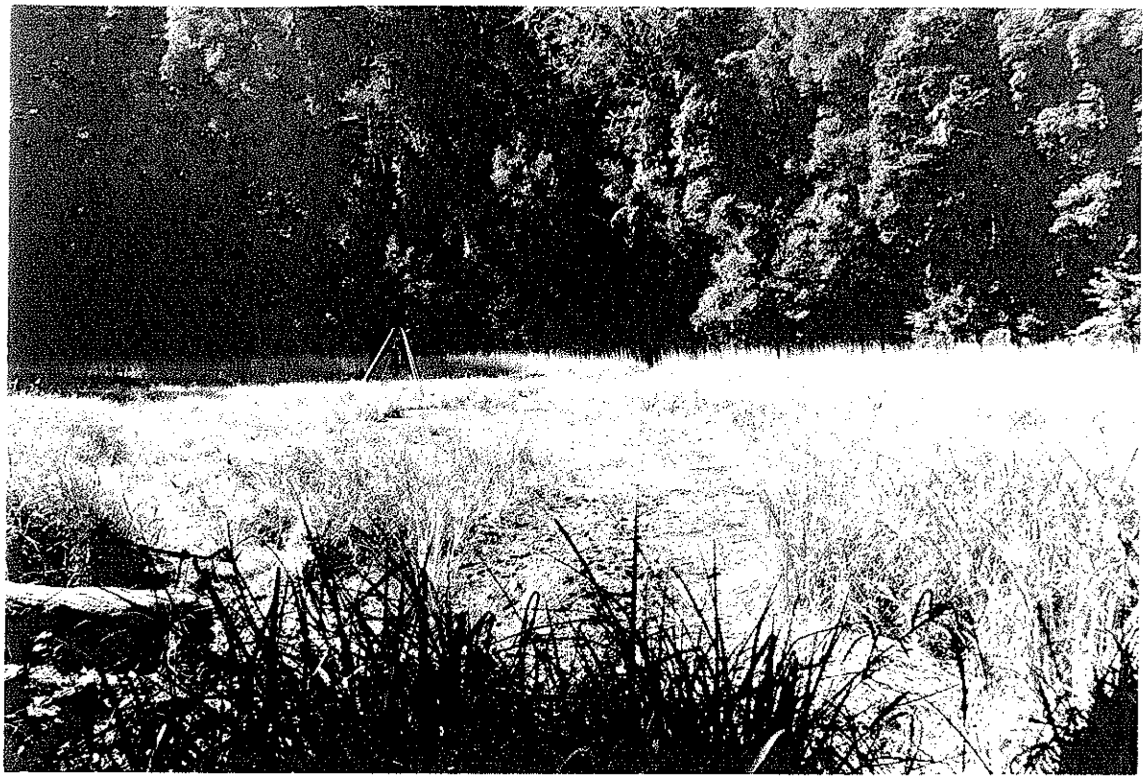


Figure 3.3.1 (i)
Tripod set up to extract the second core with the Livingston Corer.

Preparing the corer for sediment extraction

3.4 POLLEN PREPARATIONS

3.4.1 PREPARATION OF STANDARDISED EXOTIC POLLEN SUSPENSION

Alnus rugosa pollen was used as the exotic marker. Pure defatted *Alnus rugosa* pollen was obtained from Greer Laboratories, Inc., Lenoir, U.S.A. The concentration of the stock suspension of *Alnus* was calculated to be 2.76 x 10^4 grains / mL. The stock suspension was mixed on a magnetic stirrer for 24 hours before samples were taken and added to the sediments (Moore et al., 1991).

3.4.2 PREPARATION OF ALL POLLEN / SPORE MATERIAL

Sediment samples (0.2 gram of peat, 0.5 gram of clay, 1.0 gram of gravel or sandy gravel) were spiked with a known volume (hence concentration) of standardised *Alnus rugosa* pollen suspension, treated with concentrated hydrofluoric and hydrochloric acids to remove mineral matter, dispersed with 10% potassium hydroxide to enhance the breakdown of undesirable organic matter and assist deflocculation, disaggregated with ultrasonic vibration and sieved through an 0.18 mm sieve. This was followed by standard acetolysis (Moore et al., 1991).

Reference pollen/spores for comparison with fossil grains were collected in the study area or its vicinity or pollen bearing material was obtained from the UNSW Herbarium or from the National Herbarium at the Royal Botanic Gardens in Sydney.

The moss polsters and soil samples were dispersed with a little water, sieved and allowed to settle for 72 hours treated with 10% sodium hydroxide, acetolysed by the standard procedure.

The dry, herbarium material was placed in a dry centrifuge tube, crushed gently with a dry glass rod and followed by standard acetolysis procedure.

All pollen/spore preparations were mounted following the same procedure. After acetolysis, the material was dehydrated and retained in silicone oil (viscosity 2000 centistokes). Then, four slides of each sample were mounted simultaneously. A grade 0 coverslip (22mm x 40mm) was added, gently pressed to distribute the sample evenly. Slides, where the material seeped out from the coverslip edges, were discarded. Edges of the coverslips were sealed with clear nail polish.

3.5 PRODUCTION OF POLLEN DIAGRAM

3.5.1 GRAIN IDENTIFICATION

Pollen and spores were identified by comparing them with reference pollen / spores. Identification to species was only rarely possible for example, *Nothofagus moorei*. Mostly, identification was made only to genus, for example, *Casuarina* spp., or to family, for example, Poaceae. Pollen groups are plotted in the pollen diagram. The definitions of these groups are outlined.

Although the pollen of the family Poaceae cannot be identified with taxa within the family, size analysis may indicate the presence of different taxa. Fifty Poaceae grains were measured in samples which contained a high Poaceae pollen count and the size frequencies graphed.

In many cases identification was hampered by the deteriorated state of the grains. Some of the samples contained a disproportionately large number of deteriorated grains. It was possible to distinguish different types of deteriorations such as corrosion, degradation, crumpling and breakage. Descriptions used (Appendix 3) are those according to Cushing and Wright (1967). All categories of indistinguishable grains are combined in one group when graphed as Indeterminable Pollen.

3.5.2 POLLEN AND SPORE COUNTS

All fossil and exotic *Alnus* pollen and spores were counted along transects on several slides. In most of the samples, between 200 and 500 fossil grains were counted. Clumps of similar grains and tetrads, were treated as single units. Once counting was completed, samples were scanned to record rare grains which were not encountered along the transects. They were recorded as grains which were "sighted, not in count".

3.5.3 POLLEN DIAGRAM

Pollen/spore percentages are calculated using the total pollen and spore count (excluding algal spores) as the pollen sum. This method of calculating the pollen sum is used because it requires the fewest assumptions about the ecological niche of the taxon in the vegetation and where necessary, assumptions are made during the interpretation of the data.

Where total terrestrial pollen is used as the pollen sum (e.g. Dodson and Myers, 1986; Singh and Geissler, 1985), a decision must be made as to whether a pollen type represents dryland or wetland environments. For example, the families Poaceae, Cyperaceae and Restionaceae all contain both dryland and wetland species (Sainty and Jacobs, 1981; Harden, 1992), yet pollen of these families is rarely identifiable to species. Even woody shrubs such as *Leptospermum*, *Baeckea* and *Callistemon* may be found in swamps as well as on dry land. Other pollen sums, e.g. inferred regional or distant sources (Martin, 1986, 1999; McKenzie, 1997) also require assumptions about the source of the pollen. A pollen type, e.g. Poaceae, may be derived from a regional source, or it may have a local wetland origin.

During this current study, a comparison is done between two methods of calculating the pollen sum: using total pollen count and terrestrial pollen (where the aquatic pollen were overproducing). It was found that the more restricted pollen sum provides a greater exaggeration of the trends (see Appendix 4). The trends, however, are similar and no extra information is added by the restriction of the pollen sum.

When there is a high count of one pollen type, such as the wetland *Myriophyllum*, it depresses the percentage of the other pollen groups. In these circumstances, pollen concentrations (independent values for each fossil pollen type), can assist with the interpretations. A combination of both pollen percentage and concentrations leads to better interpretations. Pollen/spore concentrations were calculated from the ratio of the exotic pollen, *Alnus rugosa*, to the fossil pollen.

The 95% confidence intervals (limits) for pollen percentages indicate the precision of the data (Maher, 1972). The computation of the limits considers the total number of pollen counted. In this study, the intervals were derived from a computer programme designed on Mosimann's equation (Maher, 1972). The limits are denoted by error bars plotted for each pollen percentage. When the error bars do not overlap, the change in the pollen percentage is accepted as being significant.

3.5.4 ZONATION

Pollen spectra have been zoned subjectively, with the zone boundaries based on change in several of the major pollen groups at a specific level. A percentage change is accepted as being real when percentage changes between levels are greater than the extent of the error bars, that is, the error bars do not overlap.

There are objective techniques employing statistical computer programmes to zone pollen diagrams. However, although zoning pollen diagrams objectively may remove personal biases, such systems could be still misleading if not critically appraised. "All zonation systems should be viewed with some degree of caution; they are mere aids to interpretation. Even an objective system of zonation could be misleading if accepted without critical appraisal." (Moore et al., 1991, p.179).

Chapter 4 RESULTS

4.1 VEGETATION

4.1.1 Vegetation in the forest surrounding Burraga Swamp

Burraga Swamp is in the midst of a cool temperate rainforest and there are stands of eucalypt forest within 100 m and mixed subtropical rainforest about half a kilometre away (Fig. 4.1.1). Some photographs of the surrounding forest and swamp vegetation are included in this chapter.

The following outline of the constituent plants is compiled from the result of vegetation surveys around the swamp; the Boonabilla Management Area Map by the Forestry Commission of N.S.W. 1983; Fraser and Vickery (1938, 1939) and from Dodson and Myers (1986). The species identified at the forest surface sample sites are also listed. A table of all species identified in the Burraga Swamp area is given in Appendix 1.

The cool temperate rainforest around the swamp has a tree stratum 10-30 m tall with a foliage projective cover of more than 70%. This layer has *Nothofagus moorei* dominant (with many young plants in the forest). *Doryphora sassafras* and *Orites excelsa* are sub-dominants. Other species present are *Schizomeria ovata, Ackama paniculata, Syzygium australe, Acmena smithii, Diospyros australis, Quintinia sieberi, Rapanea howittiana, Daphandra tenipes, Symplocos* sp., *Citriobatus* sp., *Cryptocarya erythoxylon* and *Eucalyptus saligna*. *Tristaniopsis laurina* and *Tristaniopsis collina* are found in disturbed areas.

A small tree stratum 2-10 m tall is composed of *Coprosma quadrifida, Solanum* sp., *Hymenanthera dentata* and *Duboisia myoporoides*. The tree fern *Dicksonia antarctica* is usually over 2 m and is particularly abundant in moist depressions. There may be shrubs less than 2 m, such as *Coprosma quadrifida, Rubus rosifolius* and around the swamp, *Rubus hillii* and the introduced stinging nettle, *Urtica urens*.

Ground covering plants are found mainly in light breaks and are usually herbaceous and less than 1 m tall. *Carex appressa, Hydrocotyle tripartita, Dianella* sp., *Juncus usitatus* and *Lomandra spicata* are found here. Trailing or twining plants include

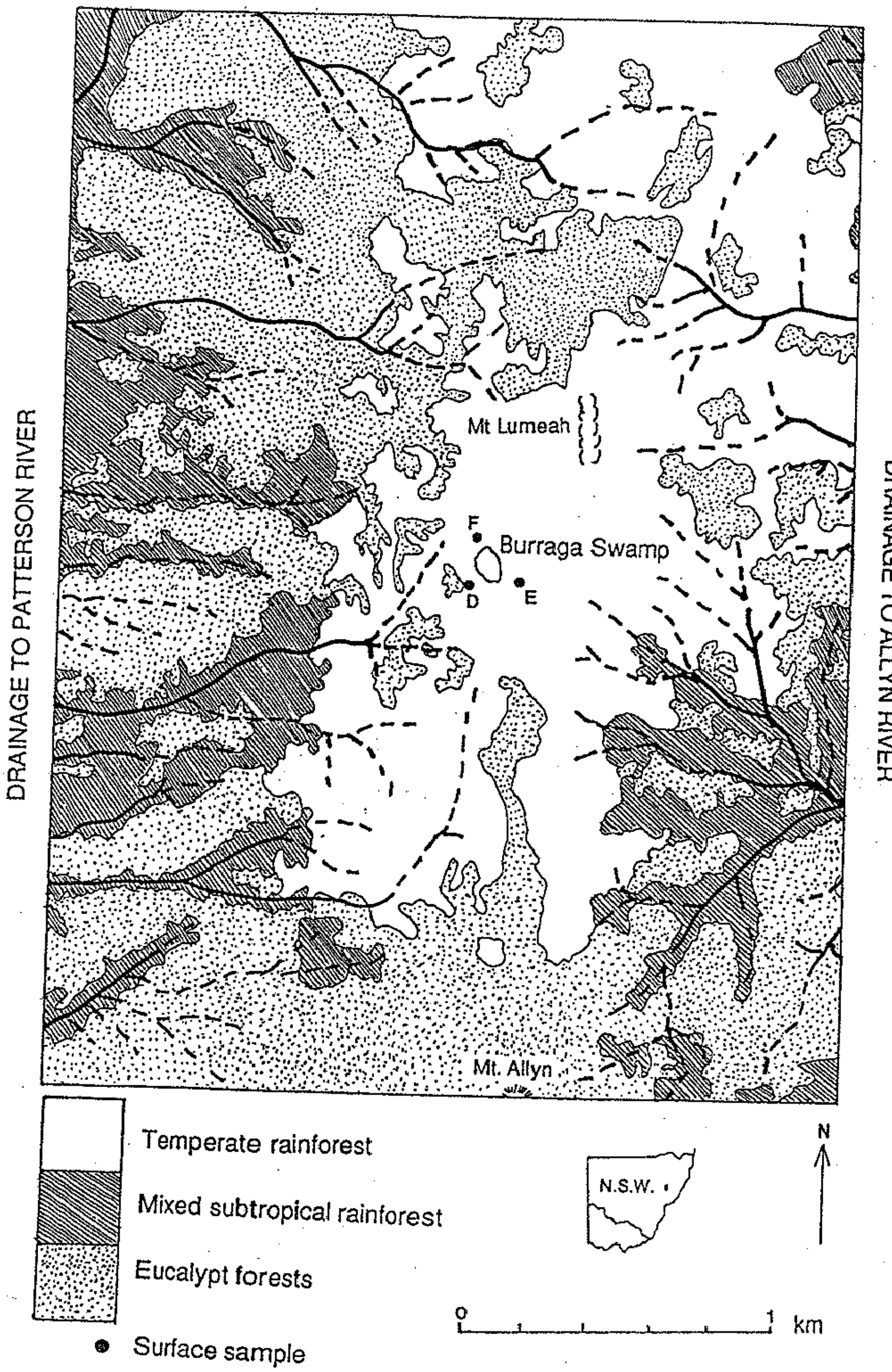


Figure 4.1.1 The vegetation of the area around Burraga Swamp, modified from the Boonabilla Management Area Map (Forestry Commission of N.S.W. 1983).
Dominant species are given in the text and all species identified in the area are given in Appendix 1.

Morinda jasminoides, Pandorea pandorana, Parsonsia staminea, Polygonum subsessile, Polygonum decipiens, Dioscorea sp. and *Cayratea clematidea*.

Ferns are very common in the ground cover also. The species include *Hymenophyllum flabellatum, Pellaea falcata, Lastreopsis microsora, Hypolepis* sp. and marginal to the forest, *Pteris* sp. The epiphitic ferns *Microsorium diversifolium, Microsorium scandens* and *Arthropteris tenella* are present also. Mosses and lichens are also present.

In the 30 m stratum of the mixed rainforest the major tree constituents are: *Doryphora sassafras, Orites excelsa, Ackama paniculata, Diploglottis australis, Elaeocarpus grandis, Citronella moreei, Toona australis, Schizomeria ovata, Litsea reticulata, Dysoxylum fraseranum, Cinnamomum oliveri, Cryptocarya erythoxylon, Tristaniopsis laurina* and *Laportea gigas* (Forestry Commission of N.S.W., 1983).

Eucalypt forests form extensive tracts in the Burraga Swamp area and in them, *Nothofagus moorei* peters out. The eucalypt forest near Burraga Swamp is a semi-moist hardwood forest, with the heights of trees ranging from 40 m to almost 60 m (Forestry Commission of N.S.W., 1983). The forest is mainly (75%) *Eucalyptus saligna* with *E. laevopinea, E. quadrangulata,* with a moist understorey (Forestry Commission of N.S.W., 1983). Forests in which *Eucalyptus laevopinea / E. campanulata* dominate with *E. saligna, E. quadrangulata, E. acmenioides, E. canaliculata* and *E. punctata* in a dry or moist understorey are also found in the region (Forestry Commission of N.S.W., 1983).

The following species were identified at the surface sample sites in the forest (sites are indicated on Fig. 4.1.2):

Site D: Junction of *Eucalyptus laevopinea* and *Nothofagus* forests

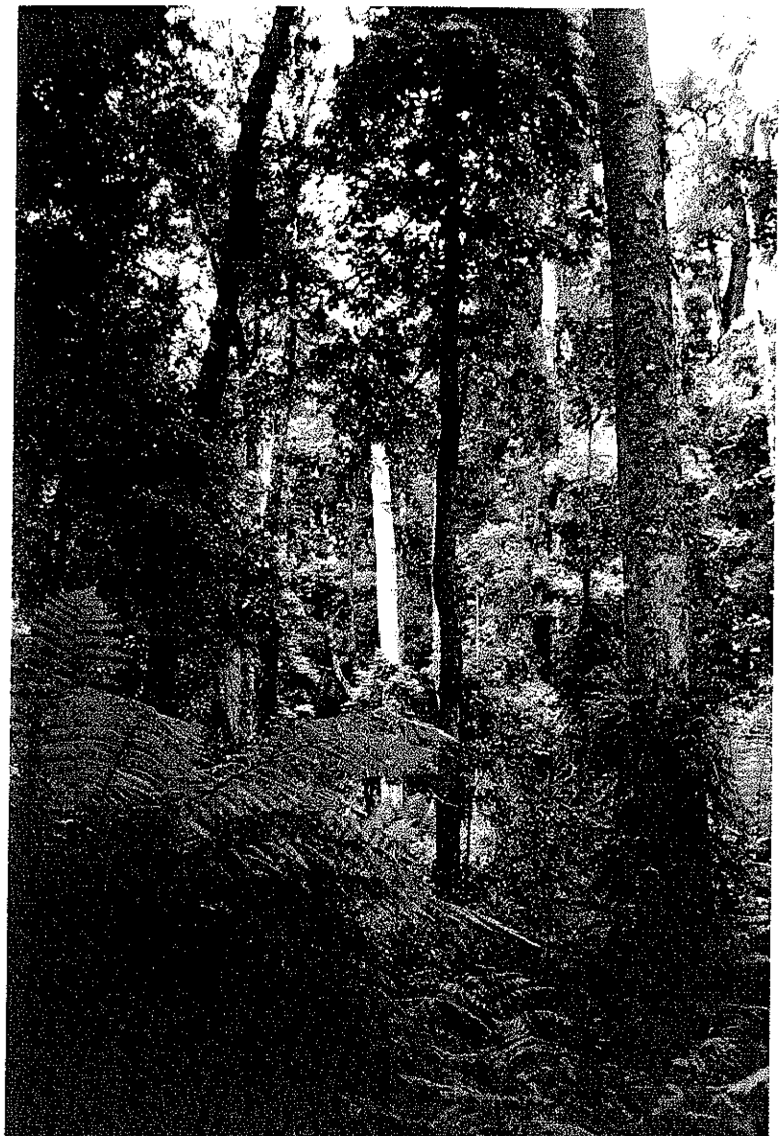
Eucalyptus laevopinea, Eucalyptus saligna, Nothofagus moorei, Caldcluvia paniculosa, Schizomeria ovata, Orites excelsa, Syzygium australe, Doryphora sassafras, Daphandra tenipes, ground ferns.

Site E: South East Forest, around Burraga Swamp

Nothofagus moorei, Orites excelsa, Doryphora sassafras, Syzygium australe, Caldaluvia paniculosa, Daphandra tenipes, Citriobatus sp., *Dicksonia antarctica*, ground and tree creeper ferns. *Hymenanthera dentata, Symplocos* sp., *Cryptocarya erythoxylon.*

F: North Side Forest, around Burraga swamp

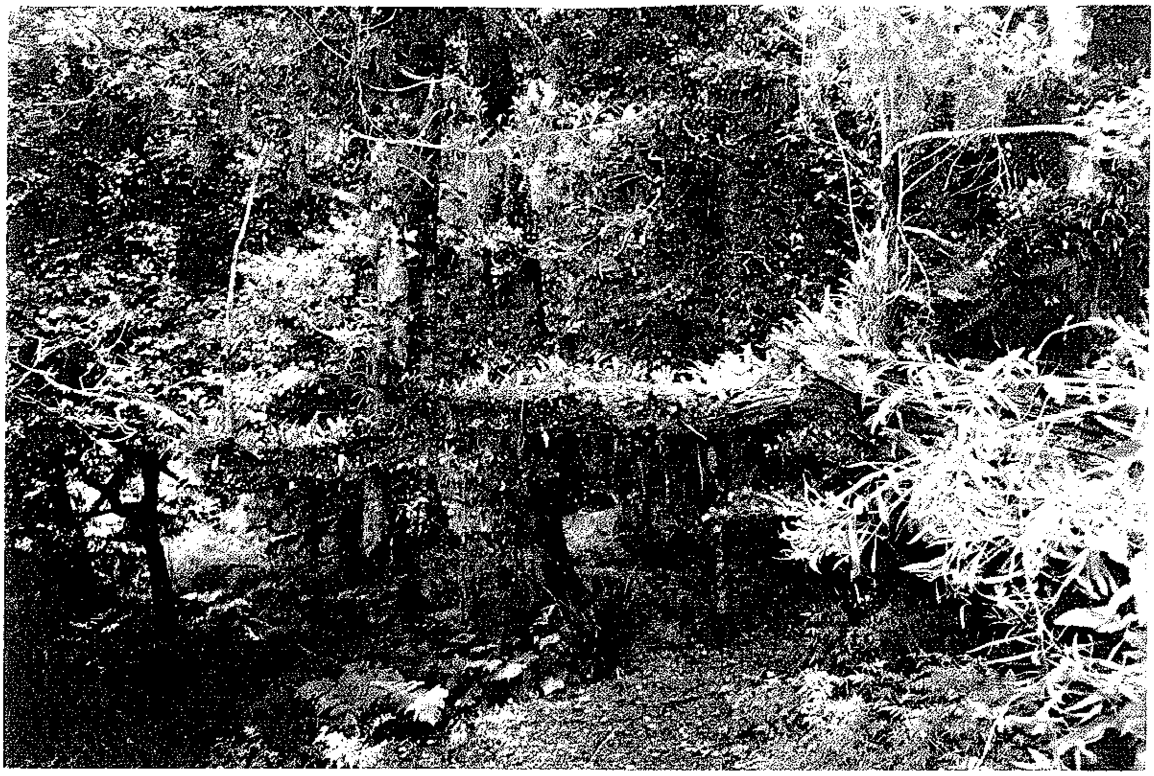
Nothothofagus moorei, Caldcluvia paniculosa, Syzygium australe, Schizomeria ovata, Diploglottis australis, ground and tree creeper ferns.



Section of the cool temperate rainforest which includes *Eucalyptus saligna*. *Dicksonia antarctica* and other ferns are also abundant.

Forest on the south side of the swamp, showing *Nothofagus moorei* with some young plants at the base. There is evidence of fire in this area.

Forest at the entrance to Burraga Swamp. Trees are fern and moss covered.



Section of cool temperate rainforest.

A grove of *Dicksonia antarctica* in a depression near the swamp.

4.1.2 Vegetation on the Swamp

The dominants are *Phragmites australis, Cyperus lucidus* and *Glyceria australis*. Five communities have been defined and these are shown on Fig 4.1.2. The composition of the communities are as follows:

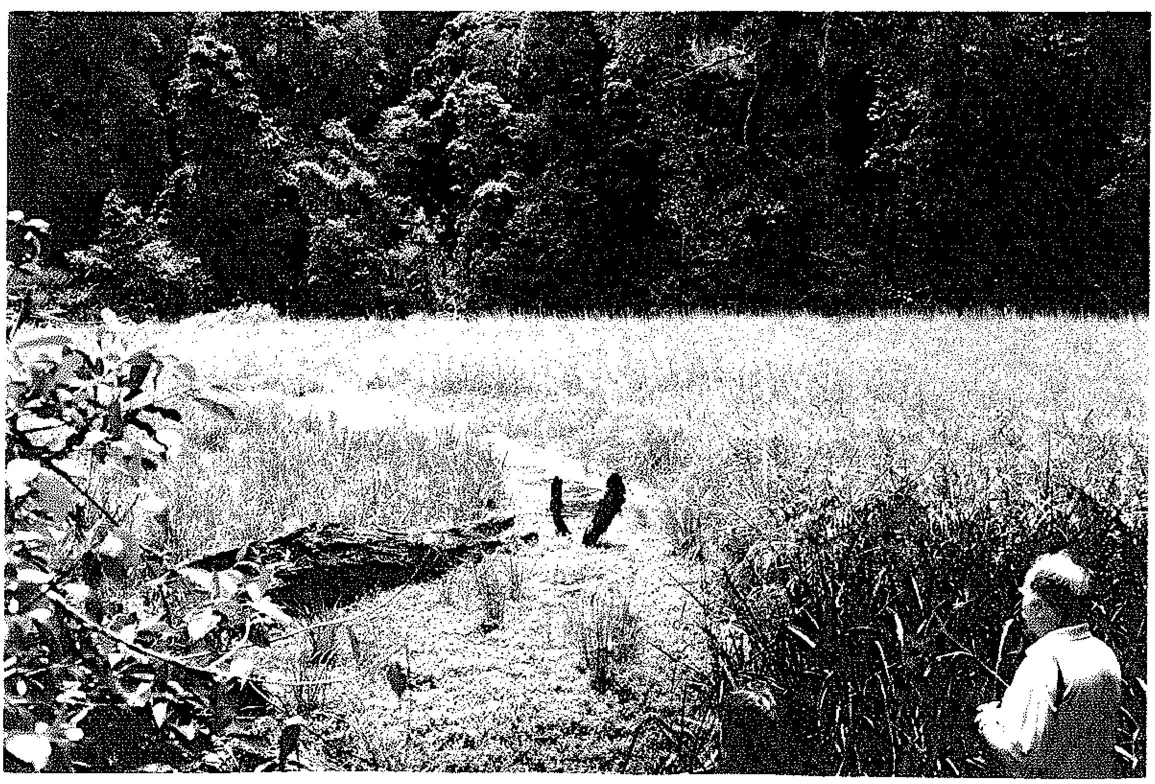
1. Dense *Phragmites australis* community: 40-50% *P. australis*, 60-50% *Cyperus lucidus* (community present at swamp surface sample site C).

2. Patchy *Phragmites australis* community with *P. australis*, *C. lucidus*, *Glyceria australis*, mosses and *Lastreopsis microsora.* Very hummocky (community present at swamp surface sample site B).

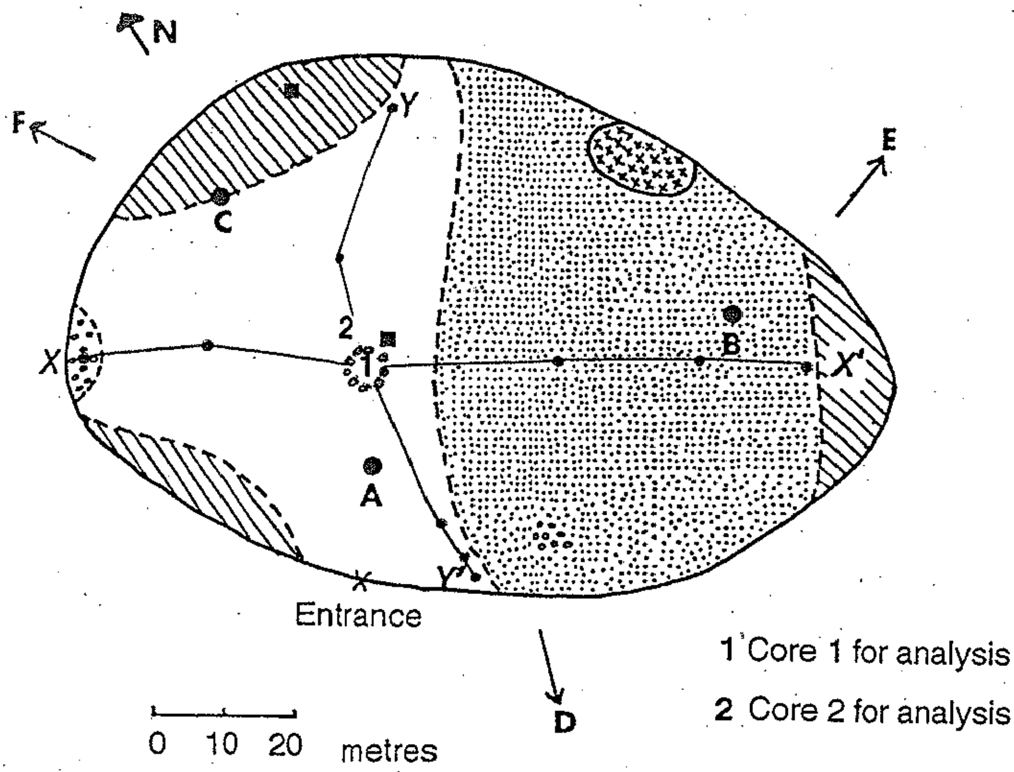
3. *Glyceria australis* community with 70% *G. australis*, 15% *Cyperus lucida*, 10% moss and 5% *L. microsora.*

4. *Glyceria australis/Phragmites australis* community with 50% of each and some moss (community present at swamp surface sample site A and Core 2 site).

5. Mainly bare ground with a moss cover and a little *G. australis* (community present at Core 1 site).



View from the swamp entrance. A section within the *Glyceria australis/Phragmites australis* community has been trampled down and largely taken over by herbs. The photograph was taken during a wet period when there is free standing water on the swamp.



A B C Swamp surface samples **D E F** Direction of forest surface samples

X—X' and Y—Y' Transect across swamp with • stratigraphic core

■ Approximate position of core by Dodson et al. (1994)

<u>Swamp vegetation types</u>

1 Dense *Phragmites australis* community

2 Patchy *Phragmites australis* community

3 *Glyceria australis* community

4 *Glyceria australis, Phragmites australis* community

5 Mainly bare ground

Figure 4.1.2 Burraga Swamp showing vegetation; cores for pollen analysis, dating and stratigraphic mapping; swamp surface sample sites and direction of forest surface sample sites. The approximate position of the cores studied by Dodson et al. (1994) are shown.
Species identified at surface sample sites are given in the text.

Looking towards the north side of the swamp. Dense *Phragmites australis* community can be seen in the background, thick cool temperate rainforest behind it and *Juncus usitus* at the front edge of the swamp.

Looking from a *Glyceria australis/Phragmites australis* community, across to a *Phragmites australis* community near the forest on the eastern side of the swamp.

4.2 SEDIMENTS

4.2.1 RADIOCARBON DATES

Table 4.2.1 presents the ^{14}C dates.

The 3 dates from the peat were taken from the first core and the remainder from the second core. The basal peat date from 260-270 cm in the first core corresponds with the basal peat level 246-249 cm in the second core.

The oldest date, 38,050 years, is a minimal age for the 647 cm level. The basin base is likely to be at least 40,000 years old.

The date of 9,630 ± 50 years at 395 cm appears anomalous, but it could be contamination.

Table 4.2.1 Radiocarbon age of sediments

Depth (cm)	Sediment Type	Reference No.	Age (years BP)
100-110	peat	NSW 345	5490 ± 120
240-250	peat	NSW 348	6150 ± 130
260-270	peat	NSW 347	6520 ± 130
296	silt / clay	OZE 566	14680 ± 140
355	silt / clay	OZE 567	17300 ± 150
380	gravelly clayey sand	OZC 982	16800 ± 190
395	silt /clay	OZE 568	9630 ± 50
495	gravelly clayey sand	OZE 569	17430 ± 90
555	clayey fine sand	OZE 570	21350 ± 250
600	silt / clay	OZC 981	29700 ± 600
647	silt / clay	OZE 571	38050 ± 600

4.2.2 DESCRIPTION OF SEDIMENT

Sediments can record sudden environmental changes and so they are very useful aids in interpreting variations in the climate.

Table 4.2.2a describes the sediment of Burraga Swamp. Table 4.2.2b records the grain size analysis. Table 4.2.2c provides data on humicity. Organic carbon content and relative charcoal estimation are plotted in Fig. 4.3b. Photographs of longitudinal sections of the sediment cores, are included (Fig. 4.2.2a(i)). The sediments appear to be a continuous record of the depositional processes and thus are sensitive recorders of the environment and its modifications.

The sediment can be divided into two major sections: Mineral and Peat. Within the sections, further divisions are made as shown in Fig. 4.2.3.

4.2.2.1 The Mineral Section

4.2.2.1.1 Sedimentary Unit 1, 655 - 600 cm, about 40,000 - 29,700 years BP.

This unit consists of alternating bands of dark grey and yellowish grey silt/clay where the clay particle size of the oldest sediments is less than 45 µm diameter. The sediments become sandier towards the top of the unit. There is a vertical crack filled with dark sediments from 605 to 630 cm. Red, crumbly sandy clay occurs betwen 633 and 635 cm.

Microscopic charcoal particles occur in relatively small numbers overall, with none at 600 cm. The carbon content is low, average of 6%, varying between 4.3% and 7.0%, with an increase to 10% in the vertical crack. Humicity ranges from 3 between the base and 640 cm to 0 - 2 above.

4.2.2.1.2 Sedimentary Unit 2, 600 - 510 cm, 29,700 - about 19,000 years BP.

This unit contains very dark grey, grading to light grey, reddish and yellowish brown clayey sand.

The amounts of microscopic charcoal particles fluctuate between zero and low quantities, until 540 cm from where there were many pieces up to the top of this sedimentary unit. The carbon content is low, average of 5%, ranging from 4.3% to 6.0%. Humicity is low, from 1 - 2, except at 530 cm where it is 3.

4.2.2.1.3 Sedimentary Unit 3, 510 - 375 cm, 19,000 - about 17,000 years BP.

This unit is characterised by brown to grey mixtures of varying amounts of clay, sand and reddish gravel with stem / root fragments. At about 440 and 398 cm, specks of wood are found. Within this unit, dark bluish grey or yellowish/grey brown thin bands of sand/silt/clay occur. The more gravelly sections are wetter.

This unit is recognisable in the first core at 400 - 500 cm (Fig. 4.2.4).

No charcoal particles occur between 480 and 450 cm and at 400 cm. Then, there were very many charcoal pieces between 450 and 375 cm. Overall, the gravelly sediments contain more charcoal. The carbon content is low, average of 6%, varying between 4% and 8%. Humicity is essentially very low, between 0 and 1, but is 3-4 where plant material is present or carbon values are above the average.

4.2.2.1.4 Sedimentary Unit 4, 375 - 249 cm, about 17,000 - 6,500 years BP.

The sediments in this unit, are silt/clay with frequent changes in colour, ranging from very dark grey brown to light olive brown/yellow. The paler bands are drier. There are traces of fine sand in most of the unit, except around 300 to 290 cm where the sediment is 100% silt/clay. A greyish brown band of silt/clay with an earthy odour, at 300 to 298 cm, is sandwiched between very dark greyish brown silt/clay sediments. There are plant fragments between 375 and 335 cm. Between 298 and 276 cm, leaf fragments occur and roots, stems and seeds occur between 276 and 249 cm. There is a dark staining of the clay between 249 and 256 cm.

Microscopic charcoal particles occur in very small quantities. The carbon values are slightly higher in this unit, averaging at 8.6%, ranging from 6% to 11.7%. Humicity is around 2, but is 4 - 5 where plant fragments occur (indicating that some plant matter at least, had disintegrated) or the sediment is very dark.

4.2.2.2 Peat Section

4.2.2.2.1 Sedimentary Unit 5, 249 - 11 cm, 6,500 - about 800 years BP.

The unit begins (249-244 cm) with the transition between peat and clay. This layer is a very dark clayey peat. The unit was deposited unevenly in the basin (Fig. 4.2.4).

Between 162 and 155 cm, the sediment is particularly black and has a strong smell like benzene. Between 213 and 11 cm, there are leaves, wood, roots, seeds and sheets of cells embedded in the disintegrated organic matter which decreases up the profile.

The wood and leaf remnants in the peat are not found together. Between about 190 and 176 cm pieces of wood are found. Between about 176 and 171 cm leaves and flat macro-pieces are found. These macrofossils are similar to the leaves and flower bases of the UNSW Herbarium specimen 10731 *Nothofagus moorei* leaves and flower bases. Seeds which are found above 130 cm were identified as *Eleocharis sphacelata,* cf *Scirpus* sp, *Carex fascicularis* and *Carex brownii* (K. Wilson pers. comm.), species which do not occur on the swamp today. Seeds are found in similar strata throughout the swamp (Fig. 4.2.4).

Medium quantities of microscopic charcoal particles are found in the peat. The carbon content is high, with the average in the peat of 73%, ranging from 28% in the transition zone to 94% in the peat. Humicity values are essentially 3 - 5, with values around 2 in places where plant macrofossils are in abundance, such as between 162 and 220 cm.

4.2.2.2.2 Sedimentary Unit 6, 11 - 0 cm, about 800 years BP - present

The top 11 cm of the sediment is basically a root mat, with non disintegrated organic material. The carbon content is 81% in the middle of this unit and the humicity value is a very low value of 1.

Table 4.2.2a Description of sediment from 0 – 249 cm.

Depth (cm)	Unit	Munsell colour	Description
0-10	**6**	5YR 3/2	Dark reddish brown herbaceous peat with roots.
11-25		10YR 2/1	Black peat, with the proportion of disintegrated organic matter increasing with depth.
25-59		5YR 2.5/2	Very dark reddish brown peat, roots thicker and more abundant than 11-25 cm section.
59-76		2.5YR 2.5/2	Very dusky red peat.
76-155		5YR 2.5/2	Reddish brown peat gradually becoming darker; seeds at around 130 cm.
155-162		10YR 2/1	Black peat with smell resembling benzene.
162-171		5YR 2.5/1	Dark reddish brown peat , with leaves and flower bases.
171-213		5YR 2.5/1	Dark reddish brown peat , with many fragments of wood at 176-190 cm.
213-221		2.5YR 2.5/2	Very dusky red peat.
221-225	**5**	2.5YR 3/0	Very dark grey peat.
225-227		2.5YR 4/0	Dark grey clayey peat.
227-231		2.5YR 3/0	Very dark grey peat.
231-233		2.5YR 4/0	Dark grey clayey peat.
233-236		10YR 2/1	Black peat.
236-240		10YR 3-4/2	Dark to very dark greyish brown peat.
240-243		10YR 2/1	Black peat.
243-244		10YR 3-4/2	Dark to very dark greyish brown peat.
244-246		10YR 2/2	Very dark brown clayey peat.
246-249		2.5Y 2/0	Black clayey peat.

Table 4.2.2a Description of sediment from 249 – 375 cm.

Depth (cm)	Unit	Munsell colour	Description
249-254		2.5Y 3-4/2 with 2.5Y 5/4	Non homogeneous mixture of dark to very dark greyish brown and light olive brown silt/clay.
254-270		2.5Y 4/1 alternating with 2.5Y 6/4 One band of 2.5Y 7/4	Alternating bands, of unequal sizes, of dark greyish with light olive yellow silt/clays (with a slightly yellower brown silt/clay band at 254-256), with penetrating black roots, stems and seeds to 270 cm. Variation in moisture occurs – yellower bands being drier.
270-276.5		2.5Y 4/2 alternating at about 1.5 cm intervals with 2.5Y 3/2	Alternating bands of dark greyish brown silt/clay with very dark greyish brown silt/clay. Lighter bands are crumbly.
276.5-298	**4**	grade into 2.5Y 3/0	Becoming gradually greyer and greyer reaching a homogeneous colour of very dark greyish brown/black silt/clay. Organic material present eg leaf type fragments at 290 cm.
298-300		10YR 5/2	Greyish brown silt/clay sediment has smell of soil, is drier than surrounding sediments
300-310		10YR 3/1	Very dark grey stiff silt/clay, with no traces of plant fragments; samples to 330 cm, when dry, impossible to disaggregate with reasonable force.
310-342		10YR 5/1	Silt/clay becoming gradually lighter, to grey; no traces of plant fragments.
342-350		2.5Y 4/4	Olive brown silt/clay.
350-375		10YR 5/1 grading to 10YR 5/2	Grey grading into brown grey/black silt/clay. 360-375 cm, reddish with black 'swirls of mud'.

Table 4.2.2a Description of sediment from 375 - 655 cm.

Depth (cm)	Unit	Munsell colour	Description
375-392	**3**	7.5YR 4/6 grading to 7.5YR 4/2	Brown with reddish tinge of gravels (in places) and sands; long strands of plant roots or stems vertically penetrating.
392-398		2.5Y 7/6 to 2.5Y 5/2	Faintly yellowish/grey brown silt/clay.
398-400		5B 4/1	Dark bluish grey silt/clay without plant fragments (except for a few specks of wood).
400-417		7.5YR 4/4	Brown gravelly clayey sand with reddish tinge of gravels and sands; vertically penetrating roots/stems; core darker in centre; 404-406 cm much wetter.
417-419		7.5YR 4/4	Brown fine sandy silt/clay.
419-423		7.5YR 3/4	Dark brown-black gravelly sandy clay with paler (oxidised?) outside.
423-430		7.5YR 3/4	Dark brown clayey sand.
430-450		7.5YR 3/4	Dark brown gravelly clayey sand; fragment of wood at 440 cm.
450-453		10YR 3/2	Very dark greyish brown clayey sand.
453-463		7.5YR 3/4	Dark brown gravelly clayey sand very wet sediment.
463-469		10YR 3/4-6	1 cm bands of dark sandy clay alternating with yellowish brown sandy clay.
469-474		10YR 3/6	Dark bluish grey sandy clay with oxidised outside; embedded blue clay pellets.
474-510		10YR 5/3	Brown to dark grey wet gravelly clayey sand; with small fibrous roots in places.
510-569	**2**	5YR 3/1 5YR 4/3	Very dark grey clayey sand (fine sand increasing down the profile); 524 cm clayey sand notably wet; 524-526 cm dry, crumbly; at 530 cm white mineral matter; sections reddish brown.
569-576		10YR 7/1	Dark grey clayey sand with light grey outside; blue clay pellets at 576 cm; crumbly texture.
576-600		10YR 3/4	Yellowish brown clayey sand; with occasional dark grey lines; crumbly texture.
600-655	**1**	10YR 7/1	Alternating bands of dark grey and yellowish grey clay with finer fractions increasing down the profile, the base being 100% clay; 628-631 cm reddish; 604-637 cm contains a vertical crack filled with darker sediment.

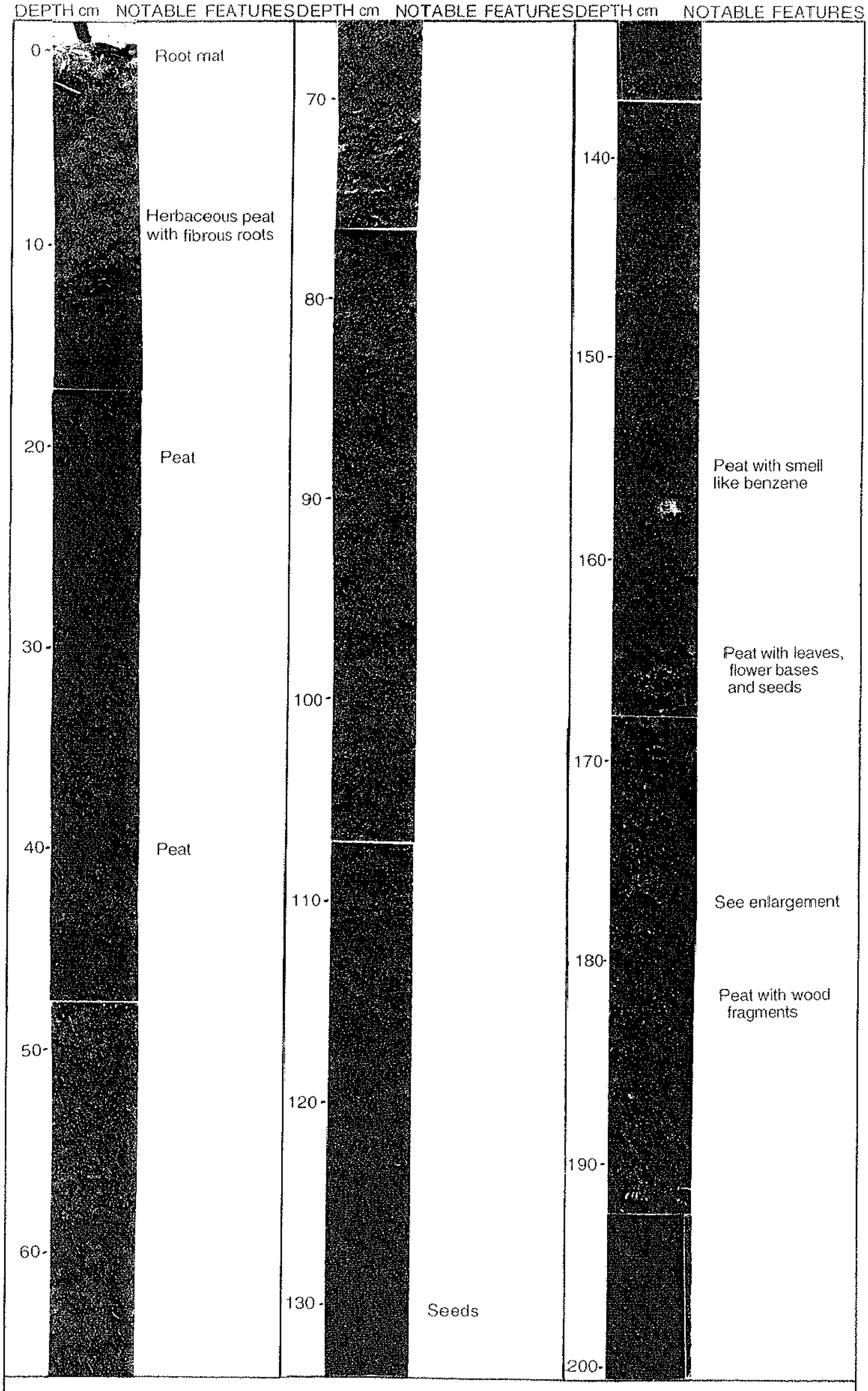


Figure 4.2.2a (i) Longitudinal sections of sediment cores: 0 - 200 cm.

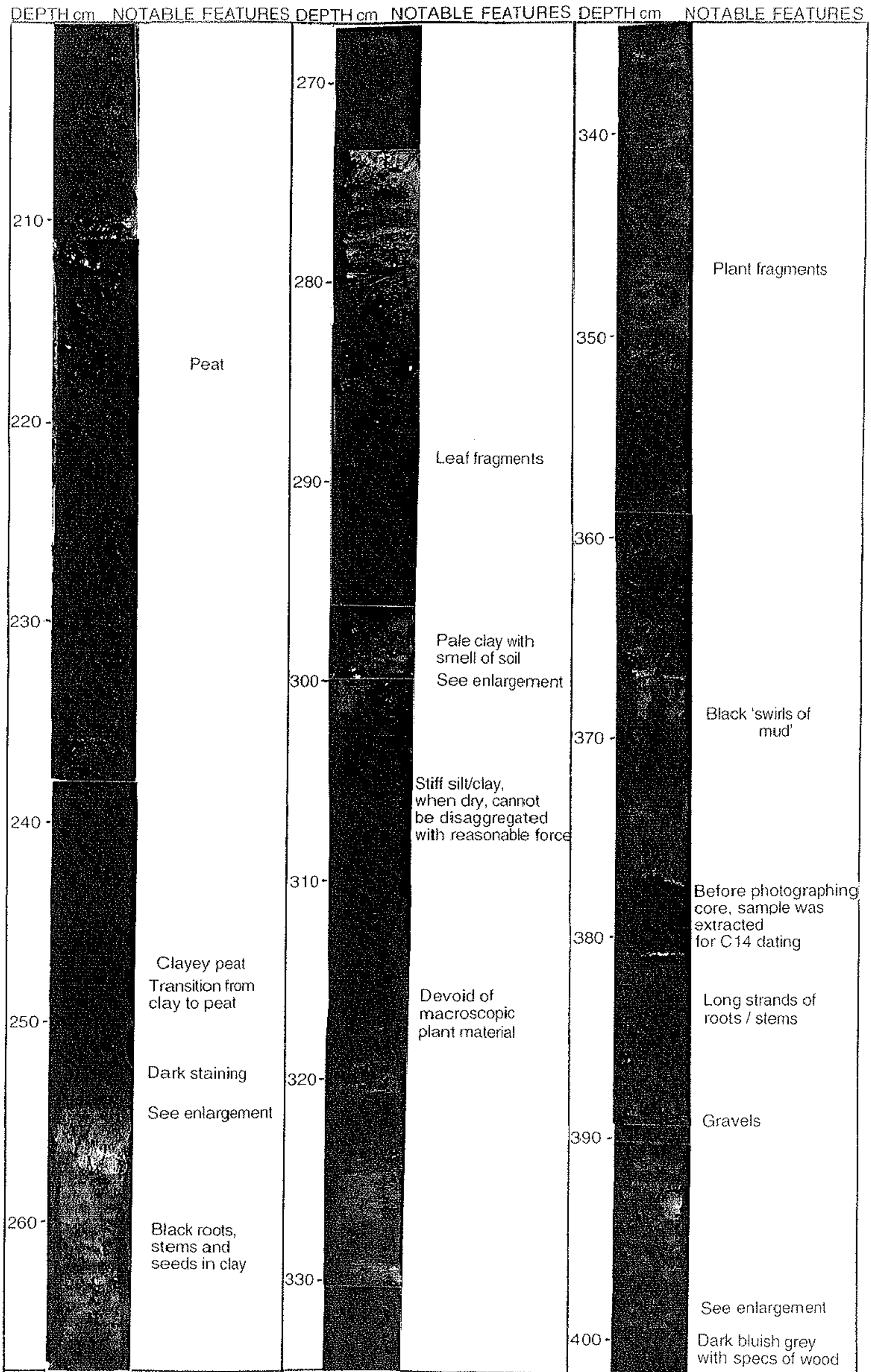


Figure 4.2.2a (i) Longitudinal sections of sediment cores: 200 - 402 cm.

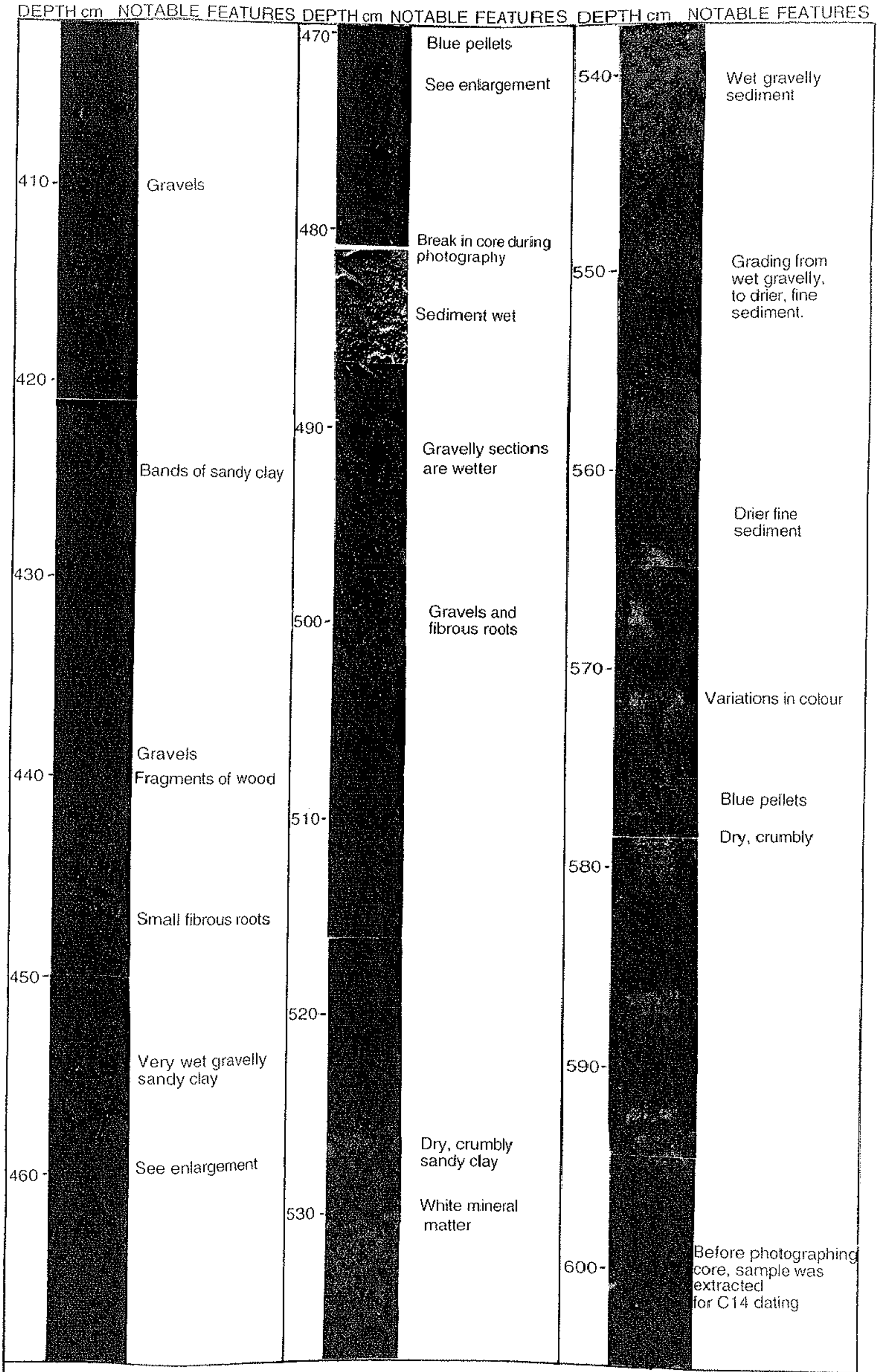


Figure 4.2.2a (i) Longitudinal sections of sediment cores: 402 - 605 cm.

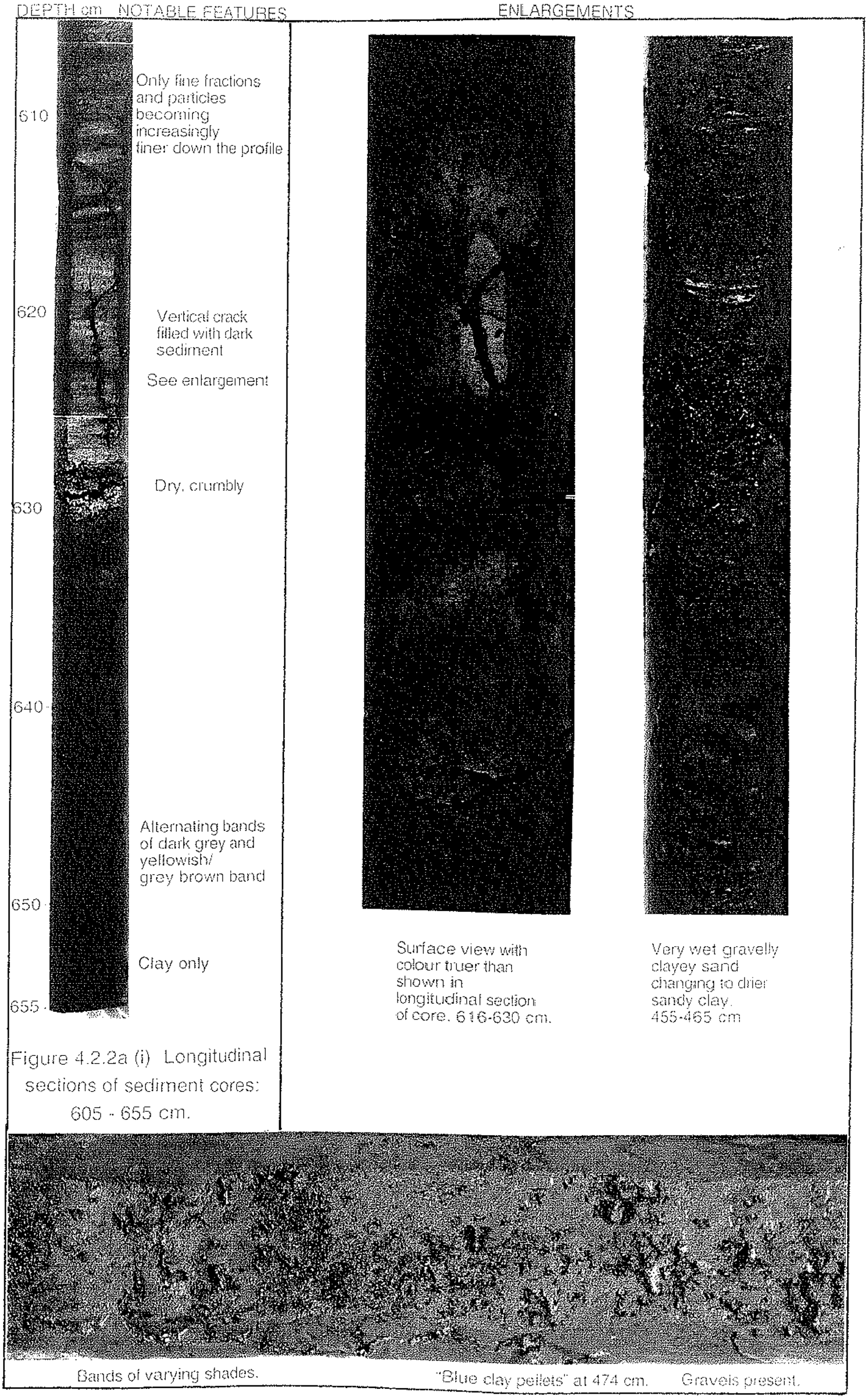
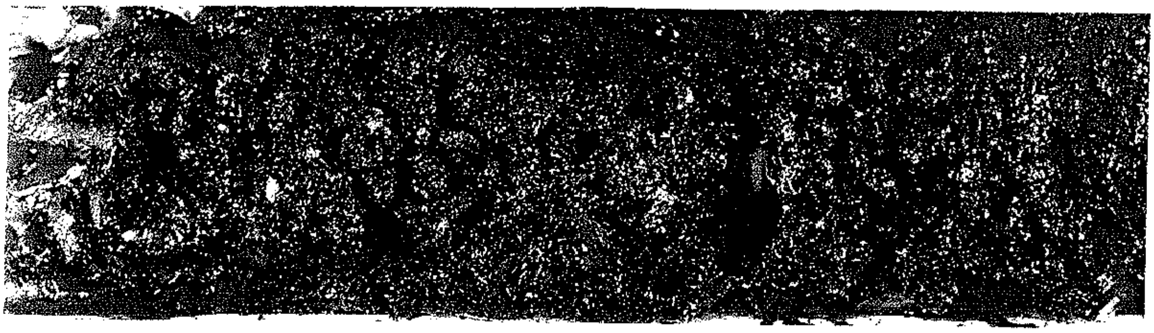


Figure 4.2.2a (i) Longitudinal sections of sediment cores: 605 - 655 cm.

Enlargements of longitudinal sections of sedimentary cores

(increasing depths from left to right)



167-180 cm peat with leaves, flower bases, seeds and wood.

Boundary between the peat and mineral sediments. Sediment becoming organic at 250/249 cm; stained below 254 cm. Below that, the colour and moisture of the silt/clay varies and contains penetrating roots/stems, seeds.

298-300 cm dry, soil smelling greyish brown silt/clay. Very stiff and very dark grey silt/clay below.

At 392 cm yellowish/grey brown silt/clay. At 400 cm dark bluish grey silt/clay. Then until 417 cm, brown/reddish brown gravelly clayey sand.

Table 4.2.2b Grain size fractions in the mineral sediments below the peat.

Depth cm	gravel %	coarse sand %	fine sand %	silt/clay %
260	0	0	traces	100
290	0	0	0	100
300	0	0	0	100
305	0	0	traces	100
320	0	0	traces	100
330	0	0	traces	100
350	0	0	traces	100
360	0	0	traces	100
370	0	0	traces	100
380	10	45	34	11
394	0	0	traces	100
400	0	0	traces	100
410	9	43	36	12
418	0.2	5	37	57.8
440	9	38	42	11
470	0	1	6	93
500	15	35	36	14
530	0	14	52	35
600	0	2	65	34
635	0	0	traces	100
650	0	0	0	100

Table 4.2.2c Humicity of sediments analysed for pollen.

Depth (cm)	Humicity	Depth (cm)	Humicity	Depth (cm)	Humicity
0	1				
10	1	274	2	470	0
20	2	280	2	480	1
40	4	290	4 – 5	490	4
50	4	300	1	500	0
60	3	310	4	510	1
70	2	320	2	520	2
100	3	330	2	530	3
110	2	340	2	540	1
120	4	350	2 – 3	550	2
140	2	360	5	560	2
160	4	370	2	570	0
180	2	378	0	580	4
200	1	380	0	590	3
220	2	390	3	598	1
230	3	400	3	600	2
245	5	410	1	610	1
250	3	420	1	620	0
255	1	430	2 – 3	630	0
260	2	440	0	640	3
270	2	450	0	650	3
272	2	460	0	652	3

4.2.3 DISCUSSION OF SEDIMENTARY HISTORY

From 40,000 years BP, a lake in an enclosed basin, accumulated clays washed in from the surrounding slopes (X-ray diffraction of sediments indicate that the sediments are of basalt origin and not wind blown from inland Australia [Nanson, pers.comm.]). The homogeneous nature of the fine grained sediments and the slow rate of sediment accumulation, 0.06 mm per year (Fig. 4.2.3), indicate a constant sedimentation in permanent open water conditions under relatively stable conditions (Edney et al, 1990; Lloyd and Kershaw, 1997; Nanson, pers. comm.). The lake may have been upto 3 m deep (as indicated by the large quantity of *Myriophyllum* pollen occasionally occurring in masses). Since the organic carbon content is quite low and humicity medium, it is likely that not many plants grew directly on the core site which may have been too deep for rooted vegetation.

About 33,000 years BP, the change to coarser grained sediments indicates a drop in water depth. The increase in sand was gradual and by 30,000 years BP, the water depth could have been quite low. The lake may have dried out periodically since the sediment at 600 - 605 cm has the appearance of being oxidised. Here, shrinkage may have caused the crack from 605 cm down to 630 cm which was later infilled with a fine black more organic sediment.

The rate of sedimentation remained constant at 0.06 mm per year until 21,350 years BP when it increased to about 0.15 mm per year, indicating some degree of slope instability. At 18,000 years BP the rate increased markedly to about 1.54 mm per year (Fig. 4.2.3). The gravelly sandy sediments probably accumulated as a result of slope instability caused by periglacial activity. Some sections of the gravelly layer had trapped and retained water around the gravels. The thin silt/clay layers contained in this unit suggest short periods of deeper water and more stable slopes. The whole of this unit was deposited in a relatively short time of about 1,000 years. The coarse sediments indicate shallow to no water in the basin (Nanson, pers. comm.). Pollen was not recovered from this unit, except for one thin clay band.

About 17,000 years ago, the rate slowed to 0.23 mm per year and the fine grained sediments suggest the slopes had stabilized and deeper water was filling the lake. From 15,000 years ago, some leaf fragments, fluctuating carbon, humic and mineral content suggest fluctuating conditions of deposition which slowed further to 0.06 mm per year until the peat began to form at 6,520 years ago. The sediments between 280 and 249 cm which showed frequent colour changes with some of the layers having been somewhat oxidised, suggest that conditions fluctuated. There may have been either period(s) of non-deposition (G. Hope, pers. comm.) or simply hydrologic and biological changes in the lake. The stratification may have been caused by thermal variation resulting from significant changes in temperature between seasons or be due to changes in the lake status and trophic levels, which in turn may indicate changes in effective precipitation (Williams et al., 1998). However, it is possible that the paler clays are a result of inorganic minerals precipitated from the surface waters in which the chemical composition was changed due to an algal bloom (Williams et al., 1998).

The transition from clay to peat occurred between about 6,700 and 6,500 years BP (249 to 244 cm). Leaching of the organic chemicals from this zone was possibly responsible for the vertical dark staining of the clays (Nanson, per. comm.). From about 6,500 years BP, the water level would have remained low enough for swamp vegetation to colonize the whole of the surface and produce the peat up to the present day. Once the peat began to form, the rate of sedimentation increased considerably. The substantial amount of wood pieces in the sediments around 6,000 years ago, suggests that trees, or at least woody shrubs grew on the swamp surface, or at the edge. The rate of peat accumulation was a rapid 1.41 mm per year until 5,490 years ago, when it slowed to 0.19 mm per year (Fig. 4.2.3), assuming that deposition has been continuous to the present and the surface has not been eroded.

Results of diatom analyses concurred with the water level changes described above (Tibby, pers. comm.).

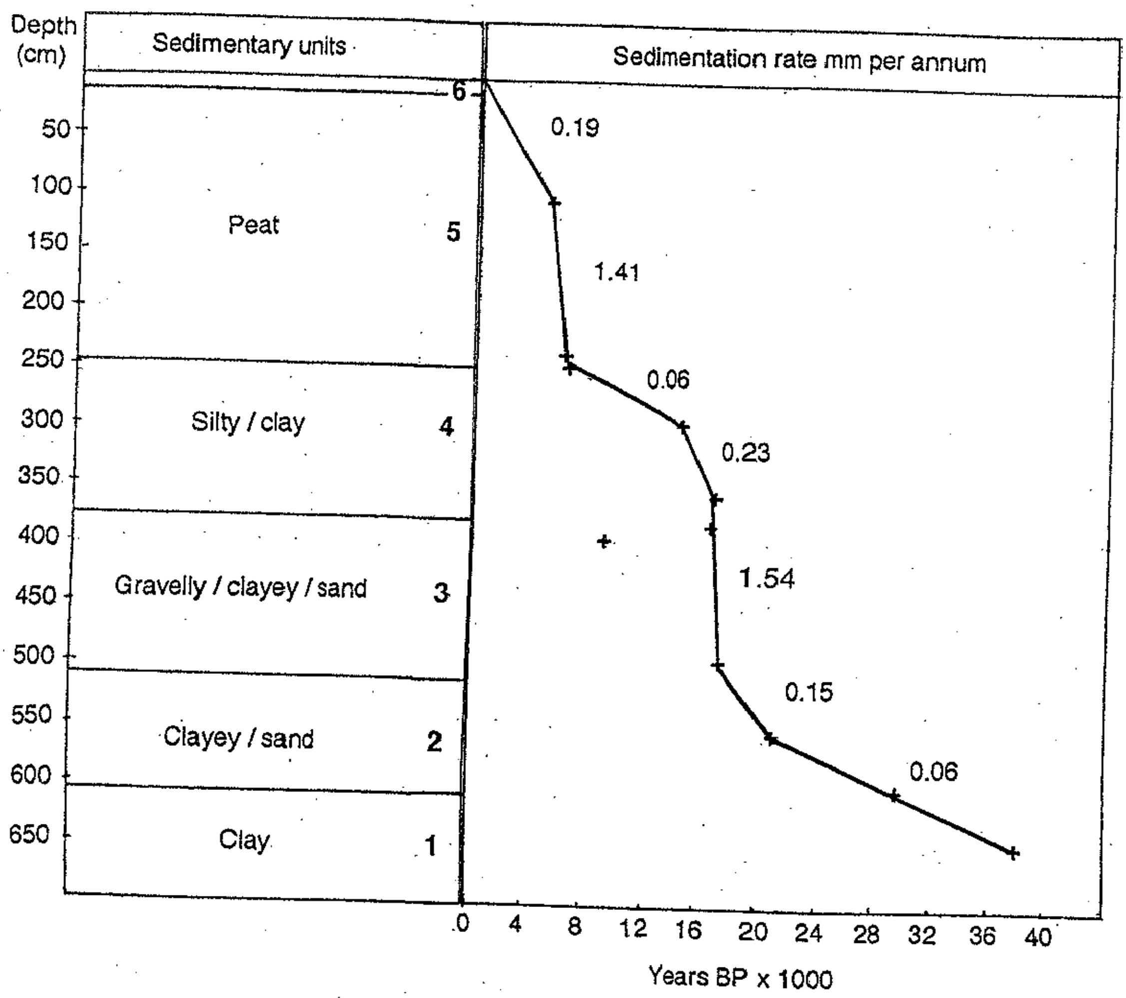


Figure 4.2.3 Sedimentary Units and Rates of Sedimentation

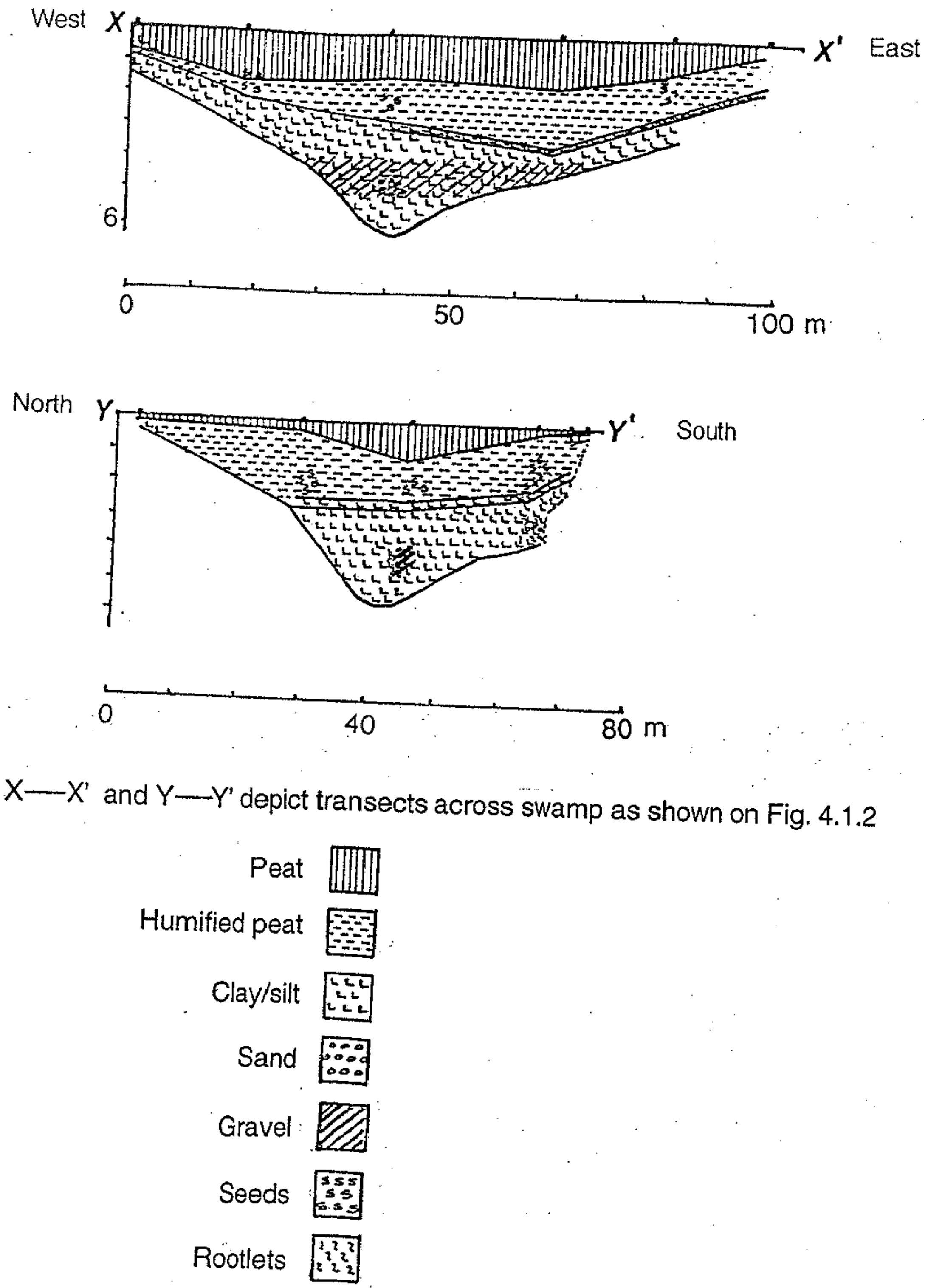


Figure 4.2.4 Stratigraphic profiles of Burraga Swamp

4.3 DESCRIPTION OF POLLEN AND ALGAL SPECTRA

Definitions of the major pollen and algal groups on the pollen diagram are outlined in Tables 4.3a and 4.3b. The pollen spectra of the major pollen, spore and algal groups and their zonation are shown on Fig. 4.3a and 4.3b. Surface sample spectra are provided in Fig. 4.3a and included are surface sample pollen and spore spectra for Polblue Swamp, Barrington Tops Plateau. Rare and low pollen frequency taxa (1% or less) are recorded in Table 4.3c.

4.3.1 TOTAL POLLEN AND ALGAL CONCENTRATION

Total pollen concentration is relatively high at the base, increasing to exceptionally high concentrations between 640 and 620 cm. Then values gradually decrease to low, at 560 cm. Total algal concentrations roughly parallel the total pollen concentration trends. The overlying sections 550 to 410 cm and 390 to 360 cm have too few grains to provide reliable interpretation. Between these poor polleniferous zones, at 400 cm, the total pollen concentration is moderate and similar to those at 580 and 570 cm. There is a comparable moderate magnitude of the pollen content between 360 and 245 cm, except at 272 cm where a high concentration occurs. Then moderate concentrations occur to the top, except for a very high concetration at 50 cm. Algal concentrations are very low at 400 cm, between 350 and 330 cm and at 280 and 180 cm. At 300 cm there is a relatively very high algal concentration and moderately high at 274 cm. Moderate values occur until 70 cm, and then algae are absent above this level.

4.3.2 POLLEN SPECTRA

Nothofagus moorei pollen occur in low percentages at 400 cm (the oldest record) and at 300 cm. Then from 274 cm it is consistently present in low numbers until the base of the peat at 245 cm above which its presence is 10% and over. Values comparable with those of the surface samples are reached at about 200 cm.

The Myrtaceae pollen type was divided into three types: *Eucalyptus*, *Leptospermum* and Other Myrtaceae. A large clump of indistinguishable Myrtaceae was observed at 272 cm.

Between the base and 550 cm, *Eucalyptus* pollen occurs in low percentages and reasonably high concentrations. Then in the poor polleniferous levels upto 360 cm, *Eucalyptus* pollen were occasionally sighted. Then very low concentrations occur between 350 and 310 cm, and percentages are similar to the lowest section. There are fluctuating percentages and concentrations between 300 cm and the top with some high values particularly in the top section of the mineral sediments and at 70 cm in the peat. *Leptospermum* is first found at 260 cm near the top of the mineral sediment. At 220 and 200 cm the percentage has increased. An increase in concentration occurs at 70 cm with a further very large increase at 50 cm, both commensurate with an increase in the total concentrations. At the 50 and 40 cm levels, spikes in *Leptospermum* percentages occur. Above 40 cm, *Leptospermum* disappears. The Other Myrtaceae type is low until 270 cm after which percentages and concentrations are higher all the way to the top. The percentage at 400 cm is similar to those above 270 cm. The maximum percentage is attained at the top.

Casuarinaceae pollen occur in small percentages and concentrations throughout most of the profile. Since the Casuarinaceae are wind pollinated heavy pollen producers, small amounts of a pollen in the profile indicate long distance transport.

Values of Poaceae are low at the base and increase dramatically at 600 cm. This level has a very high concentration and percentage, reflecting the high total pollen concentration. Poaceae concentration then decreases markedly until 560 cm, reflecting a conspicuous decrease in total pollen concentration. Percentages also decline, but the decrease is less than the decrease in total concentration. Poaceae pollen is present in many of the low polleniferous samples. At 400 cm and between 350 and 310 cm, concentrations are relatively low, reflecting total concentrations, but percentages are some of the highest for the profile. These high percentages mean that Poaceae is the most important pollen group at these levels. From 300 to 270 cm, Poaceae declines noticeably and is a very minor component of the peat section above 245 cm. An exception is the 20 cm level, which is similar to the 300 to 270 cm zone. At 600 cm, 590 cm, 320 cm and 272 cm, many of the Poaceae grains are found in clumps. A size analysis (Fig. 4.3c) of the Poaceae pollen shows that at 600 cm, the majority of grains have a diameter of 40 µm and some have 30 µm diameter. Most of the 20 µm diameter grains are in clumps. At 320 cm the main grain type is 30 µm diameter, many in bunches and there is a small peak of grain sizes of 40 µm. At 272 cm, the main grain size is 30 µm diameter with another peak of grain sizes of

50 µm. The clumps are of 30 µm and 20 µm diameter. This size analysis indicates that possibly different species were involved.

From the base to 620 cm, Cyperaceae pollen values increase to some of the highest in the profile. Then quantities drop and remain relatively low throughout the inorganic sediments. Cyperaceae pollen are present in the low polleniferous sediments of 540 to 410 cm levels. There is an increase above 245 cm and values remain moderately high throughout the rest of the peat. In the peat, concentrations are generally low and percentages are higher where total concentrations are low. Clumps of the grains occur in each sample from 640 to 610 cm, in 590 and 272 cm.

Very high percentages of *Myriophyllum* pollen, of more than one type, occur at the base. A gradual decrease to very low percentage at 600 cm is followed by a gradual increase to a moderate level at 570 and 560 cm. Then, no *Myriophyllum* pollen is encountered until a very low amount at 350 and 330 cm. *Myriophyllum* reappears at 270 cm, after which quantities oscillate until 70 cm when *Myriophyllum* pollen virtually disappear from the profile.

Dicksonia antarctica spores first appear at 400 cm and then at 310 and 300 cm. Large percentages and relatively large concentrations are encountered at 290 and 280 cm, towards the top of the mineral section. There is a drop to a very low value at 274 cm, with an increase to relatively high concentrations and moderate percentages at 272 and 270 cm, disappearing until 250 cm. Very low values (with occasional absences) are maintained from then on to the top.

Asteraceae is almost entirely Tubuliflorae, with small amounts of Liguliflorae found sporadically below 310 cm (Table 4.3b). Between 650 and 560 cm there are fluctuating low percentages of Asteraceae. Then relatively moderate percentages occur at 400 and 350 to 290 cm, these being the highest values for the profile. Then, percentages and concentrations are low. Relatively little is found above 160 cm and then Asteraceae presence is low and sporadic in the peat.

Percentages and concentrations of *Ranunculus* are very low from 650 to 220 cm, after which the pollen disappear. At 280 cm, the concentration and the percentage spike, but the total pollen concentration does not.

The first appearance of *Hydrocotyle* pollen type is at 560 cm and it is present sporadically to the top. *Hydrocotyle* is best represented at 300 and 274 cm. A large clump of grains was observed at 272 cm.

Low quantities of Chenopod type pollen are found in the inorganic sediments and sporadically in the peat. Slightly higher percentages are found at 350 and 340 cm.

Low values of monolete and trilete fern spores (other than *Dicksonia*) are found at 400 cm and consistantly from 300 cm upwards. Maximum values of about 25% of the total pollen count are found between 270 and 255 cm. Lower levels are then maintained to the top.

Indeterminable grains are found in greater proportions in the mineral sediments than in the peat, probably because in the former, grains were transported to the site of deposition whereas in peat, deposition was on site. Grains were crumpled or corroded or broken or partially concealed. Such concealment occurred more in some samples than in others: 580 cm, 320 cm, 310 cm, 300 cm, 290 cm, 274 cm, 250 cm, 245 cm. Indeterminable grains owing to their twisted / crumpled nature are more predominant in some samples: 620 cm, 610 cm, 590 cm, 580 cm, 560 cm, 400 cm, 380 cm, 310 cm, 300 cm, 280 cm, 274 cm, 250 cm. At 580 and 600 cm many of the twisted indeterminable grains are either Poaceae or Cyperaceae, but since they could not be distinguished from each other, they could not be included in either category. Although corroded grains can often be identified, some samples contain a high proportion of unrecognisable corroded pollen, for example, 400 cm, 280 cm, 270 cm. The proportion of badly preserved grains in a sample is a useful indication of the reliability of an analysis (Cushing and Wright, 1967). Grains change from well preserved to indeterminable or they disappear all together. These alterations are cumulative and continuous or occur in discrete steps. Therefore, since the change from good preservation to complete destruction involves more than one step, data on the degree of grain preservation in a sample can be useful (Cushing and Wright, 1967).

4.3.3 ALGAL SPECTRA

The algal types were grouped into *Pediastrum, Spirogyra, Zygnema, Mougetia* type, *Debarya* and unknowns. On the whole, the paler clays contained more algae than the darker strata.

Pediastrum was only found in the peat and formed the total algal content in the peat between 70 and 240 cm.

Both reticulate and smooth forms of *Spirogyra* are included in the total. *Spirogyra* occurs in all the mineral sediments which contained algae. It was 100% of the total algae at 280 cm where the total algal concentration was very low. Occasional relatively high percentages are seen.

Zygnema occurs throughout much of the mineral profile. The highest percentages occur at 300 and 274 cm, both samples which contain relatively high total algal concentrations and at 250 cm.

Mougetia type is represented sporadically, with highest percentages at 330 and 290 cm.

Debarya is present in only a few samples and mainly below 560 cm. The highest representation is at 650 cm.

A number of unidentified algal types occur in many samples and is highest at 630, 400 and 270 cm. High values also occur at 620 and 240 cm.

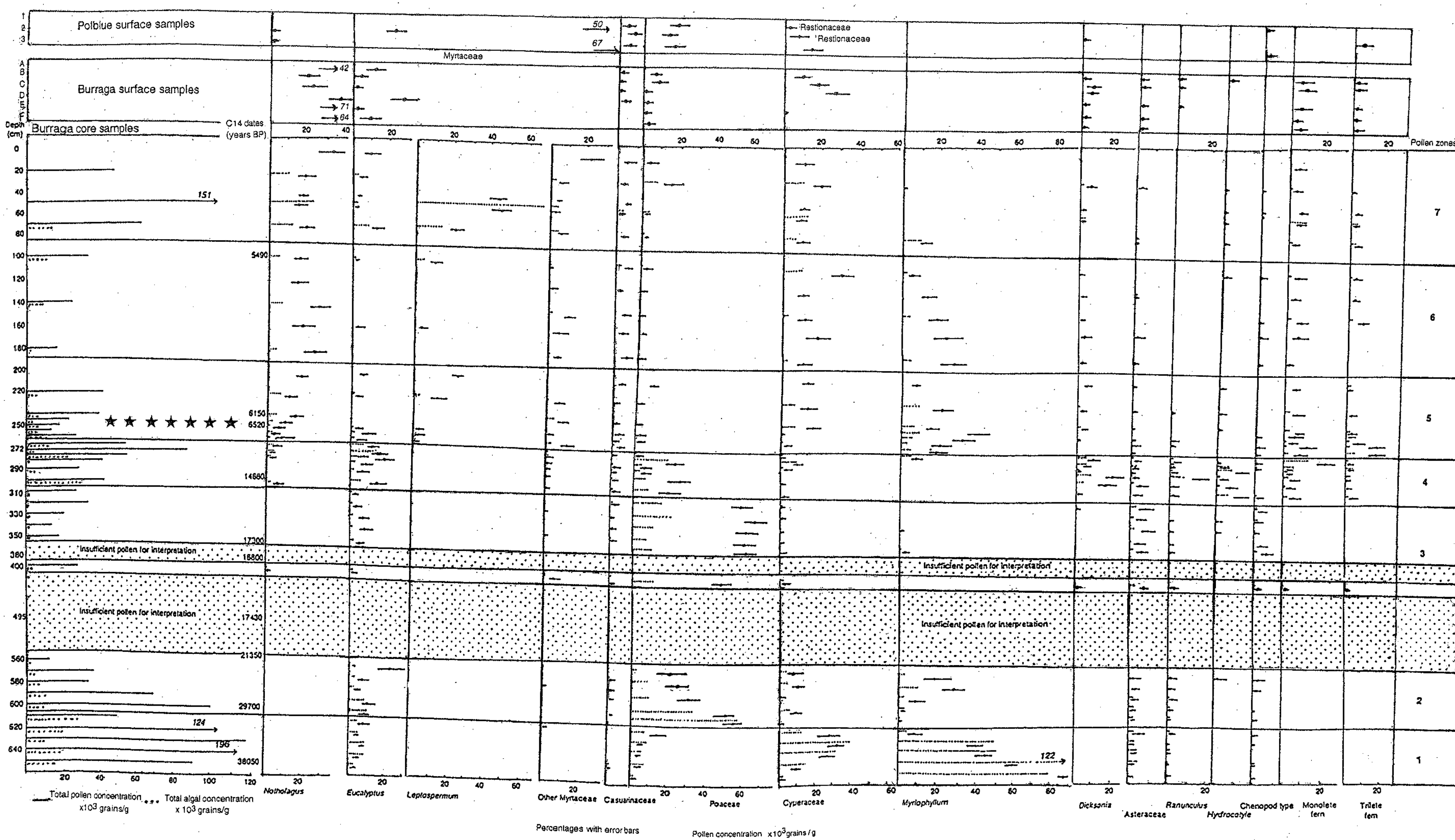


Figure 4.3a Pollen diagram for Burraga Swamp: Total pollen and algal concentrations, pollen/ spore concentrations and pollen/spore percentages which were based on total pollen/ spore counts. Scales for pollen concentrations and percentages, are shown at the top and bottom of the diagram. The percentages are shown with confidence limits. Where pollen concentrations and percentages exceed the scale, the values are shown in italics. Data for the peat section was extracted from Core 1 (Sweller and Martin, 1997) and for the mineral section, from Core 2 (Sweller and Martin, in press). For definition of the pollen groups, see Table 4.3a.

★ marks the boundary between the peat and mineral sediments.

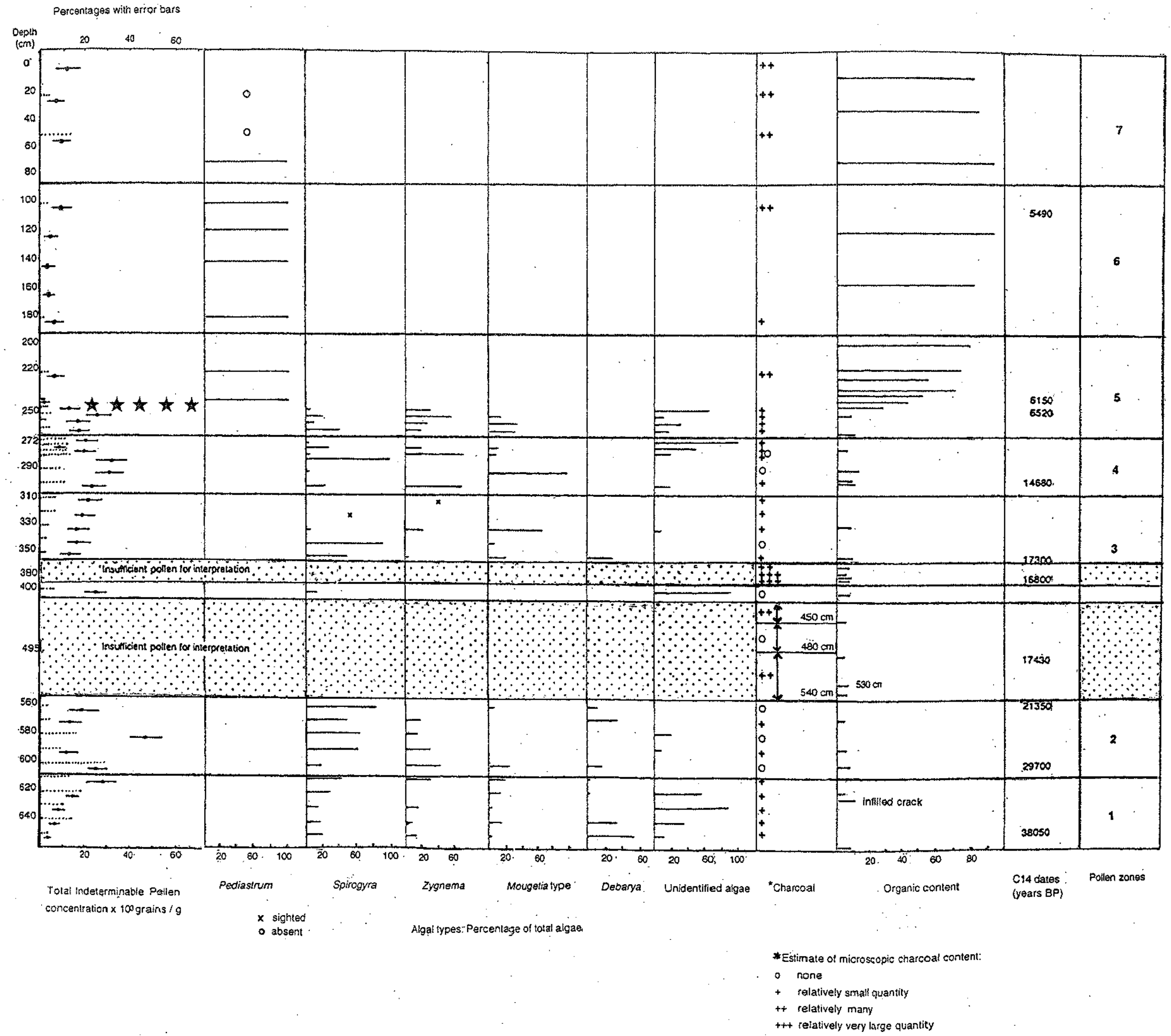


Figure 4.3b Concentrations and percentages of indeterminable grains; algal types expressed as percentages of total algae; charcoal estimates and organic carbon percentages. For ecology of the algal groups, see Table 4.3b.

★ marks the boundary between the peat and mineral sediments.

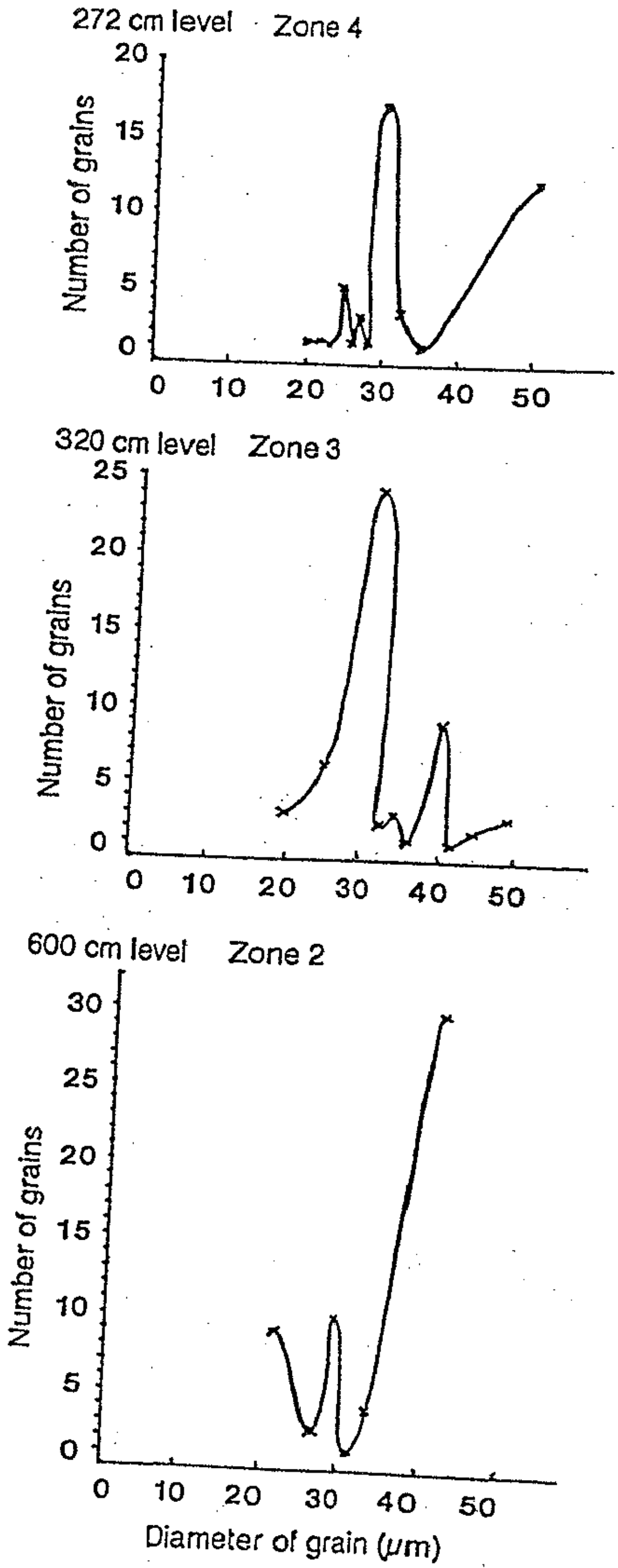


Figure 4.3c Size analysis of Poaceae grains for selected levels in the profile. Relevant pollen zones are also indicated.

4.3.4 POLLEN ZONES

Zone 1, 650-610 cm, 40,000-30,000 years BP. Exceptionally high concentrations of Cyperaceae and *Myriophyllum* distinguish this zone.

At the base of the core, there is a *Myriophyllum* spike. Then *Myriophyllum* and Cyperaceae are both high until near the top of the zone. Between 640 and 610 cm there are many bunches of Cyperaceae grains, indicating that possibly mature or immature flowers were washed into the sediment (Faegri and van der Pijl, 1979). At 610 cm the percentage of Cyperaceae remains very high while the concentration has dropped (as has the total concentration), indicating that the perceived Cyperaceae increase is due to the decrease of another grain (*Myriophyllum*) rather than a real increase in Cyperaceae. The percentages of Poaceae are low and their concentrations are relatively moderate.

There is a diversity of herbaceous low pollen frequency taxa and the shrubs *Lomatia*, *Podocarpus* and *Tasmannia* are present. *Eucalyptus* pollen, although occurring in low percentages, are present in relatively high concentrations, thus signifying that they are the main tree/shrub in this zone. Asteraceae (including Liguliflorae), *Ranunculus* and the Chenopod type occur in low percentages and concentrations.

Concentrations of indeterminable grains (which are mainly crumpled), fluctuate and their percentages increase up the profile, suggesting that conditions for pollen preservation were deteriorating over the 10,000 years.

The algal concentrations are moderate to high, with many types represented. The highest concentration of *Debarya* in the profile is at the base.

Zone 2, 600-560 cm, 30,000-21,000 years BP. The zone is distinguished by a much reduced *Myriophyllum* and Cyperaceae and an increased Poaceae.

The zone begins with a very high Poaceae content. A size analysis of the Poaceae grains (Fig. 4.3c) shows the majority of the grains are about 43 µm diameter. At the beginning of the zone many grains occur in clumps of thicker walled grains, sized about 20-25 µm, indicating that possibly immature anthers were preserved. Cyperaceae grains also occur in clumps, suggestive of the deposition of flower heads (Faegri and van der Pijl, 1979).

The *Eucalyptus* content is similar to Zone 1, except for the top of the zone where the percentage is higher but its concentration is low, suggesting that the vegetation was an open *Eucalyptus* community. Asteraceae, *Ranunculus* and the Chenopod type are similar to Zone1 and *Hydrocotyle* is present at the top of the zone. There are fewer and only herbaceous, low pollen frequency taxa.

600 cm level contains the highest concentration and 580 cm the highest percentage of indeterminabe grains, mostly crumpled, in the whole profile. A main contributor to the indeterminable group is Poaceae/Cyperaceae. At 590 cm Poaceae pollen occur in clumps and thus are distinguishable.

The algal population, which decreases up the zone, principally consists of *Spirogyra*. Water was possibly less available for algal growth.

550-410 cm, 21,000-about 17,000 years BP.

The total pollen concentrations are very low, too low for reliable interpretation, algae are absent, but plant macrofossils and microscopic charcoal particles are preserved. Conditions during this period were seemingly not conducive to pollen preservation.

Poaceae pollen is present in most of the clay samples but not in the gravels. Cyperaceae is less well represented. Other groups represented by a few grains, sporadically, are *Eucalyptus,* Casuarinaceae, Asteraceae (including Liguliflorae) and Chenopod type, *Podocarpus*, Brassicaceae, Asclepiadaceae and *Persicaria.*

The sand and gravel sediments, which appear to have been deposited very rapidly, did not allow pollen to be concentrated in them.

Zone 3, 400-310 cm, about 17,000-15,000 years BP. High percentages of Poaceae and very low Cyperaceae with only sporadic occurrence of *Myriophyllum* characterise this zone.

Size analysis of Poaceae grains at 320 cm (Fig. 4.3c) show mainly 30 µm grains, hence the common species here are likely to be different from the larger grained species in Zone 2. Many of the common sized grains occur in clumps.

A thin clay band at 400 cm, contains traces of the mesic taxa *Nothofagus moorei, Dicksonia antarctica* and monolete and trilete ferns. Present are Poaceae, *Eucalyptus,* the Other Myrtaceae, Asteraceae (including Liguliflorae), *Ranunculus,* Chenopod type and a diverse group of low pollen frequency taxa including *Tasmannia.* There is a relatively high percentage of indeterminable, mainly crumpled, grains. The percentage of Poaceae is similar to that at the base of Zone 2, but the concentration is similar to the much lower quantity in the middle of Zone 2 and higher in Zone 3, but the percentage at the 400 cm level is just significantly less than the percentages higher on the zone. The lower percentage is due to the higher proportion of indeterminable grains. There is a small concentration of algae, largely of an unknown type.

Between 390 and 360 cm, plant roots, sheets of cells and the largest quantity of charcoal in the profile occur but there is insufficient pollen for interpretation. Only a few grains of Poaceae, Cyperaceae, *Eucalyptus*, Casuarinaceae, Asteraceae, Chenopod type, *Podocarpus*, Brassicaceae, *Epilobium* and *Typha* are seen. Algae are almost absent.

In the upper part of the zone, between 350 and 310 cm, the percentages of *Eucalyptus* are similar to those in Zones 1 and 2 (below 20%), but concentrations are lower. Asteraceae (above 6%) and the Chenopod type (in the main Caryophyllaceae), are higher than in the zones below. Between 350 and 310 cm there are high levels of Poaceae, with very low Cyperaceae and only sporadic occurrence of *Myriophyllum*. The Other Myrtaceae and *Hydrocotyle* are sporadically represented with a consistent low presence of Ranunculaceae. Low pollen frequency taxa e.g.*Tasmannia, Typha, Epilobium* are represented. The concentrations and percentages of indeterminable grains, increase up the profile. Between 340 and 310 cm, there are no plant fragments. The content of algae is very low with only a bare representation at 320 and 310 cm.

Zone 4, 300-270 cm, 15,000-10,000 years BP. A peak for *Dicksonia, Hydrocotyle, Ranunculus* and at 274 cm Scrophulariaceae type, a consistent presence of other fern spores and a little *Nothofagus,* distinguish this zone.

Eucalyptus, overall, is slightly higher than in the rest of the profile and the total Myrtaceae concentration spikes at the dark 272 cm layer. The Other Myrtaceae grains are consistently present, in very low quantities. *Dicksonia* spikes in the middle of the zone (in sediments containing leaf fragments), just before the beginning of a consistent appearance of *Nothofagus.* Ferns other than *Dicksonia* are consistently present with a Monolete spore spike at the top of the zone.

Ranunculus and *Hydrocotyle* reach peaks here. There is a moderate representation of low pollen frequency taxa, of which *Tasmannia* and Scrophulariaceae are the most common. Poaceae is moderate, with a spike at 272 cm, where a size analysis of the grains (Fig. 4.3c) show mainly 30 µm grains, as in the lower part of Zone 3, but there is a secondary peak at 50 µm. Large clumps of 20 µm grains occur and some of the 30 µm size. Cyperaceae values are low, with increased presence at 272 cm level.

Myriophyllum reappears only at the top of this pollen zone. Simultaneously with the return of *Myriophyllum,* is the marked decrease in the concentration and percentage of Asteraceae, *Ranunculus*, *Hydrocotyle* and Chenopod type.

The concentrations of indeterminable grains are consistently moderate and the percentages fluctuate. At 272 cm the concentration is similar to that of the other levels, but the percentage is significantly lower, since the total grain concentration is much higher than of other levels. 274 and 270 cm have low percentages, similar to the mineral sediments of Zone 5. Overall, there is no one type of indeterminable grain.

The concentrations and types of algae vary between levels in this pollen zone. At 300 and 274 cm the concentrations are relatively high, consisting largely of *Zygnema* type. The small number of algae at 290 cm consist largely of the *Mougetia* type. At 280 cm there are only very few algae, all *Spirogyra*. The low concentration of algae at 272 and 270 cm are mainly unidentifiable. The water regime during this zone was variable.

Zone 5, 260-190 cm, 9,000-6,000 years BP. Deposition of peat begins during this zone. Characteristics of this zone are the consistency of and increases in *Nothofagus*; appearance of *Leptospermum*; concentrations and percentages of *Eucalyptus* are lower and that of the Other Myrtaceae higher; decreases of *Dicksonia* and herbs such as *Ranunculus* which then disappears permanently from the profile.

At the top of the zone the value of *Nothofagus* is comparable with surface samples taken from the swamp. Poaceae is low and Cyperaceae and *Myriophyllum* are moderate, with some higher values for the latter. The monolete and trilete fern spores reach some of their highest values at the base of the zone. There is a moderate representation of low pollen frequency taxa, with e.g. *Cardamine* in the mineral sediments only and *Typha* almost throughout.

There are few indeterminable grains in the peat sediments.

Algae occur in moderate quantities. Between 260 and 245 cm they are mainly unidentified but 250 cm contains largely *Zygnema*. In the peat, only *Pediastrum* is present.

Zone 6, 180-90 cm, 6,000-4,500 years BP. This zone is defined by consistently high *Nothofagus*; sporadic presence of *Eucalyptus*, *Leptospermum* and Asteraceae.

Poaceae is very low and Cyperaceae and *Myriophyllum* are moderate in this zone. At 100 cm there is a percentage peak for Cyperaceae, with the value equivalent to the high values in Zone 1 but with a lower concentration, paralleling the lower total concentration. *Dicksonia* is low, other ferns fluctuate. The Other Myrtaceae is consistently present. There is a diversity of low pollen frequency taxa with *Orites* and Urticaceae the most common. Most of the values for the pollen groups are within the variation found amongst the surface samples from the swamp.

There are low concentrations and percentages of indeterminable grains.

The algal concentration is very low at the base of the zone and increases to medium. *Pediastrum* is the only algal type present.

Zone 7, 80-0 cm, 4,500 years BP to present. This zone is characterised by high to very high total pollen concentrations; some very high values for *Leptospermum* and the disappearance of *Myriophyllum*.

A high concentration of *Nothofagus* occurs at 50 cm and the percentage is not depressed significantly by an exceptionally high quantity of *Leptospermum*. Above here, *Leptospermum* is absent. High values of *Nothofagus* and Other Myrtaceae occur at the top of this zone. *Eucalyptus* occurs in low quantities except at 70 cm and the top of the zone, where they reach the values in Zone 4. Above 70 cm *Myriophyllum* is almost unrepresented. Other features are much the same as the zone below it, but the low pollen frequency taxa are particularly well represented with Apiaceae, Cunoniaceae, *Orites*, Papilionaceae and Scrophulariaceae the most common. There is a slight increase in Poaceae near the top.

There are low concentrations and percentages of indeterminable grains.

The moderate concentration of algae at 70 cm consists only of *Pediastrum*. No algae is found in samples above 70 cm.

Table 4.3a Definition of the pollen groups on the pollen diagram (Fig. 4.3a) and their distribution in the present vegetation

Pollen type on pollen diagram	Plant species represented by pollen type	Current distribution in the vegetation	
		Around the swamp	Regional vegetation
Nothofagus	*N. moorei*	Restricted to temperate rainforest	Restricted to temperate rainforest
Eucalyptus	*Eucalyptus* spp	*Eucalyptus* forests	Wet and dry eucalypt formations
Leptospermum	*Leptospermum* spp	Not present	Eucalypt forests, fringing thickets to wetlands
Other Myrtaceae	All other species in the family	*Tristaniopsis* in mixed rainforest *Acmena* in *Nothofagus* forest *Backhousia* in riverine forest	Subtropical rainforests, rainforest margins, cool temperate rainforests, wet and dry eucalypt forests
Casuarinaceae	*Casuarina / Allocasuarina* species	Not present	At least 11 km distant from swamp, in eucalypt formations, rainforest margins.
Poaceae	All species of the family	Swamp surface	Wet and dry eucalypt formations, plateau grasslands, sub-alpine forests, grasslands and swamps.

Table 4.3a Definition of the pollen groups on the pollen diagram (Fig. 4.3a) and their distribution in the present vegetation

Pollen type on pollen diagram	Plant species represented by pollen type	Current distribution in the vegetation	
		Around the swamp	Regional vegetation
Cyperaceae	All species of the family	Swamp surface and in light breaks in *Nothofagus* forest	Wetland and dryland formations, rainforest margins, sub-alpine forests, grassland and swamps.
Myriophyllum	Probably *M. pedunculatum*, *M. propinquum*, *M. verrucosum*	Not present.	*M. pedunculatum*: in mud. *M. propinquum*: fresh water up to 1 m deep, with floating stems in deeper water; damp land surrounding swamps and lakes. *M. verrucosum*: fresh or brackish water of few cm to 4 m; persists and flowers in dampland. Sainty and Jacobs, 1981).
Dicksonia	*Dicksonia antarctica*	Rainforest and wet eucalypt forest	Rainforest and wet eucalypt forests, cool temperate rainforest on plateau.
Asteraceae	All species of family	Swamp surface	Eucalypt formations, grasslands, swamps, forests of upper spurs and plateau.

Table 4.3a Definition of the pollen groups on the pollen diagram (Fig. 4.3a) and their distribution in the present vegetation

Pollen type on pollen diagram	Plant species represented by pollen type	Current distribution in the vegetation	
		Around the swamp	Regional vegetation
Ranunculus	*Ranunculus* spp	Swamp surface	Sub-alpine swamps, grassland, forests.
Hydrocotyle	Probably *Hydrocotyle tripartita*	Swamp surface and rainforest	Rainforest margins, eucalypt formations, sub-alpine forests, grasslands and swamps.
Monolete fern	Mostly *Lastreopsis microsora, Hypolepis* sp, *Microsorum scandens* and *M. diversifolium*	Swamp surface and rainforest	Rainforests, damp habitats in eucalypt forests.
Trilete fern	Probably a mixture of *Hymenophyllum* sp. *Pellaea falcata, Pteris* sp.	Rainforests	Eucalypt forests, plateau forests, damp gullies in rainforests.
Chenopod type	Chenopodiaceae, ?Caryophyllaceae	Not present	Eucalypt and sub-alpine formations.

Chenopod type on pollen diagram Reference: Harden (1990 – 1993)

Chenopodiaceae	S	*Einadia* spp: in heavy soils of Northern Tablelands. *Rhagodia parabolica* poor soils of semi-arid or areas of higher rainfall.
Caryophyllaceae	H	*Stellaria*: moist shady places in gullies and margins of rainforest; swamps and seasonally flooded sites.
		Polycarpaea: widespread; herb of arid regions.

Table 4.3b Definition of the algal groups on the pollen diagram (Fig. 4.3b) and their ecology

References: Chapman, 1964; Hoshaw and McCourt, 1988; Van Geel and Grenfell, 1996 (Volumes 1 and 3).

Spore type on diagram	Ecology of algal type (representing any of a variety of species)
The first four algal types belong to the Zygnemataceae	Ubiquitous in fresh water habitats, typically in stagnant, shallow water in ponds or ditches, in moist soils or bogs, as well as in rapidly moving fresh water, larger bodies of standing water and lake margins. Populations in floating mats grow rapidly in nutrient poor pools. Zygospores indicate: clean, oxygen rich, shallow stagnant mesotrophic water in seasonally warmed habitats. However, the spores enable the algae to withstand unfavourable conditions, eg. drying out or freezing of the habitat.
Spirogyra	Near surface of stagnant water and universally present and the most abundant of these genera.
Zygnema	Also frequent in situations outlined for the family.
Mougetia type	Can occur when a local rise of the water table produces shallow water.
Debarya (glyptosperma)	Fossils are common in cold or cool climates in high –mountains above the treeline.
Pediastrum	Common in fresh water. Associated with reasonably nutrient rich and alkaline conditions. Inhabits mainly eutrophic but also oligotrophic lakes.

Table 4.3c Taxa with low pollen frequencies in peat. Habit: A, aquatics; C, climbers; H, herbs; S, shrubs; T, trees.

Pollen type and Habit	0	20	40	50	70	100	120	140	160	180	200	220	240
Apiaceae H, S	+	+	+		+			+		+	+		
Araliaceae C, S, T			+	+	+	+							
Brassicaceae H	+	+			+								+
Cardamine H				+									
Cunoniaceae S, T	+	+	+	+				+					
Dodonea S						+							
Elaeocarpus S, T		+	+	+									
Epilobium H		+						+	+				
Gonocarpus/Haloragis H												+	
Labiate H	+												
Meliaceae S, T	+		+										
Orites T	+	+	+	+		+	+	+		+	+		+
Papilionaceae S	+	+	+	+				+	+	+		+	
Pinus T	+												
Podocarpus S, T			+										
Quintinia S, T							+						
Rubiaceae H, S, T	+		+										
Scrophulariaceae H	+	+	+		+			+	+	+		+	
Tasmannia S						+							
Triglochin A		+	+	+						+	+	+	+
Typha A			+					+		+		+	+
Urticaceae H, S		+		+		+	+	+	+	+			+

Table 4.3c Taxa with low pollen frequencies in lake sediments. Habit: A, aquatics; C, climbers; H, herbs; S, shrubs; T, trees.

Pollen type and Habit	245	250	255	260	270	272	274	280	290	300	310	320	330	340	350
Araliaceae C, S, T		+	+			+									
Asteraceae (Liguliflorae)											+		+		
Banksia S												+			
Brassicaceae H						+							+	+	+
Cardamine H	+	+	+	+	+	+									
Epilobium H								+				+	+	+	
Gonocarpus/Haloragis H												+			
Parsonsia C														+	
Persicaria H	+				+							+		+	
Podocarpus S, T									+			+	+		
Scrophulariaceae H	+	+		+		+	+			+					
Tasmannia S						+	+		+				+		
Triglochin A			+												
Typha A	+	+	+	+	+	+									+
Urticaceae H, S								+	+					+	

Table 4.3c Taxa with low pollen frequencies in lake sediments. Habit: A, aquatics; C, climbers; H, herbs; S, shrubs; T, trees.

Pollen type and Habit	400	560	570	580	590	600	610	620	630	640	650
Acronychia S	+	+	+	+	+	+					+
Apiaceae H, S									+	+	
Asclepiadaceae C, H	+	+									+
Asteraceae (Liguliflorae)								+	+	+	
Banksia S						+					
Brassicaceae H	+	+	+	+	+	+			+	+	+
Cardamine H	+										+
Epilobium H	+			+				+			+
Gonocarpus/Haloragis H										+	+
Lomatia S								+	+		
Pimelia H, S, T	+							+			
Podocarpus S, T								+		+	+
Polygonaceae C, H, S										+	
Rubiaceae H, S, T	+										+
Tasmannia S			+	+		+	+	+	+	+	+
Triglochin A	+										+
Typha A	+	+						+	+	+	
Urticaceae H, S						+		+	+	+	+

4.3.5 DISCUSSION OF VEGETATION HISTORY

From about 40,000 to 21,000 years BP, the vegetation was probably an open community in which *Eucalyptus* was the only tree. On the one hand, the landscape may have been sparsely treed with a grass understorey, but surface samples for grassland and alpine areas all contain some *Eucalyptus* pollen (Dodson, 1983; Dodson and Myers, 1986; Martin, 1986, 1999), hence the vegetation immediately around the site may have been grassland.

Between 40,000 and 30,000 years BP, aquatic and swamp vegetation flourished, with an abundance of *Myriophyllum* and Cyperaceae, a little *Triglochin*, *Typha* and mesic vegetation which was represented by a diversity of mesic (Appendix 2), low pollen frequency shrubby and herbaceous taxa. The variability of *Myriophyllum* pollen grains suggests that more than one species of *Myriophyllum* existed (Appendix 5) and these may have represented both water and/or mud types. After 30,000 years BP, the mesic shrubs, such as, *Tasmannia* and *Lomatia,* were reduced. Thus, while there was little change in the *Eucalyptus* representation through this time, other strata of the vegetation were being impoverished.

About 32,000 years ago, the lake was shallow and conducive to algae which thrive in stagnant water (Chapman, 1964; Hoshaw and McCourt, 1988; van Geel and Grenfell, 1996). However, the algal numbers then continually decreased as the lake level was dropping. By 30,000 years BP, both *Myriophyllum* and Cyperaceae were much reduced and Poaceae increased markedly. The high concentrations and the clumped state of the Poaceae pollen about 30,000 years ago suggest a local source, i.e. it was possibly a swamp grass around the edge of the lake. After about 26,000 years BP, concentrations became much lower, suggesting that the swamp Poaceae had disappeared and only dryland species were represented in the spectrum. Thus there were considerable changes in the wetland vegetation: from abundant Cyperaceae/*Myriophyllum*, to abundant Poaceae to a much reduced wetland after 26,000 years BP. Between 21,000 and 17,000 years ago where pollen is lacking, there is insufficient evidence about the vegetation.

The traces of mesic taxa e.g. *Nothofagus, Dicksonia,* other ferns, present at 390 cm in the first core taken with a Hiller corer, can be dismissed as contamination. However, the traces in the 400 cm clay band in the second core taken with the Livingstone corer, are not so easily dismissed as contamination, but they cannot be explained readily.

From 17,000 to 15,000 years BP, the landscape would have been virtually treeless and grasslands were well developed. The common grass was different from that at 30,000 years BP. There was minimal swamp/aquatic vegetation. The vegetation may have been an alpine community, since the pollen spectrum during this period contained the important indicators, such as, Ranunculaceae, Caryophyllaceae, for alpine vegetation (Dodson, 1983), but may also conform to a grassland.

By 15,000 years BP, a sparse tree cover, similar to pre-glacial times, had returned. After about 15,000 years BP a *Eucalyptus* forest developed, mesic elements of *Nothofagus* appeared and *Dicksonia* and other ferns became established, probably as a relatively minor part of the vegetation.

Between about 13,000 and 12,000 years ago *Dicksonia* became prolific, heralding the transition to cool temperate rainforest. Today around Burraga Swamp, the tree ferns are common, but their spores are represented in low numbers in pollen surface samples (Fig. 4.3a). Thus 13,000 / 12,000 years ago the tree ferns were more abundant than at present. The concentration of *Dicksonia* remained relatively high until 10,000 years BP. Then until around 9,500 years BP herbs grew on the swamp surface. After this period *Myriophyllum* grew on the sediments once more and small herbs and *Dicksonia* were much reduced.

After 9,000 years BP, *Nothofagus* increased, *Eucalyptus* forests decreased somewhat, other Myrtaceae types increased and *Leptospermum* appeared. The percentage of Cyperaceae and *Myriophyllum* increased significantly. By 6,000 years ago, *Nothofagus* had reached levels comparable with those in the cool temperate forest surrounding the swamp today. Most of the present day communities had become established by about this time but Poaceae declined once peat started accumulating. There were some fluctuations in the tree component of the vegetation during the upper part of the Holocene, but it would have been within the limits of the variability in the vegetation found in the region today. *Leptospermum* is the exception. It is not found at the site today, but in the past, it was occasionally abundant. Dodson (Dodson et al., 1994) found abundant *Leptospermum* in his central core on Burraga Swamp between 2,140 and about 300 years BP, but the pollen was absent from the core studied on the swamp edge. This suggests that *Leptospermum* may have grown on the swamp surface. There were only minor occurrences after 300 years BP.

In the present study, the peak of *Leptospermum* around about 4,000 years BP, coincided with the disappearance of algae and *Myriophyllum,* which indicates that a shrub community had colonised the swamp, only to disappear and be replaced by a Poaceae and Cyperaceae community. Although Cyperaceae is present throughout, species have changed with time. Identifications from seeds do not match any of the species growing there today.

During the *Leptospermum* phase, *Nothofagus* percentages were not significantly decreased (as shown by the error bars), indicating that probably the forest had remained stable. It is likely that the vegetation which existed during the period containing the top of the profile, was similar to that currently occurring to the south of the swamp today, since the pollen in the 0 cm level of the profile mirrors that in forest surface sample D.

The variation in the representation of *Nothofagus* over the last 6,000 years, may indicate changes in proximity of the forest trees to the core site and the effect of the filtering effect of the swamp vegetation. This suggestion is based on the data provided by surface samples (surface samples Figs 4.2.4 and 4.3a). Surface samples E and F, which are from within the cool temperate rainforest, contain very high percentages of *Nothofagus* pollen. However, swamp surface samples B and C, which are nearest to E and F, contain the lowest *Nothofagus* percentages, possibly since both B and C are beneath dense Poaceae / Cyperaceae vegetation which may act as filters for forest vegetation pollen. Surface sample A, which is in more open vegetation, contains higher values of *Nothofagus* pollen.

4.3.6 FIRE HISTORY

Relative quantities of charcoal are recorded on Fig. 4.3b. The charcoal pieces found in the first core (Sweller and Martin, 1997), appear to have been very localised.

Charcoal is low from 40,000 to 21,000 years BP and increases to moderate between 21,000 and 17,000 years ago. Moderate to very high quantities occur in the sandy gravelly layers of the 17,000 Ka period (particularly where pollen is rare) but charcoal is negligible in the clay bands, regardless of the fossil pollen content. The sediments which incorporate the most gravels contain large pieces (upto 200 µm) of microscopic charcoal. Then from 17,000 to about 6,500 years BP, which is the base of the peat, values were low to absent and then medium in the peat.

These results may indicate that relatively little burning occurred in pre-glacial maximum times. At face value, burning was more prevalent during the glacial period, but depositional factors may have influenced the relatively large quantity of charcoal accumulated during the latter part of the 17,000 Ka period. Erosion of the sparsely vegetated slopes may have carried down the accumulated charcoal and deposited it in the sediment. In post glacial maximum times, burning was low and moderate burning occurred once rainforest became established. Thus, fire has always been part of the environment, but intensity and/or frequency has varied.

The present forest has been burnt as can be seen in the forest around the swamp today. If the fire is not very severe, *N. moorei* regenerates vegetatively through coppice shoots from the intact tree and through coppicing due to a proliferation of dormant buds, particularly under the soil, beyond the fire's limit (Turner, 1981). When some bare soil is available in this high light condition, seeds have a greater chance to survive and *Nothofagus* can regenerate. Today, examples of coppicing and regeneration can be seen in the forest around the swamp.

Chapter 5 A COMPARISON OF BURRAGA WITH OTHER QUATERNARY STUDIES

The earliest phase of sediment deposition at Burraga Swamp, about 40,000 years ago, corresponds with mid-Stage 3 of the Marine Oxygen Isotope Curve (Martinsen et al., 1987; Fig. 1.2). The curve indicates that temperature levels oscillated with an overall cooling and drying trend at levels somewhere between the glacial lows and interglacial highs. Moisture would have followed similar trends. The open *Eucalyptus* vegetation at Burraga (Section 4.3.5) fits in with this model. Moisture levels were falling and conditions were drier than the present but not as dry as it would become in glacial times (Fig. 5.1).

The vegetation 40,000 years ago at Burraga indicates a drier climate when the lake was several metres deep. This apparent contradiction may result from conditions of lower temperatures leading to lower evaporation and the fewer trees causing less evapotranspiration, both of which would allow higher lake levels to be maintained under conditions of lower rainfall. Lake levels were also high elsewhere in Australia during about 50,000 to 36,000 years BP (Dodson, 1975; Bowler, et al., 1976; Edney et al., 1990), in part, leading Nanson (Nanson and Young, 1988; Nanson et al., 1992) to propose a sub pluvial period during the second half of Stage 3. However, not all lakes were high during the whole of this interval (Dodson, 1977; Edney et al.,1990).

At Burraga between 40,000 and 30,000 years ago, the vegetation overall was relatively drier than the present. Palynology at some other sites indicate similar conditions (Dodson, 1975, 1977b; Kershaw, 1976, 1985, 1994; Colhoun et al., 1982), similar to Burraga. However, exceptions occurred (McKenzie, 1997; Chalson, 1991).

Between 30,000 and 21,000 years ago, the lake level at Burraga gradually decreased (Section 4.2.3). During this period other lakes in eastern Australia may have been low, oscillating or full (Dodson, 1975; Bowler et al., 1976; Singh and Geissler, 1985; Edney, et al., 1990) and a compilation of a large number of eastern Australian lake depths indicates that the number of deep lakes increased from 30,000 years BP to a maximum at 26,000 years BP (Harrison and Dodson, 1993).

The drier climate at Burraga between 30,000 and 21,000 years ago, was insufficient to cause any marked disruption in the dryland vegetation (Section 4.3.5). Elsewhere in southeastern Australia, the vegetation, although somewhat drier than before, was not

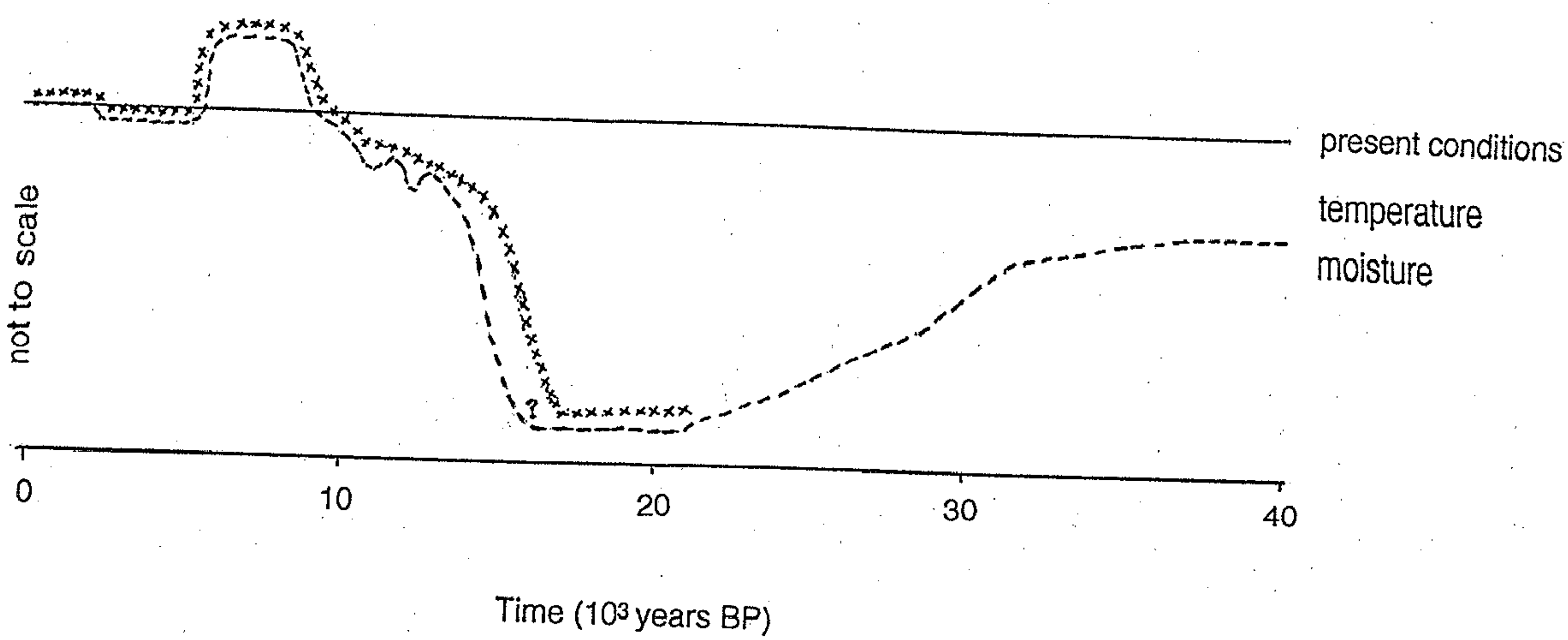


Figure 5.1 Temperature and moisture changes inferred at Burraga Swamp over the last 40,000 years.

dramatically changed (Kershaw, 1971; Colhoun, 1978, 1980; Colhoun et al., 1982). Some localities still contained wetter elements (Colhoun, 1978, 1980; Hope, 1978; Singh and Geissler, 1985). In the south-central highlands of Victoria, the treeline had temporarily risen (McKenzie, 1997), indicating a local increase in temperature or moisture (Hope, 1989).

At about 24,000 years BP (boundary of oxygen isotope Stages 2 and 3), a rapid decline in temperature levels is indicated (Martinsen et al., 1987; Fig. 1.2). At about 21,000 years ago, slope instability began around Burraga and the lake was at its shallowest between 18,000 and 17,000 BP (Section 4.2.3). During this time 69% of the lakes on the Australian continent were also shallow (Harrison and Dodson, 1993). At about 17,000 years BP the lowest moisture levels can be inferred from the oxygen isotope curve (Martinsen et al., 1987; Fig. 1.2). Burraga data agrees with this trend (Fig. 5.1).

During 17 Ka the instability at Burraga increased, possibly as the result of solifluction at the height of the glacial maximum when the whole of the gravelly clayey sand unit was deposited (Section 4.2.3). The steep slope of Mt. Lumeah to the east (Fig. 2.1d) would have been vulnerable to considerable erosion under destabilizing conditions, such as the disruption of the vegetation cover under periglacial activity. Snow may have covered the area (Section 1.3.1). However, during the height of the last glacial maximum when the harshest conditions existed, several thin silt/clay bands formed at Burraga and are suggestive of brief periods of relative slope stability.

During the severe climatic period at Burraga, conditions for pollen preservation were unfavourable, except for the period when a narrow band of fine sediment was deposited at 400 cm (during 17 Ka). Interpretation of the small amount of rainforest type pollen (discussed in Section 4.3.4 Zone 3) is problematical, but if the climate had ameliorated for sufficiently long, a few rainforest elements may have established in this locality. There is recent evidence of short period, high amplitude, rapid climatic fluctuations during the last glacial stage with vegetational responses (Dokken and Jansen, 1999; Nimmergut et al., 1999; Birks and Ammann, 2000; Peteet, 2000). Similar fluctuations may have occurred at Burraga. However, the rainforest pollen in this 400 cm pollen sample at Burraga, could result from long distance dispersal in the sediment (Campbell et al., 1999) brought by the strong predominantly south easterly winds at this time (Thom et al., 1994), supporting the notion of rainforest refugia to the eastern and southern sheltered areas of the Barrington

Tops (Dodson, et al., 1986; Dodson, 1991). In a montane area such as Barrington, a range of microclimates would exist providing a variety of environments over short distances to give possible suitable locations for the development of *Nothofagus* (McKenzie, 1995). Current anomalous *N. moorei* distributions occur, such as at Carters Brush, on the dry western side of Mt. Patterson, in the Barrington Tops National Park (Fig. 5.3).

On periglacial evidence, the estimate of mean temperatures at the height of the last glacial maximum for montane mainland eastern Australia, would have been 9˚C lower than the present (Galloway, 1965 and Barrows et al., 2000 in Section 1.3.1 of this thesis). It is likely that Burraga experienced similar temperature drops (Fig. 5.1). The oxygen isotope curve indicates that the lowest temperatures occurred about 17,000 years ago (Martinsen et al., 1987; Fig. 1.2).

The vegetation at Burraga was virtually treeless, as was most of southeastern Australian vegetation at this time (Hope, 1978; Colhoun et al., 1982; Colhoun, 1985; Colhoun and van de Geer, 1986, Markgraf, et al., 1986; Singh and Geissler, 1985; Dodson, 1989; Edney et al.,1990; Chalson, 1991; Robbie, 1998). Burraga is the most northerly identified site (Fig. 1.4) of the treeless terrain. The only palynological studies of the glacial period in the eastern highlands to the north of Burraga, are in the Atherton Tablelands. Here in northeastern Australia, the glacial vegetation was dry sclerophyll forests (Kershaw, 1976, 1985, 1994).

The treelessness is usually attributed to aridity but it may be in part due to lower CO_2 in the atmosphere. The 30 - 50% reduction of atmospheric CO_2 during glacial times, would have stressed the vegetation, reducing tree growth and favouring C4 grasslands and shrublands (Watts, et al., 2000 in Section 1.3.3).

At Burraga, conditions improved after 17,000 years BP. The catchment stabilised and was covered by a grassland (Section 4.3.5). The post glacial climatic amelioration was rapid after 17,000 to about 9,000 years BP, as shown by the oxygen isotope curve (Martinsen et al., 1987; Fig. 1.2). There were local and regional variations in the timing of the climatic recovery in eastern Australia. In some locations there was an increase in temperature around 17,000/16,000 years BP (Macphail, 1979; Macphail and Colhoun, 1985; Martin, 1986; Miller et al., 1997). Ice retreat began about 15,000/14,000 years ago and at Carruthers Creek in the Snowy Mountains, NSW, glaciers had largely disappeared by 14,500 years BP. However, conditions remained dry (Bowler et al., 1976). At Burraga the lake returned between about 17,000 and 15,000 years ago, possibly as a result of snow melt. Generally in eastern Australia from 18,000 years BP, lake levels were low, with an increase in some lakes between 15,000 and 13,000 years ago (Harrison and Dodson, 1993).

At Burraga, about 15,000 years ago, some mesic elements, such as ferns and *Nothofagus moorei* appeared in low quantities, an *Eucalyptus* cover became established and herbs grew on the sediments (Fig. 4.3a and Section 4.3.5). During the 15,000 to 10,000 years BP period at Burraga, water fluctuated between a very shallow lake and an almost dry surface (Section 4.3.5), causing the variability in the sediments (Sections 4.2.2.1.4, 4.2.3) and indicating climatic oscillations. Such fluctuations are noted elsewhere (Dodson et al., 1986), in some cases sufficiently severe to reverse ameliorating climatic trends (Macphail, 1979; Hope et al., 2000). Water-table fluctuations may be produced when temperatures rise faster than precipitation, producing excess evaporation and moisture stress and/or if evapotranspiration increased due to increased vegetation (Macphail, 1979; Markgraf et al., 1986; Dodson et al., 1986).

About 15,000 to 10,000 years BP elsewhere in southeastern Australia, the vegetation changed to a more wooded type, but the nature and timing of such vegetational changes varied from region to region (Markgraf et al., 1992). During this time, there were large changes in temperature and moisture regimes under unstable climatic conditions. In this period, changes in different climatic factors were reported from studies of the vegetation in different locations in eastern Australia. In some places, particularly at higher altitudes, only temperature changes were apparent (Raine, 1974; Bowler et al., 1976; Martin, 1986; Macphail, 1979; McKenzie, 1997; Kershaw et al., 1991b; Colhoun, 2000), while in some areas, vegetation shifts indicated dry conditions and temperature changes are not apparent (Kershaw, 1976, 1985, 1994; Colhoun, et al., 1982; McKenzie, 1997).

In some parts of eastern Australia, however, at about 12,000 years BP, vegetation (Kershaw, 1995) and lake levels (Harrison and Dodson, 1993) indicate maximum aridity. This is later than suggested by the oxygen isotope curve as mentioned earlier, but regional hydrological factors may have been involved.

At about 13,000 to 12,000 years BP, many southeastern highland swamps began development and indicated regional climatic improvements (Binder and Kershaw, 1978). It was during this period that *Dicksonia antarctica* increased to a peak at Burraga (Fig. 4.3a), showing that moisture levels increased there at that time (Jones, 1998; Hill and Macphail, 1985; Harle et al., 1993). Across Southern Tasmania, after 12,000 years ago, there was an increase in rainfall (see Section 1.4.9) and lakes in eastern Australia began to fill (Harrison and Dodson, 1993).

Similar *Dicksonia* peaks occurred elsewhere, around 10,500 to 7,000/6,000 years ago (Macphail and Jackson, 1978; Ladd, 1979b; Macphail, 1984; Dodson et al., 1986). Thus the *Dicksonia* peak at Burraga (290 to 280 cm), at 13,000 to 12,000 years BP, occurs earlier than elsewhere. At Burraga, Hope (per. comm.) suggests that there may have been a period of non-deposition (above 300-298 cm) in the lake sediment (a conceivably oxidised layer), before the *Dicksonia* peak and some mixing of sediments above 298 cm, thus changing the timing of the *Dicksonia* peak to early Holocene, to coincide with those of previous studies. However, the date of 14,680 years BP from 296 cm, is from material above the possibly oxidised sediment where the break in sedimentation may have occurred, thus not altering the timing of the *Dicksonia* peak. *Dicksonia* flourished when ecological conditions were particularly favourable and there is no reason why these conditions had to occur at the one time in different regions.

The *Dicksonia* peak appears to have heralded the cool temperate rainforest. It is a logical precursor to rainforest since it can migrate easily. It colonises wet lands in forest clearings (Duncan and Gold, 1986) and in the forests of Barrington Tops, *Dicksonia antarctica* is most abundant in damp hollows (Turner, 1976). Today, in locations near high density *Dicksonia* populations, spores may not be well represented in surface samples (Fig. 4.3a; Dodson and Myers, 1986). Therefore, at Burraga, the high percentage and concentration of *Dicksonia* spores could indicate the existence of a fern population much denser than present today. *Dicksonia antarctica* "frequently grows in extensive stands" (Jones, 1998, p. 189), forming "sizeable groves" (Duncan and Gold, 1986, p.102). However, since the spores of *Dicksonia antarctica* can be dispersed over long distances (Salas, 1983) by water (Ladd, 1978), the ferns could have been growing elsewhere and the spores channelled by flowing water, into the basin (D'Costa and Kershaw, 1997).

The oscillations in moisture levels between 15,000 and 11,500 years ago at Burraga, may have been responsible for the sporadic presence of *Nothofagus* during that period (Fig. 4.3a). Moisture is the major limiting factor for *Nothofagus* (Read and Brown, 1996; Adam pers.comm.) although it also has requirements for minimum temperatures. *N.*

moorei forests can occur along snow covered, sheltered gullies, out of the direct drying action of wind (Frazer and Vickery, 1938; Adam, pers. comm.). It has been shown that *Nothofagus cunninghamii,* which shares a common ancestor with *N. moorei* and has similar ecological constraints, can withstand the cold, (is common as a shrub in the subalpine/alpine mountains of Tasmania [Macphail and Jackson, 1978]), but is limited by moisture (McKenzie, 1995). When rainfall is low, *Nothofagus* may grow along watercourses (Baur, 1957) or where there is sufficient groundwater (Read and Brown, 1996). Thus, it could be supposed that in the region of Burraga, by 15,000 years ago, moisture had reached levels greater than virtually any time within the last 40,000 years and consequently high enough for the beginning of the development of cool temperate rainforest in the region of Burraga Swamp. *Nothofagus moorei* pollen tends to be under-represented, despite a large production of wind dispersed pollen (Sweller and Martin, 1997). Thus, the small percentage of *Nothofagus* pollen recorded (Fig. 4.3a), may represent a distant (even just two kilometres away) source, or a few trees within about 100 m of the swamp (Dodson, 1988; Dodson, 1991). The Polblue surface samples in this current study (Fig. 4.3a) have very low *Nothofagus* pollen percentages. There is no *Nothofagus* forest at Polblue Swamp.

By about 11,500 years BP, effective moisture had increased sufficiently to allow *N. moorei* to become permanently established near Burraga, possibly as an understorey in an eucalypt forest. If conditions were still only marginal, the trees may have grown in stunted, possibly coppicing, form (Poole, 1987). After 10,000 years BP, representation of *Nothofagus* was increasing and after 9,000 years ago, the cool temperate rainforest became permanently established (Section 4.3.4 Zones 4 and 5). The vegetation at Burraga between about 9,000 BP and 6,500 BP implies an increase in effective precipitation (Section 4.3.5).

N. moorei was present in small percentages on the Barrington Tops Plateau, by 10,000 years BP (Dodson et al., 1986) and Figure 5.2 summarises the history of *Nothofagus* at eight Plateau sites and Burraga (see Fig. 2.1c for sites). About 8,500 years BP, a peak in *Nothofagus* was registered at Killer Bog (about 12 km northeast of Burraga). At Black Swamp (about 7 km north/northeast of Burraga), *Nothofagus* peaked about 6,000 years BP, at about the same time as at Burraga and on the northerly end of the Plateau at Boggy Swamp (about 25 km north/northeast of Burraga). At Horse Swamp (about 18km north/northwest of Burraga) the *Nothofagus* peak occurred around 1,000 years BP.

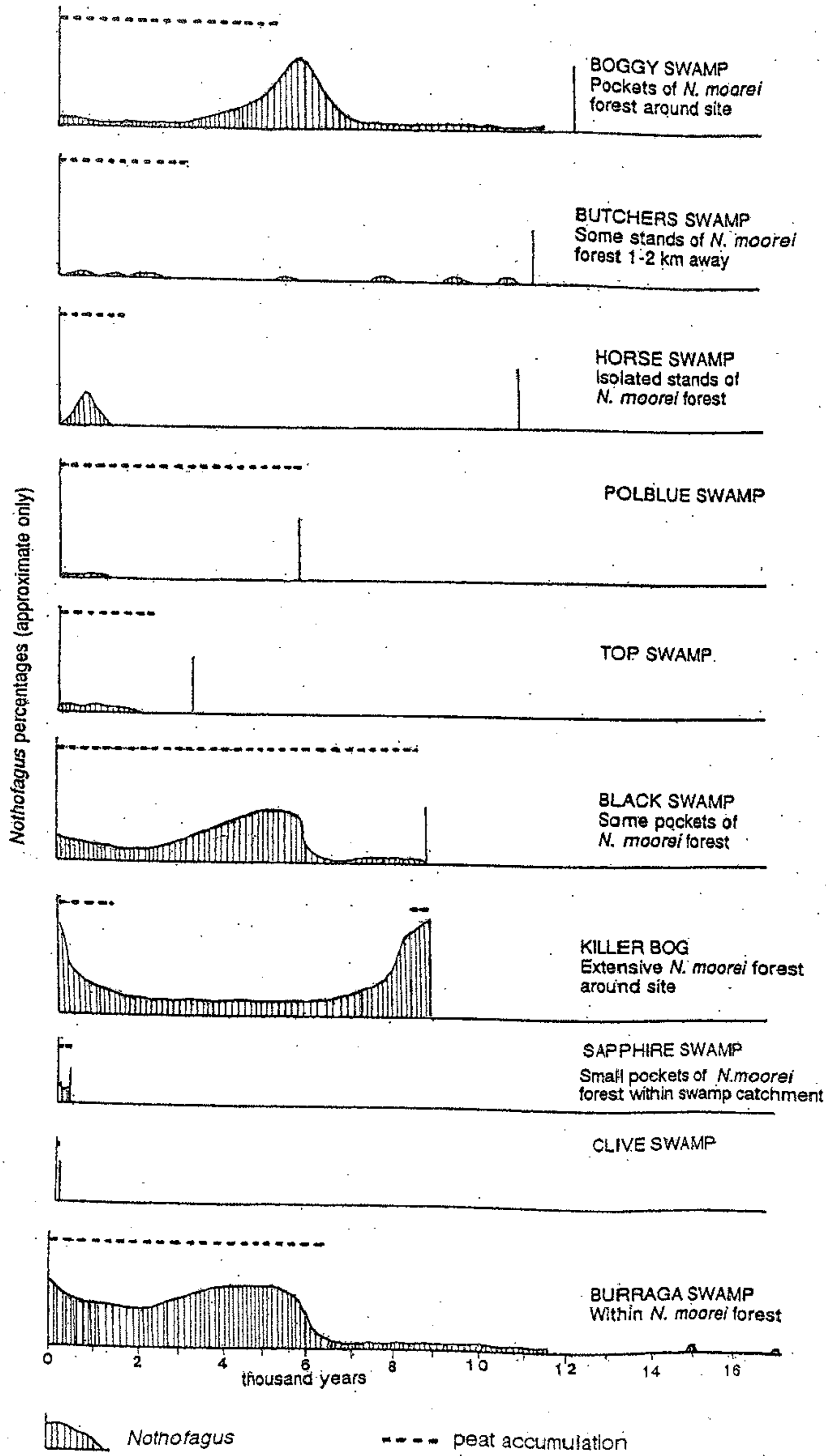


Figure 5.2. A comparison of the *Nothofagus* content and the start of the peat accumulation, at the Barrington Tops Plateau sites (Dodson et al., 1986; Dodson, 1987) with Burraga Swamp (this study). All sites are plotted to a uniform time scale and the percentages of *Nothofagus* are approximate only.
For location of all the sites, see Fig. 2.1c.

Evidently, conditions suitable for the establishment for *N. moorei* forests were achieved at different times over the Plateau. At most of the sites, *Nothofagus* declined from its peak and there are only a few isolated stands near the site today. However, at Killer Bog and at Burraga Swamp, there are second peaks of *Nothofagus* near the present time. Both swamps are currently within *Nothofagus* forests. Thus, *Nothofagus* forests have had a complex pattern of increase and decline over the Plateau, during the Holocene.

The current distribution of *Nothofagus moorei* rainforest at Barrington and Gloucester Tops, is shown in Fig. 5.3. The present distribution of *N. moorei* on the Plateau is "along the sheltered valleys and drainage lines" (Dodson, 1991, p. 75).

Nothofagus moorei requires a mean annual temperature of 1 - 20˚C, with the mean annual rainfall of 1,113 - 2,372 mm, of which 50 mm fall during the driest month (Boland et. al., 1984; Read and Farquhar, 1991; Read and Hope, 1996) with no defined dry season (Frazer and Vickery, 1937). The restriction of *N. moorei* to cool, commonly fog-bound sites, suggests that a constant high humidity is required (Howard, 1981). These conditions must have been reached in the eastern parts of the Barrington Tops around 9,000 years ago.

Suitable conditions for *Nothofagus cunninghamii*, are similar to the requirements of *N. moorei*, and these were reached at a slightly earlier time in the Victorian southern highlands and in western Tasmania, than at Barrington Tops. *N. cunninghamii* forests which have been present for the last 40,000 years (possibly escaping the glacial conditions in refugial sites) (McKenzie, 1997; McKenzie and Kershaw, 2000; Colhoun, 2000) redeveloped in western Tasmania after 14,000 years BP. They increased and reached maximum development at different places at varying times, between 10,000 and 7,000 years BP (Macphail, 1979; Markgraf et al., 1986; Colhoun, 2000). At the Victorian sites, *Nothofagus* was increasing along an altitudinal gradient by about 10,000 years BP, reaching beyond current distribution between about 7,000 and 4,000 years BP (McKenzie, 1997; McKenzie and Kershaw, 2000). Thus, *N. cunninghamii* as well as *N. moorei* had a variable history of progression across its southeast Australian range.

For other vegetation types, optimum conditions were reached at somewhat varying times across southeastern Australia, also. Changes to wetter vegetational communities also indicated increases in effective precipitation and temperature by 10,000 years BP, reaching

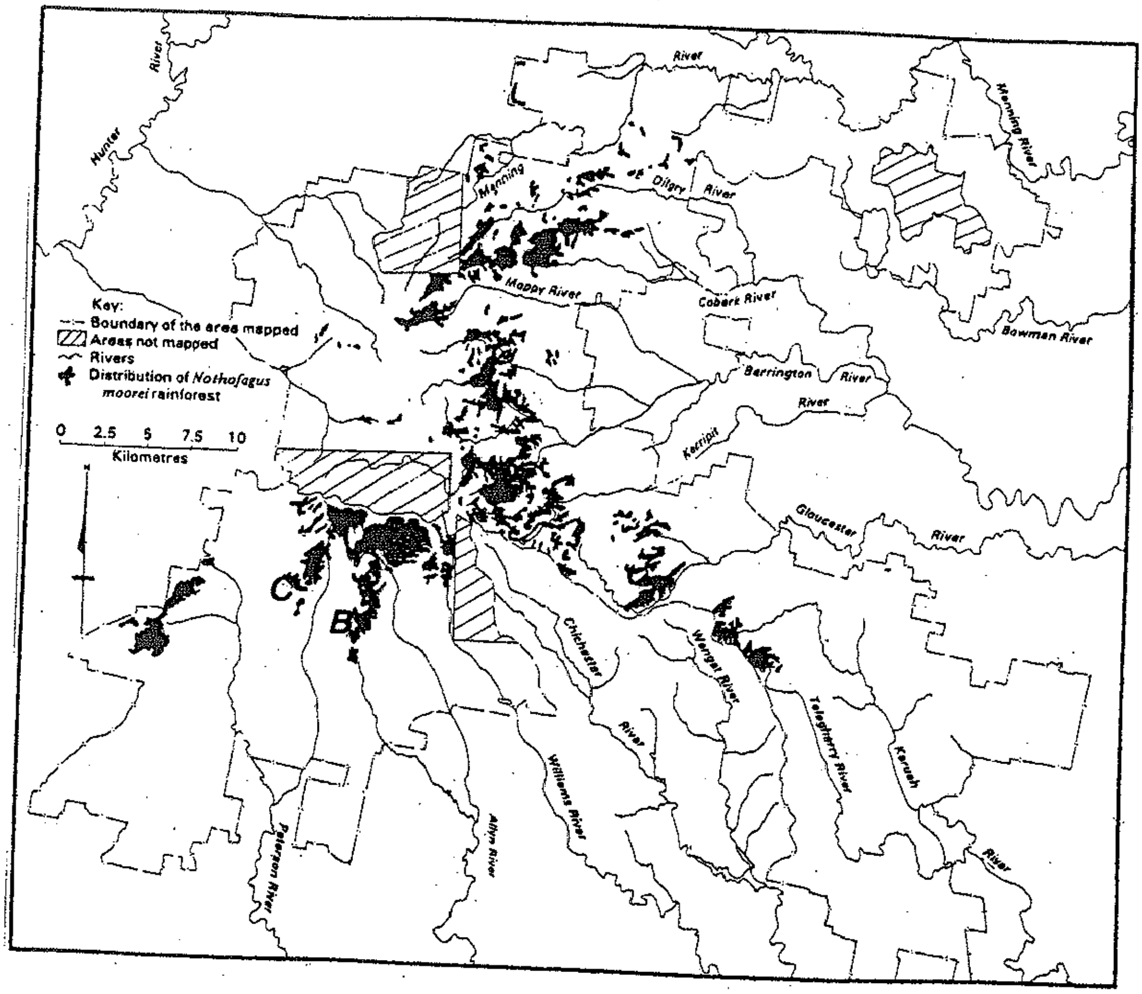


Figure 5.3 Distribution of *Nothofagus moorei* rainforest on Barrington and Gloucester Tops Plateaux (adapted from Dodson, 1991). ***B***: Burraga Swamp, ***C***: Carters Brush.

the maximum (beyond today's) between 8,000 and 6,000 years ago (Dodson, 1977b; Binder, 1978; Binder and Kershaw, 1978; Colhoun, 1978; Williams, 1978; Ladd, 1979a; Macphail, 1979; Macphail, 1984; Markgraf et al., 1986; Dodson et al., 1986; Chalson, 1991; Robbie, 1998; McKenzie, 1997; Martin, 1999) and in Northeast Queensland by 6,500 to 5,500 years BP (Kershaw, 1971), during the period of maximum Holocene sea level (Nanson et al., 1992).

Within Burraga basin, the transition to peat occurred between about 6,700 and 6,500 years BP (Section 4.2.3). By this time there was a good local forest cover (Section 4.3.4 Zone 5), comparable with that of today and the resultant high evapotranspiration probably reduced runoff, so the water level of the swamp remained low enough to allow rooted vegetation to flourish and peat to form. The forest cover also would have stabilised the slopes, resulting in reduced erosion and mineral sedimentation into the swamp. On Barrington Tops Plateau, peat formation began about 8,500 years BP. The timing of the peat formation varies from swamp to swamp and has continued to have been initiated until very recently (Fig. 5.2; Dodson et al., 1986; Dodson, 1987).

The beginning of the peat formation at Burraga and on most of the sites on the Plateau, coincided with the establishment of the cool temperate rainforest. For example, at Killer Bog, peat development started at 8,500 years BP, the time of the first *Nothofagus* peak. Then followed a long section of mineral sedimentation and very little *Nothofagus*, with both peat formation and a *Nothofagus* peak returning at 1,200 years BP (Fig. 5.2). Not all the swamps follow this pattern. At Polblue, peat formation starts well before any *Nothofagus*, which remains minimal throughout the profile (Fig. 5.2). However, Polblue is the swamp at the highest elevation and lacks any *Nothofagus* in its vicinity. Moisture content is controlling both peat and *Nothofagus* forest developments and results from the correct hydrological conditions which may be achieved at different times in different localities.

At Burraga the development of the swamp slowed after 5,500 years BP (Fig. 4.2.3). Burraga Swamp may have been drier between about 4,000 and 2,000 years BP (Section 4.3.5). After 230 years BP there was an increase in the rate of swamp growth (Dodson et al., 1994). However, the material deposited during most of this latter period was largely an unconsolidated root mat (Table 4.2.2a; Fig. 4.2.2a(i)) and this lack of compaction may give the illusion of faster accumulation. On the Plateau also, conditions became drier and cooler from about 3,500/3,000 to 2,000 years BP (Dodson et al., 1986; Dodson, 1987). The rate of peat accumulation increased in the last few hundred years in some of the Plateau swamps, for example, Boggy, Butchers, Polblue Swamps and Killer Bog. As at Burraga this increase may be due to the lack of compaction, but it more or less coincides with the formation of the new peatlands: Sapphire and Clive Swamps (Dodson, 1987). Conditions on the Plateau were possibly wetter from about 2,000 years BP, with possible increases in temperature after 1,000 years BP (Dodson, 1987).

Similar climatic changes have been noted over other parts of eastern Australia as well, with some regional temporal variation. In Northern Australia (Lees, 1992) and elsewhere (Macphail, 1979; Markgraf et al., 1986; Robbie, 1998), cool and dry conditions were registered from 6,000/5,000 years BP, while in many southern Australian locations, the timing was between about 4,000/3,500 years BP and 2,000 years BP (Hope, 1974; Bowler et al., 1976; Binder and Kershaw, 1978; Williams, 1978; Ladd, 1978, 1979a; McKenzie, 1997). However, in some locations, climatic deterioration occurred somewhat later, after 2,000 years BP (Kershaw, 1971; Hope et al., 2000; McKenzie, 1997). Lake levels also indicate a shift to drier conditions between 5,000 and 3,000/2,000 years BP but by 1,000 years ago, wetter than present conditions are implied (Harrison and Dodson, 1993; Harrison, 1989).

The charcoal in the sediments may not be related to fire events, but may record fire-rainfall-erosion episodes (Head, 1989). As discussed in Section 4.3.6, changes in erosional conditions alone may have been responsible for the charcoal "peaks" during the Last Glacial Maximum. There is no evidence of actual fire driven changes during the history of Burraga Swamp (Dodson et al., 1994; this study). The swamp vegetation, when dried out, would burn easily and the fires may have invaded the margins of the forest. One consequence of burnt *Nothofagus* forest, is the growth of young *Nothofagus* plants (Section 4.3.6), which are currently present in the forest around Burraga Swamp. However, rainforests rarely burn and then only under exceptionally dry conditions. On Barrington Tops Plateau also, fire seems to have had no direct responsibility for any major vegetation shifts. Until about 3,000 years BP, fires on the Plateau were low in intensity and frequency, thereafter increasing (Dodson et al., 1986). However, Dodson's charcoal influx study indicated that “ fire was probably one of the main driving forces of the dynamics within” the sclerophyll vegetation system (Dodson, 1988, p.205). Nevertheless, the role of fire is unclear in the Early Holocene expansion of *N. moorei* at Boggy Swamp and elsewhere on the Plateau (Dodson, 1988).

The changes of *Nothofagus* at Burraga, in the last 6,000 years are within the range of surface sample variations (Fig. 4.3a). There are many young plants in the forest at present. On the Barrington Tops Plateau from about 1,500/1,000 years ago to now, the cool temperate rainforest has expanded (Dodson et al., 1986). However, at the lower elevation of around 900 m, *Nothofagus* is not replacing itself sufficiently (Turner, 1976, 1981). Instead, the species which regenerates in greater proportions in the cooler areas of its range (Read and Brown, 1996), appears to be migrating upwards, possibly under the influence of climatic warming (Turner, 1976, 1981), which affects effective moisture, which in turn would limit the growth of *Nothofagus* and possibly increase fire frequency. Repeated fires in eucalypt forests adjoining rainforest, can push back the rainforest boundaries. If the fire is not very severe, *N. moorei* can regenerate vegetatively through coppice shoots from the intact tree or from dormant buds particularly under the soil beyond the fire's limit. In the prolonged absence of fire, rainforest can advance into *Eucalyptus* forests (Turner, 1981).

Chapter 6 CONCLUSIONS

About 40,000 years ago, Burraga was a small lake with abundant aquatic and swampy vegetation. It was surrounded by a sparsely treed, shrubby landscape with a variety of mesic herbs. At this time, the climate was drier than present.

Soon after 30,000 years BP, the water level in the lake was dropping and the aquatic/swampy vegetation disappeared. The herbaceous element decreased, shrubs disappeared, grasses became more prolific, but there was little change in the *Eucalyptus* representation. However, by 21,000 years BP, the vegetation was a sparsely treed grassland/herbfield. Erosion of the slopes was increasing and sand was being deposited in the lake. The climate had become drier than previously.

During 17 Ka, sand and gravel were deposited into the basin, probably due to substantial slope instability caused by periglacial activity. There were occasional stable periods during which times silt/clay was deposited into the basin. The vegetation had become a treeless grassland/herbfield. The climate was drier than previously, thus being very much drier and colder than today.

Soon after 17,000 years BP, the slopes stabilized and fine grained sediments were deposited in the lake. Until about 15,000 years BP, the vegetation was still a treeless grassland/herbfield. Temperatures began to increase and snowmelt would have added water to the basin.

After 15,000 years BP, some mesic elements were present in a limited way and the vegetation remained sparsely treed. Herbs grew on the mud of the basin. *Dicksonia antactica* reached a peak, heralding the appearance of rainforest. There were periodic, short term climatic fluctuations but overall rainfall and temperatures increased. Effective precipitation reached levels greater than at any time since 40,000 years BP.

From 9,000 years BP onwards, *Nothofagus moorei* and other mesic elements were established. Swamp and aquatic vegetation returned and by 6,500 years BP peat began to form in the basin. By about 6,000 years BP, cool temperate rainforest had reached full development. Maximum moistures and temperatures (higher than present) were reached between about 9,000 and 5,000 years BP. Subsequently, with cooler and drier conditions, the swamp dried somewhat until about 2,000 years ago, after which present conditions were established. The cool temperate rainforest has remained on the site to the present day with peat deposition continuing to the present.

The initiation of peat formation, the peak in *Dicksonia* and the development of *Nothofagus* forests are all recognisable at Burraga, the other sites on the Plateau and elsewhere in southeastern Australia. While the trends of the occurrences are similar, the precise timing of the events vary in different localities. Evidently, the required environmental factors were achieved at somewhat different times in the diverse localities.

Burraga extends the record of treeless conditions during the height of the last glacial maximum to 15,000 years BP, to a more northerly locality than previously known.

Recommendations for future research

The extent of the Last Glacial Maximum grasslands north of Burraga, could be the focus of future studies.

In this current study, Burraga is at the southern limits of the *Nothofagus moorei* distribution. Studies of sites further north are needed to discover the history of *N. moorei* throughout its range.

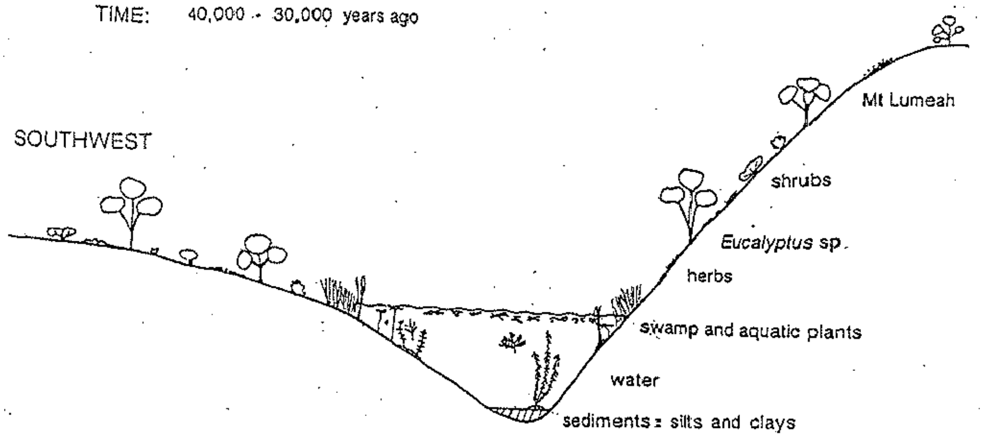
Figure 6

The following pages present diagrammatic representations of

40,000 years of change at Burraga

1

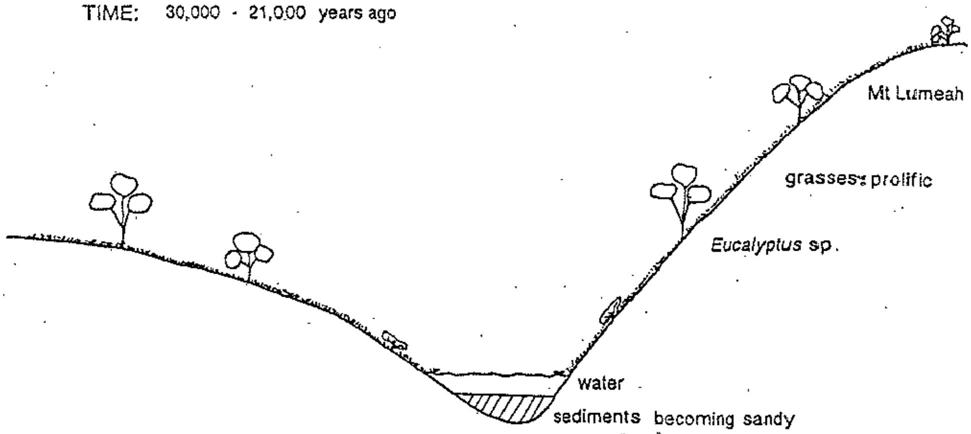
TIME: 40,000 - 30,000 years ago



CLIMATE: drier than present

2

TIME: 30,000 - 21,000 years ago

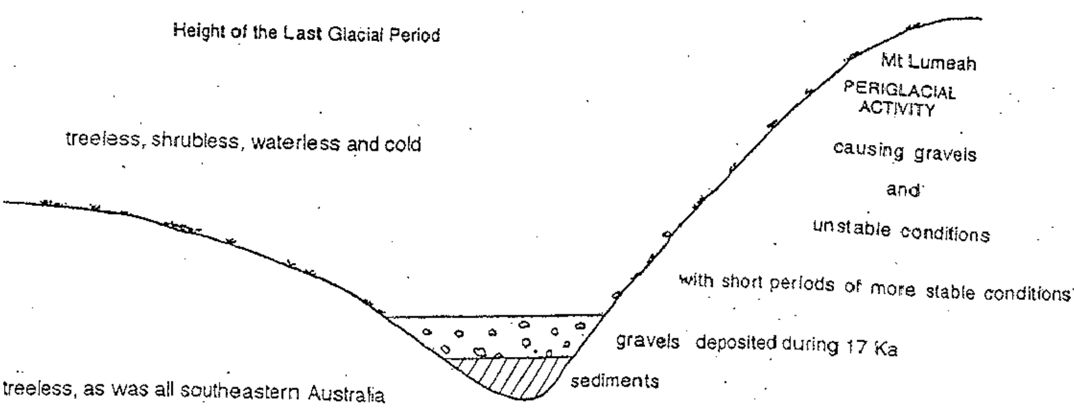


CLIMATE: drier than previously

3

TIME: 21,000 - 17,000 years ago

Height of the Last Glacial Period

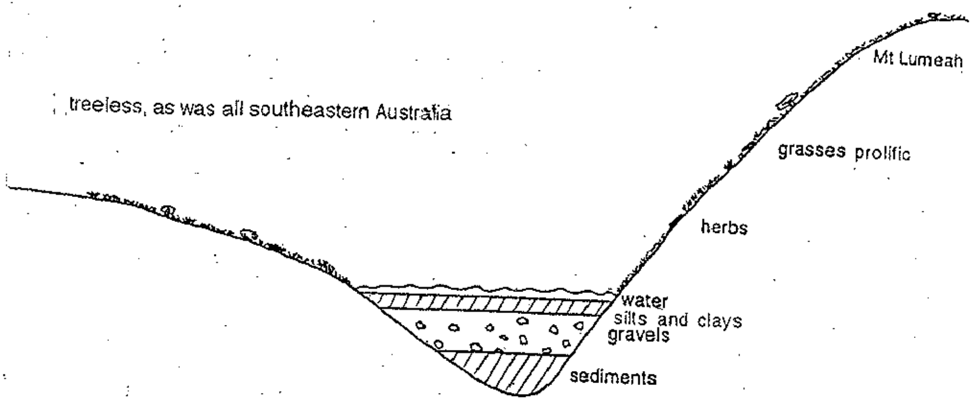


CLIMATE: drier than previously and much drier than today (50% less precipitation)
much colder than today (≈ 9°C lower)

summers were like winters are now

4

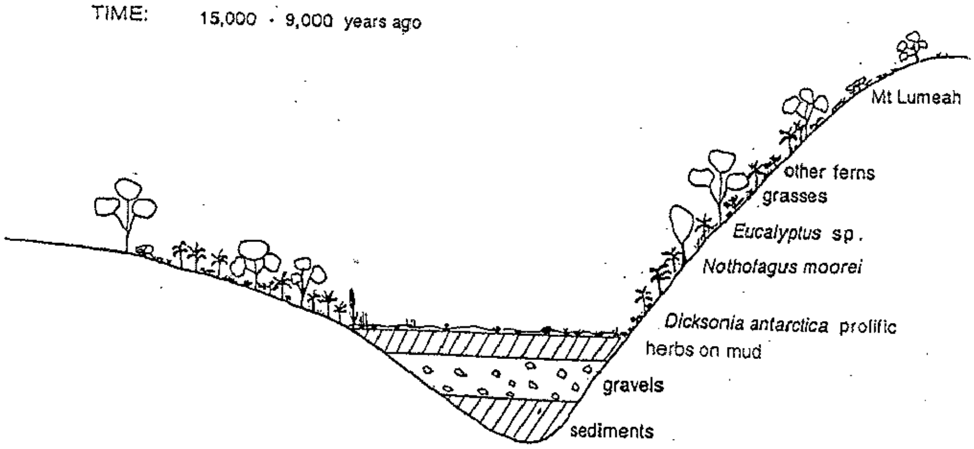
TIME: 17,000 - 15,000 years ago



CLIMATE: temperature increasing

5

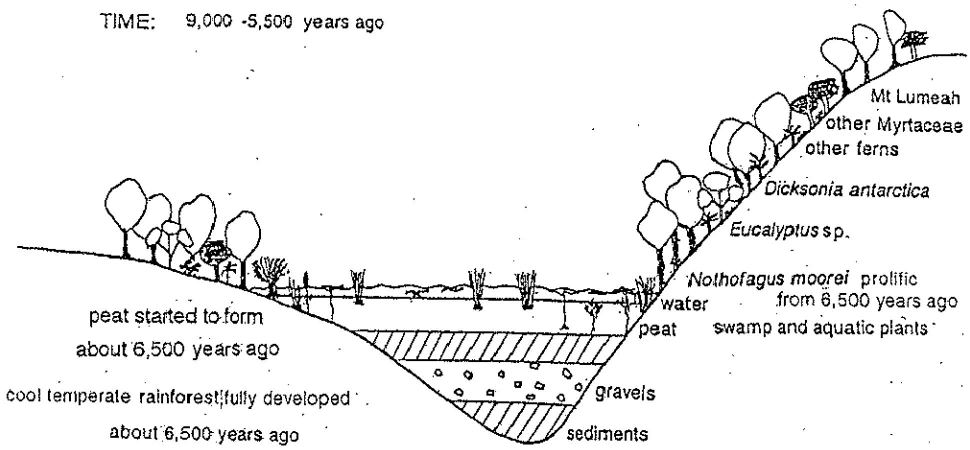
TIME: 15,000 - 9,000 years ago



CLIMATE: rainfall increasing
temperature increasing
seasonality greater than at present

6

TIME: 9,000 -5,500 years ago

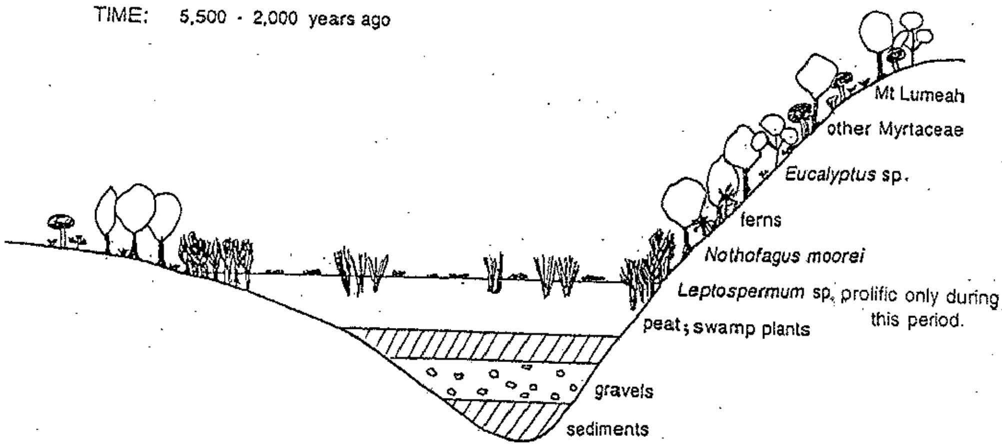


CLIMATE: maximum moisture (≈5 - 10% higher than present)

maximum temperature (≈1 - 2 °C higher than present)

7

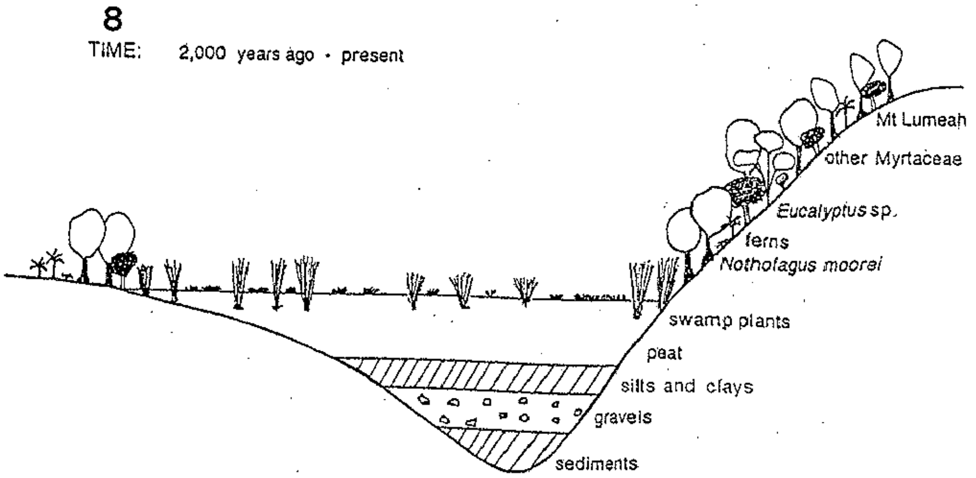
TIME: 5,500 - 2,000 years ago



CLIMATE: drier and cooler than just before and after

8

TIME: 2,000 years ago - present



CLIMATE: cool - humid to sub - humid (as at present)

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APPENDICES

APPENDIX 1 Species identified in the study area.

1, the swamp surface.
2, *Nothofagus* forest around the swamp.
3, Riverine subtropical forest, 11 km from the swamp.
d, disturbed areas. e, edge of forest. l, in light breaks.

SAMPLE SITES	1	2	3
Mosses			
Campylopus introflexus	+		
Dicronoloma dicarpum	+		
Holomitrium perichaetate		+	
Papillaria		+	
Pteridophytes			
Arthropteris tenella		+	
Dicksonia antarctica		+	
Hymenophyllum flabellatum		+	
Hypolepis sp.		+	
Lastreopsis microsora	+	+	
Microsorum diversifolium		+	
M. scandens	+	+	
Pellaea falcata		+	
Polystichum proliferum		+	
Pteris sp.	+e		
Angiosperms			
Apiaceae: *Hydrocotyle tripartita*	+	+	
Apocynaceae: *Parsonsia straminea*		+	
Asteraceae: *Gnaphalium gymnocephalum*	+		
Bignoniaceae: *Pandorea pandorana*		+	
Boraginaceae: *Ehretia* sp.			+
Brassicaceae: *Cardamine hirsuta*	+		
Casuarinaceae: *Casuarina* sp.			+
Cunoniaceae: *Ackama paniculata*		+	
Caldcluvia paniculosa		+d	
Schizomeria ovata		+	
Cyperaceae: *Carex appressa*		+l	
C. inversa	+		
C. lobolepis	+		
Cyperus lucidus	+		
Scirpus inundata	+		
Dioscoreaceae: *Dioscorea* sp.		+	
Ebenaceae: *Diospyros australis*		+	
Escalloniaceae: *Quintinia sieberi*		+	
Euphorbiaceae: *Croton verreauxii*			+
Fabaceae: *Acacia melanoxylon*			+
Cassia sp.			+
Fagaceae: *Nothofagus moorei*		+	

SAMPLE SITES	1	2	3
Juncaceae: *Juncus usitasus*		+	
Lauraceae: *Cryptocarya erythoxylon*		+	
Liliaceae: *Dianella* sp.		+	
Malvaceae: *Hibiscus* sp.			+
Meliaceae: *Synoum glandulosum*			+
Monimiaceae: *Doryphora sassafras*		+	
Daphandra tenipes		+	
Moraceae: *Ficus coronata*			+
Myrsinaceae: *Rapanea howittiana*		+	
Myrtaceae: *Acmena smithii*		+	
Backhousia sp.			+
Eucalyptus laevopinea		+	
E. saligna		+	
Syzygium australe		+	+
Tristaniopsis collina		+d	
T. laurina		+d	
Onagraceae: *Epilobium* sp.	+		
Orchidaceae	+		
Pittosporaceae: *Citriobatus* sp.		+	
Poaceae: *Agrostis avenacea*	+		
Echinopogon ovatus	+		
Glyceria australis	+		
Microlaena stipoides	+		
Phragmites australis	+		
Polygonaceae: *Polygonum subsessile*		+	
P. decipiens		+	
Proteaceae: *Orites excelsa*		+	
Rosaceae: *Rubus hillii*		+d	
R. rosifolius		+e	
Rubiaceae: *Coprosma quadrifida*		+	
Morinda jasminoides		+	
Rutaceae: *Melicope micrococca*			+
Sapindaceae: *Diploglottis australis*		+	
Scrophulariaceae: *Gratiola peruviana*	+		
Solanaceae: *Duboisia myoporoides*		+	
Solanum sp.		+	
Sterculiaceae: *Commersonia* sp.			+
Symplocaceae: *Symplocos* sp.		+	
Violaceae: *Hymenanthera dentata*		+	
Vitaceae: *Cayratia clematidea*		+	
Xanthorrhoeaceae: *Lomandra spicata*		+	

APPENDIX 2 Distribution of low frequency taxa. Habit: A, aquatics; C, climbers; H, herbs; S, shrubs; T, trees; ST, small tree; MT, medium tree; TT, tall tree

Reference: Harden (1990 – 1993)

Taxon	Habit	Distribution of taxon
Acronchia sp.	S to MT	In warmer rainforests and on their margins.
Apiaceae, not *Hydrocotyle* poss. *Oreomyrrhis ciliata* Or *O. eriopoda*	H, S	In and around bogs, often above treeline in alpine and subalpine areas south from Barrington Tops. In forest, alpine herbfield and heath at higher altitudes, south of Dorrigo.
Araliaceae poss. *Polyscias* sp.	C, S, T	Wet sclerophyll forest, in or on margins of sub-tropical warm or cool temperate rainforest, widespread in coast and ranges.
Asclepiadaceae poss. *Marsdenia rostrata*	C, H	Rainforest and wet sclerophyll forest, inland to Liverpool Ranges and Goulburn River valley.
Asteraceae Liguliflorae		
Banksia sp.	S	Heath and dry sclerophyll forest and woodland.
Brassicaceae eg. *Rorippa*	H	Mud or shallow water; forest.
Cardamine sp.	H	Moist sites from lower ranges to alpine regions. Damp forest on tablelands south from Barrington Tops. Grasslands at higher altitudes.
Cunoniaceae	S, T	Cool temperate rainforest dominated by *Nothofagus moorei*, often along streams.
Dodonea eg. *D. rhombifolia*	S, ST	Shrubland, in basaltic soil by creeks.
Elaeocarpus	S, T	In or on margins of cooler rainforest to 1500 m. Mainly on the ranges in gullies , or along water courses often in tall eucalypt forest.
Epilobium sp.	H	Along creek beds and in swampy areas; moist places.

Distribution of low frequency taxa. Habit: A, aquatics; C, climbers; H, herbs; S, shrubs; T, trees; ST, small tree; MT, medium tree; TT, tall tree

Reference: Harden (1990 – 1993)

Taxon	Habit	Distribution of taxon
Gonocarpus / *Haloragis*	H	Open forest; understorey of wet sclerophyll forest or rainforest. *G. humilis* in damp places, especially around creeks and drainage lines extending to Barrington Tops.
Labiate	H	*Prostanthera lasianthos* in rainforest, sclerophyll and subalpine woodland, mainly along water courses and in moist gullies.
Lomatia	S, ST	Heath, sclerophyll woodland, tablelands. *L. arborescens*-small tree in cooler rainforest or moist situations in wet sclerophyll forest at higher altitudes north from Barrington Tops, on margins of cool and warm temperate rainforest in mountainous areas.
Meliaceae	S, T	Subtropical and dry rainforest , warmer rainforest.
Orites	T	Cooler rainforest especially at higher ranges.
Papilionaceae	S	Wet sclerophyll and rainforest margins; heath and forest, often in swampy to well drained places. Some in dry sclerophyll; subalpine to alpine grasslands or woodland south from Barrington Tops.
Parsonsia	C	Cool and warm temperate rainforest south from Dorrigo district, woodland, vine thicket, dry rainforest.
Persicaria	H	Margins of swamps, lagoons, bank of streams.
Pimelia *Pinus*	H, S, ST T	Forest and grasslands. In open forest and heath, chiefly on ranges, south of Barrington Tops. Introduced and grown in plantations on Barrington Tops, approx. 20 km upland from swamp; a few trees on Mt Allyn Rd 7 km SE of swamp, at lower elevation.
Podocarpus	S, T	Alpine shrub; in and around rainforest.
Polygonaceae	C, H, S,	Moist situations in forests and rocky slopes near streams at higher altitudes.

Distribution of low frequency taxa. Habit: A, aquatics; C, climbers; H, herbs; S, shrubs; T, trees; ST, small tree; MT, medium tree; TT, tall tree

Reference: Harden (1990 – 1993)

Taxon	Habit	Distribution of taxon
Rubiaceae	H S, T	*Galium* sp.: grasslands and woodlands esp. at higher altitudes; moist shaded sites in rainforest or wet sclerophyll. *Asperula gunnii*: wooded and grassland areas in damp sites at higher altitudes in Barrington Tops district. *Coprosma*: damp sites at higher altitudes, usually on hillsides in woodland or scrub, sclerophyll forest and cool temperate rainforest, usually along creeks; *C. nitida*: eucalypt woodland recorded only from Barrington Tops.
Scrophulariaceae	H	Damp places; in silt and mud of swamps, streams and shallow water or on dried ground; depressed areas after flooding; wet sclerophyll forest and rainforest. *Veronica* sp: moist eucalypt woodland, grassland or swampy sites 1,000 – 1,500 metres altitude in Barrington Tops area; *Euphrasia ciliolata*: grassy sites or near bogs or swamps and in subalpine woodland chiefly in Barrington Tops.
Tasmannia	S	Small creeks or drainage lines near or along edge of *Nothofagus moorei* rainforest and in tall moist eucalypt forest usually above 1,000 m altitude at Barrington Tops.
Triglochin	A	Stationary or flowing fresh water in a variety of habitats; shallow seasonal or ephemeral wetlands.
Typha	A	Swamps, margins of lakes and streams.
Urticaceae	H, S	Mountain gullies, well drained sites, moist shady situations in forests, at higher altitudes in *N. moorei* forest.

APPENDIX 3 Grain identification

(i) Deterioration

Deteriorated pollen and spore grains have been classed according to the following key devised by Cushing and Wright (1967).

Type of grain deterioration	Description
Corroded	Distinctive etching or pitting randomly all over surface.
Degraded	Usually entire exine affected equally; aperture recognisable, but difficult to resolve sculptural and structural detail; walls may become amorphous.
Crumpled	Badly folded, wrinkled or collapsed, twisted or distorted so original shape cannot be reconstructed; exine normal but may be thinner; endexine attacked.
Broken	Exine ruptured, break must extend through ecktexine.

(ii) Certainty of identification

Cushing and Wright (1967) suggested the following "rules" and these were used in this thesis.

Determinable grains	(a) can be assigned to recognisable taxon OR (b) can be recognised as distinctive type, but cannot be assigned to any formally named taxon
Indeterminable grains	(a) cannot be differentiated into distinct type but precise description is possible and grains are recognisable whenever encountered. (b) concealed: essential features obscured by particles surrounding or adhering to them.

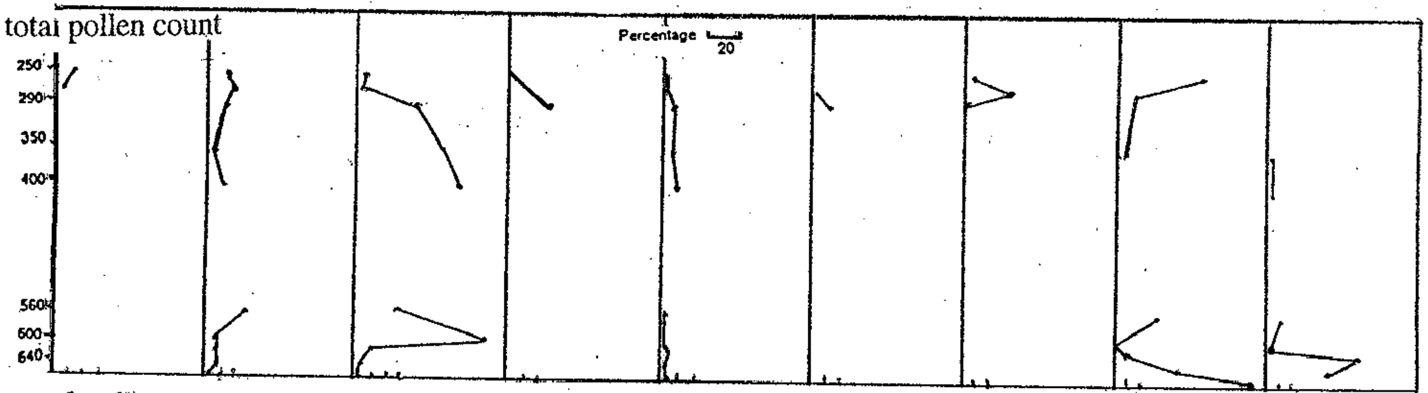
APPENDIX 4 Graphs comparing two different ways of expressing pollen sum:

(i) pollen sum = total pollen count

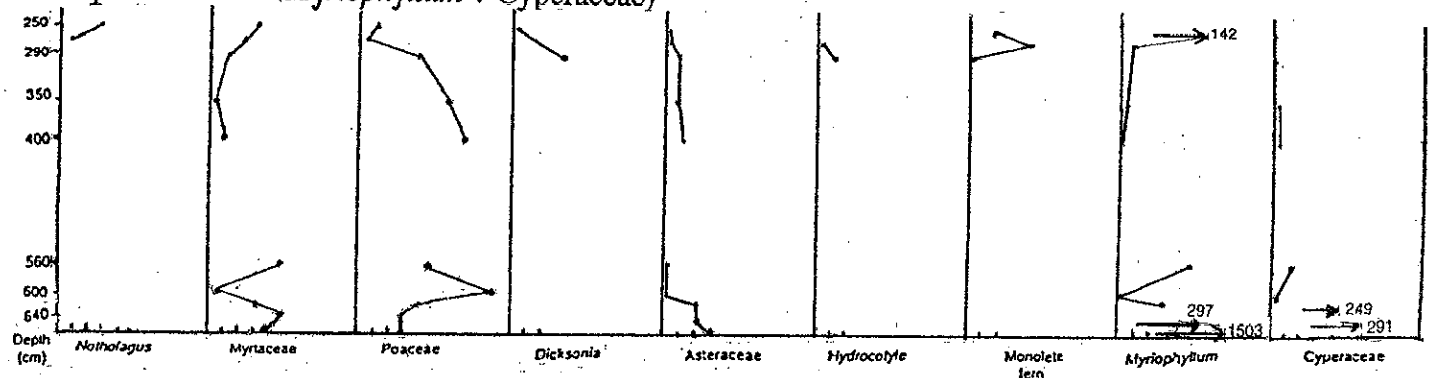
(ii) pollen sum = total pollen count excluding over producing pollen (aquatics, *Myriophyllum* and Cyperaceae)

Only selected pollen types and selected levels in the mineral section are graphed.

Graph (i) Pollen sum = total pollen count



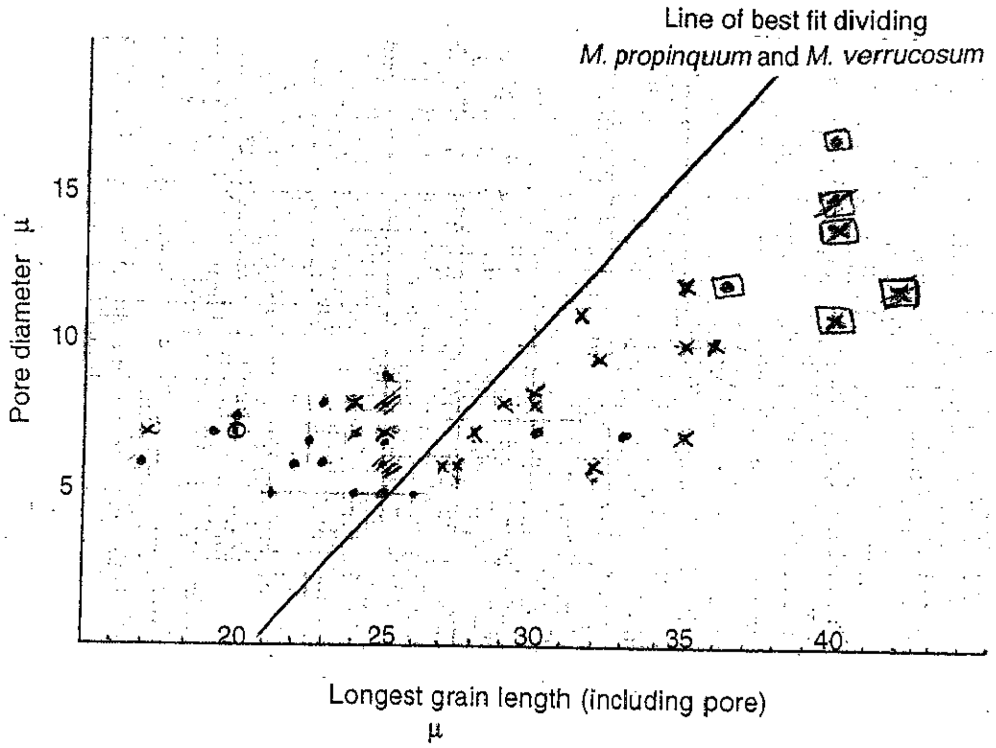
Graph (ii) Pollen sum = total pollen count - (*Myriophyllum* + Cyperaceae)



These graphs indicate that changing the pollen sum by excluding over producers, simply causes the percentage values to be exaggerated. The smaller the numbers of grains counted for a particular species (thus lower percentages), the larger the effect. For example, the low Asteraceae count translates into a large exaggeration in graph (ii); similarly, a low Poaceae count near the base is greatly exaggerated while around 600 cm level, a large percentage count is almost unaffected. Thus, it is preferable to use total pollen count as the pollen sum and glean extra information from grain concentrations.

APPENDIX 5 Differentiating *Myriophyllum* species on grain / pore size.

Pollen of *Myriophyllum propinquum, M. verrucosum* and *M. pedunculatum* were measured for grain length and pore size. The results were plotted on the graph below.



M. propinquum • 3 pored

M. verrucosum × 4 pored

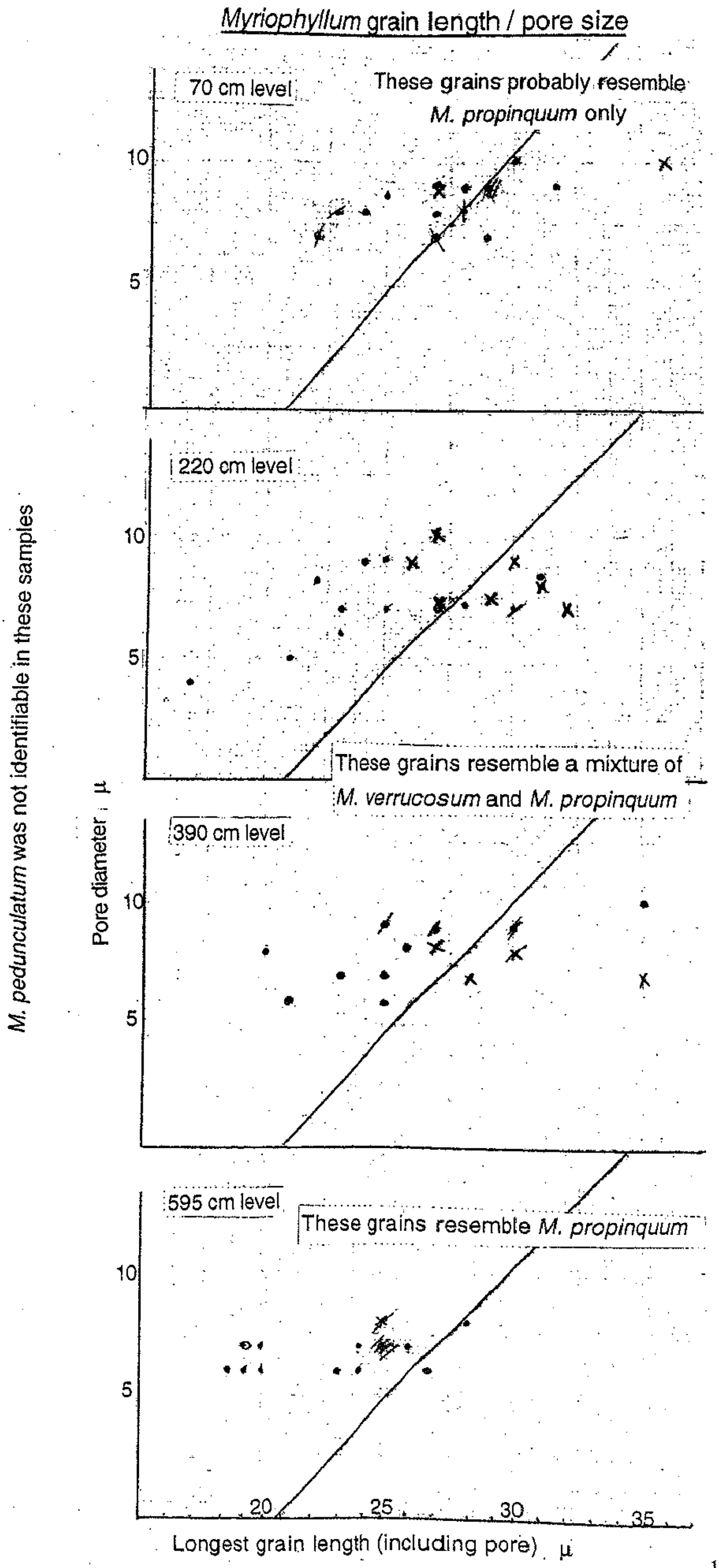
M. pedunculatum ▣ 3 pored and ⊠ 4 pored

Each / denotes extra grain. ⦿ 2 pored

The line of best fit from the above graph is used on the analysis graphs on the next page.

Selected levels from Core1 were used for the following analysis. Measurements of grain length and pore diameter of *Myriophyllum* grains were taken and plotted on the graphs on the following page. It appears that during the history of Burraga Swamp, more than one species of *Myriophyllum* inhabited the basin.

The ecologies of these three *Myriophyllum* species are outlined in Table 4.3a.



Myriophyllum grain length / pore size
70 cm level
These grains probably resemble M. propinquum only
220 cm level
These grains resemble a mixture of M. verrucosum and M. propinquum
390 cm level
595 cm level
These grains resemble M. propinquum
10
5
20
25
30
35
Pore diameter μ
Longest grain length (including pore) μ
M. pedunculatum was not identifiable in these samples

APPENDIX 6

Copy of

Sweller, S. and Martin, H.A. (1997). History of the vegetation at Burraga Swamp, Barrington Tops National Park, Upper Hunter River Region, New South Wales. *Proceedings of the Linnean Society of New South Wales,* **118,** 23-50

APPENDIX 7

Copy of

Sweller, S. and Martin, H.A. (In Press).

A 40,000 year vegetation history and climatic interpretation of Burraga Swamp, Barrington Tops, New South Wales.

Quaternary International, **82-83.**