

Late Quaternary environmental change and the impact of Melanesian colonisation in New Caledonia

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Late Quaternary Environmental Change and the Impact of Melanesian Colonisation in New Caledonia

By
Janelle Stevenson

A thesis submitted for the degree of Doctor of Philosophy
at the University of New South Wales
Sydney, November 1998.

Abstract

Relatively little is known of the long term environmental history of tropical south Pacific islands. In addition there is some debate as to whether pollen evidence for vegetation disturbance in the late Holocene is an appropriate proxy for human presence and whether such evidence can contribute to debates concerning island colonisation in the south Pacific.

This thesis reports the results of vegetation history analyses carried out in New Caledonia. Three lowland sites from the main island (all below 10 m asl) were investigated using pollen and spore counts, charcoal counts and stratigraphic analysis. Plum Swamp on the leeward coast of New Caledonia provides a continuous record from the last glacial maximum (LGM) to the present, while the sediments analysed from Lac Saint Louis and Canala Swamp are mid to late Holocene in age.

The results of the study are:

- 1) Littoral forest and lowland rainforest in the Plum River Valley did not undergo dramatic change during the last glacial maximum. The valley remained forested.
- 2) Vegetation disturbance associated with fire occurred between 16 - 12,000 yr BP, but the composition of the vegetation did not change significantly.
- 3) Present day climatic conditions appear to have been in place around 12,000 yr BP.
- 4) A dramatic vegetation shift from littoral forest and lowland rainforest to a *Melaleuca* woodland and open shrubland occurred around 3000 yr BP, coinciding with the commencement of the archaeological record for the island.

Plum is one of only two truly lowland sites in the tropics to record persistent rainforest cover during the LGM. This suggests that reduction of precipitation during the LGM in tropical islands may not be as great as generally thought. Given the lack of data from Pacific islands, this has important implications for global reconstructions of LGM climate. While vegetation disturbance caused by fire has a long history in the New Caledonian environment, it is the arrival of people at around 3000 yr BP that has had the most dramatic impact on the island's vegetation since the LGM. The pollen records suggest that the vegetation surrounding the sites has changed little over the last 3000 years.

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In 1995 Ian took up a position with CSIRO in Canberra and so I was generously given visitor status with the Department of Archaeology and Natural History at the Australian National University. I am grateful to the Department for providing me with the space and resources that allowed me to carry on here in Canberra. In particular I would like to thank Geoff Hope for taking on the role as my supervisor and all that that entails. Mike McPhail whose awesome knowledge of pollen taxonomy has been invaluable to this project is also thanked. Special thanks go to Simon Haberle, who has been a visiting fellow in ANH for the last twelve months and a constant source of enthusiasm, support and ideas, and who very generously read this manuscript. A big thankyou to Jean Kennedy who has kindly proof read the opening chapters of the thesis and for her valuable comments.

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Chapter 1

Introduction

This thesis investigates the causes of vegetation change on New Caledonia over the last 20,000 years through the technique of fossil pollen analysis. It focuses on the issue of human impact, whether it can be detected in the palaeoenvironmental record, and if so, is it in accordance with the archaeological record for the island and the region. To assess the role people may have in changing landscapes, the longer term record must also be analysed and vegetation change examined in light of the major climatic shifts of the last 20,000 years. The thesis thus endeavours to make a contribution to our understanding of the response of island ecosystems to climate change, the timing of change in the region and its global implications. These questions are investigated by detailed stratigraphic and palynological studies of lowland swamp sediments combined with modern pollen rain studies. Archaeological evidence of the once widespread and intensive agricultural practices of New Caledonia's indigenous population, as well as historical accounts of their plant usage, are also considered when unraveling the story of human impact on the landscape. Overall the thesis contributes to our understanding of climatic change and human history in New Caledonia and the southwest Pacific region.

1.1 Prehistory and environmental history of the Southwest Pacific

Our current knowledge of southwest Pacific archaeology and environmental change is being reviewed in this section for two purposes. Firstly it is necessary to put the thesis in the context of current scientific debates concerning the human colonisation of the southwest Pacific and the records of human impact on Pacific island landscapes. Secondly, it is important to review what is known about the palaeoenvironmental history of the region since the Last Glacial Maximum (LGM) as climate change is a forcing factor in vegetation change. An understanding of the climatic changes that have occurred in the region is important for establishing how we might separate natural from humanly induced changes to the landscape in the fossil record and whether records of vegetation change are admissible as proxy records of colonisation.

Human Colonisation of the Southwest Pacific

The Archaeological Evidence

Pleistocene occupation sites in the Bismarck Archipelago and on Buka Island at the northern end of the Solomon Islands chain record the early movement of people into northwest Island Melanesia (Allen *et al.*, 1988; Allen and Gosden, 1991; Wickler and Spriggs, 1988). It is thought that people could have moved quite quickly through the Solomon chain given the short inter-island distances, which were even narrower prior to 6000 yr BP¹ than they are today (Wickler & Spriggs 1988; Spriggs, 1997:23). Nevertheless, no evidence of this early movement has yet been uncovered, and the oldest archaeological evidence from the southeastern Solomons is from Guadalcanal, dated to around 6000 yr BP (Roe, 1993). There is consensus that for the islands east of the Solomons colonisation took place from around 3200 yr BP, with most early sites containing a distinctive pottery known as Lapita. Over the next millennium or so, there are numerous archaeological sites containing Lapita pottery that stretch as far as Samoa in the east (Figure 1.1). Pottery is rarely found beyond Tonga and Samoa and human settlement is defined by other archaeological evidence. This evidence suggests that the Cook Islands, the Marquesas Islands, the Society Islands, Easter Island and Hawaii were all colonised between 2500 - 1000 yr BP (Kirch and Ellison, 1994; Spriggs and Anderson, 1993). New Zealand was colonised later, probably around 600 yr BP (Anderson, 1991). Some islands, such as Lord Howe island, appear never to have been settled, whilst others, such as Norfolk Island, were abandoned prior to European contact.

The time gap that exists between the colonisation of the Solomons and the islands to the east led to speculation about an earlier movement of people into the southwest Pacific, specifically one predating Lapita pottery. New Caledonia in particular tantalised the imagination in this respect with its large earthen mounds, or tumuli, three of which have published dates which span 13,000 to 3,000 yr BP (Green and Mitchell 1983). The tumuli, with their central 'concrete' cylinders, were thought originally to have a cultural origin. This proposition was largely discounted after the discovery of *Sylviornis neocaledoniae*, a large flightless bird, assumed to have had a mound building habit, which became extinct shortly after human arrival (Green and Mitchell 1983; Balouet

¹ "yr BP" refers to uncalibrated years Before Present inferred from radiocarbon dating or other age determinations.

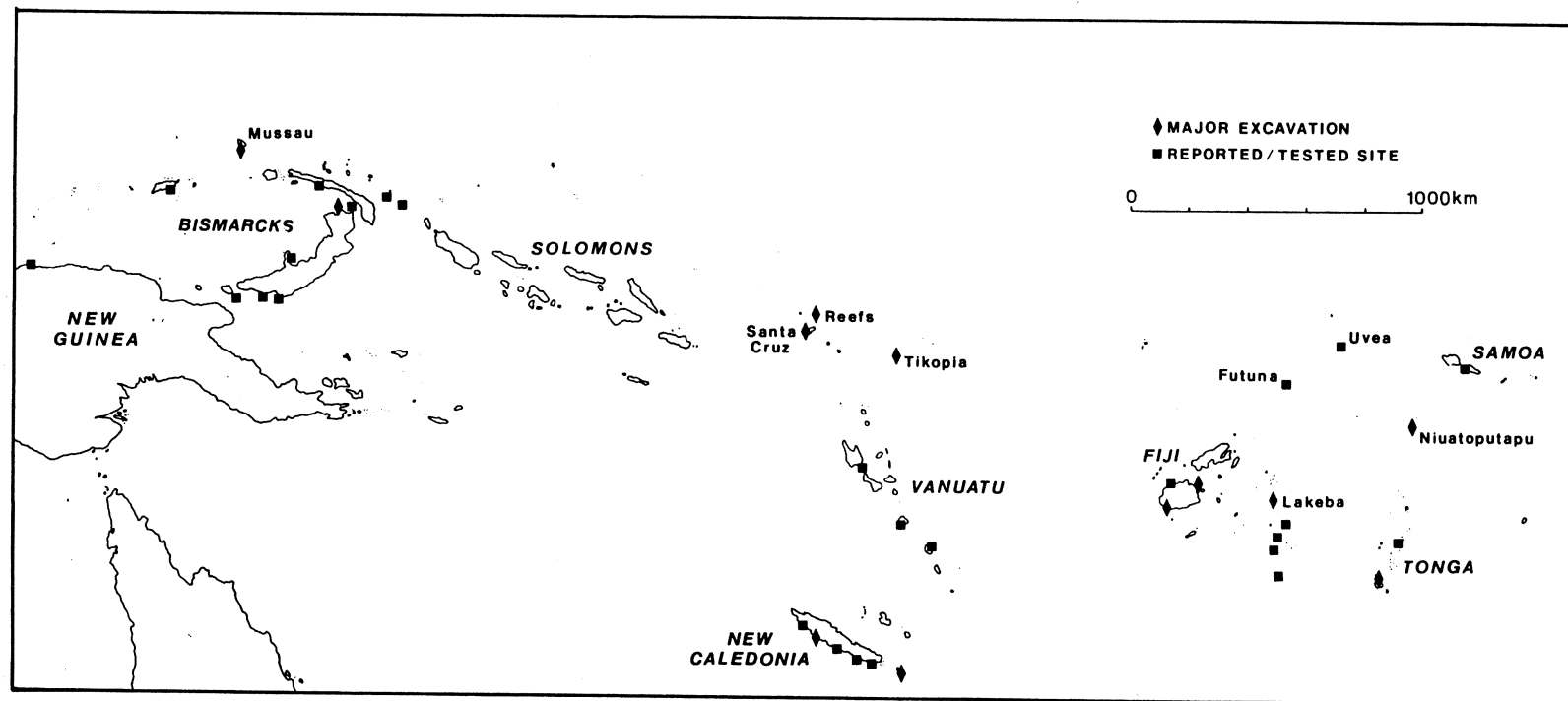


Figure 1.1: Map of the southwest Pacific region, showing the locations of known Lapita sites which have been excavated or reported. Modified from Kirch (1998).

and Olson, 1989). However, *Sylviornis* is no longer considered a megapode and *Megapodius molistructor*, also extinct, is now considered the most likely candidate for a natural origin (Balouet, 1991; Golson, 1996). The only remains found that associate the mounds with humans, have been a single skeleton thought to have been incorporated at a later date (Green and Mitchell, 1983). However, while no cultural material apart from this has been found, neither have any bird remains. The origin of the mounds thus remains somewhat unresolved (Golson, 1996) but a natural rather than cultural mechanism is generally preferred (Green 1988; Sand 1996). The tumuli of New Caledonia have been the only evidence proposed in support of an earlier colonisation of the southwest Pacific east of the Solomons.

Evidence of Human Impact

Indirect evidence of human colonisation includes environmental change attributed to humans, for example vegetation disturbance, the introduction of non-native flora and fauna, extinctions and geomorphic change. The colonisation of the Pacific has been investigated largely through archaeological and linguistic evidence, with only a few fossil pollen records providing a backdrop of environmental change. Here the question is whether palynological studies can provide evidence for human presence, just as they do for climate change.

A growing body of evidence exists to suggest that human activities have significantly modified environments wherever settlement has occurred in the Pacific. The debate over whether signs of human impact in pollen and sedimentary records can be accepted as primary evidence for human presence has increased following work undertaken in the Cook Islands, where vegetation change from forest to open grass/fermland at around 2500 yr BP was detected through pollen analysis and interpreted as a result of early human impact. Significantly, this vegetation change precedes the archaeological evidence for first occupation by 1500 yr (Anderson, 1994, 1995; Ellison, 1994; Kirch and Ellison 1994). A central hypothesis with regard to vegetation and geomorphic change on Pacific islands is that colonisation was accompanied by the rapid deforestation of hill slopes for swidden agriculture, utilising fire. This is assumed to have led to increased rates of erosion and later to be followed by more conservative agricultural practices such as the construction of irrigated terraces (Kirch, 1997; Spriggs,

1997b). The initial colonisers also brought about extinctions in the native fauna (Olson and James, 1984; Steadman, 1989, 1997). Many tropical Pacific islands support large tracts of depauperate vegetation, largely consisting of grasses and ferns, which are considered to be of anthropogenic origin. While there are floristic differences between grass/fernland communities from the different islands, the maintenance of each community by fire is a common feature. Latham (1983) and Nunn (1994) have disputed the anthropogenic origin of these landscapes on Fiji, pointing to the correlation of the grass and fernlands with an environment of low rainfall and low soil fertility, and thus seeing a natural origin as more plausible. The alternative view to large scale anthropogenic impact thus suggests that human impacts on Pacific island environments, especially in terms of vegetation and geomorphic change, have been overestimated and non-human impacts such as climate change have been underestimated (Nunn, 1994).

Kirch (1997) has reviewed the changing attitudes of Pacific researchers since the initial voyages of discovery by Europeans in the late 18th Century, and has highlighted how very recently it has come to be generally accepted that people were responsible for the creation and maintenance of many secondary vegetation types seen on tropical Pacific islands. Once this was recognised, hypotheses were put forward concerning the part that the initial colonisers played in this landscape change. Accounts in the Pacific archaeological literature of how the initial colonisers of Pacific islands rapidly altered their island landscapes through deforestation of hillslopes for gardening are fairly commonplace. Yet until recently, evidence for vegetation change has been slight and theories regarding this have been based primarily on the preliminary study of Hope and Spriggs (1982) from Vanuatu; the Easter Island work of Flenley and King (1984); and the unpublished work of Southern (1986) (Figure 1.2). Extrapolation from the relatively large body of work conducted in New Zealand has also been influential (see McGlone 1983 and 1989 for an account of early New Zealand work). Significantly, it is the apices of the Polynesian triangle, settled much later than Melanesia, that have been the most influential in shaping our views of human impact in the Pacific. In recent years more sites have been published from tropical south Pacific islands and a number of studies have evidence of vegetation change to a more open landscape coincident with the start of the archaeological record (Figure 1.3). Although not shown in Figure 1.3,

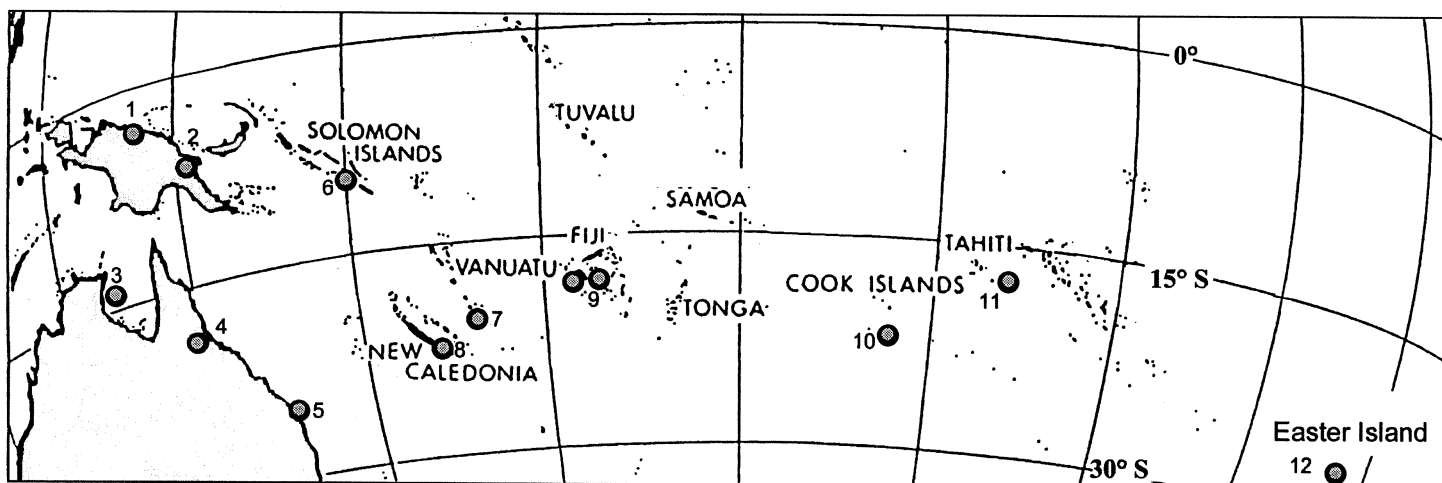


Figure 1.2: Map of the south Pacific between 0° and 30° S showing the locations of fossil pollen sites. For New Guinea only the lowland sites are shown. Listed below are the sources and age depth of each site. Pleistocene sites in ***bold italics***.

1. ***Lake Hordorli (Hope and Tulip, 1994) 0-60,000 BP.*** 2. Markham Valley (Garett-Jones, 1979) 0-10,000 BP.
3. Groote Eylandt (Shulmeister, 1992) 0-10,000 BP. 4. ***Atherton Tableland (Kershaw, 1976, 1986) 0-190,000 BP.***
5. ***Fraser Island (Longmore, 1997) 0-possibly 600,000 BP.*** 6. Guadalcanal (Haberle, 1996) 0-3000 BP.
7. Aneityum (Hope and Spriggs, 1982) 0-6500 BP. 8. ***Plaine des Lacs (Hope and Pask, 1998) basal sediments > 40,000 BP.*** 9. Fiji (Southern 1986) ***Tavenui 0-23,000 BP,*** Viti Levu 0-4000 BP. 10. Cook Islands; Atui (Parkes, 1997) 0-9000; Mangaia (Ellison, 1994) 0-8000 BP. 11. Mo'orea (Parkes, 1997) 0-2500 BP.
12. ***Easter Island (Flenley et al., 1991) 0-40,000 BP.***

similar records have been published from Micronesia (Athens and Ward, 1995) and Hawaii (Athens and Ward, 1993; Athens, 1997).

The pollen records from Guadalcanal in the Solomon Islands are somewhat different to the other data illustrated in Figure 1.3, as they are younger than the substantive archaeological record for the island. The pollen composition and charcoal values from two sediment cores change between 3200 and 2100 yr BP (Haberle, 1996). Essentially this change is an increase in disturbance taxa associated with an increase in charcoal particles. While these changes are not as dramatic as those recorded for the other smaller Pacific islands, they are in accordance with archaeological theory for the island, which suggests that people began to move inland at this time for the purpose of more intensive agricultural practices (Roe, 1993).

Vanuatu, Fiji, the Cook Islands, and further to the east the Society Islands and Easter Island all have records that show various types of lowland tropical forest replaced by savanna or a grass/fermland associated with charcoal around the time of initial settlement (Figure 1.3). At Bonatoga Bog in Fiji, the vegetation change from coastal forest to secondary forest and grass around 3200 yr BP is not accompanied by a significant increase in charcoal. Southern (1986:186,217) speculated that the presence of charcoal throughout the Fiji record may have been evidence that colonisation of the island occurred before the accepted archaeological date of 3000 yr BP. On Mangaia in the Cook Islands, Ellison (1994) has two sites that show declining values of forest pollen, the appearance of charcoal and an influx of clay sediments at around 2500 yr BP, some 1500 years earlier than the archaeological evidence for human occupation. Anderson (1994) argued that the 2500 yr BP dates were too old, or, if not, that events may be natural and not anthropogenic. From here the debate over the chronology has continued (Kirch and Ellison, 1994; Anderson 1995; Kirch, *et al.*, 1995; Kirch, 1996). The vegetation change is certainly in keeping with records accepted elsewhere in the Pacific as being the result of human activity and so the debate has essentially become one of how accurately the pollen core has been dated. Further dating on a range of materials associated with the critical level in the sediments of the sites may resolve this issue.

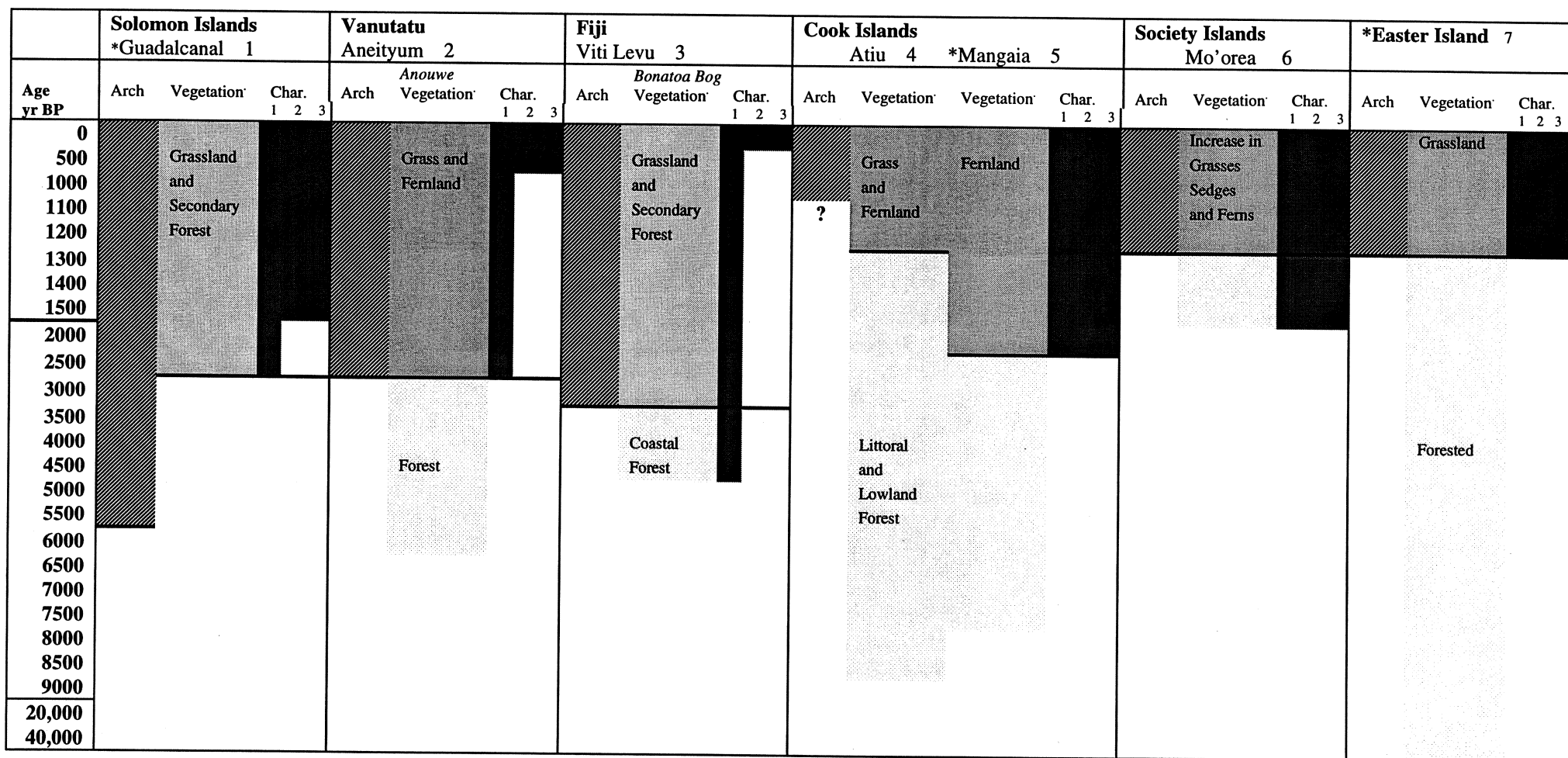


Figure 1.3: A summary of the pollen records from the tropical south Pacific that have interpretations of human impact associated with them. Shows age in yr BP of the substantive archaeological record (Arch), the age in yr BP of the pollen records, the human impact boundary for each location, the vegetation change observed and a diagrammatic representation of the charcoal curves (1 low levels; 2 moderate levels; 3 high levels). The charcoal levels are representative of internal changes only, and cannot be compared between islands. * indicates where two or more sites have been amalgamated. Note change of time scale at 2,000 and 9,000 yr BP. The sources are 1. Haberle (1996); 2. Hope and Spriggs (1982); 3. Southern (1986) and Hope *et al.* (in press); 4. Parkes (1997); 5. Ellison (1994); 6. Parkes (1997); 4. Flenley *et al.* (1991). Age of archaeological record is derived from a variety of sources, notably Spriggs and Anderson (1993).

The timing from indirect evidence of initial colonisation in New Zealand has also become a contentious issue. The late colonisation of New Zealand (around 600 yr BP (Anderson, 1991) relative to the rest of the Pacific makes it an ideal location for assessing human as opposed to climatically induced vegetation change in Holocene pollen records, keeping in mind that it is a more temperate and much larger landmass than the tropical islands under closer review. The general picture that emerges from such records is for vegetation disturbance associated with fire to be a natural part of the Holocene environment (McGlone, 1989). However, large scale vegetation disturbance associated with much higher charcoal levels resulted in the formation of extensive grasslands after Polynesian occupation and with continued burning the creation of large tracts of fernland dominated by *Pteridium esculentum*. Some studies have suggested that this dramatic vegetation change occurred as early as 1000 yr BP (see McGlone and Wilmshurst [*in press*] for relevant studies). A review of the human impact records from New Zealand (McGlone and Wilmshurst, *in press*) concluded that the clays and silts of lake and swamp sediments give less accurate age determinations than ombrophilous peat bogs. While a number of factors can account for inaccurate age estimations, the most serious in this case was felt to be contamination by old carbon washed into the site. This has been highlighted by sites with tephra layers of a known age, where overlying sediments return an older date. Such a review may well prove useful for assessing the dates associated with human impact from the more contentious sites in the tropical Pacific such as the Cook Islands. However, there is so little published data from any one region that evaluating the results in a similar manner to McGlone and Wilmshurst (*in press*) is not possible as yet.

Geomorphic change following initial colonisation has been just as dramatic on some islands as vegetation change. The study of Hughes *et al.* (1979) of the small island of Lakeba, Fiji, is an important piece of early research which contributed to theories of landscape change by the initial colonisers. The study investigated the sedimentation histories of two coastal swamps, and the same data appears in Latham *et al.* (1983), with the addition of a third swamp. Vegetation change could not be studied from the sediments as they proved unsuitable for pollen analysis, containing only poorly preserved pollen. However, the authors concluded, based largely on the results from

Waitabu, the most extensively dated site, that colonisation of the island by people resulted in deforestation in association with fire, followed by massive hillslope erosion. While there is no positive evidence from the records regarding vegetation change the increased accumulation of sediment after 1900 yr BP does appear significant. However, there are age reversals in the sequences and the reliance on a single sediment core from each site suggests that greater effort is required to resolve the chronology and genesis of each site before using these sedimentation histories as positive evidence for major geomorphic change following deforestation. The study remains important however, because it attempts to relate accumulation rates within the swamp to catchment erosion even though it is dependent on a fairly poor chronology. This is something that is rarely attempted elsewhere, as most of the valleys studied are not closed systems and the losses from coastal river valleys to the sea are difficult to quantify.

Two more islands that have served as benchmarks in this area of research are Tikopia and Aneityum. Tikopia, which is only 4.6 km² in area has had its land area increase by around 40% since the arrival of people around 3000 years ago (Kirch and Yen, 1982; Kirch, 1983). It is believed that deforestation of the island's volcanic cone led to massive rates of erosion (Kirch and Yen, 1982:147-160; Kirch, 1983). On Aneityum, Spriggs (1981, 1986) describes alluvial deposits on a coastal plain overlying fringing reef now 400 m from present coastline. The tectonic stability of Aneityum over the last 4000 yr suggests massive coastal progradation since the arrival of people around 3000 yr ago (B. Pillans *pers. comm.*). The dramatic vegetation change in the pollen record from Aneityum is also associated with the inwashing of inorganics. More recent geomorphic studies from elsewhere support the idea of increased erosion of hillslopes and increased sedimentation in the valleys, as well as subtle changes to coastal foreshores as part of the overall signal of human impact. These include Aitutaki, Cook Islands (M. S. Allen, 1997), Mo'orea, Society Islands (Lepofsky *et al.*, 1996), Oahu, Hawaii (J. Allen, 1997). However, Nunn (1990 and 1994) has been critical of the interpretations of increased erosion and sedimentation in coastal valleys being the result solely of human impact, and argues for the greater significance of sea level change to explain the geomorphological alteration of coastal landscapes. In addition he cites major

landsliding under forested catchments in Fiji during extreme rainfall events in 1986 as evidence for the important role climate plays in landscape disturbance (Nunn, 1990).

Nevertheless, the nature of the human impact data from the tropical south Pacific so far increases confidence that island landscapes were dramatically transformed shortly after initial colonisation and that improving this data base should allow vegetation and geomorphic change to be used as proxy evidence for human presence where archaeological evidence remains elusive.

Prehistory of New Caledonia

Having considered aspects of Pacific prehistory and records of human impact in general for the tropical south Pacific, a review of the prehistory of New Caledonia is presented, as the timing of colonisation and the ensuing modification of the landscape are two central issues being addressed by this thesis. Until recently Green and Mitchell's (1983) paper was the only review of New Caledonia's prehistory available in English. Since that time, but particularly since the beginning of the 1990's, a large body of work has been carried out and published largely by researchers at the New Caledonian Museum. Sand (1996) has comprehensively reviewed what is now known of the island's prehistory and it is from this in particular that much of the following is drawn.

While there are many archaeological sites recorded for New Caledonia, few have been excavated in detail. What we do know is that the archaeological record commences with ceramics at around 3000 yr BP, although the possibility of a pre-ceramic population for the island still has a place in the current archaeological research program (Sand, 1996). The prehistory of the territory can be classified into three periods, each defined by ceramics. The first, the Koné period, contains Lapita pottery which is characteristic of initial settlement across island Melanesia. Galipaud (1990) and others prefer to call this first period Koné, rather than Lapita (the latter term more generally used across the southwest Pacific) as this period contains another style of pottery called Podtanean contemporaneous with Lapita. For some time the possibility that there had been two distinct groups of potters was entertained, but evidence now seems to suggest that the Podtanean style complemented Lapita and was probably utilitarian, whereas

Lapita was a more prestigious ware (Galipaud, 1990; Sand, 1996). Figure 1.4 sets out the chronology for New Caledonia's known prehistory. Many aspects of the island's prehistory are still unresolved hypotheses.

The oldest ages from archaeological excavations are shown in Table 1.1. The three oldest radiocarbon ages (shaded) are discounted by Sand (1996) based on problems he feels exist with the stratigraphic context, sampling, sample chemistry, possible disturbance and lack of correlation with other dates. Green and Mitchell (1983) also pointed to problems with the Vatcha level IV date. The earliest archaeological evidence for human occupation is therefore commonly accepted to be around 3000 yr BP, which is in keeping with dates for initial colonisation of the region from Vanuatu to Fiji (Kirch and Hunt, 1988; Spriggs, 1990).

The evolution of the ceramic and non-ceramic material culture is reviewed in Sand (1996) readers are directed to this. More pertinent to my research is evidence for the exploitation of the island's natural resources and the development of horticultural sites.

Shell remains from archaeological levels of the Koné period indicate that bivalves formed a staple of the diet initially, with a move toward gastropods over time. Fish otoliths indicate a preference for small fish found close to shore or in mangroves, with crab and crayfish also part of the diet. There are also deep water fish and turtle remains that indicate offshore fishing took place (Sand 1996).

The terrestrial fauna was also exploited by these early colonisers and the bone remains of *Sylviornis neocaledoniae* (a large flightless bird), *Mekosuchus inexpectatus* (a type of land crocodile), *Meiolania mackayi* (a horned tortoise) and a *Varanus* sp. (large lizard) are found in archaeological deposits (Balouet, 1991). It is hypothesised that these, as well as at least 40% of New Caledonia's non-perching birds and a number of other elements of the New Caledonian endemic fauna became extinct through over-exploitation and habitat loss (Balouet and Olson 1989; Balouet, 1991). Faunal extinctions, but particularly bird extinctions, following the arrival of people are now

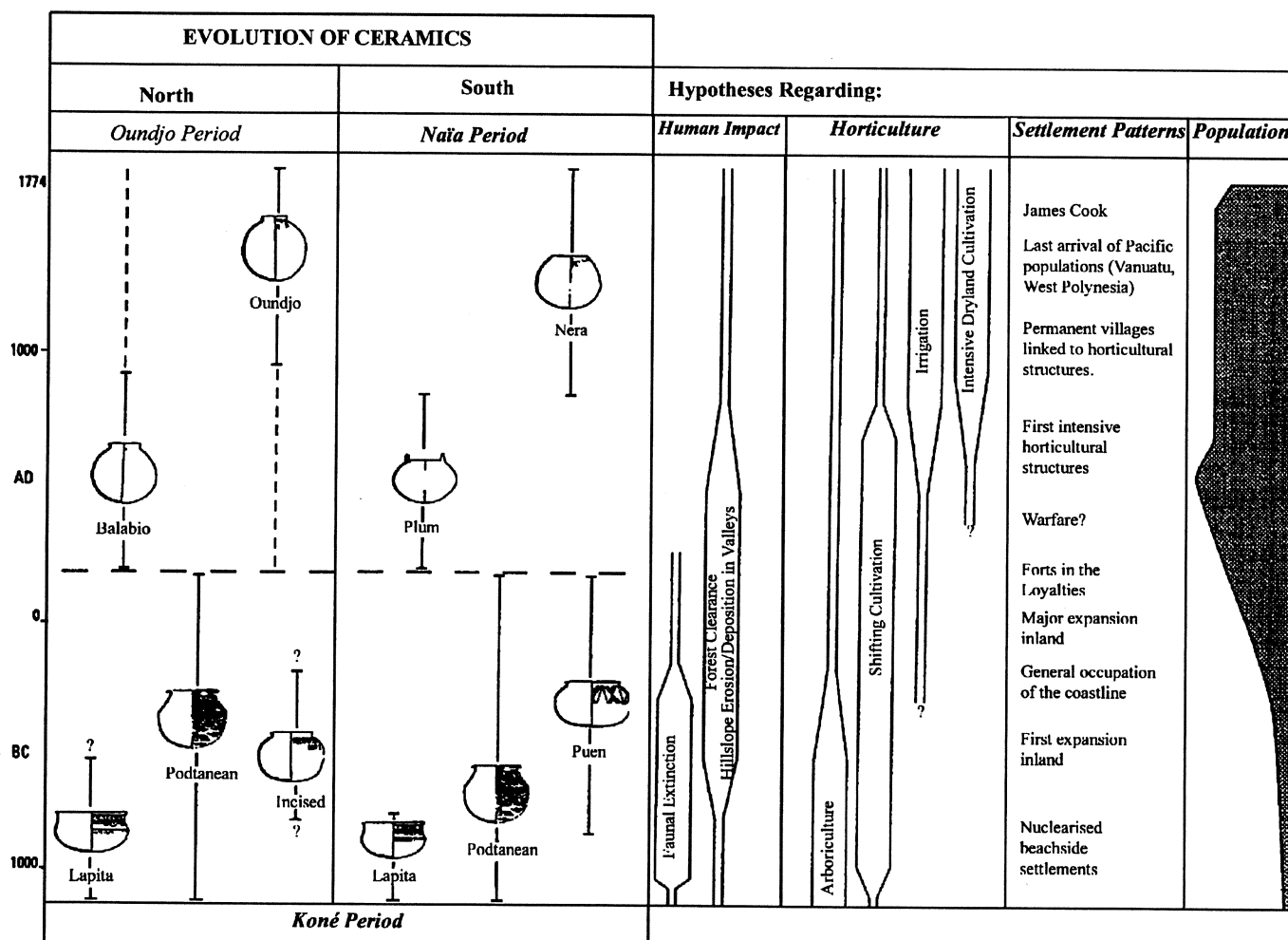


Figure 1.4: Summary diagram of New Caledonia's prehistoric chronology. Modified from Sand (1996).

Table 1.1: Radiocarbon age determinations for the oldest archaeological levels in New Caledonia

Site Number	Site Name	Laboratory Number	C ¹⁴ Age yr BP	Calibrated Age yr BP (range) 2 σ	Calender Age yr BP (range) 2 σ	Material Dated
KVO 003	Vatcha, Horizon IV	Gak	4010 ± 130 BP			<i>Placostylus</i> shell from hearth Material unknown Material from oven
SGO020	Tiwi, Layer 14	Beta 44650	3420 ± 220 BP			
TON-7, Naia		ANU 96	3165 ± 120 BP			
<i>Main Island</i>						
WKO013A	Lapita, Swamp level	Beta-75585	3050 ± 60 BP	3250 (3370-3070)	1310 BC (1420-1120)	Charred material
WKO013A	Lapita, Lower Level	Beta 75584	2900 ± 120 BP	2990 (3360-2760)	1050 BC (1410-809)	Charred material
WKO013A	Lapita, Lower Level	Beta 74603	2800 ± 60 BP	2870 (3070-2770)	920 BC (1120-820)	Charred material
WKO013B	Lapita, Layer C	Beta 61955; CAMS-6498	2850 ± 60 BP	3150 (3150-2790)	1000 BC (1200 -840)	Charcoal
WBR001	Nessadiou, Level III	UWA 471	2875 ± 170 BP	2960 (3350-2760)	1020 BC (1400-810)	Charcoal
WPT056	Naia, Layer 1	ANU 259	2855 ± 95 BP	2950 (3250-2760)	1000 BC (1300-810)	Charcoal
<i>Isle des Pins</i>						
KVO 003	Vatcha, Horizon II	ANU 262	2855 ± 170 BP	2950 (3380-2720)	1000 BC (1430-770)	Charcoal
<i>Lifou</i>						
LWT008	Hnajoisisi, Base	Beta 80045; CAMS-18586	2760 ± 60 BP	2850 (2970-2750)	900 BC (980-830)	Charred material
LWT054	Keny, Base	Beta 82661	2680 ± 60 BP	2770 (2870-2730)	820 BC (920-780)	Charred material
<i>Maré</i>						
LMA020	Patho, Base	ANU 6616	2590 ± 110 BP	2740 (2880-2350)	790 BC (830-540)	Charcoal
LMA020	Patho, Base	Beta 50604	2500 ± 90 BP	2580 (2770-2340)	590 BC (820-390)	Charcoal

Compiled from Green and Mitchell (1983) and Sand (1996). Calibrated using Stuiver and Reimer (1993). Sand (1996) considers shaded dates to be unsound.

well documented for a number of islands within Melanesia and Polynesia (see Anderson 1984, Cassels 1984; Steadman 1989, 1997).

The only domestic animals kept by the Melanesians at the time of European arrival in the 18th century were chickens. Pigs and dogs were both absent and as a consequence were deemed an appropriate gift by James Cook (Beaglehole, 1968:534). On his departure these animals were removed to the uninhabited island of Balabio, where in 1861 the French discovered a herd of 500 wild pigs (Lyons, 1986:3). Remains of pig and dog do not appear in archaeological deposits.

Given the affinities of the New Caledonian flora with those of Australia, New Guinea and Malesia (Morat *et al.*, 1984), many aspects of the native flora were probably familiar to the colonisers of 3000 years ago. It is thought that people probably brought some cultivars with them, for example taro and yams (Hather 1994; Sand 1996) and then employed swiddening techniques around settlements. There is no archaeological evidence for this. However, stones interpreted as nut crackers have been found in early archaeological deposits, possibly indicating a tradition of nut consumption (Sand, 1996). This aspect of the island's ethnobotany will be dealt with in more detail in Chapter 2.

Horticultural practices probably became more intensive over time and in the 18th century many hills were covered in terraces for wet cultivation of *Colocasia* (taro). New Caledonia is renowned for extensive and elaborate taro terraces now mostly abandoned in the hills of the main island. It is thought that these intensive irrigation practices began sometime after the Koné period, and Sand (1996) refers to work conducted on the taro terraces at Col de la Pirogue which have a single radiocarbon age of around 1200 yr BP. Most of the terraces were in use up until European colonisation in the 19th century and those found on very steep hillsides usually have retaining structures such as stone walls and wooden posts. Much smaller examples of this type of horticulture can be found around settlements in the valleys and many small garden sites (either abandoned or still in use) are found behind coastal swamps. Barrau (1965) refers to the common method of land reclamation within coastal freshwater swamps for taro cultivation within areas of Polynesia. Although common in Polynesia, he does not cite this as a practice

for 20th century New Caledonia, but logically this would have accompanied or followed the swiddening phase and preceded irrigation.

Some debate exists over the origin of irrigation in the southwest Pacific, with diffusionist theory suggesting that such knowledge came with people out of southeast Asia (see Spriggs, 1990). The case for independent development as a response to population or environmental pressure has also been put forward (Kirch, 1994; Kirch and Lepofsky, 1993), based on archaeological evidence as well as linguistic studies of the terms associated with agriculture.

Today dry crops form the major part of a traditional Kanak diet, and *Dioscorea* (yam) is the main tuber grown on mounds or crescent-shaped terraces on hill slopes. At Tiwaka, on the northeast coast there is a large plain with a chequerboard of mounds covering 35 ha. These were used for wet and dry cultivation and they are currently being studied from an archaeological perspective (Sand, 1996).

Other examples of people modifying the landscape to suit their needs are the building of dams and, on the Loyalty Islands, low stone walls to create space for gardens. In the Yaté region three dams were discovered which divert creeks to dry out marshy areas that are still under cultivation. These structures are thought to be very old and work aimed at unraveling the history of the area is still in progress (Sand and Ouetcho, 1993). In the same region, old shorelines and coral platforms are buried under alluvium, while peat levels 1.5 km inland from the present shoreline are buried under 3m of sediment and date to around 1500 yr BP. Sand (1996) has proposed that forest clearance of the mountainside led to erosion and burial of a coastal swamp.

Avias (1950) reported the recovery of pottery associated with the Koné period from beneath more than six metres of sediment during a well excavation on the Moindou River floodplain. While at face value this may strengthen arguments for massive erosion events following the colonisation of the island, there are no radiocarbon ages associated with the site and the geomorphology of the plain has not been studied in detail.

Work in the Koumac valley in the north of the main island has identified permanent as well as more transitory sites from the earliest period of colonisation (Sémah *et al.*, 1995; Guillard and Sémah, 1997). Evidence of pre-European dryland cultivation has been found in the lower reaches of the valley and taro gardening in the upper reaches. The valley fills from this region as well as the Yaté studies will potentially lead to a greater understanding of geomorphic change over the period of settlement and make important contributions to this aspect of human impact studies across the Pacific.

The first palaeoecological study for New Caledonia was undertaken in 1991 with the expressed intention of looking for signs of human impact (Stevenson, 1991). As a preliminary study, only grass, fern spores and charcoal content were examined from Lac Saint Louis, a small coastal swamp surrounded by ridges where the inner slopes are terraced for yams. The record has an increase in charcoal and evidence of a more open landscape coinciding with the beginning of the archaeological record at 3000 yr BP (Stevenson and Dodson, 1995). Large scale erosion or an increase in the rate of deposition is not evident in this site over the last 3000 yr.

In summary, from what is known so far, the initial colonisers of New Caledonia arrived at around 3000 yr BP. They were coastal dwellers who after a few centuries began exploring inland and, within a short time of their arrival, had brought about a number of extinctions in the native fauna. Their initial horticultural practices are thought to have been small scale, primarily swidden agriculture with periods of long fallow within the vicinity of settlement. It is assumed that as the population grew, horticulture became more intensive and widespread with the creation of intricately irrigated terrace systems. This would have led to greater clearing of the landscape. In the absence of detailed geomorphic and palynological studies the hypotheses of Kirch (1983) and Spriggs (1986) have been extended to New Caledonia and it is assumed that forest clearance and large scale erosion followed the colonisation of the main island.

Environmental change in the southwest Pacific since the Last Glacial Maximum.

The environmental history of tropical south Pacific islands for the late Pleistocene and early Holocene is known only from a few sites (Figure 1.2)². In the tropical southwest Pacific there are only two islands with records that extend back into the Pleistocene: New Caledonia and Fiji. Hope and Pask (1998) have two late Pleistocene pollen cores from lowland lakes in New Caledonia, Lake Suprin and Lake Emeric. However, the cores are reported to have either severely mixed Holocene records or no late Holocene records at all. On the island of Taveuni, Fiji, Lake Tagimaucia has a continuous pollen record from around 14,300 yr BP to the present (Southern, 1986). A 7m peat section from Wainisavulevu Creek, Viti Levu has a single date from the upper layers of around 23,000 yr BP. These two diagrams have recently been published together in Hope (1996), however, the LGM is unrepresented in the Fijian records. The Galapagos Islands and Easter Island in the eastern Pacific are the only other Pleistocene records from south Pacific islands between 0 and 30°S (Colinvaux, 1972; Flenley and King, 1984). The remaining pollen records from the tropical south Pacific are Holocene in age. While the long records have focussed on vegetation change as a proxy of climate change, the Holocene records have focussed on the issue of human impact. There is a much larger and better understood body of work from Australia, New Zealand and the highlands of New Guinea, and while it would be wrong to assume that small island ecosystems respond in the same way to climatic change as these larger landmasses, they do provide context for the climatic changes in the southwest Pacific. Emphasis is given to New Guinea and northeastern Australia because of their tropical nature and hence greater relevance to New Caledonia. The pollen evidence along with other proxies of climate change in the region have appeared in a number of reviews, the most recent being Harrison and Dodson (1993), Kershaw (1995) and McGlone *et al.* (1996).

The Last Glacial Maximum

The last glacial cycle is considered to have been initiated around 116,000 yrs ago, with the extremes of lower temperature, precipitation and sea level occurring approximately 18,000 yr BP at the Last Glacial Maximum (LGM). It is important to note that glaciers

² While only lowland pollen sites are shown in Figure 1.2 for the island of New Guinea, there are many high altitude sites that play an important role in estimations of climate change during the late Quaternary. See Haberle (1993) and Harrison and Dodson (1993) for reviews of sites.

were not confined to the temperate latitudes, and that there is evidence of widespread glaciation in tropical island locations above 3600 m, such as Borneo, New Guinea and Hawaii (Hope and Peterson, 1976; Flenley and Morley, 1978; Porter, 1979). At one time it was thought that tropical rainforest was probably little affected by the glaciations and other climate changes that had such a profound effect on ecosystems outside the tropics. However, palynological evidence from the tropics suggests that vegetation did undergo change at this time although the records they contain of temperature and precipitation change are often difficult to separate.

From fossil pollen studies as well as other lines of proxy evidence such as lake levels, dune mobility and glacial moraines, it is accepted that the LGM in the southwest Pacific region was generally drier and cooler than today. On average it is estimated that temperatures were 4-6° cooler than present for southeast Australia and New Zealand (greater for montane areas in New Guinea); that precipitation was 30 - 50 % less than present in northeastern Australia and that sea level was approximately 120 m below its present level (Chappell and Shackleton, 1986; McGlone *et al.*, 1996). In general the vegetation changes apparent in the pollen diagrams from sites at altitude are considered to be responses to lower temperatures, while changes from low altitude sites are considered to be driven by changes in precipitation. In the highlands of New Guinea the lowering of the treeline by 1500 m from its present day level of 3600 m asl is considered to reflect temperatures 6-8°C lower than present (Powell, 1970; Hope 1976; Walker and Flenley, 1979; Haberle, 1998). By contrast, in northeastern Australia, the replacement of araucarian rainforest by sclerophyll forest during the LGM at Lynch's Crater is seen primarily as a response to a precipitation depression of between 30 and 50 % rather than the effects of lower temperature (Kershaw, 1976, 1993; Kershaw and Nix, 1988).

The summary pollen diagrams from tropical lowland sites in the southwest Pacific region spanning the LGM are shown in Figure 1.5. The most important aspect of the diagram is how little data there is and how few truly lowland sites there are. There are inherent dangers in illustrating the data from the region in this fashion, such as the misrepresentation that might occur at some sites through poor chronological control (for example Suprin) and by classifying usually fairly complex data into such broad

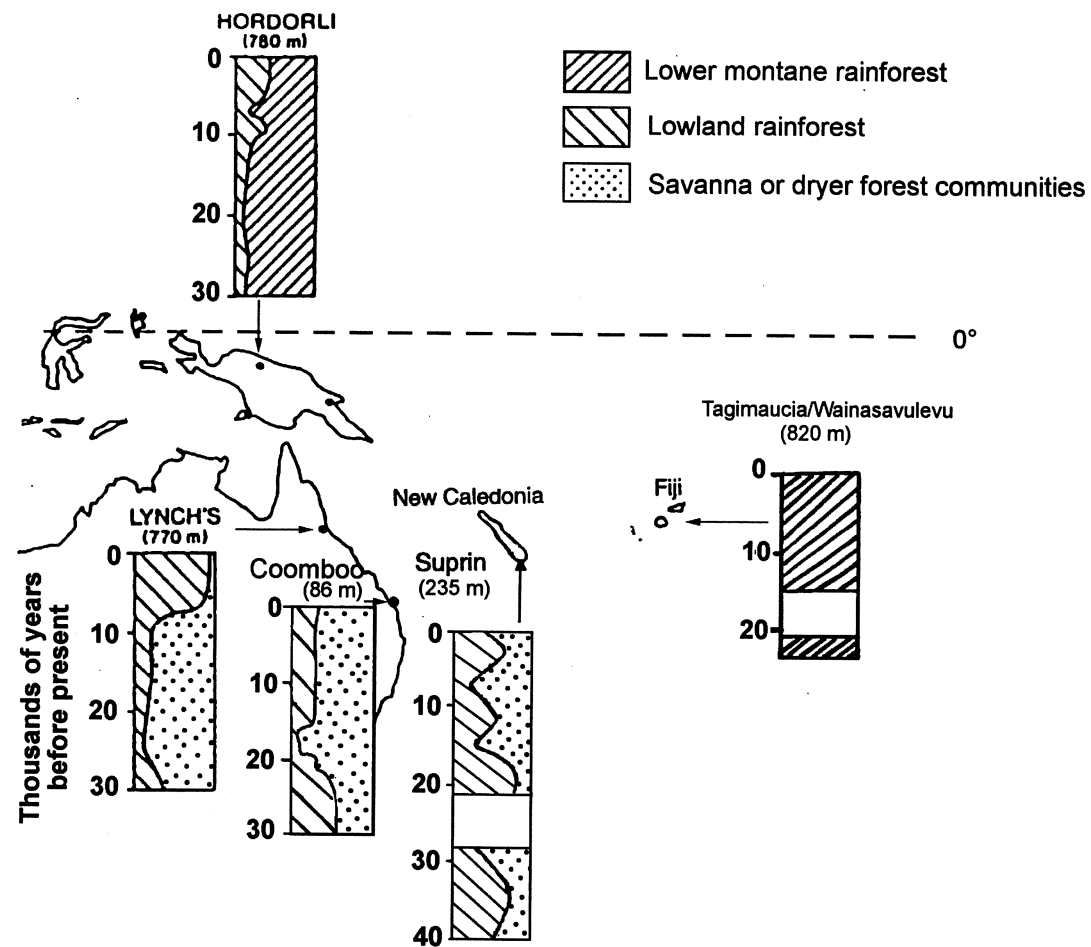


Figure 1.5: Summary of vegetation change from lowland Pleistocene sites in the tropical southwest Pacific. Modified from Flenley (1998). [Sources: Hordorli (Hope and Tulip, 1994); Lynch's (Kershaw, 1986) Coomboo (Longmore, 1997); Suprin (Hope and Pask, 1998); Tagimaucia (Southern, 1986)]

categories. The few sites studied are also widely dispersed and from quite different topographical settings further complicating any synthesis. However, it is apparent from the diagrams that statements attempting to generalise temperature and precipitation depression at the LGM in the lowland tropical southwest Pacific may not have a basis in the data as yet.

Lake Hordorli, Lake Tagimaucia and Wainisavulevu Creek are all elevated sites (>700 m asl) in very wet locations (>3500 mm of precipitation per annum) and are therefore unlikely to be sensitive to precipitation depression. Hordorli is at the boundary of lowland and montane forest and from an increase in pollen indicative of montane rainforest species during the LGM, Hope and Tulip (1994) suggest temperatures were cooler than present. The fossil pollen assemblage from Wainisavulevu, Fiji is interpreted as representing a climate that was approximately 2°C cooler than present at around 23,000 yr BP with a lower cloud base and more seasonal precipitation (Southern, 1986:205-208, 217). There is no record spanning the LGM from Fiji, however the period from 14,300 to 13,000 yr BP from the Lake Tagimaucia record is thought to have been around 4°C cooler than present, less cloudy and with seasonal rainfall. Southern (1986:205-208, 217) speculated from her Lake Tagimaucia evidence of slightly drier or more seasonal conditions during the late glacial in windward Taveuni, that the leeward vegetation of Fiji at this time was likely to be savanna. However, there are no pollen sites from leeward Fiji that are older than mid-Holocene in age and so this remains speculation.

Coomboo Depression (Fraser Island) (Longmore, 1997) and Lynch's Crater (Atherton Tableland) (Kershaw, 1976, 1986), both record vegetation changes from rainforest to drier sclerophyllous forests and woodlands in association with a dramatic increase in the quantity of charcoal at the LGM. At both sites these changes are interpreted as a decrease in precipitation, but at Atherton the influence of Aboriginal burning is also considered significant (Kershaw, 1986). Estimates of temperature or precipitation change have not been made from the New Caledonian cores of Hope and Pask (1998). Of the two cores, Lake Suprin is the most robust in terms of radiocarbon dating and pollen counting. The drier forest elements shown in Figure 1.5 for Lake Suprin are

fluctuations in *Gymnostoma* (Casuarinaceae) pollen and there is an increase in *Gymnostoma* at or shortly after the LGM, based on the current chronology for the site. The record also has a number of similar *Gymnostoma* increases at other times in the record. However, the chronology of Lake Suprin is still poorly understood, with the sediments at 38 cm and 85 cm dating to 16,850 yr BP and 17,500 yr BP respectively. Age-depth extrapolation suggests the lake contains no Holocene record, but this interpretation does not conform easily with the fact that the lake system is accumulating sediment in the present day. Hope and Pask (1998) have suggested that cyclones may be responsible for removing the Holocene records. Another point of interest from these records is that charcoal is found throughout the sediment, however, its fluctuations do not appear to be linked to any of the vegetation changes (Hope and Pask, 1998).

Further to the east, on Easter Island, the pollen evidence suggests that the environment was cooler and drier than present from 26,000 to 12,000 yr BP (Flenley and King, 1984; Flenley *et al.*, 1991). The LGM sediments from lakes on the Galapagos Islands do not contain pollen, but this lack of positive evidence has been interpreted as indicating drier conditions (Colinvaux, 1972; Colinvaux and Schofield, 1976).

The Late Glacial Transition

Deglaciation of the New Guinea highlands began around 15,000 yr BP with most areas ice free by around 9,000 yr BP (Löffler, 1982). Mauna Kea in Hawaii and Mount Kinabalu in Borneo were also deglaciated by around 9000 yr BP (Flenley and Morley, 1978; Porter *et al.*, 1977).

From a sudden shift in tree line Walker and Flenley (1979) infer a rapid rise in temperature between 16,500 and 13,500 (around 3°C per 1000 years) followed by a slower rise to present temperatures around 9,000 yr BP. Haberle (1998) also found the late glacial transition to have two phases of warming in the highlands: an initial period of climatic instability from 14,500 to 12,000 yr BP, followed by a more consistent warming from 12,000 to 8500 yr BP. Throughout the highlands of New Guinea vegetation was close to its present distribution and zonation by around 9000 yr BP. In

lowland New Guinea there is an increase in lowland rainforest taxa between 10,500 and 7,500 (Hope and Tulip, 1994).

In north-eastern Australia, sclerophyll forest remained around the Lynch's Crater site until just after 9000 yr BP, when replacement by angiosperm rainforest began (Kershaw, 1976, 1986). Mean annual precipitation levels similar to today were in place by 7000 yr BP, although temperatures were 1°C lower throughout the year (Kershaw, 1993; Kershaw and Nix, 1988). For Fiji, temperature and precipitation increases are considered to have taken place primarily after 13,000 yr BP, with present day conditions not reached until around 6000 yr BP (Southern 1986:208).

There is a tree ring study from New Caledonia on a log of *Neocallitropsis pancheri* that dates to around 14,000 yr BP (Suprin and Hope, *in prep*). The authors estimate that the tree was approximately 240 years old at the time of death and suggest that the growth of this species at around 14,000 yr BP is suggestive of moister conditions. However, no environmental data has been extracted from the tree rings as yet.

The Middle to Late Holocene

The Holocene is generally viewed as a period of relative climatic stability. However, terrestrial records become increasingly difficult to interpret in terms of climatic change due to the likely increase of human impact on the landscape. Between 9000 and 5000 yr BP global temperatures are considered to have been higher than present, although on average this increase is less than 1°C (McGlone *et al.*, 1996). This interval is commonly referred to as the early to mid-Holocene warm period or 'climatic optimum'. In the Australasian records it is expressed as fuller lakes, reduced glacier size and more moisture-demanding vegetation (McGlone *et al.*, 1996). Bioclimatic estimates from the Atherton Tableland data suggests that mean annual precipitation was similar to present day levels by 7000 yr BP, but that the highest levels of temperature and precipitation occurred between 5000 and 3600 yr BP (Kershaw, 1993; Kershaw and Nix, 1988).

Another major environmental change during the Holocene is the stabilisation of sea level at its present day position after 6000 yr BP, with local variation as to the exact

timing of this (Pirazzoli, 1991). New Caledonia's sea level history is presented in Chapter 2, a chapter which deals specifically with the New Caledonian environment.

Glacier data from New Guinea and New Zealand (glacial moraines and buried soils) suggest that there has been some climatic fluctuation over the last 3000 years. In New Guinea there were four glacial advances and retreats with estimated temperature changes of 1.5 to 2.5 °C (Hope and Peterson, 1976). Many glaciers in the Southern Alps of New Zealand advanced over the last 3000 years, with glaciers in both New Guinea and New Zealand retreating rapidly only over the last 50 yr (McGlone *et al.*, 1996).

A climatic phenomenon which is topical in the present day is the El Niño/Southern Oscillation (ENSO). The dominant effect of this system in the southern Pacific is to increase the variability of precipitation. An area of current research interest is to what extent ENSO is expressed in palaeoenvironmental records. As most records from which climate change is inferred from this region are coarse in their resolution (well over a decade between samples), the separation of greater inter-annual variability from a general shift in climate does not seem feasible. Often cited as evidence in pollen records for a more variable climate is an increase in charcoal and a move to vegetation interpreted as drought tolerant (McGlone *et al.*, 1992, 1993; Shulmeister and Lees, 1995; Harrison and Dodson, 1993). The focus at present seems to be whether there was a crucial time in the late Holocene when ENSO 'switched on' or suddenly became more intense. At present, suggestions are that this occurred between 5000 and 3500 yr BP (McGlone *et al.*, 1992; Shulmeister and Lees 1995; Sandweiss *et al.*, 1996). However, other researchers in South America point to geomorphic evidence of large scale flood events that date back to 40,000 yr BP (Wells and Noller, 1997) and supposed weaknesses in using thermally anomalous molluscan assemblages as evidence for El Niño (De Vries *et al.*, 1997).

The only records really suitable for extracting ENSO and related kinds of information are fine resolution records, preferably tree ring or coral data, or annually laminated lake

sediments. However, annually laminated lakes are rare in the Australasian region generally and tropical southwest Pacific specifically. A seasonally sampled coral study is the first published fine resolution study of this kind from New Caledonia (Quinn *et al.*, 1998). At present the record extends back 335 years and has significant temperature variation in the El Niño band. Further work is in progress to push the record back further and extract additional information from the corals. Such fine resolution studies are obviously important not only for detecting climatic variation during the late Holocene, but provide an additional source of data against which the terrestrial records of human impact can be assessed.

1.2 Issues in Lowland Tropical Palynology

Despite the interest in tropical rainforests as centres of biodiversity and their importance in the storage of terrestrial carbon there is little consensus as to the nature of late Quaternary vegetation in the tropical lowlands and what role people have played in changing vegetation over this time (Richards, 1996). The amount of tropical data extending back into the LGM is quite small, widely dispersed and from topographically quite different locations. Therefore the lack of consensus in changes seen from the LGM to the Holocene may result from true regional variability or perhaps reflect too small a data set to account for internal variability. Debate over why the tropics are so species rich has been an issue in tropical research for some time and is highlighted by the work carried out in the Amazon basin. The most widely accepted and influential model has been the refugial hypothesis put forward by Haffer (1969) which argues for the lowland forests of the Amazon being fragmented during glacial episodes of the Quaternary, with the resulting forest remnants becoming centres of evolutionary divergence. The degree to which tropical lowland rainforest was fragmented at the LGM and how extensive the expansion of savanna was has become one of the more central issues in palaeoecological research in the Amazon. At present there is only one lowland pollen record that extends back to the LGM, Lake Pata, which at 18,000 yr BP was surrounded by lowland rainforest (Colinvaux *et al.*, 1996). The descent of several montane species into lowland rainforest suggests that conditions were cooler but not necessarily drier. Work on the Amazon fan found that no more grass pollen was carried

by the river system at the LGM than during the Holocene or the previous interglacial (Haberle, 1997). Such sets of data increasingly suggest that only a moderate expansion of savanna took place during the LGM in the Amazon.

When using vegetation change as a proxy of climate change it is often difficult to unravel the temperature and precipitation fluctuations in pollen records from the tropics. This results from the pollen assemblage encompassing the complex interactions between climate, biology and geological setting which are still poorly understood and difficult to quantify. In addition, and by necessity, most estimates of climatic change focus on annual temperature and precipitation, when other factors such as seasonality of temperature and precipitation, cloud cover, prevalence of drought and the occurrence of frosts are biotically as important as changes to annual temperature and precipitation (McGlone *et al.*, 1996). New fields of research include the effects of altered CO₂ concentrations on vegetation (cf. Street-Perrott *et al.*, 1998) and the relationship between UVB radiation and high altitude vegetation (see. Flenley, 1996) during the LGM. These factors may have led to vegetation changes that are currently being misinterpreted as a response to straight temperature or precipitation depression. However, as research into these fields is still in the early stages of development they do not as yet contribute to our understanding of climate change since the LGM in the tropics.

Interpretation of tropical pollen diagrams is also hampered by the realisation that plant communities rarely shift as a whole in the face of environmental change. Instead it is generally accepted that plant taxa respond as individuals to environmental change. The implication from this is that some associations seen in the fossil record may not have modern day analogues, the technique most commonly used to reconstruct past environments. A refined understanding of the ecological limits of key species in the pollen assemblage may therefore provide a more appropriate insight into past climate change.

In general the tropics are considered to have been much cooler and drier than today during glacial periods (Bonnefille *et al.*, 1990; Van der Hammen and Absy, 1994; Van

der Kaars and Dam, 1995; Thompson *et al.*, 1995; Colinvaux *et al.*, 1996). However, the anomalies first highlighted by Rind and Peteet (1985) between the CLIMAP Project Members' (1981) estimates of tropical sea surface temperatures (SST's) at the LGM and the terrestrial data still persist and illustrate the considerable uncertainty regarding tropical climate during the last glacial. A recent review (Farrera *et al.*, submitted) has focussed on tropical climates at the LGM because of continuing interest in the problem of reconciling these two lines of evidence. This latest synthesis of the terrestrial data concludes that lowland areas in the southwest Pacific were around 2°C cooler than present which is keeping with the latest SST reconstructions from deep ocean cores in the region (Thunnell *et al.*, 1994; Barrows *et al.*, 1996). Farrera *et al.* (submitted) have concluded that a colder than present ocean surface in the tropics produced a weaker hydrological cycle, more arid continents and steeper than present terrestrial lapse rates. A number of earlier researchers hypothesised that steeper lapse rates may have been responsible for the apparent discrepancy between sea surface data and data from altitude (e.g. van der Hammen, 1974, 1991; Walker and Flenley, 1979) but such hypotheses met with resistance from climatologists (e.g. Webster and Streten, 1978; Kutzbah and Guetter, 1986). New data and a growing refinement of computer technology and modeling sees greater reconciliation between the data (Farrera *et al.*, submitted). What is obvious from this synthesis however, is the lack of data from tropical Pacific islands.

Possibly at odds with the estimates of SST from the deep sea cores as well as the synthesis of Farrera *et al.* (submitted) is work from Vanuatu on corals that suggests sea surface temperatures in the region were 4-6 °C cooler than present at around 10,000 yr BP, reaching present day temperatures around 4200 yr BP (Beck *et al.*, 1997). These temperature depressions are similar to the coral SST records from Barbados which show that the tropical Atlantic was 5-6 °C cooler than present around 10,000 yr BP (Beck *et al.*, 1997). Because the Vanuatu record so far only covers the Holocene, it cannot be determined yet if the SST's from the region had remained cold since the LGM, or whether the low temperatures and rapid rise represent only a relatively short-term anomaly in the deglacial climate (Beck *et al.*, 1997). Further coral work will also establish whether similar temperature depressions are found elsewhere in the region.

1.3 Palynology in New Caledonia

The analysis of pollen from lake and swamp sediments within lowland tropical forest environments is a young science and taxonomically rudimentary compared with analyses conducted in the temperate regions of North America and Europe. Palynological studies only began in New Caledonia in 1991 (Stevenson, 1991) and the large flora of around 3000 flowering plants (80% endemic) means that pollen analysis is very much in the pioneering phase. There are several issues concerning tropical palynology that are universal and apply also to New Caledonia. The problems of silent plant taxa (i.e. present in the vegetation but not recorded in the pollen analysis) and high proportions of unknown taxa are common ones for tropical locations. However, initial fears that the pollen influx from lowland tropical forests would be low (Faegri, 1966) because of the large numbers of insect pollinated taxa are in general unfounded. While some studies show that tropical pollen influx is low (e.g. Kershaw and Hyland, 1975) in other cases it has been shown to be comparable with that of temperate regions (e.g. Flenley, 1973, 1979:36; Bush, 1991) and has not hampered pollen analytical studies.

Disentangling natural processes from anthropogenic influences in the pollen records from the Pacific generally is potentially difficult owing to the lack of direct indicators for crop plants on the one hand and the possibility of climate change on the other (Flenley, 1994). The dominant Pacific crop plants are insect pollinated plants that are harvested for their tubers. This results in either the plant being harvested before flowering (e.g. taro), or if allowed to flower (e.g. yam and sweet potato) the pollen production and dispersal mechanisms of the plant are so poor that the pollen does not find its way into swamp and lake deposits. There is some suggestion that the pollen of sweet potato does not preserve well, but results from experimental work have not been published as yet. The situation in the southwest Pacific is in contrast to other cultural settings such as southeast Asia where crop plants are principally from the grass family (Poaceae) which are wind pollinated and by comparison well dispersed.

The assumption that charcoal particles within lake and swamp sediments are indicators of anthropogenic activity in the tropics must be used with some caution, as natural fires do occur in tropical lowland rainforest. This is documented for prehistoric (Goldammer

and Seibert, 1989; Saldarriaga and West, 1986) as well as modern times (Johns, 1986). However, there is no documented evidence of grasslands or other forms of open vegetation being sustained after these natural events.

The broad set of criteria listed below have been adapted from Haberle (1993:22; 1994) and are the basis upon which human impact in the pollen records of New Caledonia are to be distinguished from other natural changes.

- 1) Evidence for vegetation disturbance
 - more open vegetation
 - more secondary forest/shrub vegetation
 - less forest cover
 - the presence of weeds and economic plants
- 2) An abrupt and significant increase in charcoal particle accumulation synchronous with vegetation disturbance and sustained through to the present (particularly if non-synchronous with climatic fluctuations or hydroseral influences).
- 3) Non-synchronous vegetation disturbance events across a number of sites.
- 4) Vegetation changes unparalleled in earlier periods of presumably more extreme climate than present (e.g. last glacial maximum).

1.4 Thesis Outline

The primary objective of this thesis is to determine what vegetation changes have occurred over the last 20,000 years in New Caledonia in areas sensitive to human impact. Three coastal swamps were chosen for analysis, two from the drier leeward side of New Caledonia and one from the wetter northeastern coast.

The leeward sites are situated within a region that receives some of lowest annual rainfall for the island and one of the sites is surrounded by abandoned yam terraces. These factors make them locations that should be sensitive both to precipitation depression and human influence. The site on the wetter northeastern coast was chosen

so that a comparison could be made of records under the very different rainfall regimes. All three sites overlap in time with the archaeological sequence. A site remote from human influence and at altitude was considered desirable, and although potential sites have been identified, logistically it was not possible to carry out the work and so they do not form part of the present study.

Fieldwork began in 1991. Part of this field season was taken up with establishing contact with local agencies and obtaining relevant permits. Extensive reconnaissance work was also carried out, as well as surface sample collection for the modern pollen rain studies and the initial collection of sediment cores. The two major fieldwork seasons were carried out in February 1992 and November 1993. During the 1992 field season pollen cores were collected from all three sites plus some reconnaissance level stratigraphic investigation of a river valley in which one of the sites was situated. Coring at this site was halted during the 1992 field season when the material became too stiff to penetrate. The 1992 field season also included a reconnaissance fieldtrip to the Isle des Pins which does not appear to contain sediments useful for pollen analysis. In November 1993 coring resumed where it had left off in 1992, this time with extra field assistance. Stratigraphic cross sections were done for the two leeward sites and some stratigraphic work carried out at the northeastern site. During all fieldwork seasons botanical specimens were collected for the purpose of constructing a pollen flora. Back in Australia this was supplemented by floral collections from the Herbarium at the Royal Botanic Gardens, Sydney. This pollen flora appears in photographic form in Appendix 2. November 1993 marked the end of any further fieldwork in New Caledonia.

The study is presented as follows. Chapter 2 describes the physical environment of New Caledonia along with a summary of what is known about the ethnobotany. The modern pollen rain study is presented in Chapter 3. This chapter also includes the methods used for pollen processing, pollen identification and diagram construction throughout the thesis. The environmental history of the Pleistocene site is presented in Chapter 4. This has been interpreted from radiocarbon dating, pollen and charcoal analyses, valley stratigraphy, x-ray diffraction analyses and mineral magnetic analyses. Chapter 5

presents the pollen and stratigraphic work carried out at the horticultural site and Chapter 6 the northeastern site. In Chapter 7 the findings from all three sites are discussed in light of climatic and anthropogenic records from New Caledonia and other sites in the tropical south Pacific. The bearing of this evidence on theories of vegetation change during the LGM in lowland tropical environments is considered, as is the question of whether records of vegetation change from pollen cores compliments the existing archaeological evidence for human colonisation in the Pacific.

Chapter 2 New Caledonia

2.1 Overview

In describing the physical setting of New Caledonia, emphasis has been given to those aspects that are of greatest relevance to the sites studied. The three study sites, Lac Saint Louis, Plum Swamp and Canala Swamp, occur in the southern half of the main island and are in coastal or lowland settings. As a consequence little attention is given to the northern half of the main island, the surrounding islands or the montane landscape. One site is situated within an ultramafic catchment, while the other two lie in close proximity, so considerable attention is given to this unusual terrain. The three sites are described in detail at the end of this chapter.

2.2 Location and Physiographic Setting

The main island of New Caledonia is narrow and approximately 500 km long and 50 km wide. It lies within the latitudes 20° to 23° south, and between longitudes 164° and 168° east (Figure 2.1). The territory of New Caledonia comprises of Grande Terre, the Isle des Pins and the Belep and Loyalty Islands, which together constitute a landmass of around 19,000 km². The main island is surrounded by a barrier reef enclosing a wide lagoon with an average width of 10 km. The lagoon can be regarded as New Caledonia's continental shelf, the barrier reef marking the transition to the continental slope which dips steeply to the basins surrounding New Caledonia (Fontes *et al.*, 1977). Fringing reefs are scattered along the coastline except in the sheltered bays where mangroves are often found. There is a mountain chain running the length of the main island, but offset to the east, so that the plains are confined mostly to the west coast. This mountain chain contributes to the marked rainfall gradient between the east and west coasts. Mount Panié is the highest peak on the island at 1628m.

2.3 Tectonic History and Geology

New Caledonia is part of the Norfolk Ridge that runs from just north of New Caledonia south to New Zealand. The ridge, as part of the Melanesian island arc which includes

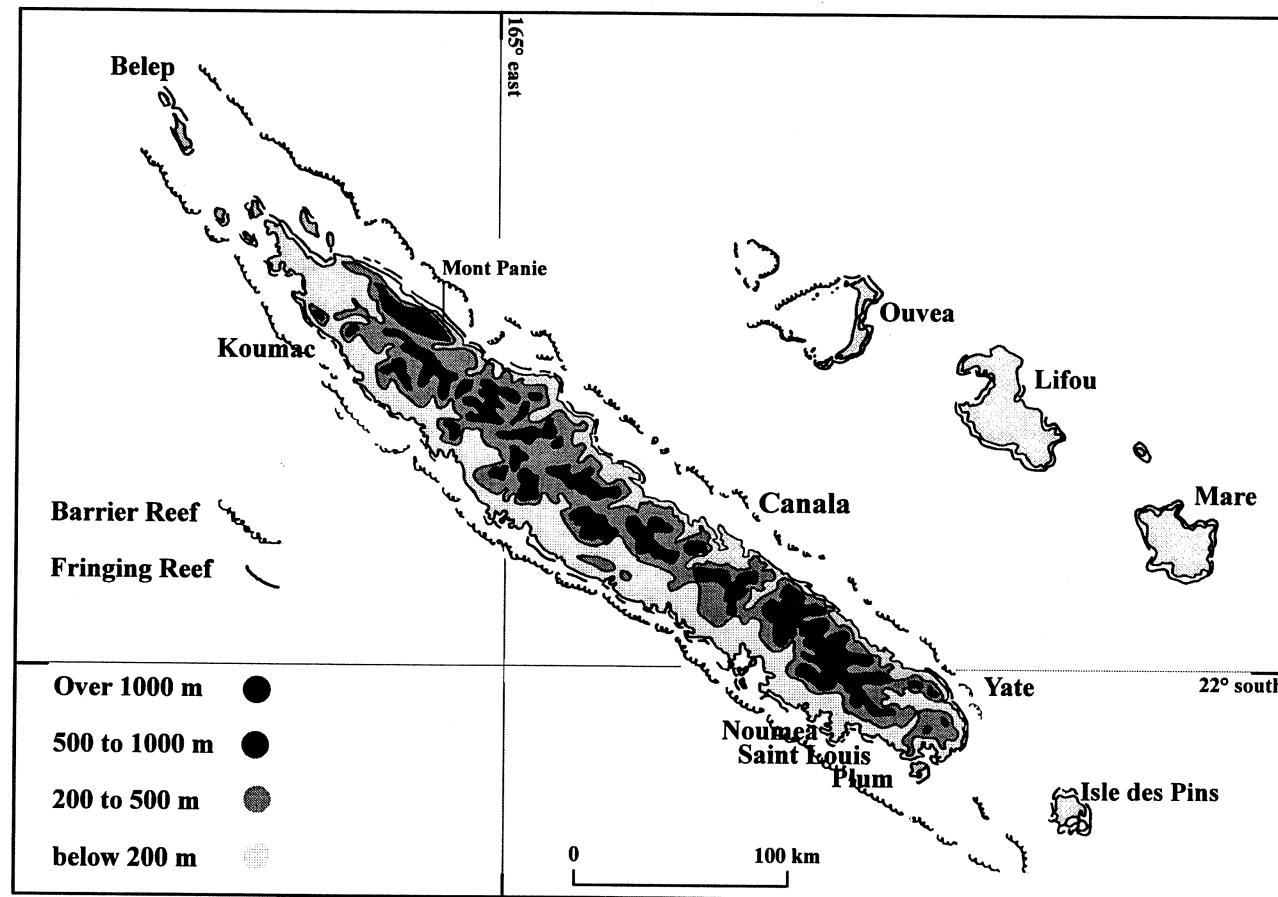


Figure 2.1: Relief map of New Caledonia and location of fringing and barrier reef systems. The fossil pollen sites of Plum, Saint Louis and Canala are shown. (Adapted from Renson, 1989a; 1989b).

New Guinea, underwent its first orogenic uplift during the Permian, leading to New Caledonia's emergence from the oceans (Paris, 1981). Although New Caledonia today lies approximately 1,600 km to the east of Australia, its original position as part of the Gondwanan landmass approximated the present day position of the Great Barrier Reef (Morat *et al.*, 1984; Paris, 1981). The archaic and continental elements of New Caledonia's flora stem from this era.

During the lower Cretaceous (between 110 and 135 mya) the bulk of the Australian continent, as part of the Indian-Australian Plate, began a northward movement. In conjunction with sea floor spreading, this led to the opening of the Tasman Sea and the isolation of New Caledonia and New Zealand by around 80 mya (Morat *et al.*, 1984; Veevers *et al.*, 1991).

By far the most important event in New Caledonia's geologic history, from the perspective of this research, was the overthrusting of a sheet of oceanic lithosphere during the upper Eocene at around 35 - 40 mya (Aitchison *et al.*, 1995; Paris, 1981). Covering almost the entire island to a thickness of up to 2000m, it has since been fragmented through erosion and today covers around one third of the island's total land surface, mainly concentrated in the south (Figure 2.2). These ultramafic rocks form a highly selective substrate, being deficient in aluminium and the plant nutrients potassium, phosphorus and calcium while having excesses of magnesium, chromium and nickel (Brooks, 1987). As a result of this the ultramafic terrain has its own characteristic vegetation, maquis, which is shown on the vegetation map of New Caledonia (Fig. 2.5). The ultramafic geology plays a central role in New Caledonia's economy. One third of the world's exploitable ferro-nickel reserves are found in this terrain and it is the basis of the Territory's wealth, with mining activity having an enormous and deleterious impact on the New Caledonian landscape. Along the west coast, north of the ultramafic massif that dominates New Caledonia's southern third, Eocene basalts and flysch are found, while the mountain chain is composed primarily of Permian and Jurassic volcanic sediments, making the geology of New Caledonia the oldest of any island in the southwest Pacific (Paris, 1981).

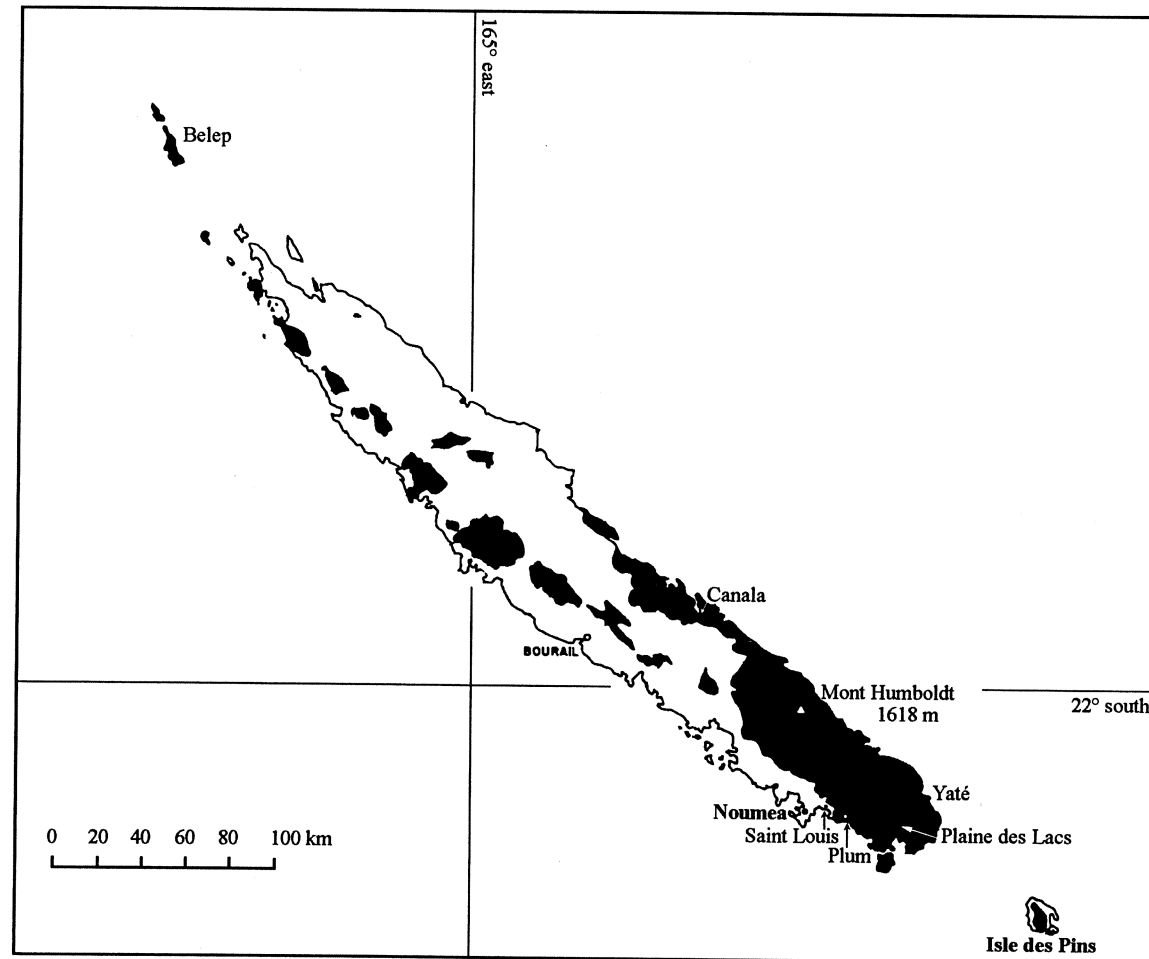


Figure 2.2: Distribution of ultramafic substrates in New Caledonia. (Adapted from Jaffré *et al.*, 1987).

Sea level data for New Caledonia has been compiled from a number of sources and is shown in Figure 2.3. The rapid post-glacial sea level rise is illustrated by the dates obtained on mangrove sediments by Baltzer (1970). Sea level from these samples appears to have stabilised around 5500 yr BP (Figure 2.3). However, a number of coral samples from the northeast coast near Yaté (Coudray and Delibrias, 1972; Fontes *et al.*, 1977; see Figure 2.3) suggest that mean sea level was higher than present 3500 years ago. These samples are porites coral found above the present day upper growth limit. Apart from one date, all evidence for a higher sea level stand after 5500 yr BP comes from the northeast coast at the eastern end of the main island. Cabioch *et al.* (1996) concluded that from the general position of the last interglacial (125,000 yr BP) fringing and barrier reefs, the main island has undergone subsidence in a northward and southwestward direction from a relatively more stable and possibly uplifting central zone that includes Bourail to the west and the Yaté/Tara and Hienghène areas to the east (see Figure 2.3). They concluded that this warping has been continuous over the last 125,000 yrs and that locally higher than present sea level stands were a result of local tectonics. Therefore, sea level for New Caledonia probably stabilised at its present level around 5500 yr BP.

2.4 Geomorphology and Soils

The relief of New Caledonia has been developing since the early Tertiary following the overthrusting of the peridotite sheet. The upper parts of New Caledonia's river basins are mountainous and much of the east coast falls away abruptly to the coast, the most dramatic regions being where there are fault scarps 300 to 400 m high bounding the ultramafic massifs, with slopes in places of greater than 50° (Bird *et al.*, 1984). The northern half of the west coast is a more gently sloping landscape composed mainly of alluvial fans, with mangrove-fringed deltas. Further south the landscape is more hilly and promontories are more prevalent. The tidal ranges for the main island are around 1.8 m (Dandonneau *et al.*, 1981) and wave action is governed by the easterly and southeasterly trade winds within waters extensively protected by a barrier. Pleistocene dunes have been found on some of the outer islands, but in general dunes are rare on New Caledonia (Bird *et al.*, 1984).

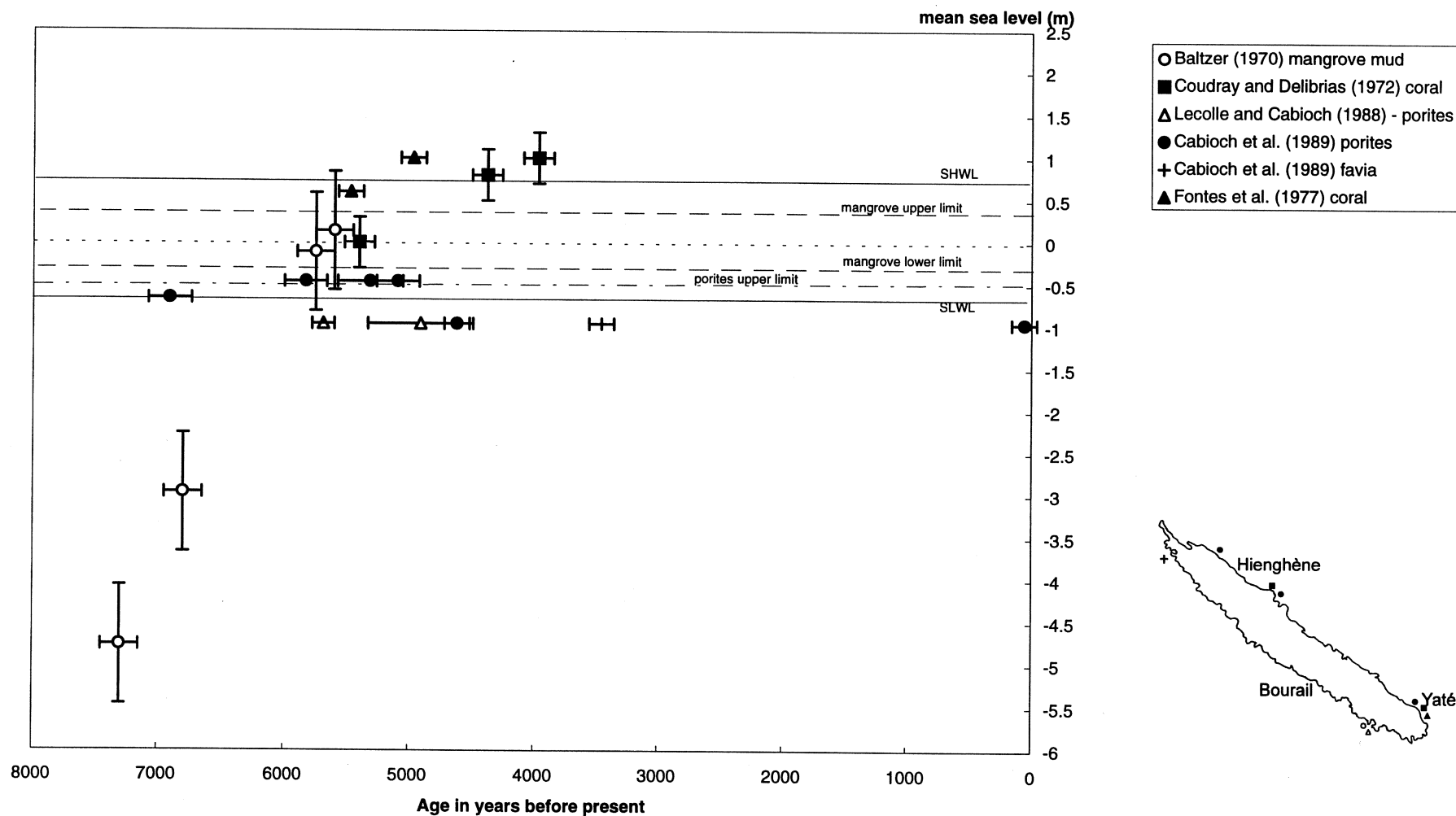


Figure 2.3: Mean sea level data for the main island of New Caledonia since 8000 yr BP. Data are heights of sample collection relative to present mean sea level. Shown are the spring high and low water levels (SHWL and SLWL), the upper and lower limit of the mangrove zone, and the upper limit of porites coral growth.

The ultramafic massifs of New Caledonia are in general weathered to a depth of 20 - 30 metres. These deep lateritic substrates contain nickel, chromium and cobalt which are sought after by the mining industry. Karstic features in the form of enclosed depressions are common in this landscape. These depressions have formed by the leaching of magnesium silicate beneath a porous ironstone crust known as "cuiresse" and are common in the Plaine des Lacs region in southern New Caledonia (Iltis, 1981).

The colluvial fans fronting the steep slopes of the central mountain chain are thought to be Quaternary landforms. Bird *et al.* (1984) have interpreted the sediment sequences within the fans as alternations between times of rapid slope erosion and episodes of gentler activity. The rapid erosion phases are defined by sediments made up of sand and gravel to cobble and boulder size material, while the gentler episodes are defined by sediments of sand, silt and clay and weathering profiles suggesting a relatively stable fan surface. Bird *et al.* (1984) also suggest that while rapid erosion in the uplands of New Caledonia may be a result of tectonic uplift, it is more likely to be due to climatic fluctuations with the most intensive erosion being the result of either higher annual rainfall or brief episodes of torrential discharge brought about by a more arid environment with sparser vegetation cover. They speculated that under natural conditions (no modification of the vegetation and land surface by human activity) the colluvial fans would have remained relatively stable under the present climate. Instead many are deeply incised through the actions of mining upslope. By comparison, in the catchments that remain fairly well vegetated and undisturbed by mining activity, the sediment transported by runoff is fine grained and is carried to the sea by narrow and shallow watercourses across alluvial fans (Bird *et al.*, 1984).

During periods of low sea level during the Quaternary, the sea floor area bordering New Caledonia emerged and rivers extended their course seaward incising to lower base levels. Conversely, submergence following sea level rise has resulted in the flooded river valleys and deltaic plains. Bird *et al.* (1984) make several generalisations about New Caledonia's rivers and coastal features following Holocene sea level rise. Rivers draining the deeply weathered ultramafic areas formed river deltas, while those draining the sedimentary and volcanic formations, where the weathered mantle is relatively thin,

formed estuarine mouths or flooded river valleys. It should be noted that there are exceptions to this generalisation and no account has been taken of valley size which is also a factor in delta formation.

The long and varied geologic history of New Caledonia has led to a diverse array of soils, with the role of the ultramafic geology undeniable. There are numerous other physical factors, however, that lead to the varied substrates. These include the contrast in climate between east and west coasts, past climates, and the relationship of the soils to topography and vegetation (Latham, 1981). Many of the soils of New Caledonia took shape in the Miocene, and since then a high degree of laterisation, hardening and reworking have occurred (Latham, 1981).

The marked differences in rainfall between the eastern (windward) and western (leeward) coasts has led to markedly different soil types. The wetter eastern slopes and central range have ferallitic and pre-ferallitic soils, while on the more arid slopes vertisols and eutrophic brown soils, plus leached ferallitic soils with podzolic tendency predominate (Latham, 1981). From soil studies conducted on the west coast, Podwojewski (1995) cites the formation of carbonates and gypsum in the profiles as evidence of the last glacial maximum being drier than present on New Caledonia.

Soil type is largely dependent on the geologic substrate and the soils yielded by the ultramafics are typically brown eutrophic hypermagnesian or ferallitic ferritic (oxisols) (Latham, 1981). The oxisols are by far the best represented on the ultramafic rock and are composed mainly of oxides and hydroxides of iron which are enriched due to the removal of magnesium and silica (Brooks, 1987). Brooks refers to these soils as lateritic, given their iron rich-mineralogy, but they are not all indurated. Brown eutrophic soils form at the base of the ultramafic massifs and are shallow and poorly developed on the slopes (Brooks, 1987).

The alluvial soils and vertisols on the basalts, flysch and greywackes of the coastal plains and hills of the west coast are the most productive in terms of landuse, which is primarily cattle grazing. The steep topography and thin soils of the mountain chain are

avoided as they have limited potential for contemporary agriculture. There is no agricultural activity in the ultramafic terrain either, as the poor nutrient status effectively excludes grasses. Some plantation forestry has been attempted in this terrain with a commercial *Pinus* species having apparently limited success.

2.5 Climate

New Caledonia has a tropical climate influenced by the prevailing easterly air flow (the southeast trade winds). The weather on New Caledonia is influenced by the relative position during the year of the south Pacific convergence zone (SPCZ) and subtropical anticyclone belt. The warmest and wettest part of the year is from December to April when the SPCZ is at its southernmost limit. During this period the islands are affected by tropical storms or tropical cyclones which are irregular in number and strength and greatly influence the rainfall of this season.

Rainfall

The great majority of New Caledonia's rainfall is on the northeast coast. The uneven distribution of rainfall arises from the predominance of the moist southeast trade winds and the presence of the central mountain chain inducing orographic rainfall and a marked dry zone on the leeward west coast (Figure 2.4). The east coast routinely receives rainfall in excess of 4000 mm/yr, whereas the west coast may receive less than 1000 mm/yr (Section d'Hydrologie, 1981). There is a marked seasonality to the island's rainfall with the highest rainfall in January, February and March as a result of tropical depressions and the dry season occurring between September and November. Rainfall is also highly variable from year to year due to the unreliability of the SPCZ, and is most variable on the west coast given the rainshadow effect described above. In some years the SPCZ may bring tropical cyclones and many metres of rainfall, while in others it fail to produce any significant precipitation (Renson, 1989). Years of rainfall shortage are linked to El Niño - Southern Oscillation (ENSO) (Morliere & Rebert, 1986).

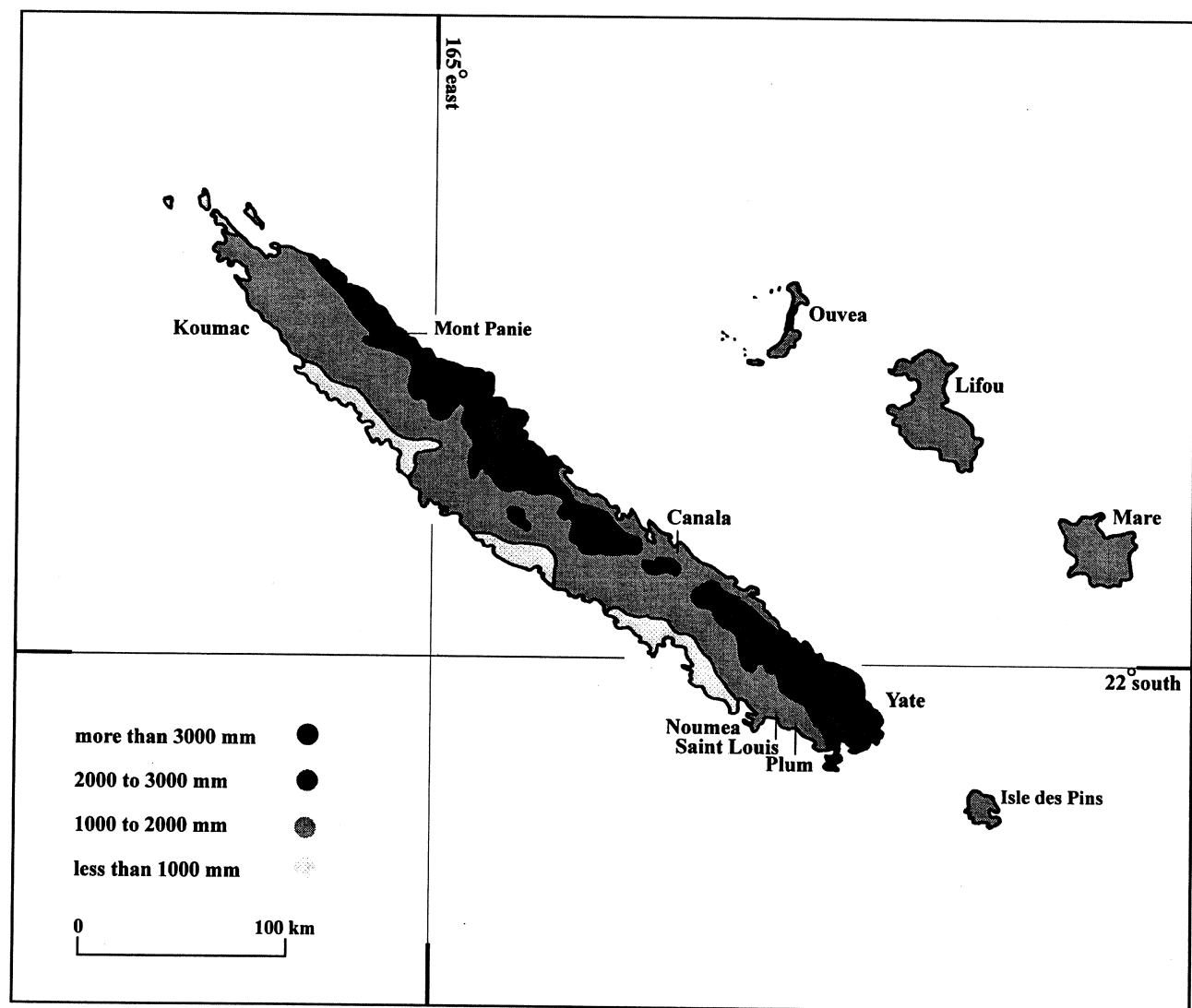


Figure 2.4: Annual rainfall map for New Caledonia. The fossil pollen sites of Plum, Saint Louis and Canala are shown. (Adapted from Renson, 1989c)

Temperature

The average temperature is between 22° - 24°C, with the maximum in February and the minimum in July and August. There have been maxima recorded of around 38° C and minima of less than 3° C (Section d'Hydrologie, 1981). Sea surface temperatures for the waters surrounding New Caledonia range between 25° C and 29° C from December to March and are less than 25° C from June to September (Eldin, 1989).

Cyclones

The cyclone season for New Caledonia extends from November to April, with most occurring between December and March. New Caledonia lies in a region of the Pacific that experiences, on average, 18 tropical cyclones every 10 years, with the Belep islands and northern tip of the main island the areas most affected by cyclone activity (Section d'Hydrologie, 1981). ENSO events shift the cyclone origin point so that in El Niño years the territory is less likely to experience them (Revell and Goulter, 1986; Hastings, 1990). While the lagoon surrounding the main island affords some protection from ocean swell, there are devastating floods from the intense rainfall produced by a cyclone in conjunction with the steep and short mountainous river basins (Danloux, 1989). New Caledonia's largest river, the Diahot, rose by 13 metres in less than 8 hours with the passing of cyclone Delilah in January, 1989 (Danloux, 1989). The highest rainfall for a 24 hour period was recorded at Ouaième and associated with cyclone Gyan in January 1981. 1,700 mm of rain fell in 24 hours causing the river discharge to rise from 100 to 10,400 m³/s in 19 hours (Danloux, 1989; Papineau, 1989). The rainfall intensities associated with cyclones can be extreme. A recent example is from a site near Goro on the southeast coast, where 100 mm of rain fell in 15 minutes during the passage of cyclone Drena in 1997 (S. McCoy pers. comm.). The rainfall associated with this cyclone caused gulying on some of the bare hillsides and roads in the Plaine des Lacs region. Despite the destruction to settlements, mining and agriculture, the heavy rainfall is important for restoring the water table on some of the small islands devoid of rivers (Section d'Hydrologie, 1981).

2.6 Vegetation

New Caledonia is renowned for its rich and highly endemic flora. The modern flora, which includes exotics, has over 4,500 species of vascular plants, with more than 3,200 of these being native (Morat, 1993). The native flowering plants are represented by 3,061 species, from 788 genera and 165 families, with a high degree of endemism at each level (Table 2.1). The 260 species of ferns on New Caledonia come from 26 families with 40% endemic at a specific level. While having 5 endemic families (Amborellaceae, Paracryphaceae, Strasburgeriaceae (1 species each), Oncothecaceae (2 species), and Phellinaceae(14 species)), the island's flora is distinct from many other tropical regions in lacking certain common families, such as Balsamiaceae, Begoniaceae, Dichapetalaceae, Maranthaceae, Ochnaceae (Jaffré *et al.*, 1994a).

Table 2.1 : Native Angiosperms and Gymnosperms of New Caledonia

	Gymnosperms	Dicotyledons	Monocotyledons	Total
Families				165
Endemic families				5
Total genera				788
Endemic genera				108 (14%)
Total species	44	2349	578	3061
Endemic species	43	2142 (88%)	263 (45.5%)	2448 (80%)

[From Morat, 1993.]

The tectonic and geologic history of Grande Terre was described earlier and accounts for the uniqueness of the flora. As a Gondwanan fragment isolated since the early Cretaceous New Caledonia's phytogeographical affinities lie predominantly with Australia and New Guinea giving the flora its continental aspect (Morat *et al.*, 1984; 1986). A number of what are termed relict species are preserved in the flora. These include 44 species of Gymnosperm, of which 43 are endemic, as well as a number of primitive or archaic angiosperms (Table 2.2). This long period of isolation also explains why many typically Australian taxa of recent origin are absent; for example phyllodinous *Acacia*, *Banksia*, *Eucalyptus*, and some forest Proteaceae (Morat *et al.*, 1984). However, the flora presumably continued to be enriched from the Cretaceous onward by long distance transport.

The overthrusting of the peridotite sheet during the upper Eocene was a slow phenomenon (Morat, 1993), but one that had major repercussions for the vegetation of the island. This highly selective substrate produced a distinctive vegetation type known as the maquis through adaptive radiation in a fraction of the Eocene floristic base (Morat, 1993). With the ensuing fragmentation of the ultramafic sheet into outcrops, speciation continued by the phenomenon of vicariance. Today 90% of the species found in the ultramafic terrain are endemic to the territory, with 60% of those endemic to the ultramafic outcrops (Jaffré *et al.*, 1994a).

Table 2.2: Archaic elements of the New Caledonian flora

Gymnosperms			
Araucariaceae	<i>Agathis</i> (5)	Podocarpaceae	<i>Acmopyle</i> (1)
	<i>Araucaria</i> (13)		<i>Dacrydium</i> (4)
Cupressaceae	<i>Callitris</i> (2)		<i>Dacrycarpus</i> (1)
	<i>Libocedrus</i> (3)		<i>Falcatifolium</i> (1)
	<i>Neocallitropsis</i>		<i>Parasitaxus</i> (1)
Taxaceae	<i>Austrotaxus</i> (1)		<i>Podocarpus</i> (7)
			<i>Prumnopitys</i> (1)
			<i>Retrophyllum</i> (2)
Primitive Families - vessels absent			
Amborellaceae	Balanopaceae	Paracryphiaceae	Trimeniaceae
Annonaceae	Chloranthaceae	Piperaceae	Winteraceae
Atherospermataceae	Menispermaceae	Sphenostemonaceae	

[Compiled from Jaffré *et al.*, 1994a; 1995; Morat, 1993] (1) = number of species in genus

Table 2.3: Number of species by vegetation type in New Caledonia

Vegetation Type	Gymnosperms and Angiosperms		Ferns and Allies	
	Species (n)	Endemic (%)	Species (n)	Endemic (%)
Wet evergreen forest	1799	87%	212	44%
Maquis	1107	91%	35	31%
Sclerophyll	380	60%	29	31%
Coastal	180	13%	5	0
Mangrove	24	4%	1	0
Savanna	101	13%	5	0

Wet evergreen forest at all altitudes and on all substrates; Maquis on ultramafics and on schist.
[From Morat (1993) with figures updated from Jaffré *et al.* (1994a)]

Morat *et al.* (1981) identify six vegetation types for New Caledonia (Table 2.3). All except savanna are related to climatic, topographic and edaphic conditions. Savanna covers over 50% of the island, with its present extent stemming from anthropogenic activity, in particular the land use practices of European colonisers who cleared large tracts of the west coast for cattle grazing (Barrau, 1980; Schmid, 1987). On the main island the native or natural vegetation in all its forms is confined to the steep slopes of the central mountain chain or unexploited regions within the ultramafic terrain. What remains of New Caledonia's rainforest covers around 20 % of the main island, and the maquis, which is restricted to the ultramafic terrain, around 30%.

Appendix 7 is an authority list for all species referred to in the text.

Wet Evergreen Forest (rainforest)

Rainforest covers 22% of the territory (which includes the Loyalty Islands) on a variety of geological substrates in areas of the highest reliable rainfall (Figure 2.5) (Morat, 1993). Of New Caledonia's 1799 rainforest species, 87% are endemic. Through anthropogenic activity, lowland rainforest or closed forest is today restricted to island like fragments. While it may occur near sea level on the windward east coast, on the leeward coast it generally starts at around 300 m, with annual rainfall of over 2000 mm precipitation. At around 800 to 1000m elevation it changes structurally and floristically into montane and cloud forests (Mueller-Dombois and Fosberg, 1998). However, rainforest does descend to near sea level in the sheltered valleys of the west coast where annual rainfall is around 1500 mm. Some uncertainty therefore exists over the present lower limit of rainforest on the west coast due to the influence of human activity, in particular the use of fire by the indigenous population and in more recent times by Europeans (Plate 2.1).

In general the lowland rainforest canopy is 20 - 25 m tall, with a few emergents such as *Araucaria* and *Agathis* species reaching heights of 30 - 35 m. The principal constituents of the upper strata include Araliaceae, Cunoniaceae, Lauraceae, Myrtaceae and Sapotaceae, with *Calophyllum*, *Montrouzieria*, *Albizia*, and Proteaceae as common elements (Schmid, 1987; Jaffré, 1995; Mueller-Dombois and Fosberg, 1998). Other

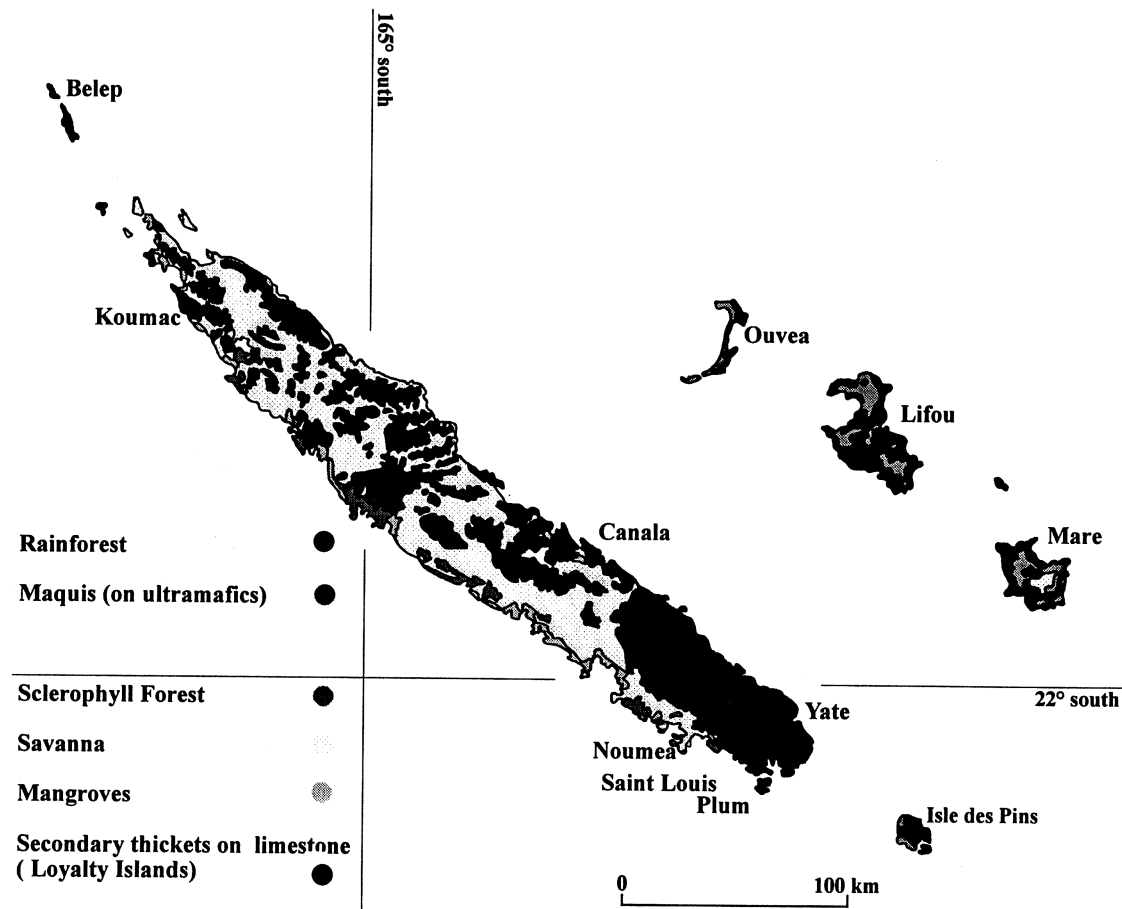


Figure 2.5: Vegetation map of New Caledonia. The fossil pollen sites of Plum, Saint Louis and Canala are shown. (Adapted from Jaffré, 1989).

elements that characterise New Caledonia's rainforests are the diverse array of Gymnosperms (35 of the 44 species), the large number of palms (32 species) and the 10 species of treefern which are restricted to the rainforest (*Cyathea* 8 species, *Dicksonia* 2 species). In addition the rainforest understory has large ground ferns, the grass-like *Joinvillea elegans*, lianas such as *Freycinetia*, epiphytes, orchids and smaller ferns (Jaffré, 1995; Mueller-Dombois and Fosberg, 1998).

Lowland rainforest occurs on ultramafic and non-ultramafic substrates, and there are no obvious floristic differences apart from more palms and figs in rainforests from the north of the island (Mueller-Dombois and Fosberg, 1998). This is interesting as the landscape surrounding the pockets of rainforest is markedly different between substrates. In the ultramafic terrain maquis is the vegetation that surrounds the forests, with a ground cover of Cyperaceae and ferns. Away from the ultramafic substrate the forest patches are surrounded by savanna.

Nothofagus is also found in the rainforests of New Caledonia, but it also forms monospecific stands, principally in the ultramafic terrain. The five different species found on New Caledonia belong to the sub-genus *Brassospora*, which today is limited to tropical latitudes. Read *et al.* (1995) examined several *Nothofagus* rainforest patches to determine if the monodominance of the canopy was due to a lack of disturbance or the characteristics of the ultramafic soil. Their findings so far suggest that disturbance is a requirement of regeneration in these forests, and that in the absence of this, they will move toward a mixed rainforest. However, they hypothesise that if the disturbance is too extreme, or its frequency too high, local extinctions may result. The soils under these forests seem to play a minor role in determining the floristic structure of the *Nothofagus* patch, as the soil variables measured were within the range of those recorded for mixed rainforest and maquis in the same area (Read *et al.*, 1995).

Montane rainforest and cloud forest become structurally distinctive from lowland rainforest at around 800 m, where rainfall is usually around 3500 to 4000 mm per annum or more. Apart from being much wetter, it is also considerably cooler, with daytime temperatures of the coldest month averaging around 15° C (Sarlin, 1954; Jaffré,

1995). Frost can also occur. In general the angiosperm forest elements are around 10 m tall with a tall open canopy of gymnosperms (usually *Araucaria* or *Agathis*) reaching around 20 m. It is thought that the structure of these upper canopy trees make them ideal for harvesting cloud moisture (Mueller-Dombois and Fosberg, 1998). The montane forests are rich in gymnosperm taxa: *Araucaria*, *Agathis*, *Podocarpus*, *Dacrydium*, *Libocedrus*, and *Acmopyle*, while notable angiosperm taxa include *Nothofagus*, *Metrosideros*, *Weinmannia* and *Quintinia*. Above 1100 m in the ultramafic terrain, montane forest gives way to high altitude maquis (patchy scrub vegetation), reinforcing the impression that this terrain is harsh for plant growth (Mueller-Dombois and Fosberg, 1998). In other parts of the island between 1100 and 1600 m montane forest continues to grow. Although the montane forests are fragmented into topographic islands along the central mountain chain, which gives rise to unique species combinations in some areas, Mueller-Dombois and Fosberg (1998) note that there are no outstanding floristic differences in montane forest throughout the island.

Maquis

The maquis of New Caledonia is found predominantly in the ultramafic terrain of the main island (Figure 2.5) with a small area found on schist, hence the term *maquis minier* (mining scrub). In many parts of the world ultramafic floras are species poor, but on New Caledonia the flora is extremely rich, its 1107 species being only slightly less rich than the rainforests of the island (Brooks, 1987). Many of the genera found in the rainforests of New Caledonia are also found in the maquis. The maquis covers 30% of the main island from sea level to the highest summits and appears independent of rainfall, being found in regions with yearly rainfall averages of between 1200 mm and 4000 mm (Jaffré *et al.*, 1994a). It was noted above that while rainforest formations are also found in the ultramafic terrain, the maquis dominates, covering 80-90% of this substrate.

Typically, maquis is an evergreen, sclerophyllous, bushy formation which has a relatively open herbaceous strata with Cyperaceae an important element but grasses virtually absent (Plate 2.2). Most maquis species are light demanding and occupy open sites. The sclerophyllous nature and low stunted habit of the maquis stems from the low

nutrient availability of the ultramafic soils, which are typically low in the plant nutrients nitrogen, potassium, phosphorus and calcium, while having an excess of magnesium, chromium and nickel. The physiognomy and diversity of species in New Caledonian maquis is highly variable from one locality to another. While the Myrtaceae have the highest number of species in the maquis (135), it is the Casuarinaceae and Epacridaceae which are more conspicuous in the landscape due to their sheer abundance (Jaffré *et al.*, 1994a). Cyperaceae (sedges) dominate swamp surfaces and tall tree species such as *Araucaria* spp., *Agathis ovata* and *Arillastrum gummiferum* may form an open tree stratum. Characteristic shrub genera include *Phyllanthus* (Euphorbiaceae), *Psychotria* (Rubiaceae), *Pancheria* (Cunoniaceae), *Hibbertia* (Dilleniaceae), *Pittosporum* (Pittosporaceae), *Eugenia*, *Xanthostemon* (Myrtaceae), *Alyxia* (Apocynaceae), and the families Goodeniaceae, Casuarinaceae, Myrsinaceae and Rhamnaceae (Jaffré *et al.*, 1994a). The ultramafic soils found associated with the maquis have led to a diversification of the Cyperaceae, making it the predominant ground cover, while virtually excluding the more modern families Poaceae and Asteraceae.

The ligno-herbaceous maquis (cyperaceous maquis) is a formation that is essentially Cyperaceae interspersed with a discontinuous cover of shrubs (Plate 2.3). This is considered to be a secondary formation, although on the human timescale it seems relatively stable (Jaffré, 1995).

Until recently, comments in the literature on the role of fire in the maquis were essentially anecdotal. Severely burnt or degraded environments in the ultramafic terrain have very open pioneer communities composed primarily of *Pteridium esculentum* and Cyperaceae. How long these communities exist in the landscape before shrubs of the maquis take over is under study by Jaffré, but after 15 years the monitored sites are still dominated by *P. esculentum* and Cyperaceae (S. McCoy per. comm.). McCoy *et al.* (in press) have examined the role of fire in the maquis of New Caledonia and concluded that its floristic and structural composition is dependent on fire frequency. That is, the more fire there is in the landscape the more maquis elements are found within forest, until the return time of fire is so high as to exclude forest altogether. Although charcoal is found throughout the late Pleistocene record (20 to 40 k BP) of Hope and Pask



Plate 2.1: Burning of rain forest on the west coast of New Caledonia during the dry season. Photograph taken on Route 1 south of Tontuta. Grassland savanna in foreground.

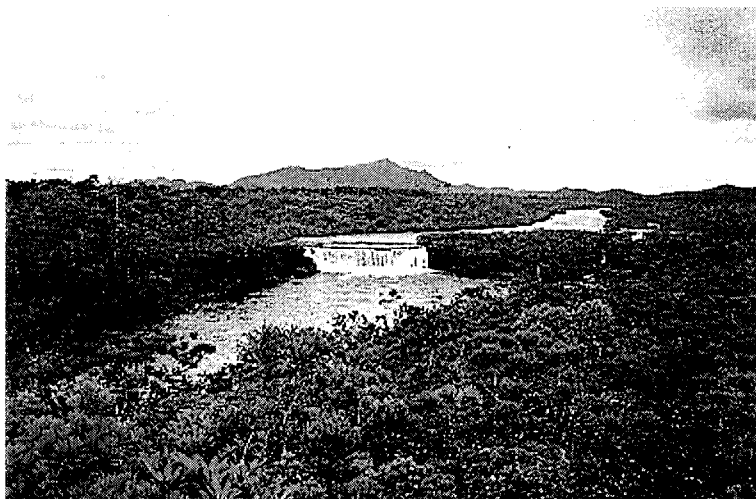


Plate 2.2: Maquis at Chutes des Madelaine, Plaine des Lacs. *Gymnostoma*, *Xanthostemon* and *Dracophyllum* in foreground.



Plate 2.3: Ligno-herbaceous maquis, Plaine des Lacs.

(1998), the alternations between *Gymnostoma* maquis and *Nothofagus* forest apparent in the pollen record do not appear to be linked to changing levels of charcoal concentration.

A number of reviews of the maquis discuss its origins and the impact people may have had on it, particularly through the use of fire. The maquis has a rainforest base and so its phytogeographical affinities, like those of the rainforest, lie with Australia and New Guinea (Morat *et al.*, 1984; 1986). It is thought that fire has caused the progressive destruction of rainforest and the extension of the cyperaceous maquis which covers a majority of the ultramafic terrain. A number of species of the genera *Montrouziera*, *Garcinia*, *Codia*, *Hibbertia*, *Scaevola* and *Tristaniopsis* resprout after fire, with *Montrouziera* and *Garcinia* thought to be indicative of frequent fires (Morat *et al.*, 1986).

In 1875 the mineral wealth of the ultramafic terrain was recognised and nickel, iron and chrome mining began. Nickel mining supplies 90% of the island's exports, with New Caledonia possessing one third of the world's economic nickel ores (Brooks, 1987). Erosion from mining now scars the landscape and is one of the island's major environmental problems as is the revegetation of mine sites (Jaffré *et al.*, 1994b).

Sclerophyll Forest

Sclerophyll forest (or dry forest) was once widespread along the west coast occupying, along with the maquis, some of the driest areas of New Caledonia at altitudes below 300 m (Figure 2.5). It is thought that it was once continuous, but it is now found as isolated fragments, which together total 350 km², or less than 3% of the main island (Jaffré *et al.*, 1993). Growing on a number of different substrates except for the ultramafics, this type of formation is found in many other tropical regions, although the ecological conditions are often different as is the floristic make up (Jaffré *et al.*, 1993). There are now very few intact stands remaining, with most of these suffering some degree of degradation (Jaffré and Veillon, 1991).

Sclerophyll forest is a low formation, dominated by semi-deciduous trees with a lower strata of woody evergreen sclerophyllous trees and shrubs and a discontinuous ground

cover of Cyperaceae and Poaceae (Morat, 1993). 57% of the 409 species are endemic, although only 59 species are restricted to the formation.

The tree strata is dominated by species such as *Arytera chartacea*, *A. collina*, *Cupaniopsis globosa*, *Diospyros fasciculosa*, *Drypetes deplanchei*, *Dysoxylum bijugum*, *Homalium deplanchei*, *Planchonella cinerea*, *Sarcomelicope leiocarpa*, *Euroshinus obtusifolius*, *Ficus* spp., *Vitex* spp. and *Terminalia* spp.. The genera which are particularly abundant in the shrub strata include *Eugenia*, *Austromyrtus*, and *Cleidon*, with a large number of lianes also present: *Alyxia*, *Capparis*, *Geitmoplesium*, *Hypserpa*, *Melodinus*, *Smilax* and *Ventilago*. Cyperaceae, Poaceae and ferns of the genera *Adiantum*, *Asplenium*, *Pteris* and the endemic and monospecific genus *Cionidium* constitute the ground cover (Jaffré *et al.*, 1993)

The character of sclerophyll forest changes with the moister conditions in the valleys and beside ephemeral streams. The trees (*Aleurites moluccana*, *Mammea neurophylla*, *Olea paniculata*, *Syzigium densiflorum*) exceed 20m and the shrub strata is less developed given the more filtered light conditions from the denser canopy. Notable absences from the sclerophyll forest include the Gymnosperms, the palms, Pandanaceae, Winteraceae, Elaeocarpaceae, Symplocaceae, Epacridaceae and Fagaceae all of which are abundant in the rainforest (Jaffré *et al.*, 1994a).

A number of formations have been derived from sclerophyll forest mainly through the actions of people. One such formation is that defined by the dominance of the shrub *Acacia spirorbis* (gaiac). *A. spirorbis* occurs naturally as isolated trees in sclerophyll forest and becomes more abundant as the forest is degraded. Severe degradation leads to its ultimate replacement by savanna.

Savanna

The savanna of New Caledonia is a secondary formation and has been greatly extended through the clearance of forests for agriculture and the widespread use of fire. It is characterised by a continuous herb layer with scattered shrubs and small trees and is absent from the ultramafic terrain (Jaffré and Veillon, 1991). Mueller-Dombois and

Fosberg (1998) suggest that the small *Melaleuca* swamp forests in the north of the island may be the source from which the tree spread as the former sclerophyll forests and lowland forest were destroyed by fire.

While it can take a number of forms the two most common are an herbaceous savanna (Plate 2.1) and the one dominated by *Melaleuca quinquenervia* (naiouli) (Plates 2.4 and 2.5). A naiouli savanna which is typically a grassland with scattered trees or shrubs of *Melaleuca quinquenervia* stretches almost uninterrupted from Noumea in the southeast to the northern tip of the main island along the flat to undulating leeward coast. The naiouli savanna begins near the coast, often directly behind a mangrove forest, or next to dry sclerophyll forest and extends well into the central mountain chain. It not usually found above 600m as it is sensitive to the cooler montane temperatures (Sarlin, 1954). With the exclusion of fire, secondary forest develops in the more humid areas of the savanna (Sarlin, 1954; Mueller-Dombois and Fosberg, 1998).

Other forms of savanna include that dominated by *Casuarina collina* (bois de fer), another by *Acacia farnesiana* and one by *Psidium guajava* (Jaffré and Veillon, 1991).

Mangroves, Strand Vegetation and Littoral Forests

Mangroves occur mostly along the southwest coast of the main island along sheltered bays and estuaries (Figure 2.5). The mangrove stands are generally of low stature, many only shrubs, with maximum tree heights of around 10 m. (Jaffré *et al.*, 1994a; Mueller-Dombois and Fosberg, 1998).

There are around 20 species found in the mangrove zone of New Caledonia. All are Indo-Pacific species (there are no endemics) and include *Rhizophora* (7 spp.), *Bruguiera gymnorhiza*, *Avicennia marina*, *Lumnitzera* (2 spp.), *Sonneratia* (1 sp.) (Jaffré *et al.*, 1994a; Mueller-Dombois and Fosberg, 1998). *Rhizophora* forms the seaward zone mixed with *Bruguiera gymnorhiza*. *Avicennia*, *Sonneratia* and *Lumnitzera* become more abundant inland. Occasionally on the southwest coast saltmarshes are found behind the mangroves with a low and sparse cover of *Suaeda* and

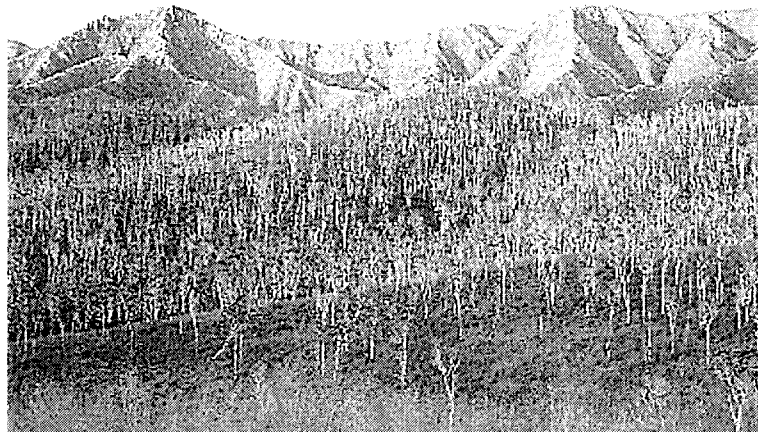


Plate 2.4: *Melaleuca quinquinervia* savanna in the north of the main island.



Plate 2.5: *Melaleuca quinquinervia* woodland next to Plum Swamp, east of Noumea. Note the rich understorey of ferns and grass.

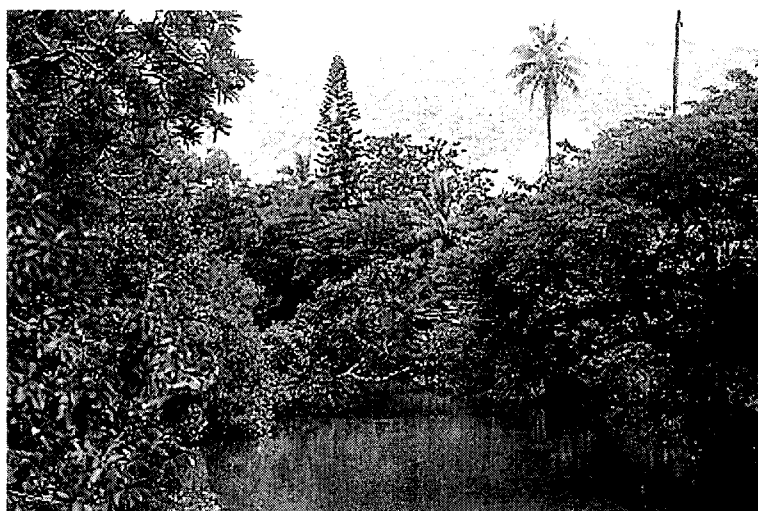


Plate 2.6: Littoral forest near mouth of Plum River. *Araucaria* and *Cocos nucifera* in centre background.

Salicornia. Monocotyledons are absent and there is only one species of fern associated with the mangrove vegetation, *Acrostichum ureum* (Jaffré *et al.*, 1994a).

The mangrove and saltmarsh vegetation eventually gives way to savanna, sclerophyll forest or a strand vegetation which has a composition common to many southwest Pacific islands. Pacific beach vines such as *Ipomoea* and *Canavalia* are common as are shrubs of *Atriplex*, *Euphorbia* and *Scaevola*.

Littoral forest is found immediately adjacent to the coastal vegetation and along the sides of coastal rivers (Plate 2.6). Large trees of around 15 m include *Cerbera manghas*, *Calophyllum inophyllum*, *Barringtonia asiatica*. The small tree and shrub species include *Acacia simplex*, *Acropogon bullatus*, *Casuarina equisetifolia*, *Cocos nucifera*, *Hernandia* spp. *Manilkara dissecta*, *Mimusops elengi*, *Planchonella cineria* and *Pandanus* spp. (Jaffré *et al.*, 1994a; Mueller-Dombois and Fosberg, 1998). Twenty species of liane are also found (Jaffré *et al.*, 1994a). All are trees common to littoral forest through much of the southwest Pacific.

A coastal tree unique to New Caledonia is the spectacular *Araucaria columnaris*, which reaches heights of around 60m. While found scattered throughout coastal forests, the densest populations occur on the rugged limestone cliffs bordering the sea throughout the territory (Jaffré *et al.*, 1994a).

2.7 Fire

It has long been assumed that fire, and in particular fire as a result of human activity, has had a key role in shaping the present day vegetation distributions of New Caledonia. Evidence of European fire use is unambiguous, and the literature is full of references to the use of fire by pastoralists to clear large tracts of land and to encourage palatable regrowth for their cattle (Barrau, 1980; Jaffré and Veillon, 1991; Schmid, 1987; Virot, 1956). However, the extent to which the Kanak people altered the New Caledonian landscape prior to European settlement remains unclear. Observations by early explorers such as Cook and the writings of various naturalists from the 19th and 20th

centuries note that villages and gardens were scattered amongst savanna woodlands and grasslands, riverine forests and rainforests (Avias, 1953; Barrau, 1980; Beaglehole, 1961; Viot, 1956). The humid forests are thought to have been the dominant natural vegetation of the lowland areas which were modified over the millennia through the use of fire, possibly beginning as swidden cultivation within the forests (Viot, 1956). The extension of the savanna also had some economic benefit to the Kanaks as the wood and bark of *Melaleuca quinquenervia* was used in house construction and the leaves of the grass *Imperata* for thatching (Barrau, 1980).

The scenes described above occupied the fertile valleys and coastal lowlands of the northern two thirds of New Caledonia, with the large ultramafic region of the south uninhabited when Europeans colonised in the 19th century (Avias, 1950). In such terrain the poor nutrient status of the soils effectively prohibits cultivation and so the pre-European link between fire, people and the ecosystems found here is less certain.

Ethnological evidence suggests that fire may have been used to keep paths open, for hunting, for wild food gathering and for timber felling (Vieillard, 1862; Viot, 1956). Barrau (1980) observed, while conducting ethnobotanical research in the 1950's, that fire was used with care within the gardened landscape of the village but not so outside. Fire was also frequently used in warfare when not only the villages of adversaries would be set alight but also their surrounding lands. Viot (1956) hypothesises that unfavourable winds and low humidity during such an episode may have led to large tracts of forest being destroyed.

Preliminary work on the research described here established that fire was present in the landscape before 3,000 BP, but increased in association with the commencement of the archaeological record (Stevenson, 1991; Stevenson and Dodson, 1995). Hope and Pask (1998) have no Holocene records, but do have evidence for a natural fire regime from the ultramafic terrain in the south of the island during the Pleistocene. It is assumed that lightning would be the natural cause of ignition. It has been observed that thunderstorms with lightning are rare but when they do occur are most common in the wet season (Viot, 1956). To the best of my knowledge, there are no records for

lightning strike kept by Service Territorial de la Météorologie in Nouméa, as written enquiries about such information have gone unanswered. Records of human versus natural ignition do not appear to be kept by any of the Parks services either. Records of this nature would give some insight into the likelihood of natural ignition.

Today, as in so many other places, most bushfires are the result of carelessness, poor judgement in lighting control burns or pyromania. Pleas for greater control over the use of fire in pastoral areas to halt the increasing loss of rainforest and hence biodiversity were made as early as the 1950's (Viro, 1956). More recently a poster campaign (*Halte aux Feux*) was mounted by the Province Nord and Province Sud authorities to deter people from lighting fires for amusement, particularly in the maquis.

While the degree of impact the Kanak population had on the landscape is still to some extent a matter of conjecture, the impact of European colonisation is more evident. Sandalwood traders began visiting the islands in 1842, and sandalwood (*Santalum* spp.) became the territory's first extractive industry (Lyons, 1986). By 1853, the year France took possession of New Caledonia, the sandalwood resource was almost exhausted. At this time it was common for the Kanaks to burn large tracts of forest in search of sandalwood stumps (Vieillard, 1862) which were then removed and traded. Timber extraction continued after French colonisation, mainly for kaori (*Agathis*), and many of the tall forests were cleared (Schmid, 1987). Although the French had laid claim to the territory primarily to establish a penal colony, free settlement was also encouraged, most notably for cattle ranching in the savanna lands (Barrau, 1980; Lyons, 1986). The Kanak population living in the southwest of the island was thus promptly dispossessed of its land and forced to inhabit the more inhospitable interior regions (Lyons, 1986). Impoverishment of the grasslands came about quickly through overgrazing and soil erosion dramatically increased, while extensive burning adopted by the graziers to encourage palatable regrowth led to further invasion by *Melaleuca quinquenervia*, as well as the introduced shrubby weeds *Lantana camara* and *Psidium guajava* (Barrau, 1980).

2.8 Ethnobotany

An understanding of the indigenous knowledge and utilisation of plants is important for an understanding of human impact in the palaeoenvironmental record. The following draws heavily on the 19th century ethnobotanical observations of Vieillard (1862), the work of Barrau (1956, 1958, 1962) and the review of Cherrier (1990). Barrau's work is concerned largely with indigenous agriculture and nutrition in the 20th century, and how far back in time we can take the observations of any of these authors is certainly debatable.

This review is by no means exhaustive, but what is apparent even from the modest lists that follow is the range of economic resources found in the native vegetation. As a Gondwanan fragment New Caledonia's floristic affinities lie with Australia and New Guinea and hence one can surmise that many plants would have been familiar, at least at the generic level, to people reaching New Caledonia 3500 years ago. European introductions have been omitted from the tables below, even though many now have a primary role in the diet of rural Kanaks. The following is a discussion of plant utilisation with regard to the major food plants cultivated or tended, other foods that are gathered in the wild, and the uses made of plants for things such as construction materials, fibres for textiles and ornaments. For most species an indication of the plants lifeform and where it is found in the landscape has been given. Medicinal plants are reviewed by Rageau (1973) and are not included here. Most of the 600 species he documents are introduced or have a cosmopolitan distribution and grow in and around settlements, primarily in the coastal zone. New Caledonia's endemic plants remain relatively unstudied from this point of view.

Staple Food Plants

Agriculture forms the basis of traditional Kanak society and it is the traditional plants and their cultivation that are best documented. It should also be noted that food plants can be separated into those that form a staple part of the diet and those that are supplementary. Table 2.4 summarises the staple food plants, some of which are intensively cultivated, while others are either tended or gathered from the wild. Since the arrival of Europeans in New Caledonia traditional agriculture has declined steadily

and today it is the simpler forms of subsistence cultivation that remain, with only a few areas still supporting the elaborate and sophisticated systems of the past.

The two principle crops in pre-European times were yam (*Dioscorea* spp.) and taro (*Colocasia esculenta*), both crops being maintained by vegetative reproduction. Yam is a dryland crop with a place of central importance in Kanak society. It is associated with male symbols and accompanies all the important moments of social life, such as births, deaths and marriages. The history of a clan's birth and development is commonly compared to the different stages of yam growth (Bourret, 1981). Respect for the yam is apparent in the many taboos that surround its handling and the indigenous calendar that decides its cultivation (Dahl, 1985). It is a seasonal crop with clearing or soil preparation carried out in July, planting in September and October, and harvesting around March. The cultivation calendar is determined by celestial events or other events in nature and, once harvested, yams can be stored in cool dry conditions for 6 to 10 months (Dahl, 1985). The mounding system used for yam cultivation was described in Chapter 1.

Table 2.4: Staple Food Plants of New Caledonia.

BOTANICAL NAME		COMMON NAME	PART OF PLANT EATEN
<u>ARACEAE</u>		Taros	
<i>Alocasia macrorrhiza</i> (L.) Schott			Tuber
<i>Colocasia esculenta</i> (L.) Schott	C		Tuber, leaves, flowers
<i>Xanthosoma</i> spp.			Tuber
<u>CONVOLVULACEAE</u>			
<i>Ipomoea batatas</i> (L.) Lamk.	C	Sweet Potato	Tuber
<u>DIOSCOREACEAE</u>		Yams	
<i>Dioscorea alata</i> L.	C	Greater Yam	Tuber
<i>D. bulbifera</i> L.	C	Bitter Yam	Tuber (cultivation simple fallow)
<i>D. esculenta</i> (Loureiro) Burkill	C		Tuber
<i>D. glabra</i> Roxb.			Tuber (semi gathered)
<i>D. nummularia</i> Lam.	C		Tuber
<i>D. pentaphylla</i> L.			Tuber
<u>MUSACEAE</u>		Bananas	
<i>Musa paradisiaca</i>			Fruit
subsp. <i>sapientum</i> (L.) Kuntze	C		
<i>M. paradisiaca</i>			Fruit and Rhizomes
subsp. <i>sapientum</i> (L.) Kuntze			
var. <i>oleracea</i> Baker	C		
Other Banana Species Utilized			
<i>Musa discolor</i> Hort	C		Fruit
<i>M. troglodytarum</i> S. Kurz.			Fruit

Compiled from Barrau (1956, 1958), Bourret (1981) and Vieillard (1862). C = cultivated.

There are 10 species of yam present on New Caledonia (Bourret, 1981). Of these six are considered ancient and appear in Table 2.4. *Dioscorea alata* and *D. esculenta* are the two species of yam intensively cultivated, while *D. bulbifera* and *D. pentaphylla* are largely collected in the wild or cultivated in simple fallow (Sand, *in prep.*; Vieillard, 1862). *D. alata* and *D. esculenta* are considered to have been introduced by people 3500 years ago (Bourret, 1981) although the origins of the Pacific yams remain unresolved (Yen, 1993; 1996).

Taro is regarded as female and is a wet cultivated crop that needs saturated or continually humid conditions. It can only be stored for a few days after harvesting but can be planted year round. The seasonal and irregular rainfall in New Caledonia makes irrigation essential, but the non seasonality of the tubers is thought to be the principal justification for maintaining elaborate irrigation systems manifest in kilometres of now unused taro terraces (Barrau, 1980; Dahl, 1985). It is speculated that soil fertility may have been a problem with perhaps only one or two harvests before the beds of taro and yam would have been left fallow (Dahl, 1985). This view stems largely from the number of abandoned gardens and terraces found at the time of European colonisation, although Sand (1996) attributes these to a society that had collapsed between Cook's 1774 visit and the beginning of French colonisation in the 19th century. Sand (*in prep.*), also suggests the counter view that the labour in constructing the elaborate irrigation systems of New Caledonia may have been justified partly by allowing for a shorter fallow time.

As elsewhere in Melanesia, sweet potato (*Ipomoea*), is regarded as a relatively recent introduction, although possibly introduced prior to European colonisation by sailors from Tonga (Sand, *in prep.*). However it did not attain a central role in the diet and agriculture of Kanak people until after colonisation. Sand (*in prep.*) highlights the difficulty in identifying why introductions such as sweet potato remain in a marginal role and why others failed to be embraced altogether. He suggests that acceptance may have lain in the need to fit in with the complex set of religious beliefs that governed agriculture until recently. *Alocasia* and *Xanthosoma* are often found in gardens but are staples of much less importance than those already mentioned (Barrau, 1958).

Of the banana species, *Musa paradisiaca* and *M. discolor* are cultivated, while *M. troglodytarum* is largely gathered (Vieillard, 1862; Barrau, 1956). There are no special techniques employed with the cultivation of bananas and they are usually found in clumps around villages and bordering yam mounds (Vieillard, 1862). Since European colonisation, other banana species have been introduced and are an important part of the Kanak diet.

It should be noted that several secondary crop plants such as sugar cane were grown in and around village gardens. In particular the slopes of yam mounds were often planted with sugar cane, banana and some greens to retain the soil (Dahl, 1985). Ti (*Cordyline terminalis*) is common across the southwest Pacific and is considered male and magical on New Caledonia. It is grown around the villages largely for ritual purposes (Table 2.5) and although classified as a male plant, it is also grown around taro terraces if the slope is too wet (Barrau, 1958; Dahl, 1985). Cherrier (1990) records the roots as being eaten as they still are in New Guinea.

Other Food Plants

As comprehensive a list of plants as possible was constructed for this and the following sections to give an indication of the variety and contexts of plant use. Descriptions of plant use were found throughout the texts of Barrau (1956, 1958, 1962), Cherrier (1990) and Vieillard (1862). Compiling these descriptions into table form makes the information abbreviated and much more accessible. Given the size of the tables, they have been placed in Appendix 6.

Most of the secondary food plants exploited are from coastal or lowland forest, with only two species exploited from the maquis (both *Grevillea* species). However, rainforest in the ultramafic terrain was probably exploited like any other lowland rainforest if the resources were there. A majority of the foods were gathered from the wild, with the notable exceptions of coconut (*Cocos nucifera*), sugar cane (*Saccharum officinarum*), breadfruit (*Artocarpus incisus*) and *Hibiscus manihot*. All of these were semi-cultivated or tended around settlements. Breadfruit is most common on the east

coast and on the smaller islands, but is not found in large numbers anywhere in the New Caledonian territory (Cherrier, 1990).

A number of plants in Appendix 6 have several different uses and appear in more than one of the tables. Good examples of this are *Cocos nucifera* and *Pandanus* which apart from supplying food also supply fibre for string, and leaves for a variety of purposes including mats and thatching houses. While many secondary or supplementary food plants such as coconut are commonly found in and around village gardens, *Pandanus* is not, which seems strange given the economic importance of the genus. All of the Pandanaceae found on New Caledonia, including the genus *Freycinetia*, were exploited for their fruit (Appendix 6: Table A6.2) and cultivation of the genus is common in other parts of Melanesia (Barrau, 1958; Yen, 1990, 1996). One possibility is that stands of these trees were, and still are, semi-cultivated, and this aspect of their exploitation has been overlooked in the ethnobotanical work reviewed here.

The foods collected in the wild are noted as being searched for with care (Barrau, 1958, 1960; Vieillard, 1862), but apart from this there is little indication as to foraging technique or whether any practices have been used to encourage growth of certain species. The literature tends to concentrate on the processing of the food item. A number of plants are only foraged for in times of poor yield from the traditional staples, such as the tuber of *Pueraria* sp., the new shoots of *Hibiscus tiliaceous* and a number of ferns (Barrau, 1958). The treefern *Cyathea vieillardii* has the core of its trunk prepared in a similar way to sago (Vieillard, 1862). The sago palm, *Metroxylon*, is not found on New Caledonia.

The history of tree use in the Pacific is still relatively unknown although arboriculture of some time depth does seem likely for northern Melanesia (Gosden, 1992; Kirch, 1989; Mathews and Gosden, 1997; Yen, 1990, 1996). While many nut tree species may not have been cultivated on New Caledonia in the recent past, they were certainly foraged for, and stones identified as nutcrackers uncovered in an archaeological context are evidence that nut consumption has some antiquity (Sand, 1996). On islands in the

southwest Pacific north and east of New Caledonia the cultivation of various *Canarium* species is common (Yen, 1996).

While there are four endemic species of *Canarium* on New Caledonia none of the major and widespread cultivated species are found here, for example *C. indicum* and *C. harveyi*. Vieillard (1862) and Barrau (1956) both refer to the gathering of *Canarium oleiferum* nuts and Cherrier (1990) suggests that all four species were exploited. However, exploitation of the genus on New Caledonia is seldom included in discussions of the prehistory or history of Pacific nut consumption (Yen, 1990, 1996). This may be due to the absence of cultivation today and the allocation of all the New Caledonian species to the separate *Canariellum* section within the genus.

The absence of *Canarium indicum* and *C. harveyi* on New Caledonia could be for a number of reasons. A lack of continued contact with the surrounding region (just as in the absence of pigs and kava) is one possibility, as is the lack of any need to take up an introduction if a suitable species is already available. Another possibility is that the location of New Caledonia may be beyond the ecological limits of these otherwise widespread species.

While the exploitation of plant species may not be consistent across the southwest Pacific, Table A6.2 in Appendix 6 highlights the genera found in archaeological sites from northern Melanesia based on Gosden *et al.* (1989), Hayes (1992), Kirch (1989) and Mathews & Gosden (1997). At the generic level at least, there is some overlap.

Other Plant Usage

People exploit plants for purposes other than obtaining food, such as in the production of fibres and textiles for the making of such things as baskets, fishing nets, matting and costume. Plant poisons were also used to stun fish, and Barrau (1956) comments on the cultivation in traditional gardens of *Euphorbia kanalensis* for this purpose. The toxin in the nuts of this species is extremely corrosive to skin and great care has to be taken in its preparation.

Once again it is the lowland and coastal forests that were exploited, with very few plants from the maquis utilised. Tapa, a soft felt-like fabric made by beating the bark of several species is common across the southwest Pacific. The tree that carries the common name Tapa on New Caledonia, *Broussonetia papyrifera* (Urticaceae), was once cultivated on the island but today is quite rare (Cherrier, 1990).

The use made of *Melaleuca quinquenervia* in cladding and lining the walls of houses is interesting given the predominance of this species in the landscape today. Consideration should be given as to whether its exploitation was opportunistic, or whether people actively encouraged its proliferation through various landuse practices, particularly fire, as suggested by Barrau (1980). This is not something that can be answered by the present research.

Cherrier (1989) has reviewed the literature and local knowledge on trees traditionally exploited for canoe building. Of the 13 species listed by Cherrier (1989), most are found in a range from coastal and lowland forest communities to mid-altitude forests. *Hibiscus tiliaceus* and juveniles of *Elaeocarpus* species were used for the outriggers. *H. tiliaceus* was cited earlier as a source of famine food and fibre, and it forms dense thickets in the wet coastal zones. Resin from three *Gardenia* species were used to caulk the canoes.

Collecting expeditions into the rainforest to obtain Houp (*Montrouziera cauliflora*) for either the centre pole of the chief's house or canoe building were grand affairs which required peaceful relations between tribes and involved the entire village (Avias, 1950). Felling the tree was achieved by lighting and maintaining a fire at the base. Presumably the fire in this procedure was used with reasonable care to preserve the tree, but it is an example of how fire is utilised in the landscape and the potential for more profound impacts than the felling of an individual tree if unfavorable conditions exist.

The difficulties and uncertainties surrounding the detection in pollen diagrams of plants that are utilised by people was touched upon in Chapter 1. While the tables in Appendix 6 highlight the large number of plants exploited by indigenous people, in reality only a

small number have any potential for showing up in the palaeoenvironmental record as an indication of human exploitation. The cultivated plants (yam, taro and sweet potato) obviously offer the greatest potential but continue to elude palynologists (cf. Flenley, 1994; Haberle, 1994; Maloney, 1994). This is partly due to the fact that the flowers are insect pollinated and so the large sticky grains do not travel great distances. Also, the plants are exploited for their tubers and not their fruits, so flowering may not always take place to any great extent. Experiments with sweet potato pollen have shown that poor preservation may be another factor (Atkin, in prep.). Therefore some of the secondary cultivated plants such as coconut, ti, sugarcane or bananas might prove useful, as would species that were indicative of ruderal vegetation. In all cases the detection of cultivated plants relies heavily on site selection and its suitability to answer questions related to plant cultivation.

The detection of arboriculture in the secondary forest signal has only been marginally successful (cf. Flenley, 1994; Haberle, 1994; Maloney, 1994) but the tables in Appendix 6 provide some guidelines for assessing the pollen record. On New Caledonia the possibility exists that arboriculture took place in the past, *Canarium* and *Pandanus* being the two tree types with most uncertainty surrounding them.

Appendix 6 provides guidelines for the detection of economic plants in New Caledonia's pollen diagrams. However, apart from the small number of cultivated plants, the exploitation of most species is likely to be difficult to discern.

2.9 Study Sites

Three sites, all in the south of the main island of New Caledonia, have been chosen to address the aims set out in Chapter 1. All are coastal or lowland, two on the west coast and one on the wetter east coast, and all are currently accumulating organic matter. Higher altitude sites as a comparison to these lowland sites would be useful, but access is difficult to the few sites located on topographic maps and aerial photographs and not possible without considerable support from local agencies. Funding for this project was insufficient to contract the services of local people and there was not enough interest

amongst local scientific bodies for collaboration. The Plaine des Lacs region is on average above 100 m altitude in the midst of the ultramafic terrain that dominates the southern part of the island. Several lakes were unsuccessfully cored by ourselves in 1991. Since that time Geoff Hope has extracted several late Pleistocene cores, however no Holocene sediments have been recovered.

The two swamp sites on the southwest coast lie either side of Mont Dore approximately 18 km east of Nouméa. Plum Swamp is a large backswamp around 10 m asl on the Plum River to the east of Mont Dore. Today the catchment is deforested and the valley floor and slopes are covered by a straggly and stunted maquis vegetation. The impact of mining in the catchment is prevalent. Lac Saint Louis is a small coastal swamp 3 - 4 m asl to the west of Mont Dore. The swamp lies around 150 m from the mangrove zone amongst grassland and is surrounded by abandoned yam terraces. The third site, Canala Swamp, is on the much wetter east coast and lies just above sea level directly behind a mangrove zone. The landward vegetation is predominantly grassland with patches of secondary forest.

All three sites were selected for their potential to address the aims set out in Chapter 1 as well as provide insight into more local questions:

For Plum these questions include:

- 1) How long have the present day vegetation communities existed in the catchment?
- 2) Were the few pockets of rainforest found in the valley today once more widespread, and if so, when did they contract?
- 3) What has been the role of fire in this catchment over time?

For Saint Louis questions surrounding horticulture are of interest, such as:

- 1) Can the utilisation of the yam terraces be detected in the pollen and/or stratigraphic record and when does this begin?
- 2) Can secondary plant exploitation be detected in the pollen signal?

- 3) Is the savanna grassland a human induced landscape and what has been the role of fire?
- 4) What record of sea level rise is recorded within the swamp sediments and how does this compare with the published data?

Canala's position on the wetter coast makes a good comparison for the east coast sites and may answer questions such as:

- 1) How does the establishment of savanna on this coast compare to that on the west coast?
- 2) How does this compare with the archaeological record for the island?
- 3) What has been the role of fire?

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3.1 Introduction

Studies of modern pollen production, dispersal and deposition provide an essential link between the fossil pollen and spores preserved in sediment and the reconstruction of past vegetation. The interpretation of the fossil record from modern pollen rain studies is known as the modern analogue technique. Modern pollen rain studies are essential because of the different pollen production and dispersal strategies of plants, and the biases introduced by sorting during transport and deposition (Birks and Birks, 1980). While there are a number of strategies for collecting pollen rain they fall into two main groups, manufactured traps and natural traps. The use of manufactured traps allows absolute measures of pollen rain to be obtained and gives the analyst control over where the rain will be collected from, enabling the different components of production and dispersion to be sampled. Natural traps such moss polsters, surface soils or surface muds samples are generally easily and quickly collected, however there is no accurate measure of deposition rate. In each case samples are collected from within representative vegetation communities. For logistical reasons only natural traps have been used in this study.

Tauber's (1965) classic model for pollen transfer identifies the four components of pollen deposition to sedimentary basins:

1. pollen carried by wind through the trunkspace of the forest
2. pollen carried by wind above the canopy
3. pollen rained-out from the atmosphere
4. pollen transported by streams and surface runoff.

About the same time Janssen (1966) developed a model that describes the relationship between the magnitude of pollen deposition, site area and origin of pollen. These two models were integrated by Jacobsen and Bradshaw (1981) who defined a fifth component of pollen rain, gravity. Their model is illustrated in Figure 3.1 and in essence it relates the surface area of a deposition site to the contribution of pollen from different sources. This goes some way to identifying the 'pollen source area', a palynological problem emphasised by Oldfield (1970). Jacobsen and Bradshaw (1981)

define *local* pollen as originating from plants growing within 20 m of the edge of the sampling basin, *extralocal* pollen as coming from plants growing between 20 and several hundred metres of the basin, and *regional* pollen as derived from plants at greater distances. These terms will be used throughout the thesis when discussing the possible source areas of pollen. The curves in Figure 3.1 will also vary for individual pollen types based on their morphology, dispersion strategies and source (Jacobson and Bradshaw, 1981). For example wind verses insect pollinated species. For surface samples the Jacobsen and Bradshaw (1981) model predicts that as the vegetation becomes more open, the representation of extralocal and regional pollen increases.

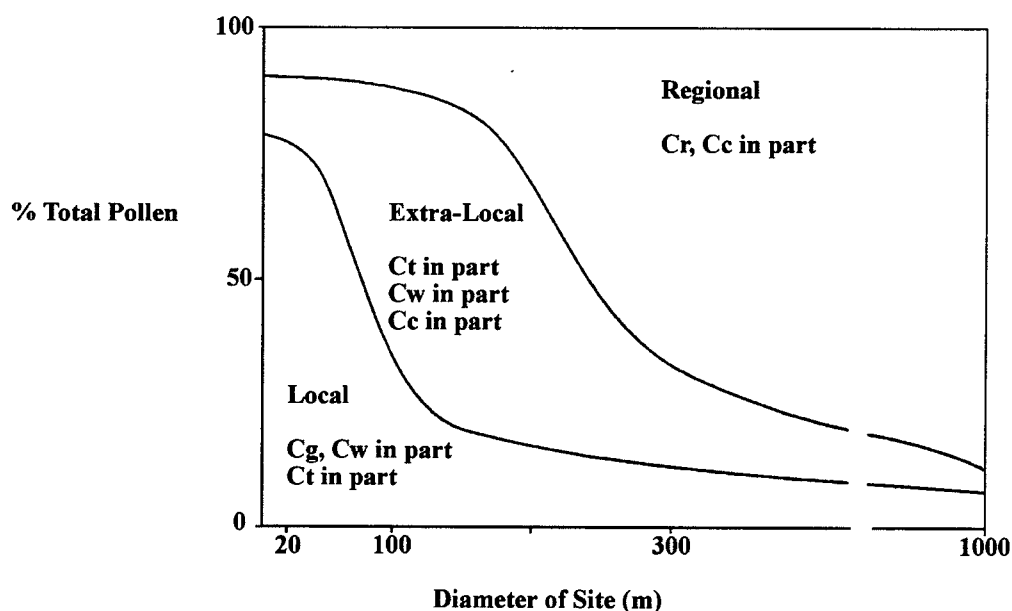


Figure 3.1: Relationship between the size of a site that has no inflowing stream and the relative proportions of pollen originating from different areas around the site. Cr = pollen brought down by rain, Cc = pollen carried above the forest canopy, Ct = pollen carried through the trunk space in the forest, Cw = pollen carried by surface runoff, and Cg = pollen dropped directly on the site through the influence of gravity. (Adapted from Jacobson and Bradshaw (1981)).

The above models were developed for the temperate deciduous forests of the northern hemisphere, where the processes of pollen production and dispersal are quite different to those that govern pollen rain in tropical regions. The first major difference lies with pollen production and the dispersal vector. Temperate forests of the northern

hemisphere are dominated by wind pollinated species which as such produce large amounts of pollen. Tropical forests tend to be dominated by insect pollinated species. These plants may still produce large amounts of pollen, but because the pollen is intended for dispersion by insects, the grains may not be easily entrained into the atmosphere, either through lack of aerodynamics or flower morphology. A second major difference between forest types which results in different dispersal processes is the forest structure. Temperate forests of the northern hemisphere have a leafless period that precedes flowering which allows the pollen to be easily carried through the trunkspace by air currents. Most tropical forests however, have no leafless period, flowering is aseasonal and wind through the trunkspace minimal.

A shortcoming of the modern analog technique as a whole is that the sampling of pollen rain from within a vegetation community is quite different to the pollen rain accumulating outside such a community in a sedimentary basin. Trapping from within closed lowland forests in southeast Asia, Australia and New Guinea has found that most of the pollen is local in origin (Flenley, 1973; Garrett-Jones, 1979; Kershaw and Strickland, 1990). Linskens (1996) found no pollen in either moss polsters or exposed slides for Sabah and Sarawak in Borneo, where the canopy closure varied from 90 - 100 %, but this seems anomalous when compared to results from other closed forest sites. The more open pollen trapping sites, such as sedimentary basins record varying levels of pollen source, and the complexity of the neighbouring forest structure is not always represented (Beuning, 1996; Garrett-Jones, 1979; Kershaw and Hyland, 1975). There is often a strong regional signal from these forest margin sites, usually from well dispersed wind pollinated species such as *Nothofagus* or *Casuarina* (Garrett-Jones, 1979; Kershaw and Hyland, 1975; Kershaw and Bulman, 1994). For tropical locations with large diverse floras identification of pollen is usually only possible to family or genus level with the relative abundance of unknowns reaching as high as 80%, but more commonly 20-30% (Bush 1991; Flenley, 1979; Garrett-Jones, 1979). In addition taxa which characterise the vegetation type may be absent from the pollen rain. In tropical montane areas there is often a net upward movement of pollen. In the present study this is not a consideration as all the sites investigated are lowland or coastal. Garrett-Jones

(1979) did find some downward movement of pollen at his sites in New Guinea, but predominantly from well dispersed *Nothofagus* and *Casuarina* species.

In spite of these difficulties and uncertainties however, it has been demonstrated that identifiable pollen rains are produced by diverse lowland tropical pollen. Examples include the Amazon Basin in South America (Bush, 1991), east Java (Beuning, 1996); lowland New Guinea (Garrett-Jones, 1979), northeast Queensland (Kershaw, 1973; Kershaw and Hyland, 1975; Kershaw and Bullman, 1994) and Fiji (Southern, 1986). The greatest difficulty foreshadowed for New Caledonia is the separation of the maquis shrubland from the various rain forest communities given the significant overlap at generic level between these two different formations.

While it may not be appropriate to apply the Jacobsen and Bradshaw (1981) model directly to closed tropical rainforest sites, there is a wide range of tropical environments in New Caledonia, some which are very open. It is assumed therefore that the extralocal and regional components of the pollen rain will increase as sites become more open, however the data collected on the vegetation composition and floristics for each site is not comprehensive enough to test rigorously the relative contributions from each source area.

3.2 Sample Collection

Surface samples were collected from within a number of the vegetation types described in Chapter 2 in order to identify their pollen signatures. All the sites analysed, except Vallée de Ni, are below 500m altitude, and cover the following vegetation types; maquis and ligno-herbaceous maquis, mid-altitude rainforest, lowland forest, *Nothofagus* rainforest, *Melaleuca* woodland, sclerophyll forest, swampland and garden regrowth. These vegetation types differ structurally as well as floristically: from closed to open, from tall to ligno-herbaceous, and from complex to virtually monospecific. All are found in the southern half of the main island and the general collection areas are illustrated in Figure 3.2.

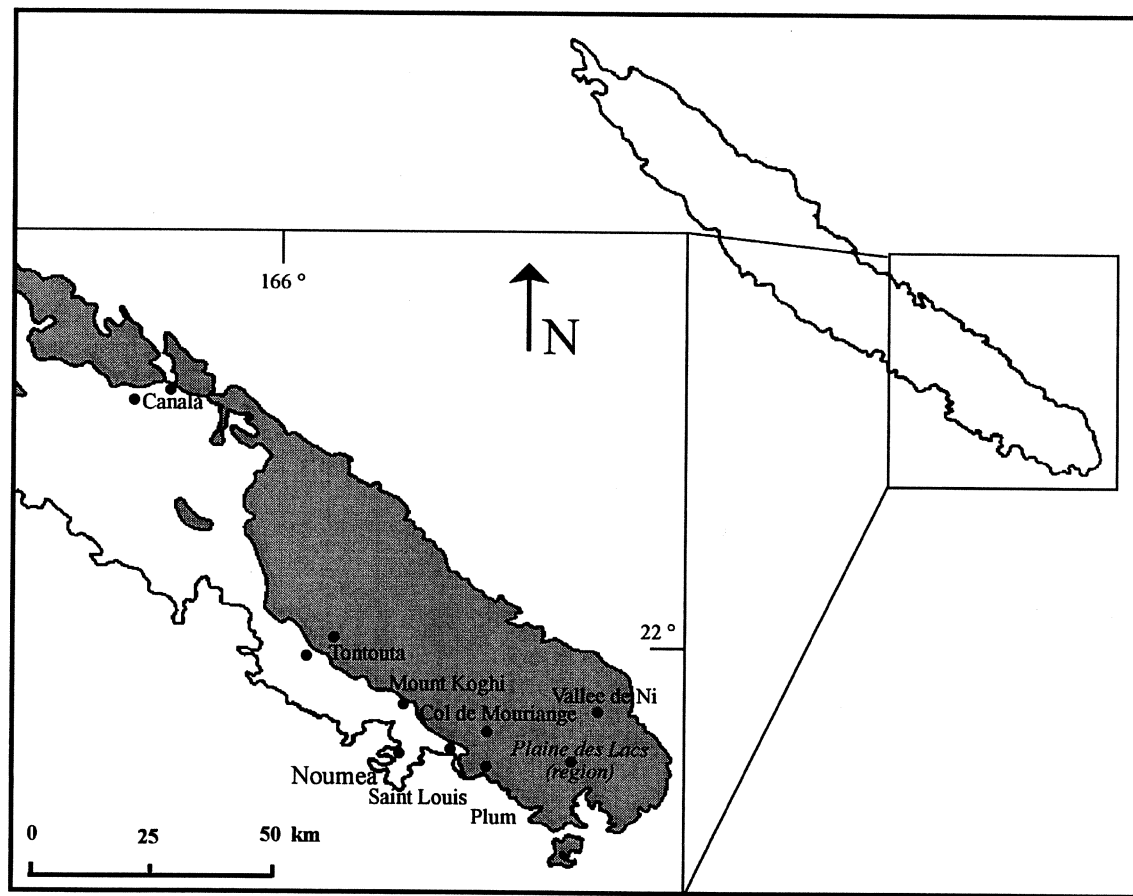


Figure 3.2: Locations of surface sample sites. Shaded area is the ultramafic terrain.

At each site moss polsters or surface sediments (approximately 2 cm in depth) were collected and the dominant vegetation within a 10m radius recorded. In most cases additional samples were collected within 5m to 10m of the central sample, then bulked together. This strategy attempts to minimise any local bias in a single sample.

3.3 Preparation, Identification and Counting

The pollen preparation procedures used throughout this thesis are given in Appendix 1. In general these all follow the standard acetolysis technique described by Moore *et al.* (1991). Identification of pollen and spores throughout the thesis was aided by a pollen reference collection which was compiled from flowering material collected during fieldwork and material collected from herbarium specimens held at the New South Wales Royal Botanic Gardens, Sydney. This reference collection appears as a pollen atlas in Appendix 2. In addition, use was made of the extensive pollen reference collection held at the Department of Archaeology and Natural History, Research School of Pacific and Asian Studies, Australian National University as well as several publications (Huang, 1972; Roubik and Moreno, 1991; Thanikaimoni, 1987). Unfortunately, herbarium specimens held at ORSTOM, Noumea, were not available to us for the compiling of a pollen flora. Commonly occurring pollen types from both the modern and fossil samples are tabulated in Appendix 3 along with notes on the living taxa. The full pollen counts for all modern and fossil samples can be found in Appendix 4.

Counting was carried out on a number of different microscopes over the period of study (due to availability of equipment) but principally on a Zeiss photomicroscope. All counting was carried out at 400x magnification with at least 200 terrestrial pollen grains counted per sample. Cyperaceae pollen and fern spores were counted outside this sum. In some cases the target of 200 grains could not be met due to low pollen concentrations, while 7 of the original 26 surface samples contained either no material or material was so badly preserved that they could not be analysed. Dr. Geoff Hope kindly made available an additional 10 surface samples, of which 7 contained pollen. It

should be stressed that the samples analysed cover an ecological range and vegetation types more limited than that found on the main island of New Caledonia.

3.4 Constructing the Pollen Diagrams

From the 26 surface samples 140 pollen taxa were distinguished, although not all were identified. Many of the genera on New Caledonia contain a large number of species, therefore the best level of identification obtained is at the genus level or family level. This broad level of classification makes assigning ecological groupings to the data difficult (e.g. forest, shrubland, non-woody) as a large number of genera cross these boundaries. In some cases assigning a specific lifeform to a particular taxon is also difficult as a pollen type may have several possible plant sources with distinctly different lifeforms and habitat requirements. The pollen data has therefore been classified as trees, shrubs, herbs, an undifferentiated class and unknown types. A key to the labels used on the summary pollen diagrams is found in Table 3.1. Notation concerning the degree of confidence associated with the identification of individual pollen types throughout the thesis follows Benninghoff and Kapp (1962).

Table 3.1: Key to pollen sum categories.
(See Appendix 3 for the lifeform and habitat of commonly occurring taxa.)

Category	Total Pollen Sum	Terrestrial Pollen Sum
Trees		Taxa that are strictly trees
Shrubs		Taxa that are strictly shrubs, though some genera and families may have tree lifeforms.
Trees and Shrubs	All tree and shrub taxa	
Herbs	Herbaceous taxa	Herbaceous taxa
Undifferentiated	Families and genera that encompass a range of lifeforms; trees, shrubs, herbs, lianes and vines	Families and genera that encompass a range of lifeforms; trees, shrubs, herbs, lianes and vines
Unknown Types	Regularly occurring pollen types that have been attributed a number but no name.	Regularly occurring pollen types that have been attributed a number but no name.

Relative abundance values of the individual curves (Figures 3.6 and 3.7) are calculated as a percentage of the total dryland pollen taxa, which excludes fern spores, Cyperaceae and *Typha*. Although Cyperaceae is not strictly an aquatic in New Caledonia, as it occurs in abundance outside of a wetland environment, this pollen sum was chosen as it removes the over-representation of Cyperaceae and *Typha* in the swamp samples and

thus presents a clearer picture of the dryland taxa ratios. Even though the ligno-herbaceous maquis for example is dominated by Cyperaceae and *Pteridium esculentum*, empirical observations demonstrate that Cyperaceae and *Pteridium* are under-represented in the pollen rain for such environments. Charcoal was also subjectively assessed for each sample and given a numerical value; absent (0), scarce (25), moderate (50 - 75) and abundant (100).

Rarefaction analysis (Birks and Line, 1992) allows the palynological richness of a pollen spectrum to be determined. This subroutine within PSIMPOLL (Bennett, 1997) was run for all pollen data in this thesis. The method takes a standardised count (which must be less than the actual count) and compares the richness between samples. If the size of the standardised count is kept constant it is then possible to compare the richness between sequences (Bennett, 1997). Although a standardised count of 100 is possibly too low for a tropical location, standardising the count to 200 or 250 leads to too many of the samples being left out of the analysis due to too low terrestrial pollen concentrations. The purpose for the New Caledonian sites as a whole will be simply ascertain if the more simple vegetation types separate out from the more complex vegetation types in terms of the richness of the pollen rain.

The pollen diagrams are described according to the groups defined by principal components analysis (PCA). Detailed site information accompanies the presentation of results for each group.

Principal Components Analysis

Since the objective of a modern pollen rain study is to determine if there are pollen signatures for particular vegetation types, a principal components analysis (PCA) was carried out within the program PSIMPOLL (Bennett, 1997). Ordination is an attempt to find the best fitting two dimensional plane through a high dimensional species space, with the resulting map usually presented in either 2D or 3D form (Clarke and Warwick, 1994). It attempts to reflect the similarity of communities by defining them in meaningful spatial patterns. That is, nearby points have similar communities, and points far apart have few species in common or the same species at different levels of

abundance (Clarke and Warwick, 1994). This aspect of PCA is conceptually simple and one of its strengths. The aim of using PCA throughout this thesis is to summarise the information contained in the fairly complex and detailed pollen diagrams and present the relationship between samples in a format that is easier to interpret.

The methodology involved excluding all aquatics and ferns and reducing the terrestrial taxa to only those with a value of 2% or more in at least one sample. This resulted in a data set of 62 pollen types and 26 samples. A square-root transformation was applied to the data to reduce the influence of over-represented taxa, especially the wind pollinated species such as Casuarinaceae. The result of the PCA is a table of eigenvalues, with those axes considered to be interpretable highlighted (Table 3.2).

Often the first and second axes may explain no more than 40 - 50 % of the total variation in a data set. Clarke and Warwick (1994) believe that for many PCA's presentation of only these first two axes may result in an inadequate and potentially misleading picture of the relationship between samples, but suggest that 70 - 75 % probably describes the overall structure rather well. The result of the PCA on the modern pollen rain data leads to the first and second axes explaining 46 % of the variation in the data set (Table 3.2). With the inclusion of the third axis 62 % is explained. Because no analyses are being undertaken on the axes, only the first two, PC1 and PC2, have been mapped to illustrate the relationships between samples (Figure 3.3). The vectors for the principal species defining the groups are also shown.

The PCA has defined 4 distinct groups designated Group A, B, C and D. Group A is defined by Casuarinaceae, *Melaleuca* and Poaceae pollen, Group B by Myrtaceous pollen other than *Melaleuca*, Group C by Cunoniaceae pollen and Group D by *Nothofagus* pollen. Group D has the least in common with the other three groups.

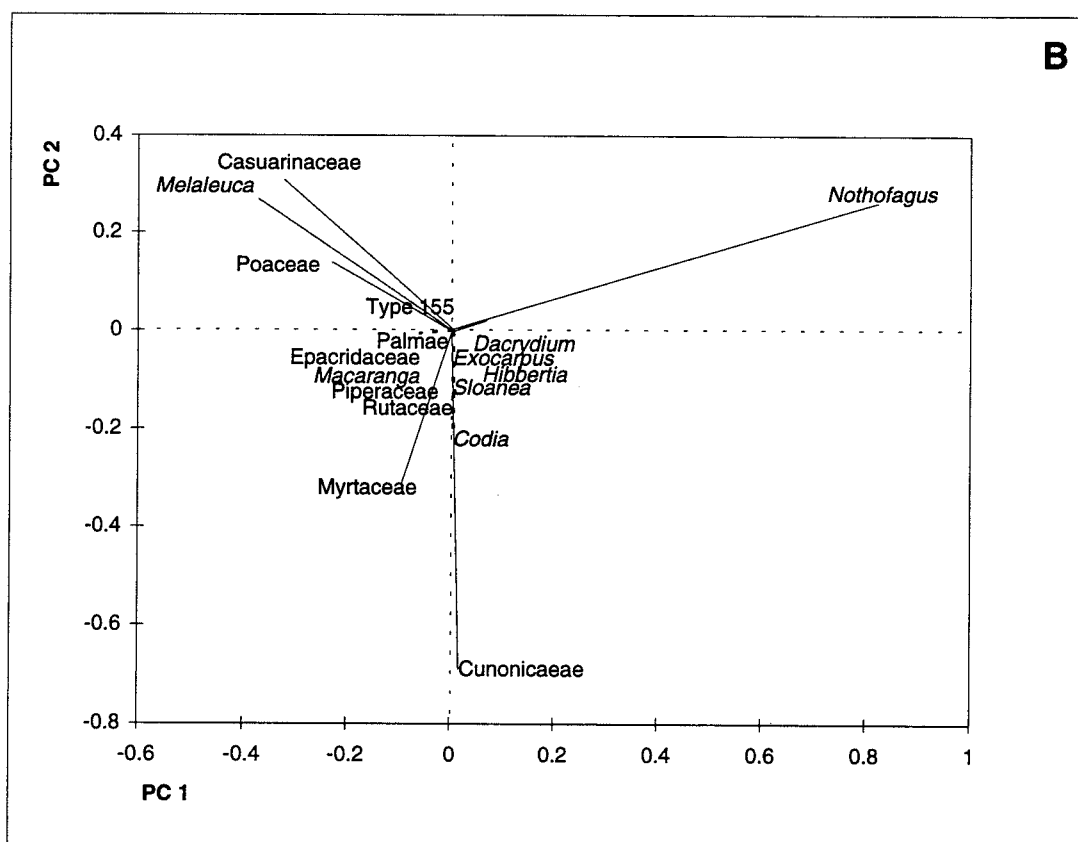
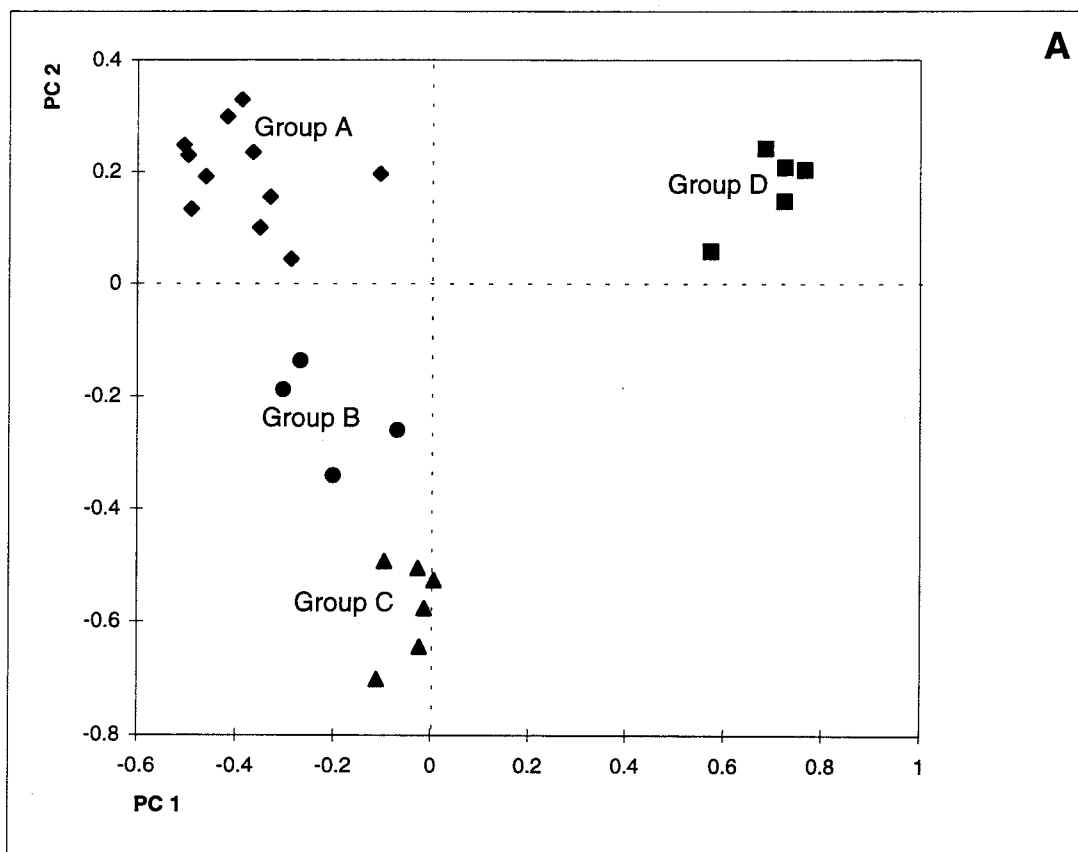


Figure 3.3: PCA bi-plots of modern pollen rain data.
A) Surface samples B) Pollen taxa.

Table 3.2: Eigenvalues from Principal Components Analysis - single iteration.

	Value	Proportion Explained	Cumulative Proportion
PC1	0.171340	0.279574*	0.279574
PC2	0.113882	0.185819*	0.465393
PC3	0.097263	0.158703*	0.624096
PC4	0.039584	0.064589*	0.688685
PC5	0.032435	0.052924*	0.741609
PC6	0.022936	0.037424	0.779033

NB: * = Interpretable axis.

3.5 Modern Pollen Deposition

Group A: Savanna and *Gymnostoma* woodland.

This group consists mainly of sites from savanna or *Gymnostoma* woodland. All samples are defined by high values of Casuarinaceae pollen (> 10 %), with *Melaleuca* pollen (up to 60 %) and Poaceae pollen (up to 20 %) making a significant contribution. Seven of the 11 sites are from a lowland swamp or lake edge. Neither of the pollen summary diagrams (Figure 3.4) reveal any consistent or coherent pattern tying the group together.

Plum swamp is one of the fossil pollen sites (Figure 3.2). Plum 1, Plum 2 and Plum 3 are all from within *Melaleuca* woodland and this is reflected in the 50 - 70 % *Melaleuca* pollen (Figure 3.5). The Myrtaceous understories of Plum 1 and Plum 2 (Table 3.3) are also well represented in the pollen from these sites (15 %), but Plum 3, which has no shrub understory, also has high values of Myrtaceae pollen (25 %) (Figure 3.5). *Casuarina* shrubs are found at the local and extralocal scale for these three sites, with Casuarinaceae pollen constituting 15 - 20 % of the terrestrial pollen (Figure 3.5). All three sites have an understory of grasses, Cyperaceae and ferns (Table 3.3) which is evident in the pollen diagram for Plum 2 and Plum 3, but not for Plum 1 (Figure 3.7). This may be due to a portion of the Plum 1 sample coming from lichen in a tree notch above the woodland floor (see Table 3.3). Plum 2 is surface mud from the edge of Plum swamp and 25% of the total pollen sum belongs to Cyperaceae. The rich understory of ferns for Plum 3 (Table 3.3) is reflected in the high fern spore values (85% of the total pollen sum) (Figure 3.4). The fern spores are composed of *Pteridium esculentum*, Polypodiaceae spores and Trilete Type A (Figure 3.7).

Table 3.3: Group A: Vegetation communities and major taxa around surface sample collection sites.

Site ID	Sample Type	Vegetation Type	Dominant Tree Taxa	Other Tree and Shrub Taxa	Dominant Understory or Groundcover Taxa
Plum 1	wet algae and soil layer, lichen from tree notch of <i>M. quinquenervia</i> . 4 subsamples	<i>Melaleuca</i> woodland.	<i>Melaleuca quinquenervia</i> , <i>Casuarina equisetifolia</i>	<i>Baeckea</i> sp., <i>Cloezia artensis</i> , <i>Mimosa pudica</i> , <i>Rhodammia</i> sp., <i>Stachytarpheta indica</i> , <i>Tristaniaopsis guilleni</i> , <i>Geissois pruniosa</i>	<i>Pteridium esculentum</i> , <i>Gleichenia</i> sp., <i>Sphenomeris deltoidea</i> , <i>Imperata</i> sp., <i>Convolvulus</i> sp., <i>Cuscuta</i> sp., <i>Gahnia</i> sp., <i>Labiatae</i> sp., <i>Lepyrodis</i> sp., <i>Megastylus gigas</i> , <i>Passiflora suberosa</i> , <i>Scaevola montana</i> , <i>Smilax</i> sp., unidentified Lily.
Plum 2	surface mud from swamp edge	Border of <i>Melaleuca</i> woodland and Cyperaceous swamp	<i>Melaleuca quinquenervia</i>	<i>Baeckea</i> sp., <i>Cloezia artensis</i> , <i>Mimosa pudica</i> , <i>Smilax</i> sp.	Grasses (including <i>Imperatum</i> sp.), <i>Carex</i> sp., <i>Pteridium esculentum</i> , <i>Gleichenia</i> sp., <i>Blechnum</i> sp., <i>Sphenomeris deltoidea</i> , <i>Passiflora suberosa</i> .
Plum 3	moss polster	<i>Melaleuca</i> woodland	<i>Melaleuca quinquenervia</i>		Ferns (dominant cover) include <i>Pteridium esculentum</i> , <i>Gleichenia</i> sp., <i>Blechnum</i> sp. plus other unidentified ferns
Plum 4	surface mud	<i>Melaleuca</i> swamp forest	<i>Melaleuca quinquenervia</i>	<i>Barringtonia</i> sp. plus 3 other unidentified trees.	<i>Juncus</i> sp. (dominant cover) Other surrounding ground vegetation: <i>Blechnum</i> sp., <i>Gleichenia</i> sp., <i>Pteridium esculentum</i> , <i>Sphenomeris deltoidea</i> , <i>Buamea</i> sp., <i>Cuscuta</i> sp., <i>Megastylus gigas</i> ; small amount of Poaceae
Saint Louis 1	surface mud	Cyperaceous swamp	<i>Melaleuca quinquenervia</i>	Surrounding: <i>Cocos nucifera</i> , <i>Melaleuca quinquenervia</i> , <i>Musa</i> sp., <i>Mangifera indica</i>	Surface vegetation: <i>Eleocharis cylindripifolia</i> (dominant cover of site), unidentified fern Surrounding vegetation: Poaceae, <i>Pteridium esculentum</i> , <i>Ipomea</i> sp.; <i>Mimosa</i> sp.
Saint Louis 2	surface mud	Cyperaceous swamp	<i>Melaleuca quinquenervia</i>	Surrounding: <i>Cocos nucifera</i> , <i>Melaleuca quinquenervia</i> , <i>Musa</i> sp., <i>Mangifera indica</i>	Surface vegetation: <i>Eleocharis cylindripifolia</i> (dominant cover), unidentified fern Surrounding vegetation: Poaceae, <i>Pteridium esculentum</i> , <i>Ipomea</i> sp., <i>Mimosa</i> sp.
Canala 1	moss polsters 3 subsamples	Lowland Rainforest (adjacent creek)	<i>Barringtonia neocaledonica</i>	<i>Agathis</i> sp., Apocynaceae sp., Araliaceae sp., Arecaceae, Sapotaceae sp., Sapindaceae sp.	Poaceae, <i>Hymenophyllum</i> sp., other ferns
Canala 2	moss polsters 2 subsamples	overgrown garden beside abandoned dwelling	<i>Cocos nucifera</i> , <i>Musa</i> sp., <i>Mangifera</i> sp., Lianas	<i>Casuarina</i> sp.	Poaceae, Cyperaceae, unidentified fern
Plaine des Lacs 8	surface litter	<i>Gymnostoma</i> /Myrtaceae woodland	<i>Gymnostoma</i>	Not available	Not available
Plaine des Lacs 9	mud from lake edge	Maquis	<i>Polyscias</i>	Not available	Not available
Plaine des Lacs 10	mud from lake edge	<i>Gymnostoma</i> woodland	<i>Gymnostoma</i>	Not available	Not available

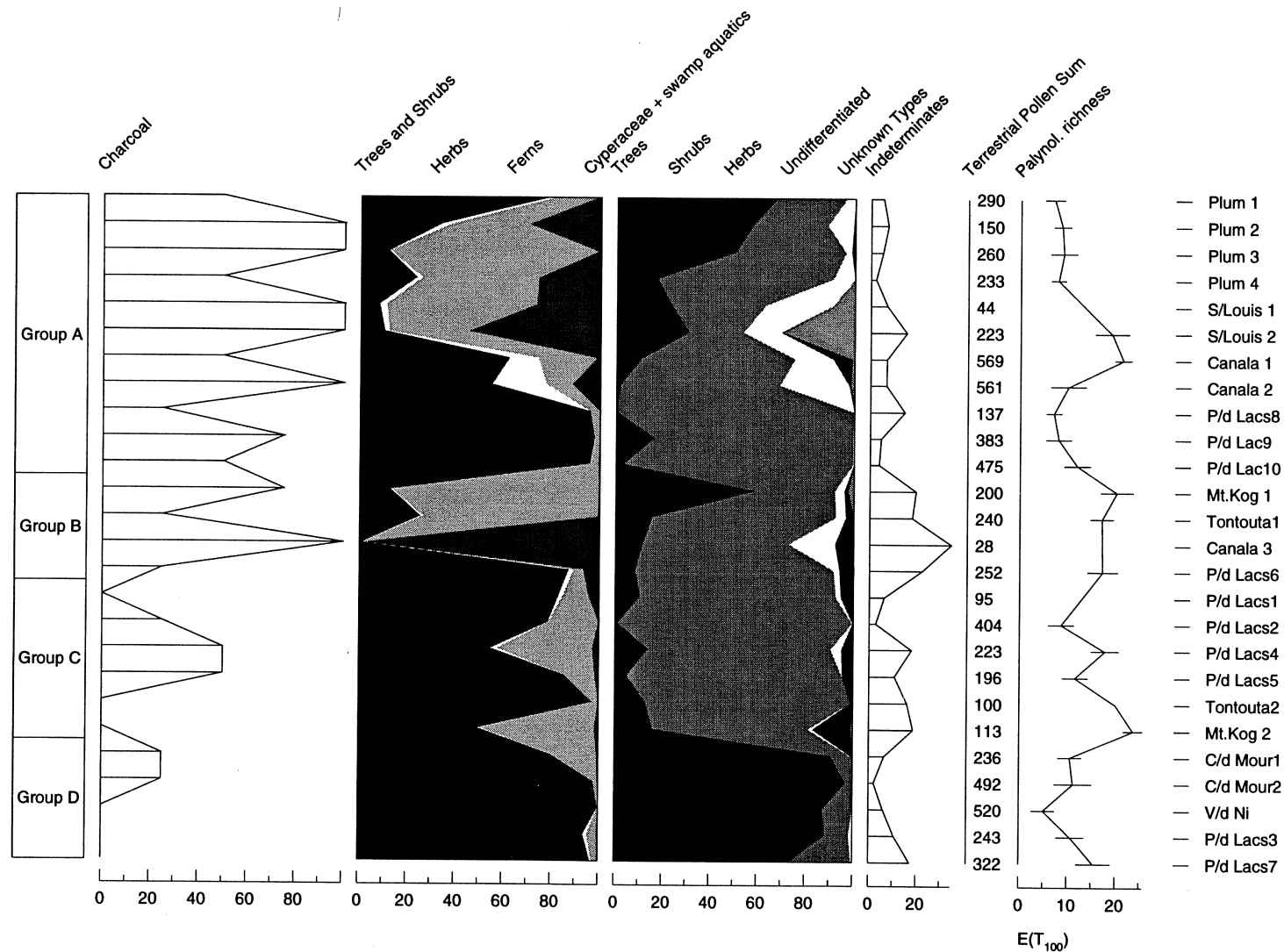


Figure 3.4: Summary pollen diagrams for modern pollen rain samples. The total pollen sum is presented first followed by the terrestrial pollen sum. The diagram also includes charcoal determinations and estimates of palynological richness. $E(T_n)$ = expected no. of pollen taxa calculated from standard count of 100. Plotted with 95% confidence intervals.

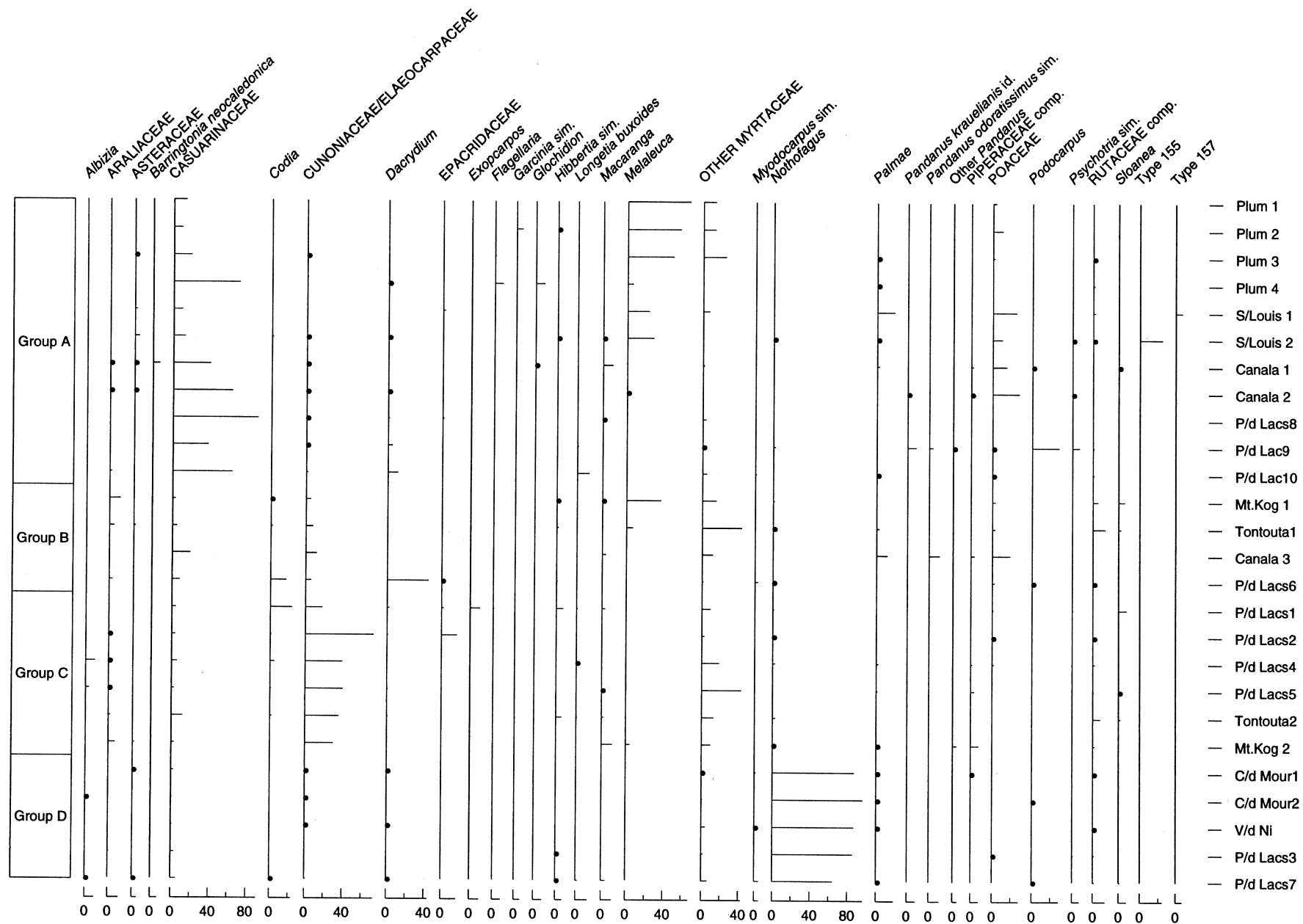


Figure 3.5: Individual pollen curves for modern surface samples. Shown are all taxa that have a value of 5 % in at least one sample.

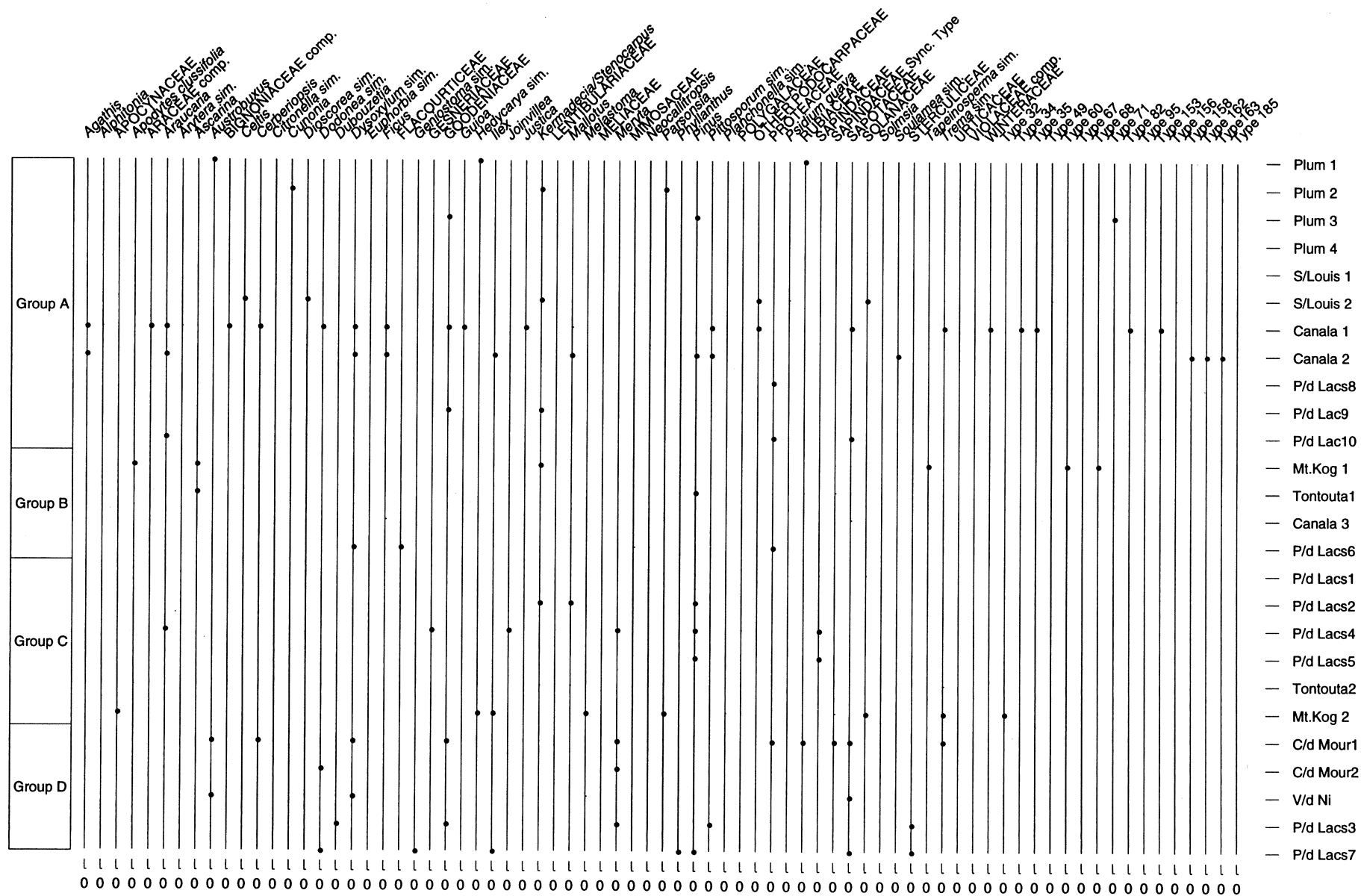


Figure 3.6: Terrestrial pollen taxa for modern surface samples with values of less than 5 % in all samples. Dots indicate presence of taxon at a value of less than 1 %.

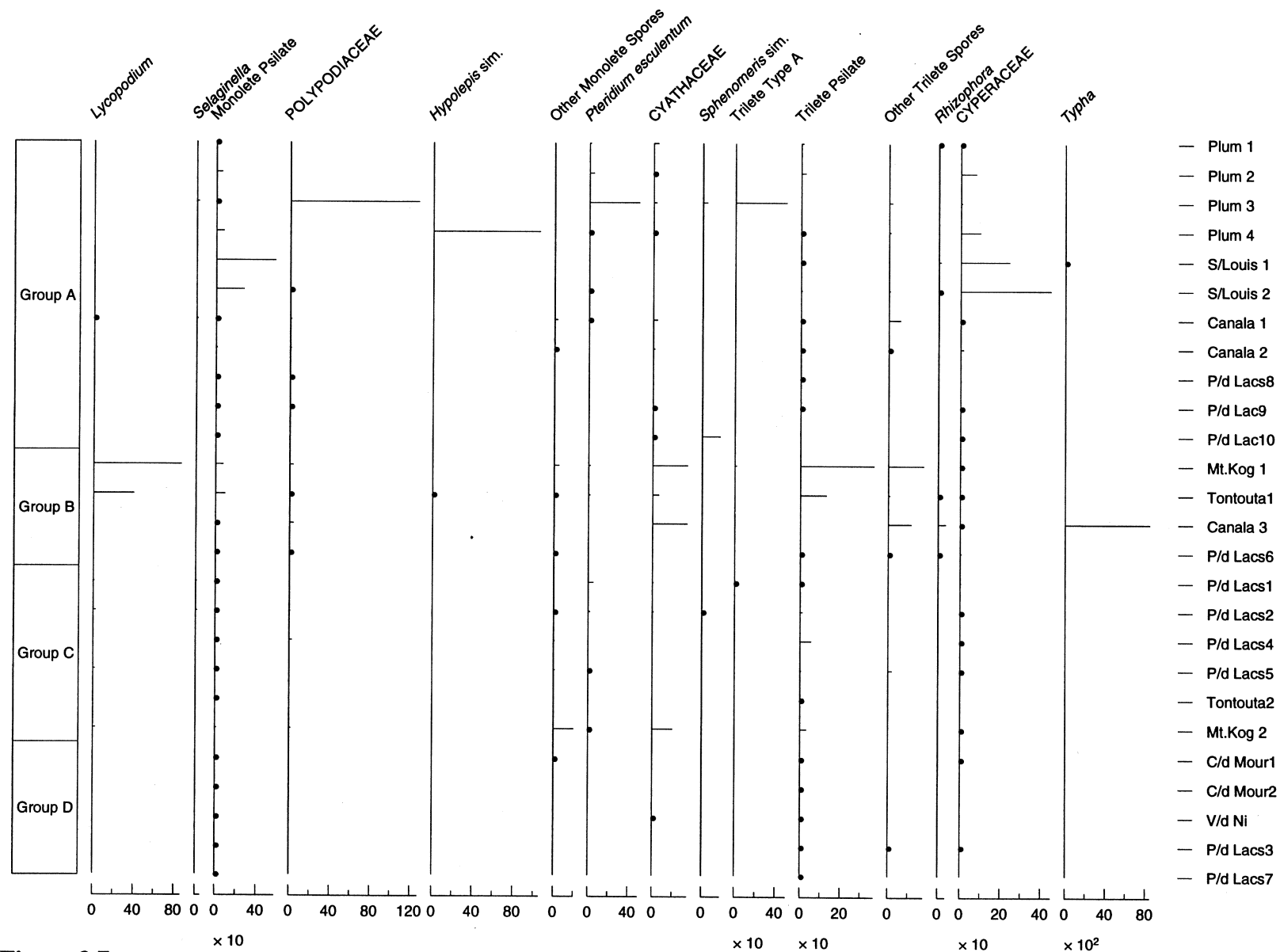


Figure 3.7: Ferns, Cyperaceae and other taxa expressed as percentages outside the terrestrial pollen sum.

Plum 4 is surface mud from *Melaleuca* swamp forest. While *Melaleuca* is the dominant tree taxa around the site (Table 3.3) Casuarinaceae pollen dominates the terrestrial pollen taxa at 70 % (Figure 3.5). *Casuarina* is found throughout the area, and this component in the pollen rain reflects an extralocal or regional source. Some grass pollen is recorded, but in general the count, like the *Melaleuca* pollen, has been diluted by the *Casuarina* pollen. The ferns and Cyperaceae surrounding the swamp are well represented.

Charcoal particles were moderate to high in all the Plum surface samples, and the palynological richness of the samples is low.

Lac Saint Louis (Figure 3.2) is the second of the fossil pollen sites for which the modern pollen rain was investigated. Saint Louis 1 contained very little terrestrial pollen (Figure 3.4) and so the results are less meaningful than those for Saint Louis 2. The total pollen sum of both samples is dominated by fern spores and Cyperaceae pollen (Figure 3.4). This reflects the overwhelming input of pollen from the surface vegetation in a swamp environment (Table 3.3). The surrounding slopes are grass covered with scattered *M. quinquenervia*. Individuals of *M. quinquenervia* are also found on the swamp surface. The terrestrial pollen sum is divided almost evenly between trees, shrubs, herbs and unknown types. Palynological richness estimates are high for Saint Louis 2. An estimate of palynological richness could not be done for Saint Louis 1 as the pollen count was too low.

Melaleuca and Poaceae together make up 40 - 45% of the terrestrial pollen sum (Figure 3.5). *Casuarina* is not found in the immediate vicinity of the swamp, however, around 10 % of the pollen belongs to this pollen type (Figure 3.5). The spores of *Pteridium esculentum* and the pollen of *Mimosa pudica*, were not found in the surface muds, even though these plants are common around the edge of the swamp. An unidentified fern found throughout the surface vegetation is probably responsible for the large number of psilate monolet fern spores (Figure 3.7). Palms are common at the coastal end of the swamp and have a value of around 20 %, while the mangrove system some 300 m beyond the site contributes less than 5 % *Rhizophora* pollen (Figures 3.5 and 3.7).

Dioscorea type pollen was found in the Saint Louis 2 sample along with Solonaceae pollen. While the former is indicative of traditional horticultural practices, the latter is indicative of European introductions and the current horticultural activity beyond the southern end of the swamp. There are a large number of unknown types for the Saint Louis surface samples (30 %) (Figure 3.4).

Canala 1 and Canala 2 are sites from the wetter northeastern side of the island (Figure 3.2) and the samples are dominated by Casuarinaceae and Poaceae pollen (Figure 3.5). Canala 1 is lowland rainforest bordering the River Kondaou at an altitude of around 200 m asl. Approximately 20 m from the sample site a *Barringtonia neocaledonica* tree was in flower at the time of sampling. This large distinctive grain contributes around 7% to the terrestrial pollen rain (Figure 3.5). The nature of the site is littoral which makes it somewhat open and as a result there is a large extralocal component of Casuarinaceae pollen (40 %) from a stand approximately 100 m from the site. Poaceae pollen values are relatively high (15 %) and probably originate from grasses along the creek line (Figure 3.5).

Canala 2 is from an overgrown garden beside an abandoned dwelling in Canala village. A value of over 60% Casuarinaceae pollen reflects the local presence of these source trees and shrubs (Table 3.2; Figure 3.5). The large number of Casuarinaceae grains within the sample meant that the pollen count was extended to over 500 grains. Together Casuarinaceae and Poaceae account for 90% of the pollen taxa (Figure 3.5). Pollen of the associated garden trees *Cocos nucifera*, *Musa* or *Mangifera* (Table 3.3) were not recorded in the sample.

There is abundant charcoal in the Canala 2 sample, but for Canala 1 where human influence is less intense, there is much less charcoal.

Plaine des Lacs (PdL) 8, PdL 9 and PdL 10 are all dominated by Casuarinaceae pollen, but unlike the Canala sites above, there is no grass pollen. For the PdL sites this is due to their location within the large ultramafic massif that dominates the southern third of the island and from which grass is virtually absent (Figure 3.2). PdL 8, PdL 9 and PdL

10 are all from maquis sites on iron pan (cuirasse) in the Plaine des Lacs. The total pollen sum is dominated by tree and shrub pollen, with around 5 % ferns (Figure 3.4). PdL 8 is from a *Gymnostoma*/Myrtaceae woodland and the pollen spectra is dominated by Casuarinaceae pollen (90%) and Myrtaceae pollen (5%) (Figure 3.5). PdL 9 is from the margin of Lake Suprin where the nearby vegetation is dominated by *Polyscias* (Araliaceae) and *Gymnostoma* (Table 3.3). Casuarinaceae pollen accounts for 40% of the pollen, but there was no Araliaceae pollen recorded. The remaining 60% of the pollen is made up of *Dacrydium*, *Podocarpus*, *Pandanus* and *Psychotria* (Figures 3.5 and 3.6). PdL 10 is from the margin of Lake Xero Wapo next to a mature stand of *Gymnostoma*. Casuarinaceae pollen here is around 65%, with *Dacrydium* and *Longetia buxoides* (Euphorbiaceae) being the other two major contributors (Figure 3.5). Charcoal levels are scarce to moderate for these three sites.

Group B: *Melaleuca* woodland, maquis and grassland savanna.

The surface samples in this group are an odd assortment of vegetation types, which form a rather scattered group lying between Group A and Group C on the PCA bi-plot (Figure 3.3). The Mount Koghi 1 sample is from a *Melaleuca* woodland at an altitude of around 300m (Figure 3.2; Table 3.4). The total pollen sum for this site is dominated by fern taxa (Figure 3.4). These are predominantly psilate trilete spores (Figure 3.7), possibly from *Gleichenia* which is part of the ground cover. The terrestrial pollen sum is dominated by trees and shrubs. The tree pollen is essentially *Melaleuca* pollen (35 %) and Araliaceae pollen (10 %). While a *Myodocarpus* sp. is common in the Mount Koghi 1 sample area, the pollen identified as Araliaceae type did not match with the *Myodocarpus* examples in the pollen reference collection. Of the 10 species of *Myodocarpus* in New Caledonia only 3 are in the pollen reference collection in Appendix 2. However, the Araliaceae counts possibly reflect its presence. The shrub pollen is dominated by Myrtaceae pollen, possibly *Baeckea*, although other types were also recorded. *Lycopodium* was abundant in the landscape and large numbers of these spores were also counted.

The rainforest boundary is located approximately 100m from the sample site and a number of rainforest elements are recorded in the pollen spectra: *Apodytes clusiifolia*

Table 3.4: Group B: Vegetation communities and major taxa around surface sample collection sites.

Site ID	Sample Type	Vegetation Type	Dominant Tree Taxa	Other Tree and Shrub Taxa	Dominant Understory or Groundcover Taxa
Mt. Koghi 1	moss polsters 5 subsamples	<i>Melaleuca</i> woodland	<i>Melaleuca</i> sp. and <i>Myodocarpus</i> sp.	<i>Baeckea</i> sp., <i>Parsonia</i> sp., <i>Pittosporum</i> sp.	Ferns: <i>Gleichenia</i> sp., <i>Platyserium</i> sp., <i>Sticherus</i> sp., <i>Pteridium esculentum</i> Other: <i>Dianella</i> sp., <i>Dracophyllum</i> sp., <i>Ghania</i> sp., <i>Joinvillea</i> sp., <i>Lonicera</i> sp., <i>Styphelia</i> sp. <i>Lycopodium</i> sp.
Tontouta 1	Lichen 3 subsamples	<i>Arillastrum</i> forest	<i>Araliaceae</i> spp., <i>Arillastrum</i> <i>gummiferum</i> , <i>Tristaniopsis</i> <i>guillini</i>	<i>Acridocarpus austrocaledonica</i> , <i>Baeckea</i> sp., <i>Casuarina</i> sp., <i>Cloezia arctensis</i> , <i>Dodonaea</i> sp., <i>Dracophyllum</i> sp., <i>Grevillea</i> sp., <i>Hibbertia pancheria</i> , <i>Loranthaceae</i> sp., <i>Montrouzeria sphaerioides</i> , <i>Phyllanthus chryseus</i> , <i>Pittosporum</i> sp., <i>Rubiaceae</i> sp., <i>Sapotaceae</i> sp., <i>Scaevola</i> sp., <i>Styphelia</i> sp.	<i>Pteridium esculentum</i> , <i>Cyperaceae</i> spp.
Canala 3	surface mud	<i>Typha</i> swamp	<i>Typha</i> sp.		
Plaine des Lacs 6	moss and lichen 4 subsamples	Maquis dominated by <i>Neocallitropsis</i> , <i>Dacrydium araucarioides</i> , <i>Grevillia gillivrayii</i>		<i>Agathis ovata</i> , <i>Alphitonia neocaledonica</i> , <i>Alyxia</i> sp., <i>Baeckea</i> sp., <i>Boronella</i> sp., <i>Casuarina/Gymnostoma</i> spp., <i>Coprosma</i> sp., <i>Dracophyllum</i> spp., <i>Flagellaria</i> sp., <i>Garneria</i> sp., <i>Hibbertia pulchella</i> , <i>Hibbertia</i> sp., <i>Montrouzeria</i> sp., <i>Myodocarpus</i> sp., <i>Palmae</i> , <i>Parsonsia</i> sp., <i>Rapanaea</i> sp., <i>Scaevola beckii</i> , <i>Smilax</i> sp., <i>Styphelia</i> sp., <i>Tarenna</i> sp., <i>Tristaniopsis guillanii</i> ,	<i>Schizea</i> sp., <i>Gahnia</i> sp., Other <i>Cyperaceae</i> , <i>Lomandra neo-caledonica</i> , <i>Megastylus gigas</i> , <i>Poaceae</i> , <i>Pteridium esculentum</i> , unidentified common fern

(Icacinaceae), Araliaceae, Cunoniaceae / Elaeocarpaceae, *Sloanea* (Elaeocarpaceae) (Figures 3.5 and 3.6). The values of Cyatheaceae (35 %) are the highest for this taxon recorded at any site (Figure 3.7). All these pollen and spore types represent an extralocal component. This is definitely the case for *A. clusiifolia* which is a rainforest canopy tree. Charcoal content was assessed as moderate for this site.

Tontouta 1 is from within an *Arillastrum gummiferum* forest, an open formation with a diverse understory (Figure 3.2; Table 3.4). Like Mt. Koghi 1 the total pollen sum is dominated by ferns, while trees and shrubs dominate the terrestrial pollen sum (Figure 3.4). In particular Myrtaceae pollen is the dominant pollen type (40 %) (Figure 3.5). Myrtaceae species form the dominant tree cover and are part of the understory (Table 3.4). Differentiating between the different Myrtaceae however, proved difficult given the large number of genera and species found on New Caledonia and the small reference collection available for comparison. The dominant ground cover taxa, Cyperaceae and *Pteridium esculentum*, have values of less than 1 %. Palynological richness is high for the Mount Koghi 1 and Tontouta 1 samples and charcoal is scarce.

Canala 3 is surface mud from Canala Swamp, the fossil pollen site analysed from the wetter northeastern side of the main island (Figure 3.2). The swamp surface is covered with *Typha* sp. and the footslopes adjacent to the site have secondary lowland forest interspersed with grassland. *Typha* overwhelms the pollen spectra and as a result only 28 terrestrial pollen grains were counted, although a large number of unknowns were also recorded (35%) (Figure 3.4). Casuarinaceae and Poaceae pollen were found in the greatest abundance, the remainder being made up of Cunoniaceae, Myrtaceae, Palm and *Macaranga* pollen (Figures 3.5 and 3.6). *Rhizophora* and *Acanthus* pollen are from the mangrove system bordering the eastern end of the swamp. There is abundant charcoal in the sample.

PdL 6 is a diverse maquis dominated by *Neocallitropsis pancheri* (Cupressaceae) and *Dacrydium araucariodes* (Table 3.4). The total pollen sum is dominated by trees and shrubs, with only 15 % of the belonging to ferns and Cyperaceae. The terrestrial pollen sum is dominated by shrubs, in particular *Dacrydium* (45%) (Figure 3.5).

Neocallitropsis accounts for (<5%), while *Codia* and the Cunoniaceae/Elaeocarpaceae category together account for 25% of the pollen (Figure 3.5). Even though *Casuarina* and *Gymnostoma* species are found locally, Casuarinaceae pollen only constitutes around 5% of the pollen rain. The palynological richness is high relative to the more simple vegetation types and charcoal is scarce.

Group C: Maquis, sclerophyll forest and lowland rainforest.

The 5 surface samples in this group have in common large percentages of the undifferentiated class Cunoniaceae/Elaeocarpaceae (20 - 4- %) and significant amounts of Myrtaceae pollen (> 5 %). While all samples are from quite different vegetation types, all except the sclerophyll forest site are from ultramafic terrain. The total pollen sum is dominated by tree and shrub pollen, with fern percentages reaching 50 % in only 2 of the 6 sites. The terrestrial pollen sum is dominated by shrubs and three of the six samples had very low pollen concentrations which resulted in low pollen counts (Figure 3.4).

Surface samples were collected along a transect from maquis shrubland to a ligno-herbaceous maquis in the Plaine des Lacs region. A number of these samples contained only poorly preserved pollen that could not be counted. PdL 1 and PdL 2 are two sample sites from this transect and both can be regarded as fairly open (Table 3.5). PdL 1 is dominated by *Codia* (Cunoniaceae) and the Cunoniaceae/Elaeocarpaceae category. *Codia* can be separated out as it is a very distinctive 2 colporate grain (see Appendix 2). PdL 2 is also dominated by Cunoniaceae/Elaeocarpaceae, but neither family was recorded in the local vegetation (Table 3.5). Some locally recorded taxa are preserved in the sample, for example *Dracophyllum* (Epacridaceae), *Exocarpos* (Santalaceae) and the Myrtaceous shrubs (Figure 3.5). Cyperaceae and *Pteridium esculentum* appear to be vastly under-represented in the local pollen and spore rain. An assessment of palynological richness could only be done for PdL 2 and this was low. Charcoal was absent in PdL 1 and scarce in PdL 2.

Sites PdL 3 to PdL 5 form a transect from a *Nothofagus* forest through to an open and struggling *Pinus* plantation with a maquis understory (Table 3.5). Once again not all samples collected proved to contain pollen. PdL 3 is from *Nothofagus* forest and is clustered in Group D and discussed below. PdL 4 is situated 100 m from the *Nothofagus* forest of PdL 3 and contains less than 5% *Nothofagus* pollen. The total pollen sum for this site is 50 % tree and shrub taxa and 50 % ferns. The terrestrial pollen sum shows that the tree and shrub taxa belong almost entirely to shrub taxa (Figure 3.4). In particular Cunoniaceae/Elaeocarpaceae (40 %) and Myrtaceae pollen (20 %). PdL 5 is approximately 500m from PdL 3 and contains virtually no *Nothofagus* pollen (Figure 3.5). The pollen from the site is very similar to PdL 4 with the exception that fewer fern spores were recorded. *Pinus* has a value of less than 1% for each site and its representation in the modern pollen rain here is less than many of the other sites. The understory of grass, Cyperaceae and *Pteridium* appears once again to be vastly under-represented. Grass in the understory also indicates that ultramafic conditions not extreme. The palynological richness for the two sites is moderate.

Tontouta 2 (Figure 3.2) is from sclerophyll forest, and is characteristically dominated by the tree *Acacia spirorbis* (Table 3.5). The total pollen sum is dominated by tree and shrub taxa with ferns being less than 5 %. Once again the terrestrial pollen sum is dominated by shrub taxa, primarily Cunoniaceae, Casuarinaceae *Hibbertia* and Myrtaceae. Significantly no *Acacia* pollen was recorded and very little Cyperaceae or grass. However, the rainforest canopy tree *Apodytes clusiifolia* was recorded for the sample (Figure 3.6). Charcoal was absent from the sample and the pollen count was too low for palynological richness to be assessed (Figure 3.4).

The total pollen sum for Mount Koghi 2, lowland rainforest site (Figure 3.2), is shared evenly between tree and shrub category and ferns. Although shrubs dominate the terrestrial pollen sum primarily Cunoniaceae/Elaeocarpaceae (25%) and Myrtaceae (10 %) in this case they are probably trees. Other abundant taxa include Araliaceae, *Freycinetia* (Pandanaeae), Piperaceae, *Planchonella* (Sapotaceae), Sapindaceae, and Cyatheaceae (Figures 3.5 - 3.7). Pollen from the disturbed edges includes Solanaceae and *Macaranga*. Charcoal is absent and palynological richness is high.

Table 3.5: Group C: Vegetation communities and major taxa around surface sample collection sites.

Site ID	Sample Type	Vegetation Type	Dominant Tree Taxa	Other Tree and Shrub Taxa	Dominant Understory or Groundcover Taxa
Plaine des Lacs 1	moss & lichen 4 subsamples	Open maquis dominated by shrubs <2m high.		<i>Alphitonia neo-caledonica</i> , <i>Argophyllum</i> sp., <i>Dracophyllum</i> spp., <i>Exocarpus neo-caledonica</i> , <i>Flagellaria</i> sp., <i>Myodocarpus</i> sp., <i>Myrtopsis</i> sp., <i>Pittosporum</i> sp., <i>Scaevola beckii</i> , <i>Styphelia</i> sp., <i>Tarrena</i> sp., <i>Tristaniopsis glauca</i> , <i>T. guillainii</i>	<i>Costularia</i> spp., <i>Megastylus gigas</i> , <i>Pteridium</i> <i>esculentum</i>
Plaine des Lacs 2 (500m from PdL 1)	moss & lichen 4 subsamples	Ligno-herbaceous maquis		<i>Alphitonia neo-caledonica</i> , <i>Baeckea</i> sp., <i>Coprosma</i> sp., <i>Hibbertia pulchella</i> , <i>Myodocarpus</i> sp., <i>Scaevola beckii</i> , <i>Stenocarpus milnei</i> , Unidentified shrub.	<i>Costularia</i> spp., <i>Schizaea bifida</i> , Other Cyperaceae, <i>Megastylus gigas</i> , <i>Pteridium esculentum</i> , unidentified fern
Plaine des Lacs 4 (100m from PdL 3)	moss and lichen 4 subsamples	Pine plantation with maquis understory	<i>Pinus</i> sp.	<i>Codia</i> sp., <i>Hibbertia pancheri</i> , <i>Myodocarpus</i> sp., <i>Menispermaceae</i> sp.	<i>Imperata</i> sp., <i>Joinvillea</i> sp., <i>Lepyrodia</i> sp., <i>Pteridium</i> <i>esculentum</i>
Plaine des Lacs 5 (500m from PdL 3)	moss and lichen 4 subsamples	Pine plantation with maquis understory	<i>Pinus</i> sp.	<i>Pandanus</i> sp., <i>Hibbertia pancheri</i> , <i>Myodocarpus</i> sp., <i>Menispermaceae</i> sp.	<i>Imperata</i> sp., <i>Joinvillea</i> sp., <i>Lepyrodia</i> sp., <i>Pteridium</i> <i>esculentum</i>
Tontuta 2	lichen & algal crusts 3 subsamples	Sclerophyll forest	<i>Lethedon</i> sp., <i>Acacia</i> <i>spirorbis</i>	<i>Alphitonia</i> sp., <i>Baeckea</i> sp., <i>Cloezia arctensis</i> , <i>Cuscuta</i> sp., <i>Dodonaea</i> sp., <i>Hibbertia</i> sp., <i>Stenocarpus milnei</i> , <i>Wikstroemia indica</i> , <i>Xanthostemon laurinum</i>	<i>Gahnia</i> , <i>Shizea</i> sp., <i>Themeda</i> sp.
Mt. Koghi 2	moss polsters 4 subsamples	Lowland Rainforest	<i>Sloanea koghiensis</i> , <i>Sterculia</i> sp., <i>Agathis ovata</i> <i>Ochrosia sylvatica</i>	<i>Cyathia neocaledonica</i> , Apocynaceae, Araliaceae, <i>Flagellaria</i> sp., Guttiferae sp., Juglandaceae?/Macadamia?, Rubiaceae, Sapotaceae <i>Freycinettia</i> sp., <i>Geitonoplesium</i> sp., <i>Smilax</i> sp., Numerous other Lianas Disturbed Edges: <i>Solanum</i> sp., <i>Rhodammia</i> sp., <i>Rubus</i> sp., <i>Omalanthus</i> sp.	<i>Asplenium</i> sp., <i>Hymnophyllum</i> sp., <i>Selaginella</i> sp.

Table 3.6: Group D: Vegetation communities and major taxa around surface sample collection sites.

Site ID	Sample Type	Vegetation Type	Dominant Tree Taxa	Other Tree and Shrub Taxa	Dominant Understory or Groundcover Taxa
Col de Mouriang 1	surface litter	<i>Nothofagus</i> forest	<i>Nothofagus aequilateris</i>	Not available	Not available
Col de Mouriang 2	surface litter	Boundary of <i>Nothofagus</i> forest and mixed forest	<i>Nothofagus aequilateris</i>	Not available	Not available
Vallée di Ni		Mixed high altitude rain forest (850 m)	<i>Nothofagus</i> sp.	Not available	Not available
Plaine des Lacs 3	moss and lichen 4 subsamples	<i>Nothofagus</i> forest	<i>Nothofagus</i> sp.	<i>Albizzia</i> sp., <i>Alphitonia neo-caledonica</i> , <i>Hibbertia pancheri</i> , <i>Joinvillea</i> sp., <i>Menispermaceae</i> , <i>Myodocarpus</i> sp., <i>Pandanus</i> sp., <i>Rapanea</i> sp.	<i>Shizea bifida</i> , Other <i>Cyperaceae</i> , <i>Pteridium esculentum</i>
Plaine des Lacs 7	moss & lichen 5 subsamples	<i>Nothofagus</i> forest	<i>Nothofagus</i> sp., <i>Palmae</i> , <i>Pandanus</i> spp.	<i>Agathis</i> sp., <i>Araucaria</i> sp., bamboo, <i>Albizzia</i> sp., <i>Araliaceae</i> sp., <i>Cordyline</i> sp., <i>Guttiferae</i> sp., <i>Joinvillea</i> sp., <i>Lepidospermum</i> sp., <i>Sapotaceae</i> sp., <i>Scaevola</i> sp.	<i>Juncus</i> sp., <i>Blechnum</i> sp., other ferns

Group D: *Nothofagus* rainforests

Col de Mouriane 1 and 2, Vallée de Ni and PdL 3 and 7 are all from *Nothofagus* rainforests (Figures 3.2; Table 3.6). All have distinct pollen signatures with between 65 to 98% *Nothofagus* pollen. Pollen from the other associated trees, shrubs and ground cover are overwhelmed by the *Nothofagus* pollen. Charcoal is absent to scarce and the palynological richness values are low.

3.6 Discussion

While in other tropical lowland situations identifiable pollen rain signatures have been found, in this case, it is only the more simple vegetation types that can be separated out and used as analogues, such as *Nothofagus* forest, *Melaleuca* woodland and grassland. It has been demonstrated that for forests with a closed canopy, pollen does not travel more than 20 - 30 from source (Jacobsen and Bradshaw, 1981). The five *Nothofagus* forest sites and Mount Koghi 2 are the only ones analysed for New Caledonia that physically reflect this situation, the other forest sites being more open. Certainly the *Nothofagus* forest sites are dominated by the local pollen rain, but for the Mount Koghi 2 rainforest site the results remain more ambiguous due to the poor taxonomic resolution of the diverse array of pollen. Here there is no single taxon, or combination of taxa that are exclusive to or define the rainforest and thus separate it out from the drier and more open forest formations. Unlike studies from New Guinea for example, *Nothofagus* appears to contribute little to the extralocal or regional pollen rain on New Caledonia. Outside of *Nothofagus* forest, *Nothofagus* pollen accounts for 2 % or less of terrestrial pollen sum.

A problem cited by Oldfield (1970) and as yet unresolved is differentiating between a few individuals of well dispersed taxa and a larger number of individuals at a greater distance; pollen source strength. Using Casuarinaceae percentages as an indicator of vegetation type is more complex than the *Nothofagus* pollen because of the high contribution from plants at an extralocal scale once the vegetation becomes more open. The Group A sites all cluster together in the PCA bi-plot due to the high Casuarinaceae percentages. All sites are representative of quite different vegetation types, from grassland and *Melaleuca* woodland on non-ultramafic substrates to a maquis of

Gymnostoma on ultramafic terrain. Therefore large amounts of Casuarinaceae pollen does not mean that a *Casuarina* woodland or *Gymnostoma* shrubland is present. In fact it may only be a small stand or scattered individuals near to an open site. Pollen trap data may overcome some of the uncertainty that surrounds Casuarinaceae pollen values and determine to what extent Casuarinaceae pollen is a component of the regional pollen rain. In addition, taxonomic work on the pollen of New Caledonia's Casuarinaceae may allow the differentiation of *Gymnostoma* and *Casuarina* pollen.

As foreshadowed, it is difficult to separate out the maquis shrubland and the rainforest simply from visual inspection of the pollen spectra, which is exemplified by the mixed class in Group C composed of maquis, ligno-herbaceous maquis, rainforest and sclerophyll forest. The high levels of Cunoniaceae/Elaeocarpaceae pollen in both rainforest and maquis samples is one reason why it is hard to separate out these two different vegetation types. Another is the large degree of overlap at generic and family level between the maquis and rainforest. For many sites it is hard to establish just where the large Cunoniaceae/Elaeocarpaceae contribution originates. However, as most sites are extremely open the Cunoniaceae/Elaeocarpaceae values must constitute an extralocal or regional component when these families are not recorded in the local vegetation. The pollen from the rainforest canopy tree *Apodytes clusiifolia*, must constitute a regional input in the all of the sites in which it was recorded.

It should also be noted that the data for the maquis and rainforest is somewhat skewed, as the sites of poorest preservation or where pollen was entirely lacking from samples came primarily from these situations. This is why only two lowland rainforest samples appear in the analysis. Separating out maquis from other forest communities may only be overcome with further work focussed on this issue, but would provide more rigorous guidelines for future palaeoecological work on the island.

Representivity is commonly used when describing pollen diagrams and is usually defined qualitatively. Work by Davis (1963) has led to the following guidelines being commonly adopted:

- i) *Over-represented*: pollen percentage is greater than the percentage of source plants within the vegetation.
- ii) *Well-represented*: pollen percentage is approximately equal to percentage of the source plants within the vegetation.
- iii) *Under-represented*: pollen percentage is markedly smaller than percentage of the source plants within the vegetation, or zero.

Taxa that were commonly over and under-represented at the local scale in this study are summarised in Table 3.7. *Nothofagus* and Casuarinaceae pollen are consistently cited as being well to over-represented in the modern pollen rain from Australia and New Guinea, no doubt because of their wind dispersion (Flenley, 1973; Harberle, 1993; Hope, 1973; Macphail *et al.*, 1994), while Cunoniaceae pollen is regarded as being under-represented in the pollen rain from Australian rainforests (Macphail *et al.*, 1994). The large values of Cunoniaceae pollen in this study stem partly from the large number of individual Cunoniaceae plants found in the maquis shrublands and the different dispersal conditions that apply there.

Table 3.3: Under and well to over represented pollen taxa

UNDER-REPRESENTED	
<i>Agathis</i>	Cyperaceae (dryland)
<i>Alphitonia</i>	<i>Pteridium esculentum</i>
Apocynaceae	Poaceae
Epacridaceae	
<i>Hibbertia</i>	
<i>Mimosa pudica</i>	
<i>Myodocarpus</i>	
Sapotaceae	<i>Cocos nucifera</i>
<i>Scaevola</i>	<i>Mangifera indica</i>
<i>Smilax</i>	<i>Musa sp.</i>
WELL TO OVER-REPRESENTED	
<i>Casuarina/Gymnostoma</i>	Cyatheaceae
Cunoniaceae	
<i>Nothofagus</i>	Cyperaceae (as swamp cover)
Myrtaceae	
Asteraceae*	
<i>Macaranga</i> *	

* not recorded in the surrounding vegetation of any surface sample.

Wind dispersion is no guarantee that pollen types will be well represented in the pollen rain however, and outside of a swamp environment Cyperaceae is nearly always under-represented in the pollen rain (Dodson, 1983; Harberle, 1993; Hope, 1973; Macphail, 1975). The lack of any clear signal for the ligno-herbaceous maquis which is dominated by Cyperaceae and *Pteridium* is disappointing given the large tracts of this formation within the ultramafic terrain. While occurring naturally, it also tends to be the vegetation cover of degraded land in ultramafic areas. It is hypothesised that indigenous people increased the occurrence of this particular formation (Jaffré, 1995; Virost, 1956), an hypothesis that will be hard to evaluate unless some diagnostic pollen taxa can be identified. While Cyperaceae in the terrestrial environment is under-represented, one important result that follows on from this is that high percentages of Cyperaceae pollen are diagnostic of swamp communities. This provides a reliable indicator of depositional environment.

The fossil sites of Plum, Saint Louis and Canala are areas that at present are heavily influenced by people. As a result the local vegetation is dominated by one or more of grass, *Melaleuca* and *Casuarina*, pollen types all of which are palynologically well-represented. A shortcoming of the study is the lack of surface samples from within traditional gardens which are now very restricted on New Caledonia.

In all samples taken from within landscapes that are close to some sort of habitation charcoal was abundant; Plum, Saint Louis, Canala. There were moderate levels in the maquis sites from the uninhabited Plaine des Lacs region, and in general charcoal was scarce or absent from the closed forests. Interestingly, the *Arillastrum gummiferum* forest site (Tontouta 1) had only scarce levels. This formation is fire sensitive and killed by high intensity fires (Papineau, 1989).

Palynological richness estimates do seem able to separate out the less and more diverse vegetation types, even when standardised to a count of 100 terrestrial pollen grains. The lowland rainforests (Canala 1 and Mount Koghi 2) have high values (> 20) and the more monospecific vegetation types including savanna, *Gymnostoma* woodland and

Nothofagus forest have low values (< 10). These values can be used to assess the diversity of the fossil pollen record over time.

Tentative guidelines have been established from this study for the interpretation of fossil diagrams and are presented below in Table 3.8. It is important to recognise that moss polsters and litter samples will nearly always be strongly biased toward local vegetation and that the pollen rain deposited within these samples would rarely be recorded in a more open swamp or lake environment, the very environments from which the fossil pollen is retrieved. Future studies will hopefully improve the sample size of the modern pollen rain data set and incorporate additional vegetation types such as gardens, high altitude sites, additional sites from the wetter northeast coast. Samples from within traditional gardens may prove useful for the interpretation of sites such as Lac Saint Louis, the abandoned yam garden site. What does appear to give clear pollen rain signals however, are the anthropogenic landscapes of the west coast, dominated by *Melaleuca* woodlands and grasslands and maintained by fire.

3.7 Conclusions

This chapter opened with a discussion of the possible sources of pollen based on the Jacobsen and Bradshaw (1981) model. The majority of sites in this study have shown that most of the pollen rain has a local or extralocal source. Even the very open swamp and lake sites, although overwhelmed by pollen from the surface vegetation, have terrestrial pollen signals dominated by local and extralocal vegetation. It has also been shown that well dispersed pollen such as *Nothofagus* only contributes very small amounts of pollen at a regional scale, while Casuarinaceae makes a slightly higher contribution at this scale. The correspondence of high values of charcoal in anthropogenic landscapes establishes the usefulness of using this in assessing human impact.

As the first study of its kind for New Caledonia, the modern pollen rain spectra have established that the anthropogenic and the more floristically simple vegetation types can be separated out from the more complex vegetation of the rainforests and maquis.

While the guidelines presented in Table 3.8 can assist in the interpretation of fossil pollen assemblages, the study has also highlighted the difficulties in obtaining precise results from New Caledonia. In addition, it gives focus to those areas that need more study. With 14 of the 36 samples containing only poorly preserved pollen or no pollen at all, it highlights the inappropriateness of litter collections in the rainforests and open maquis of New Caledonia and the need to adopt other sampling strategies if this work was to be extended.

Table 3.8: Some general principles for the interpretation of fossil pollen diagrams on New Caledonia

POLLEN SPECTRUM	VEGETATION INDICATED
Cyperaceae high equal to or greater than terrestrial pollen sum	Swamp Surface
Fern spores high equal to or greater than terrestrial pollen sum	Myrtaceous open woodland or Swamp Surface
<i>Melaleuca</i> high > 20%	<i>Melaleuca</i> woodland within 20 m of site. However <i>Melaleuca</i> pollen can be diluted if plants of well dispersed pollen taxa, such as <i>Casuarinaceae</i> occur within 20 m of site.
Poaceae high > 10%	Grassland or grasses abundant in local vegetation.
<i>Melaleuca</i> plus other Myrtaceae pollen high > 50%	Myrtaceous woodland.
<i>Nothofagus</i> high > 60%	<i>Nothofagus</i> forest
<i>Casuarinaceae</i> > 50%	Individuals of <i>Casuarina</i> or <i>Gymnostoma</i> nearby, but extent of vegetation hard to establish.
<i>Melaleuca</i> /Grass/ <i>Casuarinaceae</i> /Ferns/Charcoal	Anthropogenic landscape
Terrestrial Pollen Sum Trees low < 10% Shrubs high > 80% Herbs low < 5%	Possibly Maquis However, cannot separate out ligno-herbaceous and shrub dominated maquis.

Chapter 4 Palaeoecology of the Plum River Valley: 20 000 to 0 yr BP.

4.1 Introduction

This chapter presents the results of sediment and pollen analyses of the topmost Quaternary deposits found in the Plum River valley. The stratigraphy of the main river channel, its floodplain and the backswamp being analysed for fossil pollen are described and a sedimentation history for the river valley is proposed. The fossil pollen assemblage is then presented and a vegetation history for the catchment is discussed.

4.2 Study Site

The Plum River is located approximately 18 km due east of Noumea on the eastern side of Mont Dore (Figure 4.1 and Plate 4.1). Plum Swamp is a backswamp on the Plum River at an elevation of around 10 m asl. The catchment area of the Plum River is approximately 11 km² and the area of the backswamp under study is around 0.03 km². Steep slopes surround the river valley (Plate 4.1), except for the southern end, which empties into the Baie de Mouéa. The valley is just within the ultramafic terrain that dominates the southern third of the main island of New Caledonia.

The valley slopes are primarily covered by ligno-herbaceous maquis (Cyperaceae and *Pteridium esculentum*), although there are patches of bushy maquis (Plate 4.2). Two major vegetation types surround Plum swamp. An open 8 m tall *Melaleuca quinquenervia* woodland with an understory of grass occurs to the south, and a depauperate maquis dominated by *Casuarina equisetifolia* to the north (Figure 4.2). There are several small pockets of lowland rainforest to the southeast of the swamp. Within the *Melaleuca* woodland there is evidence of fire in the form of burnt and fire scarred trees. The swamp surface itself is dominated by 1 m high *Carex* sp. (Cyperaceae) with scattered juveniles of *M. quinquenervia* (Plate 4.2). The average annual rainfall for the area is between 1300 and 1500 mm per year (Section d'Hydrologie, 1981). During the 1991 wet season the lowest point of the swamp had around 1 m of standing water, while during the 1993 dry season the water table was 0.5 to 1.0 m below the surface.

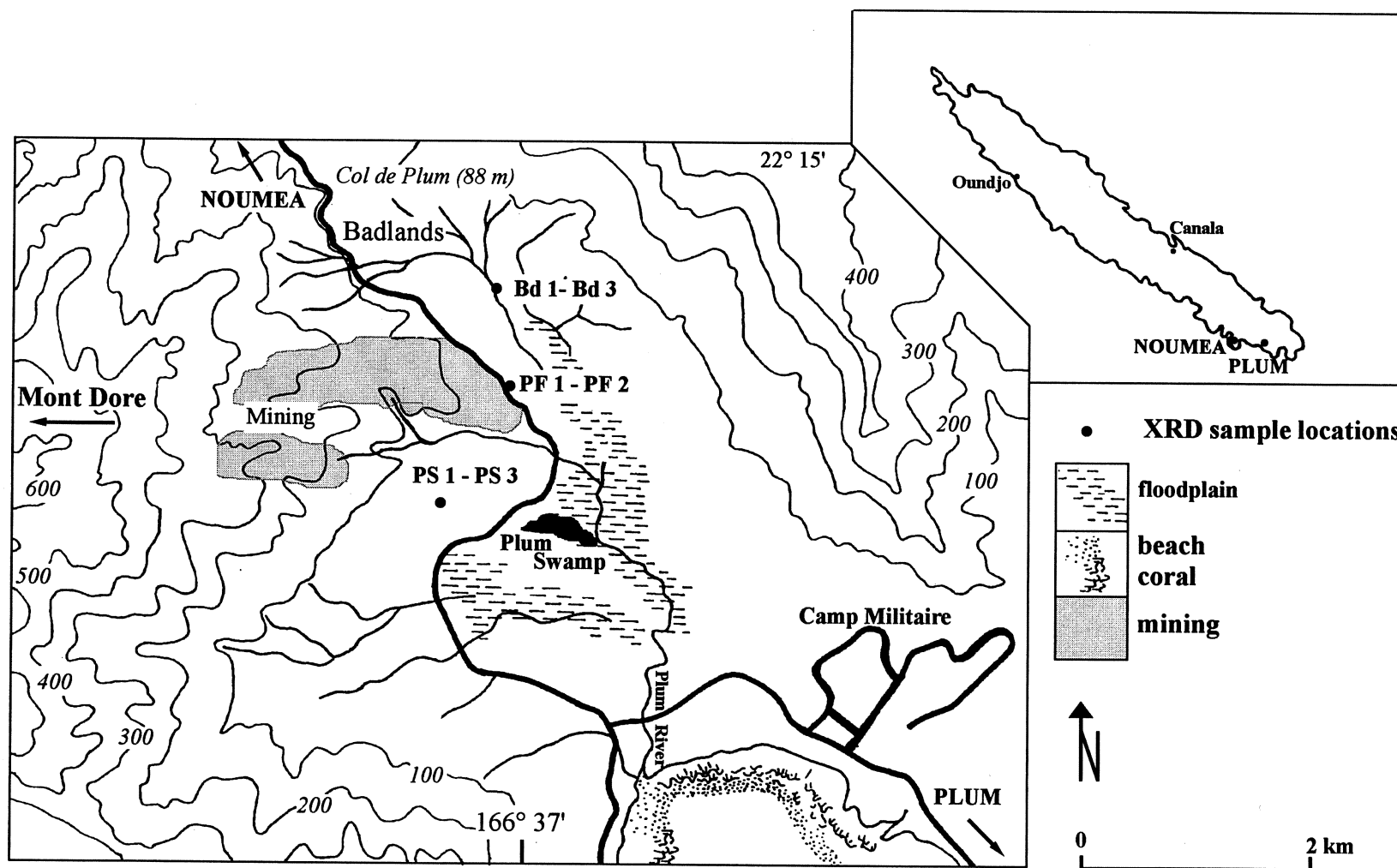


Figure 4.1: Location map of the Plum River Valley.

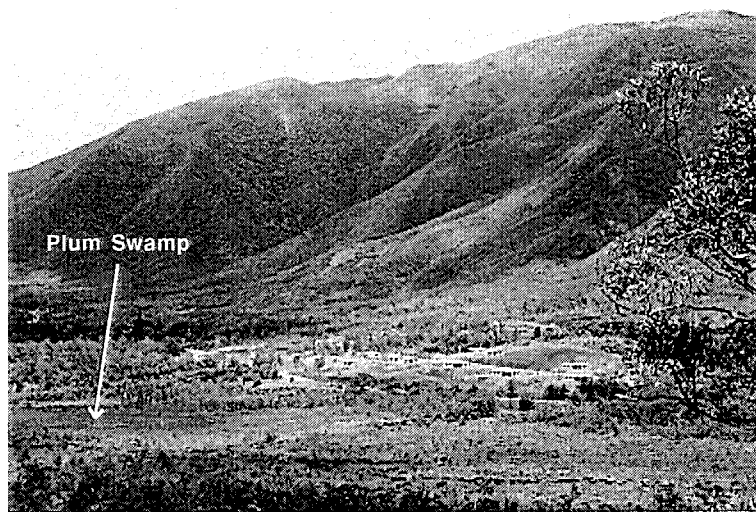


Plate 4.1: General view looking south west across Plum River valley.



Plate 4.2: A view of one of the Mont Dore mine sites, showing landslips and gullying.

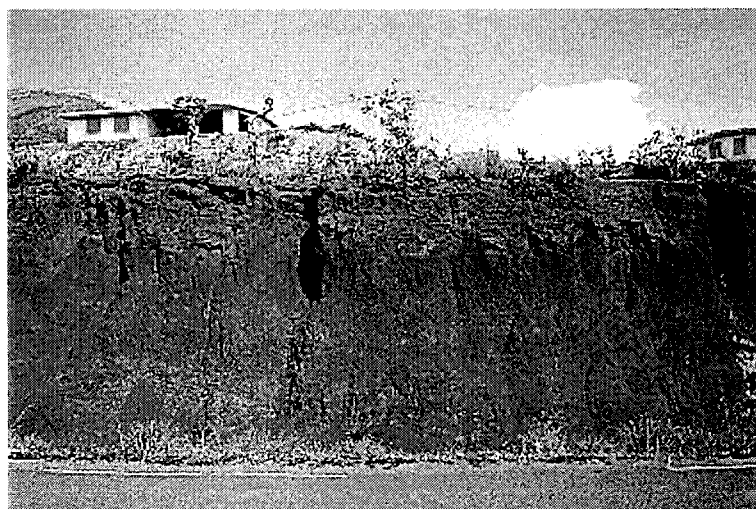


Plate 4.3: Roadcutting above swamp showing colour and depth of slope deposits.

There is no known archaeological site at Plum with ages from the start of New Caledonia's archaeological record, at around 3000 yr BP. At the mouth of the Plum River there is a coastal archaeological site containing a distinctive style of pottery, which has been given the name of the locality (Sand, 1996). Plum pottery is quite widespread and is found from Canala on the east coast, south to the Isle des Pins and along the west coast to the Koné-Oundjo region. The appearance of this pottery marks the beginning of the Naïa period with radiocarbon ages as old as 1870 yr BP (Sand, 1996). Documentation related to the pottery find at Plum, in particular the exact locality and its stratigraphic context, have been lost over time (Sand, *pers. comm.*).

A mine has operated at various times on Mont Dore since 1936 (Figure 4.1). At first mining operations were small scale (between 50 and 200 tons per year) and extraction took place in the years 1936-40, 1946-47 and 1963-64. From 1970 to 1975 extraction took place on a much larger scale with between 1,000 and 5,000 tons of ore per year extracted (Antheaume, 1981). While the mine is no longer in operation, gullying as a result of mining is widespread and landslips from the mine site are common (Plate 4.3).

4.3 Stratigraphy

The stratigraphy of the main river valley and the backswamp being analysed for fossil pollen was investigated to enable some understanding of how depositional processes may have changed over time, in particular since the presumed arrival of people on New Caledonia 3000 yr ago. The stratigraphic study was undertaken in two parts. In 1992 a reconnaissance survey of the river valley was undertaken focusing on descriptions of bank exposures within the main channel. This was followed in 1993 by a detailed coring survey of the backswamp. The results of the two investigations are brought together in a discussion at the end of this section, which proposes the likely evolution of the depositional environment within the Plum River valley.

Methods

Exposures along the main channel and tributary were described in the field and samples were taken for radiocarbon dating. The locations of the bank exposures are shown in Figure 4.2. A near north-south and east-west survey along the main axes of the backswamp was conducted using a D-section corer (Figure 4.2). With the exception of

the two cores used for pollen analysis, core descriptions were logged on site. The two pollen cores were sealed in plastic and transported back to Sydney in PVC cradles. In the laboratory they were described and samples were taken for pollen analysis and radiocarbon dating. All colours were recorded using a Munsell colour chart.

Valley Stratigraphy

The channel in the lower part of the main valley is a deep gully with bank heights of 2 - 4 m. The main tributary on the western side of the valley is also incised and originates from the Mont Dore mine (Figure 4.1). Upstream of the main tributary junction the main valley channel is discontinuous and the valley floor is peat covered with some areas of scour. The headwaters of the main valley channel are characterised by a distinctive badland. The pale creamy colour of the badland soils sets this area apart from the iron rich ultramafic soils on the surrounding slopes (Plate 4.4). Highly weathered parent materials have formed clays that shrink and swell (evidenced by cracking) making them impermeable and subject to the classic badland erosion. The slopes surrounding the main valley have large alluvial fans, some of which are gullied. The fans and mined regolith are composed of dark uniform reddish brown clays with a white precipitate. The coarse fraction is composed of small pisoliths. Regolith depth varies from less than 1 m to greater than 10 m with no discernible pattern. Road cuttings suggest that the fans are around 4 - 6 m in depth (Plate 4.5).

Between the main tributary and backswamp is a gravel splay originating from the Mont Dore tributary (Figure 4.2). The splay is composed of coarse material such as gravels and cobbles through which the present tributary channel is incised by 3 m. Incision of the tributary and main channel must postdate the mining operations on Mont Dore, as flows through these channels would not be capable of lifting cobbles and gravels overbank and onto the floodplain. Above the tributary junction in the main valley the gravels and reddish brown sediments characteristic of the mining spoil are absent (Plate 4.6).

There are three principal sediment types found in the bank exposures of the main channel and the Mont Dore mine tributary. A basal unit of dark brown to brown sandy mud (silt and clay), a middle unit of reddish brown to black peat, and an upper unit of reddish brown muddy sand, sometimes with gravels and cobbles.

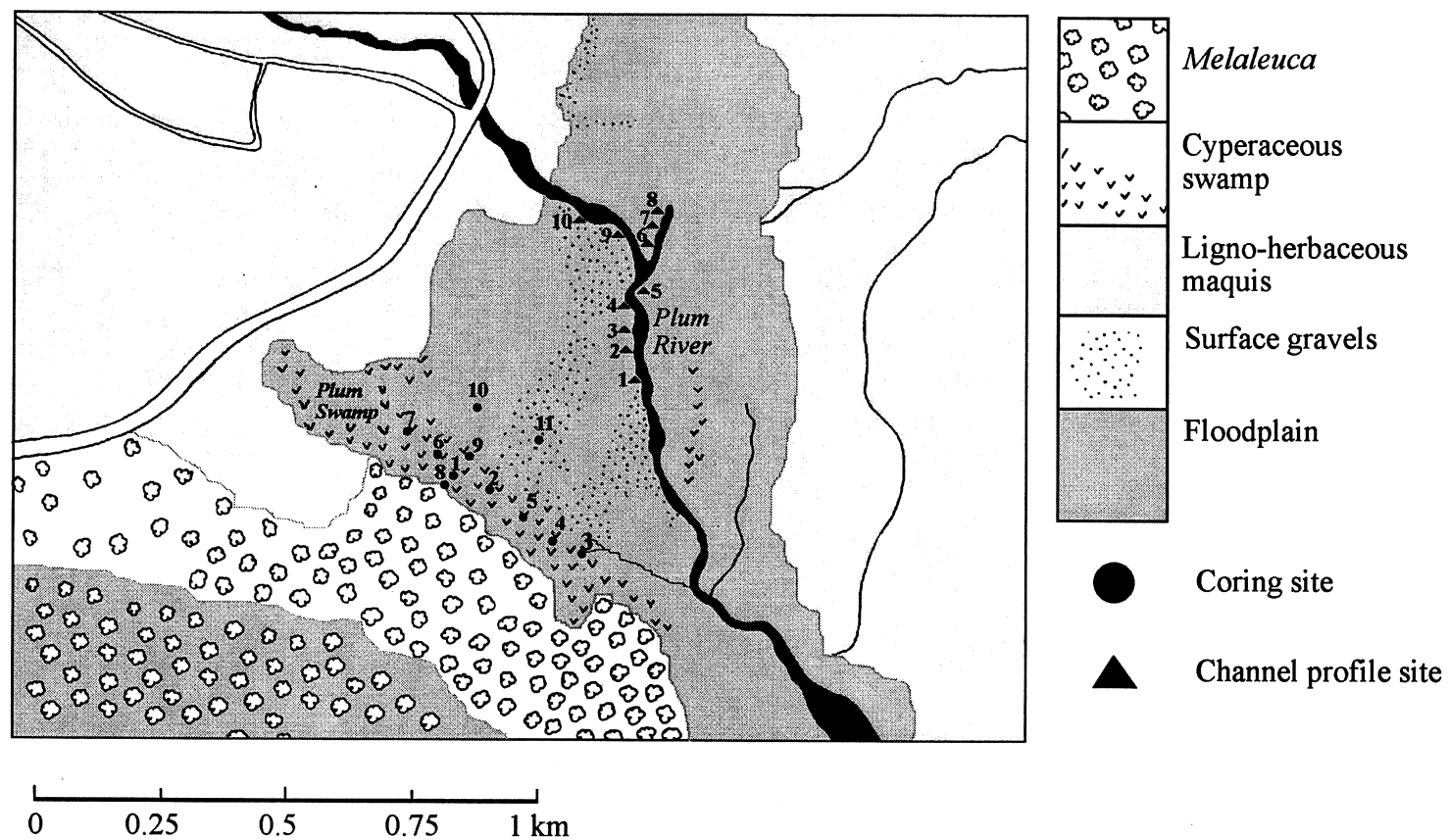


Figure 4.2: Plum Swamp. Location of pollen cores, stratigraphy coring sites and channel profiles.



Plate 4.4: Plum Swamp and surrounding vegetation. *Melaleuca* woodland to the south of the swamp.



Plate 4.5: Badland terrain in the headwaters of Plum River valley.



Plate 4.6: View from within the main channel looking south to junction with mine tributary. Note absence of orange sediment, gravels and cobbles upstream of junction.

All exposures have a 2 - 3 m deep unit of brown sandy mud (Figure 4.3). Coring beneath the channel bed at the base of profile 1 revealed that this unit extends for at least another metre in depth. The unit fines upwards and overall becomes coarser upstream, lensing out in the tributary above the bridge (see Figure 4.2 for location). In profile 1 the top of this unit is a strongly pedal, very dark reddish brown clay, with root channels. Root channels are common throughout the sandy mud unit, the density of the root channels increasing downstream and toward the top of the unit. Bands of coarse sands and gravels are found within this unit in some profiles, the occurrence and coarseness of these increasing upstream (Figure 4.3). For profiles 8 and 9, the unit is finer at the base and coarsens upward. Relative to the other main channel profiles, profile 8 is much coarser overall. In most cases there is a gradual change to the overlying peat unit.

The overlying fibrous peat undergoes a colour change from black in the lower parts of the channel to reddish brown in the upper reaches and is commonly 20 - 40 cm thick. There is a clear boundary between this and the underlying unit at profile 1, but a much more gradual change to peat was seen in profiles 2 - 6. Profiles 7, 8, 9 and 10 have a clear boundary between the peat and underlying sandy mud, although the peat in profiles 9 and 10 is a black muddy peat. There is a sharp boundary to the topmost unit of reddish brown sandy mud in all profiles except 7 and 8, where the peat unit is at the surface (Figure 4.3).

The uppermost unit is commonly a reddish brown muddy fine sand with some root channels coarsening upstream to sand, gravels and cobbles. The sands in the lower reaches are weakly horizontally bedded, while in the upper reaches of the tributary the gravels and cobbles are strongly bedded and well-sorted. Profile 6 is the only exposure upstream of the tributary junction to record this unit, although here it is a reddish brown silty clay. There is a weak band of peat, 5 - 10 cm thick, in the downstream profiles (1-5) midway through this topmost unit.

The unconformity between the middle unit of black peat and the topmost unit of muddy sand can be traced throughout the system and is represented by the solid line in Figure 4.3. The 160 cm of cobbles, gravels, sands and clays in the bank exposure at profile 10 are part of the gravel splay.

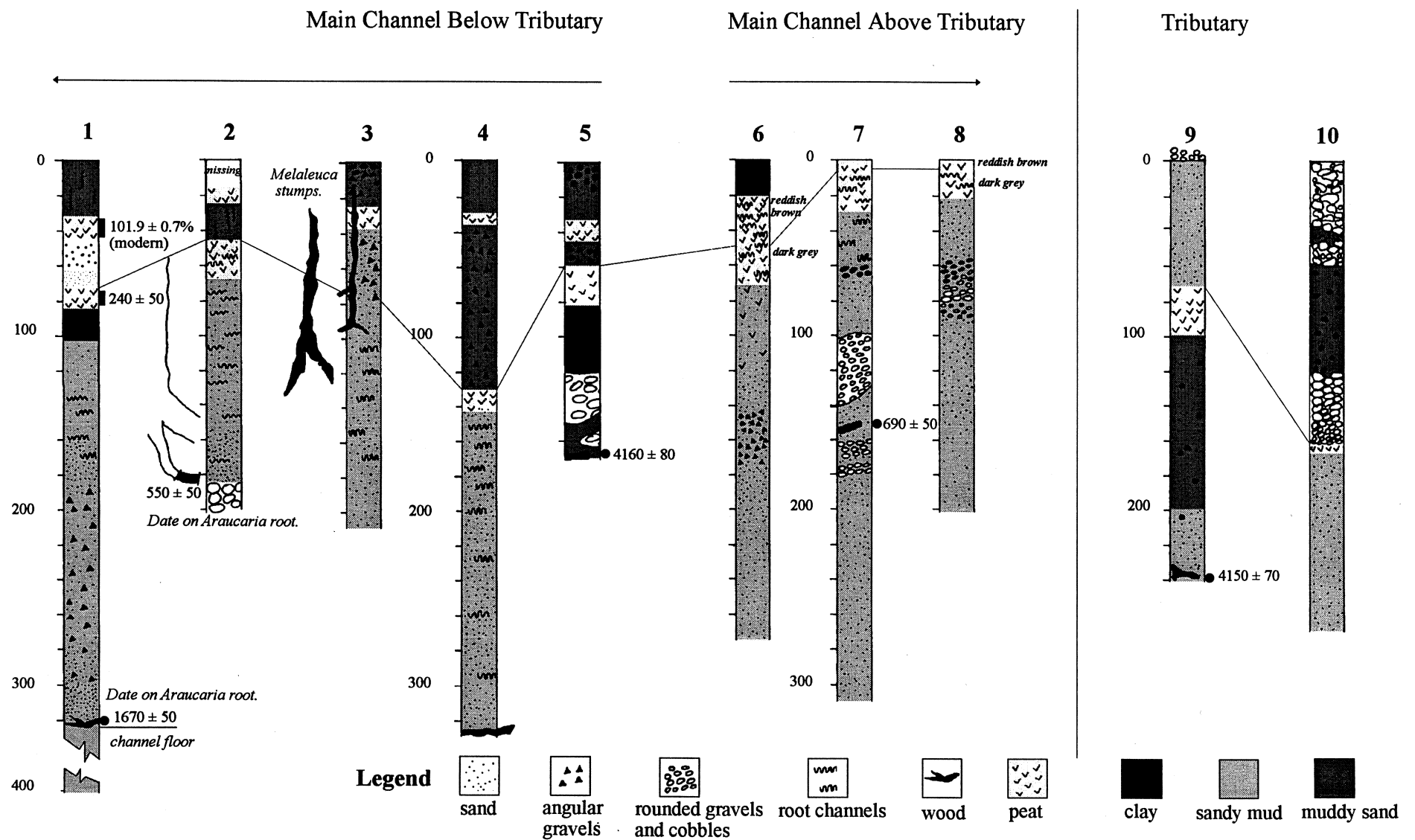


Figure 4.3: Channel stratigraphy of Plum River and main tributary. See Figure 4.2 for locations.

Seven radiocarbon dates were obtained on peat and wood within the channel to establish a chronology for the sediments (Table 4.1). From profile 1 the two peat layers and an in-situ *Araucaria* tree root from the base of the exposure, just above the channel bed, were dated. The weak layer of peat found within the topmost unit of muddy sand is modern (Table 4.1; Beta-52263) and the middle unit of black peat gave an age of 240 ± 50 yr BP, suggesting that it was accumulating up until European occupation. The sample of tree root from the base of profile 1 gave an age of 1670 ± 50 yr BP. This date and the date from the overlying peat indicates that 240 cm of the basal sandy mud unit took at least 1400 years to accumulate, while a tree root sample from the base of profile 2 returned an age of 550 yr BP. A wood sample taken from within the sandy mud unit of profile 7 gives an age of around 700 yr BP, but as the wood shows signs of being transported this is the maximum age of the deposit. Two other wood samples taken from a stump in the main channel bed opposite profile 5 and from the base of profile 9 gave ages of around 4150 yr BP. Both stumps were in growth position. It is also important to note that the latter two samples are tree trunk material and not tree root. It is estimated that root material comparable to the profile 1 and profile 2 samples is probably a metre or so below the channel bed and thus does not reflect inconsistencies in the dates, but rather in the sampling.

There are insufficient radiocarbon dates to draw firm conclusions about changing rates of sedimentation. However, the dates are internally consistent, and the tree stumps found throughout the channel system reveal that the basal unit of brown sandy mud accumulated slowly enough to allow the continued growth of *Araucaria* within the valley. However, *Araucaria* does not grow in the valley today. The ^{14}C dates show that the main layer of peat accumulated in the valley until modern times, and suggest that the uppermost unit is associated with mining. The hiatus in the accumulation of the topmost unit of reddish brown muddy sand and the return to peat accumulation is consistent with break in mining operations for 16 years between 1947 and 1963. The uppermost very coarse sediments of the gravel splay and the subsequent channel is thus probably associated with the more intense mining after 1963. The *Melaleuca* stumps, in and adjacent to profile 3, appear to be from within the last 500 years.

Swamp and Floodplain Stratigraphy

The locations of the core sites described in the coring survey are shown in Figure 4.2,

Table 4.1: Radiocarbon ages and calibrated ages for Plum River profiles.

Profile Number and Depth	Lab Number	C ¹⁴ Age years B.P.	calibrated age yr BP (range) 2 sigma	Calender Age (range) 2 sigma	Sample Type
1 (40 - 46 cm)	Beta - 52263	101.9 ± 0.7 % (modern)			Peat, between two mineral layers.
1 (74 - 80 cm)	Beta - 52264	240 ± 50	290 (500 - 0*)	1660 AD (1450 - 1955)	Peat, at top of valley fill.
2 (160cm)	Beta - 52266	550 ± 50	540 (670 - 430)	1410 AD (1280 - 1520)	Root from insitu <i>Araucaria</i> stump at base of valley fill.
7 (157 cm)	Beta - 52268	690 ± 50	655 (780 - 520)	1300 AD (1170 - 1430)	Wood in middle of valley fill. Has been transported.
1 (320cm)	Beta - 52265	1670 ± 50	1545 (1820 - 1340)	405 AD (130 - 610)	Root from insitu <i>Araucaria</i> stump at base of section.
9 (250 cm)	Beta - 52269	4150 ± 70	4640 (5030 - 4280)	2690 BC (3080 -2330)	Wood. Burnt. Insitu stump at base of profile 9.
5 (250 cm)	Beta - 52267	4160 ± 80	4690 (5210 - 4230)	2740 BC (3110 - 2280)	Wood from top of insitu stump in creek bed adjacent to profile 5.

Calibrated using Stuiver and Reimer (1993).

0* represents a "negative" age BP

1955* denotes influence of bomb C¹⁴

and the stratigraphy is illustrated in Figures 4.4 and 4.5. Core 1 was collected in 1991 as part of reconnaissance fieldwork. At the time there was approximately 50 cm of water overlying the core 1 site, which is why there is a water layer of 80 cm underlying the floating root mat. All other descriptions are from the 1993 fieldwork season when the surface of the swamp was largely dry.

All of the swamp cores, with the exception of cores 3 and 4, follow the same general pattern outlined below. Cores 3 and 4 are described separately.

Typical Swamp Profile (Figures 4.4 and 4.5)

- i) The surface vegetation is a dense cover of *Carex* sp. (Cyperaceae) around 1 m high. During the wet season water up to 1 m deep has been observed on the swamp surface.
- ii) Beneath this is a strong brown clay which contains sand in core 5 and organic matter in the remaining cores.
- iii) Underlying this clay in the central cores (5, 2 and 6) is a 10 - 40 cm layer of black peat. This layer contains some clay in core 5.
- iv) At around 100 cm depth there is a sharp boundary between the peat and a 20 to 40 cm thick layer composed of a dark yellowish brown to olive brown sandy clay with small rounded gravels and small creamy white nodules < 2 mm in diameter. This is one of the few layers that is found across all the profiles at the western end of the swamp. The white nodules are not present in core 5, but the clays and gravels are.
- v) Below this is a black peat. Cores 6 and 7 have an increasing amount of clay in the top of this layer which is absent from core 9.
- vi) There is then an abrupt change to an organic mud or organic rich clay.
- vii) The clay is underlain at around 300 cm by a black peat, 60 to 100 cm thick.
- viii) Beneath the peat is a sandy clay. By this depth impenetrable material had been reached in several cores. For profiles 1 and 8 a hard sandy and gravelly clay is reached and for profile 5 recovery was poor below this unit due to distortion of the D-section corer.
- ix) Underlying the sandy clay in the remaining cores (2, 6, 7 and 9) at a depth of around 400 cm is a black to dark brown peat, which is less humified in core 2, relative to cores 6, 7 and 9.

- xi) In cores 6, 7 and 9 the peat is underlain by a grey clay.
- x) In core 2 the peat is underlain by a black organic mud at around 500 cm with a sharp boundary to the grey clay described above at 660 cm.

Quite different swamp profiles were observed in cores 3 and 4. The record from core 4 is fragmentary as the gravels at 100 cm were too coarse to penetrate with a D-Section corer and too loose for recovery with an auger. Profile 3 is the head wall of a tributary gully at the eastern end of the swamp. This gully drains into the main river channel. The sandy clays and peat layers common to the top 100 cm of the swamp cores are found here and are underlain by small rounded gravels 3 - 4 mm in diameter in a sandy clay matrix, similar to those in core 5. From 100 cm to 300 cm there is a fine organic clay. Below 300 cm the sediment resembles the bottom sandy mud unit of the main channel exposures. The sediment at this end of the swamp clearly suggests that it is transitional between the main channel exposures and the western end of the swamp, possibly a levee.

Cores 10 and 11 are on the gravel splay between the swamp and the mine tributary. The surface is a strong brown to orange sediment scattered with gravels. The vegetation consists largely of sparse Cyperaceae and scattered individuals of *Casuarina equisetifolia*. The creamy white nodules found in the swamp cores are found in both these profiles within the top metre. Core 10 has much more sand and gravel than the swamp cores, and could not be cored past 180 cm depth. However, the top 18 cm resembles the clay of the swamp surface, while the underlying units more closely resemble the upper units of exposure 10 in the Mont Dore tributary. Probing with extension rods suggested that there is stiff clay from 350 to 500 cm and a gravel layer at around 380 cm. Core 11 is less coarse than 10. Below 100 cm it is composed primarily of a sandy clay with a layer of organic mud from 310 - 318 cm depth. Being closer to the main channel the topmost units contain more sand. Peat with a large amount of wood was recovered from 470 - 600 cm and coring was not possible beyond 600 cm because of the wood. Core 11 seems to represent an intermediate state between the swamp and the river channel. The 360 cm of olive brown sandy clay beneath the creamy white nodules appears similar to the bottom sandy mud unit in the river channel exposures, and the peat unit may be related to the lowest peat unit in the backswamp between 4 - 5 m depth.

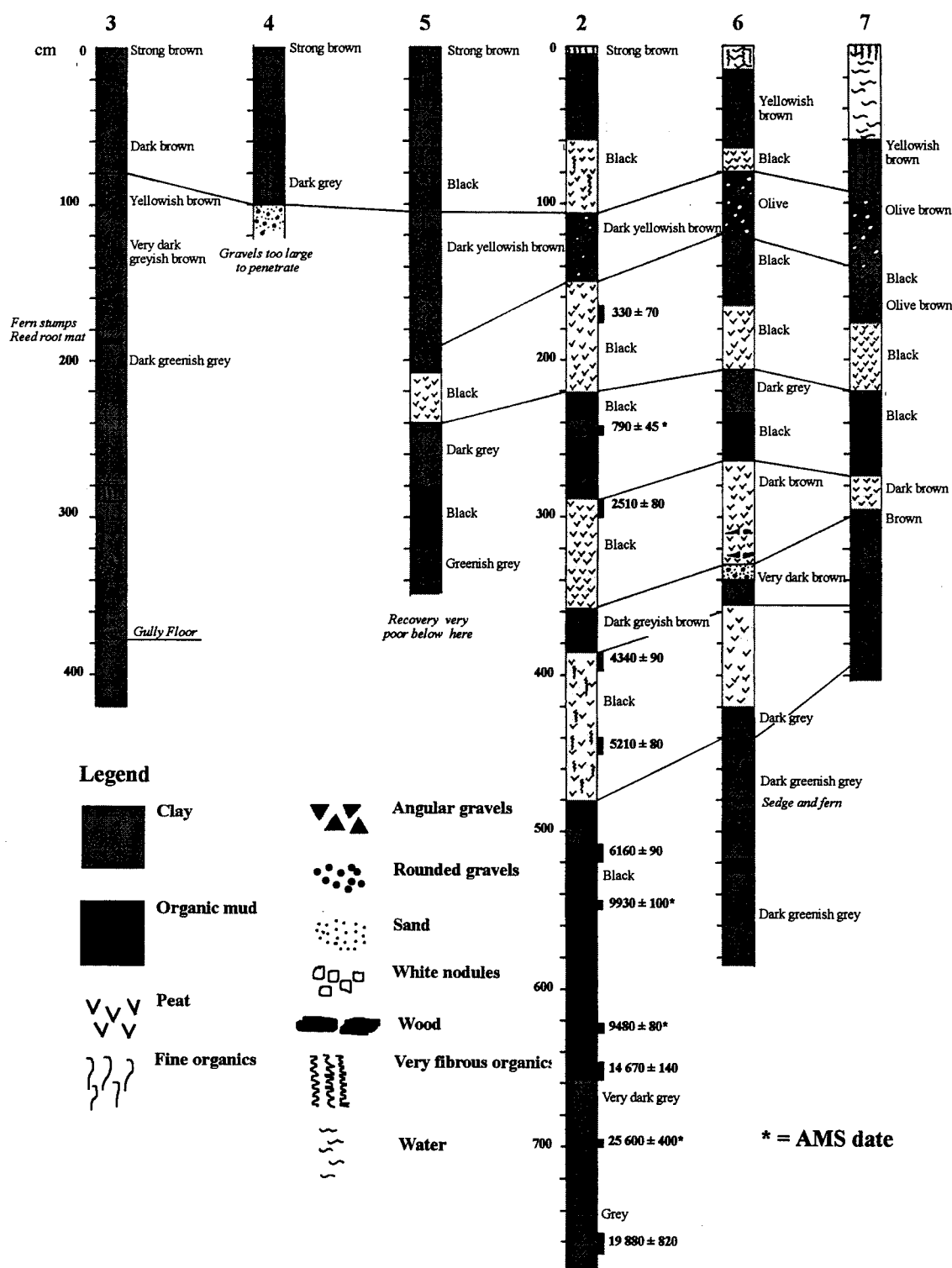


Figure 4.4: Backswamp stratigraphy. East-west transect.

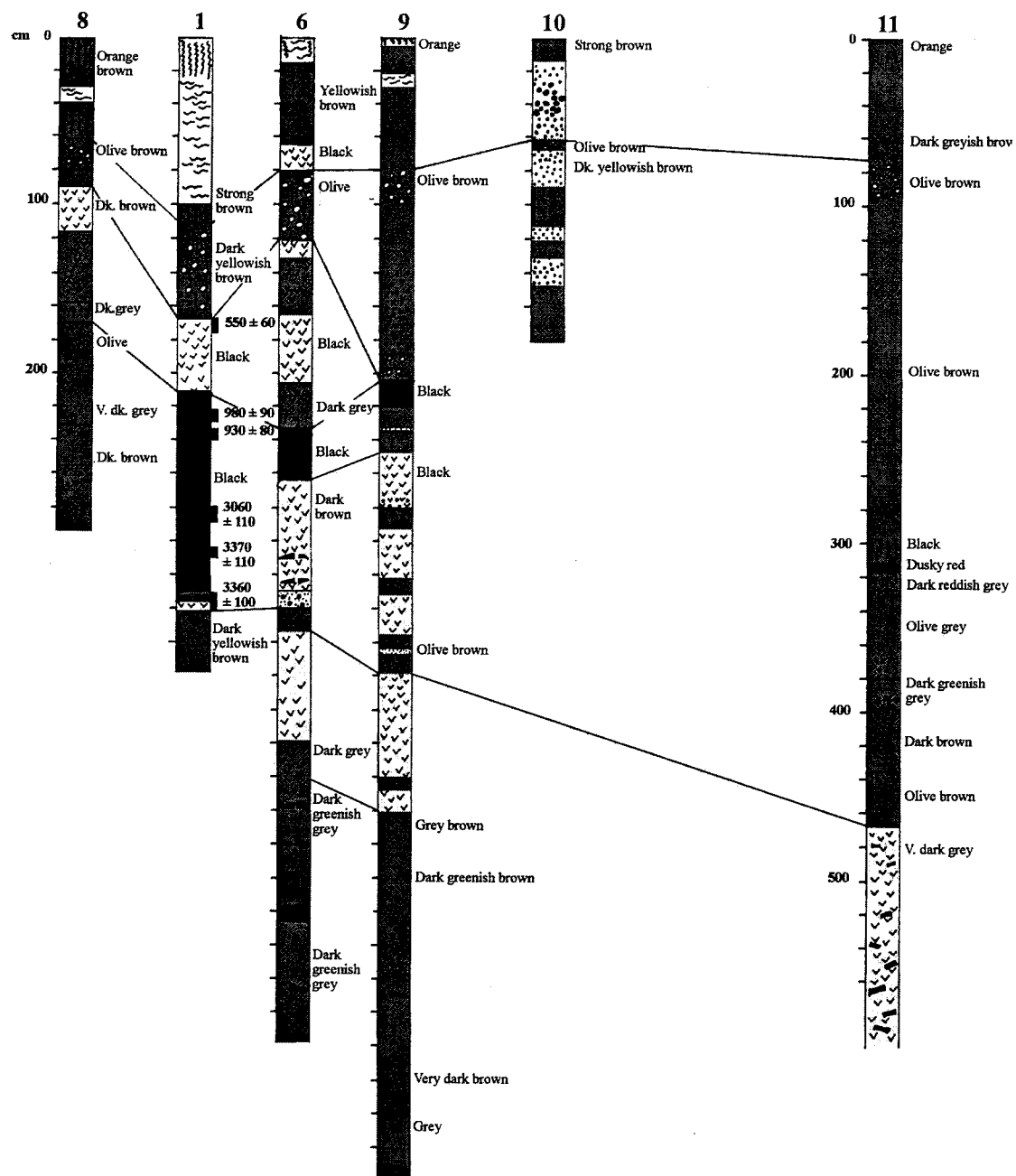


Figure 4.5: Backswamp stratigraphy. North-south transect. See figure 4.4 for key.

In general the backswamp sequence fines away from the main channel and organic input increases with distance from the channel. The sediments are finer at the base of the deepest sediments, increasing in coarseness toward the surface.

Samples for radiocarbon dating were taken from the two pollen cores, cores 1 and 2. Core 2 is the longer and more central core, and from this eight conventional radiocarbon dates were obtained with 4 additional AMS dates from the less organic sediments. Six radiocarbon ages were obtained for core 1, the edge core. The ages for both cores are reported in Table 4.2 as conventional ages in years BP. The dating reveals that the basal sediments of core 2 were accumulating during the last glacial maximum. By contrast the basal sediments of core 1 are late Holocene in age.

An age depth relationship is illustrated in Figure 4.6. Several age models were investigated based on different lines of reasoning, including the stratigraphic changes within the core. However, a sound model is to treat the dates above 500 cm and the dates below 500 cm as two separate populations, and to then place a straight line of best fit through each series. Even though the date at 510 cm appears to fall in a straight line with the upper dates, it is included in the lower population based on the stratigraphy of the core. In this way all of the organic mud samples are together in the one series. The two age-depth curves are plotted in Figure 4.6. It can be seen that the ages obtained for the upper part of the core are effectively a linear function with depth, except for the AMS date at 245 cm. Below 500 cm, the line of best fit is accompanied by an envelope which denotes the extent of possible ages and illustrates how much uncertainty surrounds the dates from this part of the core.

The most important aspect of obtaining robust dates and as a consequence a robust age model for the lower part of the core is the timing of the transition from inorganic clay to organic mud at 660 cm. This change in sediment type could mark the transition from the LGM to a post-glacial environment. Based on the dates obtained so far, this transition in sediment type lies anywhere between 12,500 and 22,000 yr BP (Figure 4.6). Only additional dating of material from these sediment units can resolve this issue.

The age depth model suggests that the change in sedimentation rate for the core occurs at 510 cm, however this is merely a result of sample position. The most likely point for

Table 4.2: Radiocarbon ages from Plum Swamp.

Core 2 (Plum Centre) sample depth in cm	Lab Number	C ¹⁴ Age yr B.P.	Calibrated Age yr BP (range) (2 sigma)	Calender Age (range) (2 sigma)	Bulk Sample Type
166-176	Beta – 53530	330 ± 70	390 (510 - 0*)	1560 AD (1440 - 1955*)	peat
242 - 247	OZA – 957	790 ± 45 #	690 (780 - 660)	1260 AD (1170 - 1290)	slightly organic clay
286 - 296	Beta – 53531	2510 ± 80	2570 (2760 - 2340)	620 BC (810 - 390)	peat
342 - 350	Beta – 76835	3510 ± 70	3760 (3930 - 3620)	1810 BC (2020 - 1670)	peat
387 - 397	Beta – 53532	4340 ± 90	4870 (5260 - 4650)	2920 BC (3310 - 2700)	peat
440 - 450	Beta – 52262	5210 ± 80	5940 (6180 - 5850)	3990 BC (4230 - 3800)	peat
508 - 518	Beta – 70396	6160 ± 90	7020 (7220 - 6850)	5070 BC (5270 - 4850)	organic mud
545 - 550	OZA – 958	9930 ± 100 #	11010 (11880 - 10960)	9060 BC (9930 - 9010)	organic mud
623 - 628	OZA – 959	9480 ± 80 #	10520 (10910 - 10230)	8580 BC (8960 - 8280)	organic mud
648 - 658	Beta – 70397	14670 ± 140	17560 (17910 - 17200)	15610 BC (15960 - 15250)	organic mud
696 - 700	OZA – 960	25600 ± 400 #			slightly organic clay
757 - 767	Beta – 70398	19880 ± 820			slightly organic clay
Core 1 (Plum Edge) sample depth in cm					
168 - 176	Beta – 43682	550 ± 60	542 (650 - 500)	1410 AD (1300 - 1450)	peat
223 - 231	Beta – 43683	980 ± 90	920 (1062 - 690)	1030 AD (890 - 1260)	organic mud
232 - 240	Beta – 438684	930 ± 80	830 (970 - 670)	1120 AD (980 - 1280)	organic mud
280 - 288	Beta – 43685	3060 ± 110	3260 (3470 - 2940)	1310 BC (1520 - 990)	organic mud
305 - 310	Beta – 43686	3370 ± 110	3620 (3880 - 3360)	1670 BC (1930 - 1410)	organic mud
330 - 340	Beta – 43687	3360 ± 100	3610 (3840 - 3370)	1660 BC (1890 - 1420)	slightly organic clay

Calibrated using Stuiver and Reimer (1993).

AMS date

0* represents a "negative" age BP

1955* denotes influence of bomb C¹⁴

the transition from a lower sedimentation rate in the bottom, to the higher one in the top is at 480 cm with the change from organic mud to peat which is a distinct boundary in the stratigraphy of the site. It is therefore difficult to assign ages to specific samples that lie in the region between 480 and 510 cm as they too have an envelope of error surrounding them.

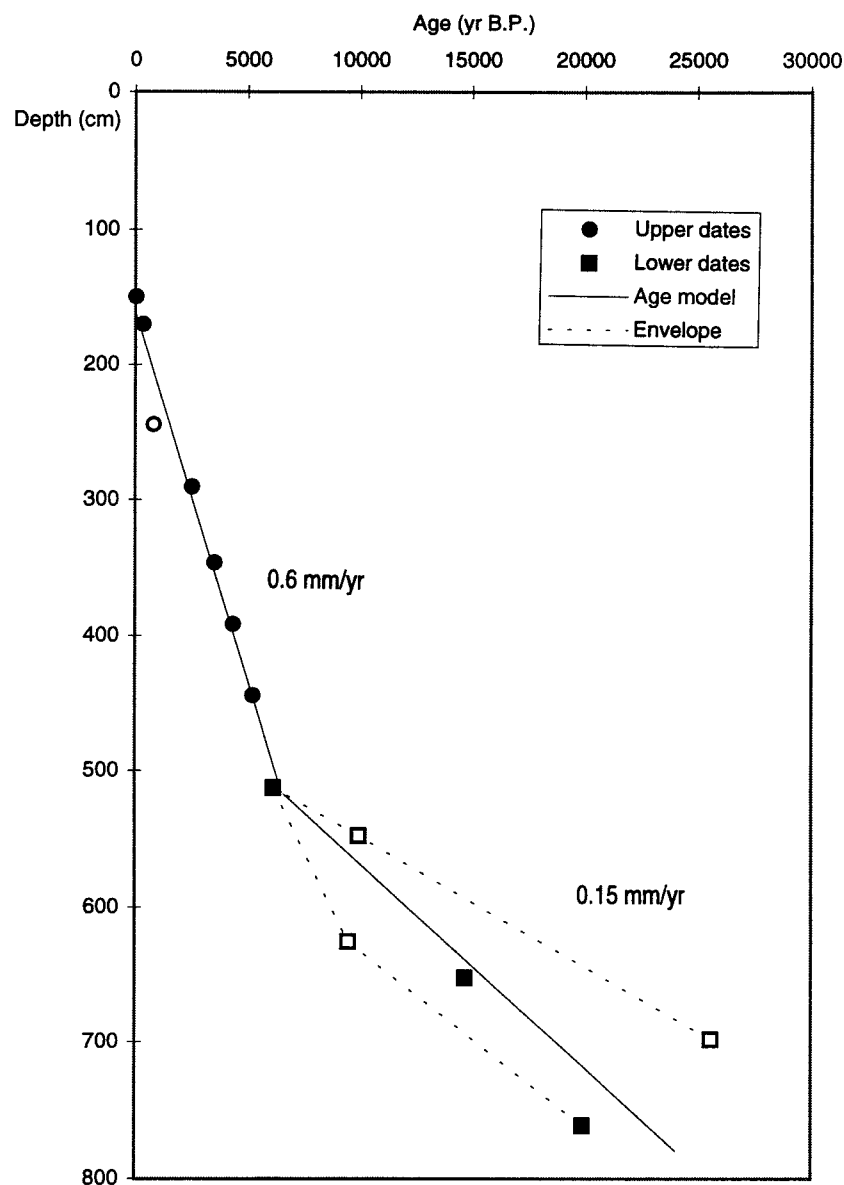


Figure 4.6: Age depth model for Plum Centre core. Hollow symbols equal AMS dates.

The sandy clay unit with the creamy white nodules found within the top 150 cm of all cores except 3, 4 and 5, is a good stratigraphic marker. The two dates from the peat layer below this unit suggest that it is probably modern. This is in keeping with the age of the peat layer in the channel exposures, which was found to be around 240 yr BP.

Like the river channel exposures, there is a return to peat accumulation within the upper inorganic layers, which is probably attributable to the 16 year pause in mining activity. Mining has led to the deposition of sand, gravels and clays along the river channel and across the floodplain, with only the clays reaching the back of the swamp. There has been 1 to 2 m of sediment deposited in the swamp and across the floodplain since 1936, at an average of 25 mm/yr. This is markedly different to the pre-mining environment where on average 0.6 mm was being deposited per year.

XRD Analysis

Xray diffraction (XRD) analyses were carried out on sediments from the backswamp and surrounding valley to broadly investigate the major sources of sediment to the backswamp over time. Identifiable sources seemed possible given the quite different geologic nature of the badland area in the headwaters of the valley, in comparison to the surrounding slopes. Sediments were analysed from core 2, from the badlands area and from two slope deposits.

The Department of Geology, University of New South Wales, carried out the analyses. For the bulk mineralogical analyses, samples were ground to a fine powder then pressed into aluminium sample holders. XRD traces were then recorded on a Philips X'pert system and the results are reported in Table 4.3.

All samples except the earth above bedrock (PS2) contained quartz. However, free quartz is not available in ultramafic terrain which poses the question of source for the quartz. The geology of the river valley is no doubt more complex than pure ultramafics as the badland terrain already suggests. Very fine particles could also be blown inland from the coast.

Goethite, smectite and siderite dominate the secondary minerals in the bulk sediment analysis. Smectite is the defining mineral for the badlands area and mineralogically sets these deposits apart from the slope deposits (Table 4.3). Three of the core samples also have abundant smectite 718-720 cm, 552-555 cm and 247-250 cm, and lack the iron rich mineral of the slope deposits. Goethite is the defining mineral of the slope deposits, and the remaining core samples are mineralogically more like the samples from the slope and fan deposits.

Table 4.3: XRD results for bulk mineral analysis.

Sample	quartz	goethite	haematite	siderite	kaolinite	smectite	talc	anthophyllite	chrysotile	chlorite	enstatite	ferro- glaucophane	gibbsite	maghaemite
Core 2 125 cm														
White nodules	**			*****										
Core 2 37-40 cm														
Sediment	***	*****		**			**		**					
Core 2 130-132 cm														
Sediment	****	**		***			*		**					
Core 2 247-250 cm														
Sediment	****				***		*							
Core 2 282-285 cm														
Sediment	****	*****			*		*							
Core 2 372-375 cm														
Sediment	***	***		***			*		***					
Core 2 552-555 cm														
Sediment	***				*		**							
Core 2 718-720 cm														
Sediment	*****				*		*	**						
Plum Fan 250 cm (PF1)														
C horizon sediment	****	***			**									
Plum Fan 250 cm (PF1)														
Weathered stone	*****		**				*							
Slope Deposit (PS1)														
Pisolitic upper soil	**	*****												
Slope Deposit (PS1)														
Earth above bedrock		*****			*								**	**
Badland 1 (Bd1)														
Remnant of A2 horizon	**						**		**	**	**	**		
Badland 2 (Bd2)														
B horizon	**						**		**	**				
Badland 3 (Bd3)														
Sediment coming out of badland	***						**			**	*	**		

(PF1) = abbreviation used on Figure 4.1

***** dominant (>60%) **** abundant (40-60%) *** moderate (20-40%) ** small (5-20%) * trace (<5%). Shading is intended to highlight the similarities between certain samples.

The creamy white nodules found in the upper 1.5m of the swamp proved to be siderite, an iron carbonate. Siderite and goethite were found in the samples from 372-375 cm, 130 to 132 cm and 37 -40 cm. The sample from 282-285 cm contained goethite only. Siderite will precipitate out in a reducing environment with a pH above 8 (Drever, 1988), that is a fairly typical swamp environment.

It would appear that the inorganic fraction of the basal clay and the organic mud originates from the badlands in the headwaters. The origin of clay layers after 5000 yr BP is predominantly from the slopes and fans, and is likely to be those surrounding the swamp at the western and southern end as the clay bands cannot be traced across the swamp. The 247-250 cm clay band is within the human occupation period and is dominated by smectite suggesting the material is largely from the headwaters. An AMS date from the clay gave an age of 790 yr BP, although the age model adopted gives it a slightly older age. This clay band could be indicative of a major change within the catchment as no clay layers of predominantly smectite composition have been deposited since LGM.

The clay fraction ($\leq 2 \mu\text{m}$) of the samples was also analysed. This was separated out from the bulk sample using gravimetric techniques, pipetted onto a glass slide and dried at room temperature. XRD traces were then recorded on a Philips X'pert system. The clay fraction analysed was inconsistent with the bulk mineral analysis and is possibly due to the clays being very hard to disperse. An example is kaolinite, which was found to be one of the minerals present for sample PF1 when the bulk mineral analysis was done, but was lacking in the clay fraction analysis. Therefore the results of the clay fraction analysis are felt to be inconclusive and are not further presented here.

Discussion

At the LGM the Plum River valley was probably deeply incised as a response to lower sea level. Sediment was accumulating at the backswamp site at this time, but the material being deposited and the deposition rate were different to the present day. Dates from the clay layer at the base of core 2 are reversed and have much uncertainty surrounding them. These predominantly inorganic sediments originate primarily from the badland area in the headwaters, and the gleyed colour of the unit suggests that it has

been water-logged for some time. Just how sedimentation and a constantly damp environment were maintained is not clear, but it is possible that the fan along the southern margin of the swamp has acted as a barrier to water flow down the river valley. The natural spring at Col de Plum, may also have been more active at this time, especially if tree cover was reduced.

The transition to organic mud within the backswamp may mark the onset of postglacial conditions, but this interpretation of timing has much uncertainty surrounding it given the rather scattered dating results. The increasing amount of organics may be a reflection of warmer and moister conditions, with the primary source of inorganic sediment to the backswamp still originating from the badlands at Col de Plum. The accumulation rate for this lower part of the core is assumed constant based on the dating available so far and the age model adopted.

From around 6000 yr BP the nature of the sediments and the accumulation rate change. The sediment in the backswamp became a peat and the main river channel began to aggrade with a sandy mud as sea level approached its present height, although the origin of the valley fill and the process of aggradation is unknown. There are two bands of sandy clay within core 2, one between 4000 and 3700 yr BP and another between 2400 and 2100 yr BP. These clay bands are found in neighbouring cores and being dominated by goethite the sediments originate primarily from the slopes and fans bordering the river valley and not the badlands in the headwaters. The badlands are permanently susceptible to erosion, whereas the ferralitic soils are stable under natural vegetation cover. Therefore the dominance of goethite in the two clay layers suggests an disturbance and mobilisation of these normally stable soils. Although the cause for this change in sediment source is not known, it is not sustained and cannot be easily correlated to any of the main channel stratigraphy suggesting it may also be a localised feature. The main river channel continued to aggrade over the last 4000 yr BP with no major episodes of incision recorded in the present channel walls.

The alternation between clay and organic mud in the backswamp stratigraphy from 2100 to 1200 yr BP may be recording different freestanding water phases in the swamp or erosional episodes on the slopes. The backswamp surface was accumulating peat again at 1200 yr BP, and this continued on until European arrival. The valley floor, at least

within the vicinity of the present day channel, seems also to have been peat covered for several hundred years prior to European arrival.

The concentration of peat and organic mud toward the back of the swamp, and the edge and fan effects, recorded in the outer cores, are evidence for Plum being a back swamp. The only sediment that might not be part of the back swamp is the inorganic clay at the base of core 2, which is quite unlike any of the overlying deposits. The accumulation of clays, sands and gravels at core sites 3 and 4, instead of peat and organic mud is indicative of their position relative to the main channel (see Figure 4.2) and resembles the present day processes. Only large scale events flowing through the main channel reach the back of the swamp, with the coarse fraction being deposited close to the main channel. Post-mining debris is recorded in the sediments at the back of the swamp as clays with no sand and gravel in the upper most strong brown sediments. Although 1.5 to 2 m of sediment can be attributed to mining activity since 1936, relative to the main channel and bordering floodplain, the backswamp has been only marginally affected by this major disturbance within the river catchment. This was probably the situation in the past as well.

Buried *Araucaria* stumps in the main channel span 4600 to 550 yr BP, indicating that there were once individuals, if not a forest of these trees during the recent past. *Araucaria* is not found in the river valley today, although it is found down around the Baie de Mouea.

In the channel profiles and swamp cores, the European era is markedly different due to the primary source of sediment, Mont Dore mine. These recent sediments contrast with the older sediments in terms of colour, particle size and bedding. Above the tributary junction the main valley is a reflection of pre-mining conditions. It would appear that initially mining waste flowed down the tributary and was deposited as a fan across the valley floor. At some point during the later phase of mining activity incision of the fan and the main valley occurred forming the present day channels. Laganier (1991) reports from monitoring studies of the Ouenghi, a large river catchment in the north of Grande Terre directly affected by mining, that right from the start of prospecting activities an increase in the solid loads of river systems becomes apparent. The most significant movement of materials in these river systems have coincided with major rainfall events

associated with tropical depressions and cyclones. This scenario seems fitting for the ephemeral streams and gullies of the Plum River Valley.

While the channel profiles and swamp cores reflect major stratigraphic change in relation to mining activity on Mont Dore, the impact of New Caledonia's first inhabitants remains less convincing. While the organic mud and clay units post 2100 yr BP may reflect changes in deposition brought about by people; that is, an increasing amount of inorganic material, the overall accumulation rate is not affected.

Summary Points

- i) The deepest parts of Plum Swamp have sediments LGM in age and alternate between peat and organic mud or clay for most of the sequence.
- ii) All channel *exposures* have a valley fill unit 2 - 3 m thick that has accumulated in less than 2000 years. There is at least 2 metres of this unit below the present channel bed and the unit is also found in two of the swamp cores closest to the main channel.
- iii) *Araucaria* stumps and roots from within the valley fill and channel bed span 550 to 4600 yr BP and suggest that accumulation in the river valley was slow enough to allow continued growth.
- iv) The topmost sediments in the backswamp and the main channel below the tributary junction originate from the Mont Dore mine. The reddish brown to strong brown sands and clays overly a peat unit in both the main valley and the backswamp, but are absent from the main valley above the tributary junction.
- v) The environment prior to mining was an unincised peat which probably covered most of the valley floor, just as it does today above the tributary junction.

4.4 Palaeoecology of Plum Swamp

Two cores were collected from Plum Swamp for pollen analysis. These cores also formed part of the stratigraphic study described in the previous section. Plum Centre (core 2) has the longest record in terms of depth and time and is the main focus of the pollen analysis. The second core, Plum Edge (core 1) is a much shorter record and is used to assess whether there is spatial variation in the backswamp fossil pollen.

Methods

Core collection and transport was described in the previous section, and the location of the two cores can be found in Figure 4.2. Samples for pollen and charcoal analysis were sampled and analysed in the following way:

Plum Centre (Core 2)

- 1 cm³ samples were taken for analysis every 10 cm from 0 to 7.5 m.
- Pollen was counted every 10 cm from 1.5 to 4 m, then every 20 cm from 4 m to 7.5 m depth.
- Charcoal was counted every 10 cm from 0 to 7.5 m depth.

Plum Edge (Core 1)

- 1 cm³ samples were taken every 10 cm from 2.0 to 3.4m depth.
- Pollen was counted every 10cm from 2.0 to 3.4 m depth.
- Charcoal was counted every 10 cm from 2.0 to 3.4 m depth.

Processing of the samples followed standard procedures which are set out in Appendix 1. Species abundance curves (number of pollen types vs total pollen counted) were constructed at the outset of counting to establish a target count. Although the point of inflection of the curve routinely occurred after 50 to 100 grains had been counted, the curve never approximated a plateau and the steepness of the curve varied greatly between samples. As a result the somewhat standard arbitrary target of between 200 and 300 terrestrial pollen grains was adopted. Cyperaceae pollen and fern spores were always counted outside the terrestrial pollen sum. *Pandanus* pollen overwhelmed the lower samples and so at least 100 terrestrial taxa were counted for these levels in addition to the *Pandanus*. Carbonised particle counting was based on Clark's (1982) point count method which is outlined in Appendix 1.

In addition to pollen and fern spores, the zygospores of filamentous green algae were also counted. These grow in shallow water or along the littoral zone of lakes and often form associations with certain plants (Hoshaw and McCourt, 1988). Many appear to thrive in extreme habitats and they are most often taken to indicate stagnant, shallow freshwater conditions, although some are found in brackish water. On a global scale

relatively little is known about the ecology of the Zygnematales, and there appears to be no literature at all on the New Caledonian species. Three types of spore were routinely encountered, *Pseudoschizea circula*, *Debarya* and *Zygnema* (Hoshaw and McCourt, 1988; Kuhry, 1988; van Geel, 1996).

Mineral magnetic measurements were carried out to assess whether there had been significant input of sediment from the slopes and fans to the swamp sediments over time, or whether this was a fairly recent phenomenon. Due to the iron rich nature of the soils, saturated isothermal remnant magnetism (SIRM) was considered to be the most effective measurement. Isothermal remnant magnetism is a measure of the magnetism retained after exposure to a steady field at a given temperature (Thompson and Oldfield, 1986). The maximum remnance carrying capacity of a material is the saturated isothermal remnant magnetism. All remnance carrying minerals contribute to the SIRM, but it primarily reflects the ferrimagnetic concentration (Oldfield, 1988). SIRM can range from virtually zero, which are materials devoid of iron and manganese minerals, to greater than $100 \text{ nAm}^2 \text{ kg}^{-1}$.

Materials can be classified into three main groups; diamagnetic, paramagnetic, and ferromagnetic (Thompson and Oldfield, 1986). Diamagnetic materials exhibit weak negative magnetism whilst in a magnetic field and do not retain magnetism once removed from a strong magnetic field. Common diamagnetic minerals include quartz, feldspar and calcite. XRD analysis showed that quartz was abundant in all samples analysed.

Paramagnetic materials exhibit a weak but positive magnetisation whilst in a magnetic field, however, these minerals do not exhibit remnant magnetisation. Examples of paramagnetic minerals include olivine, pyroxene, biotite, carbonates of iron, manganese. XRD analysis showed that siderite (an iron carbonate) was common in the upper clay bands of the swamp.

Ferromagnetic materials, such as iron, are characterised by a strong remnant magnetism. The main natural magnetic minerals are variants of ferromagnets, known as ferrimagnets (e.g. magnetite) and antiferromagnets. Antiferromagnetic materials normally exhibit zero magnetisation, however, *imperfect* antiferromagnets do exhibit magnetisation in the

absence of a magnetic field. Hematite and goethite are examples of imperfect antiferromagnetic minerals (Maher and Thompson, 1992). XRD analysis revealed that goethite was abundant in the soils of the neighbouring slopes.

For Plum Centre, 2 cm slices of a D-section core were taken every 10 cm from 0 to 7.5m, with care taken not to combine different stratigraphic units. Appendix 6 contains the details of the methodology, instrumentation and the calculations used to construct the SIRM curve. Following the magnetic measurements the samples were used to estimate organic content by loss on ignition (LOI). The procedures and calculations are standard and can be found in Appendix 7.

Construction and Description of the Pollen Diagrams

The fossil pollen diagrams are percentage diagrams plotted using the program PSIMPOLL (Bennett, 1997). Two summary pollen diagrams are shown for each core. The total pollen sum includes all pollen and fern spores counted but excludes obligate aquatics. Cyperaceae is not considered an obligate aquatic as it is found in dryland and swamp environments and is therefore included in the total pollen sum. The terrestrial pollen sum excludes all aquatics, including Cyperaceae, and the fern spores. In this way it is the very broad changes occurring on and around the swamp that are depicted by the total pollen sum and the major components of the terrestrial pollen rain that are identified by the terrestrial pollen sum.

The individual pollen curves are based on the terrestrial pollen sum, ensuring that the fern spores and Cyperaceae pollen, which can be over-represented, do not obscure the finer scale changes in terrestrial vegetation. The individual curves are broken down further into taxa which have a value of 5 % or more in at least one sample (Figure 4.8) and taxa that have values of less than 5 % for all samples. The former is considered to carry the bulk of the interpretative information, with the latter mainly contributing to the analysis of species richness and possibly indicating select environments.

Accumulation rates were not selected for presenting the pollen data because a well defined chronology is required to establish sedimentation rates. For this reason charcoal is presented as an area concentration in the form $\text{cm}^2\text{cm}^{-3}$. Accumulation rates are often considered desirable as they make each curve independent removing the effects of

fluctuations in other taxa. The age depth model in Figure 4.6 suggests that even though there are changes in sediment type in Core 2 above 480 cm, the accumulation rate has been fairly consistent averaging out at around 0.6 mm / yr up until this century. However, below 480 cm there is much uncertainty surrounding the dates and although an average sedimentation rate is indicated on Figure 4.6 it is considered to be unsatisfactory for calculating the yearly influx of pollen grains. It should also be noted that the detection of large scale changes will not be dependent on either percentage or accumulation rate data. To verify this an accumulation rate diagram is presented for the taxa with a value of 5 % in at least one sample from 480 cm to 170 cm.

Zonation of the pollen diagrams was carried out using the program PSIMPOLL (Bennett, 1997). Only the terrestrial pollen data were used, with a value of 1% or more in at least one sample required for inclusion. The data underwent square root transformation and the zones were arrived at using binary splitting by sum of squares (Bennett, 1997). This resulted in 2 significantly different zones, labelled zone PC-A and zone PC-B for Plum Centre, and PE-A and PE-B for Plum Edge.

The diagrams are described according to the zones defined by the zonation procedure, with the age ranges accompanying each description inferred from the age depth model of Figure 4.6. The description starts at the base of the core and proceeds upwards, following the accumulation history of the site. The categories plotted in the summary diagrams are the same as those for Chapter 3 and a key is given below in Table 4.4.

Table 4.4: Key to pollen sum categories.
(See Appendix 3 for the lifeform and habitat of commonly occurring taxa.)

Category	Total Pollen Sum	Terrestrial Pollen Sum
Trees		Taxa that are strictly trees
Shrubs		Taxa that are strictly shrubs, though some genera and families may have tree lifeforms.
Trees and Shrubs	All tree and shrub taxa	
Herbs	Herbaceous taxa	Herbaceous taxa
Undifferentiated	Families and genera that encompass a range of lifeforms; trees, shrubs, herbs, lianes and vines	Families and genera that encompass a range of lifeforms; trees, shrubs, herbs, lianes and vines
Unknown Types	Regularly occurring pollen types that have been attributed a number but no name.	Regularly occurring pollen types that have been attributed a number but no name.

Plum Centre

The stratigraphy of the pollen core is presented in a simplified form on the pollen diagrams (see Figure 4.7) and is described below. Accompanying the stratigraphic description are the results of the loss-on-ignition curve and SIRM measurements which can be seen in Figure 4.7.

Table 4.5: Stratigraphic description of Plum Centre core.

Depth cm	Stratigraphic description
0-10	A dark brown root mat underlain by clayey fibrous material. The surface was damp at the time of collection, however the water table was over 1 metre below the surface.
10-66	Below this is a strong brown fibrous clay, the fibrous component being abundant poorly humified sedge stems and roots. There is a colour change to dark brown between 58 and 66 cm. The SIRM measurements are extremely high at around $80 \text{ nAm}^2 \text{ kg}^{-1}$. LOI is low at 10 %.
66-105	There is then a sharp boundary to an underlying black very fibrous peat. LOI values are between 30 and 40 % at the bottom of the unit and decrease toward the top. The converse is seen in the SIRM measurements, which increase toward the top of the unit with increasing inorganic content.
105-150	Beneath the peat there is a sharp boundary to a dark yellowish brown sandy clay. This clay unit contains sedge fibres, minor gravels and creamy white nodules which through XRD analysis were shown to be siderite, an iron carbonate. SIRM is high and LOI low at around 10 %.
150-220	Underlying the clay is a black clayey peat which gradually changes to a black highly humified peat. LOI values go from around 50 % at the top of the unit to around 30 % at the bottom. SIRM is low.
220-273	The peat is underlain by a unit composed mainly of a black organic mud with a dark grey clay layer between 234 and 250 cm. XRD analysis showed this to be dominated by smectite which is only weakly magnetic and hence the absence of any peak in SIRM. There are no SIRM peaks for the organic mud either. LOI values are between 20 - 30 %.
273-286	Underlying the organic mud is a dark greyish brown sandy clay. Although shown through XRD analysis to be dominated by goethite, there is no SIRM peak and LOI is around 15 %.
286-357	This is underlain by a black highly humified peat, with increasing fibres down the core. LOI is mostly high at around 50 %, falling in the upper

	part of the unit to around 20 %. SIRM is low, rising slightly at the top of the unit with the fall in LOI values.
357-387	A very dark greyish brown sandy clay to 379 cm, changing to a dark brown clayey sand with a little gravel to 387 cm. XRD analysis on a sample from 372 - 375 cm showed it to be dominated by goethite and siderite. This results in a large SIRM peak (around $40 \text{ nAm}^2 \text{ kg}^{-1}$).
387-480	Black fibrous peat. LOI values are high at around 50 % and there is a small SIRM peak ($10 \text{ nAm}^2 \text{ kg}^{-1}$) at 450 cm that corresponds to a trough in the LOI measurements.
480-498	A very dark grey organic mud with small occasional fibres. LOI is around 30 % and SIRM is low.
498-508	Very dark grey, slightly silty clay. Unfortunately the LOI sample for the clay band between 498 and 508 cm was lost prior to measurement. SIRM is low. There was no additional material available from this band for XRD analysis.
508-660	A black organic mud with small occasional fibres. There are small scattered pieces of wood below 590 cm and sedge fibres between 624 and 640 cm. The LOI values are around 30 % for the top of the unit, falling to around 15 % for the section that contains the wood fragments, then rising to around 25 % for the section that contains the sedge fibres. SIRM values from the bottom to the top of the unit rise steadily, falling during the high LOI values at the top of the unit. An XRD sample from 552-555 cm in the upper part of the unit revealed that the inorganic fraction is dominated by smectite.
660-770	The basal unit is a grey silty clay which gets less organic and increasingly silty with depth. LOI is around 20 % for the top of the unit and effectively zero for the basal sample. SIRM is low relative to measurements higher up in the core. XRD analysis on a sample from 718-720 cm showed that this unit is dominated by smectite.

While SIRM is referred to as being low for most of the core ($< 5 \text{ nAm}^2 \text{ kg}^{-1}$) this is only relative to the iron rich 1.5 m at the top of the core and the clay band between 350 and 390 cm depth. Thompson and Oldfield (1986) report that the median value for 1000 naturally occurring samples was around $0.58 \text{ nAm}^2 \text{ kg}^{-1}$, suggesting that the overall measurements are high relative to environments outside of this unusual terrain.

Zone PC-A

770-275 cm Inferred Age - approximately 20,000 to 2100 yr BP.

The pollen of zone P-A is dominated by trees and shrubs of lowland forest, in particular *Pandanus*, and there is a vegetation change coincident with charcoal between 16,100 and 12,700 yr BP (Figures 4.7 and 4.8). Figure 4.9 illustrates that the bulk of the taxa that occur at less than 5 % in all samples are found in both zone PC-A and zone B. Of the taxa found exclusively in zone PC-A many are trees, such as, Araliaceae, *Euroshinus*, *Ficus* and *Melastoma*, which are all found in lowland forest. The *Colocasia* Type pollen found in zone PC-A belongs to the family Araceae. Many of these large leaved shrubs occur naturally in closed damp forest. Zone PC-A was subdivided on the basis of significant stratigraphic breaks and poor pollen preservation into Zones PC-A1, PC-A2, PC-A3 and PC-A4.

Sub-zone PC-A1

770 – 660 cm Inferred Age - approximately 20,000 to 16,100 yr BP.

PC-A1 is defined by its unique stratigraphy relative to the rest of the core. The sedimentation rate for this lowest unit appears slow and based on Figure 4.6 was possibly less than 0.15 mm/yr. There are charcoal fragments in this zone, and although their concentration is extremely low, they are an indication that fire is not entirely absent from the environment (Figure 4.7).

The *total* pollen sum (Figure 4.7) is dominated by tree and shrub taxa which begin to decline with the corresponding increase in Cyperaceae and unknown pollen types toward the top of the zone. The *terrestrial* pollen sum (Figure 4.7) reveals that some of the highest percentages of tree pollen taxa occur in this zone, while the palynological richness values are average in relation to rest of core (Figure 4.7). Major tree taxa include *Apodytes clusiifolia*, *Pandanus* and *Nothofagus* (Figure 4.8). The *Pandanus* pollen has been assigned the name *P. krauelianis* Type, in the absence of a *Pandanus* pollen reference material from New Caledonia. However, this species is not found in New Caledonia. Values of 40 - 50 % for *Pandanus*, and the littoral nature of the genus in general, suggests that the pollen source is local, probably growing on the margin or surface of the site. From the modern pollen rain work, the *Nothofagus* percentages suggest that the source is not growing locally and that this is possibly a regional component of the pollen rain. Casuarinaceae pollen percentages of 10 – 20 % in the

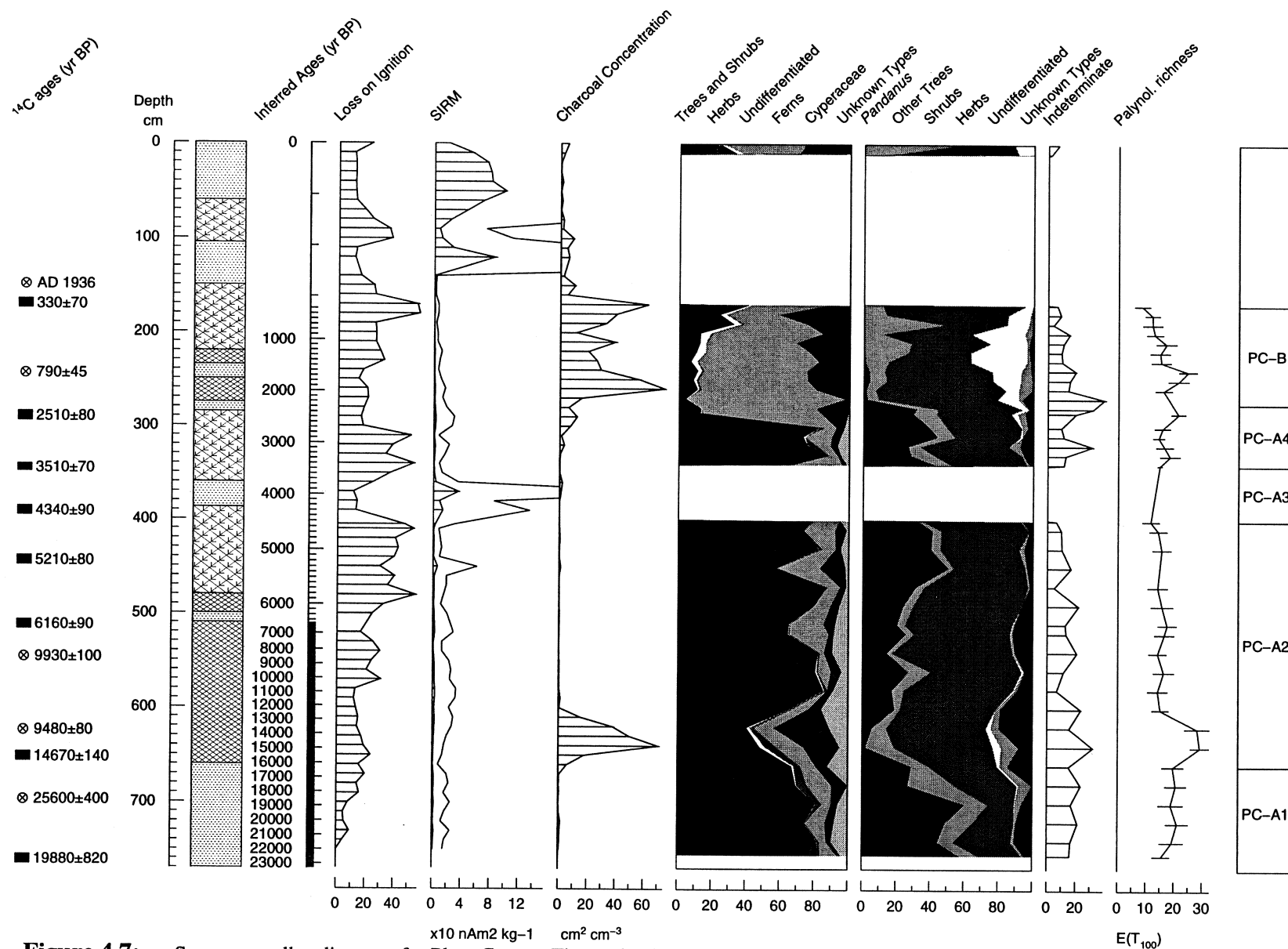


Figure 4.7: Summary pollen diagrams for Plum Centre. The total pollen sum is presented first followed by the terrestrial pollen sum. The diagram also includes SIRM, LOI and charcoal concentration.

Plum Centre

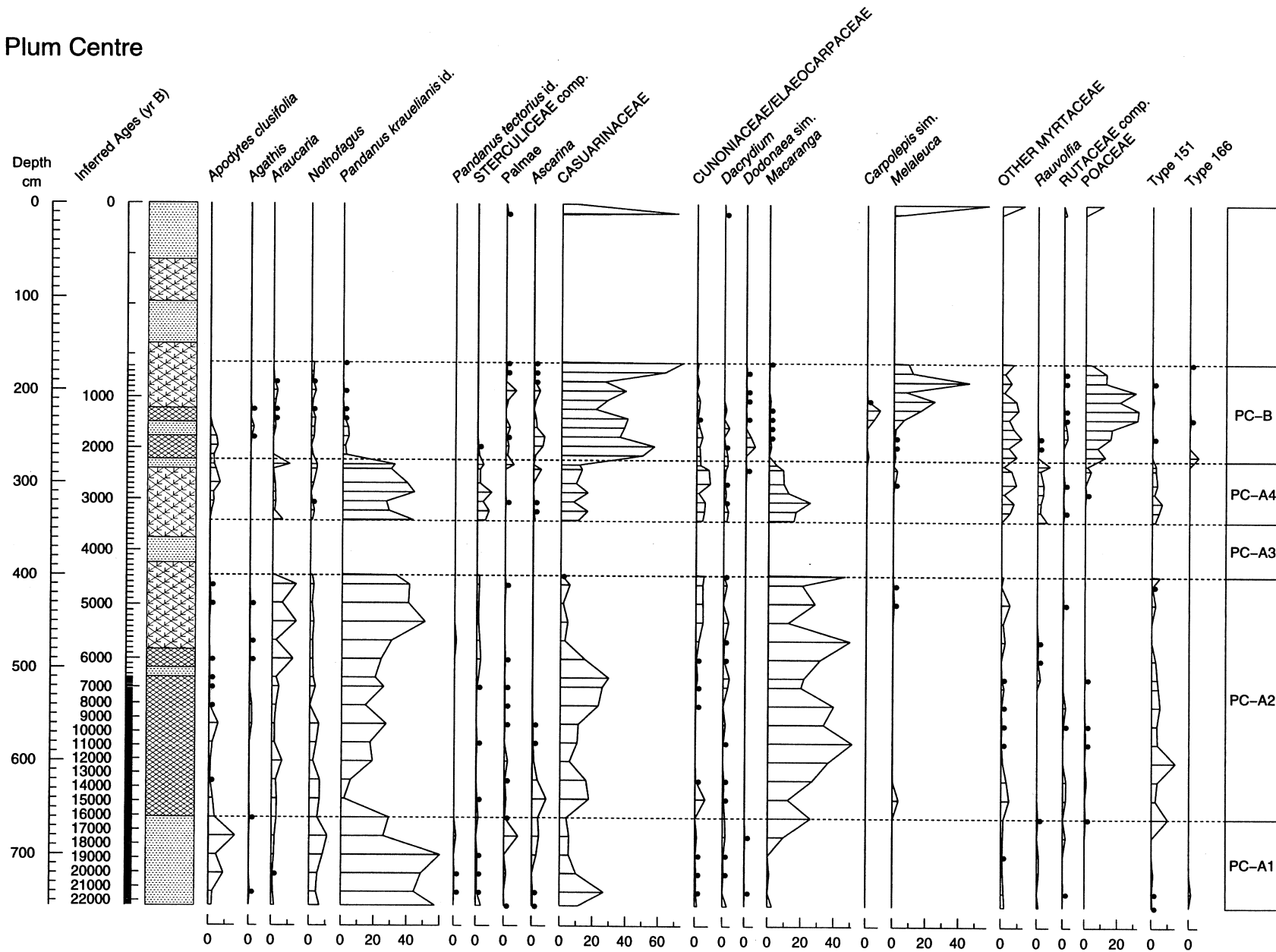


Figure 4.8: Individual pollen curves for Plum Centre. Shown are all taxa that have a value of 5% in at least one sample. Dots indicate presence of taxon at a value of <1%.

Figure 4.9: Terrestrial pollen taxa for Plum Centre core with values of less than 5 % in all samples. Dots indicate presence of taxon at a value < 1 %. Diagram is arranged from left to right; taxa found only in Zone A, taxa found in both Zone A and Zone B, taxa only found in Zone B.

Plum Centre

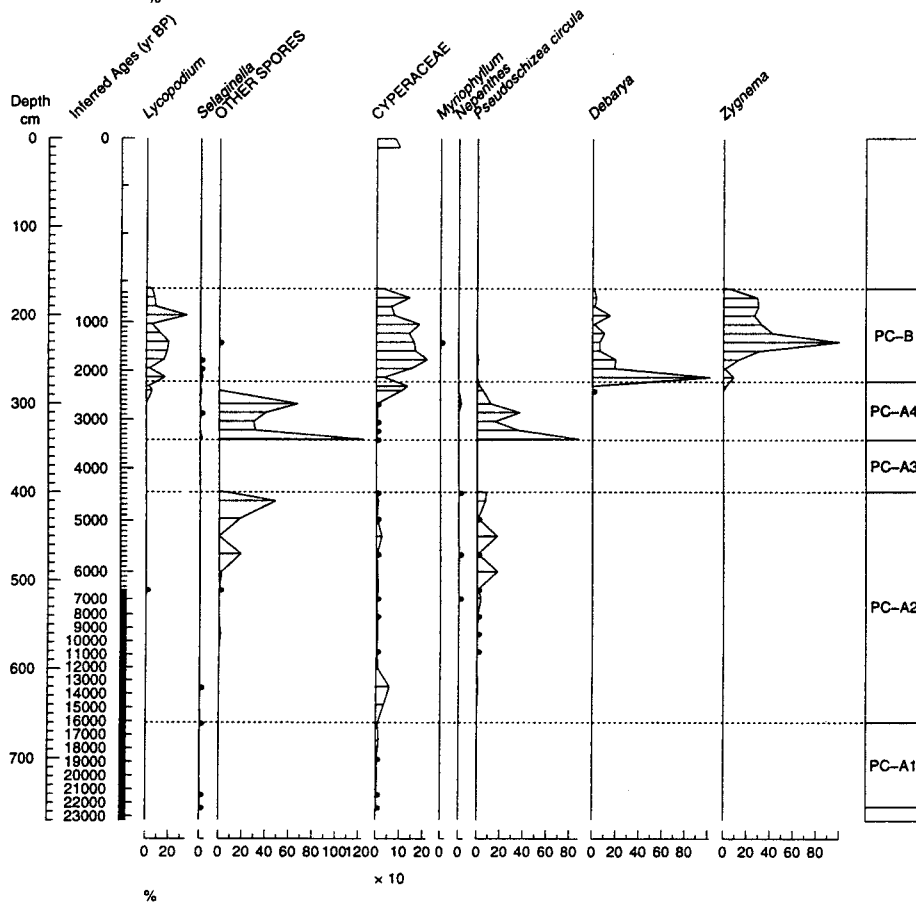
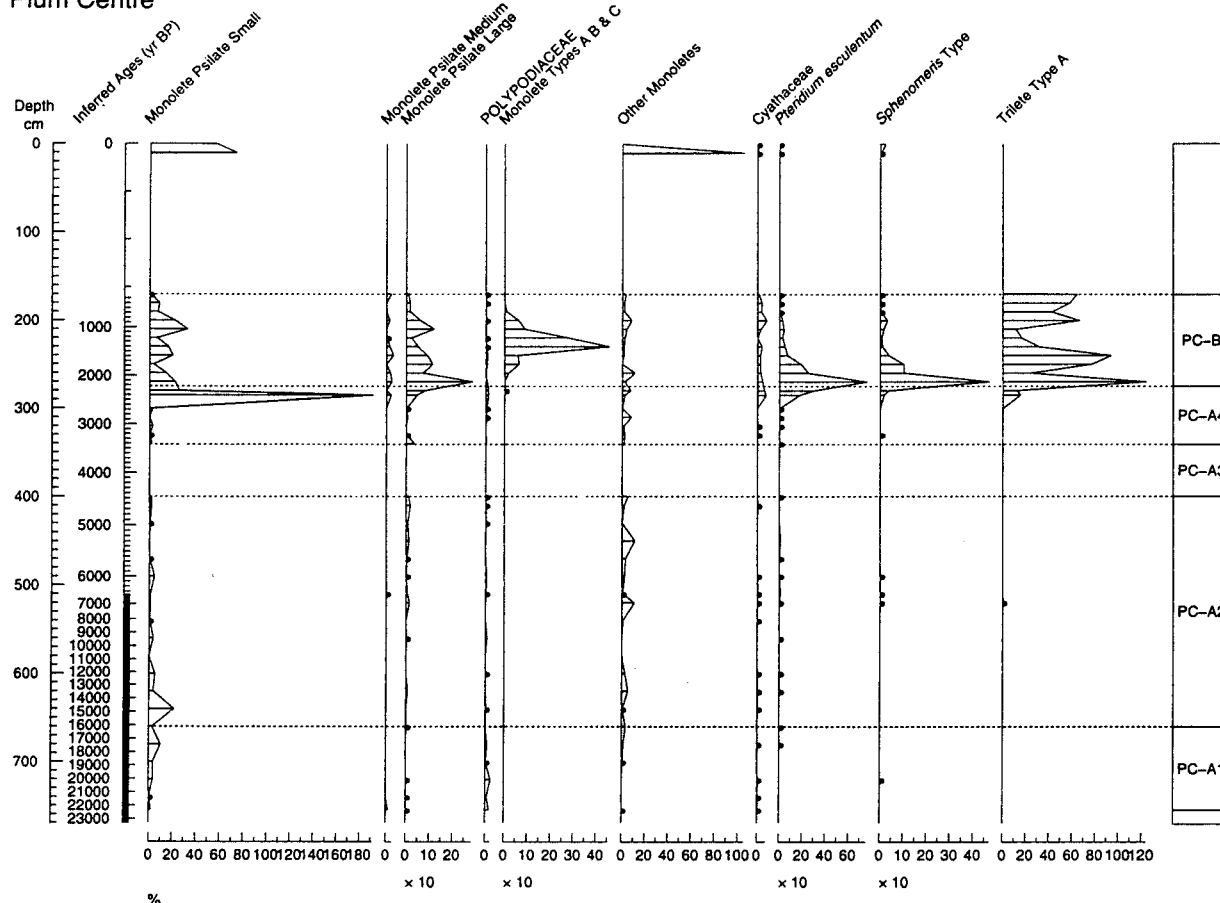


Figure 4.10: Fern and other spore taxa for Plum Centre. Note that some axes are x10.

bottom of zone PC-A1 probably have a regional source also. *Araucaria* pollen is represented at less than 5% (Figure 4.8), but with no modern analogues from the modern pollen rain study, evaluating its proximity to site is difficult. *Pandanus* pollen begins to decline after 700 cm (18,750 yr BP), in conjunction with the increase in *Palmae*, *Ascarina* and *Macaranga* (Figure 4.8). There are only two species of *Ascarina* on New Caledonia, both are found as either shrubs or small trees on a variety of terrain in wet evergreen forest or maquis, and usually between 150 - 1500 m asl. The highest values of *Apodytes clusiifolia* also coincides with this decline in *Pandanus*. This is an endemic rainforest tree growing from 8-25 m in height depending on substrate and altitude. It is found on a variety of substrates from 0-1000 m asl and is noted as being one of the principal species of rainforest above 750 m altitude (Cherrier, 1982; Villiers, 1980). *Macaranga alchorneoides* is a principal species of lowland rainforest found in the valleys of the ultramafic terrain (Cherrier, 1982). Identification can only be made to genus level at this stage for the Plum samples. Fern spores are low to absent throughout zone PC-A1 (Figure 4.10).

sub-zone PC-A2

660 – 400 cm Inferred Age 16,100 – 4400 yr BP.

The most significant change within zone PC-A2 is the charcoal peak and corresponding vegetation change between 660 and 610 cm (16,100 - 12,700 yr BP) (Figure 4.7). Curiously, charcoal enters the record in significant amounts with the change in sediment type at 660 cm, that is once the organic mud starts to accumulate. However, whether there is any direct link between these two factors is not clear.

The highest values of Cyperaceae pollen and the lowest values of tree and shrub pollen coincide with the peak in charcoal values at 640 cm (Figure 4.7). Sedge fibres in the stratigraphy between 624 and 640 cm suggest that Cyperaceae may have been on the surface of the site.

The *terrestrial* pollen sum reveals that it is those pollen types that can be positively identified as tree pollen that are decreasing in abundance during this period of disturbance, while the more ambiguous category of trees and shrubs increases (Figure 4.7). Some of the largest percentages of unknown types and indeterminate taxa are also recorded during this period in zone PC-A2. The major tree pollen taxa that decrease

with the peak of charcoal are *Apodytes* and *Pandanus* (Figure 4.8), while the tree and shrub taxa that increase significantly during this period are *Ascarina*, Casuarinaceae, Cunoniaceae, *Melaleuca* and the Myrtaceae in general. As an emergent of rainforests, *Apodytes* pollen is taken to represent pollen rain from the forest canopy, and its decline suggests that fire had an impact on more than just the local vegetation. *Macaranga* pollen which entered the record in zone PC-A1 decreases with the peak in charcoal. Very small amounts of Poaceae (grass), and the highest percentages of Asteraceae and *Trema* pollen (Figure 4.8 and 4.9) also occur. All are good indicators of disturbance and more open habitats.

The *terrestrial* pollen sum diagram (Figure 4.7) shows that following the charcoal peak, tree pollen remains low and only starts to attain its previous levels toward the top of zone PC-A2 at around 450 cm (5300 yr BP). The major tree pollen taxa contributing to this increase in the upper part of zone PC-A2 are *Araucaria* and *Pandanus* (Figure 4.8). The tree and shrub pollen in the upper part of zone PC-A2, following the charcoal peak, is dominated by Casuarinaceae and *Macaranga* pollen, with the two curves the inverse of each other. The percentages of Casuarinaceae pollen decrease dramatically once peat starts to accumulate at the site at around 5700 yr BP. The modern pollen rain study suggests that the levels of Casuarinaceae pollen recorded throughout zone PC-A2 indicate a regional or extra-local source.

Above 550 cm (around 8750 yr BP) there is a slight increase in fern spore counts (Figure 4.7), predominantly monolete fern spores (Figure 4.10). In Figure 4.10 the 'OTHER SPORES' category in the top right of the diagram refers to a small, round, highly decorated spore which could not be identified. Its source is likely to be a plant growing on the site surface as its highest values are associated with peat accumulation in zones PC-A2 and PC-A4. Of the Zygnemataceae, *Pseudoschizea circula* is the only one present in zone PC-A2 with its highest values recorded in the upper part of the zone (Figure 4.10).

The highest values of palynological richness in zone PC-A2 coincide with the charcoal peak and are associated with a large number of unknown pollen types (Figure 4.7). In the upper part of zone PC-A2 the palynological richness values resume levels similar to those recorded from before the charcoal peak.

sub-zone PC-A3

400 – 340 cm Inferred Age 4400 – 3250 yr BP.

The zone is defined by poorly preserved pollen and spores. There is a bias toward the partial preservation of robust pollen types, such as Casuarinaceae and trilete fern spores, with a further bias introduced by these grains being easily distinguished even when poorly preserved, whereas other pollen types are not. Therefore the results for this section are not included in the palaeovegetation analysis. Charcoal is low to absent throughout this zone. Of the Zygnemataceae only the *Pseudoschizea circular* was identified.

sub-zone PC-A4

340 - 275cm Inferred Age 3250 – 2100 yr BP.

The remaining 55 cm of humified black peat has good pollen preservation and the *terrestrial* pollen sum diagram for zone PC-A4 looks much the same as zone PC-A2. Changes in the major tree pollen taxa include increased values of *Apodytes* pollen and a decrease in *Araucaria* pollen, while *Pandanus* percentages remain high (Figure 4.8). These changes are also seen in the accumulation rate diagram for the upper part of the core in Figure 4.12. Of the tree and shrub taxa Casuarinaceae pollen increases, although it's probable that the values still represent an extra-local or regional signal and in general are lower than zone PC-A2. Myrtaceae pollen other than *Melaleuca* enters the record in significant amounts and *Macaranga* pollen decreases in the upper part of zone PC-A4. *Rauvolfia* can be a tree or shrub of primary or secondary forest, but prefers constantly damp soil and is often found along river banks and in open places. It's highest values are in zone PC-A4 (Figure 4.8).

Charcoal is low at the bottom of zone PC-A4, but begins to rise in the top of the section at around 300 cm (2700 yr BP). The *total* pollen sum diagram indicates that this coincides with a dramatic increase in fern spores, plus an increase in Cyperaceae pollen. All of the ferns increase in the top of zone PC-A4 and their composition can be seen in detail in Figure 4.10. The same change is not illustrated in the *terrestrial* pollen sum and the individual pollen curves show that on the whole pollen deposition from terrestrial tree and shrub taxa is relatively unchanged at this point (Figure 4.7 and 4.8). However, herbaceous taxa such as Poaceae and Asteraceae pollen begin to increase along with the ferns (Figures 4.8 and 4.9). It is worth remembering that it is the

terrestrial pollen sum that has been used to define the zones.

The highly ornate spore thought to be associated with peat accumulation is very high in the base of zone PC-A4, but decreases to zero with the increase in charcoal and fern spores. Of the Zygnematales, *Pseudoschizea circula* has its highest values at the base of zone PC-A4, decreasing toward the top of the zone, with *Debarya* and *Zygnema* spores seen in small amounts at the top of the zone (Figure 4.10). All of these factors taken together suggest that the site surface is undergoing change.

Zone PC-B

275 – 150 cm Inferred Age 2100 yr BP. – AD 1936

Zone PC-B stands out with its sharp rise in charcoal, which remains high up into this century, and the dramatic changes in the pollen and spore ratios (Figure 4.7). The first big charcoal peak at 260 cm (1900 yr BP) corresponds with the lowest values of tree and shrub pollen and the highest values of fern spores in the record. The *terrestrial* pollen sum in zone PC-B is dominated by the shrub category and the herbaceous taxa, primarily grass (Poaceae). Significant changes in individual pollen types that occur across the PC-A and PC-B boundary include an abrupt decline in *Pandanus* pollen and the abrupt increase in Casuarinaceae and grass pollen (Figure 4.8).

Other significant changes in zone PC-B include the disappearance of *Apodytes* pollen and a significant increase in *Melaleuca* after 1500 yr BP (Figure 4.8). The Myrtaceae pollen values of zone PC-A4 are maintained in zone PC-B. *Nothofagus* pollen appears to remain at a regional pollen rain scale. Of interest is the small but continued input of *Araucaria* pollen up until around 700 yr BP, remembering that there is evidence of *Araucaria* tree stumps buried in the main valley channel. A number of the rarer types found exclusively in zone PC-B are indicative of an open shrubby environment. In particular *Longetia buxoides*, *Soulamea* Type, *Glochidion* and *Grevillea* (Figure 4.9).

Palynological richness is high for zone PC-B, just as it was for the disturbance between 16,100 and 12,700 yr BP in zone PC-A2 (Figure 4.7). It declines after 190cm (700 yr BP) as the record becomes dominated by *Melaleuca* and Casuarinaceae pollen. The values of both these taxa appear to indicate a local presence throughout zone PC-B (Figure 4.8).

Cyperaceae pollen and fern spores dominate the total pollen sum of zone PC-B (Figure 4.10). The source of Cyperaceae is likely to be the surface of the site and the ferns predominantly from the edge. *Debarya* and *Zygnema* dominate the Zygnemataceae of zone PC-B, *Zygnema* outnumbering *Debarya* from 235 cm. The upper 20 cm of peat has poorly preserved pollen in low concentration and so the pollen record ends at 170 cm (300 yr BP).

The concentration of charcoal in zone PC-B has the appearance of being comparable to the charcoal in found in the lower part of zone PC-A2. It is for this reason that the accumulation rate of charcoal has been calculated for the core using the average sedimentation rates for the upper and lower parts of the core. Figure 4.11 illustrates the difference between these two periods when fire appears to have been prevalent. The different magnitude curves could reflect many things; proximity to site, intensity or return interval. While none of these parameters can be quantitatively estimated it is apparent that post 2300 yr BP a greater amount of charcoal was deposited into the site and fires from this time onward had a much greater impact on the vegetation of the valley.

Figure 4.12 illustrates the changes in pollen accumulation for selected taxa across the PC-A and PC-B boundary. The same overall change is still present, that is the shift from a record dominated by *Pandanus*, *Macaranga* and *Casuarina* to one dominated by *Casuarina*, *Melaleuca*, grass, ferns and Cyperaceae. However, the abrupt change seen in the percentage diagrams is not seen in the accumulation rate diagram (Figure 4.12). Instead the sandy clay layer has very low concentrations of pollen and it is around 500 years before total accumulation rates once again exceed 5,000 grains cm⁻² yr⁻¹. Throughout the period of low pollen accumulation however, the highest accumulation rates for *Pteridium* are recorded at almost 1000 grains cm⁻² yr⁻¹. While the accumulation rate for terrestrial pollen appears low throughout this period, the total pollen accumulation rate is keeping with zone PC-A4 and the upper part of zone PC-A2 (Figure 4.12). The accumulation rates of both pollen sums increase after 250 cm, around 1000 yr BP *Apodytes* is gone by 1600 yr BP and *Araucaria* by 700 yr BP. Conversely *Nothofagus* is constant and low throughout this part of the record, in keeping with it being part of the regional pollen rain.

Plum Centre

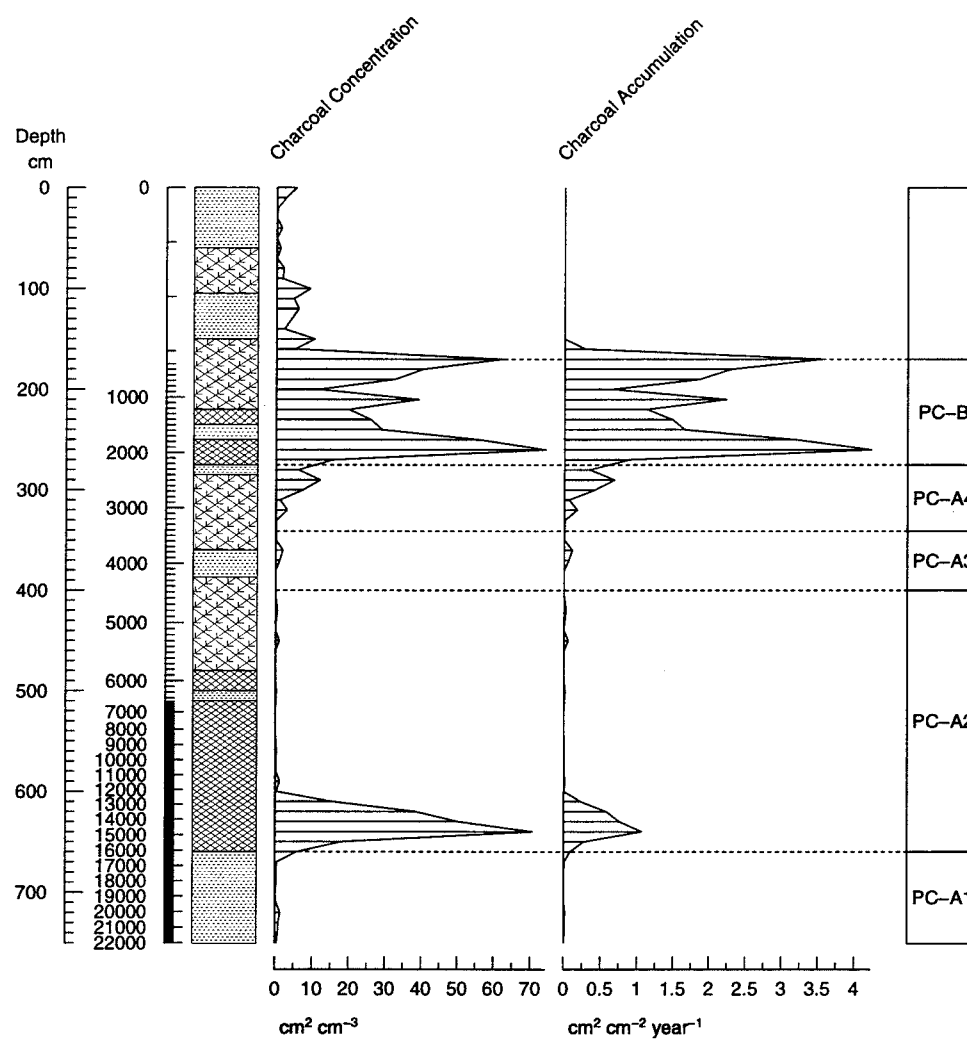


Figure 4.11: A comparison of the concentration and accumulation rate curves for charcoal in the Plum Centre core.

Plum Centre

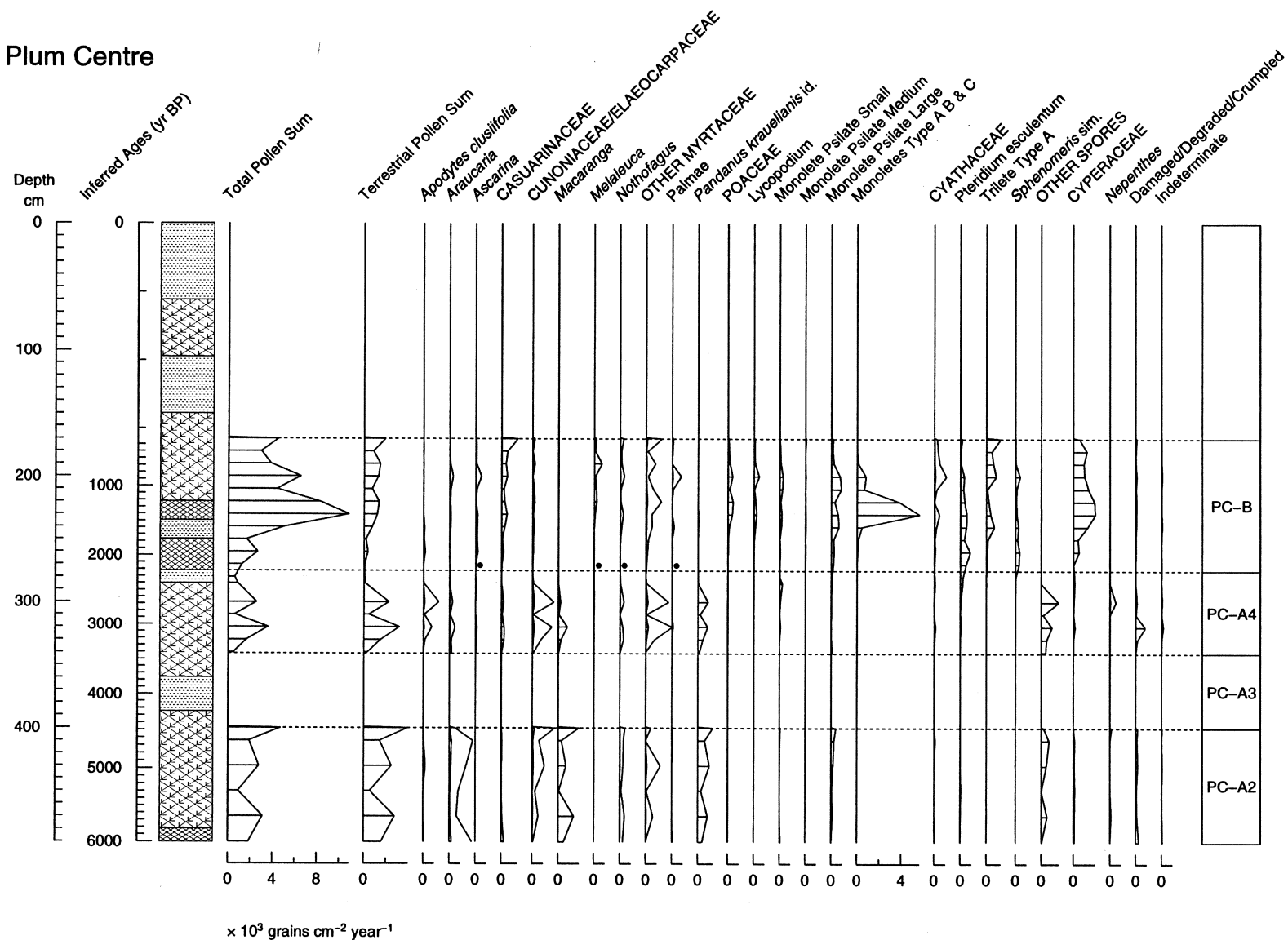


Figure 4.12: Accumulation rate diagram for selected taxa from upper part of Plum Centre core. Hollow graphs = x10 exaggeration.

150 – 0 cm AD 1936 to present

In Section 4.3 this upper part of the core was interpreted as mining spoil deposited via the Mont Dore mine tributary. The average accumulation rate is high at around 25 mm/yr, so while the charcoal concentration is low the rate of deposition is so high in this upper part of the core that it cannot be sensibly compared with the previous levels and does not indicate less fire in the environment. The conversion of the concentration values to accumulation rates for this section of the core leads to them exceeding by orders of magnitude the previous charcoal values. Pollen was not counted for this upper section given its extremely low concentration. The two uppermost pollen samples are surface samples collected from the edge of the swamp and originally presented in Chapter 3. The relative values of the dominant taxa resemble those of around 500 yr BP, suggesting that the vegetation of the river valley has changed little since that time.

Plum Edge

Taken from the edge of Plum Swamp this is a much shorter core spanning only the last 3300 yrs. Pollen preservation is quite poor for many of the samples and several, although counted, have not been included in the analysis. The general patterns seen in the pollen diagrams of Plum Centre for this age range are also seen here. Zonation using the terrestrial pollen data was carried out and once again two significant zones were defined. Zone PE-A, 340 to 265 cm, and zone PE-B, 265 to 220 cm (Figure 4.13).

The stratigraphy of Plum Edge varies slightly from Plum Centre. From 380 to 340 there is a dark yellowish brown sandy clay overlain by a 3 cm band of black peat which in turn is overlain by a 10 cm band of dark brown slightly sandy clay. There are large pieces of wood scattered throughout this section with occasional sub-angular gravels of around 10 mm. This correlates with the start of peat accumulation at around 360 cm in Plum Centre. From 328 to 220 cm is a black organic mud with a 2 cm dark yellowish brown clay band between 229 and 231 cm. The organic mud above this changes gradually to a highly humified peat and from 168 to 115 cm is a the dark yellowish brown clay with minor gravels and siderite nodules interpreted as mining spoil. The top 5 cm of sediment from 115 to 100 cm is a strong brown to very fibrous clay. Above this, at the time of collection in 1991, was a metre of water and plant material and a floating root mat of around 26 cm. Six radiocarbon dates were obtained for the core,

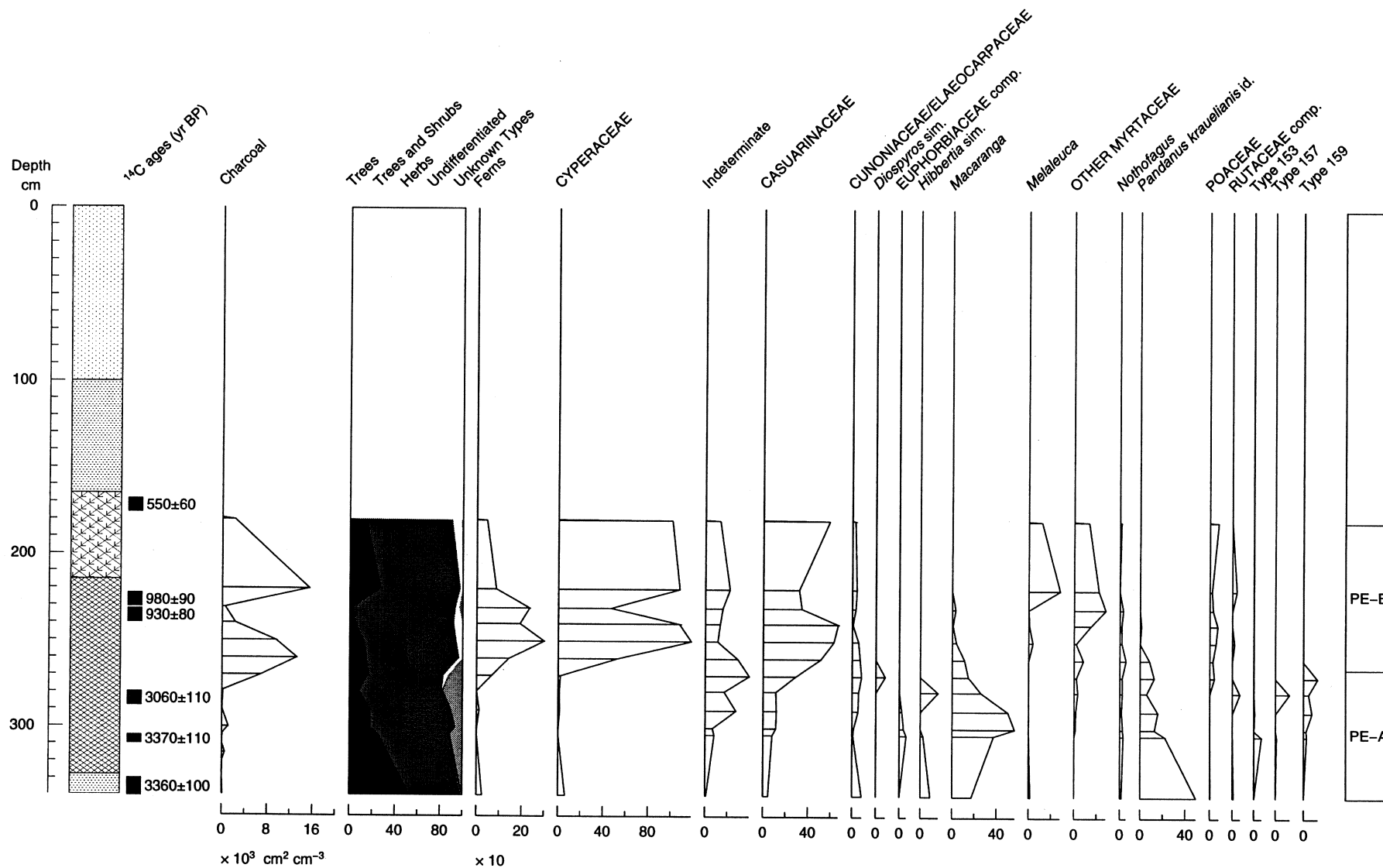


Figure 4.13: Summary pollen diagram for Plum Edge. The pollen sum shown is the terrestrial pollen sum. The individual pollen curves are all taxa that have a value of 5% in at least one sample. The diagram also shows charcoal concentration.

Plum Edge

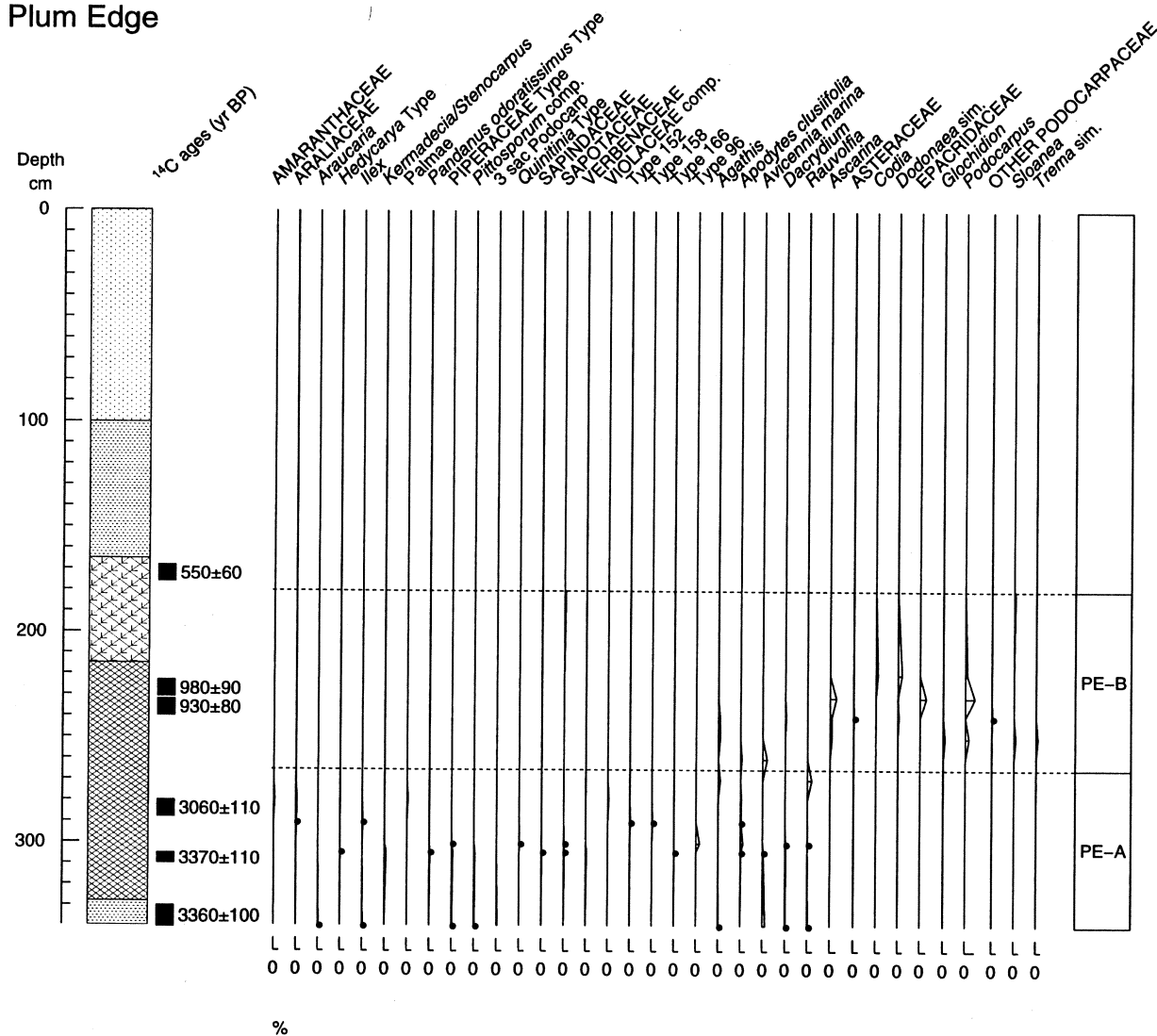


Figure 4.14: Terrestrial pollen taxa for Plum Edge core with values of less than 5 % in all samples. Dots indicate presence of taxon at a value < 1 %. Diagram is arranged from left to right; taxa found only in Zone A, taxa found in both Zone A and Zone B, taxa only found in Zone B.

Plum Edge

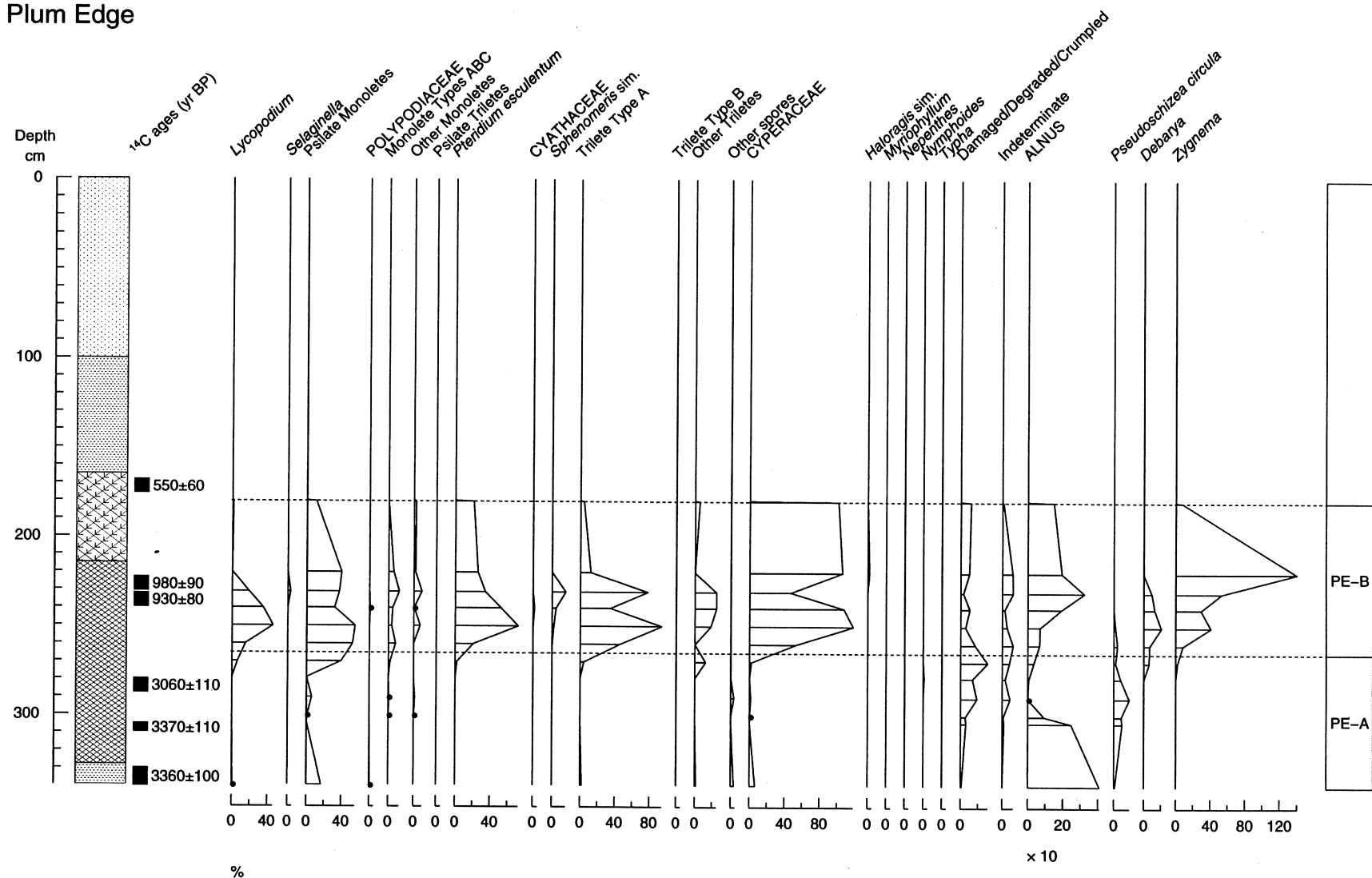


Figure 4.15: Fern and other spore taxa for Plum Edge core.

with a linear age depth model inferring an age of around 2200 yr BP for the boundary between zones PE-A and PE-B.

Charcoal is present in low concentrations in the bottom section of zone PE-A, increasing significantly just before zone PE-B (Figure 4.13). This is in keeping with the changes in charcoal seen for this time period in Plum Centre. The broad changes in pollen composition seen across the PC-A and PC-B boundary in Plum Centre are also seen here. *Pandanus krauelianis* Type and *Macaranga* pollen dominate zone PE-A and disappear in zone PE-B. Casuarinaceae, *Melaleuca* and other Myrtaceae pollen dominate zone PE-B. Poaceae pollen in the Plum Edge core never approaches the values found in the Plum Centre core, but nevertheless grass pollen is most abundant in zone PE-B. A significant number of pollen types are only found in zone PE-A, but the pollen counts are too low for estimates of palynological richness to be done.

Like Plum Centre ferns increase significantly with the first large peak of charcoal at the top of zone PE-A (Figure 4.13 and 4.15). The highest values of damaged and crumpled grains also appear in this sample, suggestive of some reworking, although there is no suggestion in the stratigraphy of any dramatic change in sediment type. Zygospores of the Zygnemataceae follow the same pattern as the Plum Centre core, with *Pseudoschizea* most abundant in zone PE-A and *Debarya* and *Zygnema* most abundant in zone PE-B (Figure 4.15). *Zygnema* dominates the upper most samples.

Principal Components Analysis

An ordination of the Plum Centre samples and the modern pollen rain samples was carried out to assess the similarities between the core samples and the modern pollen analogues. This was undertaken using principal components analysis (PCA) within the program PSIMPOLL (Bennett, 1997).

Ordination is an attempt to find the best fitting two dimensional plane through a high dimensional species space, with the resulting map usually presented in either 2D or 3D form (Clarke and Warwick, 1994). It attempts to reflect the similarity of communities by defining them in meaningful spatial patterns. That is, nearby points have similar communities, and points far apart have few species in common or the same species at different levels of abundance (Clarke and Warwick, 1994). This aspect of PCA is

conceptually simple and one of its strengths. The aim for the Plum data was to summarise the information contained in the fairly complex and detailed pollen diagrams and present the relationship between samples in a format that is easier to interpret.

The methodology involved merging the two data sets, excluding all aquatics and ferns and reducing the terrestrial taxa to only those with a value of 5% or more in at least one sample. This resulted in a data set of 38 pollen types and 64 samples. The PCA is based on a covariance matrix of the pollen taxa, where the percentage data has been square-root transformed to reduce the influence of over-represented taxa, especially the wind pollinated species such as Casuarinaceae. The result of the PCA is a table of eigenvalues, with those axes considered to be interpretable highlighted (Table 4.6).

Often the first and second axes may explain no more than 40 - 50 % of the total variation in a data set. Clarke and Warwick (1994) believe that for many PCA's presentation of only these first two axes may result in an inadequate and potentially misleading picture of the relationship between samples, but suggest that 70 - 75 % probably describes the overall structure rather well. The result of the PCA on the Plum Centre samples and the modern pollen rain samples leads to the first and second axes explaining 48% of the variation in the data set (Table 4.4). With the inclusion of the third axis 60 % is explained. Because no analyses are being undertaken on the axes, only the first two, PC1 and PC2, have been mapped to illustrate the relationships between samples (Figure 4.16).

Table 4.6: Eigenvalues from Principal Components Analysis - single iteration.

	Value	Proportion Explained	Cumulative Proportion
PC1	0.171102	0.326162*	0.33
PC2	0.083485	0.159142*	0.50
PC3	0.059782	0.113959*	0.60
PC4	0.044861	0.085515*	0.70
PC5	0.029622	0.056466*	0.74
PC6	0.020497	0.039072	0.78

NB: * = Interpretable axes

The different zones described earlier for Plum Centre have been attributed their own symbol, as have the modern pollen rain samples (Figure 4.16). The vectors for selected pollen taxa exhibiting the most influence over the different quadrants are also plotted.

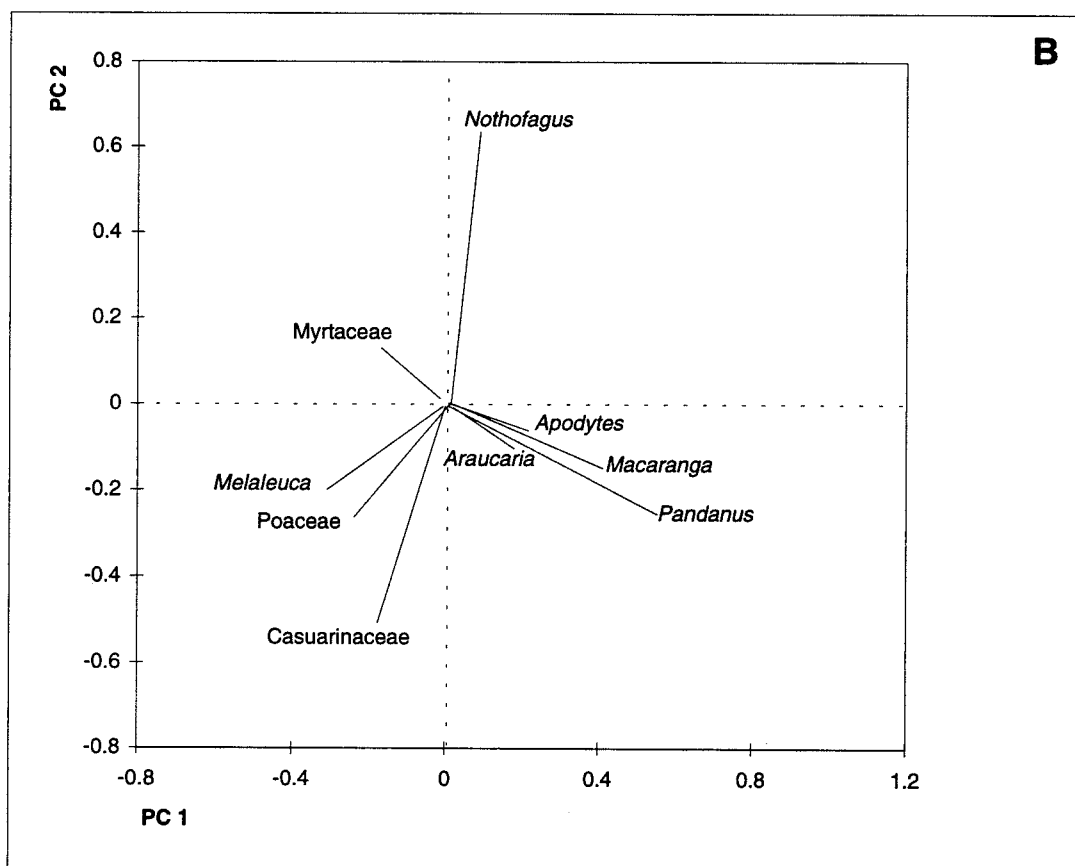
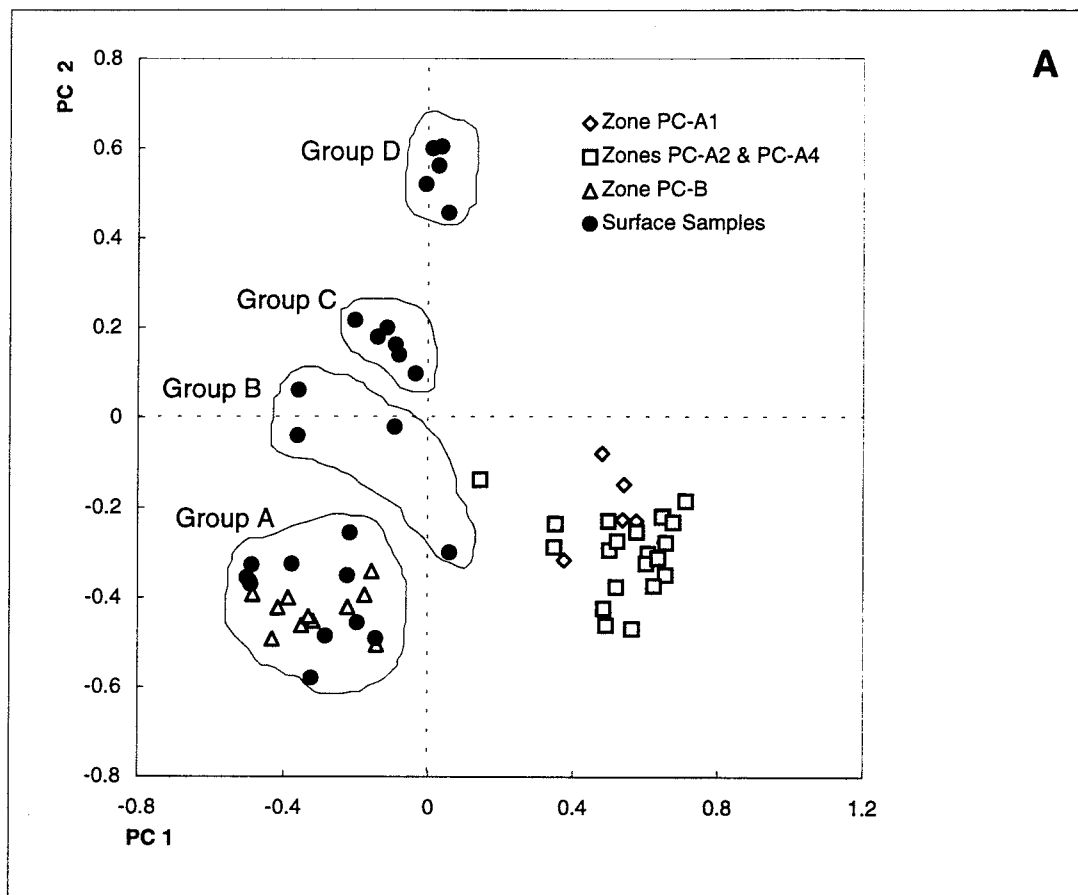


Figure 4.16: PCA bi-plots of Plum Centre fossil samples and modern pollen rain data. A) Fossil and modern samples B) Pollen taxa.

In Figure 4.16 it can be seen that all the zone PC-A samples cluster closely together, except for the zone PC-A2 sample associated with the charcoal peak and disturbance at around 640cm. The clustering of the zone PC-A samples is influenced most by their values of *Macaranga* and *Pandanus* pollen. There is only one surface sample that appears near the zone PC-A fossil samples, and that is a sample from Plaine des Lacs, which had high values of *Podocarpus* pollen. In Chapter 3 this sample was clustered within the Group B modern pollen rain samples.

The PC-B taxa cluster in the same quadrant as the Group A and Group B surface samples. This association is to be expected as most of the Group A and Group B surface samples were collected from coastal swamp situations. Those that aren't from this type of environment, but have their pollen dominated by *Melaleuca* or Casuarinaceae pollen, have separated out. The taxa that exert most influence over the clustering in this quadrant are Casuarinaceae, Poaceae and *Melaleuca* and the map is suggestive that the modern analogues of pollen rain for the region have a time depth of around 2200 yr BP. The zone PC-A samples are older than 2200 yr BP and bear no resemblance to any of the modern analogues. In addition the *Nothofagus* forest surface samples bear no resemblance to any of the Plum Centre samples.

Discussion

The clay unit which defines zone PC-A1 is LGM in origin. The pollen is suggestive of a coastal forest and the pollen rain contains rainforest elements (for example *Apodytes clusiifolia*). The site itself appears to be surrounded by *Pandanus*, and while it is possible for some *Pandanus* to grow in shallow water or constantly waterlogged conditions, there is no further evidence in the sediments to support or refute this.

The sample at around 17,500 yr BP may be indicative of shallower water conditions at the site with the decrease in *Pandanus* pollen and the increase in *Macaranga* pollen. *Macaranga*, while a principal element of lowland primary forest on ultramafic terrain, it is also common species in disturbed environments. The increase in other forest types, for example *Apodytes* and *Ascarina* pollen, may also be indicative of this. *Apodytes* is not restricted by substrate and is found from sea level to 1000 m, suggesting that it is very adaptable and possibly opportunistic.

Fire appears to have some longevity in the landscape generally, as small numbers of particles are found throughout the basal clay unit. Whether the charcoal is from fires within the Plum River Valley or further afield cannot be determined at such low concentrations. The clay sediments being washed in may also constitute a constant input of charcoal particles from a quite infrequently burnt catchment. However, Hope and Pask (1998) have evidence of fire well before the LGM on the Plaine des Lacs.

The pollen spectra of zone PC-A2 clearly indicates disturbance associated with fire at the onset of organic mud accumulation at around 16,100 yr BP. The impact that these early fires may have had on lowland rainforest vegetation is hard to assess. While *Pandanus* appears to resume its dominance around the site quite quickly, it is not until 5300 yr BP that the percentage values for the taxon reach their pre-disturbance levels. With the decline of *Apodytes* pollen there is a significant increase in *Araucaria* pollen, which may be indicative of a change in the forest emergents within the Plum River valley. However, there is no way of determining just how distant the sources of these trees may be. In general, the coarse interval of the pollen samples and the large uncertainties surrounding the dates make it difficult to draw any meaningful conclusions about the changing environment from the basal units. However, the contemporary landscape elements that we associate with regular burning on this dry leeward side of Grande Terre, *Melaleuca* and grass do not take hold in this earlier period. Neither do *Pteridium* or Casuarinaceae which are the classic indicators of disturbance on ultramafic terrain. It is possible that fire was not sufficient either in return interval or intensity to allow any of these elements to take over.

The replacement of organic mud with the accumulation of peat at around 480 cm (5700 yr BP) marks the start of more accurate age determinations.

Disturbance of some sort is indicated by zone PC-A3 and the 30 cm of sandy clay with poorly preserved pollen. This layer, which may represent a single episode, is not associated with fire, as only small background concentrations of charcoal were counted for the clay and the peat either side. The poor pollen preservation in the peat above the sandy clay unit may be indicative of ongoing environmental disturbance, possibly extreme drying episodes intermittent with moister conditions that allow the accumulation of peat. The record for Plum Edge commences around this time and the

lower most samples from zone PE-A are also characterised by low pollen concentrations and poor pollen preservation. However, by 3250 yr BP conditions at Plum Swamp are such that pollen is once again preserved and the pollen on the whole is similar in composition to that from before the barren zone.

This is also the point in the record when conditions become most favourable for algal growth. Algal growth often appears to be limited in the shallow lakes and swamps of ultramafic basins, possibly because of a lack of nutrients. *Pseudoschizea circula* is the only type seen before the human impact boundary, and is most abundant after the barren phase. This may indicate a more nutrient rich environment after the inwashing of clays from the slopes and the breakdown of organics during the subsequent drying phases.

Changes in the concentration of charcoal, ground cover and site cover start by 2500 yr BP, and at the top of zone PC-A4 is a 10 cm pollen poor sandy clay band. All of these changes were taking place after the colonisation of the island by people, as defined by the archaeological record.

Zones PC-B and PE-B clearly define a period of dramatic vegetation change within the valley. *Pandanus* is effectively removed from around the site and the dramatic change in the littoral forest vegetation of the valley is exemplified by *Macaranga*, which along with *Pandanus* dominated the pollen record to this point. The forest of the valley was quite quickly replaced, initially by a fernland of *Pteridium esculentum*, and later by Casuarinaceae, *Melaleuca* and grass, possibly as a result of reduced burning. *Melaleuca quinquenervia* and grass do not grow on ultramafic soils and so are restricted to the fan on the southern side of the swamp, which may be another reason why they are so slow to significantly enter the record. *Apodytes* is gone completely by 1500 yr BP, but *Nothofagus* continues until the end of the record. While *Nothofagus* is clearly a component of the regional pollen rain, the *Apodytes* pollen seems to be associated with the local or extralocal pollen rain in its response to changes within the river valley. The site remained suitable for algal growth throughout this period although the dominant type counted changes over time from *Debarya* to *Zygnema*.

4.5 Reconstruction of Environmental Change for the Plum River Valley

As a wet and low lying point within the Plum River valley, Plum Swamp has existed for some time. Basement was not reached at the Plum Centre coring site, however the basal clays are LGM in age or older. The clays are suggestive of open water as they contain very little organic material, although other processes may also be responsible for a lack of organics. XRD analysis suggests that at this time sediment is derived primarily from the badland terrain in the headwaters of the valley. This naturally unstable terrain therefore seems to have some time depth and the extensive erosion seen today is not a recent phenomenon.

Given Plum Swamp's proximity to the coast, the assumption is that the valley was deeply incised during the LGM in accordance with lower sea level. However, the width of this channel, its depth and changing course over time are all unknown at this point. While Plum Swamp does not appear to have been incised by the channel, there could be a hiatus in deposition between the basal clay and overlying organic mud. The pollen from this period is dominated by local sources, primarily *Pandanus*, thought to be growing at the swamp margin. The regional component of the pollen rain is difficult to assess. *Nothofagus* seems to represent a part of this as it remains at relatively constant values right up to the end of the record, and there is no *Nothofagus* growing within the valley today. Rainforest and coastal elements in the pollen rain suggest that at this time mixed lowland rainforest constituted the valley vegetation.

The clays at the base of the core are abruptly replaced by an organic mud at around 16,000 (+5600 or -3600) yr BP. While the shift from clay to organic mud may initially suggest warmer and moister conditions it coincides with a significant increase in charcoal concentration and a dramatic vegetation change. There is no SIRM or stratigraphic evidence suggesting increased erosion from the surrounding slopes. It should also be remembered that the change in vegetation had begun prior to this sedimentary change. For example, *Macaranga* pollen increased as *Pandanus* pollen decreased. This may indicate a shrinking of the littoral forest and an increase in the lowland forest in the valley. The Cyperaceae pollen and sedge fibres within the

stratigraphy that accompany the peak in charcoal, along with the scattered wood fragments that follow, are all suggestive that the site became shallower instead of warmer and moister.

There is also the question of whether the charcoal at this point in the record represents local or regional fire. It must be taken as local given the loss of *Pandanus* and *Macaranga* in the record coinciding with the charcoal and the eventual recovery of these taxa in the absence of charcoal.

The period during which the charcoal accumulates must have been a more open landscape near the site, with Asteraceae, Poaceae *Casuarina* and some *Melaleuca* all elements of the pollen rain. An edge vegetation of *Pandanus* and *Macaranga* was re-established after this disturbance, but the length of time that this took is uncertain. The lower age estimate suggests that it took around 4,000 yrs for *Pandanus* and *Macaranga* to become locally dominant again, and for the site to undergo change such that Cyperaceae is no longer growing on the surface. However, the sample interval is extremely coarse at 20 cm, which at one extreme may encompass up to 1200 yrs. It is presumed that re-establishment of the forest within the valley was slow due to the ultrabasic terrain.

Organic accumulation continued at the site with the inorganic fraction of the mud continuing to originate from the headwaters. The clay layer at 500 cm could not be analysed due to loss of the sample, but its colour and texture are more like the basal clay than the clay bands above.

A rapid change in the accumulation processes at the Plum Centre site is suggested by the sharp boundary at around 6000 yr BP between the organic mud and overlying peat. This could represent a change from permanent shallow water to periodic shallow water. From this time onward there is additional evidence for environmental change from other cores and the stratigraphic profiles from the channels. The peat layer in Plum Centre is correlated with a similar peat layer underneath the floodplain between the swamp and the main channel, at core site 11. This peat in core site 11 is suggestive that the swamp was more extensive between 4000 and 6000 yr BP than the present day, and the large fragments of wood suggest that in places there was a swamp forest. The vegetation of

this period is mixed lowland forest with the percentages of *Araucaria* pollen suggesting that it is locally important.

The 25 cm band of sandy clay dated to around 4000 yr BP in the Plum Centre core is found in all swamp cores of this depth and marks the cessation of peat accumulation at core site 11 under the present day floodplain. The absence of pollen suggests that it was probably deposited quite rapidly, but it is not associated with charcoal. It is assumed that an extreme event, such as a cyclone, led to the deposition of sandy clay across the floodplain and into the swamp. The goethite content suggests that the source of the material is from the neighbouring slopes and not the headwaters. Peat recommences accumulation after this clay layer, but it does not preserve pollen for at least 200 years, suggesting that fluctuations in the water level of the site have followed. Similar results of badly preserved pollen in low pollen concentrations from the Plum Edge core were found for this time period.

At the point where preserved pollen is once again detected in both cores, it was found that pollen deposition had changed little to that before the barren phase. *Pandanus*, *Macaranga*, and Casuarinaceae are all principal elements, with *Araucaria*, *Apodytes* and Cunoniaceae still in the background. The decline in *Araucaria* pollen may be an indication that either the aggradation phase was quite rapid and that the buried stumps uncovered in the channel were being buried by sediment, or that a change in disturbance regime may have excluded *Araucaria*.

Although the boundary marked between zone A and zone B on the pollen diagrams is at around 2200 yr BP, the actual onset of human impact is at around 2500 yr BP. This is defined by an increase in charcoal concentration accompanied by an increase in fern spore numbers, which is followed immediately by the influx of sandy clay in the Plum Centre core. While the resolution of the Plum Edge core is not as fine as the Plum Centre core it has a strikingly similar record. The boundary at 2200 yr BP was defined by the zonation and it is where the most dramatic change to terrestrial pollen occurs. After 2200 yr BP there is tree decline on an unprecedented scale in the record, with *Pandanus* almost entirely removed. Initially this disturbed landscape is a ligno-herbaceous maquis (Cyperaceae and *Pteridium*) with the later establishment of locally growing Casuarinaceae and *Melaleuca*. *Melaleuca* was presumably growing in its

present day location on the less ultramafic soils on the southern side of the swamp.

This dramatic change to the landscape is well within the time period covered by the archaeological record for New Caledonia. It is known that people were within the vicinity of the Plum River Valley from the coastal pottery find. However, dates associated with this style of pottery are so far from the period between 1800 and 1300 yr BP, after the human impact boundary defined for the swamp at around 2200 yr BP.

It has been reported that a shift to maquis increases the probability of fire per decade (McCoy *et al.*, 1998). The activities of people no doubt enhance such a system, and this could explain the massive change brought about to the vegetation from 2200 yr BP to the present and the prevalence of fire in what was probably in pre-European times a very sparsely populated region given the infertility of the soils.

Due to the proximity of the site to sea level there is no discernible evidence in the record for climate change, and the site's lack of sensitivity in this regard was anticipated. The only significant changes undergone by the vegetation have been a result of fire, although the prevalence of fire may of course have a climatic element. Charcoal in the early part of the record, around 16,000 yr BP, may stem from drier conditions leading to increased fuel loads. Interestingly, charcoal accumulation is not associated with the period when water levels are interpreted as being lowest in the swamp, that is, the barren phase between 4400 and 3250. This period is therefore probably not produced by a drier climate, but rather by changing water levels due to aggradation of the valley following an extreme event. Charcoal in the latter part of the record may result solely from the actions of people, or may be a combination of both people and climate. A consideration for this latter part of the record is that a climate shift which may have led to increased periods of drought over the last 3000 yrs, such as the El Niño phenomenon, would no doubt lead to an increase in fire frequency even in the absence of people.

An assessment of whether sedimentation increased during the time of human occupation is difficult because the valley is an open system so not all eroded sediment is necessarily trapped, and aggradation within the valley may have been affected by the rise of sea level. Therefore, comparing the rates of pre-Melanesian, Melanesian and European deposition within Plum swamp is difficult due to different processes operating at

different times and the loss of material from the system generally.

All that can be said about the human impact period and sedimentation in the swamp is that none of the units, apart from the mining spoil are unique to the human period, and that rates of accumulation appear to change little, with the radiocarbon ages falling along a straight line. There is also a trend in the valley of increasing stability in the last 2000 years, with peat dominating mineral sediment.

Summary

The pollen data and stratigraphic data from the Plum River Valley and their tentative interpretation are summarised in Table 4.5.

Table 4.7: Summary of environmental changes in the Plum River Valley since the LGM.

Period (years B.P.)	Site	Valley	Environmental Conditions
<i>before 16000</i>	Inorganic sedimentation at site; possibly open water conditions. <i>Pandanus</i> bordering site.	Mixed lowland forest. Regrowth taxa such as <i>Macaranga</i> become important around 16,000 yr B.P.	Possibly drier conditions with increase of disturbance taxa.
<i>16000-12000</i>	Abrupt change to organic sedimentation at 16,000 yr B.P. Possibly shallow water. <i>Pandanus</i> removed and Cyperaceae and ferns develop on and around site.	Open landscape and disturbance elements more pronounced. <i>Macaranga</i> decreases with loss of <i>Pandanus</i> . Casuarina increases.	Fire associated with disturbance of vegetation. Significant local impact with loss of <i>Pandanus</i> .
<i>12000-4400</i>	Organic sedimentation continues. <i>Pandanus</i> resumes dominance as site vegetation. Clay at around 6500 yr B.P. Change from organic mud to peat at 6000 yr B.P. suggests shallow water. Peat more extensive than present day site. River valley is aggrading.	Mixed lowland forest. Increase in <i>Araucaria</i> decrease in Casuarinaceae.	Valley environment becoming moister as valley aggrades.
<i>4400-3200</i>	Sandy clay. Absence of pollen suggests rapid accumulation. Peat overlying this does not preserve pollen for at least 200 years.	Unknown - no pollen	Disturbance of slopes, possibly through extreme event leads to clay deposition within swamp. Periodic dry spells follow.
<i>3200-2400</i>	Peat accumulation continues. <i>Pandanus</i> still dominant vegetation around site, with some Cyperaceae and ferns. Swamp edge closest to channel aggraded.	<i>Araucaria</i> less dominant and Casuarinaceae more dominant. <i>Rauvolfia</i> = damp environment. <i>Apodytes</i> rainforest element. Channel continues to aggrade.	Fire associated with changes to ground cover elements by 2500 yr B.P. Forest understorey changed to fernland with initial impact of fire

Table 4.7 cont'd: Summary of environmental changes in the Plum River Valley since the LGM.

Period (years B.P.)	Site	Valley	Environmental Conditions
2400-1500	Charcoal accumulation increases. Dramatic increase of ferns around 2200 yr B.P. Clay layer and loss of <i>Pandanus</i> at 2200 yr B.P. Swamp becomes a cyperaceous swamp, no surrounding forest.	Lowland forest removed and replaced by ligno-herbaceous maquis (<i>Pteridium</i> and Cyperaceae) from 2200 to 1500 yr B.P.	Human Impact. Continued occurrence of fire led to forest loss and establishment of <i>Pteridium esculentum</i> which dominated landscape for 700 years.
1500-AD136	Organic mud with band of inorganic clay suggesting shallow water. Replaced by sedge peat around 1200 yr B.P. Peatland across valley several hundred years ago, probably similar to today's environment above tributary junction.	Valley vegetation comprises <i>Melaleuca</i> woodland, <i>Casuarina equisetifolia</i> , and ligno-herbaceous maquis.	Gradual replacement of <i>Pteridium</i> dominated slopes with vegetation approximating the present day.
AD136-present	Site and lower reaches of valley covered with mining spoil. Peat accumulation resumes in swamp and main valley with pause in mining activity. Resumption of mining leads to more spoil deposited and the incision of the fan and main valley.	As above.	European impact greatest in terms of geomorphic change and not vegetation. Vegetation had already been dramatically changed by fire of Kanaks.

Chapter 5 Environmental Change at Lac Saint Louis 6000 to 0 yr BP.

5.1 Introduction

Lac Saint Louis is a small semi-enclosed coastal basin which has direct evidence of Melanesian landuse surrounding the site in the form of terraces for growing yams (*Dioscorea* spp.). In 1991 a sediment core was collected and a preliminary study examined the history of charcoal, grass pollen and fern spores (Stevenson, 1991). The aim of that work was to see if a signal of human impact could be identified from these few indicators. An increase in charcoal, grass pollen and some fern spores was found to coincide with the earliest known archaeological records in New Caledonia. The current thesis expands this preliminary work considerably, analysing all pollen types and considering in more detail the stratigraphy of the site.

5.2 Site Description

Although marked as a lake on the 1:50,000 topographic map, Lac Saint Louis is a freshwater swamp on a coastal plain at an elevation of between 3 to 5 m asl. It is approximately 8 km due east from Noumea and 7 km due west of Plum Swamp on the western side of Mont Dore (Figure 5.1a). Surrounded by ridges between 10 and 20 m high on three sides, it now has a small local catchment of around 0.025 km². The geology of the area is composed of Quaternary alluvium (Paris, 1981), but the origin of the ridges enclosing the swamp is unknown. The tidal range for the main island of New Caledonia is around 1.8 m and the average annual precipitation is the same as that for Plum, between 1300 and 1500 mm per year (Section d'Hydrologie, 1981).

The vegetation surrounding the swamp is dominated by *Imperata cylindrica* and *Melaleuca quinquenervia* (Plate 5.1). Scattered individuals of *Mangifera indica* (mango) are found on the ridgetops. *Mimosa pudica* and *Arillastrum* sp. are also found

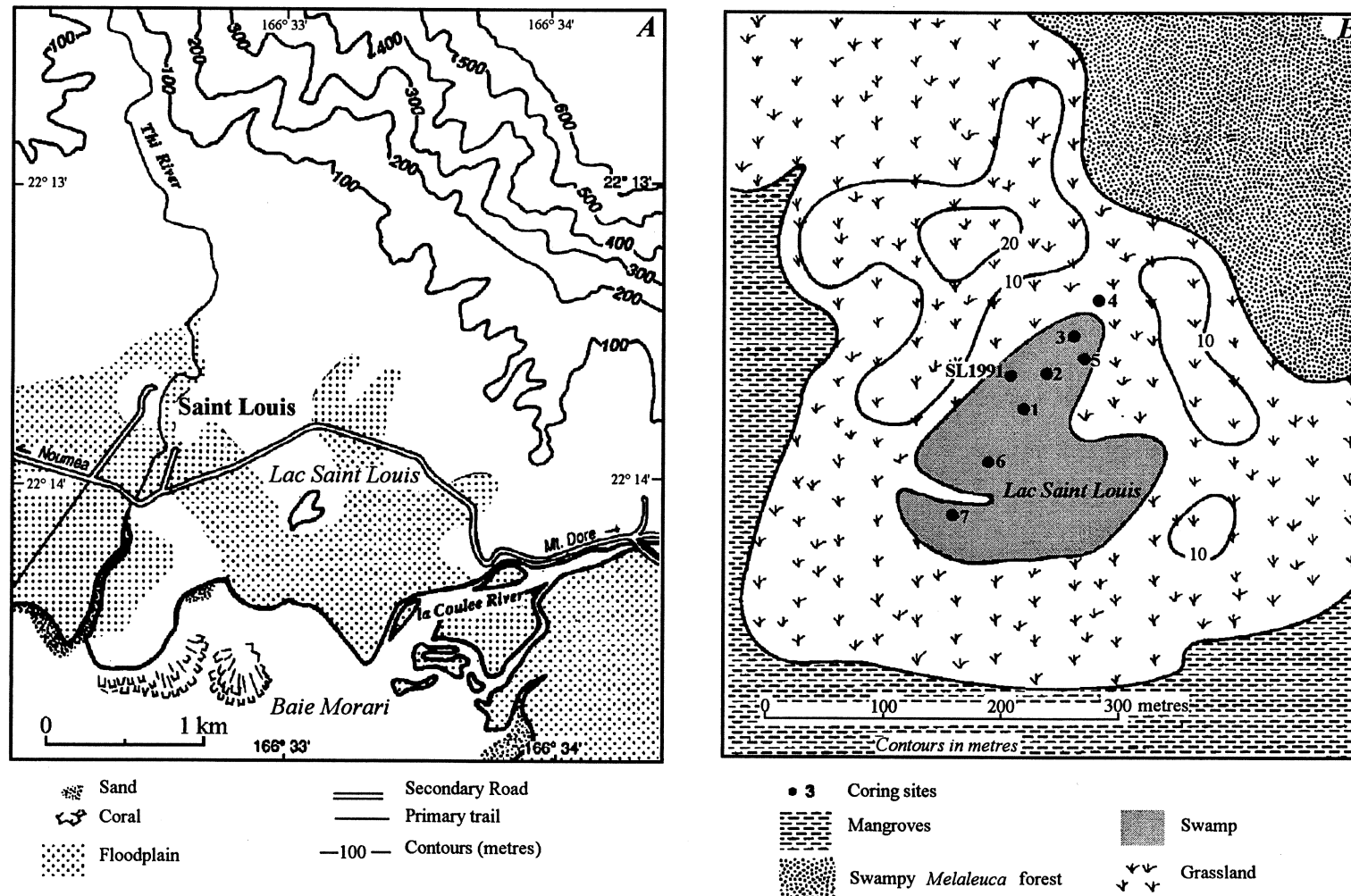


Figure 5.1 A: Locality map of Lac Saint Louis. B: Site map of Lac Saint Louis. (Taken from Stevenson and Dodson, 1995).



Plate 5.1: Lac Saint Louis. View to the south-east.



Plate 5.2: Yam terraces on ridges surrounding Lac Saint Louis.
View looking east toward Mont Dore.



Plate 5.3: Lac Saint Louis looking south toward mangrove zone.

throughout the grassland. On a more regional scale the steep slopes behind Saint Louis village (Figure 5.1A) are covered in lowland rainforest, with ligno-herbaceous maquis at higher altitudes. In 1991 the swamp surface was covered in *Elaeocharis cylindrimorphous* (Cyperaceae) (Plate 5.1), a reed over 2 m tall, and throughout the reedswamp was an unidentified fern. A fire in 1993 burnt all the vegetation and destroyed the upper layers of root mat (Plate 5.2).

The inner slopes of the ridges have terraces characteristic of yam cultivation which are no longer in use and may be of prehistoric origin (Plate 5.1 and Plate 5.2). Fires since 1993 have helped expose scattered pottery sherds of an unknown style but there appears to be no published archaeology from this area.

At the base of the ridges, on flat land bordering the swamp, contemporary small garden plots are found which have also been abandoned. Gardens growing bananas and some small plot vegetables are still in use at the southern end of the swamp, beyond which the vegetation grades into a mangrove system (Plate 5.3). The mangrove zone is composed primarily of *Rhizophora* spp. with some *Brugeria* sp. and *Sonneratia* sp. *Avicennia marina* is found on the inland side of the mangrove zone on higher ground with occasional individuals of *Lumnitzera* sp.

5.3 Methods

In 1991 a 420 cm sediment core (SL1991) was collected from Lac Saint Louis using a D-section corer then taken back to the laboratory for analysis. On a return visit in 1993 the stratigraphy of the swamp was investigated in more detail by field descriptions of a series of cores collected along a transect running through the north south axis of the swamp. The locations of these cores and a soil profile at the northern end of the swamp are shown in Figure 5.1b. Access to a more central location in 1991 was hampered by the density of the reed cover and water depth.

Samples for radiocarbon dating were taken from core SL1991 to establish the age of the sediments and the sedimentation rate. Nine bulk sediment samples were selected

between 35 and 420 cm depth. Once again mineral magnetic and Loss-on-ignition (LOI) measurements were undertaken, with 1cm samples analysed contiguously between 40 and 220 cm. In this case both SIRM and susceptibility measurements were made as the immediate catchment is not dominated by iron rich minerals.

Sampling for pollen and charcoal was based on the radiocarbon age estimates. One cubic centimetre sub-samples were taken every 3 cm from 40 to 219 cm then processed using the standard techniques outlined in Appendix 1. Pollen was counted every 3 cm from 40 - 150 cm, then every 10 cm to 219 cm, while charcoal was counted every 3 cm from 40 to 220 cm. The raw counts can be found in Appendix 4D.

The pollen diagrams are percentage diagrams and follow the same conventions as those presented for Plum Swamp (Chapter 4). Similarly, a principal components analysis was carried out on a data set which combined the fossil pollen data from Lac Saint Louis and the modern pollen rain data presented in Chapter 3.

The preliminary study from 1991 had charcoal accumulation rates, below 150 cm in the core, of between 2 and 8 cm² cm⁻² yr⁻¹ (Stevenson and Dodson, 1995). These rates are significantly higher than the rates from the overlying sediments. During 1995 circumstantial evidence was discovered that suggested samples below 117 cm may have had an insufficient volume of marker pollen added to them. Duplicate samples for charcoal determinations were therefore processed in 1995 to see if the original curve could be replicated.

5.4 Results

Stratigraphy

Core 5 (Figure 5.1b) is situated just within the swamp boundary, at the convergence of two terrace drains. Its location was chosen as one likely to yield evidence of slope disturbance. An olive to pale olive sandy clay with gravels and wood between 230 and 180 cm depth is thought to be an old soil (Figure 5.2). Overlying this is an organic mud which in turn is overlain by a sandy clay. The texture of this latter unit is the same as

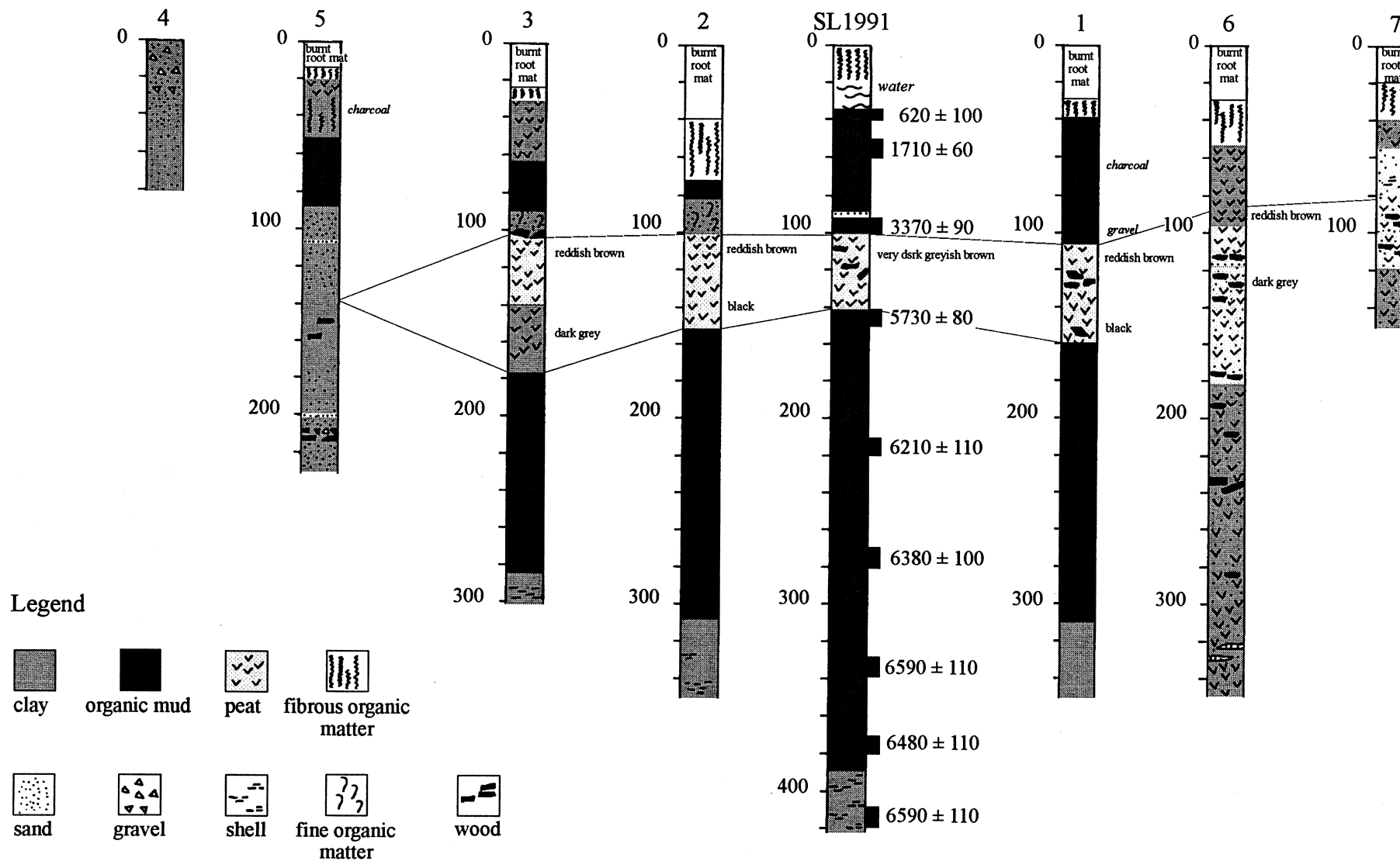


Figure 5.2: Stratigraphy of Lac Saint Louis. See figure 5.1 for core locations.

the soil in profile 4. Above the sandy clay the core reverts to an organic clay, in keeping with the stratigraphy of the cores described below.

Cores 1, 2, 3 and SL1991 are at the northern end of the north-south transect (Figure 5.1b) and all exhibit similar stratigraphic patterns. The basal clays contain fragments of marine shells and change to organic muds and peats in the upper sections (Figure 5.2). The topmost layers of peat are reddish brown in colour and are found across almost the entire site. Above this is a change to an organic sandy clay with a clayey sand layer in core SL1991. A similar sandy clay is found in core 5. Both these sand layers correlate well stratigraphically. Cores 6 and 7 at the southern end of the swamp have a clayey peat constituting the basal sediments in contrast to the organic muds in cores 1, 2, 3 and SL1991. Core 6 also has lenses of light blue quartz sand between 340 and 320 cm and the sand layer underlying the reddish brown peat in both core 6 and 7 is quartz stained black by organics. Both cores are sandier at depth than the other cores, but the sand is mainly micaceous. A more detailed stratigraphic description of the pollen core, SL1991, appears in Table 5.1.

Table 5.1: Stratigraphic description of SL1991.

Depth cm	Description
0-20	Root mat.
20-35	Water and plant material with very little sediment.
35-65	Black/brown organic mud. Large amount of fibre and root material.
65-85	Dark brown sandy organic mud.
85-89	Black/brown organic mud.
89-91	Creamy coloured sand layer with red nodules.
91-100	Black/brown organic mud.
100-140	Very dark greyish brown peat, with fragments of wood between 107 and 126 cm. Micaceous particles throughout.
140-210	Black/brown organic mud, with an increase in fibrous organic material between 188 and 196 cm.
210-370	Same organic mud but with a slight colour change to very dark brown. Large lump of charcoal 237-238 cm and an accumulation of finer charcoal from 290 to 300 cm. Another gradual colour change between 340 and 370 cm to very dark grey brown.
370-420	Very dark grey brown mud. No fibrous organic material. Shell fragments between 390 and 420 cm.

Radiocarbon Dating

The nine radiocarbon dates from SL1991 (Table 5.2) reveal that the sediments are Holocene in age with the basal sediments deposited around 6600 yr BP. Dates between 420 cm and 212 cm depth have overlapping standard deviations indicating very rapid deposition. The upper 150 cm covers the period from 5370 yr BP to present. An age model for the core is presented in Figure 5.3. The model was constructed by dividing the ages into two populations of dates and placing a straight line of best fit through each using regression analysis. The two lines intersect at around 150 cm and define a substantial change in sedimentation rate; from 2 cm/yr to 0.02 cm/yr.

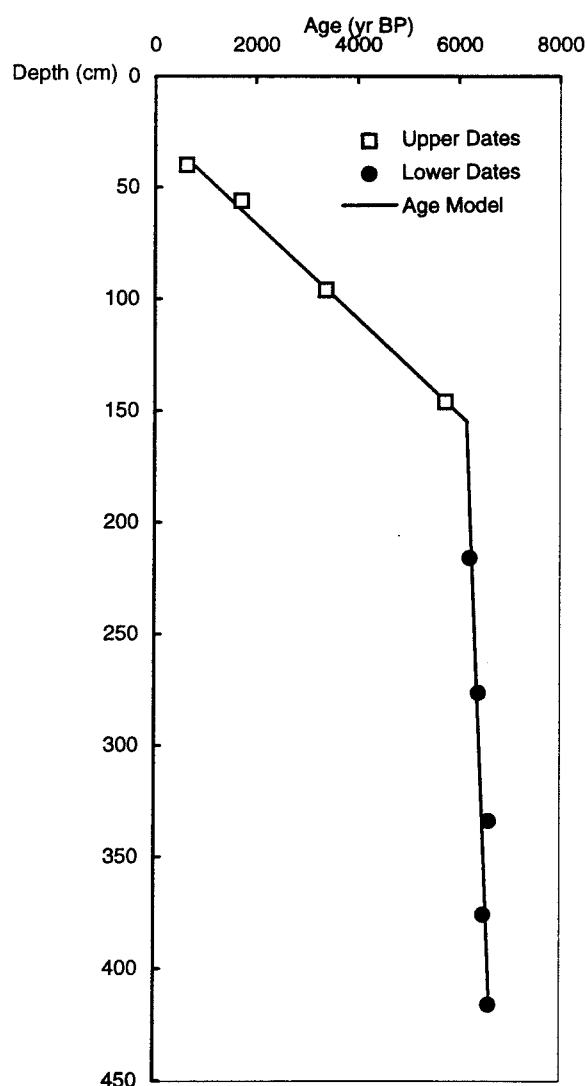


Figure 5.3: Age depth model for SL1991 core from Lac Saint Louis.

Table 5.2: Radiocarbon ages from Lac Saint Louis.

SL1991 sample depth in cm	Lab Number	Conventional Age yr B.P.	Calibrated Age yr BP (range) (2 sigma)	Calender Age (range) (2 sigma)	Bulk Sample Type
35 - 45	Beta - 45257	620 ± 80	600 (680 - 509)	1350 AD (1270 - 1440)	organic mud
52 - 60	Beta - 43688	1710 ± 60	1590 (1730 - 1500)	360 AD (220 - 450)	organic mud
92 - 100	Beta - 43689	3370 ± 90	3620 (3830 - 3380)	1670 BC (1885 - 1430)	organic mud
142 - 150	Beta - 43690	5370 ± 80	6180 (6300 - 5940)	4230 BC (4350 - 3990)	organic mud
212 - 220	Beta - 43691	6210 ± 110	7110 (7360 - 6800)	5170 BC (5410 - 4850)	organic mud
273 - 280	Beta - 43692	6380 ± 100	7240 (7380 - 7020)	5290 BC (5430 - 5080)	organic mud
330 - 338	Beta - 43693	6590 ± 110	7400 (7530 - 7230)	5450 BC (5660 - 5280)	organic mud
372 - 380	Beta - 43694	6480 ± 110	7340 (7430 - 7170)	5390 BC (5580 - 5220)	mud
412 - 420	Beta - 43695	6590 ± 110	7400 (7610 - 7200)	5450 BC (5660 - 5280)	mud

Calibrated using Stuiver and Reimer (1993).

Mineral Magnetism and Loss on Ignition

Between 420 and 200 cm depths the mineral magnetic values are relatively low and uniform and for presentation purposes have not been included in Figure 5.4. From 200 to 40 cm SIRM has similarly low values with occasional clustered and single peak values. There is a single high value at 200 cm, a more extensive series from 175 to 164 cm, a small group centred around 120 cm, and several very high values around 58 and 48 cm. There are no obvious stratigraphic markers that coincide with these values. Susceptibility values show similar clusters of peaks, with negative values of susceptibility from 107 to 94 cm, 52 to 50 cm and from 44 to 40 cm (Figure 5.4). Many of these negative values are so close to zero they appear as such in Figure 5.4, and are within the known range of values for mineral fractions such as quartz, calcite, feldspar and kaolinite (Thompson and Oldfield, 1986). Of note are the peaks of SIRM and susceptibility that coincide at 58 and 48 cm. Since both measures have high values this suggests a presence of secondary magnetic minerals, possibly fine topsoil which may also be enhanced by fire (Oldfield, 1991; Rummary, 1983; Thompson and Oldfield, 1986).

The LOI values are initially less than 30% in the organic clay then gradually rise to a peak of 80 % around 116 cm (Figure 5.4). Values then decline to less than 30% at 93 cm and remain relatively constant until they increase again to 40-50% after 56 cm (Figure 5.4).

Fossil Pollen

Zonation of the pollen diagrams was carried out using all pollen (excluding Cyperaceae and ferns) with values of more than 5% in at least one sample. This resulted in 2 significant zones, designated SL-A and SL-B. The diversity in pollen types from the site is large, with over 200 individual pollen and spore types counted. Most of the unknown types (e.g. Type 39, Type 68) are small (around 20 μm) three colporate (3C3P) pollen grains. The pollen diagrams are described from the oldest to the youngest samples, with each zone accompanied by an inferred age range derived from the age model (Figure 5.3). From this point onward positions in the core are referred to as ages rounded to the nearest 50 years.

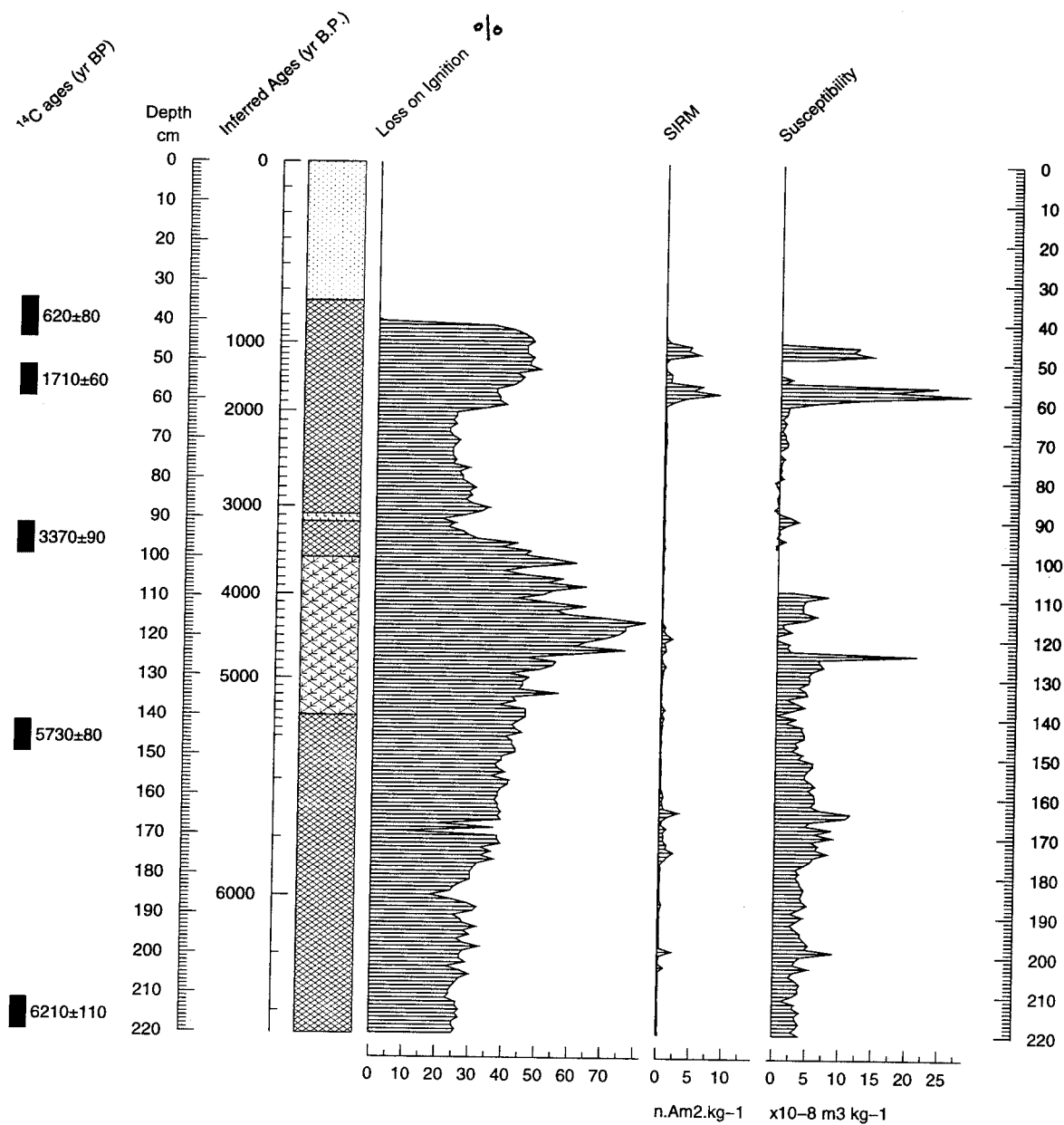


Figure 5.4: Loss on ignition, SIRM and susceptibility measurements for Lac Saint Louis.

Zone SL-A: 198-89 cm**Inferred Age 6250 - 3000 yr BP.**

Figure 5.5 presents three summary percentage diagrams; a total pollen sum showing mangrove pollen verses all other taxa, the same pollen sum showing the breakdown of non-mangrove taxa and a pollen sum that excludes ferns and Cyperaceae. Mangrove pollen comprises less than 30 % of the total pollen sum in zone SL-A. Most of the mangrove pollen is *Rhizophora*, and the other taxa are illustrated in Figure 5.6. *Brugeria* occurs throughout zone SL-A, with *Avicennia* only entering the record after 4500 yr BP.

The *total pollen* sum in zone SL-A prior to 6000 yr BP is dominated by fern spores (Figures 5.5 and 5.9). Terrestrial tree and shrub taxa dominate between 6000 and 5000 yr BP, with pollen types that are exclusive to tree taxa very low. The main components of the tree pollen taxa are *Araucaria* and *Nothofagus* (Figure 5.6). The *Nothofagus* percentages are in keeping with it being part of the regional pollen rain. The peak in tree pollen at around 5750 yrs BP comes from a single sample dominated by *Quintinia* pollen (Figures 5.5 and 5.6). The shrub pollen taxa that are most abundant can be seen in Figure 5.6. Of these, Cunoniaceae, *Macaranga* and Myrtaceae make the biggest contribution to terrestrial pollen deposition. The values of indeterminate taxa are expressed as a percentage outside of the pollen sum. In zone SL-A these are high, exceeding 50 % for several levels (Figure 5.5) and are composed of damaged and degraded pollen as well as pollen that although in good condition could not be identified (Figure 5.9).

The percentages of Cyperaceae pollen gradually increase with the accumulation of peat at the site after 5500 yr BP, until it comprises around 30 % of the *total pollen sum* by 4000 yr BP (Figure 5.5). Psilate monolet fern spores also increase with peat accumulation at the site (figure 5.9). The percentages of Cunoniaceae, *Macaranga* and Myrtaceae pollen decrease in this upper part of zone SL-A with an increase in the percentage of *Rhizophora* pollen (Figures 5.5 and 5.6). Poaceae values of less than 5 % are common for this upper part of zone SL-A (Figure 5.6). Figures 5.7 and 5.8 illustrate the taxa which are less than 5 % in all samples. The taxa have been organised to

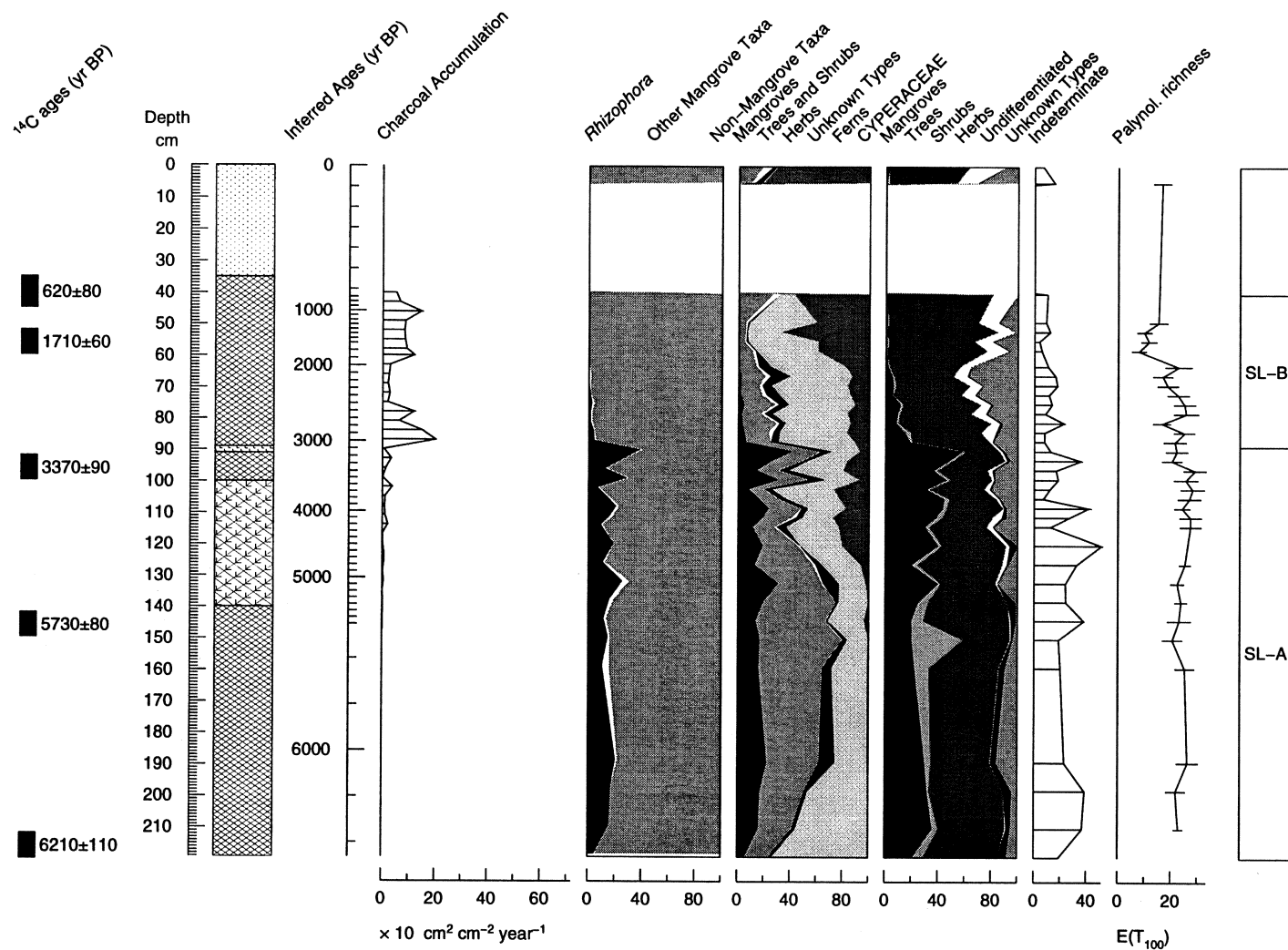


Figure 5.5: Summary pollen diagrams for Lac Saint Louis. Total pollen sum showing mangrove versus non-mangrove taxa, total pollen sum showing breakdown of non-mangrove sources, and the pollen sum excluding Cyperaceae and ferns. All are percentage pollen diagrams. Also included in the diagram is charcoal accumulation and palynological richness estimates.

Lac Saint Louis

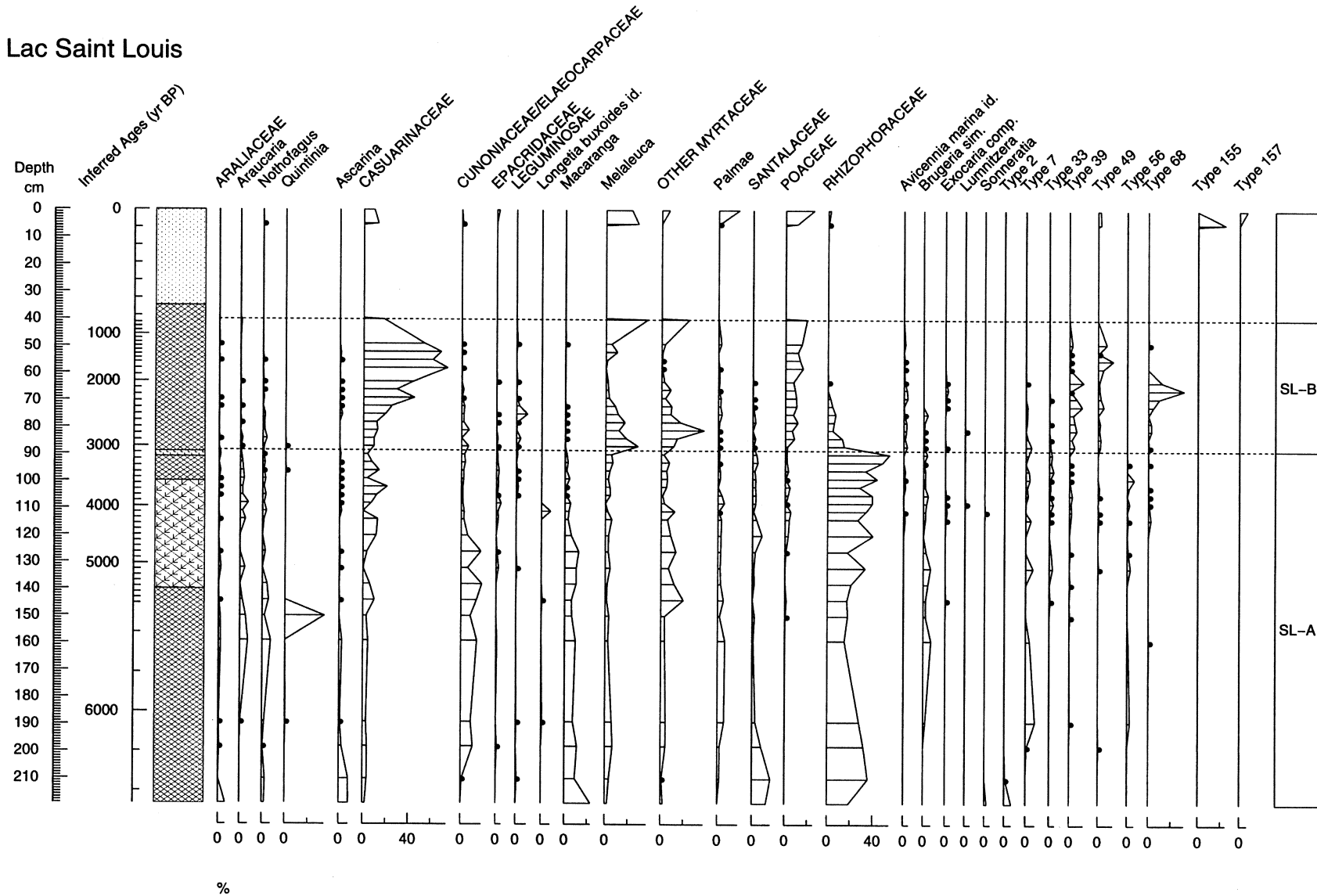


Figure 5.6: Individual pollen curves for Lac Saint Louis. All taxa that have a value of greater than 5 % in at least one sample. Dots indicate values of less than 1 %.

Lac Saint Louis

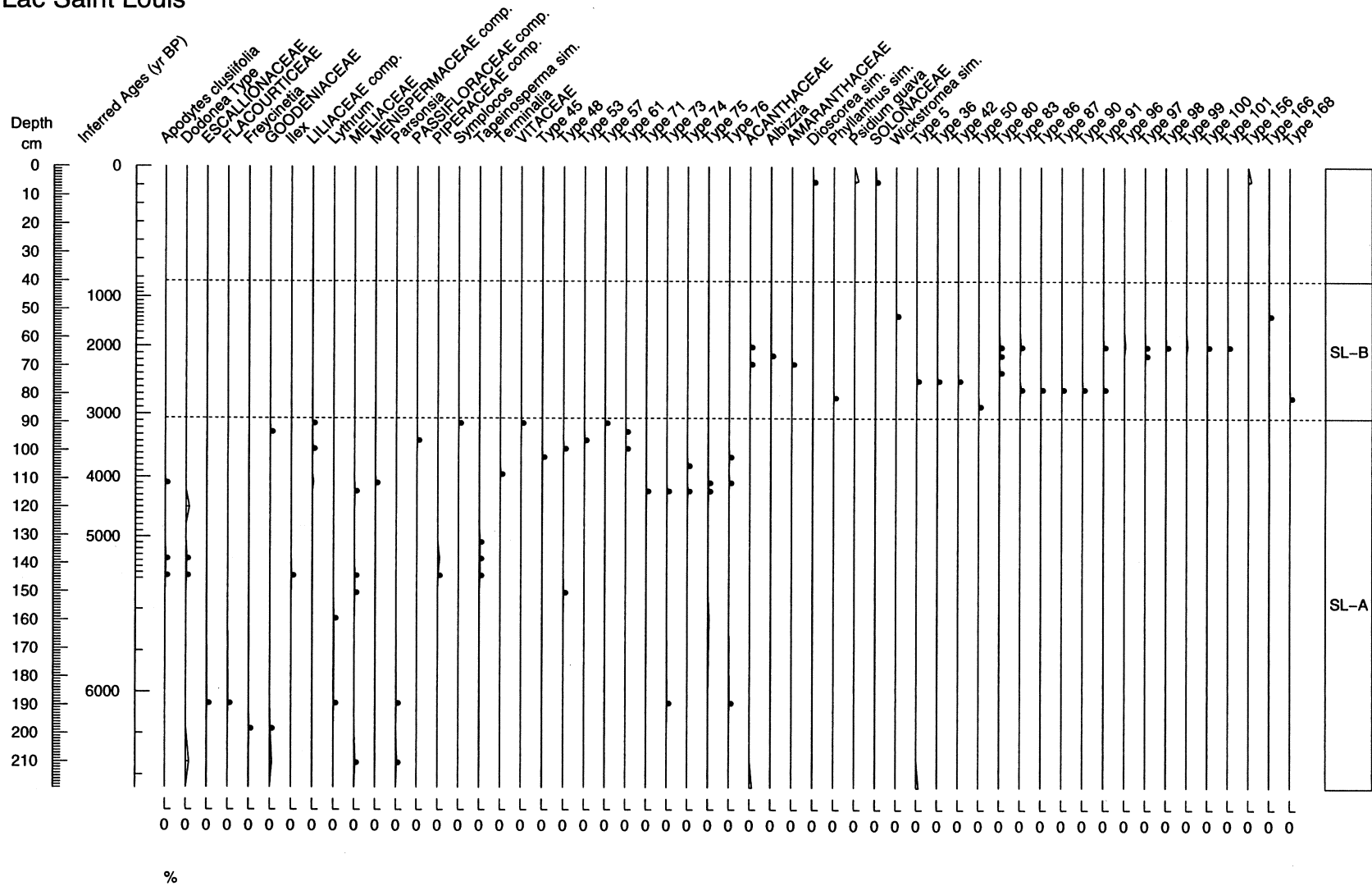


Figure 5.7: Terrestrial pollen for Lac Saint Louis with values of 5 % or less in all samples. Dots indicate a value of less than 1 %. Diagram arranged from left to right; taxa only found in SL-A; taxa only found in zone SL-B.

Lac Saint Louis

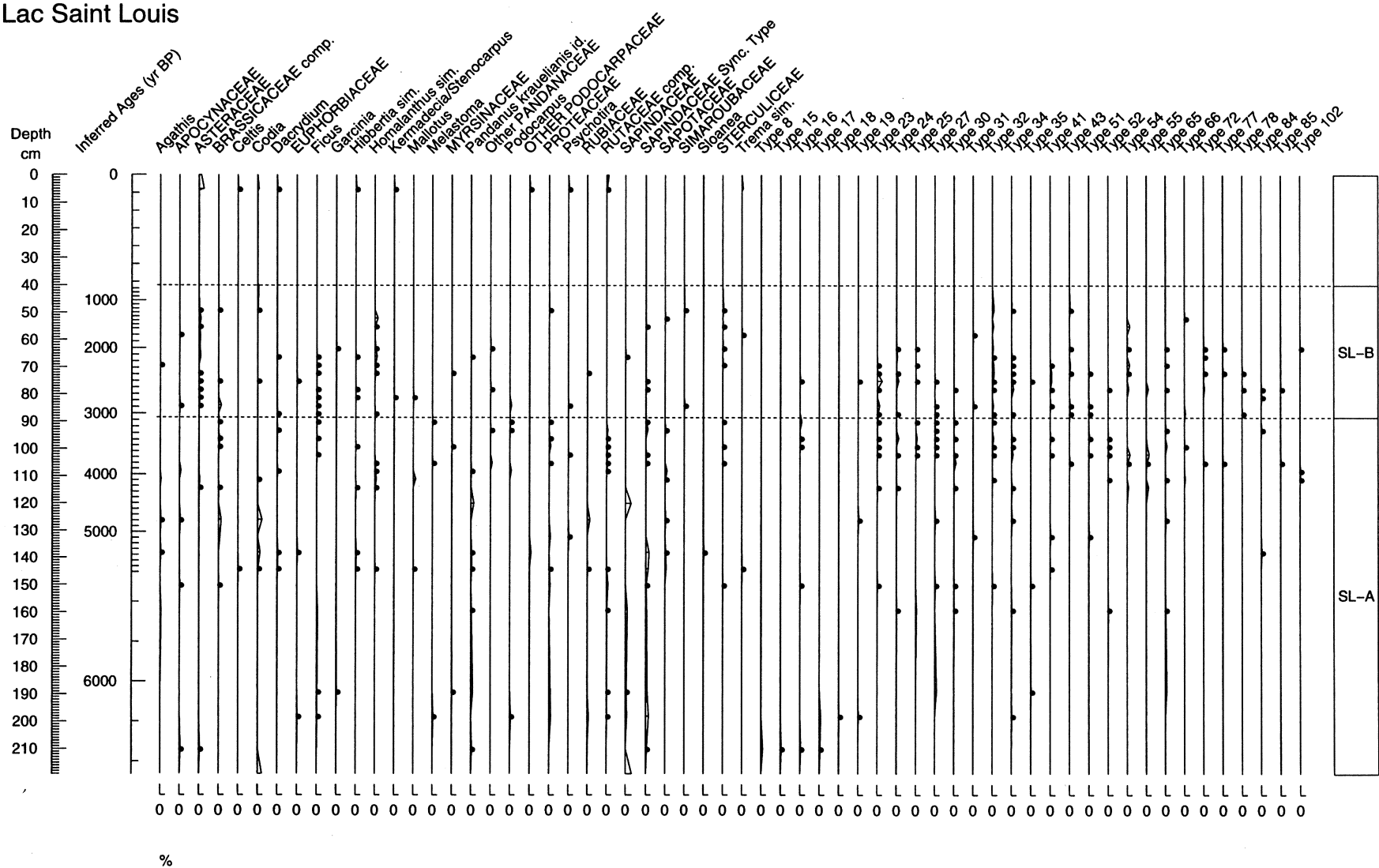


Figure 5.8: Terrestrial pollen for Lac Saint Louis with values of 5 % or less in all samples. Taxa found in both zones. Dots indicate a value of less than 1 %.

Lac Saint Louis

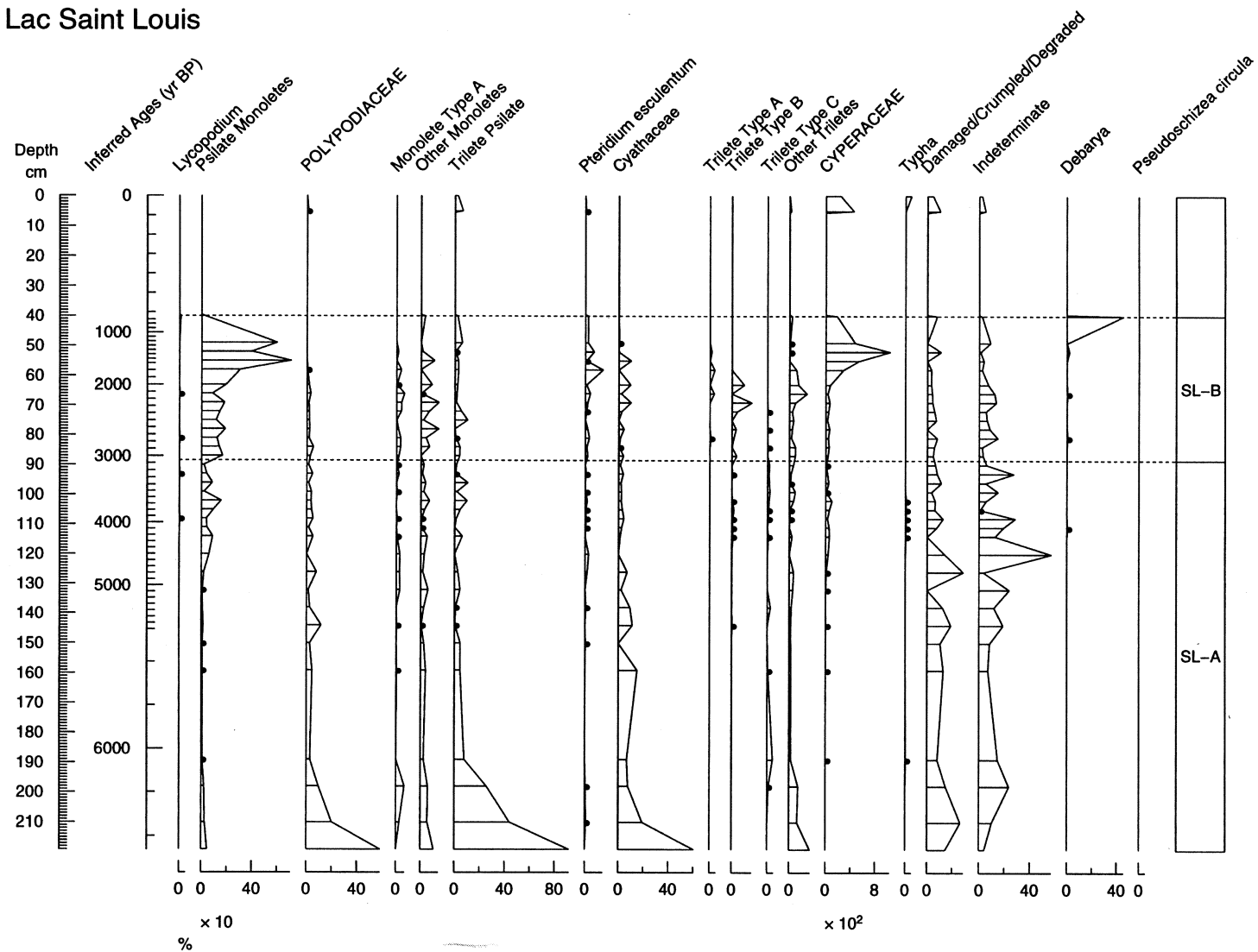


Figure 5.9: Ferns, mangroves, Cyperaceae and indeterminate taxa expressed as percentages outside the pollen sum.

illustrate those that are exclusive to zone SL-A, those which are found only in zone SL-B and those that are found in both. Many of those found only in SL-A are lowland forest taxa (Figure 5.7) as are the majority that occur in both zone SL-A and SL-B (Figure 5.8). The palynological richness estimates are high and remain fairly constant throughout zone SL-A, declining in the uppermost samples with the increase in *Rhizophora* pollen (Figure 5.5). Samples that did not have an adequate pollen sum (i.e. greater than 100) have not been included in the analysis. Charcoal is present throughout zone SL-A, although the accumulation rates are very low (Figure 5.5).

Given the rapid sedimentation rate and the low pollen concentration in the lower part of zone SL-A, it was decided not to count the samples between 160 and 190 cm.

Zone SL-B: 89 - 40 cm Inferred Age 3000 - 800 yr BP.

Charcoal enters the fossil record in large amounts from around 3000 yr BP (Figure 5.5). The *total pollen* sum is initially dominated by fern spore taxa, Cyperaceae becoming the dominant pollen type after 2000 yr BP, coincident with the virtual absence of mangrove pollen (Figure 5.5, 5.6 and 5.9). Psilate monolet ferns spores dramatically increase after 2000 yr BP along with the Cyperaceae pollen (Figure 5.9) and the highest values of *Pteridium* also occur after 2000 yr BP. The pollen sum has a notable absence of pollen taxa that are exclusively trees, with *Nothofagus* and *Araucaria* pollen the main components of the tree taxa to gradually disappear (Figure 5.6). Percentages of shrub taxa and herb taxa (essentially grass) increase throughout zone SL-B (Figure 5.5). *Melaleuca*, Myrtaceae and grass pollen percentages increase across the SL-A - SL-B boundary, later decreasing as Casuarinaceae pollen increases (Figure 5.6). They then increase again in the upper most sediments. Given the similarities in shape of the *Melaleuca* and Myrtaceae curves, the possibility exists that some of the Myrtaceae pollen belongs to *Melaleuca* but has not been identified as such.

Most of the taxa occurring at less than 5% and exclusive to SL-B are unknown types (Figure 5.7). The unknown type category in general decreases toward the top of SL-B and this is reflected in the decline of the palynological richness. The surface sample pollen is dominated by Cyperaceae pollen, with the uppermost sample having very low

pollen concentrations (Figure 5.5). The palynological richness fluctuates throughout zone SL-B, decreasing dramatically after 2000 yr BP.

The only food plant pollen counted was from the two surface samples; *Dioscorea* (yam) type pollen and Solanaceae pollen. *Psidium guajava*, a weedy Myrtaceous shrub introduced since European settlement, is also found in these surface samples. Unlike Plum Swamp there are no Zygnemataceae spores until 40 cm, when *Debarya* is found.

Charcoal Comparison

Two charcoal curves are presented in Figure 5.10. A comparison of the original charcoal curve with one produced from samples processed in 1995 suggests that insufficient marker pollen may have been added to samples below 117 cm during processing in 1991. Above 117 cm the charcoal values and curve shape are almost identical. Below 117 cm the values of the 1995 curve vary considerably from the 1991 samples however, a very similar shaped curve has been reproduced as illustrated by the 10 x exaggeration.

Pollen Concentration

A pollen concentration diagram makes changes in each of the pollen taxa independent. For this reason a concentration diagram was prepared to assess whether the abrupt decline in the mangrove pollen seen at 3000 yr BP was a result of less mangrove pollen being deposited at the site, or whether it was being affected by increases in terrestrial pollen input. Figure 5.11 illustrates how the concentration of *Rhizophora* pollen does not change significantly at 3000 yr BP. However, *Rhizophora* pollen does effectively leave the pollen record after around 2000 yr BP which is in keeping with the percentage diagrams. On the other hand all terrestrial and swamp surface pollen and spore types increase in concentration markedly at 3000 yr BP, increasing to a maximum concentration at around 2000 yr BP, then decline. The samples from the upper most sediments of zone SL-A are likely to have poor pollen concentration due to the lack of sediment compaction. It should be noted that the charcoal concentration does not mirror the pollen concentration curve.

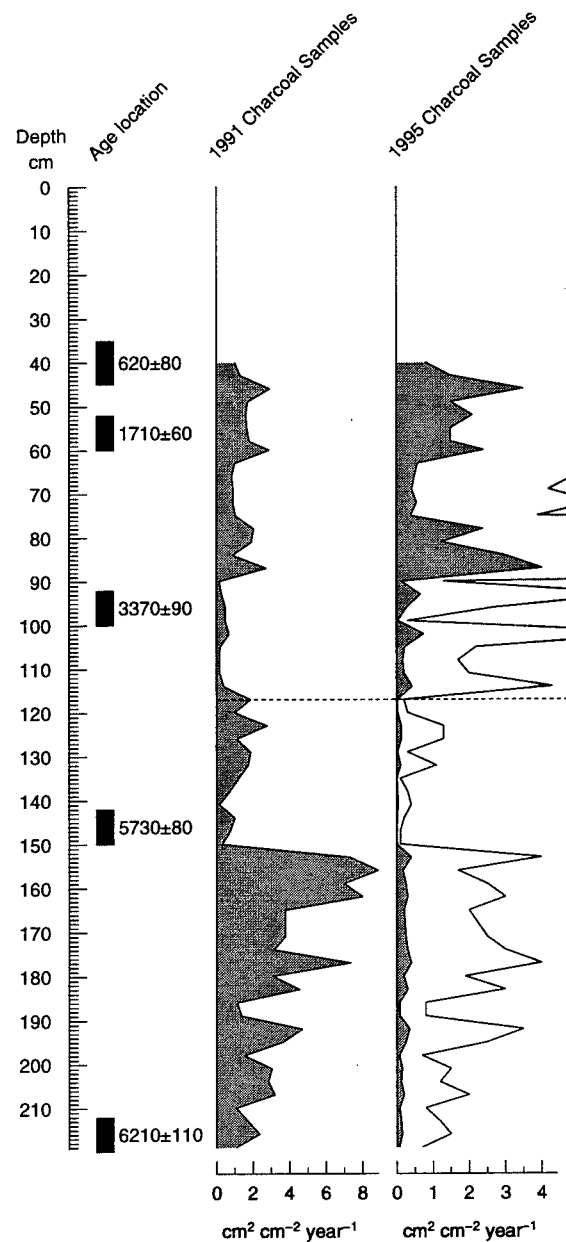


Figure 5.10: Lac Saint Louis charcoal curves. Hollow curves indicate 10 x exaggeration. Dotted line indicates 117 cm, below which inadequate marker pollen may have been added to samples. Note the different scales on each graph.

Lac Saint Louis

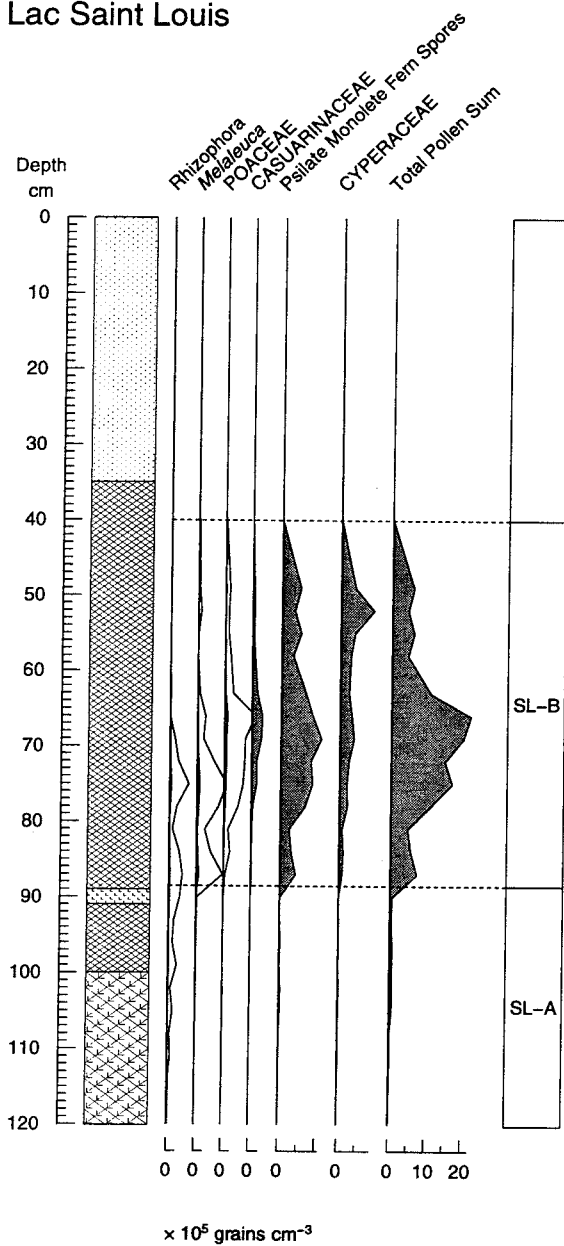


Figure 5.11: Pollen concentration curves for selected Lac Saint Louis taxa. Hollow curves indicate 10 x exaggeration.

Principal Components Analysis

An ordination of the Lac Saint Louis fossil pollen samples and the modern pollen rain samples for southern New Caledonia was carried out to assess the similarities between the core samples and the modern pollen analogues. As for Plum, this was undertaken using principal components analysis (PCA) within the program PSIMPOLL (Bennett, 1997).

Once again the two data sets were merged, excluding Cyperaceae and ferns and reducing the terrestrial taxa to only those with a value of 5 % or more in at least one sample. This resulted in a data set of 38 pollen types and 64 samples. The data underwent square-root transformation and the eigenvalues of the interpretable axes are highlighted in Table 5.3.

The first and second axes explain 43 % of the variation in the data set (Table 5.3). With the inclusion of the third axis explanation increases to 56 %. Once again only the first two axes, PC1 and PC2, have been mapped to illustrate the relationships between samples (Figure 5.12).

Table 5.3: Eigenvalues from Principal Components Analysis - single iteration.

	Value	Proportion Explained	Cumulative Proportion
PC1	0.126332	0.244513*	0.244513
PC2	0.099182	0.191966*	0.436479
PC3	0.064403	0.124652*	0.561131
PC4	0.055972	0.108333*	0.669464
PC5	0.024352	0.047133	0.716596
PC6	0.017648	0.034157	0.750753

NB: * = Interpretable axes

The different zones described earlier for Lac Saint Louis have been attributed their own symbol, as have the modern pollen rain samples (Figure 5.12). The vectors for individual pollen taxa exhibiting the most influence over the different quadrants are also plotted.

All the zone SL-A samples cluster closely together in the bottom left hand quadrant. The position of the zone SL-A samples on the far left is determined by the *Rhizophora*

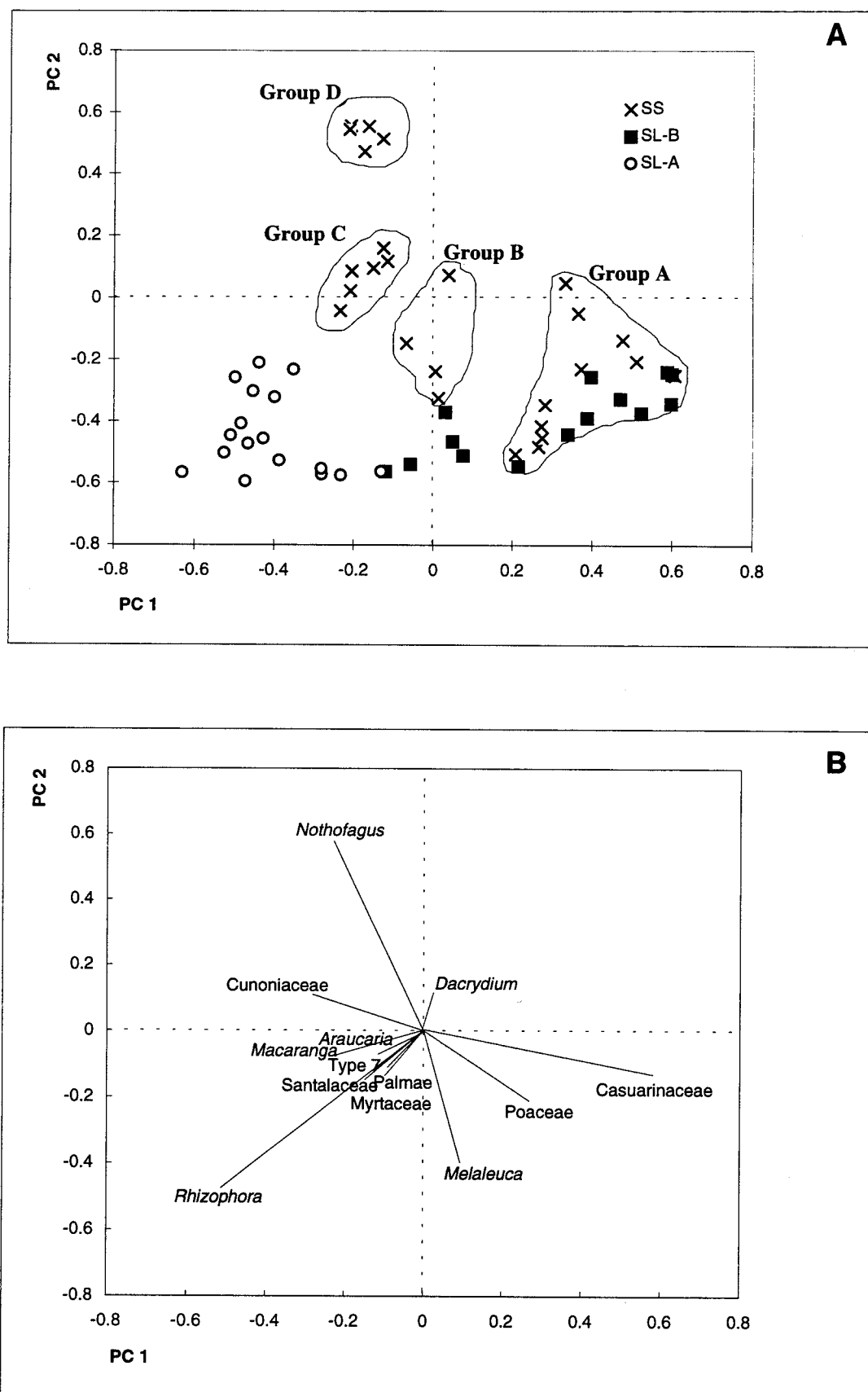


Figure 5.12: PCA bi-plots of Saint Louis fossil samples and modern pollen rain data. A) Fossil and modern samples. B) Pollen taxa. Surface sample (SS) groups are enclosed and labelled.

percentages, with this pollen type having less influence over the pollen assemblage as the boundary with zone SL-B is approached. The other taxa which influence the samples in this quadrant are also shown. They are primarily coastal rainforest taxa and plot much closer to the origin of the map. There are only two surface samples which appear in this quadrant. They are both from the Plaine des Lacs region and belong to the Group B and Group C surface samples. Their similarities with the fossil samples lie with the coastal rainforest taxa.

Most of the post 3000 yr BP samples are clustered together in the bottom right hand quadrant along with the surface samples from Group A and Group B. The two SL-B samples in the bottom left quadrant have significant percentages of *Rhizophora* pollen. *Melaleuca*, Poaceae and Casuarinaceae are the determining taxa. The Group D surface samples from *Nothofagus* forest once again bear no resemblance to the fossil samples, and the analysis shows that the coastal surface samples appear to have a time depth of several thousand years.

5.5 Discussion

The sediments retrieved from Lac Saint Louis are Holocene in age and record the rapid rise in sea level that followed global deglaciation, stabilising around 5500 yr BP. The stratigraphy and pollen records of Lac Saint Louis also record the change of the site from an open system to a closed freshwater swamp. From 3000 yr BP human impact on the landscape surrounding the site is recorded in the conversion of lowland forest to savanna.

The basal sediments from the swamp reflect both marine (the shell and blue quartz sand lenses) and fluvial (micaceous sand) origins of material, indicating an open system. The bulk of the sediments probably originate from the rapid formation of the Coulee River delta during Holocene sea level rise, and hence have a terrestrial origin. With the stabilisation of sea level at around 5500 yr BP peat accumulated at the site.

The different sands found throughout the Lac Saint Louis sediments reflect the different origins of material and hence the different processes operating over time. Micaceous fragments found throughout the lower sediments are suggestive that the site was open to flooding from the Coulee River. Micaceous sand was not deposited in the sediments after 3500 yr BP. The mineral magnetic signal also changes after 3900 yr BP, possibly reflecting less of the clay mineral deposition from the river which originates from an iron-rich catchment. The sands at the northern end of the swamp appear to arise from the ridges surrounding the site given their similarity in colour and size to that found in the soil profile sampled at the base of the ridges. The sand layers at around 1m depth in SL1991 and core 5, but which are absent from the more centrally located cores, probably reflect the proximity of these cores to the edge of the swamp. The coarse quartz sand layer underlying the reddish brown peat in cores 6 and 7, and which correlates to before 3100 yr BP, differs considerably from the other cores, suggesting an origin from outside the local catchment. Taken together this evidence suggests that prior to around 3500 yr BP the swamp was an open system, becoming closed off after 3500 yr BP. This may have resulted through floodplain deposition closing off the present basin. The sandy clay at the northern end of the swamp and peat at the southern end are suggestive of shallow water conditions, while free standing water toward the centre of the swamp led to the accumulation of organic mud.

There is wood throughout many of the cores prior to 3500 yr BP suggesting the presence of a swamp forest. The rapidly accumulating sediments and their position so close to modern sea level make a mangrove forest seem likely. While there are no macrobotanical remains indicative of mangroves, such as preserved leaves or pneumatophores, there is mangrove pollen in the SL1991 fossil pollen core. Studies elsewhere have used the ratio of mangrove pollen to non-mangrove pollen and spore taxa to determine the presence of mangrove forest (Clark and Guppy, 1988; Crowley *et al.*, 1990; Grindrod, 1985, 1988; Thanikaimoni, 1987). Values of more than 50 % *Rhizophora* pollen in this pollen sum are usually cited as evidence for the presence of a *Rhizophora* dominated mangrove forest. However, the pollen evidence from SL1991 does not support the presence of a mangrove forest during the closing stages of Holocene sea level rise. Here the values of *Rhizophora* and indeed the total mangrove

pollen assemblage is less than 30 %. From surface sample work within mangrove forest of northeastern Australia Grindrod (1985) reports on how *Rhizophora* pollen can be transported some distance inland from the source plant by wind dispersal. The percentages of *Rhizophora* at Saint Louis are more indicative of this. Conversely, *Brugeria* and *Avicennia* pollen has a more local origin (Grindrod, 1985) and the presence of *Avicennia* pollen and *Lumnitzera* pollen suggests that the landward fringe of the mangrove forest is near to the site. As no Chenopodiaceae pollen or distinctly degraded pollen was encountered in the SL1991 core, the core site appears never to have been a high tide mud flat. Today the landward edge of the mangrove zone is separated from the southern end of the swamp by a 140 m expanse of higher ground with grassland and small plot gardens.

The pollen in the percentage diagrams between 5450 and 3500 yr BP at SL1991 is suggestive of the establishment of a freshwater swamp, with Cyperaceae, *Melaleuca* and fern spores prevalent in the pollen spectrum. *Avicennia* pollen begins to accumulate after 4300 yr BP suggesting the development of the landward side of the mangrove zone.

Human impact is defined in the pollen record at 3100 yr BP with a sand layer followed by the dramatic increase in charcoal and the conversion of the surrounding landscape to savanna. Charcoal is present in the record prior to 3100 yr BP although at much lower concentrations and for most of the record from a much larger catchment. Similarly, elements that constitute savanna are also in the record prior to 3100 yr BP, although the percentages are somewhat lower and they are presumed to be growing on the site as swampland vegetation. In addition the percentages of lowland forest taxa such as *Araucaria*, Cunoniaceae, *Macaranga*, Palms and several unknown types decline after 3100 yr BP. These overlapping signals could constitute the removal or decline of forest and the expansion of *Melaleuca* and grass into the surrounding landscape.

The geomorphically dynamic position of Lac Saint Louis adds a degree of difficulty to interpreting natural verses human induced environmental change. The decline in *Rhizophora* percentages coincident with the charcoal increase and sand layer may

initially suggest that people had a direct impact on mangrove vegetation. However, the concentration diagram illustrates that the deposition of *Rhizophora* pollen did not change at 3000 yr BP, and that it is only after 2000 yr BP that its concentration declines significantly. This maybe due to a prograding coastline. Instead it is the dramatic increase in concentration of pollen from terrestrial and swamp vegetation in the sediment record at 3000 yr BP that leads to the apparent decrease in mangrove taxa, when considered in relative terms. Thus the increase in pollen concentration at this point may stem from an increasing openness of the site and an increase in the landscape of plants that produce large amounts of pollen. This was also the case at Plum, although there was some time lag.

The only date so far obtained for terrace use on New Caledonia is on the taro terraces at Col de Pirogue; 1200 yr BP (Sand, 1996). The formation of the yam terraces at Lac Saint Louis is very loosely assigned to the period after 1900 yr BP based on the changes in SIRM and susceptibility measurements which are probably related to the inwashing of fine topsoil. Charcoal accumulation resumes higher levels and the degree of organic content increases possibly as a result of nutrient enrichment from the fine clays. This is the time when Cyperaceae dominates the swamp surface. The palynological richness of the site also decreases after this time, reflecting at least in part, the changing floristic richness of the vegetation types within the pollen source area (cf. Birks and Line, 1992). This could be expected with clearance for cultivation. However, *Dioscorea* (yam) type pollen was only detected in the surface samples along with several European introductions, including pollen from some of the contemporary garden plots. Given the entomophilous nature of *Dioscorea*, very little pollen of this genus may get into the sediments. The difficulties surrounding the detection of another tuberous crop plant, sweet potato, in pollen preparations has been investigated by Atkin (in prep). No other companion planting pollen types were found in the fossil record.

The detection of food plant pollen at Lac Saint Louis may only be possible with a counting strategy that specifically targets the search for cultivars rather than attempting to count the entire suite of pollen. The processing of much larger samples may also be advantageous given the presumed low concentrations of pollen that are dispersed. As an

alternative method, phytolith analysis may also be of use in determining the beginnings of agriculture at the site. However, all the studies above need to be carried out in addition to a general reconstruction of environment, such as that already done, so that they can be placed in context.

Like Plum there is no stratigraphic evidence within the swamp sediments of large scale geomorphic change, even though burning and the creation of yam terraces took place within such a small catchment. Only further coring and drilling of the floodplain will help resolve the evolution of the site from estuarine environment to freshwater swamp and any role that people may have had in changing the geomorphic nature of this environment.

5.6 Summary

The pollen data and stratigraphic data and their tentative interpretation are summarised in Table 5.4.

Table 5.4: Summary of environmental changes at Lac Saint Louis since 6000 yr B.P.

Period (yr B.P.)	Site	Regional Environment	Environmental Change
<i>Before 5500</i>	Estuarine environment. Open to influence of bay and formation of Coulee River delta.	Coastal rainforest; input of regional pollen from Coulee River.	Holocene sea level rise recorded in the rapid sedimentation rate of these sediments below 1.5m depth. Stabilises around 5500
<i>5500 - 3100</i>	Gradual development of Cyperaceous swamp. Intermittent flooding from Coulee River. Free standing freshwater conditions after 3500 yr B.P.	Coastal rainforest. Regional pollen input from Coulee River probably became less over time. Low amounts of charcoal in swamp sediments.	Development of Cyperaceous swamp with associated change from large regional catchment to small coastal swamp with small local catchment.
<i>3100 - present</i>	Cyperaceous swamp.	<i>Melaluca</i> , Myrtaceous shrubs and grass dominate, with <i>Casuarina</i> becoming more important over time. Fern spore taxa increase dramatically and stay high and are probably indicative of ongoing disturbance. Large amounts of charcoal in swamp sediments.	Human impact at 3100 yr B.P. Sudden increase in charcoal and conversion of surrounding landscape to savanna. Creation and use of yam terraces possibly around 1900 yr B.P.

Chapter 6 Environmental Change at Canala Swamp

3000 to 0 yr BP.

6.1 Introduction

The leeward coast of New Caledonia receives considerably more rainfall than the drier southwest coast. Therefore swamp sites from this side of the island potentially provide important comparisons with the records from the southwest coast at Plum and Saint Louis where savanna or open landscapes have been interpreted as possibly resulting from the actions of people rather than climate. A reconnaissance for swamp sites on the northeast coast was carried out in 1992 and 1993 with a number of sites in the Canala region identified as being potentially suitable for examining the issue of human impact on the landscape. However, land ownership of several sites was hard to determine and hence permission to core the sites could not be given in the time available for fieldwork. As a consequence only one site was cored, a freshwater swamp behind mangrove forest in Canala.

6.2 Site Description

Canala Swamp is situated behind a mangrove forest at an elevation of only 2 to 3 m asl (Figure 6.1; Plate 6.1). While mangrove stands are well developed on New Caledonia, they occur mostly on the wind sheltered southwest coast, as much of the northeast coast of New Caledonia is composed of steep mountain sides that fall steeply toward the sea. The vegetation of the swamp surface is dominated by *Typha* and the mangrove forest is composed primarily of *Rhizophora* sp. A thicket of *Acanthus silicifolius* marks the boundary between the swamp and the mangrove system. The swamp comes under the influence of the Canala River during times of flood, providing the swamp with a potential catchment area of over 100 km². The average annual rainfall for the region is between 2000 and 2500 mm per year, in contrast to Plum and Saint Louis which receive between 1300 and 1500 mm (Section d'Hydrologie, 1981). The floodplain on which the site is located is made of Quaternary alluvium, the slopes to the south are composed of

Tertiary basalts, and the headlands to the north are primarily peridotites (Figure 6.1; Paris, 1981).

An embankment around 1.5 m high extends out onto the swamp (Figure 6.1; Plate 6.1). In 1992 this provided valuable access out onto the swamp surface which was covered in water to a depth of around 1 m. The embankment does not appear in the air photos taken in 1982, although numerous old drainage ditches do. Between January 1992 and a return visit in October 1993, drainage ditches were dug (Plate 6.2) and construction begun on an airstrip at the northern end of the swamp (Figure 6.1). Both drainage ditches originate from road culverts. Shells from the base of the eastern drainage ditch are shown in Plate 6.3.

The vegetation of the surrounding landscape has been considerably modified by people. Around 50 to 60 % of the surrounding slopes are grassland or savanna composed of *Melaleuca quinquenervia* and grass, with small pockets of secondary lowland forest in the hollows. Cultivated tree species such as coconut, banana, mango and avocado are prevalent, and small gardens growing European introductions are common throughout the area. Sugarcane is also grown and long straight lines of bamboo that resemble fence lines are found. Inland from Canala in a number of the river valleys are extensive relict taro terraces.

There is no published archaeology for the area, although a site containing Podtanean pottery, which is contemporaneous with Lapita, is shown on the map of archaeological sites for New Caledonia (Sand, 1996). Sand (1996) comments on the seeming lack of Lapita sites for the east coast, but points out that this is largely due to a lack of inventory programmes and excavations.

6.3 Methods

In January 1992 a 350 cm core was collected with the stiffness of the basal clays limiting further coring. On returning to the laboratory three bulk sediment samples were submitted for radiocarbon dating. A duplicate core was collected from Canala swamp in

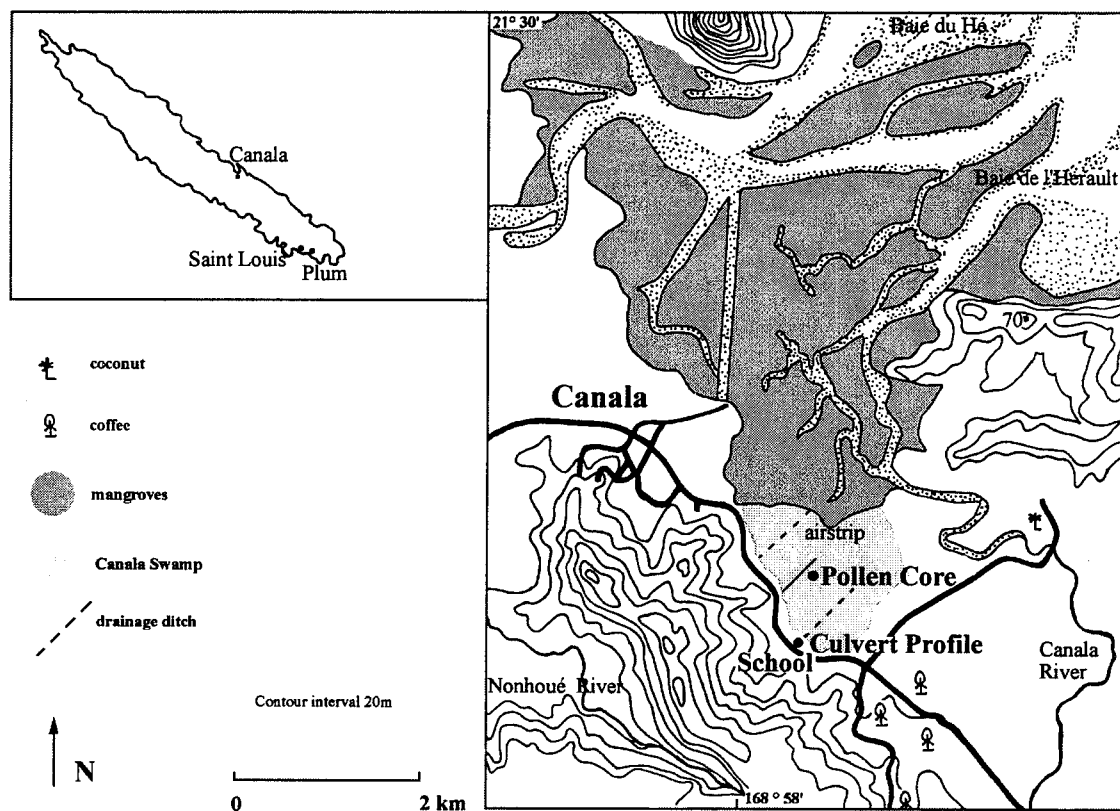


Figure 6.1: Location map of Canala swamp, showing pollen core, culvert profile, drainage ditches and approximate position of new air strip.

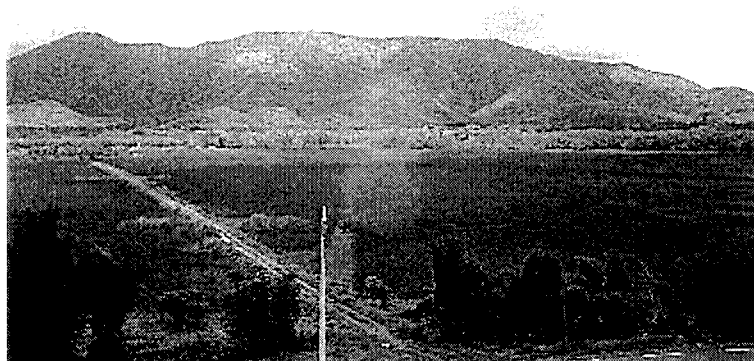


Plate 6.1: View of Canala Swamp in January 1992 looking to the east from above main road. Visible is the embankment that has been built on the swamp surface.



Plate 6.2: View of eastern drainage ditch looking inland toward school.



Plate 6.3: Shells from base of eastern drainage ditch.

1993 with one bulk sediment sample submitted for conventional C^{14} dating and 3 samples of plant material submitted for AMS dating. A stratigraphic description of the swamp sediments was recorded in the field. Sediments exposed at the road culvert near the school (Figure 6.1) were also described.

The pollen and charcoal analyses were carried out on the core collected in 1993. Samples for pollen and charcoal were taken every 10 cm to 300 cm and processed using the standard techniques outlined in Appendix 1. Charcoal concentrations were estimated using the point count method (Clark, 1982). Many of the samples are dominated by *Rhizophora* pollen and so counting proceeded in those samples until at least 200 *Rhizophora* grains were encountered. A target of 200 terrestrial pollen grains was attempted for all other samples.

6.4 Results

Stratigraphy

The locations of the culvert profile and the pollen core can be seen in Figure 6.1. The surface of the sediments described is approximately 1.5 m above the swamp surface and the description finishes at the water surface in the ditch. The water surface in the ditch lay almost at the swamp surface (Plate 6.2). The top 90 cm of the profile contains black silty organic clay alternating with gravels in a clay matrix (Figure 6.2; Table 6.1). Wood is found throughout this top 90 cm. From 90 cm to 110 cm is a very dark grey sandy clay, which is much less organic than the overlying silty clay. The contact between this unit and the underlying sandy clay with gravels slopes toward the swamp. This lower unit is more weathered than the overlying units.

The upper 250 cm of the pollen core is largely peaty clay and fairly homogenous in colour (Figure 6.2; Table 6.2). The sediments appear not to contain coarse plant remains indicative of mangrove sediments, such as leaves or wood. Below 250 cm there are sand layers and shell fragments. Shell debris from the bottom of the drainage ditch that originates from near the school was shown in Plate 6.3. The ditch is approximately 1.5 m deep. This suggests that the swamp sediments shallow inland.

Table 6.1: Stratigraphic description of culvert profile near school.

Depth cm	Description
0-22	Silty organic clay. Black.
22 - 35	Gravels in organic clay matrix. Gravels 3 - 4 mm.
35 - 48	Silty organic clay. Black.
48 - 76	Gravels in organic clay matrix. Gravels decrease with depth. Gravels up to 10 mm in diameter and sub-rounded..
76 - 90	Silty organic clay. Black.
90 - 110	Sandy clay. Less organic. Very dark grey.
110 - 180	Sandy clay with gravels. Dark greyish brown with brownish yellow mottles. Clay and gravels much more weathered than above. Gravels up to 15 mm in diameter and fairly angular. Finishes at water surface.

NB: Wood fragments throughout upper 90 cm.

Table 6.2: Stratigraphic description of pollen core.

Depth cm	Description
0 - 20	Clayey peat. Very dark greyish brown. Poorly humified. fibres vertical.
20 - 58	Peaty clay. Dark greyish brown. Very fibrous. Fibres large and not vertical. Change from clayey peat to peaty clay is gradual.
58 - 62	Peaty clay. Black and more organic.
62 - 140	Peaty clay. Dark grey. Increasing clay and becoming greyer with depth. Large pieces of sedge between 120 and 130 cm.
140 - 148	Clayey peat. Very dark grey.
148 - 250	Peaty clay. Dark grey changing gradually to dark greyish brown with depth. Sand content increases and peat decreases between 190 and 210, however sand content low.
250 -251	Coarse sand layer.
251 - 261	Peaty clay.
261 - 265	Coarse sand layer. Includes minor gravels (very round) and some shell fragments.
265 - 272	Organic sandy clay. Very dark grey.
272 - 278	Clayey coarse sand layer. Lots of rounded quartz.
278 - 330	Organic sandy clay. Dark grey. Occasional whole shells. Lense of clayey sand at 298 - 300 cm. Wood fragments also found at this depth..

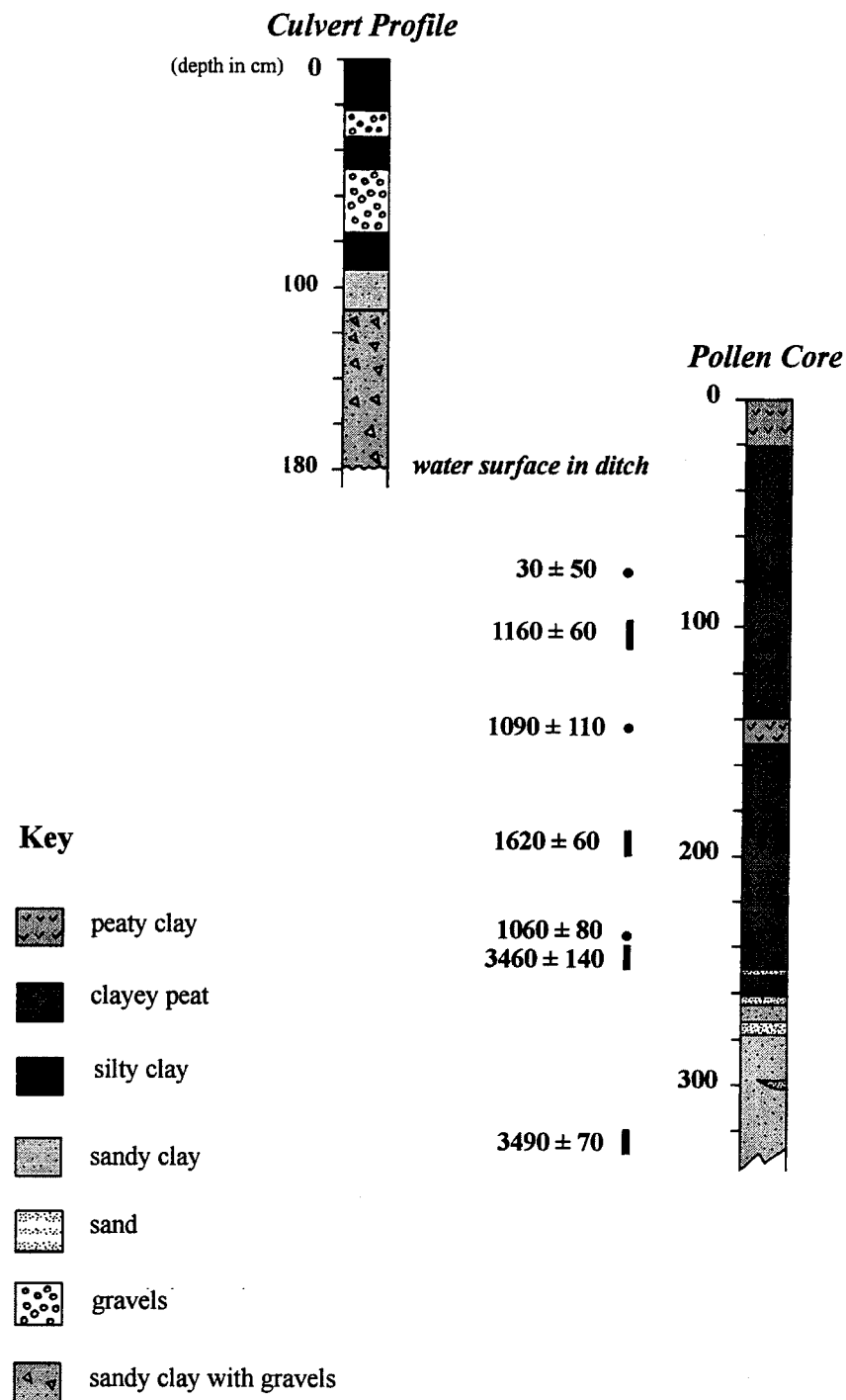


Figure 6.2: Stratigraphic diagrams of pollen core and culvert profile. Solid rectangles are conventional radiocarbon dates. Solid dots are AMS dates. Horizontal distance between profiles is around 850 m.

Radiocarbon Dating

The seven radiocarbon dates from the Canala Swamp pollen core (Table 6.3) reveal that the sediments are late Holocene in age with the basal sediments deposited around 3500 yr BP. The two dates at around 240 cm depth are not included in the age depth model (Figure 6.3) as the disparity between them is too great and cannot be reconciled. Using regression analysis, a straight line of best fit has been placed through the remaining ages giving a mean sedimentation rate of 1 mm/yr. The top 20 cm, which contains more clay than the underlying unit plus vertical plant fibres, may have been deposited more rapidly.

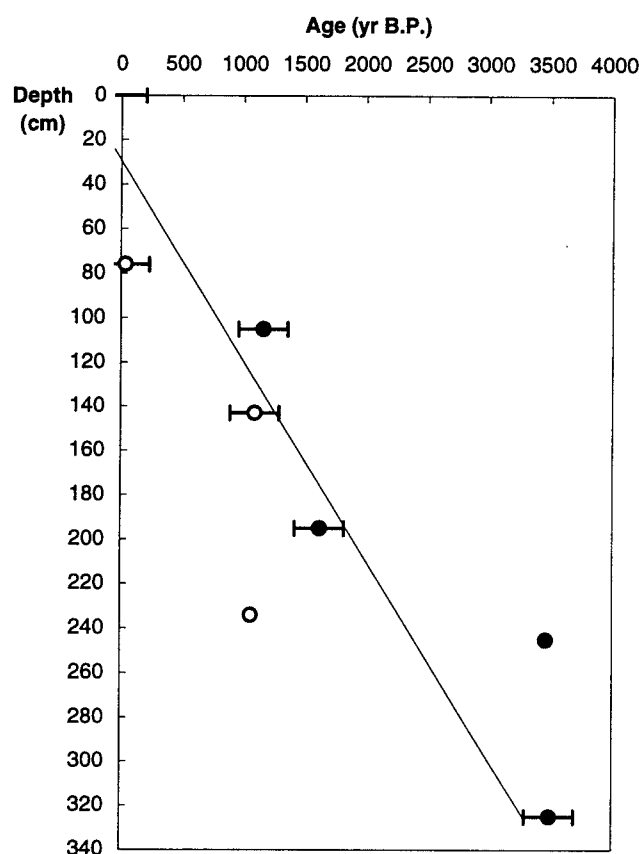


Figure 6.3 Age depth model for Canala Swamp pollen core. Standard deviation on ages shown at 2 sigma. Hollow circles indicate AMS dates. Ages without error bars are not included in model.

Table 6.3: Radiocarbon ages from Canala Swamp pollen core.

Depths in cm	Lab Number	Conventional Age yr B.P.	Calibrated Age yr BP (range) (2 sigma)	Calender Age (range) (2 sigma)	Sample Type
76-77	OZB 952	30 ± 50	0* (256 - 0*)	1955* AD (1694 - 1955*)	Horizontally bedded sedge material
99-109	Beta-52259	1160 ± 60	1062 (1232 - 939)	888 AD (718 - 1011)	Bulk sediment sample
143-144	OZB 951	1090 ± 110	972 (1079 - 750)	978 AD (871 - 1200)	Horizontally bedded sedge material
190-200	Beta-52260	1620 ± 60	1523 (1554 - 1353)	427 AD (263 - 597)	Bulk sediment sample
234-238	OZB953	1060 ± 80	953 (1161 - 785)	997 AD (789 - 1165)	Diagonally bedded organic material (bark?)
240-250	Beta-52261	3460 ± 70	3694 (3887 - 3487)	1745 BC (1937 - 1537)	Bulk sediment sample
320-330	Beta-70395	3490 ± 70	3796 (3924 - 3574)	1847 BC (1974 - 1624)	Bulk sediment sample

Calibrated using Stuiver and Reimer (1993).

AMS date

0* represents a "negative" age BP

1955* denotes influence of bomb C¹⁴

Fossil Pollen

The pollen sum used for Canala is slightly different to that adopted for the other pollen diagrams. As mentioned in Chapter 5, it is common when dealing with mangrove rich sites for the pollen sum to be calculated as the sum of all pollen and spore types. Table 6.4 is the key to the pollen sum categories presented in the summary diagram (Figure 6.4). The individual curves in Figures 6.4 and 6.5 are based on this total pollen sum.

Zonation of the pollen diagrams was carried out using the total pollen sum, and on taxa with a value of more than 5% in at least one sample. This resulted in 4 significant zones, designated Can-A, Can-B, Can-C and Can-D. The pollen diagram is described from the oldest to the youngest zone, with each zone accompanied by an inferred age range derived from the age model presented in Figure 6.3. Palynological richness was also calculated using a standardised pollen count of 100, in keeping with the other sites analysed.

Table 6.4: Key to pollen sum categories.
(See Appendix 3 for the lifeform and habitat of commonly occurring taxa.)

Category	Total Pollen Sum
Rhizophora	
Other mangroves and associated taxa	Includes all other mangrove tree and shrub pollen as well as the mangrove fern <i>Acrostichum</i> .
Terrestrial Taxa	All terrestrial tree, shrub and herbaceous taxa, including unknown types (eg, Type 39).
Ferns	All fern types except <i>Acrostichum</i> .
Typha	

Zone Can-A Inferred Age 3000 - 2800 yr BP.

The summary diagram in Figure 6.4 shows mangrove pollen verses all other pollen taxa. Figure 6.4 also illustrates all terrestrial taxa that have values of greater than 5% in least one sample. The remaining terrestrial taxa are illustrated in Figure 6.5. Zone Can-A is composed of only two samples from the organic sandy clay at the base of the core. Mangrove pollen comprises less than 10 % of the pollen sum in these two samples. The highest percentages of mangrove or associated taxa belong to *Excoecaria/Homalanthus* and the mangrove fern *Acrostichum*, at around 2% each.

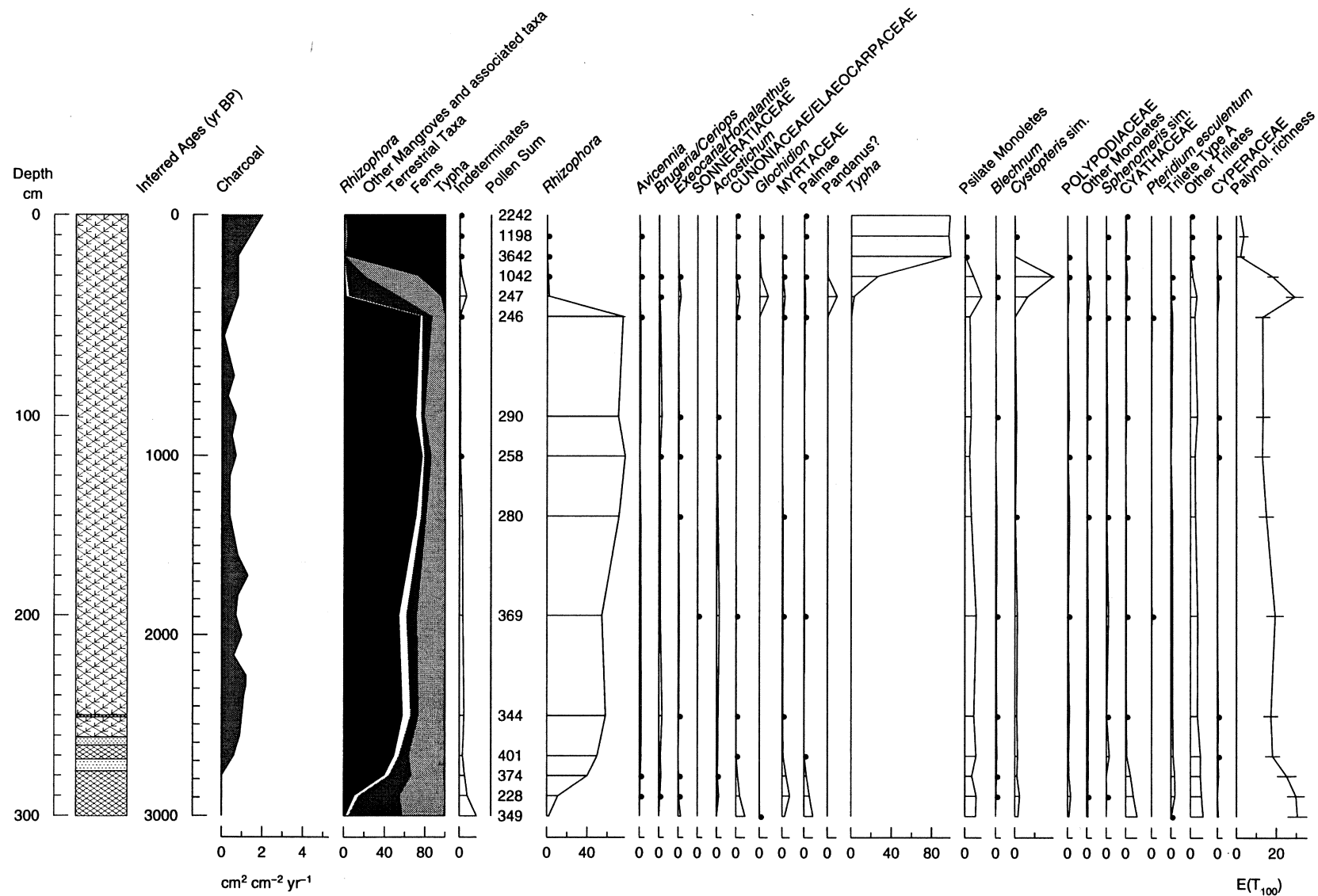


Figure 6.4: Percentage pollen diagrams for Canala Swamp. Shown is the summary diagram, terrestrial pollen with a value of greater than 5 % in at least one sample and ferns. Charcoal accumulation and palynological richness values are also shown.

Canala Swamp

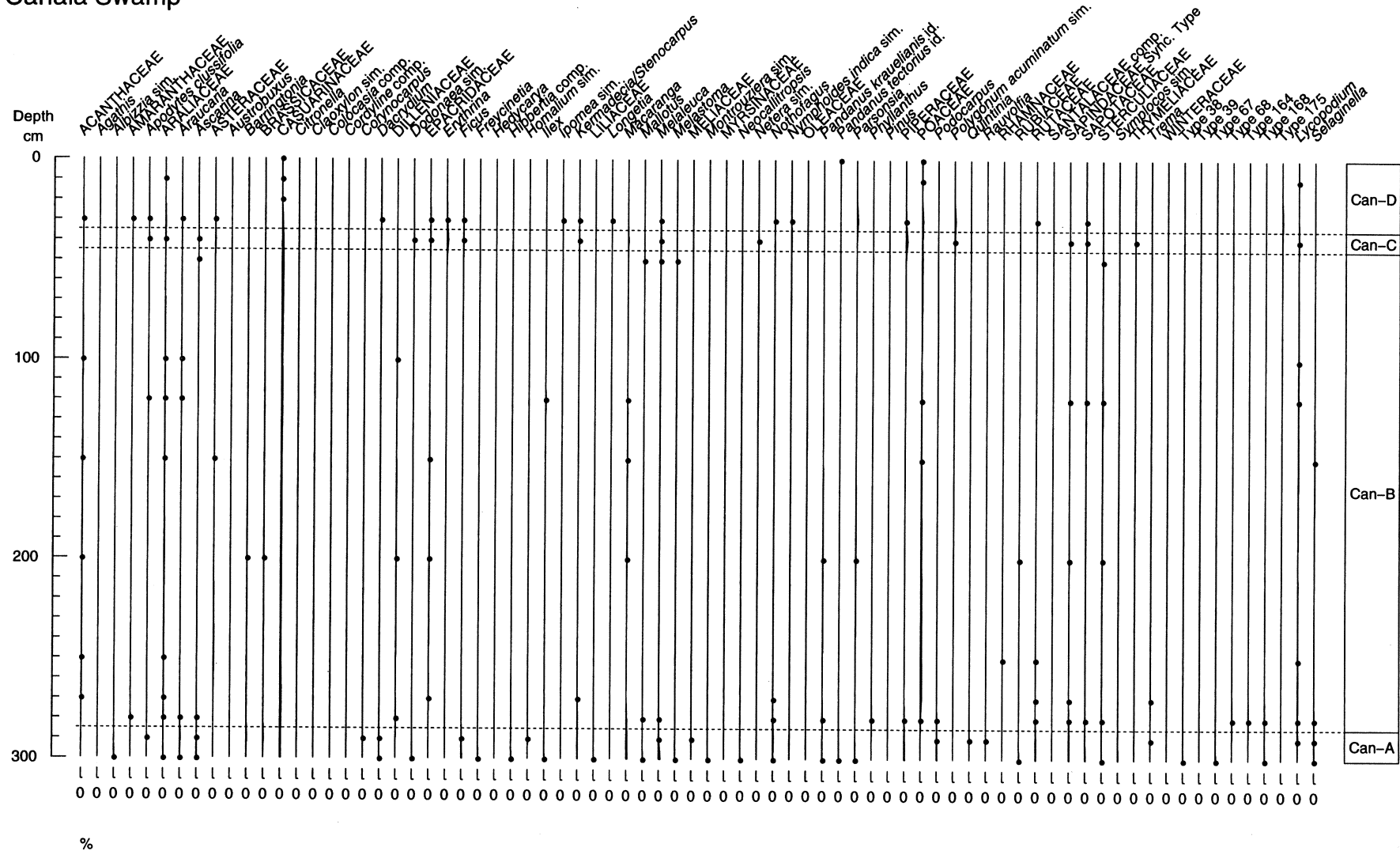


Figure 6.5: Terrestrial pollen from Canala Swamp with values of 5 % or less in all samples. Solid dots indicate a value of 1 % or less.

The pollen of *Excoecaria* and *Homalanthus* are difficult to separate, with the genera representing quite different habitats. *Excoecaria* is a mangrove genus, while *Homalanthus* can be a tree or shrub of lowland forest and is often an indication of disturbance. Fern taxa, other than *Acrostichum* account for around 40% of the pollen sum. Terrestrial taxa composed chiefly of Cunoniaceae, Myrtaceae and Palmae comprise over 40 % of the pollen sum (Figure 6.4 and 6.5) and the palynological richness values are high. There was no charcoal observed in these basal sediments.

Zone Can-B Inferred Age 2800 - 170 yr BP.

The pollen of zone Can-B is dominated by *Rhizophora* pollen (between 40 and 70 %). The terrestrial pollen accounts for less than 10 % and the fern spore percentages decrease slowly from 40 to 20 % of the pollen sum. The diversity of taxa is lower than the previous zone. Charcoal accumulation begins in this zone and in general the values are between 0.5 and 1.5 cm² cm⁻² yr⁻¹.

Zone Can-C Inferred Age 170 - 50 yr BP.

This zone is constituted by a single sample and is dominated by terrestrial taxa and ferns (Figure 6.4). *Rhizophora* pollen accounts for less than 2 % of the pollen sum. *Glochidion* pollen, and pollen grains that possibly belong to a *Pandanus* species dominate, along with Cunoniaceae and Myrtaceae (Figure 6.4). *Excoecaria/Homalanthus* is also significant at around 2%. All are common lowland forest genera. *Cystopteris* type fern spores and psilate fern spores dominate the ferns, at greater than 10 % each. Palynological richness increases and is comparable to that calculated for the Can-A samples (Figures 6.4 and 6.5). Charcoal values remain constant.

Zone Can-D Inferred Age 50 - 0 yr BP.

Zone Can-D is overwhelmingly dominated by *Typha* pollen at around 95 % of the pollen sum. Counts of all taxa other than *Typha* were usually well below 100. This makes interpretation of the surrounding vegetation difficult and resulted in palynological richness values that are the lowest calculated for any of the New Caledonian samples.

The highest values of charcoal occur in this zone, with the greatest concentration in the surface sample.

6.5 Discussion

Pollen from Canala swamp in conjunction with the stratigraphy of the core suggests a change from estuarine conditions to mangrove swamp at around 2800 yr BP. Values of more than 50 % *Rhizophora* pollen in the total pollen sum are usually cited as evidence for the presence of a *Rhizophora* dominated mangrove forest (Clark and Guppy, 1988; Crowley *et al.*, 1990; Grindrod, 1985, 1988; Thanikaimoni, 1987). The basal sediments in the pollen core at Canala contain pollen indicative of lowland rainforest in both composition and diversity. The pollen assemblage then changes to that of a mangrove swamp.

The sandy clay sediments with shells found at the base of the pollen core (3.3 m depth), as well as the shells from the base of the drainage ditch (1.5 m depth) could be indicative of coastline progradation. The sandy sediments with shell fragments and pollen from a diverse source area are in keeping with the position of the site originally being on the seaward edge of the mangrove. Progradation would then have led to the site being beneath mangrove forest, and with continued sedimentation the site emerged after 200 yr BP as a freshwater backswamp.

A local rise in sea level could also have led to the patterns observed in the pollen assemblage. However, the sand layers and sandy clay at the base of the core appear to be coarse for a swamp environment behind a mangrove zone which most commonly are composed of organic silts and clays. The shell fragments also suggest an estuarine influence.

Although only a single sample represents the initial emergence from a mangrove system, the pollen in the record at this point is suggestive of lowland forest rather than a savanna environment. The transformation of the site into a *Typha* swamp occurred sometime this century, with *Typha* being introduced since European settlement (Mackee, 1985).

Charcoal accumulation in the record and the change to a mangrove swamp commence simultaneously at around 2800 yr BP. Charcoal counts from mangrove environments are often not attempted as they can be complicated by two factors. The first is that the mineral pyrite, which is found in mangrove sediments, and charcoal may be confused. However, pyritic material is removed by hydrofluoric acid and all samples have been treated with this. A second complication arises due to the likelihood that a majority of the charcoal in the mangrove sediments is waterborne with potentially large source areas. This makes links to local changes difficult or meaningless. What is interesting at Canala, is that no charcoal is found before the mangrove phase, but from this time onward it is in good chronological accordance with the charcoal records from Plum and Saint Louis, and the commencement of the archaeological record on New Caledonia in general.

The sediments described in the drainage ditch near the road culvert appear to represent an old fan deposit overlain by younger material. The alternation between silty clay layers and gravel layers in the upper part of the section seems to represent stable episodes of soil formation and periods of slope instability when coarse erosion products were deposited. Whether the deposition of any of these units coincides in time with New Caledonia's initial colonisation, or whether they have been deposited since European occupation, cannot be answered at this point. Dating of this fan and similar deposits may shed some light on this question.

Unlike the Plum and Saint Louis sites most of the pollen record at Canala has little information that can be interpreted for the terrestrial environment and the landscape changes brought about by Melanesian people. If historical records exist for the region, they may give a better understanding of what the landscape was like at the time of European settlement. It seems likely that the old drainage lines seen in air photos stem from the European era, as the site was a mangrove swamp up to European settlement.

6.6 Summary

The pollen data and stratigraphic data and their tentative interpretation are summarised in Table 6.5.

Table 6.5: Summary of environmental change at Canala Swamp since 3500 yr BP.

Period (years BP)	Environmental Conditions
3500 - 2800	Site is estuarine on seaward edge of mangrove zone. Pollen catchment for site very large (Canala River). Pollen indicative of lowland forest. No charcoal in sediments.
2800 - 150	Mangrove swamp. Local pollen dominates. Charcoal in sediments throughout zone. Constant progradation of mangrove zone.
150 - 0	Backswamp. Initially records lowland forest pollen rain. Pollen signal overwhelmed by local pollen rain when site becomes <i>Typha</i> swamp this century. Charcoal throughout, greatest concentrations in surface samples.

Chapter 7 Late Quaternary Environmental Change and Human Impact in New Caledonia

7.1 Overview of findings

Palynological evidence in the preceding chapters provides a broad framework for assessing late Quaternary environmental change in New Caledonia, in particular the impact that human colonisation had on the landscape. The major findings arising from this research are summarised below.

- There was no large scale change to lowland vegetation at the LGM. However, the late glacial is marked by a charcoal peak and local disturbance which appears indicative of a drier environment and possibly a period of increased droughts. The charcoal is evidence that fire has a long history in the New Caledonian environment.
- Human impact is discernible in the record from 3000 yr BP, which is in accordance with the known archaeological record for New Caledonia. The primary evidence is a significant and consistent increase in charcoal concentration associated with a vegetation change towards an open landscape. Changes to sedimentation processes through human activity, such as increased slope instability, are less convincing for the catchments studied.

7.2 Climate Change in New Caledonia since the LGM

The pollen sequences and sedimentary records from Plum catchment on the leeward west coast of New Caledonia yield information on long term environmental change. The present day west coast is primarily a landscape dominated by savanna which is promoted and maintained by anthropogenic fires. Within this landscape, lowland rainforest is restricted to island like fragments usually in sheltered valleys. Lowland rainforest occurs on ultramafic and non-ultramafic substrates, with no obvious compositional differences between rainforest on the different substrates. This has always been of ecological interest as the vegetation communities surrounding the

rainforest pockets are markedly different between substrates. In the ultramafic terrain it is maquis with a ground cover of Cyperaceae and ferns, and in non-ultramafic terrain savanna.

Within the Plum River valley today, the vegetation is dominated by a stunted and species poor open maquis on the ultramafic substrate, with *Melaleuca* woodland and grass on the non-ultramafics. Coastal forest is found near the mouth of the Plum River and the surface of Plum Swamp is covered in Cyperaceae. However, during the height of the last ice age, at around 18,000 yr BP, vegetation at the site was dominated by *Pandanus* and *Casuarina*, both suggestive of littoral forest. Other abundant pollen types are indicative of a combination of littoral forest and lowland rainforest, such as *Araucaria*, *Apodytes*, Cunoniaceae, *Dacrydium*, Myrtaceae, *Nothofagus*, Palmae, and *Macaranga*. While the genus *Macaranga* is often considered a pioneer lowland rainforest species, *Macaranga alchorneoides* is a primary species of lowland rainforest in valleys near sea level on ultramafic substrates (Cherrier, 1982). The suggestion was made in Chapter 4 that the decrease in *Pandanus* and increase in *Macaranga* pollen around 18,000 yr BP may have been due to the shrinkage of littoral vegetation and expansion of lowland rainforest as the valley bottom became drier. In general though, conditions at the LGM within the Plum River catchment were such that a forested valley was maintained.

There is some evidence that an increase in periodic drought may have occurred between 16,000 and 12,000 yr BP. During this time littoral forest is briefly destroyed in association with significant charcoal accumulation. The vegetation and charcoal changes are also associated with a change from inorganic to organic sedimentation within the site at around 16,000 yr BP. The start of organic sedimentation at this time could be indicative of greater productivity in warmer and shallower water, although the significance of the older inorganic sediments has not been established as yet. What is known about the inorganic sediments is that they are derived primarily from the badland region in the headwaters of the valley, suggesting that the slopes either side of the valley remained forested and stable.

Periodic drought is only an hypothesis at this point, as the data cannot resolve such fluctuations in climate. However, this is favoured over a wholesale drying of the climate given that the main changes in the vegetation seem to be in response to fire, and forest appears to be maintained in the valley. A shift to maquis style vegetation cannot be ruled out though, as the maquis and rainforest overlap considerably at the genus level, the best resolution attainable for the majority of the pollen types.

The conditions required for the ignition of fires within rainforest on New Caledonia are hard to evaluate in the current landscape given the predominance of human activities. Fires, lit either intentionally or inadvertently, can burn rainforest up to 600 m altitude (sometimes higher), where average rainfall is greater than 3000 mm per annum. Such fires usually occur during very dry times, such as extreme El Niño years, where there is on average a 22% decrease in mean monthly rainfall for the year (Morliere and Rebert, 1986). Drought may therefore be the best modern analogue for such disturbance.

East of Plum, in the higher rainfall Plaine des Lacs region, the sites studied by Hope and Pask (1998) appear much older and their records are interpreted as not accumulating organic sediments after 25,000 yr BP. Although they are reported as not containing continuous Holocene records, there is some uncertainty surrounding the chronologies. Reconstructions of LGM vegetation for this region are therefore difficult. However, based on the available chronology for Lake Suprin, which appears the most robust in terms of radiocarbon dating and pollen counting, *Nothofagus* forest declines at the site and is replaced by *Gymnostoma* maquis around the time of the LGM. This may indicate drier conditions (Hope and Pask, 1998). LGM changes in 'humidity' were interpreted as accounting for some of the vegetation change seen in the ocean cores taken from the Loyalty Basin, between Grande Terre and the Loyalty Islands (Méon and Pannetier, 1994). These authors also found climatic interpretation from their data difficult. Latham (cited in Hope and Pask, 1998) has dated calcrete in a river terrace in the north of the main island to 18,000 yr BP and attributes the formation of this to a drier climate.

Fire may be associated with the vegetation change seen in the Plaine des Lacs data (Hope and Pask, 1998), as both sites, Lake Suprin and Lake Emeric, have charcoal

particles throughout their sediments. This indicates, along with the results from Plum, that fire has a long history in the New Caledonian environment.

Pollen types indicative of littoral forest and lowland rainforest are found in the Plum record from the LGM through to the late Holocene, punctuated by fire and vegetation change between 16,000 and 12,000 yr BP. Lowland rainforests on the west coast of New Caledonia today are maintained by precipitation and the exclusion of fire. They currently exist within an average yearly temperature range of between 23°-17°C (20° to 15°C for the coldest month) and yearly precipitation averages of between 1500 mm and 3500 mm (Sarlin, 1954; Mueller-Dombois and Fosberg, 1998; Section d'Hydrologie, 1981). Rainforest also exists in topographically moist environments that receive less than 1500 mm precipitation. The current precipitation average for Plum is around 1300 to 1500 mm per annum, with average yearly temperatures of between 26° and 20° C. Therefore the LGM estimates of a 2° to 4°C temperature depression in the tropical southwest Pacific, as outlined in Farrera *et al.* (*submitted*), can be accommodated by the Plum fossil data. Given the continued presence of pollen indicative of littoral and lowland rainforest species throughout the LGM and late glacial, it seems that precipitation depression was not significant at Plum. However, some consideration should be given to the occurrence of complete forest cover in the valley creating a topographically moist environment that may have withstood a greater precipitation depression. Vegetation indicators of rainfall less than 1000 mm in New Caledonia include sclerophyll forest and grassland on non-ultramafic terrain and ligno-herbaceous maquis on the ultramafics. There is no indication of a shift to either vegetation type in the record.

In general some of the most rapid changes to vegetation in the Australasian region occur during the transition from the late glacial to the Holocene; between around 12,000 and 9000 yr BP (Hope, 1976; Walker and Flenley, 1979; Kershaw, 1995; Haberle, 1998). At Plum the severity of what may have been drought affected years decreased significantly by around 12,000 yr BP and there was a gradual shift to a climate that presumably resembles the present day. This period was not marked by a major shift in vegetation type.

There is no evidence in the Plum pollen data for a Holocene optimum (hypsithermal) between 9000 to 5000 yr BP. The only indication of disturbance in the early part of the Holocene is the deposition of clay derived from the surrounding slopes during the mid-Holocene, around 4000 yr BP. This has been interpreted as a rapid and local event from its distribution across the swamp and the lack of any pollen. Interestingly though, the peats overlying this contain only poorly preserved pollen for a couple of hundred years. With the resumption of good pollen preservation at around 3200 yr BP the pollen record suggests that there has been little change to the composition of valley vegetation, although the relative values do change. *Macaranga* and *Araucaria* percentages decrease in percentage terms and Casuarinaceae increase. While this could be taken as evidence of slightly drier conditions, it can equally be seen as the colonisation of disturbed slopes by *Casuarina*. Slope disturbance has no precedent in the earlier part of the record.

The Saint Louis pollen record commences after sea level stabilisation at around 5500 yr BP. Peat accumulates at Saint Louis between 5500 and 3500 yr BP, with a period of poor pollen preservation similar to that of Plum at around 4500 yr BP. Deeper water conditions may have followed this given the change from peat to organic mud after 3500 yr BP. The late Holocene vegetation records from about 3000 yr BP at Saint Louis and 2500 yr BP at Plum are dominated by human impact, masking any climate signal in the record. Evidence for this is discussed at length in section 7.4.

7.3 Climate Change in the Western Pacific

Flenley (1998) illustrated how sketchy much of the lowland tropical LGM data was for southeast Asia and the western Pacific. The sparsity of data of a similar age from the tropical southwest Pacific makes meaningful comparisons of LGM climates difficult. In addition those records that do exist are separated by large distances and are taken from very different topographical and altitudinal positions in the landscape as well as different biogeographical realms. However, the available data has been summarised in Figure 7.1 and given how few LGM records there are from tropical western Pacific islands, the records from Easter island, the Galapagos islands and Hawaii are also

included. The interpretations of climate change shown in Figure 7.1 are those made by the respective authors.

Except for the equatorial (but elevated) Lake Hordorli, all sites are interpreted as having conditions slightly drier to much drier than present during the LGM (Figure 7.1). However, only one location, the Atherton Tableland, records a major vegetation shift to savanna. The sites from Atherton in northeast Australia differ significantly from the other sites in that the climate of the tableland is likely to have taken on more continental aspects during the period of lowered sea level at the LGM given the broad continental shelf in the region. The distance from LGM to present shorelines for most Pacific islands is small by comparison and the moderating influence of ocean circulation and temperature on island climate would be much greater. In addition, aboriginal burning is considered a component of the glacial record on the Atherton Tableland which, it is thought, greatly enhanced the savanna environment (Kershaw, 1986). While the environment around the Fraser island sites did not become savanna during the LGM, sclerophyllous vegetation, in association with fire, expanded across the island. Longmore (1997) does not discuss aboriginal burning as a component of the changes seen in the Fraser Island record given the lack of Pleistocene archaeology for the island. The 'possibly drier' conditions shown on Figure 7.1 for New Caledonia at the LGM is based on a consideration of the Plaine des Lacs data of Hope and Pask (1998) even though there is no evidence for drier conditions from this study alone.

The debate over whether the tropics cooled a little or a lot at the LGM stems from the lack of agreement between estimates of temperature from the deep sea ocean cores and the terrestrial data. Based on current ocean core data New Caledonia lies in a region of the tropical Pacific where SST's were around 2°C lower than present (Anderson *et al.*, 1989; Martinez *et al.*, 1994; Barrows *et al.*, 1996), although temperature data from corals around Vanuatu suggest that SST's in the region were around 4-6° C cooler at the start of the Holocene (Beck *et al.*, 1997). As Plum contains no positive data on LGM temperature depression it may prove more appropriate to investigate temperature depression for New Caledonia from a site at greater altitude. The Plateau de Dogny in

Age in yr BP.	Hordorli Lat. 2° S 780 m asl	Atherton Tableland Lat. 17° S 700 m asl	Fraser Island Lat. 25° S 100 m asl	New Caledonia Lat. 22° S 10 m asl	Fiji Lat. 17° S 800 m asl	Easter Island Lat. 28° S 100-400 m	Galapagos Islands Lat. 0° 650 m asl	Hawaii Lat. 20° N 450 m asl		
0	PRESENT CLIMATE	PRESENT CLIMATE	PRESENT CLIMATE	PRESENT CLIMATE	PRESENT CLIMATE	PRESENT CLIMATE?	PRESENT CLIMATE	PRESENT CLIMATE		
1000										
2000		WARMER AND WETTER	DRIER THAN PRESENT							
3000										
4000		PRESENT CLIMATE								
5000										
6000										
7000										
8000										
9000	FLUCTUATING				WARMING	BECOMING MOISTER				
10 000			BECOMING MOISTER	REMAINING SEASONAL						
11 000										
12 000	COOLER	COOLER AND VERY DRY	DRIER	DRIER	↑	COOLER AND / OR DRIER	NO RECORD	DRIER POSSIBLY COOLER		
13 000		COOLER AND DRIER								
14 000		POSSIBLY DRIER								
15 000										
16 000		NO RECORD		ASSUMED AS ABOVE						
17 000										
18 000										
19 000										
20 000										
21 000										
22 000										
Southern Hemisphere									Northern Hemisphere	

Figure 7.1: Summary of major climatic change documented in palaeoecological records from Lake Hordorli, Irian Jaya (Hope and Tulip, 1994); Atherton Tableland, north east Queensland (Kershaw and Nix, 1988; Kershaw 1976; 1981a; 1981b; 1994); Fraser Island, north east Queensland (Longmore; 1997); New Caledonia (this study; Hope and Pask, 1998); Fiji (Southern, 1986); Easter Island (Flenley and King, 1984; Flenley *et al.*, 1991); Galapagos Islands (Colinvaux, 1972; Colinvaux and Schofield, 1976); Hawaii (Hotchkiss, 1996). Driest and/or coldest period represented by shading. Pleistocene/Holocene transition (12,000-9,000 yr BP) bounded by dashed lines. The interpretations of climate change have been made by the respective authors.

central Grande Terre at an altitude of around 500 m is one location that may prove to have suitable sites. LGM sediments at this altitude may record the descent of montane species as is the case from other tropical locations such as Lake Hordorli (Hope and Tulip, 1994), Fiji (Southern, 1986) or Lake Pata from lowland Amazonia (Colinvaux, *et al.*, 1996).

The disturbance in the Plum record between 16,000 and 12,000 yr BP, whether reflecting a wholesale precipitation depression or increased seasonality leading to an increase in droughts, bears some similarity to other tropical records from the southwest Pacific. The Atherton Tableland and Fraser Island sites record arid conditions during this period, while on Fiji conditions were slightly drier. From New Guinea, although montane, Haberle (1998) reports a period of increased disturbance (possibly increased periods of drought) from 14,000 to 12,000 yr BP. The view for Australia and New Guinea generally, is that the increase in aridity during the late glacial arose from rapid temperature increase offsetting any precipitation increase (McGlone *et al.*, 1996).

Parallels between the spatial patterns of past climates and today, especially associated with important and well defined features of the general circulation system such as the Southern Oscillation, provide a relatively simple way of interpreting local changes in a global context (Salinger, 1981). The strongly seasonal, moist, subtropical climate of present-day New Caledonia is primarily controlled by the southeast trade winds which create the high orographic rainfall on the east coast and summits, and the rainshadow conditions on the west coast. In addition, tropical depressions generated to the north of New Caledonia in the summer are responsible for the high rainfall season between November and March and cold polar fronts from the southwest bring rainfall in winter. There is no pollen evidence in the LGM record from Plum to suggest that there was any significant temperature or precipitation depression at the site. From the vegetation changes seen in their Lake Suprin record for the LGM, Hope and Pask (1998) suggest that the modest sea level cooling proposed for the region (around 2° C or less) would have acted to greatly reduce the frequency of cyclones at this time leading to a slightly drier climate. Southern (1986:205-208) suggested that a temperature depression of greater than 2° C was required for the envisaged precipitation reduction at her windward

sites in Fiji during the late glacial. She suggested that lower SST's would have reduced cyclone genesis and other small tropical disturbances which provide much of Fiji's seasonal rainfall and that generally cooler SST's would also have reduced the moisture carrying capacity of the southeast trade winds. She also favours a weaker southern oscillation for the LGM, which would have led to less persistent trade winds thus further reducing precipitation and creating a more seasonal environment. The fires and vegetation disturbance in the late glacial record at Plum have also been interpreted as resulting from increased seasonality, namely increased periods of drought. Following Salinger's (1981) line above, the most common present day disruptions to the Southern Oscillation are El Niño years when drought is common in the western Pacific. However, SST's are not significantly lowered in the region around New Caledonia ($<1^{\circ}\text{C}$) and genesis for the rainfall shortage is situated in the eastern Pacific. The purpose of bringing ENSO into the discussion is not to suggest that this particular phenomenon was operating at the time, but rather this present-day example highlights that not all contributing factors to climate fluctuations will have an expression locally. That is, precipitation fluctuations on New Caledonia do not require local temperature reductions or the permanent movement of any of the important climatic zones. Additional independent proxy evidence for climate change from the islands and waters surrounding New Caledonia are needed before more positive statements can be made about the past climate systems that affected the island. In addition it is worth considering that the exposure of large areas of land during low sea level at the LGM and the resultant changes to atmospheric and oceanic circulations may not be analogous to the climatic patterns that exist today and the attempt to fit present-day circulation phenomena to late Pleistocene palaeoecological data may be misguided.

Unlike records from the temperate Northern Hemisphere, which have a well defined boundary between the Pleistocene and the Holocene, it is now emerging that this is not apparent for sites from the southwest Pacific. Instead a period referred to as the Pleistocene/Holocene transition (12,000 to 9,000 yr BP) is more appropriate for describing the move from glacial to interglacial conditions. While the apparent lack in synchronicity may result from real spatial differences in response to a changing climate, there seems no doubt that the interpretation of pollen data from floristically complex

locations, as well as the differing depositional processes and the varying quality of dating control must all contribute. However, it seems fair to assume that the extremes of the last glacial were over by 9000 yr BP and that most tropical islands had climates that approximated the present day. This is naturally an important assumption for the detection of human impact in the record.

Atherton Tableland and Fraser Island sites both record a significant reduction in *Araucaria* pollen at the LGM which does not recover during the Holocene. While Atherton has a mid-Holocene wet phase (Figure 7.1), the Fraser island water table data suggests that from 8000 to 2500 yr BP the environment of the island was drier than present (Longmore, 1997). By comparison the percentages of *Araucaria* pollen increase significantly during the Holocene at Plum, while *Casuarinaceae* pollen decreases. In combination with the constantly increasing *Pandanus* values this may indicate that the valley environment was moister in the early to mid-Holocene. The only form of disturbance during the mid-Holocene is a clay layer and a period of poor pollen preservation. The clay layer is thought to be the product of some form of large scale disturbance, such as a cyclone. Slightly more seasonal conditions could be responsible for the pollen-poor peat layers above this.

The search for evidence of the ENSO phenomenon, in particular its antiquity, in a wide variety of data is of particular interest at the present time given the important impacts it has on many human activities. The resolution of the data at Plum and Saint Louis is not appropriate for such an analysis as it is too coarse to pick up the inter-annual variability associated with ENSO. Therefore the pollen records constructed so far for New Caledonia cannot contribute to debates over when ENSO became a significant component of the Holocene climate. While there is some sort of catchment disturbance in the mid-Holocene, it does not seem to be maintained, and could have resulted from a single large scale event. A finer resolution study on the sediments from both Saint Louis and Plum may provide the required time intervals, but it is still questionable whether any climate signal could be obtained with the very strong signs of human impact that begin with the arrival of people in New Caledonia around 3000 yr BP.

7.4 Human Impact in New Caledonia

The Holocene records from Plum and Saint Louis both reveal major vegetation change following the colonisation of the island by people. The inferred ages for the commencement of human impact in the Plum and Saint Louis pollen cores are well within the realm of New Caledonian colonisation as determined by the archaeological record. Calibrated ages from the oldest archaeological levels in Grande Terre were presented in Chapter 1 and span around 600 years, from 3370 to 2760 yr BP. The inferred ages for the commencement of human impact in the pollen records are around 3200 for Saint Louis and 2250 for Plum.

Human impact has been determined from significantly increased levels of charcoal that are coincident with a shift from forest to an open landscape (Figure 7.2). Separating natural processes from anthropogenic influences in the palaeoecological record can be problematic in the Pacific region, owing to the lack of direct indicators for crop plants on the one hand, and possible climatic changes on the other (Flenley, 1994). So how is the conclusion of anthropogenic impact reached in the absence of direct evidence for economic plant use at Plum and Saint Louis? If people were responsible for the change at 3000 yr BP, how do we know that the 16-12,000 yr BP change does not have a human element? The primary reasoning stems from the level of disturbance and the maintenance of this new environment under present climatic and disturbance conditions. Criteria were set out in Chapter 1 to help define human impact in the record. The first of these was evidence of vegetation disturbance leading to more open vegetation, less forest cover and more secondary forest or shrub vegetation. At both Plum and Saint Louis the records shift in the late Holocene from ones dominated by taxa indicative of closed forest to ones dominated by Casuarinaceae, *Melaleuca* and grass. This vegetation change is synchronous with an abrupt and significant increase in charcoal, which is sustained through to the present. The major vegetation change is also non-synchronous between sites and is unparalleled in earlier periods of presumably more extreme climate than present. The late-glacial disturbance of the littoral forest at Plum in association with fire was not maintained and the wider catchment appears to have remained forested.

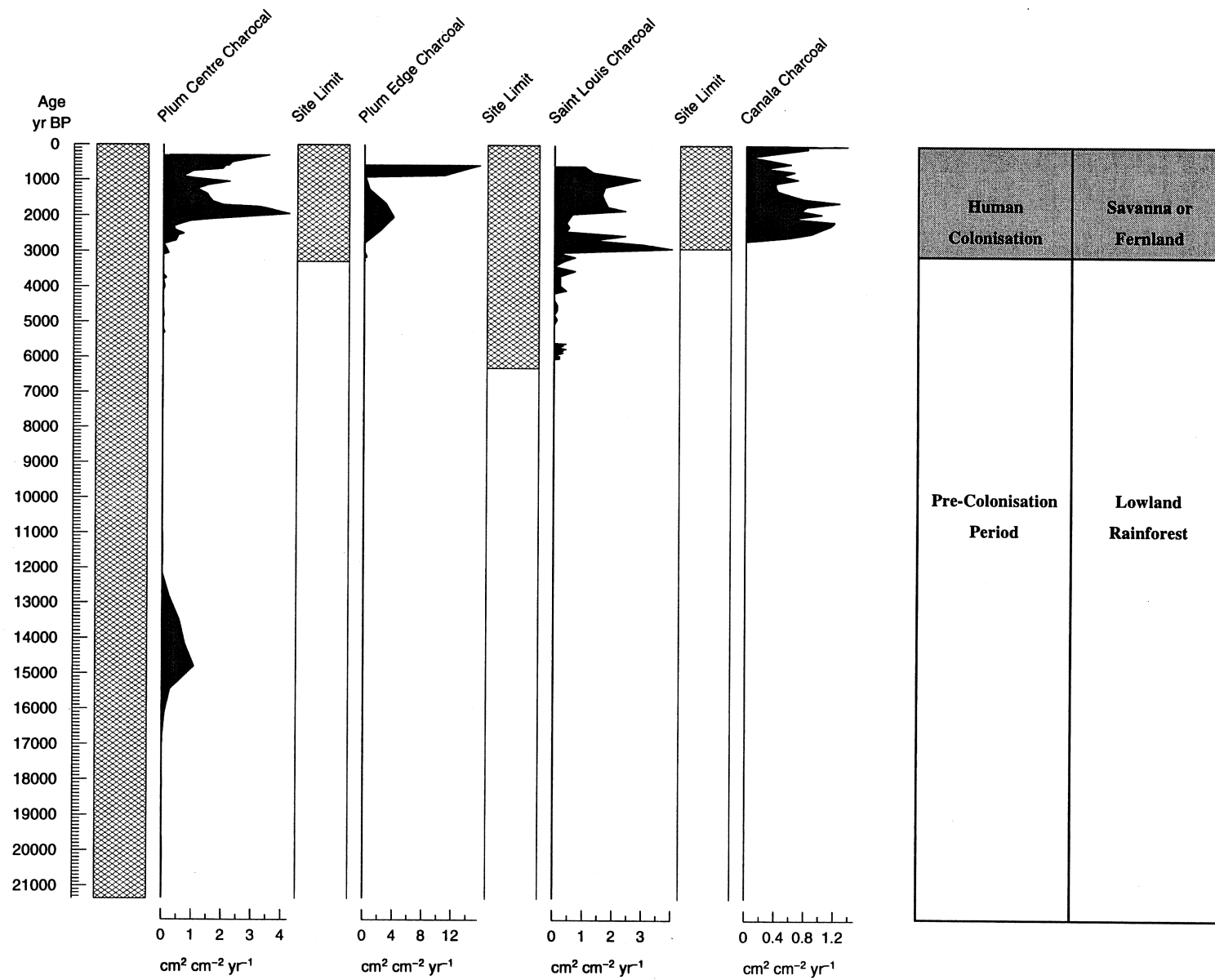


Figure 7.2: A summary of the charcoal curves for each site shown against inferred age. The major vegetation shifts alongside the colonisation history are also shown.

Maquis became established on the ultramafics in the Plum catchment after 2500 yr BP and with time *Melaleuca* colonised the non-ultramafic substrates. The best positive evidence for an open maquis landscape is the big increase in Casuarinaceae pollen. Although *Casuarina equisetifolia* is commonly a littoral forest species, today stunted specimens are abundant throughout the Plum Valley maquis. By contrast, at Saint Louis, *Melaleuca* pollen is well represented in the sediments that pre-date Melanesian colonisation. Presumably *Melaleuca quinquenervia* was a fresh water swamp element which expanded into the surrounding landscape with clearance and burning. At Saint Louis, relative to Plum, Casuarinaceae pollen lags behind and only gradually becomes more dominant with a decrease in burning. In Chapters 4 and 5 changes in the terrestrial pollen composition at the two sites were mapped individually using the results of PCA analysis. In Figure 7.3 an analysis that contains the terrestrial pollen of both sites but excludes fern spores, shows how the sites start out floristically as two quite different vegetation types, but move to a common landscape after 3000 yr BP, defined by varying amounts of *Melaleuca*, Casuarinaceae and Poaceae.

Saint Louis and Plum lie either side of Mont Dore, yet the inferred ages for the human impact boundaries at the two sites differ by between 500 and 800 years. This difference in timing could indicate the movement of people into more marginal terrain, an hypothesis that would require further testing both archaeologically and palaeoecologically. Of course consideration should also be given to the possibility that there is no real difference in timing at all between the sites, as both sites have boundaries defined by inference from radiocarbon dates on bulk sediment samples. The review of the New Zealand human impact data carried out by McGlone and Wilmshurst (*in press*) suggests that peats are a more accurate dating medium than lake sediments. However, there is not enough data as yet from New Caledonia to assess whether a bias, similar to the one detected in the New Zealand data, exists for the sites presented here. Future work that directly dates pollen from samples identified as representing the human impact boundary may be the most accurate means of establishing the age of such boundaries in these and other sites across the Pacific.

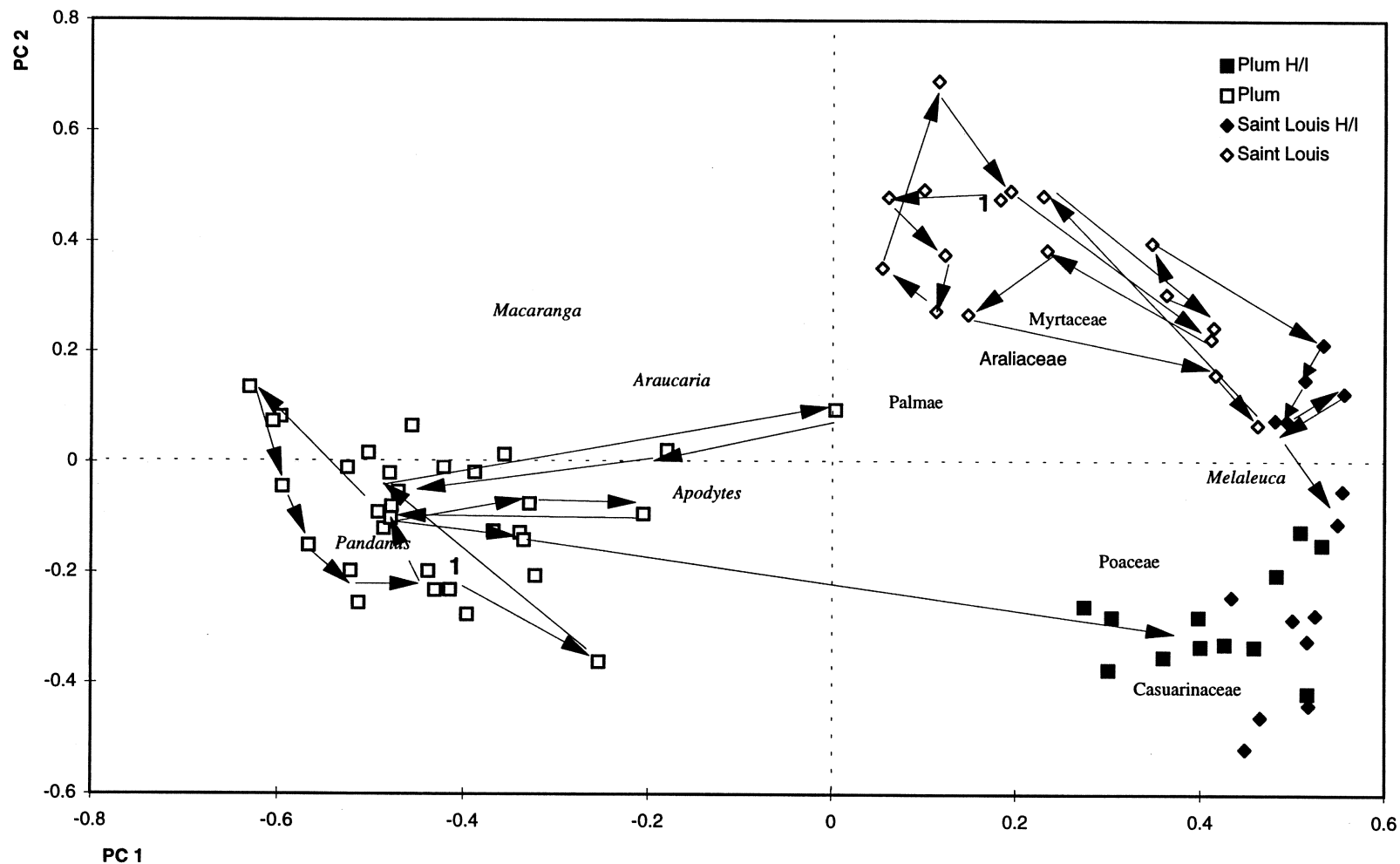


Figure 7.3: PCA bi-plot of Plum and Saint Louis terrestrial pollen. Hollow symbols represent samples from the pre-colonisation period and solid symbols represent the human impact (H/I) samples. Also shown are some of the major taxa that determine this distribution. Arrows show the direction of vegetation change at each site. 1 denotes the basal sample at each site and arrow heads the direction of change toward present.

Even though the Canala sediments have charcoal accumulation commencing around 3000 yr BP, there is no positive evidence that human impact occurred at this site until after European settlement. This may simply reflect the unsuitability of mangrove systems for recording this type of information. Canala Swamp has therefore been unable to contribute to an east coast story of human impact in any significant way. However, other sites identified in the region, for which landownership enquiries and access permission are still pending, may prove more fruitful.

In recent decades it has become accepted that the initial human colonisers of Pacific islands began to change these ecosystems from the time of first occupation and it is now generally assumed that the savannas and fernlands of many Pacific islands were created by people. Ecologically, this interpretation has been based largely on observations in historic times as European land practices greatly extend savanna boundaries and fires lit by humans maintain present communities. It has also arisen from changing perceptions of indigenous populations and abandonment of 18th and 19th century notions of the 'native' living an harmonious life against an unchanging backdrop (see Kirch, 1997). The argument that the human impact component of vegetation change across the Pacific has been overemphasised and that climate and natural fires must also have a role (see Nunn, 1990; 1994) stems largely from the correlation of savannas and fernlands with low or seasonal rainfall environments. This criticism of the degree to which people can be thought responsible may have had some validity a decade ago in light of the very sketchy palaeo-data that existed then for Pacific islands. However, palaeoecological studies centered around the issue of landscape transformation by initial colonisers has expanded considerably over the last decade (see Hope *et al.*, in press). Until this research was undertaken Easter Island was the only island that had continuous records spanning the LGM as well as the human colonisation period in the tropical Pacific. The Easter Island sites and Plum are therefore key sites as they provide long records through a climatic extreme against which the human occupation period can be assessed. Evidence from this study when combined with the evidence from other tropical south Pacific sites fits well with a model of dramatic vegetation change coinciding with human settlement across the Pacific (Figures 7.4 and 7.5).

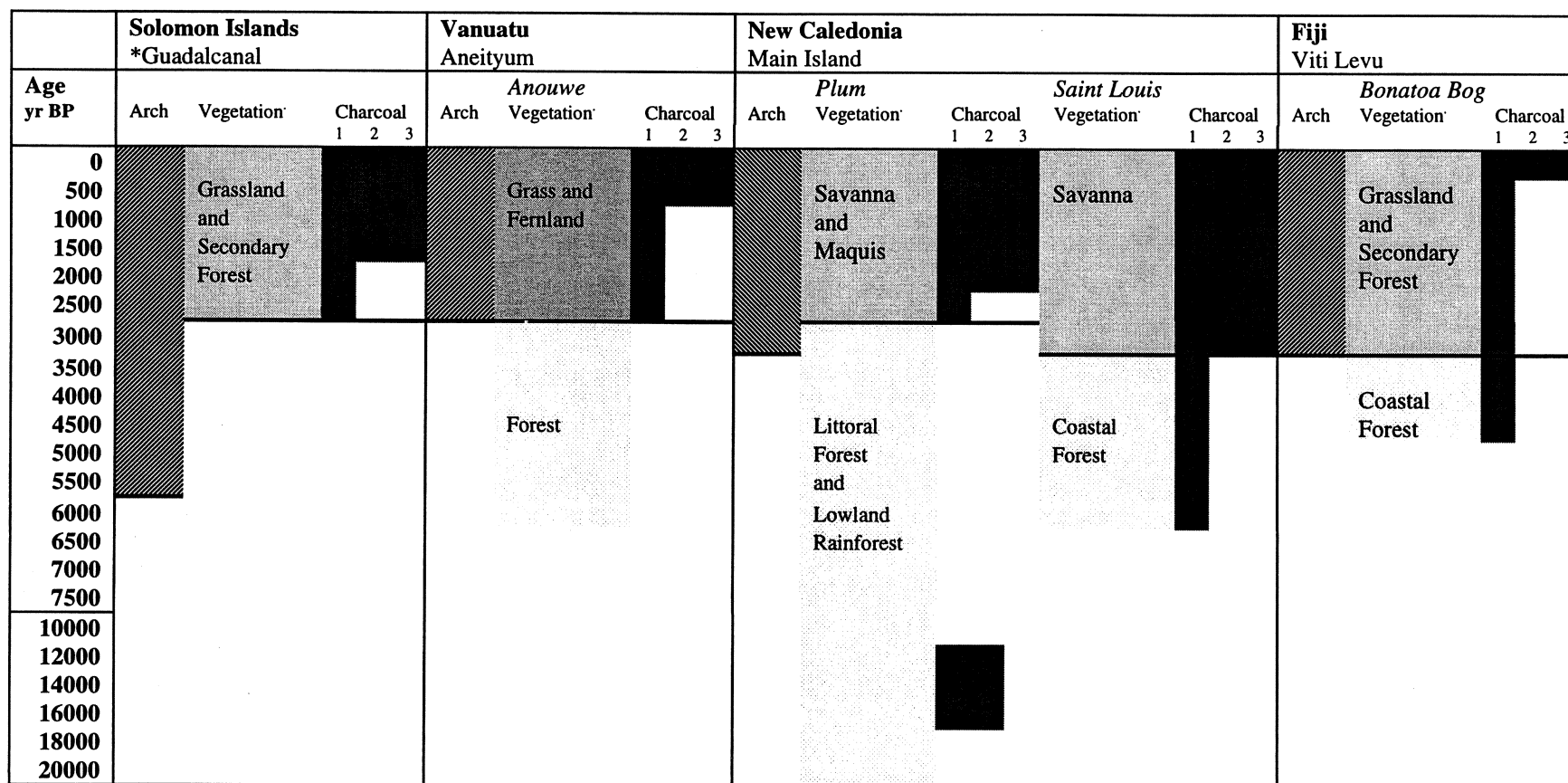


Figure 7.4: A summary of the pollen record from the tropical southwest Pacific that have interpretations of human impact associated with them. Shows age in yr BP of the substantive archaeological record (Arch), the age in yr BP of the pollen record, the human impact boundary for each location, the vegetation change observed and the a diagrammatic representation of the charcoal curves (1 low levels; 2 moderate levels; 3 high levels). The charcoal levels are representative of internal changes only, and cannot be compared between islands. * indicates where two or more sites have been amalgamated. Note change of time scale at 10,000 yr BP. The sources are 1. Haberle (1996); 2. Hope and Spriggs (1982); 3. This study; 4. Southern (1986). Eastern tropical Pacific sites are shown over the page in Figure 7.5.

	Cook Islands					Society Islands			*Easter Island 4			Hawaii		
	Atiu 1			*Mangaia 2		Mo'orea 3						*O'ahu 5		
Age yr BP	Arch	Vegetation	Charcoal	Vegetation	Charcoal 1 2 3	Arch	Vegetation	Charcoal 1 2 3	Arch	Vegetation	Charcoal 1 2 3	Arch	Vegetation	Charcoal 1 2 3
0														
500		Grass and Fernland	charcoal not analysed	Fernland			Increase in Grasses Sedges and Ferns			Grassland			Grassland 2° Forest	
1000	?													
1100														
1200														
1300							Coastal Forest							
1400														
1500														
2000														
2500														
3500														
4000		Littoral and Lowland Forest		Coastal Forest ?						Forested			Lowland Forest	
4500														
5000														
5500														
6000														
6500														
7000														
7500														
8000														
8500														
9000														
10000														
20000														
30000														
40000														

Figure 7.5: A summary of the pollen records from the tropical eastern Pacific that have interpretations of human impact associated with them. Shows age in uncalibrated yr BP of the substantive archaeological record (Arch), the age in uncalibrated years BP of the pollen record, the human impact boundary for each location (solid line), the vegetation change observed and the a diagrammatic representation of the charcoal curves (1 low levels; 2 moderate levels; 3 high levels). The charcoal levels are representative of internal changes only, and cannot be compared between islands. * indicates where two or more sites have been amalgamated. Note change of time scale at 1000, 1500 and 10,000 yr BP. The sources are 1. Parkes (1997); 2. Ellison (1994); 3. Parkes (1997); 4. Flenley *et al.* (1991); 5. Athens (1997). Age of archaeological record is derived from a variety of sources, notably Spriggs and Anderson (1993).

The small discrepancies in time that exist between vegetation and charcoal changes seen in pollen diagrams, relative to the commencement of the archaeological record at some locations, is to be expected when consideration is given to the different environments from which the two independent lines of evidence come, the different taphonomic processes, the varying quality of dating control and the number of dates providing both the archaeological and palaeoecological chronology. The possibility of directly dating the pollen from samples associated with initial human impact using AMS techniques will tighten chronologies and appeal to those concerned with 'chronological hygiene' (cf. Spriggs and Anderson, 1993).

Anouwe, Plum, Saint Louis and Bonatoa Bog (Figure 7.4) all have vegetation change associated with the earliest parts of the archaeological sequences. The records from New Caledonia add considerable strength to a model of dramatic vegetation change following the colonisation of tropical southwest Pacific islands at around 3000 yr BP, and fit well with the changes seen for the islands colonised much later, such as Hawaii and Easter Island (Figure 7.4 and 7.5). The vegetation changes seen in Mangaian records (Figure 7.5) compare well with the records from the other Pacific islands illustrated, however, until further work from the immediate region is completed to support the chronology of this record, it is bound to remain contentious (see Anderson, 1994, 1995; Kirch and Ellison, 1994). A similar although not as contentious case exists for Bonatoa Bog, Fiji. Southern (1986:186) tentatively suggested that the charcoal in the basal levels of the core, which pre-dates the archaeological sequence (Figure 7.4), may have been anthropogenic in origin. This diagram has recently been published in Hope *et al.* (*in press*) who point out some of the uncertainties surrounding the dating and conclude that the chronology of the site remains unproven. Hope *et al.* (*in press*) also present a diagram from Koumac, a coastal site in the north of New Caledonia. While charcoal appears to increase after 3000 yr BP there are only six samples counted over 1.6 metres, so it is hard to draw any conclusions from the site as yet.

Another facet of landscape change brought about by human action on Pacific islands is increased erosion and sedimentation rates. Although the geomorphic study of the Plum catchment was reconnaissance level only, it suggests that unlike river valleys from other

locations such as Tikopia (Kirch and Yen, 1982) or Vanuatu (Spriggs, 1986; 1997b), or the Lakeba swamp studies of Hughes *et al.* (1979), there was no massive geomorphic disturbance coinciding with Melanesian colonisation. Aggradation within the main valley and swamp appear fairly uniform up to and following Melanesian colonisation, and the valley floor was unincised and peat-covered prior to European settlement. In both Plum and Saint Louis the human impact boundary as defined by the pollen record is preceded by a sand layer. The large particle size plus the restriction of these layers to either the swamp margin (Saint Louis), or only partial coverage of the swamp (Plum), suggests that the sediment was probably of quite local origin. The most significant changes follow European settlement with the commencement of mining on Mont Dore. Massive amounts of debris initially flowed down as a fan into the valley, eventually incising to create the tributary and main valley channel during the 1970's.

The lack of any large scale geomorphic change during the early stages of Melanesian colonisation may not be out of step with the models for landscape change put forward by authors such as Kirch and Yen (1982), Kirch (1983) and Spriggs (1986; 1997b). Gardening of the hillslopes may well be the key to increased erosion rates, with burning alone not sufficient to create slope instability. The assumption for the Plum catchment is that if gardening was attempted on the hillslopes then people quickly discovered that a majority of the soils were unsuitable for cultivation due to their low nutrient status. Increased rates of sedimentation in swamps from the highlands of New Guinea, such as Kuk swamp, have been associated with different agricultural phases (Hughes *et al.*, 1991). In all cases the most significant rates of erosion occur in the recent past with introduction of sweet potato and the presumed intensification of agriculture (Oldfield *et al.*, 1985; Hughes *et al.*, 1991). The small semi enclosed basin of Lac Saint Louis has quite clearly been used for yam cultivation (Plate 5.2) although due to the absence of cultivated plants in the pollen record, over what time period this took place is uncertain. However, the construction and use of the arc shaped drainage terraces seem not to have contributed significant amounts of sediment to the swamp at any time. Of course insight into why the Plum River valley was burnt cannot be gained from the pollen records, but there is no evidence for pre-European agricultural activity in the valley. While agricultural activity may not have taken place to any great extent, some

consideration could be given to the possibility that burning and clearance may have been for the purpose of harvesting the timber of economically important tree species, such as *Agathis* and *Araucaria*, both of which occur in the Plum pollen record up until around 700 yr BP.

Island size and topography as well as the climatic region in which the island is situated may all contribute to the magnitude of slope instability. That is, the impact of people on geomorphic processes may be more pronounced on smaller islands that experience a large numbers of cyclones or large scale events. On New Caledonia the undulating leeward coastal plain may not have placed the same restrictions on early agriculturalists as the topography of islands such as Tikopia and Aneityum. New Caledonia also experiences fewer cyclones than the islands further to the north. Of those that do impact on the Territory, most pass across the Belep Islands off the northern tip of the main island. The Koumac valley is a large river valley in the north of the main island which is geologically quite different to Plum, containing no ultramafic substrates. The research being carried out by Guillard and Sémah (1997) has identified permanent as well as more transitory sites throughout the valley with taro gardening in the upper reaches. The valley fills from this region therefore have the potential to test the above hypothesis and offer important comparisons with other nearby islands such as Aneityum.

In all cases across New Caledonia, whether swamp sediments or valley deposits, the alteration to erosion and sedimentation processes caused by mining since European settlement has to be taken into account or eliminated for any given catchment. All rivers containing even small scale mining in their catchments have evidence of this disturbance in their valley sediments (Bird *et al.*, 1984). At Plum the two episodes of mining on Mont Dore were represented by orange clays interspersed with sedge peat. These mining sediments can be easily separated from other sediments based on their position in the core, their colour and the dating of lower sediments. The 'orange muck' produced by mining activity in New Caledonia is the most distinctive sedimentary marker throughout the island and can account for several metres of sediment.

Nunn (1990; 1994) asserts that more account should be given to a fall in sea level during the late Holocene when assessing sedimentary changes for the late Holocene. Sea level at Saint Louis stabilises at around 5500 yr BP, in keeping with the sea level study of Baltzer (1970) on mangrove sediments, and a review of the sea level data for New Caledonia found no compelling evidence for a higher stand of sea level in the mid to late Holocene. While a study of sea level has not been a component of this research, at around 2000 yr BP mangrove pollen in the Saint Louis pollen core decreases and may suggest progradation of the mangrove zone. Further work on mangrove sediments and mangrove pollen rain along the west of New Caledonia may resolve whether these changes are related to sea level fall or other sedimentary processes. Either way, the movement of the mangrove zone has no bearing on terrestrial pollen changes. At Canala the mangrove forest that covered the core site disappears after European settlement. This is possibly related to the building of infrastructure such as roads, which may have required the draining of the mangrove swamp and is unlikely to reflect a fall in sea level.

7.5 Ecological Significance of Research

The LGM is often viewed as a period when the distribution of rainforest in the tropical lowlands is restricted and savanna is greatly expanded. Flenley (1998) illustrated the palynological evidence for the expansion of savanna at lowland tropical sites in Africa, southeast Asia, Australia and South America. His review highlighted how little data there was from the southwest Pacific and in general how varied the results were for the southeast Asian and Australian region. Ecologically the Plum Swamp site is unique from this part of world as the pollen taxa suggest that it is one of only two truly lowland tropical sites that has consistent rainforest cover during the LGM, Lake Pata in the Amazon basin being the other (Colinvaux *et al.*, 1996). The present day distribution of rainforest and its relationship to annual precipitation on New Caledonia suggests that the Plum catchment is marginal for rainforest development, although theoretically it could survive here in the absence of anthropogenic fires. Several hypotheses can therefore be put forward for the maintenance of forest at Plum during LGM:

- 1) Plum was a glacial refugium on the potentially dryer southwest coast of New Caledonia;
- 2) lowland forests are more resilient to precipitation depression than their present day distribution suggests in an anthropogenic landscape;
- 3) the LGM was not significantly drier on New Caledonia.

Independent proxies of climate change from the region as well as further palynological work from other lowland basins on New Caledonia are needed to test these hypotheses.

There has been considerable debate over the potential importance of glacial refugia in the production of present-day patterns of rainforest diversity and endemism for the large continental rainforests such as the Amazon Basin (e.g. Haffer 1969; Colinvaux 1987). The isolation of New Caledonia since the Cretaceous and the specialised nutrient poor substrate laid down during the Eocene have favoured the retention of relict species in the flora as well as dramatic speciation (Jaffré *et al.*, 1987; Morat *et al.*, 1984). The role that longer term climatic fluctuations have played in creating the present day flora is uncertain. While vegetation changes beyond the LGM have not been covered by this study, the record from Plum, plus the work of Hope and Pask (1998), has illustrated the considerably long history of fire in the landscape, suggesting that it is an integral part of the island's ecology.

The important role of fire in the present day landscape of the ultramafics is recognised by McCoy *et al.* (in press) who have proposed a fire model for iron crust areas in the Plaine des Lacs region. Their model suggests that an ignition probability of less than 0.1 per decade retains maquis components within predominantly rainforest vegetation. A probability of 0.1 to 0.4 radically changes the vegetation from predominantly rainforest to predominantly maquis, and at greater than 0.6 all forest is excluded. McCoy *et al.* (in press) also suggest that disturbed forest in the iron crust terrain would regenerate within a few centuries in the absence of fire. As Plum is nutritionally a less extreme environment than the iron crust substrate, ignition probabilities are likely to be different. However, the only time that forest is excluded in the Plum catchment is after the colonisation of New Caledonia by people and the greater prevalence of fire. Late

glacial fires disrupted littoral and riparian forest around the Plum site, and if the age model for the sediments is accepted, then the recovery time of *Pandanus* to its previous levels around the site was extremely slow, around 3000 years. On a broader scale the forest in the catchment was not significantly altered by the fires. While the resolution of the present study is coarse both in time interval and taxonomically, finer resolution studies could potentially contribute significantly to ecological models such as the one outlined above.

The theory that the *Melaleuca* savanna may have had its origins in the fresh water swamps of northern New Caledonia (cf. Mueller-Dombois and Fosberg, 1998) is not borne out by the Saint Louis data. *Melaleuca* was a component of the swamp vegetation at Saint Louis prior to 3000 yr BP, spreading from this environment into the surrounding landscape with the arrival of people and the increased incidence of fire. While *Melaleuca* appears not to have been a significant component of the Plum catchment vegetation prior to 2500 yr BP, it slowly colonised the land to the south of the swamp after this time. It seems to have taken up to 800 years for *Melaleuca* to become a significant component of the local vegetation. This rate of establishment seems extremely slow in light of how rapidly *Melaleuca* has been extended since European settlement on the non-ultramafic substrates to the north.

The initial pioneering stage of palynology on New Caledonia carried out by this study and the work of Hope and Pask (1998) have revealed some of the difficulties of working with this pollen flora, but also the potential of further work aimed at addressing some of the more fundamental ecological questions surrounding the island's vegetation. Potentially, pollen analysis in the Plaine des Lacs region could reveal the link between fire and the age depth of the current vegetation distributions as well as test some of the hypotheses about the relationship that exists between the rainforest, maquis and fire. Given the species diversity of both the maquis and rainforest, the level of endemism (especially in the maquis (90%)), and the overlap between the two formations at the genus level, any further work requires a much more substantial pollen flora and the identification of key species that are palynologically visible. This high species diversity

and endemism also suggests that the New Caledonian flora has long history of coping with change.

7.6 Conclusions

This study has demonstrated the potential inherent in a palynological approach to the study of environmental change, in particular the impact of people on tropical island landscapes. The tropical southwest Pacific is relatively untouched when it comes to long records of climate change, even more so when lowland records are considered. The study has utilised fossil pollen and microscopic charcoal, stratigraphical analysis and XRD analysis of lowland deposits dating from around 20,000 yr BP and has reached three major conclusions.

- 1) Lowland vegetation on the leeward coast of New Caledonia did not undergo significant change at the LGM. Lowland forest was maintained in the Plum catchment until around 16,000 yr BP. The temperature and precipitation averages associated with the present day distribution of rainforest on New Caledonia suggest that even the most extreme temperature depressions suggested by other tropical terrestrial data could be accommodated by these lowland rainforests. It is unlikely however that an annual precipitation depression of 30 % would have enabled the continued presence of lowland forest in the catchment. Between 16,000 and 12,000 yr BP vegetation disturbance associated with fire is evident and it is hypothesised that this is a period of severe droughts.
- 2) There is no well defined transition to a Holocene climate, but it is assumed that climatic conditions approximating the present day were achieved shortly after 12,000 yr BP. There is no clear indication of climate change during the Holocene at either Plum or Saint Louis. However, the local environment of the Plum valley appears to have become moister and more stable throughout the Holocene.

- 3) Human impact following the arrival of people has a clear signal in both sites from the leeward southwest coast. The data from the northeast coast is more ambiguous. Sustained burning and the conversion of a forested landscape to an open landscape in the late Holocene environments of tropical Pacific islands appears a very robust indicator of the presence of people.

This study has highlighted the potential New Caledonia holds for further work into climates of the LGM, late glacial and Holocene periods. New Caledonia may prove to be a key site in our understanding of climate change during the LGM on islands of the tropical Pacific given the assumptions that exist concerning the conversion of forest to savanna in the lowlands. An expansion of the pollen flora and refinement of taxonomic identification may lead to better climatic envelopes for certain taxa, enabling a more positive contribution to the debate over whether LGM temperatures in the tropics were considerably cooler or not. Further research will also establish whether Plum is locally anomalous or whether the retention of lowland rainforest throughout the island was indeed widespread. Sites that complement the ones studied here have already been identified for future work. These include mid-altitude sites from the leeward coast and sites from the windward coast of New Caledonia. In addition, drilling in the Plum catchment to obtain sediments that predate the LGM will allow a better assessment of change over this period. A more extensive pollen flora will also allow palynological work to make a contribution to key questions regarding the relationship between maquis, rainforest and fire.

The present study has contributed significantly to our understanding of the landscape changes brought about by people across the Pacific. However, further refinement of anthropogenic activity in pollen diagrams, is necessary before such evidence will be accepted as a record of human presence in the regions where direct evidence remains elusive, in particular the identification of key economic plants. While the pollen of the tuberous staple food plants, taro, yam and sweet potato, is unlikely to be detected, the companion plants, such as sugar cane, banana, ti may hold the key for agricultural sites such as Saint Louis. Detecting these plants will require a different pollen counting strategy to that employed for traditional environmental reconstruction, given the

complexity of the flora. In addition further work on the aboricultural elements of New Caledonia's flora needs to be undertaken to ascertain if they were ever a significant part of the landscape. Palynological studies therefore still have much to contribute to our understanding of the movement of people through the Pacific and the manner in which they transformed their island landscapes.

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Appendix 1: Pollen and Charcoal

Fossil Pollen Preparation

1. Marker pollen

To each of the sub-samples 0.4 ml of *Alnus* stock solution was added containing approximately 2335 +/- 240 grains per 0.05 ml of solution.

2. Sodium hydroxide (NaOH)

The samples were then boiled for 10 min. in 10% NaOH to disperse the sample and break down the organic matter and humic acids.

3. Sieved

The samples were then passed through a 100 µm sieve to remove large organic and inorganic fragments. This was followed by a series of washes in distilled water.

4. Heavy liquid separation (ZnBr₂)

This step was employed to remove mineral grains. ZnBr₂ (specific gravity > 2.0) was added to a dispersed sample. It was then centrifuged for 15 min. at 1 500 r.p.m. The supernatant was vacuum filtered through cellulose nitrate filter paper (pore size 5 µm) trapping pollen and material with a specific gravity less than 2. The filter paper dissolved and washed in twice in acetone.

5. Acetolysis

To remove cellulose from the samples. The samples were washed in 30% glacial acetic acid, centrifuged, decanted. This was then repeated using 100 % glacial acetic acid. Acetolysis solution (9:1 acetic anhydride : concentrated sulphuric acid) was then added to the samples and they were boiled in a water bath for 1 min. The samples were then taken back through 100 % glacial acetic acid and 30% glacial acetic acid.

6. Hydrofluoric acid

To remove silicates. The samples were examined for silica and if present were placed in 40% hydrofluoric acid overnight.

7. Dehydration

The samples were then dehydrated through a series of alcohol washes followed by tertiary butyl alcohol.

8. Mounting

The samples were then mounted on microscope slides in silicone oil and sealed under a coverslip with nail varnish.

NB: unless otherwise stated, centrifuging was carried out at 2500 rpm for 3 minutes.

Surface Sample Preparation

Alnus marker pollen was not added to the samples and for most of the surface samples heavy liquid separation was not necessary. Otherwise processing followed the above procedure.

Reference Pollen Preparation

1. Sodium hydroxide (NaOH)

The flowers or anthers were boiled for 10 min. in 10% NaOH to disperse the sample and break down organic matter.

2. Sieved

They were then passed through a 100 µm sieve to remove large organic fragments. This was followed by a series of washes in distilled water.

3. Acetolysis

To remove cellulose from the samples and to provide colour to the pollen exine. The samples were washed in 30% glacial acetic acid, centrifuged, decanted. This was then repeated using 100 % glacial acetic acid. Acetolysis solution (9:1 acetic anhydride : concentrated sulphuric acid) was then added to the samples and they were boiled in a water bath for 1 min. The samples were then taken back through 100 % glacial acetic acid and 30% glacial acetic acid.

4. Staining

Some sample were stained with saffarin if aectolysis coloration was considered not to be strong enough.

5. Dehydration

The samples were then dehydrated through a series of alcohol washes followed by tertiary butyl alcohol.

6. Mounting

The samples were then mounted on microscope slides in silicone oil and sealed under a coverslip with nail varnish.

NB: unless otherwise stated, centrifuging was carried out at 2500 rpm for 3 minutes.

Charcoal Counting

The fossil pollen slides were used to estimate the concentration of microscopic charcoal. The marker pollen (*Alnus*) added in step 1 enable an estimate of pollen and charcoal concentrations to be made.

The point count method of Clark (1982) was used to determine the abundance of charcoal. The scale bar in the eyepiece was used, giving 11 points per field of view. A point was recorded whenever one of these fell on a dark, opaque and angular fragment greater than 5 μm in length. A minimum of 455 fields of view were counted, giving 5,005 points and an approximate confidence level of 10 %. If necessary, greater than 455 fields of view were counted to obtain this level of confidence based upon Clark's graph (1982; Figure 2). In cases where no charcoal was visible on the slide by 455 fields of view 0 charcoal hits were recorded and counting stopped. Where small amounts of charcoal were visible but no charcoal hits were being made because of the low concentration of charcoal 0.5 hits were recorded and counting stopped 455 fields of view. Concentration and accumulation rate values were generated following Clark's (1982) calculations.

Appendix 2: Pollen Flora for New Caledonia

Brief morphological descriptions and photographs of the pollen and spore reference collection from New Caledonia are contained in this appendix. Pollen grains were obtained from both herbarium and field collections. The herbarium specimens are from the Royal Botanic Gardens, Sydney. Fresh material was collected by myself during fieldwork or by Stephane McCoy during the course of his fieldwork and identified by staff at the ORSTOM herbarium, Noumea. Species identified in Noumea do not have authorities.

Reference material was prepared using standard acetolysis techniques. These are outlined in Appendix 1. The reference material was mounted in silicone oil, the same mounting medium used for the fossil pollen samples. All the images were recorded on Kodak 100 ASA colour print film using a Carl Zeiss photomicroscope under x 40 objective. An attempt was made to produce images using a x100 planapochromatic oil immersion objective. However, the silicone oil mounting medium and the equipment available lead to severe biofringence around the grains. All images were therefore produced at 400 x scale instead of the usual 1000 x. The scale on these commercially developed colour photographs is 1 mm = 1.35 μ m.

The descriptions of the pollen grains and fern spores precede the photographs and are arranged in alphabetical order by family. Terminology used is based on Erdtman (1952), Faegri and Iversen (1964) and Huang (1972). Of special note is the terminology used to describe the aperture type of the 3C3P grains. This follows Huang (1972) and is illustrated in Figure A2-1 below. Size measurements are 'typical' rather than based on a number of systematic measurements.

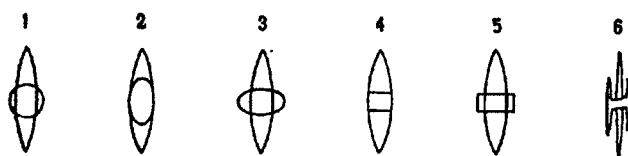


Figure A2-1: Aperture types at equatorial view

- | | |
|------------------------------|-----------------------------|
| 1 Os circular | 4 Os transversally parallel |
| 2 Os longitudinally elliptic | 5 Os rectangular |
| 3 Os transversally elliptic | 6 Os H-shaped |

Each description is accompanied by a page and plate number in brackets for the corresponding photographs. For example (243/1-2) reads as page 243, plates 1 to 2.

ACANTHACEAE

Acanthus sp.

- 3C (269/1)
Shape in equatorial view prolate (~ 50 x 25 µm); amb circular.
Reticulate; exine 1.5 µm.
Colpi almost reach poles.

AGAVACEAE

Cordyline sp.

- 1 colpate (269/2)
Elliptical (~ 28 x 21 µm); colpus to pole.
Scabrate; exine 1.5 µm.

ANACARDIACEAE

Euroshinus elegans Engler

- 3C3P (269/3)
Shape in equatorial view prolate (28 x 24 µm); amb inter-hexagonal (21 µm across).
Finely reticulate; exine >1.5 µm.
Aperture type: longitudinally elliptic.

Euroshinus sp.

- 3C3P (269/4-5)
Shape in equatorial view prolate (30 x 26 µm)
Reticulate; exine ~ 1.5 µm.
Aperture type: longitudinally elliptic.

APOCYNACEAE

Alstonia coriacea Pancher ex S.Moore

- 3C3P (269/6-8)
Shape in equatorial view circular (~ 26 µm), amb triangular concave (~ 22 µm across).
Scabrate or granular surface; exine ~ 2 µm.
Aperture type: transversally elliptic.

Cerberiopsis candelabra Vieillard ex Pancher & Sebert

- 3C3P (269/9-11)
Shape in equatorial view oblate (31 x 44 µm), amb circular (~ 41 µm across).
Granular surface; exine ~ 2.5 µm (slightly thicker along colpus edge).
Aperture drop type, circular. Colpi almost to poles.

Parsonsia sp.

- 3-5 porate (269/12-14)
Shape in equatorial view sub-spheroidal (33 x 28 µm), amb circular (~ 28 µm across).
Scabrate; exine < 1.5 µm.
Pores annulated, 4µm across.

Rauvolfia semperflorens (Muell. Arg.) Schltr.

- Parasyncolporate (269/15-17)
Shape in equatorial view oblate (24 x 35 µm), amb circular (~ 35 µm across).
Granular surface; exine ~ 1.5 µm (>3.5 µm at colpi).
Aperture type: circular. Meridional crests bordering colpi psilate.

AQUILIFOLIACEAE

Ilex serbertii Pancher

- 3C3P (269/18-20)
 Shape in equatorial view sub-spheroidal (26 x 24 µm), amb circular (~ 24 µm across).
 Gemmate; exine 5 µm thick.
 Aperture type: circular. Colpi psilate

ARALIACEAE

Apiopetalum velutinum Baillon

- 3C3P (269/21-23)
 Shape in equatorial view prolate (29 x 23 µm), amb circular (~ 23 µm across).
 Reticulate; exine > 2 µm.
 Aperture type: longitudinally elliptic. Colpi almost to poles.

Dizygothea coenosa Viguiet

- 3C3P (270/1-4)
 Shape in equatorial view prolate (30 x 26 µm); amb sub-angular (23 µm).
 Finely reticulate to scabrate; exine ~ 1.5 µm.
 Aperture type: transversally elliptic.

Meryta coriacea Baillon

- 3C3P (270/5-7)
 Shape in equatorial view prolate to sub-oblate (16 x 15 µm); amb sub-angular (15 µm).
 Reticulate; exine ~ 1.5 µm.
 Aperture type: transversally elliptic. Constriction around longitudinal colpus leads to dumb bell shape.

Meryta denhamii Seeman

- 3C3P (270/8-11)
 Shape in equatorial view spheroidal (26 µm); amb sub-angular (26 µm).
 Reticulate; exine ~ 1.5 µm.
 Aperture type: transversally elliptic.

Myodocarpus fraxinoides Brongniart & Gris.

- 3C3P (270/12-13)
 Shape in equatorial view prolate (31 x 25 µm); amb sub-angular (25 µm).
 Finely reticulate to scabrate; exine ~ 1.5 µm.
 Aperture type: transversally elliptic. Constriction around longitudinal colpus leads to dumb bell shape.

Myodocarpus pachyphyllus Harms

- 3C3P (270/14-15)
 Shape in equatorial view oblate (18 x 25 µm); amb sub-angular (25 µm).
 Reticulate; exine ~ 1.5 µm.
 Aperture type: circular. Colpi psilate.

Schefflera emilana Baillon

- 3C3P (270/16-18)
 Shape in equatorial view prolate (35 x 28 µm); amb semi-lobate (30 µm).
 Reticulate; exine ~ 1.5 µm (5 µm at pore).
 Aperture type: transversally elliptic.

ARAUCARIACEAE

Agathis moorei (Lindley) Masters

Inaperturate (271/1-3)
Spheroidal; 28 μm .
Granulate; exine $\sim 2 \mu\text{m}$.

Agathis ovata (C. Moore) Warburg

Inaperturate (271/4-5)
Elliptical to spheroidal; around 36 μm across.
Granulate; exine $\sim 2\text{-}3 \mu\text{m}$ thick.

Araucaria columnaris (J.R. & G. Forster) J.D. Hooker

Inaperturate or 1 colpate (271/6-8)
Spheroidal ($\sim 55 \mu\text{m}$).
Granulate; exine $\sim 2 \mu\text{m}$.

Araucaria laubenfelsii Corbasson

Inaperturate or 1 colpate (271/9-10)
Spheroidal ($\sim 65 \mu\text{m}$).
Granulate; exine $\sim 2 \mu\text{m}$.

BIGNONIACEAE

Deplanchea speciosa Vieillard

3C (272/1-2)
Shape in equatorial view almost spherical ($\sim 45\text{--}47 \mu\text{m}$); amb circular ($\sim 39 \mu\text{m}$).
Reticulate; exine $\sim 2 \mu\text{m}$ thick.
Meridonal colpus large tear with ragged edges.

CLUSIACEAE

Calophyllum caledonicum Vieillard

3C3P (272/3-5)
Shape in equatorial view oblate ($23 \times 25 \mu\text{m}$); amb angular ($25 \mu\text{m}$).
Psilate; exine $\sim 1.5 \mu\text{m}$.
Aperture type: transversally elliptic..

Garcinia neglecta Vieillard

Stephanocolporate (272/6-8)
Shape in equatorial view prolate ($19 \times 16 \mu\text{m}$); amb circular ($17 \mu\text{m}$).
Reticulate; exine $> 1.5 \mu\text{m}$.
Aperture type: longitudinally elliptic. Colpi psilate.

Montrouzeria gabriellae Baillon

4C4P (272/9-12)
Shape in equatorial view spheroidal ($\sim 40 \mu\text{m}$); amb square ($40 \mu\text{m}$).
Granulate; exine $1.5 \mu\text{m}$.
Aperture drop type; pore circular ($\sim 9 \mu\text{m}$ across)

Montrouzeria verticillata Planchon & Triana

4C4P (272/13-16)
Shape in equatorial view spheroidal ($\sim 31 \mu\text{m}$); amb square ($31 \mu\text{m}$).
Granulate; exine $1.5 \mu\text{m}$.
Aperture drop type, circular ($\sim 6 \mu\text{m}$ across, sometimes less)

Montrouzeria sphaeroidea Pancher ex Planchon & Triana

- 4C4P (272/17-19)
Shape in equatorial view spheroidal (~ 35 µm); amb square (35 µm).
Granulate; exine 1.5 µm.
Aperture type: rectangular.

COMBRETACEAE

Lumnitzera littorea

- 6C6P (272/20-21)
Shape in equatorial view oblate (~ 29 x 36 µm); amb circular (~ 29 µm).
Psilate to finely scabrate; exine ~ 3 µm thick.
Aperture type: longitudinally elliptic.

CUNONIACEAE

Acsmithia austrocaledonica (Brongniart & Gris) Hoogland

- 3C3P (273/1)
Shape in equatorial view spherical (~ 11.5 µm); amb sub-angular, open (~ 11.5 µm across).
Psilate to slightly scabrate; exine ~ 1.5 µm.

Acsmithia collina

- 3C3P (273/2)
Shape in equatorial view spherical (~ 9.5 µm); amb: inter-hexagonal (~ 9.5 µm across).
Psilate; exine ~ 1.5 µm.

Codia albifrons Vieillard ex Guillaumin

- 2C2P (273/3)
Shape in equatorial view prolate (~ 10 µm).
Psilate; exine ~ 1.5 µm.

Codia discolor (Brongniart & Gris) Guillaumin

- 2C2P (273/4)
Shape in equatorial view prolate (~ 10 µm).
Psilate; exine ~ 1.5 µm.

Codia nitidia Schlechter

- 2C2P (273/5)
Shape in equatorial view prolate (~ 10 µm).
Psilate; exine ~ 1.5 µm.

Codia obcordata Brongniart & Gris

- 2C2P (273/6)
Shape in equatorial view prolate (~ 10 µm).
Psilate; exine ~ 1.5 µm.

Cunonia austrorubens Schlechter

- 3C3P (273/7-9)
Shape in equatorial view oblate (11 x 15 µm); amb sub-angular (~ 11 - 15 µm).
Psilate; exine ~ 1.5 µm, thins towards colpi.
Aperture type transversally elliptic.

- Cunonia austrocaledonica* Brongniart ex Guillaumin
- 3C3P (273/10)
 Shape in equatorial view prolate (~ 13 µm); amb sub-angular (~ 12 µm).
 Psilate; exine ~ 1.5 µm, thins towards colpi.
- Cunonia bullata* Brongniart & Gris
- 3C3P (273/11)
 Shape in equatorial view oblate (~ 10 µm); amb sub-angular (~ 10 µm).
 Psilate; exine ~ 1.5 µm, thins towards colpi.
- Cunonia pterophylla* Schlechter
- 3C3P (273/12)
 Shape in equatorial view oblate (~ 10 µm); amb sub-angular (~ 13.5 µm).
 Psilate; exine ~ 1.5 µm, thins towards colpi.
- Cunonia pulchella* Brongniart & Gris
- 3C3P (273/13)
 Shape in equatorial view prolate (~ 12 µm); amb sub-angular (~ 11 µm).
 Psilate; exine ~ 1.5 µm, thins towards colpi.
 Aperture type: transversally elliptic.
- Geissois pruinosa* Brongniart
- 2C2P (273/14-15)
 Shape in equatorial view prolate (~ 12 - 14 µm).
 Finely reticulate; exine ~ 1.5 µm.
- Pancheria communis* E.G. Baker
- 3C3P (273/18)
 Shape in equatorial view oblate (~ 12 x 15 µm); amb circular (15 µm).
 Reticulate; exine ~ 1.5 µm.
- Pancheria elegans* Brongniart & Gris
- 3C3P (273/16-17)
 Shape in equatorial view prolate (~ 12 x 11 µm); amb circular (~ 11 µm).
 Psilate; exine ~ 1.5 µm.
- Pancheria engelariana* Schlechter
- 3C3P (273/21-22)
 Shape in equatorial view prolate (~ 12 x 11 µm); amb (11 µm).
 Psilate; exine ~ 1.5 µm.
- Pancheria glateroides*
- 3C3P (273/19-20)
 Shape in equatorial view oblate (~ 13.5 x 15 µm); amb circular (~ 13 - 15 µm).
 Psilate; exine ~ 1.5 µm.
- Pancheria hirsuta* Vieillard ex Pampanini
- 3C3P (273/23-24)
 Shape in equatorial view prolate (15 x 13.5 µm); amb circular (~ 13.5 µm).
 Psilate; exine ~ 1.5 µm.
 Pore 'H' shaped.

CUPRESSACEAE

Neocallitropsis pancheri (Carriere) de Laubenfels

- Inaperturate (274/1-2)
 Spherical (~ 50 µm across).
 Vesicate frill, with baculum like rods visible.
 Surface highly textured.

DILLENACEAE

Hibbertia altigena Schlechter

- 3C3P (274/3-4)
 Shape in equatorial view almost spherical (~ 16 x 14.5 µm); amb circular (~ 14.5 µm).
 Finely reticulate; exine ~ 1.5 µm thick.
 Aperture type: transversally parallel. Colpi psilate.

Hibbertia emarginata Guillaumin

- 3C3P (274/5-6)
 Shape in equatorial view almost spherical (~ 16 x 14.5 µm); amb circular (~ 14.5 µm).
 Finely reticulate; exine ~ 1.5 µm thick.
 Aperture type: transversally parallel. Colpi psilate.

Hibbertia francii

- 3C3P (274/7-8)
 Shape in equatorial view almost spherical (~ 16 x 14.5 µm); amb circular (~ 14.5 µm).
 Psilate; exine ~ 1.5 µm thick.
 Aperture type: longitudinally elliptic. Colpi psilate.

Hibbertia lucens Brongniart & Gris ex Sebert & Pancher

- 3C3P (274/9-10)
 Shape in equatorial view almost spherical (~ 16 x 14.5 µm); amb circular (~ 14.5 µm).
 Psilate; exine ~ 1.5 µm thick.
 Aperture type: transversally parallel. Colpi psilate.

Hibbertia trachyphylla Schlechter

- 3C3P (274/11-12)
 Shape in equatorial view oblate (~ 13 µm at equator); amb circular (~ 13 µm).
 Finely reticulate; exine ~ 1.5 µm thick.
 Aperture type: transversally parallel. Colpi psilate.

Hibbertia virotti

- 3C3P (274/13-14)
 Shape in equatorial view spherical (~ 19 µm); amb circular (~ 19 µm).
 Psilate; exine ~ 1.5 µm thick.
 Aperture type: longitudinally elliptic. Colpi textured.

ELAEOCARPACEAE

Dubouzetia caudiculata Sprague

- 3C3P (274/15)
 Shape in equatorial view varies from prolate to spherical (~ 11.5 x 10 µm).
 Psilate; exine <1.5 µm thick.
 Aperture type: longitudinally elliptic.

Dubouzetia elegans Brongniart & Gris

3C3P (274/16)

Shape in equatorial view varies from prolate to spherical (~ 14.5 µm).

Psilate; exine ~ 1.5 µm thick tapering in thickness toward pore.

Aperture type: longitudinally elliptic.

Elaeocarpus leratii Schlechter

3C3P (274/17-18)

Shape in equatorial view varies from prolate to spherical (~ 11.5 x 10 µm).

Psilate; exine <1.5 µm thick.

Aperture type: transversally elliptic. Constriction at longitudinal colpus leads to dumb bell shape.

Aperture type: longitudinally elliptic.

Elaeocarpus nodosus Baker f.

3C3P (274/19)

Shape in equatorial view prolate (~ 10 x 8 µm).

Psilate; exine <1.5 µm thick.

Elaeocarpus ovigenus Brongniart & Gris

3C3P (274/20)

Shape in equatorial view spherical (~ 11.5 µm).

Psilate; exine <1.5 µm thick.

Aperture type: transversally elliptic. Constriction at longitudinal colpus leads to dumb bell shape.

EPACRIDACEAE

Dracophyllum involucratum Brongniart & Gris

Tetrad (3C) (275/1-2)

Tetrad ~ 40.6 µm across.

Coarsely granular, some irregular projections; exine ~ 3 µm thick.

ESCALLIONACEAE

Argophyllum ellipticum Schlechter

3C3P (275/3-4)

Shape in equatorial view prolate (~ 36 x 22 µm); amb inter-angular.

Coarsely scabrate; exine 1.5 µm thick, thicker at pore.

Aperture type: longitudinally elliptic. Colpi appear ribbed.

Polyosma podophylla

3C3P (275/5-6)

Shape in equatorial view spherical (~ 22 µm across); amb sub-angular.

Finely reticulate; exine ~ 1.5 µm thick, tapers toward colpi.

Aperture type: circular. Colpi psilate.

EUPHORBIACEAE

Austrobuxus clusiceus (Baillon) A. Shaw

Stephanoporate (275/7-8)

Shape in equatorial view spherical (~ 33 µm across).

Echinate, elements 4.5 - 5 µm long; exine 3 µm thick (nexine 1.5 µm, sexine 1.5 µm).

Pores circular.

Austrobuxus ellipticus

Stephanoporate (275/9-10)

Shape in equatorial view spherical (~ 25 µm across).

Echinate, elements 1.5 - 2 µm long; exine > 2 µm thick..

Pores circular.

Longetia buxoides Baillon

Stephanocolporate (275/11-14)
Shape in equatorial view oblate; amb circular (~ 22 µm across).
Finely reticulate, exine ~ 2.75 µm, at pores ~ 5 µm thick..
Aperture type: vestibulum, pore circular.

Macaranga alchorneoides Pax & Liegelsheim

3C3P (275/15-16)
Shape in equatorial view oblate (~ 13 x 18 µm); amb inter-angular (18 µm across).
Reticulate; exine > 1.5 µm.
Aperture type: transversally elliptic.

Macaranga coriacea Mueller Argovie

3C3P (275/17)
Shape in equatorial view oblate (~ 14 x 18 µm); amb circular (18 µm across).
Finely reticulate; exine > 1.5 µm, thicker at pore.
Aperture type: transversally elliptic.

Macaranga fulvescens Schlechter

3C3P (275/18)
Shape in equatorial view oblate (~ 14 x 18 µm); amb inter-angular (18 µm across).
Finely reticulate; exine > 1.5 µm, thicker at pore.
Aperture type: transversally elliptic.

Phyllanthus casearoides S. Moore

Syncolporate (275/19-20)
Shape in equatorial view oblate (~ 14.5 x 20 µm); amb circular (~ 20 µm across).
Reticulate; exine 1.5 µm.
Pore circular.

Phyllanthus chamaecerasus Baillon

Syncolporate (275/21-22)
Shape in equatorial view oblate (~ 17.5 x 23 µm); amb circular (~ 23 µm across).
Reticulate; exine 1.5 µm.
Pore circular.

Phyllanthus yahouensis Schlechter

Syncolporate (275/23-24)
Shape in equatorial view oblate (~ 17.5 x 23 µm); amb circular (~ 23 µm across).
Reticulate; exine 1.5 µm.
Pore circular.

FLACOURTIACEAE

Homalium austrocaledonicum Seeman

3C3P (276/1-2)
Shape in equatorial view prolate (~ 21.5 x 12 µm).
Psilate, exine ~ 1.5 µm.
Aperture type: transversally elliptic.

Homalium deplanchei (Vieillard) Warb.

3C3P (276/3-4)
Shape in equatorial view prolate (~ 19 x 12 µm).
Psilate, exine ~ 1.5 µm.
Aperture type: transversally elliptic.

Homalium kanaliense (Vieillard) Briquet

- 3C3P (276/5-6)
Shape in equatorial view prolate (~ 21 x 13 µm).
Psilate, exine ~ 1.5 µm.
Aperture type: transversally elliptic.

FLAGELLARIACEAE

Flagellaria neocaledonica Schlecter

- Monoporate (276/7-8)
Spherical, sometimes flattened on one side (~ 20 µm).
Scabrate.

GESNERIACEAE

Coranthera clarkeana Schlecter

- 3C3P (276/9)
Spherical (~ 12 µm).
Coarsely reticulate.

GOODENIACEAE

Scaevola beckii Zahlbruckner

- 3C3P (276/10)
Shape in equatorial view prolate (36 x 26 µm).
Reticulate; exine ~ 3.5 µm.
Reticulate pattern diminishes toward colpi; colpi large and psilate.
Aperture type: transversally elliptic.

Scaevola montana Labill.

- 3C3P (276/11-13)
Shape in equatorial view prolate (40 x 36 µm); amb sub-angular (~ 36 µm across).
Reticulate; exine ~ 3.5 µm; nexine 1.5 µm, sexine > 1.5 µm.
Reticulate pattern diminishes toward colpi; colpi large and psilate.
Aperture type: transversally elliptic with vestibulum.

ICACINACEAE

Apodytes clussifolia (Baillon) Villiers

- 3P (276/14-15)
Shape in equatorial view oblate; amb angular (~ 13 µm across).
Reticulate; exine < 1.5 µm.
Pore circular to elliptic.

Citronella macrocarpa Huerlimann

- 3C3P (276/16-18)
Shape in equatorial view spherical (23 µm); amb circular (~ 23 µm across) colpi can be open or closed.
Reticulate.
Aperture type: longitudinally elliptic.

LECTHYDICACEAE

Barringtonia neo-caledonica Vieillard

- 3C (276/19-20)
Shape in equatorial view prolate (~ 45 x 32 µm); amb circular (~ 32 µm across) with very open colpi.
Reticulate; exine 1.5 µm.
Distinct margin to colpi, colpi smooth.

LILIACEAE

Xeronema moorei Brongniart & Gris

Monocolpate (276/22)
43 x 32 μm .
Coarsely reticulate.

LOGANIACEAE

Geniostoma balansaeum Baillon

3P (276/23-24)
Shape in equatorial view oblate (25 x 34 μm); amb circular (~ 34 μm across).
Finely reticulate; exine 1.5 μm , thickens at pore to ~ 4 - 4.5 μm .
Pores are common and circular; ~ 6 μm across.

Geniostoma celastrineum Baillon

4P (277/1-2)
Shape in equatorial view almost spherical; amb circular (~ 24 μm across).
Finely reticulate; exine 1.5 μm , thickens at pore to ~ 2 μm .
Pores are circular and club type; ~ 6 μm across.

Geniostoma densiflorum Baillon

3P - 4P (277/3-4)
Shape in equatorial view almost spherical; amb circular (~ 24 μm across).
Psilate; exine 1.5 μm , thickens at pore to ~ 2 μm .
Pores are circular and club type; ~ 6 μm across.

Geniostoma erythrospermum Baillon

4P (277/5-6)
Shape in equatorial view almost spherical; amb circular (~ 24 μm across).
Scabrate; exine 1.5 μm , thickens at pore to ~ 2 μm .
Pores are circular and club type; ~ 6 μm across.

Geniostoma vestitum Baillon

3P (277/7)
Shape in equatorial view almost spherical; amb circular (~ 24 μm across).
Psilate; exine 1.5 μm , thickens at pore to ~ 4 - 4.5 μm .
Pores are circular and club type; ~ 6 μm across.

MALPIGHIACEAE

Acridocarpus austrocaledonica Baillon

3C3P (277/8)
Shape in equatorial view prolate to sub-oblate; amb triangular (~ 13 μm across).
Psilate; exine 1.5 μm , ~ 3 μm at aperture.

MELASTOMATACEAE

Melastoma denticulata

6C6P (277/9-10)
Shape in equatorial view spherical (16 μm); amb circular (~ 19 μm across).
Psilate, exine < 1.5 μm .
Aperture type: transversally elliptic, colpi almost to poles.

MELIACEAE

Dysoxylum francii C. DC.

4C4P

(277/11-12)

Shape in equatorial view spherical (~ 33 µm across); amb square (~ 33 µm across).

Scabrate; exine 1.5 µm, thickening to 6 µm at aperture.

Aperture type: circular and club type.

Dysoxylum glomeratum Vieillard

4C4P

(277/13-14)

Shape in equatorial view sub-oblate (29 x 33 µm); amb square (~ 33 µm across).

Scabrate; exine 1.5 µm, thickening to 6 µm at aperture.

Aperture type: circular and club type.

Dysoxylum rufescens Vieillard

4C4P

(277/15-16)

Shape in equatorial view sub-oblate (29 x 33 µm); amb square (~ 33 µm across).

Scabrate; exine 1.5 µm, thickening to 6 µm at aperture.

Aperture type: circular and club type.

MONIMIACEAE

Hedycarya cupulata Baillon

Inaperturate

(277/17)

Shape in equatorial view almost spherical (~ 19 µm across); amb circular (~ 19 µm across).

Coarsely granulate; exine < 1.5 µm.

MYRICACEAE

Canomyrica monticola Guillaumin

3P

(277/18-20)

Shape in equatorial view oblate (22 x 27.5 µm); amb semi-angular (~ 32 µm across).

Coarsely scabrate; exine < 1.5 µm.

Pores are atrium type and circular.

(Similar to pollen grains of the Casuarinaceae).

MYRSINACEAE

Tapumosperma sp.

3C3P

(277/21-24)

Shape in equatorial view almost spherical (22 x 20 µm); amb circular (~ 20 µm across).

Psilate; exine ~ 1.5 µm.

Aperture type transversally elliptic; constriction at colpus leads to bow tie shape.

MYRTACEAE

Archirhodomirtus baladensis (Brongniart & Gris) Burret

Parasyncolporate

(278/1-3)

Polar view ~ 19 µm across (island very faint).

Scabrate; exine ~ 1.5 µm, ~ 3 µm at pore.

Aperture type: transversally elliptic.

Archirhodomirtus viellardii (Brongniart & Gris) Burret

Parasyncolporate

(278/4)

Polar view ~ 19 µm across (island very faint).

Coarsely scabrate; exine ~ 1.5 µm, ~ 3 µm at pore.

Aperture type: transversally elliptic.

- Arillastrum gummiferum* Pancher ex Baillon
- Brevi-colporate (278/5)
Polar view ~ 11.5 µm across.
Psilate; exine <1.5 µm.
Aperture type: transversally elliptic.
- Austromyrtus* sp.
- Brevi-colporate (278/6-8)
Polar view ~ 13 µm across.
Psilate; exine <1.5 µm.
Aperture type: transversally elliptic.
- Baekea le rattii* Schlecter
- Brevi-colporate (278/9-10)
Polar view ~ 15 µm across.
Psilate; exine < 1.5 µm.
Aperture type: transversally elliptic.
- Carpolepis laurifolia* (Brongniart & Gris) Dawson ined.
- Parasyncolporate (278/11-12)
Equatorial view 10 x 19 µm; polar view ~ 19 µm across.
Psilate; exine ~ 1.5 µm, ~ 2.5 µm at pore.
Aperture type: transversally elliptic.
- Cloezia aquarum* Guillaumin
- Parasyncolporate (278/13)
Polar view ~ 19 µm across; island ~ 7 µm across.
Psilate; exine ~ 1.5 µm.
Aperture type: transversally elliptic.
- Jambosa canalensis* Vieillard
- Parasyncolporate (278/14-15)
Equatorial view ~ 23 x 11.5 µm; polar view ~ 19 µm across.
Scabrate; exine ~ 1.5 µm, ~ 3 µm at pore.
Aperture type: transversally elliptic.
- Melaleuca brongniartii* Daniker
- Parasyncolporate (278/16-17)
Polar view ~ 17.5 µm across.
Psilate to slightly scabrate; exine ~ 1.5 µm, < 3 µm at pore.
Aperture type: transversally elliptic.
- Psidium guajava* L.
- Parasyncolporate (3-4 colporate, occasionally 5) (278/18)
Polar view ~ 17.5 µm across (island very faint).
Scabrate.
Aperture type: transversally elliptic.
- Piliocalyx* sp.
- Parasyncolporate (278/19-20)
Polar view ~ 23 µm across.
Psilate; exine 1.5 µm, ~ 3 µm at pore.
Aperture type: transversally elliptic.

Syzgium balanse

Parasyncolporate (278/21)
Polar view ~ 17.5 µm across.
Psilate
Aperture type: transversally elliptic.

Syzgium laterifolium Brongniart & Gris

Parasyncolporate (278/22)
Polar view ~ 9 µm across.
Psilate.
Aperture type: transversally elliptic.

Syzgium undulatum

Parasyncolporate (278/23-24)
Equatorial view 10 x 16 µm; Polar view ~ 16 µm across.
Psilate; exine 1.5 µm, ~ 3 µm at pore.
Aperture type: transversally elliptic.

Tristaniopsis callobuxus Brongniart & Gris

Parasyncolporate (?) (Material very poor quality) (279/1)
Polar view ~ 11.5 µm across.
Psilate

Uromyrtus supra-axillaris (Guillaumin) Burret

Brevi-colporate (279/2-4)
Polar view ~ 11.5 µm across.
Psilate to slightly scabrate.
Aperture type: transversally elliptic.

OLEACEAE

Osmanthus austrocaledonicas (Vieillard) Knoblauch

3C3P (279/5-6)
Shape in equatorial view prolate (20 x 16 µm); amb circular (16 µm).
Supra-reticulate; sculpturing elements in sexine visible.
Aperture type unknown.

PANDANACEAE

Pandanus krauelianis (New Guinea specimen of Haberle [1995])

Monoporate (279/7-8)
Elliptical (kidney bean shaped) (23 x 13 µm).
Psilate; exine < 1.5 µm.
Aperture type: near circular pore at or near one of the long axis poles, often annulated.

Pandanus tectorius Park.

Monoporate (279/9-10)
Elliptical to circular (~ 22 x 17.5 µm).
Echinate; exine < 1.5 µm, spine ~ 1.5 - 2 µm.
Pore not always clearly visible, rarely annulated.

PASSIFLORACEAE

Passiflora suberosa L.

Apertures not established (279/11)
Elliptical (43.5 x 35 µm).
Reticulate to rugulate.

PIPERACEAE

Piper paitensis Schlechter

Monocolpate (279/12)
Elliptical (11 x 9.5 µm).
Scabrate.

PITTOSPORACEAE

Pittosporum boudounii Brongniart & Gris

3C3P (279/13-14)
Shape in equatorial view spherical (30 µm); amb circular (30 µm).
Finely reticulate; exine < 1.5 µm, thickening to 2.5 µm at poles (sculpturing elements in sexine visible).
Aperture type: transversally elliptic.

Pittosporum deplanchii Brongniart & Gris

3C3P (279/15-16)
Shape in equatorial view spherical (27 µm); amb sub-angular (27 µm).
Reticulate; exine ~ 1.5 µm
Aperture type: transversally parallel.

Pittosporum lifuense Guillaumin

3C3P (279/17-19)
Shape in equatorial view prolate (30 x 27.5 µm); amb circular.
Reticulate; exine ~ 3 µm, nexine 1.5 µm, sexine 1.5 µm.
Aperture type: transversally elliptic (constriction at colpus leads to slight dumb bell shape).

Pittosporum loniceroides Brongniart & Gris

3C3P (279/20-22)
Shape in equatorial view prolate (27 x 25 µm); amb sub-angular (25 µm across) colpi open.
Scabrate; exine ~ 1.5 µm, colpi smooth.
Aperture type: transversally elliptic.

Pittosporum paitense Guillaumin

3C3P (279/23-24)
Shape in equatorial view spherical (28 µm); amb circular (28 µm across).
Scabrate; exine ~ 1.5 - 2 µm.
Aperture type: transversally elliptic.

Pittosporum paniculatum Brongniart & Gris

3C3P (280/1-2)
Shape in equatorial view prolate (35 x 31 µm).
Scabrate; exine ~ 1.5 µm.
Aperture type: transversally elliptic.

PODOCARPACEAE

Decussocarpus comptonii (Buchholz) de Laubenfels

Vesiculate (280/3)
Corpus scabrate.
Saccus reticulate.
Most grains crumpled and not suitable for measurement.

Decussocarpus minor (Carriere) de Laubenfels

Vesiculate (280/4-6)
Corpus scabrate. Around 31 µm long and 23 µm wide.
Saccus reticulate. Around 20 µm in width.

PROTEACEAE

Garneria sp.

- Stephanoporate (6P) (280/7-9)
 Shape in equatorial view oblate (25 x 31 μm); amb hexagonal (31 μm across).
 Echinulate; exine ~ 1.5 μm .
 Pore common and circular, sometimes has ragged appearance.

Grevillea gillvrayi W.J. Hooker

- 3P (280/10-12)
 Amb angular (~ 46 μm across).
 Coarsely reticulate; exine 3 μm thick.
 Pore circular.

Kermadecia elliptica Brongniart & Gris

- 3P (280/13-14)
 Amb angular (~ 36 μm across).
 Reticulate; exine ~ 1.5 μm .
 Pore circular.

Kermadecia pronyensis (Guillaumin) Guillaumin

- 3P (280/15-16)
 Amb angular (~ 40 μm across).
 Reticulate; exine ~ 3 μm , nexine 1.5 μm , sexine 1.5 μm .
 Pore circular.

Kermadecia rotundifolia Brongniart & Gris

- 3P (280/17-18)
 Amb angular (~ 44 μm across).
 Reticulate; exine ~ 4.5 μm , nexine 1.5 μm , sexine 3 μm .
 Pore circular.

Knightia pronyensis

- 3P (280/19)
 Amb angular (~ 30 μm across).
 Scabrate; exine ~ 1.5 μm .
 Pore circular, patterning around pore area inside grain.

Knightia strobiliana (Labillardiere) R. Brown

- 3P (280/20)
 Amb angular (~ 30 μm across).
 Scabrate; exine ~ 1.5 μm .
 Pore circular, patterning around pore area inside grain.

Stenocarpus sp.

- 3P (280/21-22)
 Amb angular (~ 33 μm across).
 Reticulate; exine < 3 μm , sexine < 1.5 μm , nexine 1.5 μm , thicker around pore.
 Pore circular.

RHAMNACEAE

Alphitonia neocaledonica Guillaumin

- 3C3P (281/1-2)
 Shape in equatorial view varies from prolate to oblate (~ 24 x 21 μm).
 Psilate; exine ~ 1.5.
 Aperture type: transversally elliptic.

RHIZOPHORACEAE

Crossostylis biflora J.R. & G. Forster

3C3P (281/3)

Shape in equatorial view prolate (~ 13 x 10 µm).

Psilate; exine < 1.5 µm.

Aperture type: rectangular.

Crossostylis grandiflora Pancher ex Brongniart & Gris

3C3P (281/4)

Shape in equatorial view prolate (~ 19 x 14 µm).

Psilate; exine 1.5 µm.

Aperture type: rectangular.

Crossostylis serbertii Brongniart & Gris

3C3P (281/5-6)

Shape in equatorial view prolate (~ 13 x 11.5 µm).

Psilate; exine < 1.5 µm.

Aperture type: transversally elliptic (constriction at colpus gives slight bow tie shape).

Rhizophora sp.

3C3P (281/7-8)

Shape in equatorial view prolate (~ 20 x 18 µm).

Psilate; exine > 1.5 µm.

Aperture type: transversally elliptic.

RUBIACEAE

Atractocarpus heterophyllus Guillaumin & Beauvisage

3P (281/9-10)

Spherical; 30 µm across.

Coarsely reticulate; exine ~ 2.5 µm.

Pore circular and annulated; ~ 3.5 µm across.

Atractocarpus sp.

3P (281/11-12)

Spherical; 30 µm across.

Coarsely reticulate; exine ~ 2.5 µm.

Pore circular and annulated; ~ 3.5 µm across.

Bikkia campanulata (Brongniart) Schlechter

3P (281/13-15)

Shape in equatorial view oblate (~ 39 x 29 µm); amb angular (29 µm across).

Granulate; exine 3 µm.

Pore elliptical and ragged.

Bikkia macrophylla (Brongniart) K. Schumann

3P (281/16)

Shape in equatorial view oblate (~ 39 x 29 µm); amb angular (29 µm across).

Granulate; exine 3 µm.

Pore elliptical and ragged.

Coelospermum balansaeum Baillon

3C3P (281/17-18)
 Shape in equatorial view spherical; amb circular (45 µm across).
 Reticulate; exine 6 µm, nexine 3.5 µm, sexine 2.5 µm.
 Aperture type: circular

Gardenia aubreyi Vieillard

Tetrad (3P) (281/19-20)
 ~ 38 µm across
 Scabrate; exine ~ 1.5 µm.
 Pore circular and thickly annulated.

Gardenia urvillei Montrouzier

Tetrad (3P) (281/21-22)
 ~ 38 µm across
 Coarsely scabrate to reticulate; exine ~ 1.5 µm.
 Pore circular and thickly annulated.

Lindenia vitensis

3C3P (281/23-24)
 Shape in equatorial view oblate (21 x 24 µm).
 Reticulate; exine 2 µm.
 Aperture type transversally elliptic, plus a circular pore.

Morieriana montana Vieillard

3C3P (282/1-3)
 Shape in equatorial view oblate; amb circular (35 µm).
 Echinate; exine ~ 4.5 µm, nexine 2.5 µm, sexine 2 µm, spines < 1 µm.
 Aperture type: longitudinally elliptic and ragged.

Normandia neocaledonica J.D. Hooker

3C3P (282/4)
 Shape in equatorial view oblate (~ 32 x 5 µm).
 Reticulate; exine < 3 µm.
 Aperture type: transversally elliptic.

Psychotria collina Labillardiere

3P (282/5-7)
 Shape in equatorial view spherical to oblate (~ 30 µm across).
 Reticulate; exine 1.5 µm.
 Pore elliptical and ragged.

Tarenna truncatocalyx (Guillaumin) Bremekamp

3C3P (282/8-9)
 Shape in equatorial view spherical (~ 26 µm); amb circular (~ 26 µm across).
 Reticulate; exine 1.5 µm, ~ 2 µm at pore.
 Aperture type: longitudinally elliptic; pore club type; colpi smooth and almost to poles.

RUTACEAE

Comptonella albiflora

3C3P (282/10-12)
 Shape in equatorial view prolate (~ 25 x 20 µm); amb sub-angular (20 µm).
 Reticulate; exine ~ 1.5 µm, 2.5 µm at poles where sexine and nexine visible.
 Aperture type: transversally elliptic.

Flindersiaournieri

3C3P (282/13-14)
Shape in equatorial view prolate (~ 38 x 26 µm).
Reticulate; exine < 1.5 µm.
Aperture type: transversally elliptic.

Halfordiakendac (Montrouzier) Guillaumin

Syncolporate (282/15-16)
Shape in equatorial view oblate (~ 17 x 19 µm); amb angular (19 µm).
Coarsely granulate; exine < 1.5 µm.
Aperture type: transversally elliptic, colpi smooth.

Zeridiumpseudo-obtusifolium Guillaumin

3C3P (282/17-20)
Shape in equatorial view prolate (17 x 14 µm); amb inter-hexagonal (14 µm).
Supra-reticulate; exine 1.5 µm, sculpturing elements in sexine visible.
Aperture type: transversally elliptic.

SANTALACEAE

Santalumaustrocaledonicum Vieillard

3C3P (282/21-22)
Shape in equatorial view prolate (32 x 27 µm).
Psilate; exine 1.5 µm, > 2 µm at pore.
Aperture type: circular to elliptic.

SAPINDACEAE

Aryteralepidota Radlkofer

Parasyncolporate (283/1-2)
22 µm across (island < 5 µm).
Reticulate; exine 1.5 µm.
Aperture type: transversally elliptic; atrium type pore.

Cupaniopsisglomeriflora Radlkofer

Parasyncolporate (283/3-4)
22 µm across (island > 5 µm).
Reticulate; exine 1.5 µm.
Aperture type: transversally elliptic; thickening around pore.

Ellatostachysapetala (Labillardiere) Radlkofer

Parasyncolporate (283/5-7)
22 µm across (island 10 µm across).
Reticulate; exine 1.5 µm.
Aperture type: transversally parallel; atrium type pore.

Guio gracilis (Pancher & Sebert) Radlkofer

Parasyncolporate (283/8)
Concave, 22 µm across (island 7 µm across).
Scabrate or finely reticulate; exine ~ 1.5 µm.
Atrium type pore.

SAPOTACEAE

Beccariella serbertii (Pancher) Pierre

- 4C4P (283/9-10)
 Shape in equatorial view prolate (33 x 22 μm).
 Psilate; exine 1.5 μm , 3 μm around pore.
 Aperture type: transversally elliptic.

Leptostylis petiolata Vink

- 4C4P (283/11-12)
 Shape in equatorial view prolate (36 x 26 μm).
 Psilate; exine < 3 μm , 3 μm around pore.
 Aperture type: transversally elliptic.

Planchonella cinera (Pancher) Royen

- 4C4P (283/13-14)
 Shape in equatorial view prolate (35 x 23 μm).
 Psilate; exine > 1.5 μm , 3 μm around pore.
 Aperture type: transversally elliptic.

Pycnandra benthamii Baillon

- 4C4P (283/15-16)
 Shape in equatorial view prolate (36 x 29 μm).
 Scabrate; exine > 1.5 μm , 3 μm around pore.
 Aperture type: transversally elliptic.

Pycnandra comptonii (S. Moore) Vink

- 4C4P (283/17-18)
 Shape in equatorial view prolate (36 x 29 μm).
 Reticulate; exine > 1.5 μm , 3 μm around pore.
 Aperture type: transversally elliptic.

Pycnandra controversa (Guillaumin) Vink

- 4C4P (283/19-20)
 Shape in equatorial view prolate (36 x 29 μm).
 Scabrate; exine 3 μm , 6 μm around pore.
 Aperture type: transversally elliptic.

Pycnandra kaalaensis (Aubreville)

- 4C4P (283/21-22)
 Shape in equatorial view prolate (33 x 29 μm).
 Scabrate; exine 3 μm , 4.5 μm around pore.
 Aperture type: transversally elliptic.

SIMAROUBACEAE

Soulamea cycloptera Guillaumin

- 3C3P (284/1)
 Shape in equatorial view prolate (30 x 22 μm); amb inter-hexagonal.
 Striate; exine ~ 1.5 μm .
 Aperture type: transversally elliptic.

Soulamea muelleri Brongniart & Gris

- 3C3P (284/2)
 Shape in equatorial view prolate (28 x 20 μm); amb inter-hexagonal.
 Striate; exine ~ 1.5 μm .
 Aperture type: transversally elliptic.

Soulamea pancheri Brongniart & Gris

3C3P (284/3-4)
Shape in equatorial view prolate (25 x 19 µm); amb inter-hexagonal.
Striate; exine ~ 1.5 µm.
Aperture type: transversally elliptic.

SMLACACEAE

Smilax neo-caledonica Schlechter

Inaperturate (284/5)
Spherical; ~ 15 µm across.
Granulate.

Smilax purpurata J.R. & G. Forster

Inaperturate (284/6)
Spherical; ~ 15 µm across.
Granulate.

STERCULIACEAE

Sterculia dzumacensis Guillaumin

3C3P (284/7-10)
Shape in equatorial view prolate (25 x 20 µm); amb inter-hexagonal (~ 20 µm).
Reticulate; exine ~ 1.5 µm.
Aperture type: transversally elliptic.

THYMELIACEAE

Solmsia calophylla Baillon

Periporate (284/11-12)
Spherical (29 µm across).
Sparsely granulate; exine 3 µm; sexine 1.5 µm and nexine 1.5 µm.
Pores circular and < 1 µm.

Wickstromia indica (L.) Mey

Periporate (284/13-14)
Spherical (25 µm across).
Densely granulate; exine > 3 µm; sexine < 1.5 µm and nexine > 1.5 µm.
Pores circular and < 1 µm.

ULMACEAE

Celtis hypoleuca Planchon

3P (284/15-16)
Spherical (20 µm across).
Scabrate; exine 1.5 µm.
Pores annulated and < 2 µm across.

VERBENACEAE

Clerodendron inerme (L.) Gaertner

3C (284/1)
Amb circular (80 µm across) colpi open.
Echinate; exine ~ 2.5 µm, spines quite fine (< 1.5 µm long) and evenly spaced (6-7 µm apart).

Ixora sp.

3C3P (284/17-20)

Spherical (20 - 23 μm in diameter).
Reticulate; exine > 1.5 μm ; nexine 1.5 μm , sexine < 1.0 μm .
Aperture type: transversally elliptic.

Oxera baladica Vieillard

3C (285/2)

Amb circular (80 μm across) colpi open.
Echinate; exine ~ 2.5 μm ; spines ~ 5 μm long and 2.5 μm at base; evenly spaced (6-7 μm apart).

Oxera microcalyx Guillaumin

3C (285/3)

Amb circular (64 μm across) colpi open.
Echinate; exine ~ 2.5 μm , spines < 1.5 μm long and ~ 1.5 μm at base; evenly spaced (6-7 μm apart).

Oxera moorieri Vieillard

3C (285/4)

Amb circular (95 μm across) colpi open.
Echinate; exine ~ 2.5 μm , spines ~ 2 μm long and 2.5 μm at base. Evenly spaced ~ 19 μm apart.

Oxera pancheri Dubard

3C (285/5)

Amb circular (75 μm across) colpi open.
Echinate; exine > 2.5 μm thick; spines ~ 2.5 μm long and ~ 2.5 μm at base. Evenly spaced (6-7 μm apart).

Oxera robusta Vieillard

3C (285/6)

Amb circular (88 μm across) colpi open.
Echinate; exine ~ 2.5 μm , spines ~ 2.5 μm long and < 2.5 μm at base. Evenly spaced ~ 13 μm apart.

PTERIDOPHYTES

BLECHNACEAE

Blechnum indicum

Monolete (286/1-3)

36 x 29 μm .
Perine gemmate and ~ 3 μm .

LINDSACEAE

Sphenomeris chinensis

Trilete (286/5-6)

50 μm across.
Psilate to lightly reticulate; exine < 3 μm .
Laurae are prominent raised ridges extending almost entire spore length.

Sphenomeris deltoidea

Trilete (286/7)

80 μm across.
Perine reticulate ~ 2 μm thick.
Lasurae ridges are not prominent and extend three quarters of spore length.

POLYPODIACEAE
Dipteris conjugata

Monolete

(286/4)

29 x 22 μm .

Psilate; exine ~ 1.5 μm .

COMMON RAINFOREST FERNS
No. 27

Monolete

(286/8-10)

Perine granulate ~ 2 μm thick; spore 43 x 28 μm .

Exine scabrate < 1.5 μm thick; spore around 29 x 20 μm .

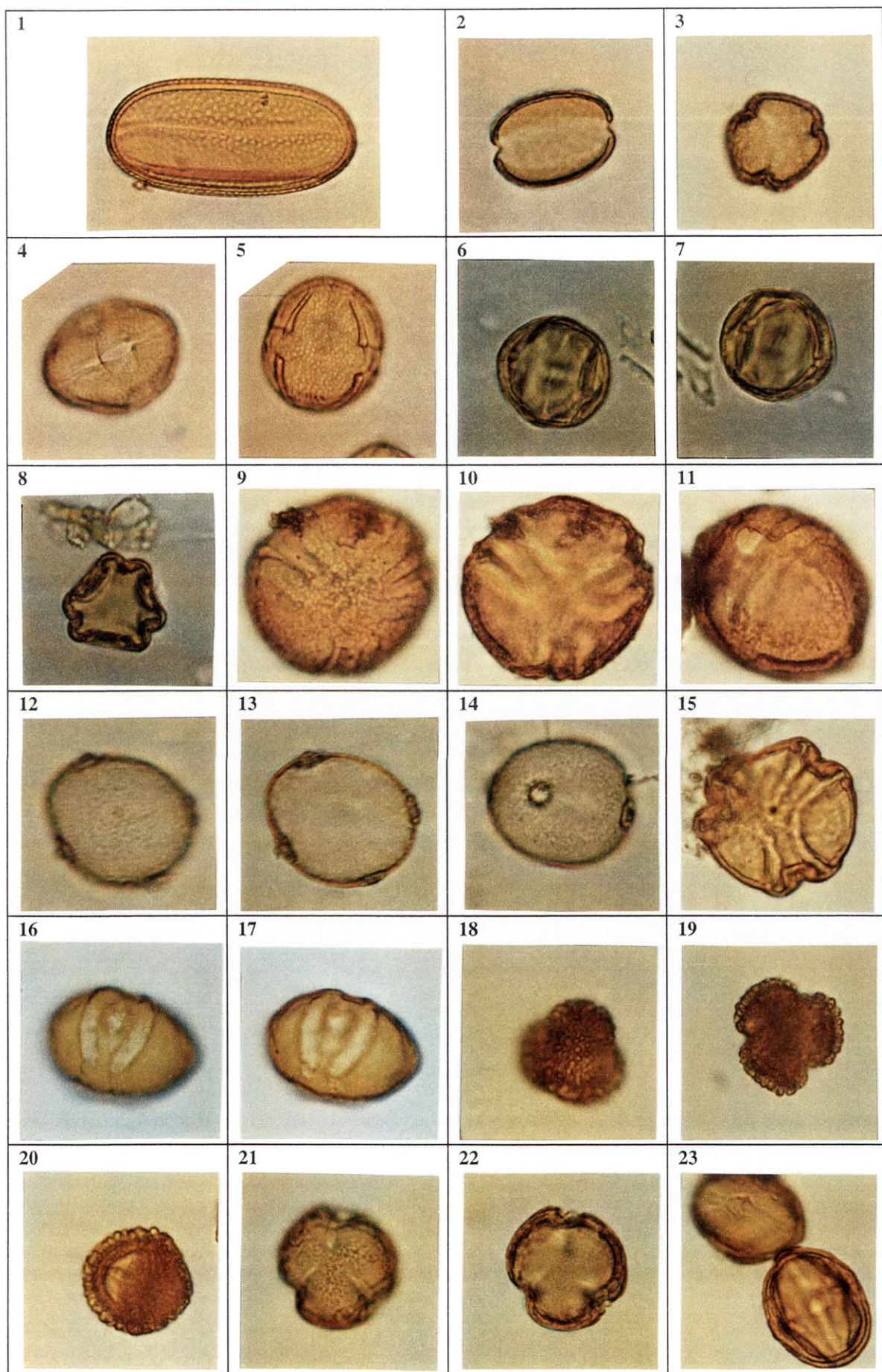
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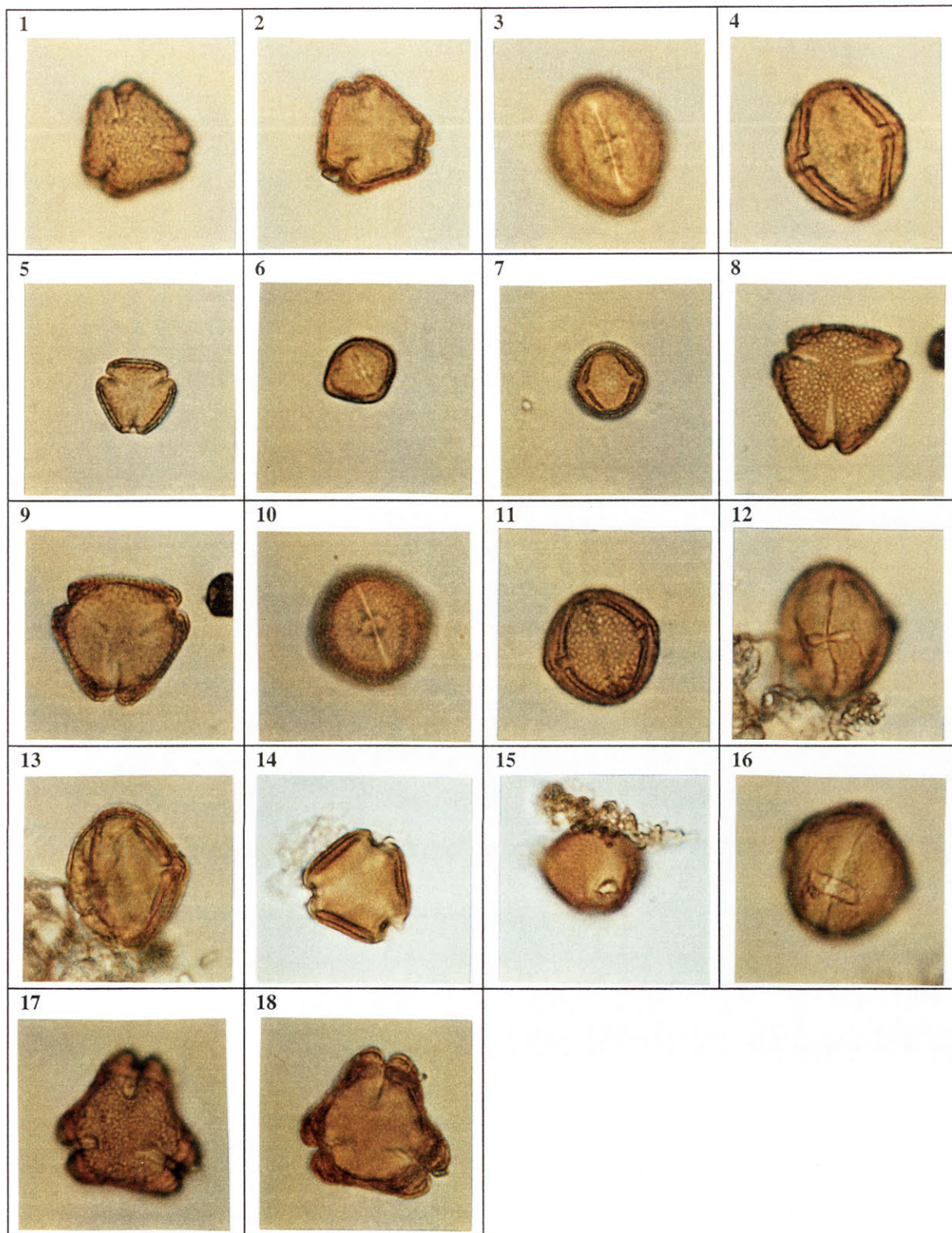
Monolete

(286/11-13)

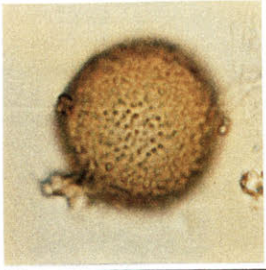
Perine echinate ~ 2 μm thick; spore 33 x 20 μm .

Exine psilate ~ 1.5 μm thick; spore 30 x 18 μm .

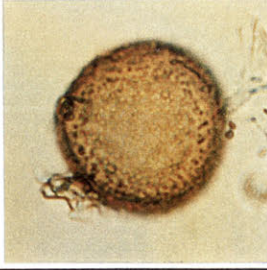




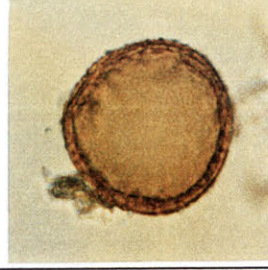
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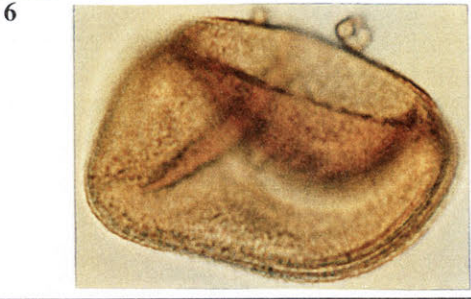
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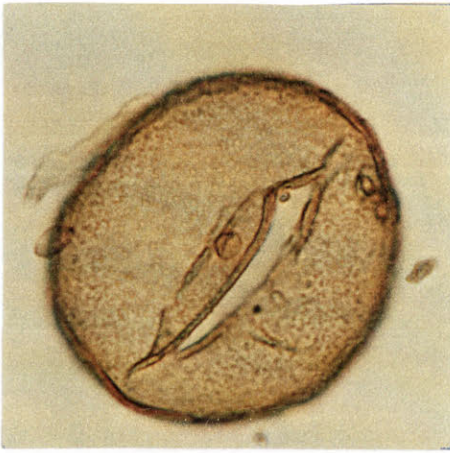
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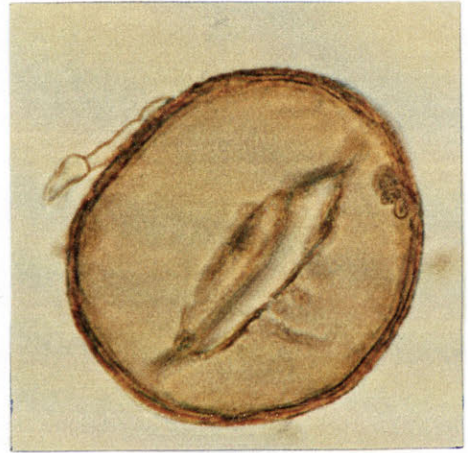
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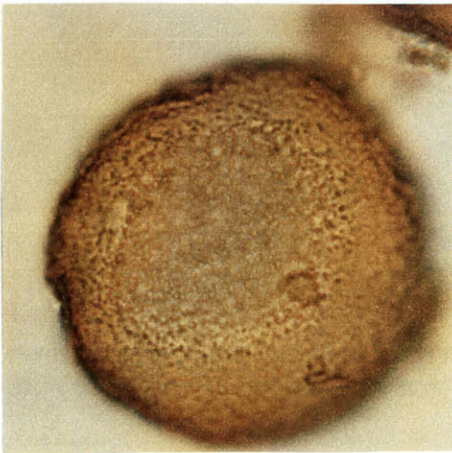
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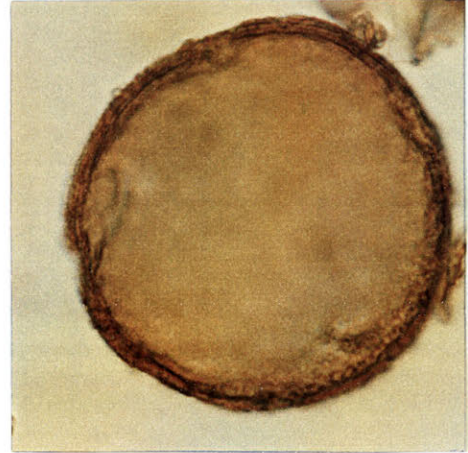
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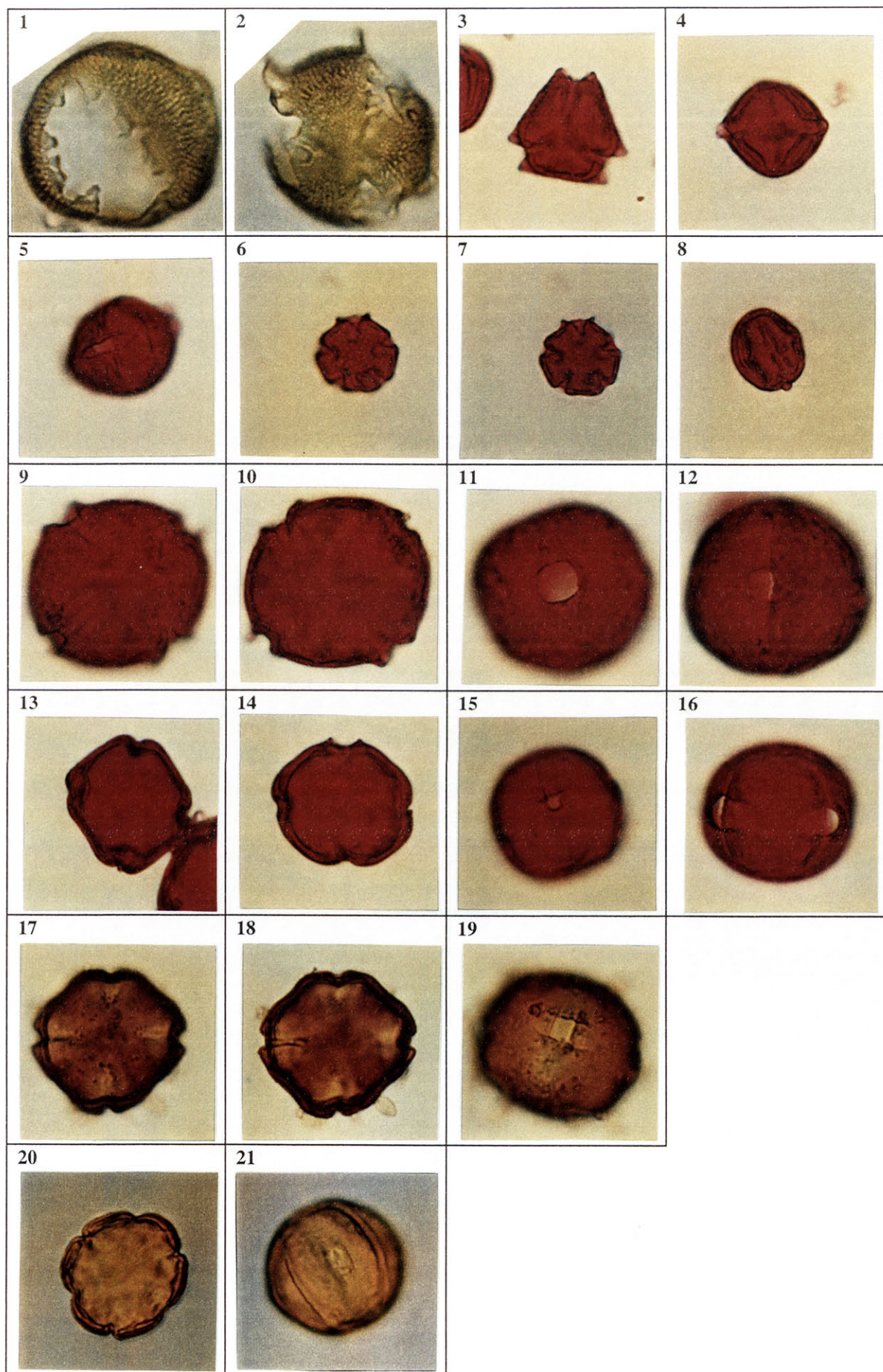


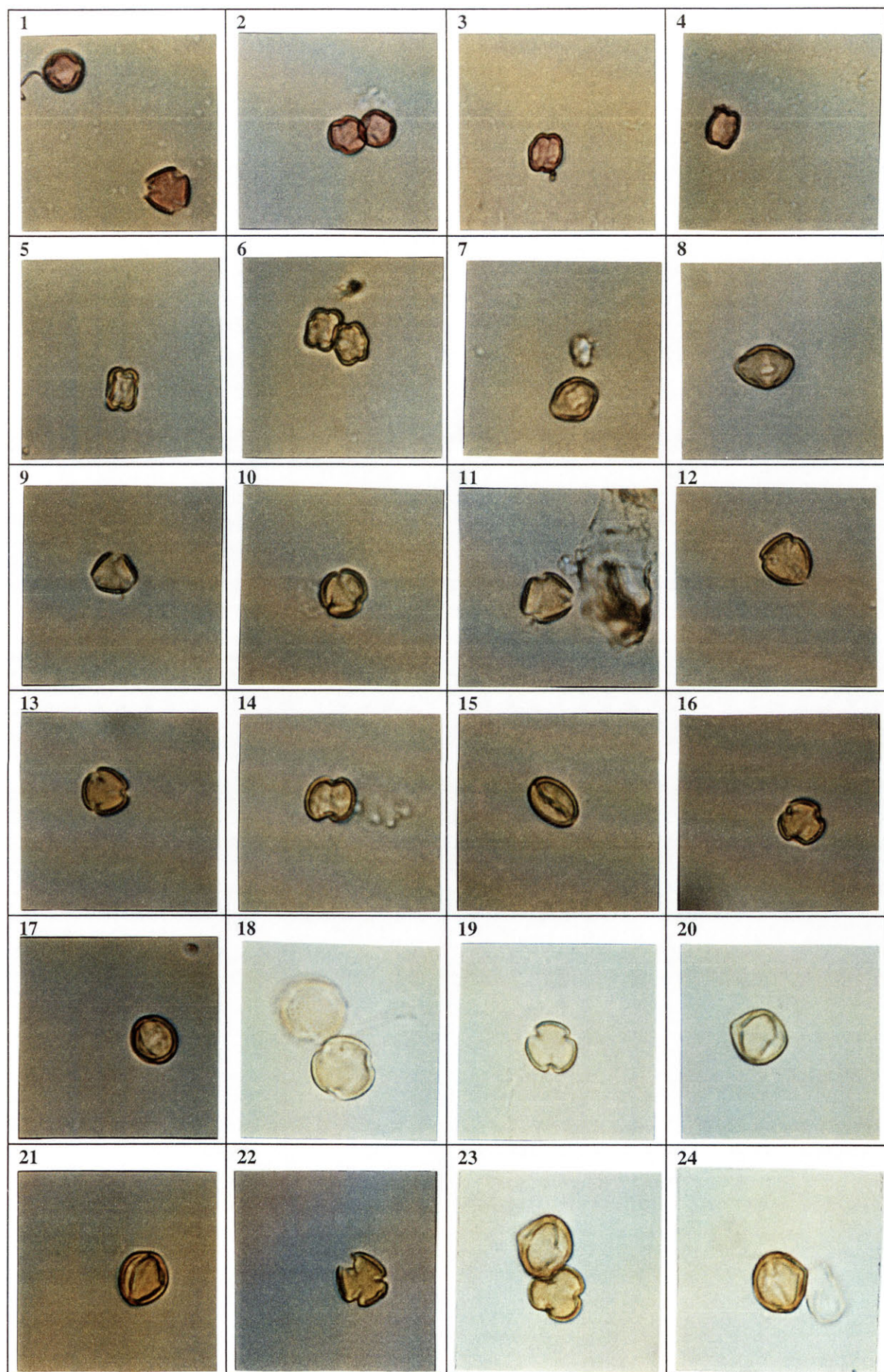
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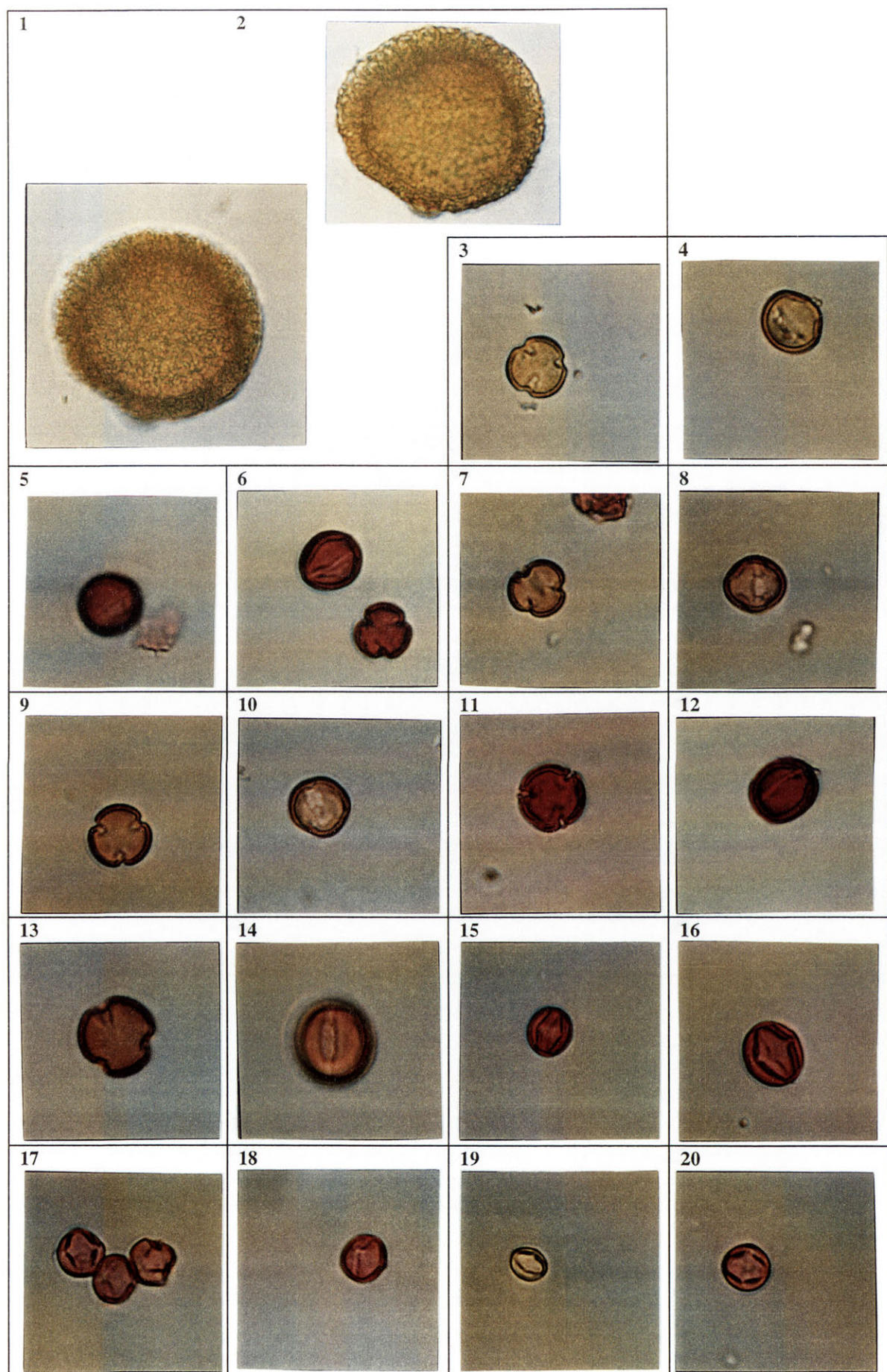


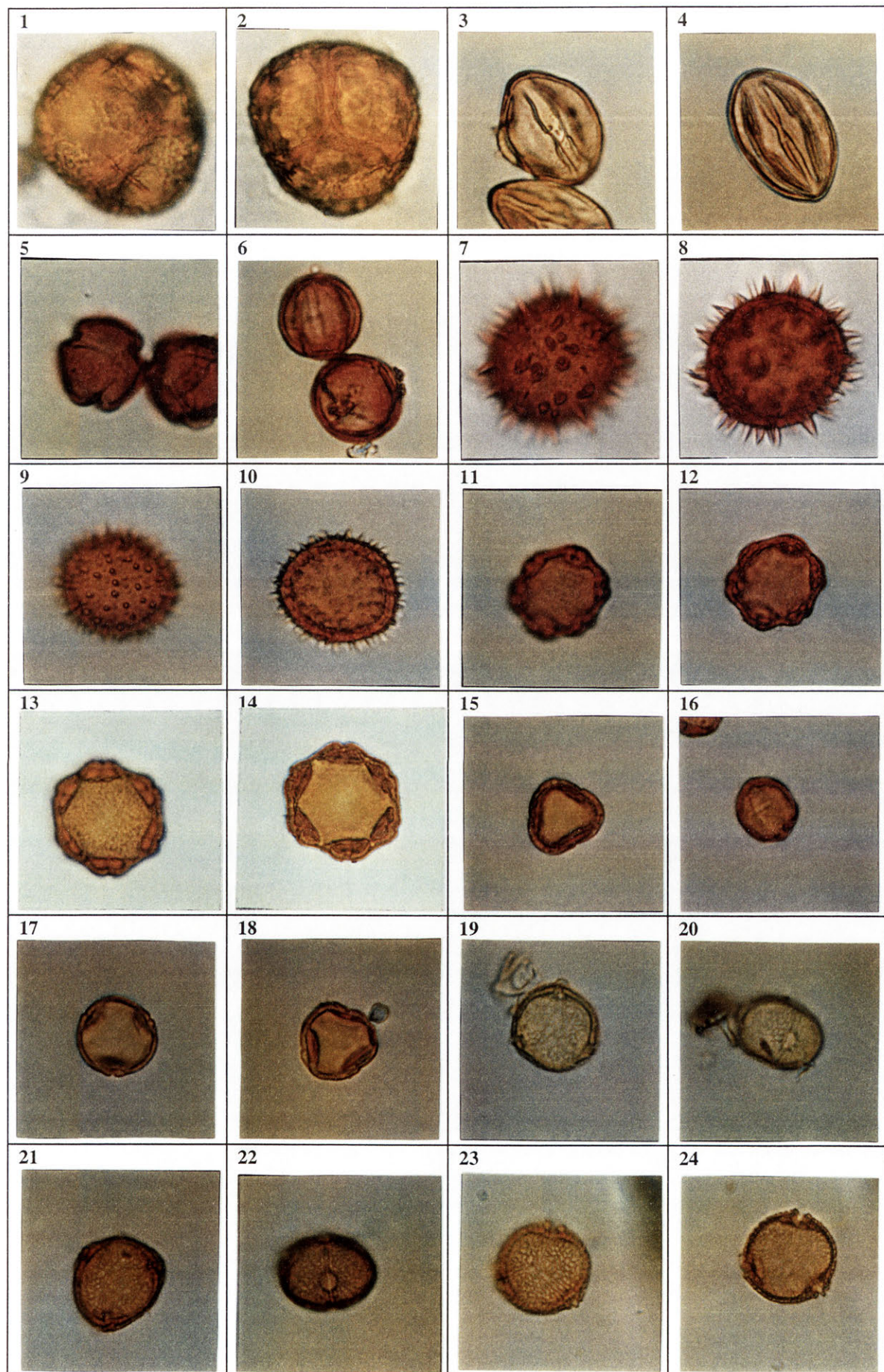
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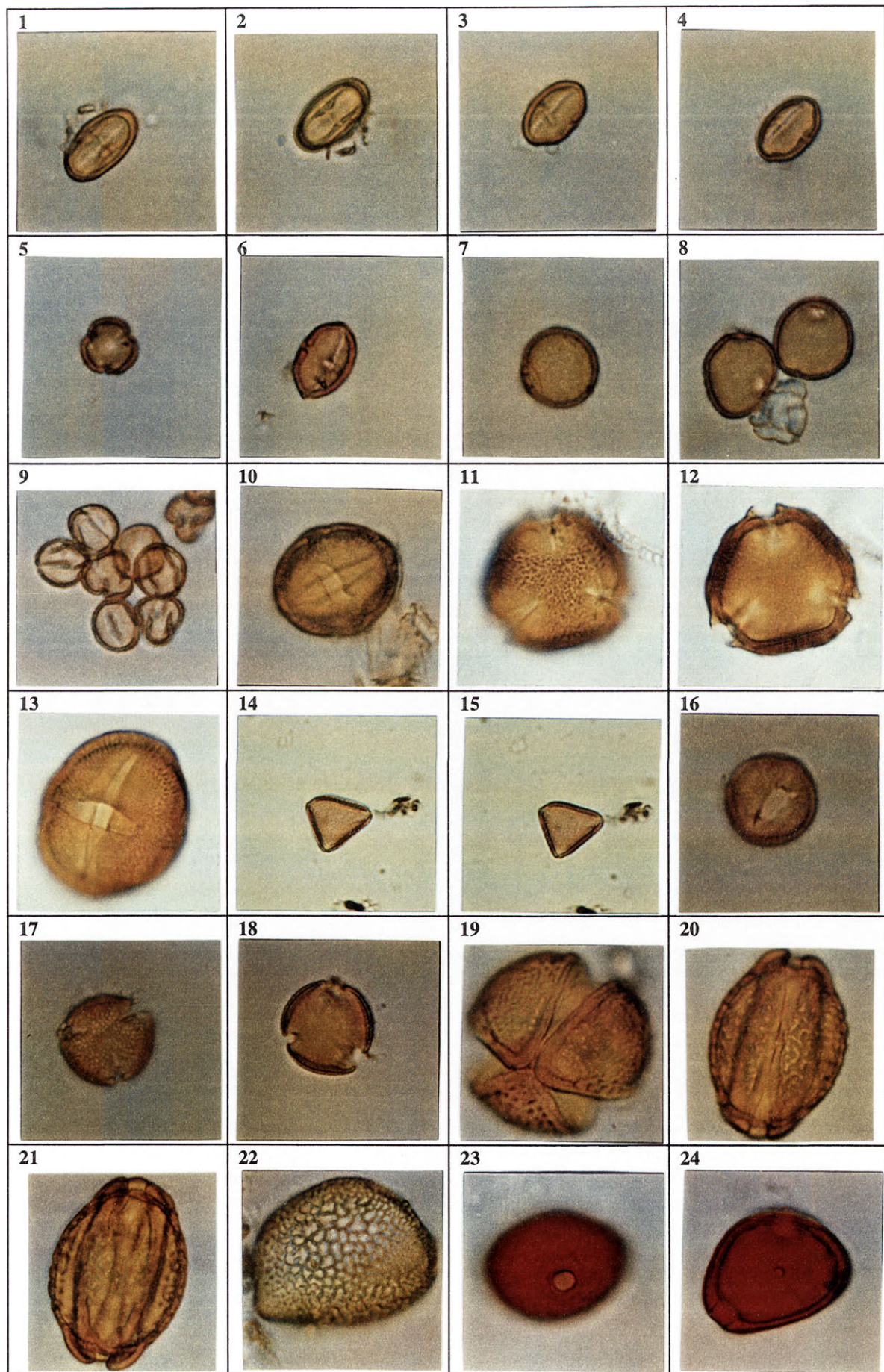


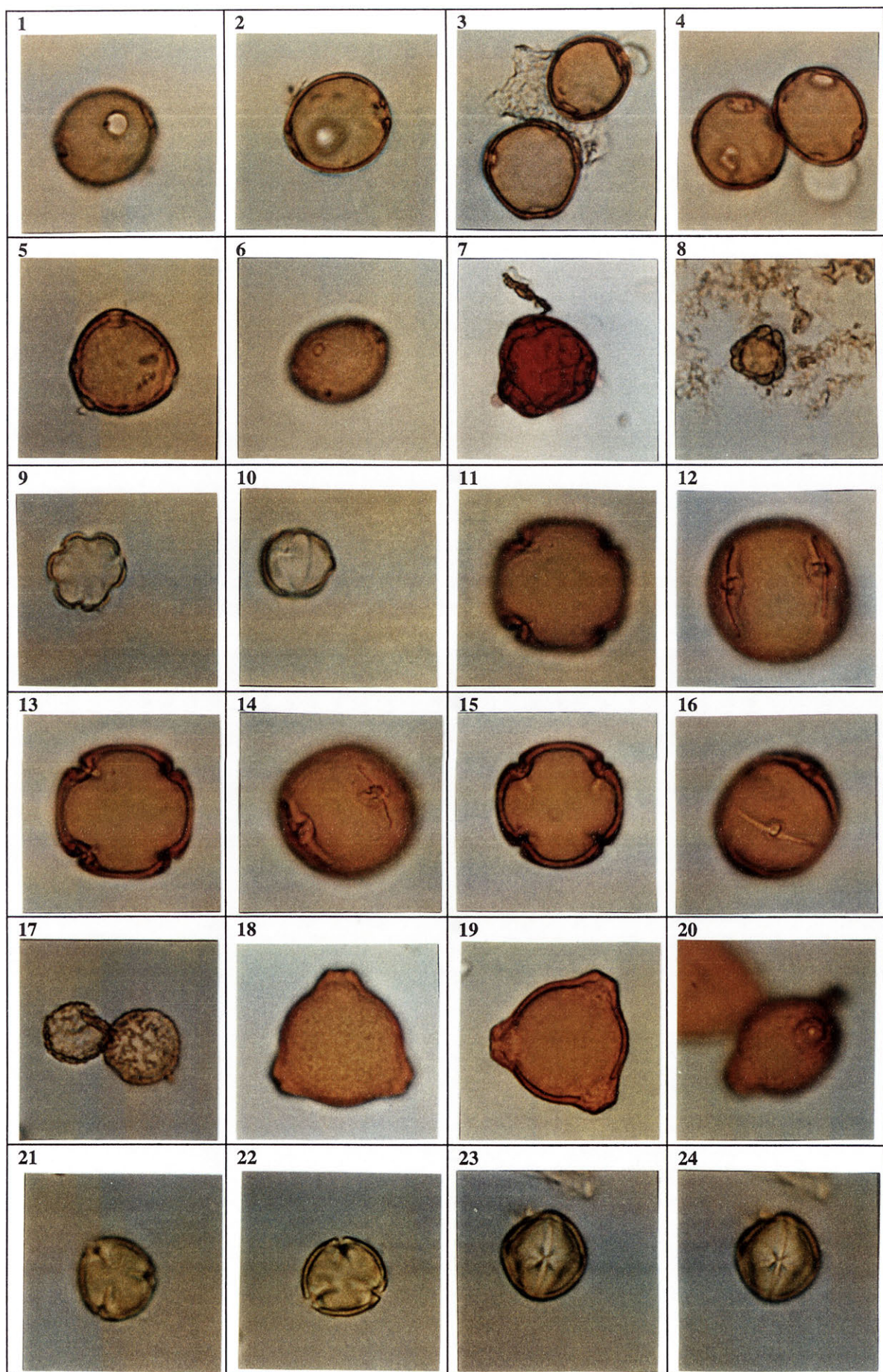


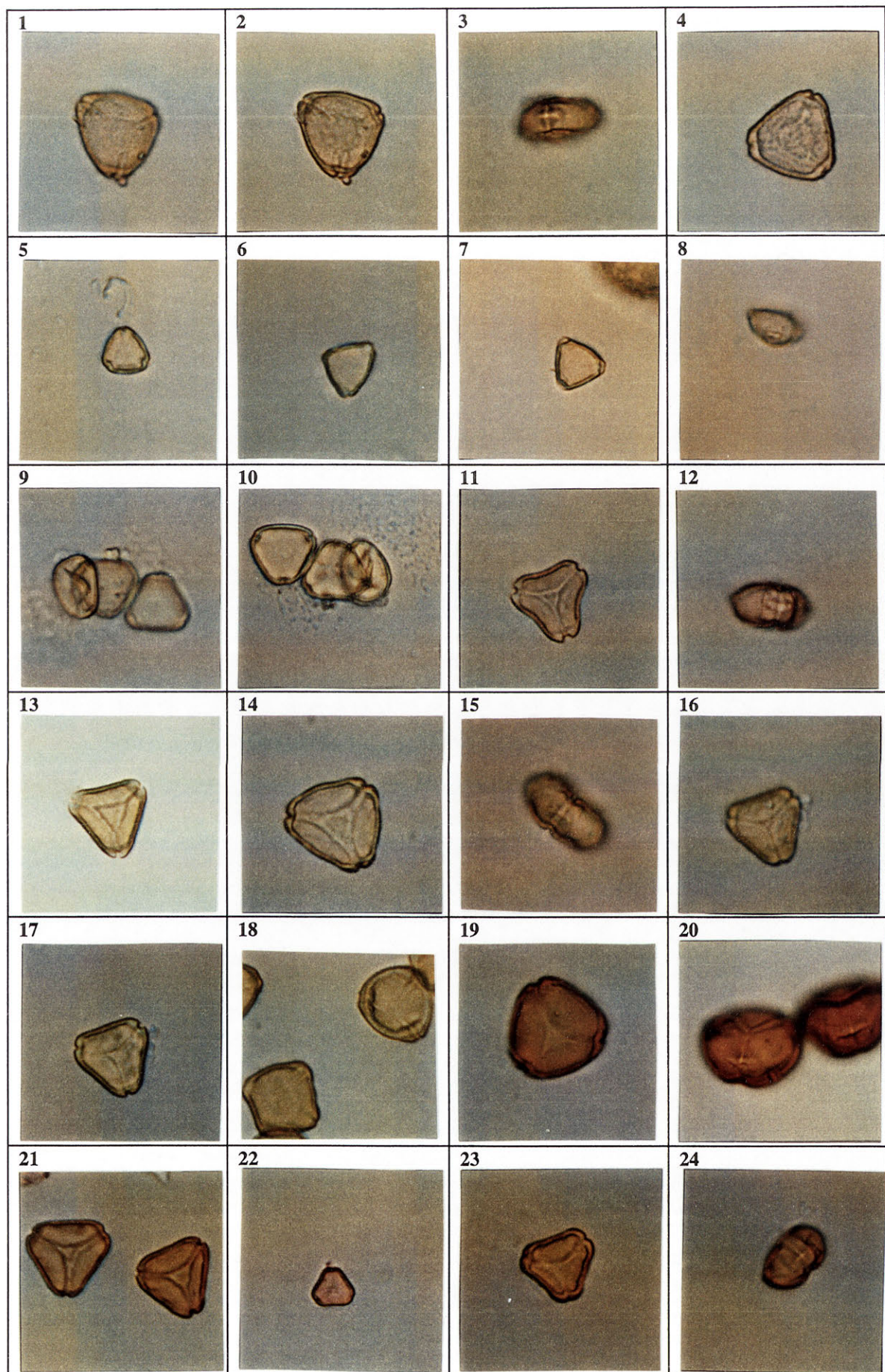


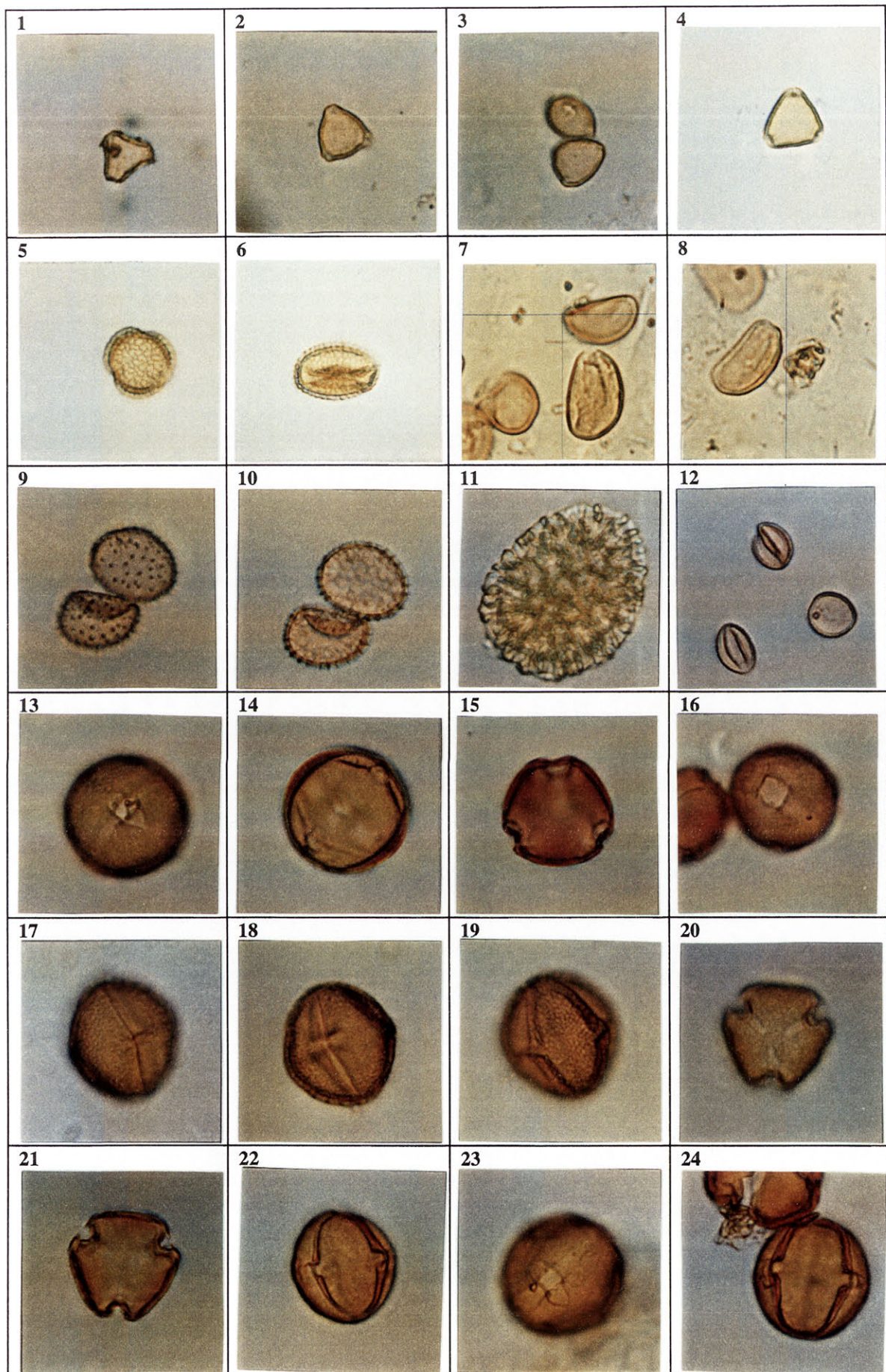


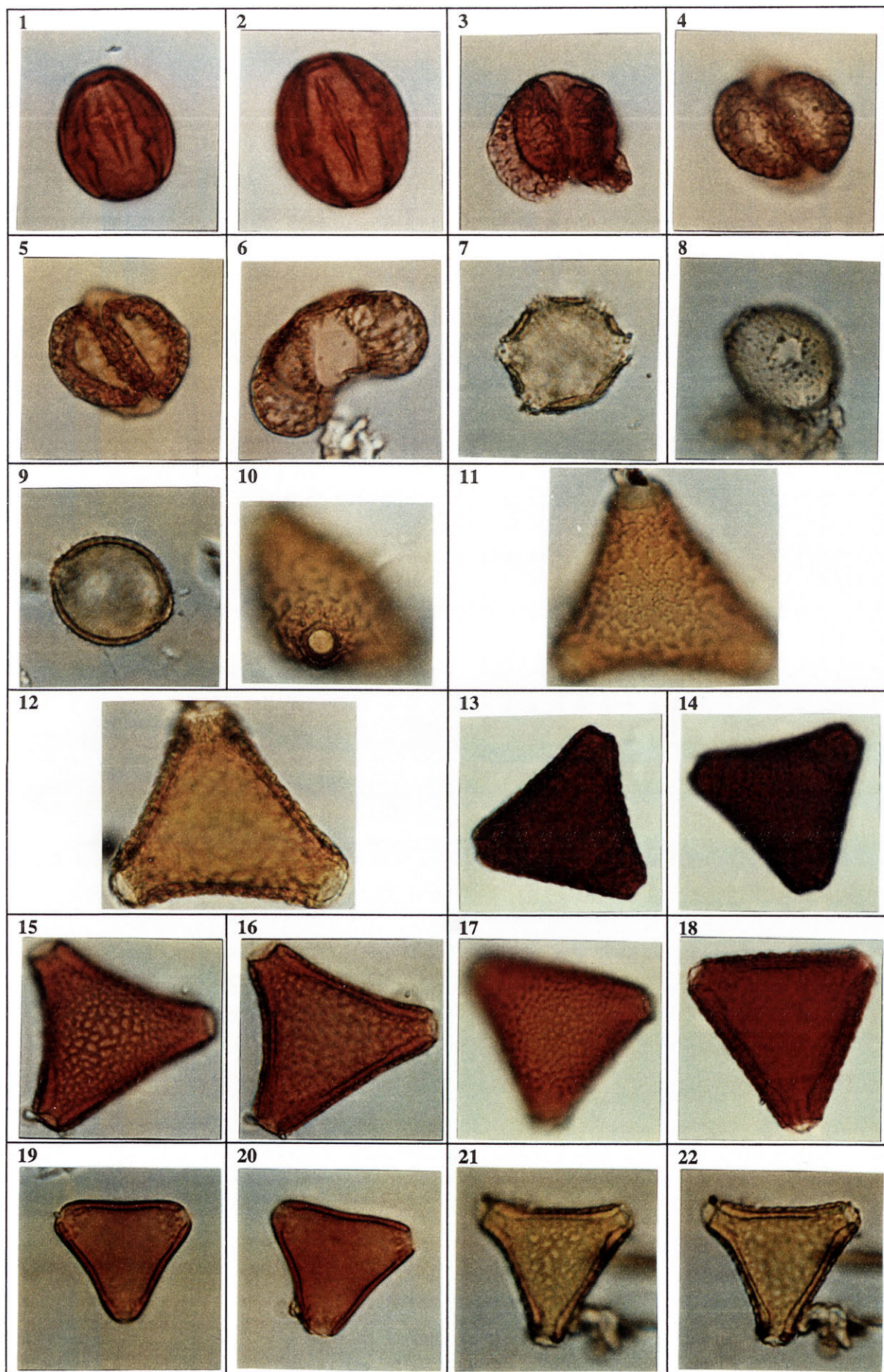


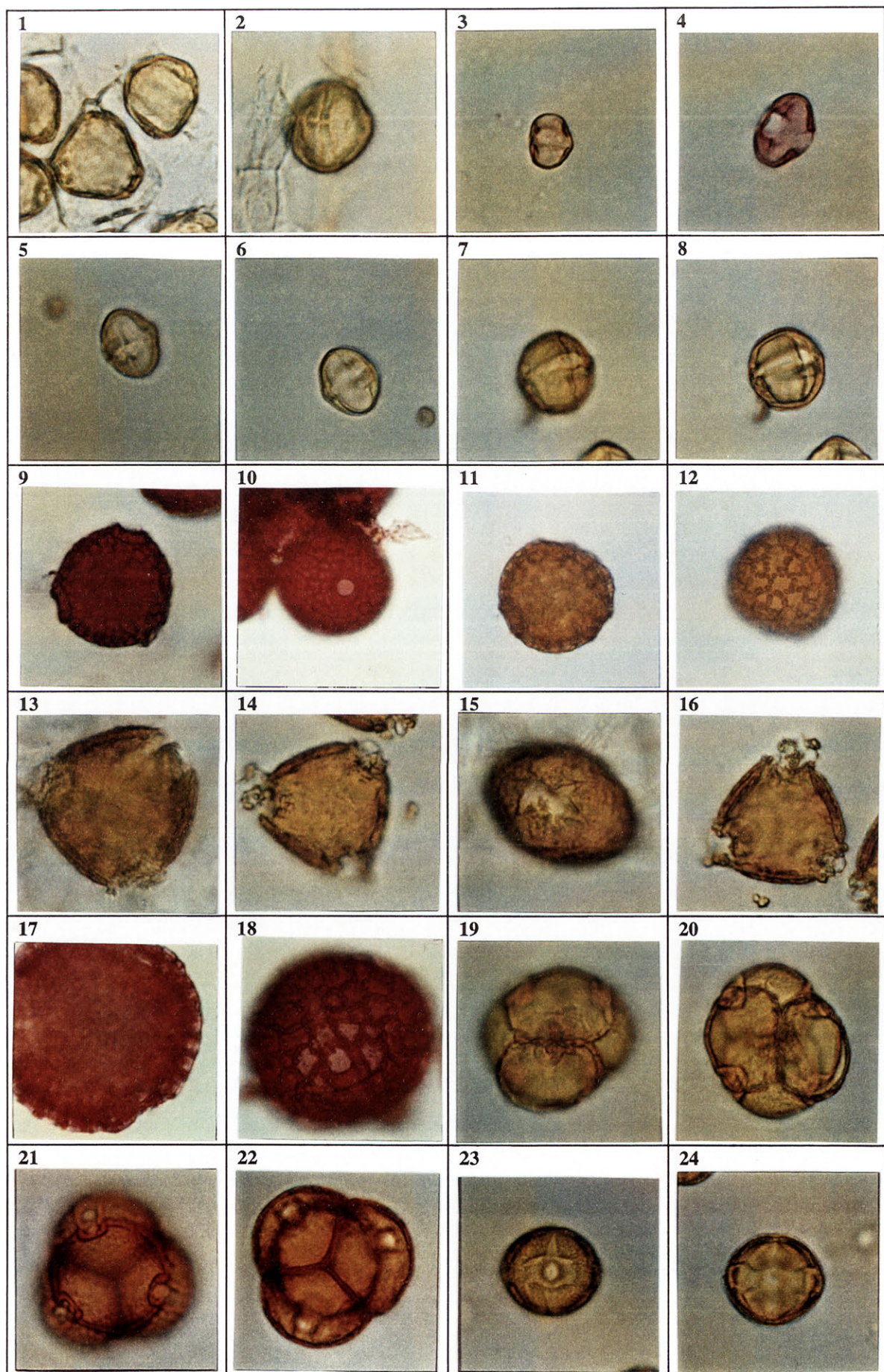


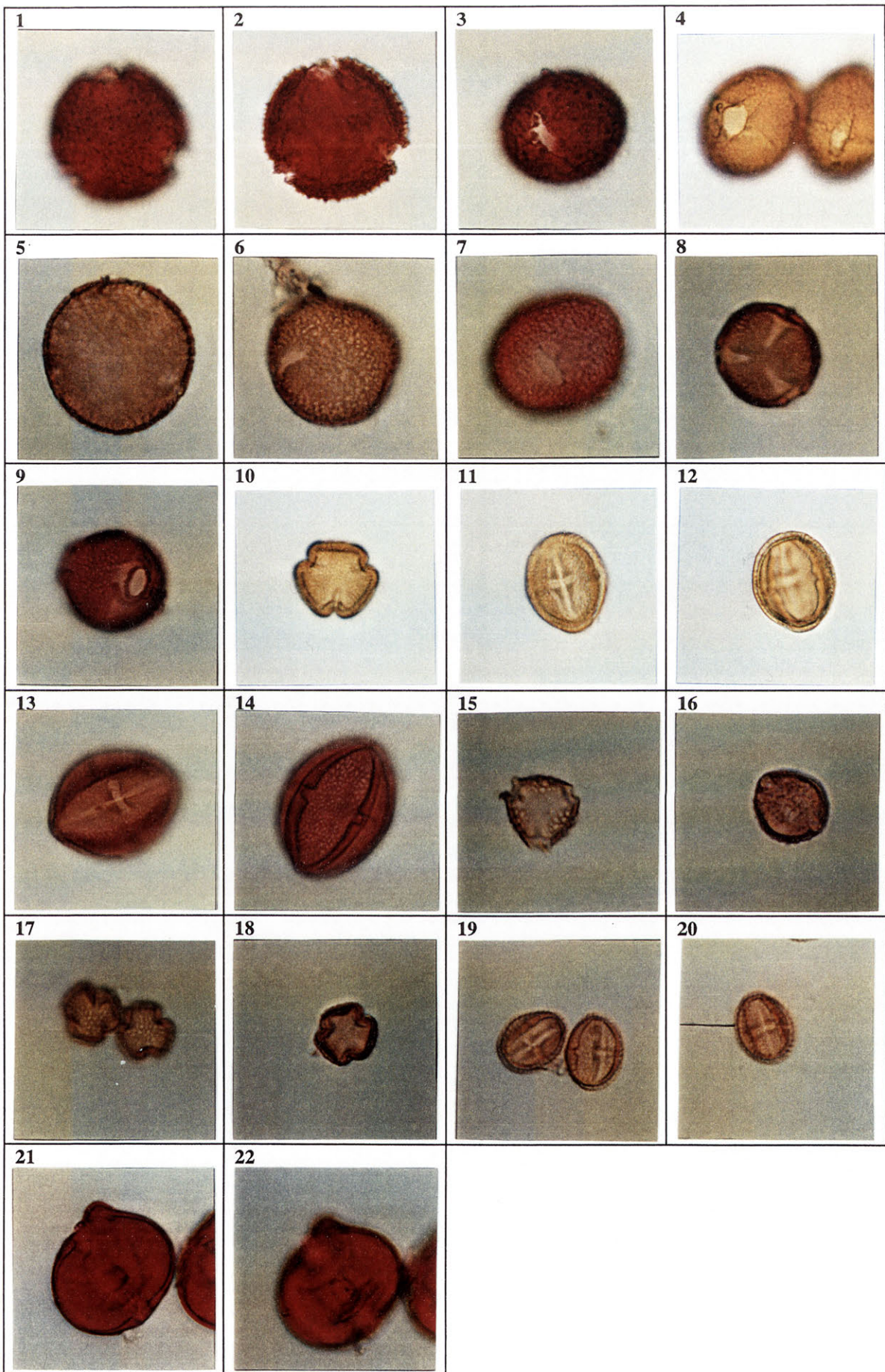


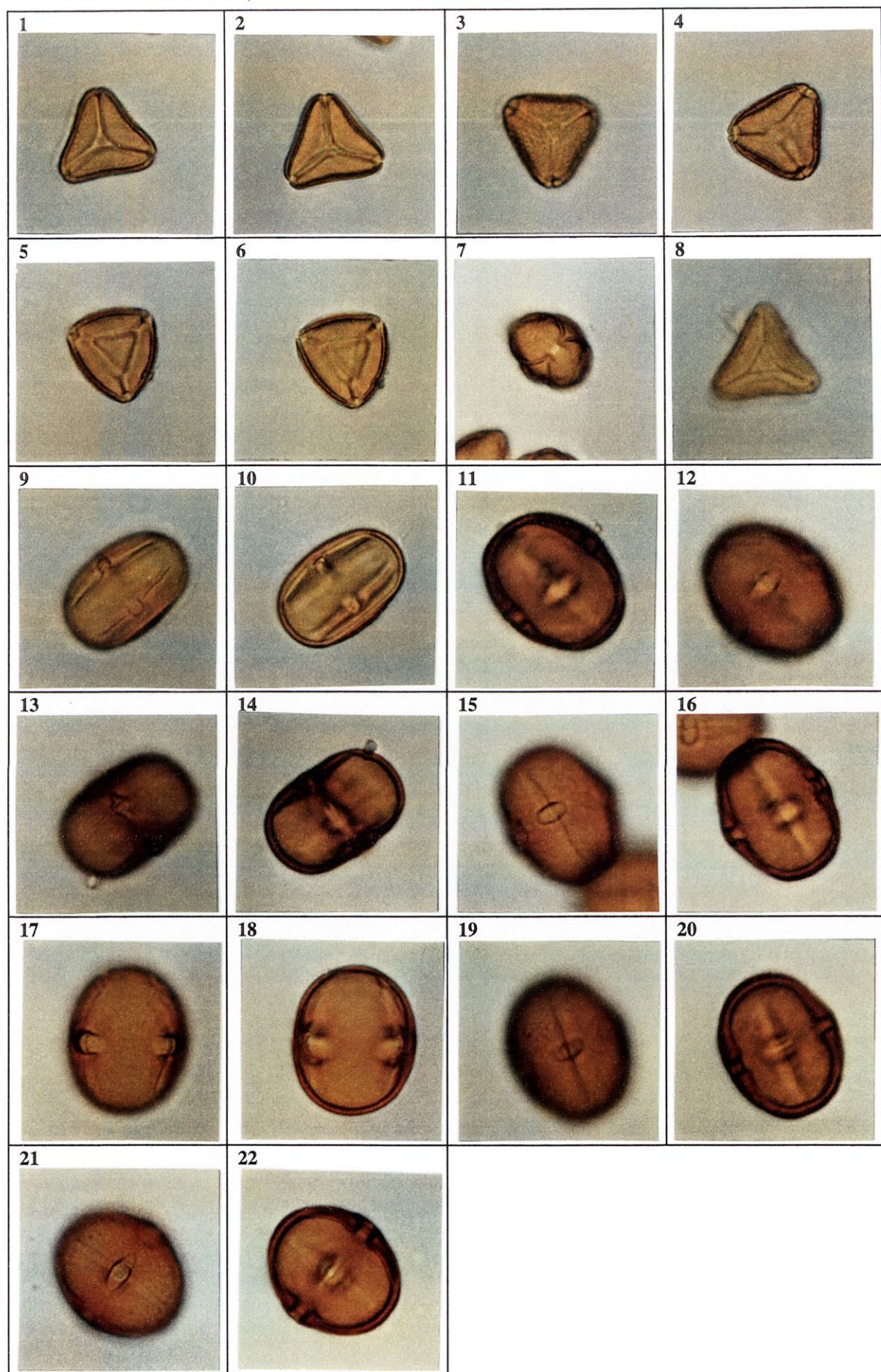


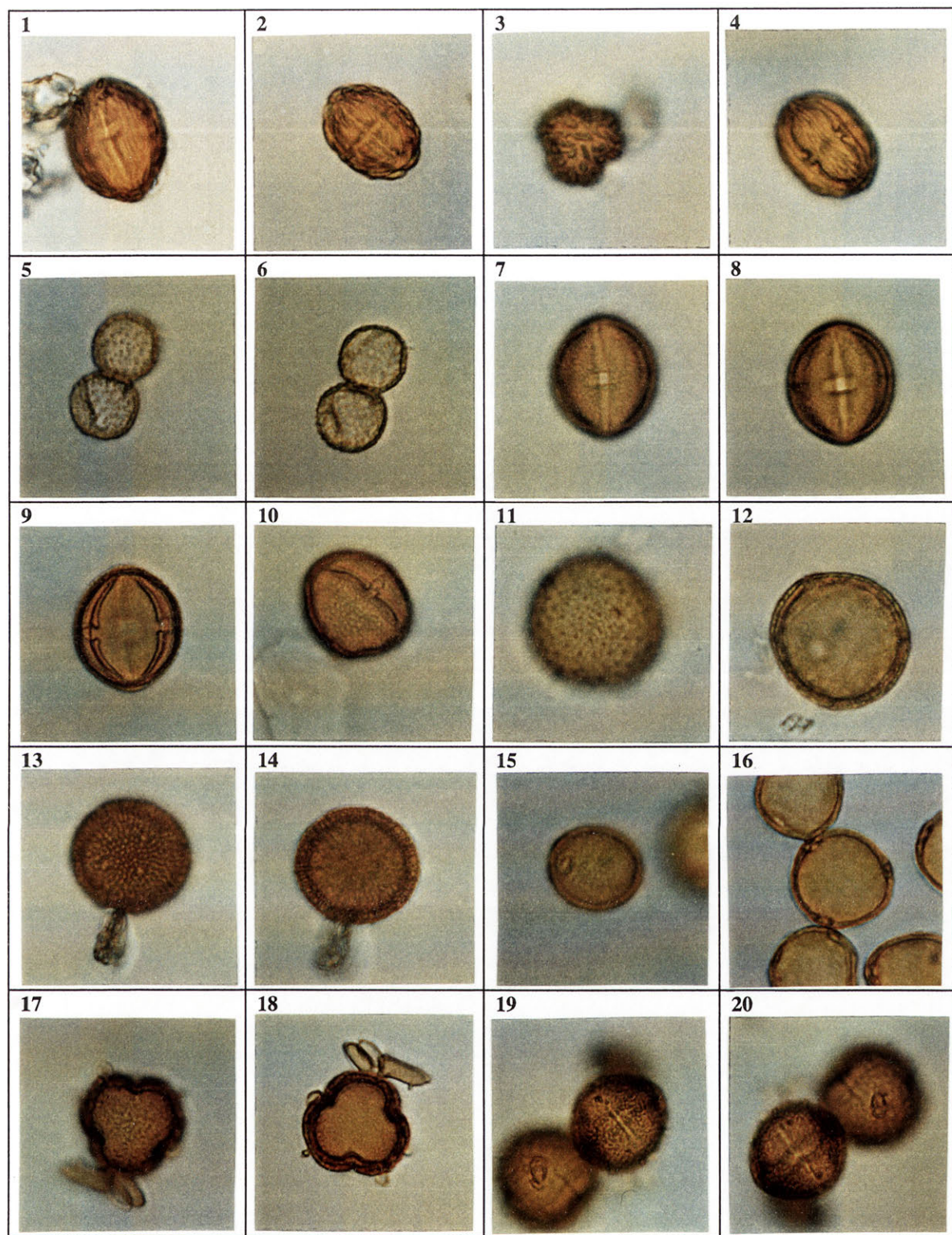




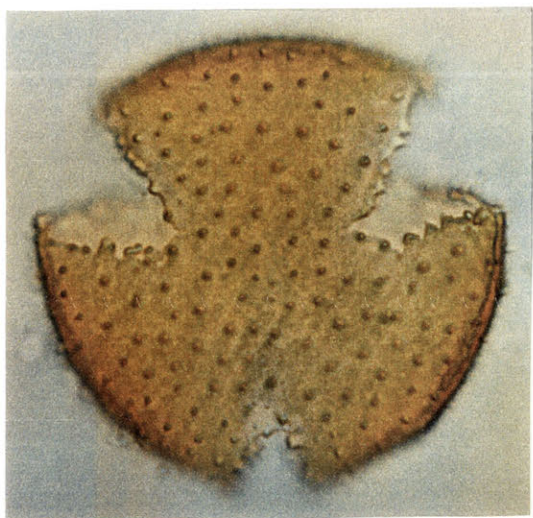




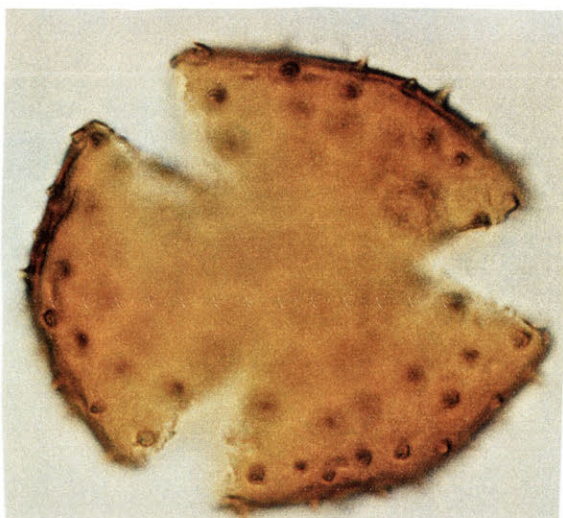




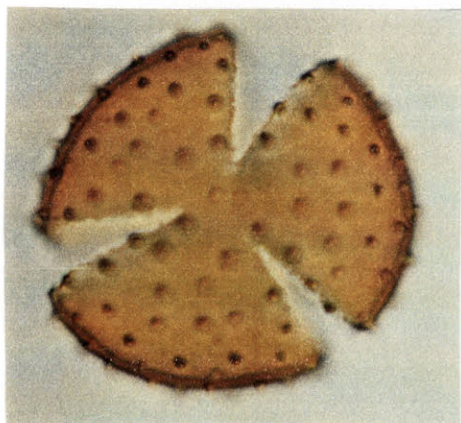
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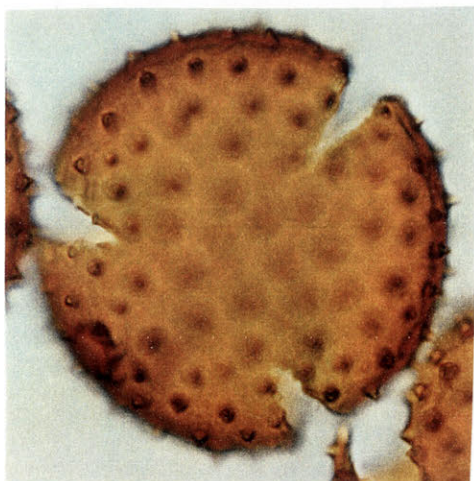
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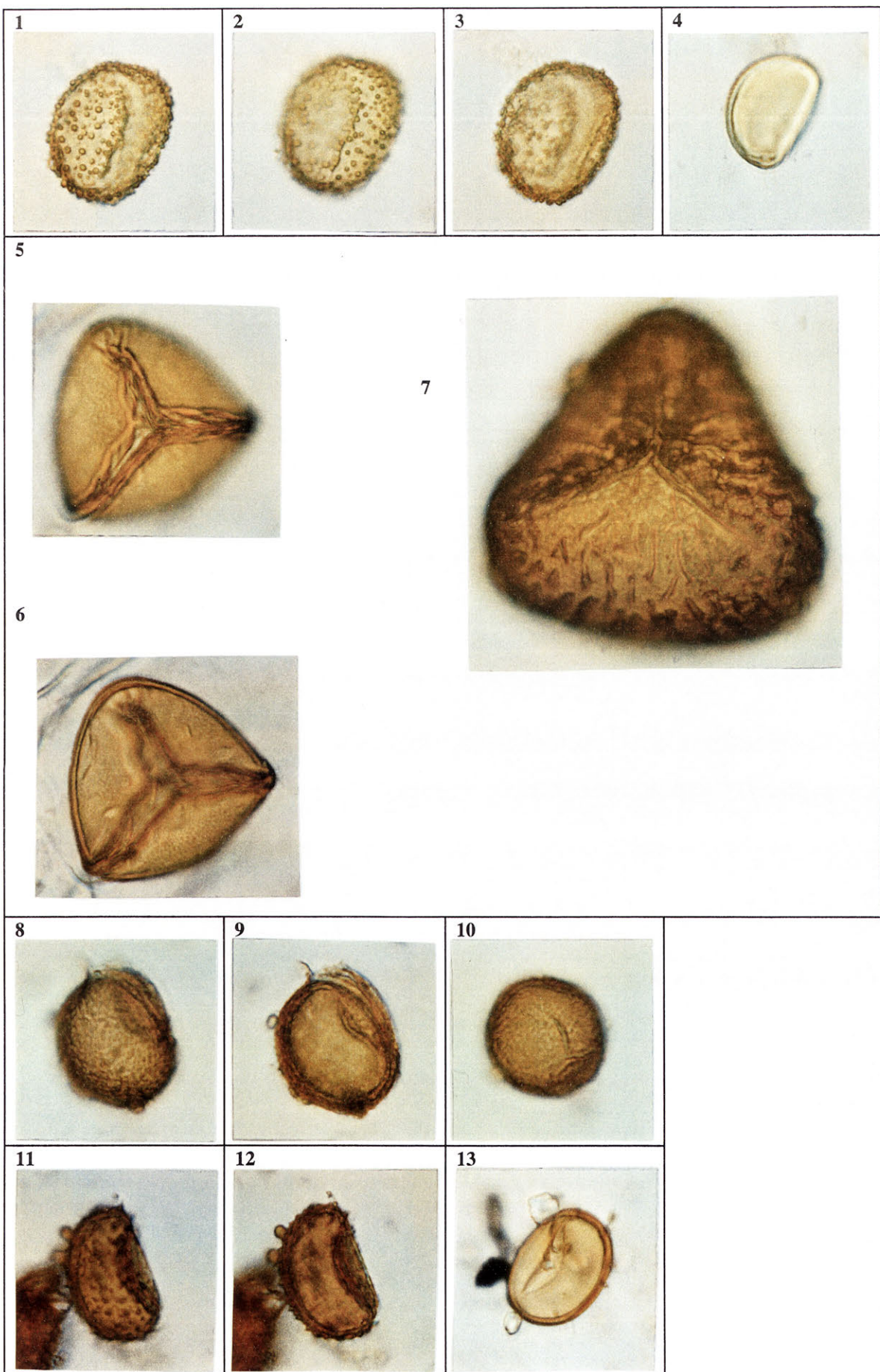


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6





Appendix 3: The lifeform and ecological setting of various pollen taxa.

Important (or well represented) pollen from all diagrams.

Sources:	∫	Flore de Nouvelle Calédonie: Familles revues.: Nomenclature et ecologie. (Cerneau et al., 1990)
	♦	Pacific Plant Areas (van Steenis, 1963 & 1975; van Balgooy, 1966)
	*	The Plant Book (Mabberly, 1987)
	+	Flore de Nouvelle Calédonie et Dependances (Villiers, 1980; Dawson, 1992; Jérémie, 1982)

Pollen and Spore Taxa		Lifeform	Ecological Setting
POLLEN			
GYMNOSPERMS			
<i>Agathis</i>	ARAUCARIACEAE	Trees ∫	Forests on ultramafic and other terrain. A. ovata also found in the maquis.
<i>Araucaria</i>	ARAUCARIACEAE	Trees & Shrubs ∫	Wet evergreen forest on ultramafic and other terrain. Also found in maquis.
<i>Dacrydium</i>	PODOCARPACEAE	Tree or Shrub ∫	Wet evergreen forest and maquis on ultramafic terrain.
<i>Neocallitropsis</i>	CUPRESSACEAE	Shrub ∫	Maquis on ultramafic terrain.
<i>Pinus</i>	PINACEAE	Tree ∫	Introduced
<i>Podocarpus</i>	PODOCARPACEAE	Trees & Shrubs ∫	Wet evergreen forest & maquis on ultramafic and other terrain.
DICOTS			
	ACANTHACEAE	Herb Shrub Liane ∫	Wet evergreen forest, sclerophyll forest, maquis and mangroves. On ultramafic and other terrain. Ruderal vegetation.
<i>Albizia</i>	LEGUMINOSAE	Trees Shrubs & Lianas *	
<i>Alphitonia</i>	RHAMNACEAE	Trees or shrubs ♦	Lowland rainforest, secondary vegetation, coastal scrub and riverine forest.
<i>Alyxia</i>	APOCYNACEAE	Liane ♦	Lowland rainforest and in maquis.
	AMARANTHACEAE	Shrubs ♦	Lowland to lower montane rainforest; also secondary forest
	ANACARDIACEAE	Trees Shrubs Lianas *	

Pollen and Spore Taxa		Lifeform	Ecological Setting
<i>Antidesma</i>	EUPHORBIACEAE	Tree *	
	APOCYNACEAE	Shrubs Trees Lianas ♦ +	Lowland rainforest, sometimes up to 2000m asl.
<i>Apodytes clussifolia</i>	ICACINACEAE	Tree +	Wet evergreen forest; canopy tree grows up to 25 m tall; ultramafic and other terrain; 0 - 1000 m asl.
	ARALIACEAE	Trees Shrubs Lianas *	
<i>Arytera Type</i>	SAPINDACEAE	Shrubs or trees ♦	Mainly lowland forest, 0 - 1500 m asl.
<i>Ascarina</i>	CHLORANTHACEAE	Shrub or small tree ♦ +	2 species, found in wet evergreen forest and maquis on variety of terrain from 150 to 1500 m asl.
<i>Austrobuxus</i>	EUPHORBIACEAE	Trees and shrubs ∫	Wet evergreen forest and maquis on ultramafic and other terrain.
<i>Barringtonia</i>	LECTHYDIACEAE	Large shrub or small tree ♦	Littoral forest along rivers and estuaries.
	CASUARINACEAE		Two genera <i>Gymnostoma</i> and <i>Casaurina</i> . Occur primarily on soils derived from the ultramafic rock, but also on other substrates. All species favour open formations such as maquis, or boundary formations such as riparian zones or forest gaps. Often form monospecific stands. Found from 0 - 1200 m asl.
<i>Celtis</i>	ULMACEAE	Tree *	
<i>Cerberiopsis</i>	APOCYNACEAE	Tree *	
<i>Codia</i>	CUNONIACEAE	Trees and shrubs *	
	CUNONIACEAE/ ELAEOCARPACEAE	Trees to low shrubs ∫	Wet evergreen forest and maquis, on ultramafic and other terrain.
<i>Dodonea</i>	SAPINDACEAE	Shrub or tree *	
<i>Dysoxylum Type</i>	MELIACEAE	Shrub or tree ∫	Wet evergreen forest, maquis and sclerophyll forest, on ultramafic and other terrain.
	EPACRIDACEAE	Shrubs ∫	Wet evergreen forest and maquis. Primarily on ultramafic terrain.

Pollen and Spore Taxa		Lifeform	Ecological Setting
<i>Exocarpos</i>	SANTALACEAE	Semiparasitic shrubs or small trees ♦	Diversity of habitats and show great diversity in ecological requirements. Most species are lowland, 0 - 1000m.
<i>Ficus</i>	MORACEAE	Tree *	
	FLACOURTIACEAE	Shrubs ∫	Wet evergreen forest and maquis on ultramafic and other terrain.
<i>Garcinia</i>	GUTTIFERAE	Trees or shrubs *	
	GESNERIACEAE	Shrubs Trees ♦	Common in dense humid forest at medium altitude.
<i>Glochidion</i>	EUPHORBIACEAE	Tree *	
	GOODENIACEAE	Shrubs Trees *	
<i>Guioa</i>	SAPINDACEAE	Shrubs or trees ♦	Usually secondary forest but also understorey of primary forest. Road or riverside edges, beaches, plantation margins. Up to 1500m. Several species on ultramafic terrain.
<i>Hedycarya Type</i>	MONIMIACEAE	Shrubs ∫	Wide variety of vegetation formations, on ultramafic and other terrain.
<i>Hibbertia</i>	DILLENACEAE	Shrubs ∫	Wide variety of vegetation formations. A number are associated with secondary forest (<i>H. lucens</i> , <i>H. pancheri</i> , <i>H. trachyphylla</i>). Nearly all on ultramafic terrain.
<i>Justica</i>	ACANTHACEAE	Herb or shrub *	
<i>Kermadecia/Stenocarpus</i>	PROTEACEAE	Trees ∫ Trees and Shrubs	<i>Kermadecia</i> : wet evergreen forest on ultramafic and other terrain. <i>Stenocarpus</i> : Wet evergreen forest and maquis on ultramafic and other terrain.
	LENTIBULARIACEAE	Herb *	Insectivorous plant of wet places.
<i>Longetia buxoides</i>	EUPHORBIACEAE	Shrub	Maquis on ultramafic terrain; 0 - 900 m asl.
	LORANTHACEAE	Parasitic Shrubs Herbs *	Lowland and montane forest.
<i>Macaranga</i>	EUPHORBIACEAE	Shrubs ∫	Shrubs found in wet evergreen forest & maquis on ultramafic and other terrain.
<i>Mallotus</i>	EUPHORBIACEAE	Liane ∫	Wet evergreen forest & sclerophyll forest on ultramafic and other terrain.

Pollen and Spore Taxa		Lifeform	Ecological Setting
<i>Melaleuca</i>	MYRTACEAE	Trees and Shrubs * +	<i>M. quinquinervia</i> (prostrate shrub to tree 25 m high): almost pure stands found where native vegetation has been destroyed by fire in non ultramafic terrain. Swamp <i>Melaleuca</i> . 0 - 500 m asl, sometimes up to 1000 m. <i>M. brongniartii</i> (shrubs 0.5 - 2 m high): confined to the ultramafic terrain in the south of the main island. 10 - 400 m asl. Maquis vegetation beside rivers in areas that flood. <i>M. gnidiodes</i> (shrubs 0.5 - 1.5 m high): limited geographic area in the ultramafic terrain in the south of the main island. Primarily in the Plaine des Lacs region. 100 - 850 m asl. Primarily rocky river banks but also in swamps.
	OTHER MYRTACEAE	Trees and shrubs	Variety of terrain and vegetation formations.
<i>Melastoma</i>	MELASTOMATACEAE	Shrubs or trees ♦	Occur most frequently in secondary vegetation, as pioneers in clearings and on the margins of lowland and montane rainforest.
	MELIACEAE	Tree *	
	MENISPERMACEAE	Shrub or Liane ♦	Lowland to montane rainforest; primary or secondary forest.
<i>Meryta</i>	ARALIACEAE	Tree ♦	Lowland to mid elevation forest. A few species found in coastal vegetation.
<i>Mimosa</i>	LEGUMINOSAE	Naturalised Shrub f	Sclerophyll forest, savanna, secondary forest, & ruderal vegetation on non ultramafic terrain.
	MIMOSACEAE	Trees Shrubs *	
<i>Myodocarpus</i>	ARALIACEAE	Trees ♦	Primary and secondary forests and maquis vegetation on ultramafic and other terrain. Sea level to summits.
<i>Nepenthes</i>	NEPENTHACEAE	Shrub ♦	Insectivorous, rainforest along rivers, creeks etc. and marsh.
<i>Nothofagus (brassii type)</i>	FAGACEAE	Trees ♦	Sheltered valleys on ultramafic and other terrain. Normally good indicator of cold to cool everwet rainforest.
<i>Parsonsia</i>	APOCYNACEAE	Lianas f	Wet evergreen forest, maquis and sclerophyll forest on ultramafic and other terrain.
<i>Phyllanthus</i>	EUPHORBIACEAE	Tree or shrub * f	Wet evergreen forest and maquis on ultramafic and other terrain.
	PIPERACEAE		
<i>Pittosporum</i>	PITTOSPORACEAE	Shrub or tree ♦	Rainforest from sea level to montane. Sometimes secondary forest.
<i>Planchonella Type</i>	SAPOTACEAE	Tree or shrub *	

Pollen and Spore Taxa		Lifeform	Ecological Setting
	POLYGALACEAE	Tree shrub herb liana *	
<i>Psidium guava</i>	MYRTACEAE		
<i>Psychotira</i>	RUBIACEAE	Tree or shrub *	
<i>Rauvolfia</i>	APOCYNACEAE	Shrub or tree ♦ +	Fertile constantly damp soil, primary or secondary forest, lowland and montane. Along river banks and in open places.
<i>Rhizophora</i>	RHIZOPHORACEAE	Tree *	Mangrove.
	RUBIACEAE	Tree Shrub Liana *	
	RUTACEAE ?	Tree Shrub *	
	SAPINDACEAE	Tree Shrub Liane Herb *	
<i>Sloanea</i>	ELAEOCARPACEAE	Trees ♦	Mainly lowland rainforest, primary or secondary.
	SOLONACEAE	Herbs and shrubs] ♦	Thrive in disturbed situations. Some found associated with rainforest; usually margin or canopy breaks. Some introduced. Found in ruderal vegetation.
<i>Solmsia</i>	THYMELIACEAE	Tree or shrub *	
	STERCULICEAE	Trees Shrubs *	
<i>Tapeinosperma Type</i>	MYRSINACEAE	Shrub or tree ♦	Undergrowth of lowland rainforest
<i>Trema</i>	ULMACEAE	Tree *	Pioneer trees (disturbance).
	WINTERACEAE	Trees Shrubs *	Wet evergreen forest; variety of terrains.

Pollen and Spore Taxa		Lifeform	Ecological Setting
MONOCOTS			
	CYPERACEAE	Herb	Primarily swamps and lignoherbaceous maquis.
<i>Flagellaria</i>		Herb ♦	Climber of rainforest and rainforest margins. 0 - 1500 m. Frequently on the inner edge of mangroves.
<i>Joinvillea</i>	JOINVILLEACEAE	Herb ♦	Reed like herb. Light dryland rainforest. Medium altitude. Often on ridges.
<i>Palmae</i>	ARECACEAE	Tree ∫	Wet evergreen forest & maquis on ultramafic and other terrain.
<i>Freycinetia</i>	PANDANACEAE	Liana	
	PANDANACEAE	Tree and shrubs	Wet evergreen forest and maquis on a variety of terrain. Prefer damp conditions though not essential.
SPORES			
<i>Lycopodium</i>	LYCOPODIACEAE	Herb *	Clubmosses.
<i>Selaginella</i>	SELAGINELLACEAE	Herb ∫	Wet evergreen forest, beside rivers and in sheltered valleys on ultramafic and other terrain. One species found in maquis, <i>S. neocaledonica</i> .
<i>Pteridium esculentum</i>		Ground fern ∫	Secondary forest, sclerophyll forest and maquis on ultramafic and other terrain.
<i>Cyathea</i>	CYATHEACEAE	Shrubs and one tree ∫	Wet evergreen forest. Two associated with secondary forest <i>C. albifrons</i> and <i>C. vieillardii</i> . Found on ultramafic and other terrain. <i>C. novacaledoniae</i> tree.

Appendix 4: Raw Pollen Counts

Lifeform Key

A	Aquatic (obligate)
F	Fern
H	Herb
L	Liane
M	Mangrove
S	Shrub
T	Tree
V	Vine

	SITE	PDL 1	PDL 2	PDL 3	PDL 4	PDL 5	PDL 6	PDL 7	PDL 8	PDL 9	PDL 10	PDL 11	PDL 12	PDL 13	PL 1	PL 2	PL 3	PL 4	SL 1	SL 2	KOG 1	KOG 2	TON 1	TON 2	CAN 1	CAN 2	CAN 3
Garcinia sim.	TS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0
Geniostoma sim.	T	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GESNERIACEAE	ST	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glochidion	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0	0	0	0	0	0	3	0	0
GOODENIACEAE	SH	0	0	1	0	0	0	0	0	0	1	0	2	0	0	0	1	0	0	0	0	0	0	0	3	0	0
Guioa	ST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0
Hedycarya sim.	ST	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0
Hibbertia sim.	ST	7	0	2	0	0	3	3	0	0	0	0	0	0	0	1	0	0	0	2	1	0	4	6	0	0	0
Ilex	T	0	0	0	0	0	3	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	
Justica	HS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	
Kermadecia/Stenocarpus	TS	0	2	0	0	0	0	0	0	0	2	0	6	0	0	1	0	0	0	1	1	0	0	2	0	0	0
LENTIBULARIACEAE	H	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Longetia buxoides	S	1	0	0	1	0	0	8	0	0	6	30	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Macaranga	ST	3	0	0	0	1	0	15	1	0	0	0	0	0	0	0	0	0	0	1	1	13	0	2	60	0	1
Mallotus	L	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	23	1	0
Melaleuca	ST	0	0	0	0	0	0	0	0	0	0	0	0	0	195	86	129	14	10	63	74	5	16	0	0	2	0
OTHER MYRTACEAE	ST	9	11	5	42	84	3	21	5	16	1	11	2	5	39	20	65	0	3	0	30	11	102	13	9	0	3
Melastoma	S	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Meliaceae	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Meryta	T	0	0	2	1	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MIMOSACEAE	TSL	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Myodocarpus comp.	T	0	0	0	0	0	8	16	0	3	0	3	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nothofagus	T	1	2	208	6	0	1	207	0	332	9	0	427	500	0	0	0	0	0	1	3	1	2	3	0	0	0
Parsonsia	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
Phyllanthus	TS	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	
PIPERACEAE comp.	V	0	0	0	4	8	0	0	0	0	0	0	2	0	0	0	0	0	0	0	10	0	0	12	2	1	
Pittosporum sim.	ST	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	0
Planchonella sim.	TS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
POLYGALACEAE	TSHL	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
PROTEACEAE	ST	0	0	0	0	0	1	0	1	0	0	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Psidium guava	TS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0
Psychotria comp.	TS	1	0	3	0	0	0	0	0	0	37	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0
Rhizophora	M	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	1	0	0	0	2
RUBIACEAE	TS	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	4	0	0	0	0
RUTACEAE comp.	TS	0	2	3	5	2	1	5	0	1	5	3	1	0	0	0	2	4	1	1	11	2	31	8	0	0	0
SAPINDACEAE	TSHL	2	0	0	2	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SAPINDACEAE Sync. Type	TSHL	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	3	5	8	0	0	0	0	
SAPOTACEAE	TS	0	0	0	0	0	0	2	0	1	0	1	2	0	0	0	0	0	0	2	0	3	0	1	0	1	
Sloanea	T	8	0	0	0	1	0	5	0	0	0	0	0	0	0	0	0	0	0	13	0	6	2	4	0	0	
SOLANACEAE	HST	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	
Solmsia	TS	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	
Soulamia sim.	TS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	

APPENDIX 4A: RAW POLLEN COUNTS FOR SURFACE SAMPLES

	SITE	PDL 1	PDL 2	PDL 3	PDL 4	PDL 5	PDL 6	PDL 7	PDL 8	PDL 9	PDL 10	PDL 11	PDL 12	PDL 13	PL 1	PL 2	PL 3	PL 4	SL 1	SL 2	KOG 1	KOG 2	TON 1	TON 2	CAN 1	CAN 2	CAN 3
STERCULICEAE	T	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tapeinosperma sim.	ST	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Trema sim.	T	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	3	0	1	0	4	1	0	0
URTICACEAE	HST	1	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
VIOLACEAE comp.	HSL	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WINTERACEAE	TS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
MONOCOTS																											
CYPERACEAE	H	5	1	1	11	4	19	0	0	0	2	2	1	0	4	117	20	231	105	1000	3	4	5	0	10	85	1
Flagellaria	V	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	0	0	0	0	0	0	0	0	0
Joinvillea	V	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Palmae	TS	0	0	0	5	2	0	1	0	1	0	1	2	1	0	0	1	2	8	2	0	1	6	0	13	0	3
Pandanus krauelianis id.	TS	0	0	0	0	0	0	0	0	0	44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Pandanus odoratissimus id.	TS	0	0	0	0	0	0	0	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Other PANDANACEAE	TS	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0
POACEAE	H	1	1	1	4	0	6	0	0	0	2	1	0	0	10	16	5	0	11	23	6	0	6	0	85	160	5
Typha	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2200	
PTERIDOPHYTES																											
Monolete Psilate	F	1	21	9	18	3	5	4	3	1	5	10	3	1	13	85	7	172	250	600	147	16	220	2	53	57	1
POLYPODIACEAE	F	0	4	0	6	0	1	0	1	0	3	0	0	0	0	0	332	0	0	2	7	2	2	0	8	6	1
Hypolepis type	F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	246	0	0	0	0	2	0	0	0	0
Monolete Type A	F	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0
Other Monoletes	F	0	2	0	3	3	0	0	0	0	0	0	3	0	0	0	0	0	0	0	10	23	2	0	12	2	0
Pteridium esculentum	F	5	9	0	0	1	0	0	0	0	0	0	0	0	4	7	130	1	0	1	4	1	4	0	3	0	0
Cyathea	F	1	6	0	0	0	0	0	0	1	1	2	0	0	14	1	8	1	0	0	70	23	15	0	24	9	9
Trilete Psilate	F	2	46	1	125	10	3	5	2	7	7	0	3	1	31	35	0	10	1	14	734	37	310	1	6	2	0
Sphenomeris Type	F	0	2	0	0	0	0	0	0	0	0	43	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0
Trilete Type A	F	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1311	0	0	0	36	0	0	0	0	0	0
Other Triletes	F	0	0	1	0	8	1	0	0	0	0	0	0	0	0	0	9	4	0	3	71	0	4	0	67	1	6
Lycopodium		1	11	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	173	3	95	0	5	0	0
Selaginella		1	7	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	6	0	0
UNKNOWN																											
Type 32		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Type 34		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Type 35		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Type 49		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	0	0	0	0	0	0	0
Type 60		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Type 67		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
Type 68		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Type 71		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0

APPENDIX 4A: RAW POLLEN COUNTS FOR SURFACE SAMPLES

	SITE	PDL 1	PDL 2	PDL 3	PDL 4	PDL 5	PDL 6	PDL 7	PDL 8	PDL 9	PDL 10	PDL 11	PDL 12	PDL 13	PL 1	PL 2	PL 3	PL 4	SL 1	SL 2	KOG 1	KOG 2	TON 1	TON 2	CAN 1	CAN 2	CAN 3
UNKNOWNNS cont'd																											
Type 82		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Type 95		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
Type 153		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Type 155		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54	0	0	0	0	0	0	0
Type 156		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0
Type 157		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
Type 158		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Type 162		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
Type 163		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
Type 185		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
TERRESTRIAL POLLEN SUM		95	404	243	223	196	252	322	137	383	475	236	492	520	290	150	260	233	44	223	200	113	240	100	569	561	28
TOTAL POLLEN SUM		110	495	255	386	225	282	331	143	392	493	293	502	522	356	395	2089	898	400	1843	1282	219	804	103	757	723	46
Dam/Deg/Crumpled		3	6	19	23	5	36	22	10	5	8	4	14	3	10	8	4	5	2	23	10	7	13	7	21	7	4
Indeterminate		3	5	7	17	16	20	34	10	18	14	5	18	8	5	3	9	0	1	11	29	14	30	9	18	31	5

APPENDIX 4A: RAW POLLEN COUNTS FOR SURFACE SAMPLES

	DEPTH	0	10	160	170	180	190	200	210	220	230	240	250	260	270	280	285	300	310	320	330	340	350	360	370	380	385
PLUM Centre																											
POLLEN	LIFEFORM																										
GYMNOSPERMS																											
Agathis	T	0	0	1	0	0	0	0	0	1	0	3	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Araucaria	T S	0	0	0	0	0	1	5	3	1	2	2	0	0	0	8	0	3	2	4	3	6	2	0	2	0	1
Dacrydium	T S	2	0	0	0	0	0	0	0	3	0	5	0	2	2	2	2	1	2	2	8	2	1	0	0	0	0
Neocallitropsis	S	0	0	0	0	0	1	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0	1	0	0	0
Podocarpus	T S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	1	0	0	1	0	0	1	0	0
OTHER PODOCARPACEAE	T S	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
DICOTS																											
ACANTHACEAE		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
Alyxia Type	L	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AMARANTHACEAE	S	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	1
Antidesma sim.	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
APOCYNACEAE	TSL	0	0	0	0	1	0	0	0	0	1	4	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0
Apodytes clusifolia	T	0	0	0	0	0	0	0	0	0	0	2	6	10	2	2	6	15	3	6	3	0	0	0	0	0	0
ARALIACEAE	T	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
Argophyllum sim.	S	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
Ascarina	S T	0	0	0	1	1	1	8	3	0	3	3	11	12	1	0	8	0	0	1	1	1	0	0	0	1	0
ASTERACEAE	H	0	0	0	1	0	0	0	1	1	2	1	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0
Austrobuxus	T S	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Barringtonia	S T	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Beauprea sim.	S T	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
CASUARINACEAE	T S	4	3	15	281	98	56	83	59	44	85	59	60	123	45	9	22	23	23	20	46	11	9	0	10	0	1
Celtis	T	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Cerberiopsis	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Citronella sim.	T	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
Codia	S T	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3	2	0	0	0	1	0	0
Corynocarpus	T	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CUNONIACEAE/ELAEOCARPACEAE	T S	0	0	0	4	0	3	0	4	3	1	3	6	4	2	2	13	21	2	14	14	4	1	0	4	0	1
Cupaniopsis sim.	T	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Desmodium sim.	S T	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DILLENACEAE	S	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
Dodonaea sim.	S T	0	0	0	0	1	0	1	1	0	1	0	5	12	0	0	1	0	0	0	0	0	0	0	0	0	0
EPACRIDACEAE	S T	0	0	1	0	0	0	0	1	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ESCALLIONACEAE	S T	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
Euroshinus sim.	T	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
Ficus	T S L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	1	0	0	0	0	0	0	0	0	0
FLACOURTICEAE	T S	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Garcinia	T S	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

APPENDIX 4B: RAW POLLEN COUNTS FOR PLUM CENTRE

	DEPTH	400	410	430	450	470	490	510	520	540	560	580	600	620	640	660	680	700	720	740	755
PLUM Centre																					
POLLEN	LIFEFORM																				
GYMNOSPERMS																					
Agathis	T	0	0	1	0	1	1	0	0	4	4	0	0	0	0	1	0	0	0	2	0
Araucaria	T S	3	38	15	13	6	30	6	10	7	4	5	18	6	5	8	5	5	2	3	5
Dacrydium	T S	1	6	0	3	2	1	10	7	0	4	1	0	2	1	4	5	2	2	0	8
Neocallitropsis	S	0	4	0	0	1	0	0	0	0	4	0	1	0	0	0	1	0	5	0	0
Podocarpus	T S	0	0	0	0	0	0	0	1	0	0	0	0	0	2	2	3	0	0	3	0
OTHER PODOCARPACEAE	T S	0	0	0	0	0	1	3	0	1	1	0	5	4	2	4	0	2	2	0	0
DICOTS																					
ACANTHACEAE		0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Alyxia Type	T S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AMARANTHACEAE	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Antidesma sim.	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
APOCYNACEAE	L	0	0	0	0	0	0	0	0	0	0	0	2	2	0	1	1	1	0	2	0
Type 150		0	1	2	0	0	1	1	1	1	15	7	3	2	4	10	45	15	25	7	6
ARALIACEAE	T	0	0	0	1	0	2	0	0	0	0	0	0	2	0	0	2	1	1	0	0
Argophyllum sim.	S	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ascarina	ST	0	0	0	0	0	0	0	0	0	1	2	3	8	14	10	12	9	0	2	2
ASTERACEAE	H	0	0	0	0	0	0	0	0	0	0	0	0	3	7	2	2	1	0	1	0
Austrobuxus Other	T S	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0
Barringtonia	ST	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Beauprea sim.	ST	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CASUARINACEAE	T S	2	15	4	4	7	36	75	62	67	30	34	17	39	29	11	16	18	28	77	32
Celtis	T	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cerberiopsis	T	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3	0
Citronella sim.	T	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
Codia	ST	1	0	1	0	0	1	0	0	1	0	0	0	0	3	0	0	0	2	0	0
Corynocarpus	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CUNONIACEAE/ELAEOCARPACEAE	T S	13	11	11	4	5	1	3	1	1	0	0	0	1	10	0	3	1	2	2	4
Cupaniopsis sim.	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Desmodium sim.	ST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DILLENIACEAE	S	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Dodonaea sim.	ST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0
EPACRIDACEAE	ST	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
ESCALLIONACEAE	ST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Euroshinus sim.	T	0	0	0	0	0	1	1	1	0	0	1	0	0	1	0	0	0	0	0	0
Ficus	T S L	0	0	0	0	1	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0
FLACOURTICEAE	T S	0	0	0	0	0	0	0	0	0	4	0	0	0	0	1	2	1	0	0	0
Garcinia	T S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1

APPENDIX 4B: RAW POLLEN COUNTS FOR PLUM CENTRE

	DEPTH	0	10	160	170	180	190	200	210	220	230	240	250	260	270	280	285	300	310	320	330	340	350	360	370	380	385
Geniostoma sim.	T	0	0	0	0	0	1	0	0	0	1	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0
GESNERIACEAE	ST	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
Glochidion Type	T	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GOODENIACEAE	SH	0	0	0	0	3	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0
Grevillea sim.	TS	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GUTTIFERAE	TSL	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Hedycarya sim.	ST	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0
Hibbertia sim.	ST	0	0	0	0	2	0	0	0	1	1	0	2	6	0	0	2	5	0	0	1	0	0	0	0	0	0
Homalanthus sim.		0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ilex	T	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kermadecia/Stenocarpus	TS	0	0	0	0	0	0	0	1	1	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Labiatae comp.	HS	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
Longetia buxoides	S	0	0	0	0	0	0	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LORANTHACEAE comp.	SH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Macaranga	ST	0	0	0	3	0	0	0	2	1	1	1	1	3	0	4	15	23	17	66	47	16	3	0	3	0	3
MALPIGHIACEAE	SL	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
Melaleuca	T	2	0	1	34	18	97	16	52	35	13	2	1	1	1	0	4	2	0	0	0	0	0	0	0	0	0
Carpolepis comp.	T	0	0	0	0	0	0	0	1	17	9	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
OTHER MYRTACEAE	TS	0	0	1	27	3	12	3	18	21	9	11	20	9	8	1	10	22	2	19	14	0	0	0	1	0	2
Melastoma	S	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Meliaceae	T	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Meryta	T	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Myriophyllum	A	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nepenthes	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	1	0	0
Nothofagus	T	0	0	0	6	2	2	6	2	1	5	3	3	0	1	3	6	4	0	2	6	1	1	0	2	5	4
Phyllanthus	TS	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PIPERACEAE comp.	V	0	0	1	0	0	0	0	0	3	0	0	0	0	0	0	0	7	0	15	1	0	1	0	0	0	0
Pittosporum sim.	ST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	3	0	0	0	0	0	0
Planchonella Type	TS	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PROTEACEAE	ST	0	0	0	1	0	0	0	2	0	0	0	0	0	2	0	2	1	0	0	0	0	0	0	0	0	0
Psidium guava	TS	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Psychotria	TS	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rauvolfia	ST	0	0	0	0	0	0	0	0	0	0	0	1	1	0	6	3	9	5	5	5	6	0	0	1	0	0
Rhizophora	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	3	0	0	0	0	0	0
RUBIACEAE	TS	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RUTACEAE comp.	TS	0	0	0	0	1	1	0	0	1	1	3	4	0	0	0	0	2	0	0	2	0	0	0	0	1	0
SAPINDACEAE	TSLH	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SAPINDACEAE Sync. Type		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SAPOTACEAE	TS	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2	0	0	0	1	0	0	0	0	0	0
Sloanea	T	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Smilax comp.	V	0	0	0	0	0	3	0	0	0	0	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0
SOLANACEAE	HST	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
Soulamia sim.	TS	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spathodea sim.	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	6	3	0	0	0	0	0

APPENDIX 4B: RAW POLLEN COUNTS FOR PLUM CENTRE

	DEPTH	400	410	430	450	470	490	510	520	540	560	580	600	620	640	660	680	700	720	740	755
Geniostoma sim.	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
GESNERIACEAE	ST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Glochidion Type	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GOODENIACEAE	SH	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Grevillea sim.	TS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GUTTIFERAE	TSL	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0
Hedycarya sim.	ST	0	0	0	0	0	0	0	0	3	0	0	0	1	0	1	0	0	0	0	0
Hibbertia sim.	ST	1	4	0	0	0	0	0	0	1	2	0	0	5	2	0	4	3	0	1	2
Homalanthus sim.		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ilex	T	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Kermadecia/Stenocarpus	TS	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Labiatae comp.	HS	0	0	0	0	0	0	0	0	0	0	0	2	3	0	0	0	0	0	0	0
Austrobuxus buxoides sim.	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LORANTHACEAE comp.	SH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Macaranga	ST	121	55	72	11	131	76	55	48	115	91	167	108	66	20	72	27	0	3	0	8
MALPIGHIACEAE	SL	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Melaleuca	T	0	1	2	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0
Carpolepis comp.	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OTHER MYRTACEAE	TS	3	0	13	1	6	0	1	4	1	1	1	3	8	8	4	3	3	3	5	6
Melastoma	S	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	3	3	1	0	0
Meliaceae	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Meryta	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Myriophyllum	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nepenthes	S	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Nothofagus	T	3	6	3	2	4	4	5	8	0	15	13	6	15	10	13	31	27	14	12	18
Phyllanthus	TS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PIPERACEAE comp.	V	5	0	4	1	1	0	1	0	4	0	1	2	0	2	0	4	1	0	0	2
Pittosporum sim.	ST	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Planchonella Type	TS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PROTEACEAE	ST	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	1	0	0	1	0
Psidium guava	TS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Psychotria	TS	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	5	0	0
Rauvolfia	ST	0	0	0	0	2	1	5	0	0	0	0	0	0	0	2	0	4	3	0	3
Rhizophora	M	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
RUBIACEAE	TS	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	2	0	1	0	0
RUTACEAE comp.	TS	0	0	1	0	0	0	0	0	5	1	0	0	5	3	0	5	0	0	1	0
SAPINDACEAE	TSLH	0	0	0	0	0	0	1	0	0	1	3	0	0	1	0	2	2	3	0	1
SAPINDACEAE Sync. Type		0	0	0	0	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0
SAPOTACEAE	TS	0	2	0	1	1	1	0	1	0	0	1	0	0	3	0	0	0	2	1	1
Sloanea	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Smilax comp.	V	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
SOLANACEAE	HST	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Soulamia sim.	TS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spathodea sim.	T	0	0	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX 4B: RAW POLLEN COUNTS FOR PLUM CENTRE

	DEPTH	0	10	160	170	180	190	200	210	220	230	240	250	260	270	280	285	300	310	320	330	340	350	360	370	380	385	
STERCULICEAE	T	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	3	3	4	12	9	20	5	1	0	0	2	0
Tapeinosperma sim.	S T	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	
Trema sim.	T	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
URTICACEAE	H S T	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
VERBENACEAE	T S L	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	
VIOLACEAE comp.	H S L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	
MONOCOTS																												
Colocasia sim.	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	
CYPERACEAE	H	0	1	26	111	221	135	164	389	296	340	258	370	320	31	110	188	7	9	12	5	4	2	0	1	2	1	
Flagellaria	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	
Joinvillea	H	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	
Palmae	T S	0	0	3	2	1	0	13	3	0	0	4	1	4	1	4	0	0	0	1	0	0	0	0	1	0	0	
Freycinetia	L																											
Pandanus krauelianis id.	T	0	0	0	1	0	0	1	0	1	2	5	6	3	2	26	51	99	62	70	81	45	9	2	9	4	2	
Other PANDANACEAE	T S	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	1	
POACEAE	H	0	0	0	15	20	27	65	44	69	67	25	26	16	11	1	6	0	1	0	0	0	1	0	0	0	1	
Typha	H	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	
PTERIDOPHYTES																												
Lycopodium		0	0	2	18	11	17	74	10	26	41	28	26	6	15	2	9	0	0	0	0	0	0	0	0	0	0	
Selaginella		0	0	0	0	0	0	0	0	0	0	0	1	2	2	0	2	0	1	0	0	2	0	0	0	0	0	
Monoletes																												
Monolete Psilate Small	F	1	2	6	3	13	15	46	69	14	34	31	6	31	20	21	332	7	0	7	1	2	0	0	0	0	1	
Monolete Psilate Medium	F	0	0	5	15	0	0	6	0	1	6	9	0	7	4	0	7	0	0	0	0	0	0	0	1	0	0	
Monolete Psilate Large	F	0	0	10	33	25	34	126	251	48	105	138	190	155	260	66	80	4	9	0	4	36	1	1	4	2	1	
POLYPODIACEAE	F	0	0	0	1	1	0	2	0	1	2	2	2	0	1	2	4	2	1	0	0	1	0	0	0	1	0	
Round Hairy Spore	F	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	171	57	78	88	130	14	9	35	2	23	
Type A	F	0	0	0	0	0	20	116	145	333	655	41	0	23	0	3	0	0	0	0	0	0	0	0	0	0	0	
Type B	F	0	0	0	0	0	0	11	37	81	152	48	28	6	0	0	0	0	0	0	0	0	0	0	0	0	0	
Type C	F	0	0	0	0	0	0	0	174	155	0	76	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Other Monoletes		0	1	0	11	3	4	17	8	5	3	2	0	24	2	6	4	0	11	4	6	2	11	1	13	0	0	
Triletes																												
Pteridium esculentum	F	7	6	17	33	7	8	57	80	61	100	110	322	545	693	246	307	3	5	5	0	1	1	0	0	1	0	
Cyathaceae	F	0	0	3	5	6	7	17	6	0	8	4	4	6	4	5	13	0	0	1	1	0	0	0	0	0	1	
Trilete Psilate	F	1	0	0	11	1	0	6	8	3	5	10	4	0	0	0	0	0	0	1	0	1	1	0	1	0	0	
Sphenomeris sim.	F	1	2	3	7	2	6	66	32	14	21	58	172	225	430	31	28	0	0	0	1	0	0	0	3	0	0	
Trilete Type A	F	3	0	5	243	90	141	24	35	68	145	131	53	116	10	27	0	0	0	0	0	0	0	0	2	0	0	
Other Triletes	F	0	0	1	15	10	9	9	8	6	10	16	16	27	15	7	12	4	1	5	3	0	1	0	1	0	0	

	DEPTH	400	410	430	450	470	490	510	520	540	560	580	600	620	640	660	680	700	720	740	755
STERCULICEAE	T	4	4	3	1	5	6	3	1	0	0	2	0	0	1	4	0	3	2	2	9
Tapeinosperma sim.	ST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Trema sim.	T	0	0	0	0	0	1	2	0	0	0	0	1	1	3	1	1	1	3	0	0
URTICACEAE	HST	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
VERBENACEAE	TSL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VIOLACEAE comp.	HSL	0	0	2	0	1	0	0	1	0	0	0	1	0	0	2	3	0	0	0	0
MONOCOTS																					
Colocasia sim.	H	0	0	1	0	0	0	0	1	0	2	0	0	0	1	0	0	0	0	0	0
CYPERACEAE	H	1	23	8	22	9	14	23	8	14	19	12	26	141	55	22	35	14	17	8	6
Flagellaria	H	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Joinvillea	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Palmae	TS	0	2	0	0	0	1	0	1	1	1	0	6	1	2	1	24	0	4	0	1
Freycinetia	L																				
Pandanus krauelianis id.	T	85	110	103	46	80	58	52	62	42	74	57	56	14	3	81	73	200	136	127	163
Other PANDANACEAE	TS	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	4	0	1	1	0
POACEAE	H	0	0	0	0	0	0	1	0	0	1	2	0	3	0	2	0	0	0	0	0
Typha	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PTERIDOPHYTES																					
Lycopodium		0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Selaginella		0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	2	1
Monoletes																					
Monolete Psilate Small	F	5	5	2	0	1	11	3	3	2	10	0	15	9	36	8	29	12	10	1	6
Monolete Psilate Medium	F	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	6
Monolete Psilate Large	F	28	48	19	11	12	2	16	36	0	8	0	0	20	0	6	0	0	7	1	6
POLYPODIACEAE	F	1	1	2	0	0	3	1	0	0	4	0	1	0	1	0	5	1	13	4	9
Round Hairy Spore	F	15	130	46	0	49	5	1	0	0	4	0	0	0	0	0	0	0	0	0	0
Type A	F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Type B	F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Type C	F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Monoletes		13	5	0	10	8	5	2	26	3	0	0	8	13	1	9	4	2	0	0	1
Triletes																					
Pteridium esculentum	F	1	0	0	10	2	1	33	2	0	1	0	2	2	0	1	5	0	0	0	0
Cyathaceae	F	0	2	0	0	0	1	2	1	1	0	0	1	2	1	0	2	0	2	2	2
Trilete Psilate	F	0	1	0	1	0	3	4	1	1	1	0	3	2	3	0	5	0	2	1	0
Sphenomeris sim.	F	0	0	0	0	0	1	3	1	0	0	0	0	0	0	0	0	0	1	0	0
Trilete Type A	F	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Other Triletes	F	1	3	0	5	0	1	0	3	1	1	0	3	3	0	4	4	6	4	2	2

APPENDIX 4B: RAW POLLEN COUNTS FOR PLUM CENTRE

	DEPTH	0	10	160	170	180	190	200	210	220	230	240	250	260	270	280	285	300	310	320	330	340	350	360	370	380	385
UNKNOWNNS																											
Type 19		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
Type 49		0	0	0	0	0	0	1	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Type 63		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
Type 65		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
Type 66		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
Type 77		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
Type 84		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
Type 89		0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Type 151		0	0	0	0	0	1	0	2	0	0	0	1	0	0	2	4	8	2	16	12	2	0	0	0	0	3
Type 152		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
Type 153		0	0	0	0	0	0	0	2	0	1	0	0	1	0	2	0	0	0	0	1	0	0	0	0	0	0
Type 157		0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	6	0	2	0	0	0	0	0	0
Type 158		0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Type 159		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
Type 160		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
Type 161		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
Type 164		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
Type 165		0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Type 166		0	0	0	1	0	0	0	0	0	2	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0
Type 167		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
Type 168		0	0	0	0	0	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Type 171		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0
ALNUS		598	202	233	265	594	468	526	934	509	567	669	494	334	735	546	749	123	338	91	206	361	494	186	367	174	414
TERRESTRIAL POLLEN SUM		8	3	23	379	155	212	211	210	212	213	154	169	217	91	82	173	258	142	263	286	105	30	3	43	13	20
TOTAL POLLEN & SPORES		21	15	101	885	545	557	1069	1277	1310	1919	1054	1517	1655	1684	591	1186	456	236	376	395	284	61	14	104	21	47
Dam/Degrad/Crumpled		0	1	2	20	8	3	19	15	15	15	15	16	26	13	14	19	15	10	69	30	7	3	0	2	2	5
Indeterminate		0	1	1	5	6	5	13	8	5	6	15	10	5	23	12	15	9	6	13	6	5	0	1	3	3	2
Zygnemataceae																											
Debarya Type		0	0	0	5	5	4	32	3	22	14	10	34	41	93	0	1	0	0	0	0	0	0	0	0	0	0
Zygnema Type		0	0	0	23	45	128	56	69	90	212	48	22	3	8	0	4	0	0	0	0	0	0	0	0	0	0
Pseudoschizea Type		0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	9	30	53	41	103	93	18	1	42	4	1

APPENDIX 4B: RAW POLLEN COUNTS FOR PLUM CENTRE

	DEPTH	400	410	430	450	470	490	510	520	540	560	580	600	620	640	660	680	700	720	740	755
Type 19		0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Type 49		0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Type 63		0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Type 65		0	0	0	0	0	0	0	0	0	0	1	0	5	0	0	0	0	0	4	0
Type 66		0	0	0	0	0	0	0	0	0	0	0	0	11	5	4	0	0	0	0	0
Type 77		0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Type 84		0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
Type 89		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Type 151		13	1	6	0	0	6	9	10	15	9	12	43	9	4	28	0	0	3	1	2
Type 152		0	2	1	2	0	0	0	4	9	1	0	8	2	0	0	0	4	11	0	0
Type 153		0	0	1	0	2	1	4	2	6	0	2	5	2	0	6	0	0	1	4	0
Type 157		1	2	5	0	1	6	3	6	0	2	7	0	4	3	0	0	2	0	4	0
Type 158		1	0	0	1	1	1	8	6	0	0	4	0	2	0	0	0	3	5	0	9
Type 159		0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3	0	2
Type 160		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	4	0	0
Type 161		0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	5	0	0	0
Type 164		0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0
Type 165		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
Type 166		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
Type 167		0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	1	0
Type 168		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Type 171		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0
ALNUS		80	228	125	203	116	188	126	134	46	128	193	99	114	58	89	203	51	61	35	54
TERRESTRIAL POLLEN SUM		261	268	255	91	265	242	255	243	290	272	327	296	247	165	279	285	332	280	287	285
TOTAL POLLEN & SPORES		326	486	332	150	346	289	346	325	312	320	339	355	440	262	331	374	367	336	308	324
Dam/Degrad/Crumpled		12	24	19	12	10	40	22	23	49	21	15	55	32	32	32	61	30	55	39	32
Indeterminate		4	2	7	3	3	13	10	9	11	10	7	15	6	21	10	6	25	5	8	13
Zygnemataceae																					
Debarya Type		0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Zygnema Type		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudoschizea Type		20	19	2	16	2	43	2	8	2	1	1	3	0	0	0	0	0	0	0	0

	DEPTH	180	220	231	240	250	260	270	279	290	300	304	339
PLUM Edge													
	LIFEFORM												
GYMNOSPERMS													
Agathis	T	0	0	0	3	1	0	1	0	0	0	0	1
Araucaria	TS	0	0	0	0	0	0	0	0	0	0	0	1
Dacrydium	TS	0	0	0	2	0	0	0	0	0	2	3	1
Podocarpus	TS	0	1	3	0	2	0	0	0	0	0	0	0
3 sac Podocarp	TS	0	0	0	0	0	0	0	0	0	0	0	2
OTHER PODOCARPACEAE	TS	0	0	0	1	0	0	0	0	0	0	0	0
DICOTS													
AMARANTHACEAE	S	0	0	0	0	0	0	0	1	0	0	0	0
Apodytes clusifolia	T	0	0	0	0	0	1	0	1	1	9	2	0
ARALIACEAE	T	0	0	0	0	0	0	0	1	1	0	0	0
Ascarina	ST	0	0	2	3	1	0	0	0	0	0	0	0
ASTERACEAE	H	0	0	0	1	0	0	0	0	0	0	0	0
Avicennia	M	0	0	0	0	0	3	0	0	0	0	2	5
CASUARINACEAE	ST	45	16	11	121	34	37	14	10	16	40	24	9
Codia	ST	0	1	0	0	0	0	0	0	0	0	0	0
CUNONIACEAE/ELAEOCARPACEAE	TS	2	2	1	1	3	5	4	5	7	5	2	17
Diospyros sim.	S	0	0	0	0	0	0	4	0	0	0	0	0
Dodonaea sim.	ST	0	2	0	2	0	0	0	0	0	0	0	0
EPACRIDACEAE	ST	0	0	2	0	0	0	0	0	0	0	0	0
EUPHORBIACEAE comp.	ST	0	0	0	0	0	0	0	0	3	13	18	0
Glochidion	T	0	0	0	0	1	0	0	0	0	0	0	0
Haloragis sim.	A	0	1	0	0	0	0	0	0	0	0	0	0
Hedycarya sim.	ST	0	0	0	0	0	0	0	0	0	0	1	0
Hibbertia sim.	ST	0	0	0	0	0	0	0	14	0	0	7	18
Ilex	T	0	0	0	0	0	0	0	0	1	0	0	1
Kermadecia/Stenocarpus	TS	0	0	0	0	0	0	0	0	0	0	5	0
Macaranga	ST	0	0	1	1	2	8	7	23	67	195	110	35
Melaleuca	ST	9	14	0	1	2	0	0	0	0	0	0	3
OTHER MYRTACEAE	ST	10	11	9	27	1	6	1	3	2	5	0	0
Nymphoides sim.	A	0	0	0	0	0	0	0	1	0	0	0	0
Nothofagus	T	1	0	1	3	1	4	1	2	2	9	9	3
PIPERACEAE comp.	V	0	0	0	0	0	0	0	0	0	1	4	1
Pittosporum sim.	TS	0	0	0	0	0	0	0	0	0	0	3	1
Qunitinia	T	0	0	0	0	0	0	0	0	0	1	0	0
Rauvolfia	ST	0	0	0	0	0	0	2	0	0	1	0	1
RUTACEAE comp.	TS	0	2	0	0	1	0	0	6	0	0	0	2
SAPINDACEAE	TSLH	0	0	0	0	0	0	0	0	0	0	1	0
SAPOTACEAE	TS	1	0	0	0	0	0	0	0	0	1	2	0
Sloanea	T	1	0	0	0	1	0	0	0	0	0	0	0
Trema sim.	T	0	0	0	0	1	0	0	0	0	0	0	0
VERBENACEAE	TSL	0	0	0	0	0	0	0	0	0	0	3	0
VIOLACEAE comp.	HSL	0	0	0	0	0	0	0	1	0	0	0	0
MONCOTS													
CYPERACEAE	H	77	53	15	195	64	38	1	0	2	1	0	13
Palmae	TS	0	0	0	0	0	0	0	1	0	0	0	0
Pandanus krauelianis id.	T	0	0	0	2	0	6	6	5	21	44	65	100
Pandanus odoratissimus	T	0	0	0	0	0	0	0	0	0	0	2	0
POACEAE	H	6	1	1	13	3	2	2	0	0	0	0	1

	DEPTH	180	220	231	240	250	260	270	279	290	300	304	339
PTERIDOPHYTES													
Lycopodium		1	0	6	63	25	11	3	0	0	0	0	1
Selaginella		0	0	1	0	0	0	0	0	0	0	0	0
Monolete Psilate Small		1	2	4	6	4	0	1	0	0	1	0	8
Monolete Psilate Medium		4	11	3	22	22	13	5	0	5	0	0	2
Monolete Psilate Large		3	7	5	30	4	25	13	0	3	2	0	24
POLYPODIACEAE													
Monoletes Type A B and C		0	3	4	9	2	6	1	0	1	1	0	0
Other Monoletes		2	1	3	1	4	0	0	0	2	1	0	0
Pteridium esculentum		16	13	11	95	39	15	1	0	0	0	0	0
Cyathaceae		0	0	0	3	0	0	0	0	0	0	0	0
Sphenomeris Type		0	0	5	8	1	0	0	0	0	0	0	0
Trilete Type A		3	6	25	63	51	33	2	0	0	0	0	4
Other Triletes		4	0	8	45	10	0	6	0	0	0	0	3
Other spores		0	0	0	0	0	0	0	0	5	0	0	7
UNKNOWN TYPES													
Type 60		1	0	0	0	0	0	0	0	0	0	0	0
Type 96		0	0	0	0	0	0	0	0	0	13	0	0
Type 153		0	0	0	0	0	0	0	0	1	0	20	0
Type 157		0	0	0	0	0	0	0	11	0	0	3	0
Type 158		0	0	0	0	0	0	0	0	1	0	0	0
Type 159		0	0	0	0	0	0	6	4	10	8	8	0
Type 165		0	0	1	0	0	0	0	0	0	0	0	0
Type 166		0	0	0	0	0	0	0	0	0	0	1	0
ALNUS		147	194	322	191	70	67	35	6	1	93	246	408
TERRESTRIAL POLLEN SUM		76	50	32	181	54	72	48	88	134	347	295	202
TOTAL POLLEN SUM		187	147	122	722	280	213	81	89	152	353	295	265
Dam/Degrad/Crumpled		9	5	1	19	3	12	15	12	25	19	18	2
Indeterminate		1	6	4	5	3	9	4	3	12	4	6	0
Zygnemataceae													
Debarya Type		0	0	3	23	11	5	3	0	0	0	0	0
Pseudoschizea Type		0	0	0	0	1	3	1	7	24	29	28	2
Zygnema Type		6	70	17	53	22	6	1	0	0	0	0	0

	DEPTH	40	49	52	55	58	63	66	69	72	75	78	81	84	87	90	93	96	99	102	105	108	111	114	120	126	132	138	144	150	159	189	198	210	219		
Lac Saint Louis																																					
POLLEN																																					
GYMNOSPERMS	LIFEFORM																																				
Agathis	T	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	1	0	0	2	0	0	0	0		
Araucaria	TS	1	0	0	0	0	1	0	0	2	0	3	0	5	2	4	5	6	10	5	5	10	4	10	0	0	6	0	5	12	14	1	0	0	0		
Dacrydium	TS	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0		
Podocarpus	TS	0	0	0	0	0	0	0	0	0	0	0	0	4	0	1	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	0		
OTHER PODOCARPACEAE	TS	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	0	2	0	0	0	0	0	0		
DICOTS																																					
ACANTHACEAE	S	0	0	0	0	0	1	0	2	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	1		
Albizia	T	0	0	0	0	0	0	1	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	0		
APOCYNACEAE	L	0	0	0	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	1	0	0	0	1	0		
Apodytes clusifolia	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0		
ARALIACEAE	T	0	1	0	1	0	0	0	1	1	0	0	0	1	0	6	0	3	1	1	1	0	0	2	0	1	3	0	1	4	4	1	2	0	3		
Ascarina	ST	0	0	2	2	0	1	1	2	1	7	0	0	0	0	4	1	1	2	1	2	1	4	0	0	1	1	0	1	0	5	2	5	9	4		
ASTERACEAE	H	0	1	4	2	3	3	7	0	1	1	1	2	1	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	1	0	
Avicennia marina	M	0	3	0	2	1	2	10	16	0	2	9	6	3	8	0	0	3	2	4	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	
BRASSICACEAE Type	H	0	1	0	0	0	0	0	0	0	1	0	0	7	0	2	0	2	2	0	0	0	0	1	0	3	2	0	0	1	0	0	0	0	0		
Brugeria sim.	M	0	0	0	0	0	0	0	0	0	5	0	2	2	2	13	1	2	1	3	9	4	4	4	0	3	6	5	5	4	9	4	0	0	0		
CASUARINACEAE	TS	16	120	137	129	158	121	103	214	78	59	41	31	23	24	13	18	29	10	49	27	10	0	27	4	4	0	7	23	7	9	6	8	4	1		
Celtis	T	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	0	1	0	0	0	0	0	0		
Ceriops sim.	M	0	0	0	0	0	0	0	0	0	7	4	0	0	0	0	0	2	4	1	1	0	0	0	0	0	3	0	0	1	5	0	0	0	0		
CHENOPODIACEAE	H	0	0	0	0	0	0	0	1	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		
Codia	ST	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	5	0	3	1	0	0	0	0	0	2		
CUNONIACEAE/ELAEOCARPACEAE	TS	0	1	1	0	1	0	6	1	8	6	7	17	0	16	10	8	4	6	3	3	2	5	5	2	20	8	22	32	20	28	18	22	1	0		
Dodonea Type	ST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	3	0			
EPACRIDACEAE	ST	0	0	0	0	0	1	0	0	0	1	1	0	3	1	4	3	5	5	4	2	6	3	4	0	1	3	0	0	0	2	0	2	0	0		
ESCALLIONACEAE	ST	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	0	0	0	0	1	0	0	0		
EUPHORBIACEAE Undiff'd	TS H	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	
Exocaria comp.	M	0	0	6	1	0	2	8	2	3	0	0	0	0	1	0	0	0	0	0	0	2	1	3	1	0	0	0	0	1	0	0	0	0	0	0	
Ficus	TS L	0	0	0	0	0	0	1	1	2	0	1	2	1	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	2	1	1	0	0	
FLACOURTICEAE	TS	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	0	0	0	0	1	0	0	0		
Garcinia	TS	0	0	0	0	0	1	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	1	0	0	0	
GOODENIACEAE	SH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	
Hibbertia Type	ST	0	0	0	0	0	0	2	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	
Ilex	T	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	0	1	0	0	0	0	0	0		
Kermadecia/Stenocarpus	TS	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
LEGUMINOSAE	TS	0	2	0	0	0	2	0	2	8	29	3	0	9	1	4	0	2	2	4	2	0	0	0	0	0	1	0	0	0	0	0	1	0	1	0	0
LILIACEAE Type	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	

APPENDIX 4D: RAW POLLEN COUNTS FOR LAC SAINT LOUIS

	DEPTH	40	49	52	55	58	63	66	69	72	75	78	81	84	87	90	93	96	99	102	105	108	111	114	120	126	132	138	144	150	159	189	198	210	219	
Longetia buxoides Type	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	2	0	0	2	0	0	0	
Lumnitzera	M	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
Lythrum	H	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	0	0	1	1	0	0	0		
Macaranga	ST	0	1	0	0	0	0	0	0	1	3	1	1	1	0	6	6	3	12	2	2	7	7	6	2	14	14	12	14	15	19	15	23	10	11	
Mallotus	L	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	5	0	0	0	0	1	0	0	0	0	0	0	0	
Melaleuca	T	33	11	20	3	0	5	8	14	26	33	60	29	45	73	19	15	8	7	9	10	0	4	12	1	3	6	2	3	8	5	12	14	4	1	
OTHER MYRTACEAE	TS	22	7	2	1	1	7	29	16	28	25	60	95	35	28	8	17	10	16	11	3	4	24	12	3	15	9	14	46	8	7	9	9	1	1	
Melastoma	S	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	
MELIACEAE	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	1	0	
MENISPERMACEAE Type	SL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
MYRSINACEAE	TS L	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	
Nothofagus	T	0	0	0	2	0	2	1	5	0	6	5	4	9	3	3	5	2	8	3	7	2	7	3	0	3	0	5	13	5	15	4	1	3	1	
Parsonsia	L	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	0	0	0	1	0	1	0		
PASSIFLORACEAE Type	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Phyllanthus Type	TS	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
PIPERACEAE Type	V	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	2	1	0	0	0	0	0	0	
PROTEACEAE	ST	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	5	0	1	0	0	0	0	0	0	2	0	1	3	0	3	4	0	0	
Psychotira	TS	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	
Quintinia	T	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	82	0	1	0	0	0	
RHIZOPHORACEAE	M	0	0	0	0	0	1	0	11	13	21	20	11	32	37	199	114	70	129	66	90	55	67	57	14	20	46	25	40	43	30	57	66	39	9	
RUBIACEAE ?	TS	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1	0	0	0	3	0	0	
RUTACEAE ?	TS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	2	2	2	1	0	0	0	0	0	0	1	4	1	1	1	0	0	
SAPINDACEAE	TS L H	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	4	2	3	0	3	
SAPINDACEAE Sync. Type	TS L H	0	0	0	1	0	0	0	0	0	1	2	0	0	0	2	5	0	0	1	1	0	0	0	0	0	0	4	6	1	2	3	6	1	0	
SAPOTACEAE	TS	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	3	1	0	0	1	0	1	3	0	0	0	0	0	0	
SIMAROUBACEAE	ST	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sloanea	T	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	1	0	0	0	0	0	0	0	
SONNERATICEAE	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	
STERCULICEAE	T	0	2	0	1	0	1	0	3	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	
Symplocos	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tapeinosperma Type	ST	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	1	1	2	0	0	0	0	0	0	
Terminalia	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Trema ?	T	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	
VITACEAE	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wickstroemia Type	S	0	0	1	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	0	0	0	0	0	0
MONOCOTS																																				
CYPERACEAE	H	161	1052	2070	1133	600	200	116	315	144	84	225	100	135	94	34	73	105	32	240	140	44	110	133	15	11	4	0	12	0	3	1	0	0	0	0
Palmae	TS	0	6	0	0	2	3	1	11	6	10	4	1	2	2	5	2	4	6	0	8	8	1	7	1	3	3	3	12	4	13	12	4	2	0	0
Freycinetia	L	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	0	0	0	0	0	1	0	0	
Pandanus krauelianis Type	T	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	2	0	1	4	0	1	0	0	
Other PANDANACEAE	TS	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	1	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POACEAE	H	17	32	22	27	33	19	30	46	31	21	39	15	20	5	5	4	6	1	10	6	1	10	8	1	1	0	0	3	1	0	0	0	0	0	0
Typha	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0

APPENDIX 4D: RAW POLLEN COUNTS FOR LAC SAINT LOUIS

	DEPTH	40	49	52	55	58	63	66	69	72	75	78	81	84	87	90	93	96	99	102	105	108	111	114	120	126	132	138	144	150	159	189	198	210	219	
PTERIDOPHYTES																																				
Lycopodium		1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
Monoletes																																				
Monolete psilate		19	1330	792	1500	651	535	302	864	451	347	666	302	346	426	71	94	180	62	365	216	55	84	189	21	22	10	12	34	20	15	15	46	29	22	
POLYPODIACEAE		0	0	0	0	1	5	11	7	6	6	8	4	13	7	5	11	3	11	8	9	7	3	11	0	9	2	3	27	6	9	6	20	22	28	
Type A		0	0	3	0	8	1	22	19	12	0	5	8	8	5	1	5	0	2	0	0	1	0	1	1	3	4	0	1	0	1	0	14	3	0	
Other		3	0	3	23	0	24	1	68	21	6	50	10	17	0	9	3	8	7	16	7	1	1	11	1	2	8	3	1	6	8	5	12	6	5	
Triletes																									0											
Pteridium esculentum		2	5	14	2	30	3	14	9	3	0	7	8	3	5	0	2	0	1	4	1	1	1	0	1	2	0	1	0	1	0	0	1	1	0	
Cyathaceae		0	1	0	21	0	26	7	47	8	0	15	3	1	10	5	9	4	7	5	7	6	5	3	0	8	3	11	26	0	30	14	16	21	29	
Trilete Psilate		2	13	1	6	6	6	6	6	16	31	0	2	10	10	5	2	22	5	23	10	2	0	13	0	3	6	1	1	11	9	16	53	48	44	
NC-SS-32 Type		0	0	3	0	8	0	12	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Type A		0	0	0	0	0	0	0	0	1	0	1	0	1	0	6	3	3	6	3	2	1	0	2	0	0	0	3	0	0	1	9	2	0	0	
Type B		0	0	0	0	0	27	0	76	14	0	12	4	0	10	0	1	0	0	1	4	1	1	2	0	0	0	0	1	0	0	0	0	0	0	
Other		2	1	1	0	12	20	50	23	7	10	8	4	12	12	12	3	2	14	8	1	1	0	5	0	4	4	2	3	3	3	3	15	7	8	
UNKNOWN TYPES																																				
Type 2		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	0	0	0	0	0	0	1	3	
Type 5		0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
Type 7		0	0	0	0	1	0	0	5	4	4	0	5	13	9	0	6	11	3	5	0	0	10	0	0	9	0	0	0	0	7	17	2	0	0	
Type 8		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	0	0	0	0	0	0	2	0	
Type 15		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	0	0	0	0	0	0	1	0	
Type 16		0	0	0	0	0	0	0	0	2	0	0	0	0	7	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	
Type 17		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	0	0	0	0	0	3	1	0	
Type 18		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	0	0	0	0	0	1	0	0	
Type 19		0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	
Type 23		0	0	0	0	0	0	2	1	15	1	0	6	2	3	0	1	1	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
Type 24		0	0	0	0	1	4	0	1	7	0	0	0	1	0	0	5	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0
Type 25		0	0	0	0	1	0	2	0	2	0	0	0	0	1	0	3	1	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	
Type 27		0	0	0	0	0	0	0	0	2	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	1	0	0	0	2	0	4	0	0	0	
Type 30		0	0	0	0	0	0	0	0	0	1	0	0	0	3	0	1	0	1	5	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	
Type 31		0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	
Type 32		0	4	0	3	0	3	1	7	6	3	2	0	3	1	3	0	3	1	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
Type 33		0	0	0	0	0	0	4	0	0	1	0	2	3	9	4	8	2	3	1	5	1	1	0	2	4	0	2	0	0	0	0	0	0	0	0
Type 34		0	1	0	0	0	2	1	1	2	8	0	0	1	0	0	2	1	4	0	0	0	2	0	1	0	0	0	0	1	0	1	0	1	0	0
Type 35		0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	
Type 36		0	0	0	0	0	0	0	0	0	1	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
Type 39		0	6	1	2	1	34	3	31	35	10	17	16	5	12	0	1	1	1	3	6	2	4	3	0	1	0	1	0	1	0	1	0	1	0	0
Type 41		0	0	0	0	0	0	2	5	5	1	0	2	0	0	0	2	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
Type 42		0	0	0	0	0	0	0	0	1	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
Type 43		0	2	0	0	1	0	5	2	0	0	0	2	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Type 45		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Type 48		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	
Type 49		0	17	1	28	10	3	5	12	16	0	7	3	6	5	0	0	0	0	3	2	0	1	2	0	0	1	0	0	0	0	0	1	0	0	0

APPENDIX 4D: RAW POLLEN COUNTS FOR LAC SAINT LOUIS

	DEPTH	40	49	52	55	58	63	66	69	72	75	78	81	84	87	90	93	96	99	102	105	108	111	114	120	126	132	138	144	150	159	189	198	210	219
Type 50		0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Type 51		0	0	0	0	0	0	0	0	2	0	0	0	1	1	0	0	2	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	
Type 52		0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	2	0	0	1	0	0	0	0	0	0	0	1	0	0	0	
Type 53		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Type 54		0	0	0	6	0	1	0	12	2	0	6	0	0	0	0	0	0	0	7	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0
Type 55		0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	3	7	2	0	0	5	0	0	0	0	0	0	0	0	0	0	
Type 56		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	18	4	0	3	0	2	0	1	4	0	0	0	2	5	0	0	
Type 57		0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Type 61		0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Type 65		0	0	0	0	0	1	0	2	0	0	2	0	0	0	0	2	0	5	0	0	0	1	0	0	1	0	0	0	0	1	3	0	0	
Type 66		0	0	1	0	0	0	0	0	0	0	0	0	0	3	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	
Type 68		0	1	0	0	0	33	111	46	14	0	9	7	0	2	0	1	0	0	1	1	1	3	5	0	0	0	0	0	0	1	0	0	0	
Type 71		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	
Type 72		0	0	0	0	0	1	1	0	2	0	4	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
Type 73		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	
Type 74		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	
Type 75		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	2	0	0	0	
Type 76		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	
Type 77		0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Type 78		0	0	0	0	0	0	0	0	2	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Type 80		0	0	0	0	0	2	2	0	2	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
Type 83		0	0	0	0	0	2	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Type 84		0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Type 85		0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Type 86		0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Type 87		0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Type 90		0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Type 91		0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Type 96		0	0	0	0	0	3	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	0	0
Type 97		0	0	0	0	0	1	2	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	0
Type 98		0	0	0	0	0	1	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	0	0
Type 99		0	0	0	0	0	3	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	0	0
Type 100		0	0	0	0	0	1	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	0	0
Type 101		0	0	0	0	0	1	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	0	0
Type 102		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Type 166		0	0	1	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	0	0	0	0	0
Type 168		0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	DEPTH	40	49	52	55	58	63	66	69	72	75	78	81	84	87	90	93	96	99	102	105	108	111	114	120	126	132	138	144	150	159	189	198	210	219
ALNUS		266	52	45	57	41	16	7	16	11	8	20	25	23	20	131	151	118	110	182	133	190	170	385	120	121	130	158	94	54	107	36	151	125	98
TERRESTRIAL POLLEN SUM		90	222	200	211	213	271	344	475	309	299	346	251	244	254	352	226	206	287	228	220	135	193	205	32	111	136	118	231	235	197	198	190	91	42
TOTAL POLLEN & SPORES		280	2624	3087	2896	1529	1118	886	1909	992	783	1343	699	790	833	500	433	533	434	903	618	257	399	576	71	175	177	154	337	282	276	268	369	228	178
Dam/deg		7	0	22	0	7	9	14	20	18	22	0	20	14	12	24	19	24	10	15	14	18	15	0	5	33	0	15	44	25	26	17	31	29	7
Indet		2	20	2	8	5	20	43	64	17	19	30	37	6	8	22	65	11	44	13	2	40	38	27	20	4	33	14	44	20	14	30	49	11	2
Zygnemataceae																																			
Debarya Type		41	0	4	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Zygnema Type		1	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	0	0	0	0	0	0	0
Pseudoschizea Type		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	0	0	0	0	0	0	0	0

	Depth	0	10	20	30	40	50	100	120	150	200	250	270	280	290	300
Canala Swamp																
POLLEN	LIFEFORM															
GYMNOSPERMS																
Agathis	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Araucaria	TS	0	0	0	1	0	0	1	1	0	0	0	0	1	4	1
Dacrydium	TS	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1
Neocallitropsis	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Pinus	T	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Podocarpus	TS	0	0	0	0	0	0	0	0	0	0	0	0	1	2	5
DICOTS																
ACANTHACEAE	S	0	0	0	1	0	0	1	0	1	1	2	1	0	0	0
Albizia sim.	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Amaranthaceae	SH	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0
Apodytes clussifolia	T	0	0	0	1	1	0	0	1	0	0	0	0	0	1	0
ARALIACEAE	T	0	1	0	11	2	0	2	1	2	4	2	3	1	0	3
Ascarina	ST	0	0	0	0	1	1	0	0	0	0	0	0	2	1	2
ASTERACEAE	H	0	0	0	3	4	0	0	0	1	0	5	0	0	0	0
Austrobuxus	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Avicennia	M	1	1	0	3	0	2	3	0	3	5	6	6	3	1	0
Barringtonia	T	0	0	0	0	0	0	0	0	0	1	0	0	0	3	0
BRASSICACEAE	S	0	0	0	0	0	0	0	0	0	2	0	0	0	3	0
Brugeria/Ceriops	M	0	0	0	3	1	3	8	2	4	5	11	6	8	2	0
CASUARINACEAE	TS	5	2	2	17	8	9	6	7	5	7	7	13	10	4	8
Citronella	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Claoxylon sim.		0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
Colocasia comp.	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cordyline comp.	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Corynocarpus		0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
CUNONIACEAE/ELAEOCARPACEAE	TS	3	1	0	1	8	1	0	0	0	1	1	1	7	9	32
DILLENACEAE	ST	0	0	0	0	0	0	1	0	0	2	0	0	1	0	0
Dodonaea sim.	ST	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1
EPACRIDACEAE	ST	0	0	0	2	1	0	0	0	1	2	0	1	0	0	0
Erythrina	T	0	0	0	8	8	0	0	0	0	0	0	0	0	0	0
Exeocaria/Homalanthus	TS	0	0	0	6	6	0	2	1	1	4	2	0	2	1	9
Ficus	T	1	0	0	1	2	0	0	0	0	0	0	0	0	1	6
Glochidion	T	0	2	0	15	21	0	0	0	0	0	0	0	0	0	1
Haloragis sim.	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hedycarya	ST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hibbertia comp.	ST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Homalium sim.	ST	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Ilex	T	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Ipomea sim.	H	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Kermadecia/Stenocarpus	TS	0	0	0	2	1	0	0	0	0	0	0	1	5	3	5
Longetia	S	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Macaranga	ST	1	0	1	0	3	0	0	1	2	2	0	0	6	6	10
Mallotus	SL	0	0	0	0	0	1	0	0	0	0	0	0	1	0	2
Melaleuca	T	0	0	0	3	2	1	0	0	0	0	0	0	2	2	15
Melastoma	S	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
MELIACEAE	T	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Montrouzieria sim.	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
MYRSINACEAE	ST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MYRTACEAE	ST	1	0	2	5	6	2	0	0	2	3	2	4	15	17	9

APPENDIX 4E: RAW POLLEN COUNTS FOR CANALA SWAMP.

	Depth	0	10	20	30	40	50	100	120	150	200	250	270	280	290	300
Netera sim.	S	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Nothofagus	T	0	0	0	1	0	0	0	0	0	0	0	1	1	5	2
Nymphoides indica sim.	H	0	0	1	4	3	0	0	0	0	0	0	0	0	0	0
OLEACEAE	ST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Parsonsia	L	0	0	0	29	0	0	0	0	0	1	0	0	0	0	2
Phyllanthus	TS	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
PIPERACEAE	V	1	0	0	3	10	0	0	0	0	0	0	0	2	3	7
Polygonum acuminatum sim.	H	0	0	0	25	2	0	0	0	0	0	0	0	0	0	0
Quintinia	T	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Rauvolfia	ST	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
RHAMNACEAE	ST	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
RHIZOPHORACEAE	M	1	1	2	9	5	185	205	200	200	201	200	200	150	25	7
RUBIACEAE	TS	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2
RUTACEAE	TS	0	0	0	1	0	0	0	0	0	0	1	1	1	4	6
SANTALACEAE comp.	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SAPINDACEAE Sync. Type	TS	0	0	1	0	1	0	0	1	0	2	0	1	3	5	7
SAPOTACEAE	TS	1	0	0	4	2	0	0	1	0	0	0	0	2	0	5
SONNERATIACEAE	M	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
STERCULIACEAE	T	0	0	0	0	0	1	0	2	0	1	0	0	2	0	1
Symplocos sim.	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
THYMELIACEAE	ST	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Trema	T	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0
WINTERACEAE	T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MONOCOTS																
CYPERACEAE	H	0	1	1	8	4	0	1	2	0	0	3	3	5	0	4
Freycinetia	L	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
LILIACEAE	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Palmae	TS	3	1	0	1	3	2	0	1	0	2	0	1	9	12	31
Pandanus krauelianis Type	TS	0	0	0	0	0	0	0	0	0	1	0	0	2	0	1
Pandanus tectorius Type	TS	3	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Pandanus?	TS	0	0	0	0	23	0	0	0	0	0	0	0	0	0	0
POACEAE	H	5	4	1	28	3	4	0	2	2	7	9	11	2	0	0
Typha	H	2200	1160	3600	275	7	0	0	0	0	0	0	0	0	0	0
PTERIDOPHYTES																
Lycopodium		0	1	0	0	2	0	1	1	3	0	2	5	2	2	0
Selaginella		0	0	0	0	0	0	0	0	1	0	0	0	1	1	1
Monoletes																
Psilate Monoletes	F	1	5	7	90	41	12	18	12	18	42	31	45	26	26	38
Blechnum	F	0	0	0	3	1	0	1	0	3	3	3	5	3	1	0
Hypolepis	F	0	2	0	400	31	0	4	3	1	9	7	11	8	11	11
Polypodiaceae	F	1	0	2	4	3	0	4	1	5	2	6	4	5	7	5
Other Monoletes	F	0	0	0	9	6	2	2	1	1	4	5	5	5	2	4
Triletes																
Acrostichum		0	0	0	0	0	0	1	1	4	10	5	5	3	5	0
Rugulate		0	1	1	2	0	1	3	3	1	8	1	12	0	1	0
Cyathaceae		9	12	7	16	2	1	2	0	1	1	2	4	18	17	39
Pteridium esculentum		0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Trilete Type A		0	0	0	2	1	4	3	0	4	6	6	9	14	9	1
Other Triletes		5	3	12	25	16	11	21	12	14	27	24	40	37	25	44

	Depth	0	10	20	30	40	50	100	120	150	200	250	270	280	290	300
UNKNOWN TYPES																
Type 38		0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Type 39		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Type 67		0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Type 68		0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Type 164		0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Type 168		0	0	0	0	0	0	0	0	0	0	0	0	3	0	1
Type 175		0	0	0	15	0	0	0	0	0	0	0	0	0	0	0
ALNUS		100	248	266	264	157	46	98	54	80	117	81	215	181	107	147
TOTAL POLLEN SUM		2242	1198	3642	1042	247	246	290	258	280	369	344	401	374	228	349
Damaged/Degraded/Crumpled		4	2	2	17	10	1	3	1	6	9	10	10	15	13	38
Indeterminate		3	1	1	5	7	0	0	1	2	4	6	3	5	5	22

Appendix 5: Mineral Magnetic Calculations

Calculations for SIRM

- 1) Determine density of sample (ρ) in SI units
- 2) Take north and south readings of sample from magnetometer
- 3) $X = \sqrt{\text{North}^2 + \text{South}^2}$ (mA.m⁻¹; miliamps per metre)
- 4) $\text{SIRM} = X / \rho \times 1,000$ (A.m⁻¹.kg⁻¹. m³)

Calculations for Mass Specific Susceptibility

Using Low Frequency range (0.1 Hz) and SI setting

- 1) Calculate initial reading $R_1 = \frac{(B+C) - (A+D)}{2}$

Where	A = 1st reading	blank
	B = 2nd "	sample
	C = 3rd "	sample
	D = 4th "	blank

- 2) Calculate Volume Susceptibility (k)

$$k = R_1 \times 10^{-5} \text{ (no units)}$$

- 3) Calculate Mass Specific Susceptibility

$$= k \times \frac{\text{volume}}{\text{mass}} \quad 10^{-8} \text{m}^3 \text{kg}^{-1}$$

Note: volume	= volume of kartell sample holder
	= $8.75 \times 10^{-6} \text{ m}^3$
mass	= mass of sample (kg)

Appendix 6: Economic Plants of New Caledonia

The tables in this appendix have been compiled from the following sources:

Barrau (1956; 1958; 1962; 1980),

Bourret (1981)

Cherrier (1989; 1990)

Vieillard (1862).

TABLE A6.1: Staple Food Plants of New Caledonia.

BOTANICAL NAME		COMMON NAME	PART OF PLANT EATEN
<u>ARACEAE</u>		Taros	
<i>Alocasia macrorrhiza</i> (L.) Schott			Tuber
<i>Colocasia esculenta</i> (L.) Schott	C		Tuber, leaves, flowers
<i>Xanthosoma</i> spp.			Tuber
<u>CONVOLVULACEAE</u>			
<i>Ipomoea batatas</i> (L.) Lamk.	C	Sweet Potato	Tuber
<u>DIOSCOREACEAE</u>		Yams	
<i>Dioscorea alata</i> L.	C	Greater Yam	Tuber
<i>D. bulbifera</i> L.	C	Bitter Yam	Tuber (cultivation simple fallow)
<i>D. esculenta</i> (Loureiro) Burkill	C		Tuber
<i>D. glabra</i> Roxb.			Tuber (semi gathered)
<i>D. nummularia</i> Lam.	C		Tuber
<i>D. pentaphylla</i> L.			Tuber
<u>MUSACEAE</u>		Bananas	
<i>Musa paradisiaca</i>			Fruit
subsp. <i>sapientum</i> (L.) Kuntze	C		
<i>M. paradisiaca</i>			Fruit and Rhizomes
subsp. <i>sapientum</i> (L.) Kuntze			
var. <i>oleracea</i> Baker	C		
Other Banana Species Utilized			
<i>Musa discolor</i> Hort	C		Fruit
<i>M. troglodytarum</i> S. Kurz.			Fruit

Compiled from Barrau (1956, 1958), Bourret (1981) and Vieillard (1862). C = cultivated.

TABLE A6.2: Other Food Plants

BOTANICAL NAME		LIFEFORM	COMMON NAME	PART OF PLANT EATEN
<u>PTERIDOPHYTES</u>				
<u>ANGIOPTERIDACEAE</u>				
<i>Angiopteris erecta</i> Hoff.				Highly prized, large rhizomes
<u>CYATHEACEAE</u>				
<i>Cyathea intermedia</i> Mett.			Treefern	Jelly from base of fronds
<i>C. novae celadoniae</i> Mett.			Treefern	Jelly from base of fronds
<i>C. vieillardii</i> Mett.			Treefern	Marrow from main stem, jelly from base of fronds
<u>DENNSTADIACEAE</u>				
<i>Pteridium esculentum</i> (Forster) Cockayne			Bracken	Rhizomes (famine food)
<u>GLEICHENIACEAE</u>				
<i>Gleichenia linearis</i> (Bum.) Clarke				Stems (famine food)
<u>OPHIOGLOSSACEAE</u>				
<i>Helminthostachys zeylanica</i> Hook.				Juvenile fronds
<u>GYMNOSPERMS</u>				
<u>ARAUCARIACEAE</u>				
<i>Agathis lanceolata</i> Warb.		Large r/forest tree	Kaori	Seeds: at beginning of season
<i>A. macrophylla</i> Masters		Large r/forest tree	Kaori	Seeds: at beginning of season
<i>A. morrii</i> Lindl.		Large r/forest tree	Kaori	Seeds: at beginning of season
<i>A. ovata</i> Moore.		Large r/forest tree	Kaori	Seeds: at beginning of season
<u>CYCADAACEAE</u>				
<i>Cycas circinalis</i> L.	A	Lowland forests		Young stems (paste) & seeds (roasted & flour making)
<u>ANGIOSPERMS</u>				
<u>ACANTHACEAE</u>				
<i>Gratophyllum pictum</i> Griff.		Coastal shrub		Leaves cooked
<u>AIZOCEAE</u>				
<i>Tetragonia expansa</i> Murr.				Leaves: green vegetable
<u>ANACARDIACEAE</u>				
<i>Semecarpus atra</i> Vieillard		Forest tree	Acajou	Nuts: roasted
<u>ARECACEAE</u>				
<i>Cocos nucifera</i> L. (many varieties)	A		Coconut	Milk and endosperm; terminal buds
<i>Kentia</i> sp.			Palm	Palm heart
<u>ASTERACEAE</u>				
<i>Wedelia biflora</i> (L.) D.C.		Lowland herb		Leaves cooked
<u>BALANOPHORACEAE</u>				
<i>Balanophora fungosa</i> Forst.		Small parasitic r/forest plant		Stems in bloom are cooked (famine food)
<u>BORAGINACEAE</u>				
<i>Cordia dichotoma</i> Forst.		Coastal tree		Nuts
<i>C. subcordata</i> Lamark.	A	Coastal tree		Nuts
<u>BURSERIACEAE</u>				
<i>Canarium oleiferum</i> Baillon	A	Tall r/forest tree		Nuts
<i>Canarium</i> spp.		Tall r/forest trees		Nuts
<u>COMBRETACEAE</u>				
<i>Lumnitzera racemosa</i>		Tall tree	Mangrove	Leaves
<i>Terminalia catappa</i> Linn.	A	Sclerophyll forest tree		Nuts
<i>T. glabrata</i> Fors.		Sclerophyll forest tree		Nuts
<u>CRUCIFERAE</u>				
<i>Nasturtium officinale</i> R. Br.		Herb	Watercress	Leaves
<i>N. samentosum</i> Schulz		Herb	Watercress	Leaves
<u>CUCURBITACEAE</u> (various spp.)				
			Squash, gourd	Seeds and flesh (many introduced but some native)
<u>CYPERACEAE</u>				
<i>Eleocharis esculenta</i> Vieillard		Sedge; swamps		Tubers
<u>CLUSIACEAE</u>				
<i>Calophyllum inophyllum</i> L.	A			Nut: oil
<i>Clusia pedicellata</i> Forst.				Fruit
<u>EUPHORBIACEAE</u>				
<i>Aleurites moluccana</i> (L.) Willd.	A	Tall l/land forest tree	Candlenut	Nut: roasted
<u>GUTTIFERAE</u>				
<i>Garcinia</i> spp.		Large r/forest trees		Fruit

Compiled from Barrau (1956, 1958, 1962), Cherrier (1990) and Vieillard (1862).

A = found in archaeological sites in northern Melanesia from Gosden *et al.* (1989), Hayes (1992), Kirch (1989) and Mathews and Gosden (1997).

Table A6.2 continued: Other Food Plants

BOTANICAL NAME	LIFEFORM	COMMON NAME	PART OF PLANT EATEN
<u>LECYTHIDACEAE</u> <i>Barringtonia</i> spp.	Shrub	Tahitian chestnut	Fresh nuts
<u>LEGUMINOSAE</u> <i>Dolichos lablab</i> L.			Fruit grilled; seed Nut: generally cooked
<i>Inocarpus fagiferus</i> (Park.) Fosberg A			
<i>Lablab perennis</i> Vieillard. <i>Pueraria lobata</i> Willd.	Herb		Seeds: roasted Tuber and leaves (famine food)
<u>LILIACEAE</u> <i>Cordyline</i> spp.	Widespread shrub	Ti	Roots Roots
<i>Curculigo stans</i> Gaud. <i>Dianella</i> spp.	Herb		Berries
<i>Eustrephus latifolium</i> R. Br. <i>Geitonoplesium cynosum</i> (R. Br.) A.Cunn.	Liane l/land forest Liane l/land forest		Young shoots eaten as asparagus Young shoots eaten as asparagus
<u>MALVACEAE</u> <i>Hibiscus manihot</i> L. (number of varieties) <i>H. tiliaceus</i> L.	Small lowland trees Small lowland tree		Leaves New shoots, bark
<u>MORACEAE</u> <i>Artocarpus incisus</i> (Thunberg) L.f. <i>Ficus</i> spp.	Village tree Trees and shrubs	Breadfruit Fig	Seeds roasted, fruit eaten Fruit and young leaves
<u>MYRTACEAE</u> <i>Melaleuca quinquenervia</i> (Cav.) S.T.Blake <i>Eugenia</i> spp. <i>Jambosa</i> spp. <i>Myrtus</i> spp. <i>Syzygium</i> spp.	L/land tree (savanna) Trees and shrubs of forests	Niaouli	Young leaves; tea Fruit Fruit Fruit Fruit
<u>OLEACEAE</u> <i>Olea paniculata</i> R. Br. <i>Ximenia elliptica</i> Forst.	Forest tree		Fruit Fruit
<u>PANDANACEAE</u> <i>Freycinetia</i> sp. <i>Pandanus macrocarpus</i> R.Br. <i>P. minda</i> Vieillard <i>P. odoratissimus</i> Lin. <i>P. pendunculatus</i> R.Br. <i>P. reticulatus</i> Vieillard	Liane; rainforest Widespread Tree Widespread Tree Widespread Tree Widespread Tree Widespread Tree		Flower bracts and fruit Fruit Fruit Fruit Fruit Fruit
<u>PASSIFLORACEAE</u> <i>Passiflora</i> spp.	Lianes		???
<u>PIPERACEAE</u> <i>Peperomia blanda</i> Kunth.			Leaves
<u>POACEAE</u> <i>Cymbopogon citratus</i> Stapf. <i>Saccharum officinarum</i> L. (~ 30 varieties)		Sugar cane	Tea Stems
<u>PROTEACEAE</u> <i>Grevillea exul</i> Lindl. <i>G. guillivrayi</i> Hook. <i>Kermadecia sinuata</i> Brongniart & Gris <i>K. leptophylla</i> Guillaumin	Maquis shrub Maquis shrub Tall rainforest tree Tall rainforest tree		Nuts Nuts Nuts Nuts
<u>RHIZOPHORACEAE</u> <i>Bruguiera eriopetala</i> Wight & Arn A <i>Rhizophora mucronata</i> Lamark	Tree Small tree	Mangrove Mangrove	Sprouted fruit cooked (famine food) Fruit and leaves
<u>RUBIACEAE</u> <i>Morinda citrifolia</i> L.	Coastal zone tree		Fruit
<u>RUTACEAE</u> <i>Murraya crenulata</i> Oliv.	Forest tree		Leaves for tea
<u>SAPOTACEAE</u> <i>Solanum repandum</i> Forst. <i>S. viride</i> Forst.	Large r/forest trees		Large fruits
<u>SONNERATIACEAE</u> <i>Sonneratia alba</i> Sm.	Tree	Mangrove	Fruit Leaves
<u>STERCULIACEAE</u> <i>Heritiera littoralis</i> Ait	Tree behind m/groves		Nut
<u>TILIACEAE</u> <i>Grewia crenata</i>	Small 2° forest tree		Leaves cooked

Compiled from Barrau (1956, 1958, 1962), Cherrier (1990) and Vieillard (1862).

A = found in archaeological sites in northern Melanesia from Gosden *et al.* (1989), Hayes (1992), Kirch (1989) and Mathews and Gosden (1997).

TABLE A6.3: Plants used for textiles and other cultural purposes.

BOTANICAL NAME	LIFEFORM	COMMON NAME	PART USED AND PURPOSE
<u>PTERIDOPHYTES</u>			
<u>BLECHNACEAE</u>			
<i>Blechnum gibbum</i> (Labill.) Mett.			Fronds used to decorate carving; wigs
<u>GLEICHENICEAE</u>			
<i>Lygodium</i> spp.	Climbing ferns		Stems used to attach yams to poles
<u>ANGIOSPERMS</u>			
<u>AGAVACEAE</u>			
<i>Cordyline terminalis</i> (L.) Kunth			Ritual and ornamental
<u>ANACARDIACEAE</u>			
<i>Semecarpus atra</i> Vieillard	Low to mid alt. tree, very common		Black dye from stems and latex
<u>APOCYNACEAE</u>			
<i>Cerbera odallum</i> Gaertn.	Coastal tree		Tattooing: violet
<u>ARAUCARIACEAE</u>			
<i>Agathis</i> spp.			Resin: laquer for pottery; fire lighting
<u>ARECACEAE</u>			
<i>Cocos nucifera</i> L.			Husk fibres; string, cord; leaves for matting & basketry
<u>BORAGINACEAE</u>			
<i>Cordia sebestena</i> Forst.	Coastal tree		Red dye from leaves
<i>Cordia subcordata</i> Lam.	Coastal tree		Red dye from leaves
<u>CASUARINACEAE</u>			
<i>Casuarina</i> spp.	Widespread lowland tree	Bois de fer	Wood: spears, club handles, gardening implements. Bark: tanning
<u>CLUSIACEAE</u>			
<i>Calophyllum inophyllum</i> L.	Large coastal tree		Yellow dye from fruit, nuts for fish poison.
<u>CUNONIACEAE</u>			
<i>Cunonia austrocaledonica</i> Guill.	Forest & maquis tree		Black dye from bark
<i>C. pulchella</i> Brongn. & Gris	Forest & maquis tree		Black dye from bark
<u>CYPERACEAE</u>			
<i>Carex</i> spp.	Sedges		Blues dye from seeds
<i>Eleocharis</i> spp.	Sedges		Cloaks, baskets
<i>Lepironia articulata</i> (Retz.) Domin.	Sedge		Basketry
<u>EUPHORBIACEAE</u>			
<i>Codium inophyllum</i> Mull.	Small lowland tree		Weapons
<i>Croton insularis</i> Baill.	Small coastal tree		Gardening implements
<i>Euphorbia kanalensis</i> Boiss.			Crushed plant for fish poison
<i>E. spp.</i>			Crushed plant for fish poison
<i>Glochidion</i> spp.	Forest trees & shrubs		Weapons
<i>Phyllanthus bupleuroides</i> Baill.	Coastal shrub		Fish poison
<u>HELICONIACEAE</u>			
<i>Heliconia austro-caledonica</i> Nob.			
<u>LABIATAE</u>			
<i>Coleus blumei</i> Benth.			Blue dye from stems
<u>LAURACEAE</u>			
<i>Cassytha</i> spp.			Stems: bracelets and belts
<u>LECTHYDIACEAE</u>			
<i>Barringtonia asiatica</i> (L) Kurz.	Large coastal tree		Nuts for fish poison
<u>LEGUMINOSAE</u>			
<i>Acacia spirorbis</i> Labill.	Lowland tree	Gaiac	Gardening implements; weapons
<i>Derris trifoliata</i> Lour.	Coastal zone liane		Stem for fish poison
<i>Desmodium</i> spp.	Woody herb		Blue dye from leaves
<i>Exoecaria agallocha</i>	Low tree behind mangroves		Fish poison
<i>Mucana gigantum</i> D.C	Liane		Hoop for fishing nets
<i>Pueraria lobata</i> Willd.	Herb		Stems for fibre; general use and fishing nets
<i>Tephrosia purpurea</i> Pers.	Herb		Fish poison
<u>LILIACEAE</u>			
<i>Cordyline terminalis</i> (L.) Kuntz	Shrub		Leaves for fibre
<i>Dianella</i> spp.	Large herbs		Black dye from berries and leaves
<i>Lomandra insularis</i>	Small maquis shrub		Leaves for fibres
<u>MALVACEAE</u>			
<i>Hibiscus tiliaceous</i> L.	Small lowland tree		Fibre from bark of young stems for number of purposes; wood as fishing net floats
<i>Thespesia populnea</i> Cav.	Small coastal tree		Bark for fibres

Compiled from Barrau (1956, 1958), Cherrier (1990) and Vieillard (1862).

TABLE A6.3 continued: Plants used for textiles and other cultural purposes.

BOTANICAL NAME	LIFEFORM	COMMON NAME	PART USED AND PURPOSE
<u>MELASTOMACEAE</u> <i>Melastoma denticulatum</i> Labill.	Low tree		Young stems: fibres for textiles. Leaves black dye
<u>MELIACEAE</u> <i>Aglaia eleagnoides</i> Benth.	Coastal tree		Gardening implements; weapons
<u>MORACEAE</u> <i>Broussonetia papyrifera</i> Forst. <i>Ficus prolixa</i> Forst. & other <i>Ficus</i> spp. <i>F. tinctoria</i> Forst.	Large trees	Fig Fig	Bark: belts, hats etc. Bark of prop roots: fabric (Tapa) Berry: dye
<u>MUSACEAE</u> <i>Musa fehi</i> Bertero <i>Musa</i> spp.			Violet dye from stems. Leaves for slings and fibre for fishing nets etc.
<u>MYRTACEAE</u> <i>Eugenia jambos</i> ?? <i>E. oraria</i> Guill. <i>E. vieillardii</i> Brongn. & Gris <i>Tristania callobuxus</i>	Shrub Maquis shrub		Fruit for dye Weapons Gardening implements Weapons
<u>OLEACEAE</u> <i>Olea thozetii</i> Panch. <i>Ximena americana</i> L.	Small lowland tree Coastal tree		Red dye for hair; gardening implements wood. Tattooing: blue
<u>PANDANACEAE</u> <i>Freycinetia</i> sp. <i>Pandanus</i> spp.	Rainforest liane Low & mid alt. trees		Blue dye Fibres for loincloth; leaves for matting & basketry
<u>PITTOSPORUM</u> <i>Pittosporum pancheri</i> Brong. & Gris	Tree		Tattooing: violet
<u>POACEAE</u> <i>Saccharum floridus</i> L.		Sugarcane	Stems: flute
<u>RANUNCULACEAE</u> <i>Clematis</i> spp.	Lowland forest lianes		Seeds for necklaces
<u>RHAMNACEAE</u> <i>Ceanthus capsularis</i> Forst.			Fire making
<u>RHIZOPHORACEAE</u> <i>Rhizophora mucronata</i> Lamark	Tree	Mangrove	Black dye from bark; pneumatophores for fishing net hoops.
<u>RUBIACEAE</u> <i>Gardenia aubryi</i> Vieillard. <i>G. oudiepe</i> Vieillard <i>G. urvillei</i> Montrouzier <i>Morinda citrifolia</i> Forst. <i>M. tinctoria</i> Roxb.	Small lowland tree Small lowland tree Small lowland tree Coastal tree Coastal tree		Resin for caulking flutes; gardening implements Resin for caulking flutes; gardening implements Resin for caulking flutes; gardening implements Fawn dye from roots Dye from roots
<u>RUTACEAE</u> <i>Achroynia baueri</i> Engl. <i>Geijera balanse</i> Schinz.	Forest tree Rainforest tree		Gardening implements Gardening implements
<u>SAPINDACEAE</u> <i>Harpulia neo-caledonica</i> Baill. <i>Podonephelium homei</i> Radlk.	Large lowland tree Small lowland tree		Fish poison Red dye for hair
<u>SIMAROUBACEAE</u> <i>Suriana maritima</i> L.	Coastal shrub		Weapons
<u>SMILACACEAE</u> <i>Smilax</i> spp.	Liane		Fishing net hoop
<u>STERCULIACEAE</u> <i>Commersonia echinata</i> Ait. <i>Maxwellia lepidota</i> Baill. <i>Sterculia</i> spp.	Tree Maquis shrub Lowland to mid altitude trees		Fibre Gardening implements Fibre from bark
<u>SYMPLOCACEAE</u> <i>Symplocos baptica</i> Brongn. & Gris	Lowland tree		Dye from bark
<u>URTICACEAE</u> <i>Broussonetia papyrifera</i> (L.) Vent. <i>Pipturus argenteus</i> (Forst.) Wedd. <i>P. nivea</i> Wedd. <i>P. oestuanus</i> Wedd. <i>P. pellucidus</i> Vieill.	Lowland tree	Tapa	Bark beaten to make fabric (Tapa); once cultivated today rare. Fibres from young stems: loincloth, belts & f/line Fibres from young stems: loincloth, belts & f/line Fibres from young stems: loincloth, belts & f/line Fibres from young stems: loincloth, belts & f/line

Compiled from Barrau (1956, 1958), Cherrier (1990) and Vieillard (1862).

TABLE A6.4: Plants used in house construction

BOTANICAL NAME	LIFEFORM	COMMON NAME	USE
<u>GYMNOSPERMS</u> <u>ARAUCARIACEAE</u> <i>Araucaria columnaris</i> (Fors.) Hook.			House centre pole
<u>ANGIOSPERMS</u> <u>ARECACEAE</u> <i>Cocos nucifera</i> L.	Coastal tree	Coconut	Trunks for light construction; Leaves for roof thatching
<u>CASUARINACEAE</u> <i>Casuarina</i> spp.	Widespread lowland trees	Bois de fer	General construction timber
<u>ELAEOCARPACEAE</u> <i>Elaeocarpus persicifolius</i> B. & Gris <i>E. speciosus</i> Brongniart & Gris			General construction timber General construction timber
<u>EUPHORBIACEAE</u> <i>Baloghia lucida</i> Endl.	Large forest tree		House posts
<u>GUTTIFERAE</u> <i>Calophyllum montanum</i> L. <i>Montrouziera cauliflora</i> Pl. & Tr.	Large rainforest tree	Houp	General construction timber Centre pole for chiefs house
<u>LEGUMINOSAE</u> <i>Acacia spirorbis</i> Labill.	Large shrub of sclerophyll forest	Gaiac	Sculptures and totems; small fence posts; wall braces; shelving
<i>Derris uliginosa</i> Benth.	Liane		Binding house posts
<u>LOGANIACEAE</u> <i>Fagraea schlechteri</i> Gilg. & Ben.	Forest tree		Wood for totems
<u>MYRTACEAE</u> <i>Melaleuca quinquenervia</i> (Cav.) S.T. Blake		Niaouli	Bark: for cladding exterior/internal house walls; timber for non-structural purposes
<u>PANDANACEAE</u> <i>Pandanus macrocarpus</i> R.Br. <i>P. minda</i> (indigenous name) <i>P. odoratissimus</i> Lin. <i>P. pendunculatus</i> R.Br. <i>P. reticulatus</i> Vieillard			Leaves for roof thatching Leaves for roof thatching Leaves for roof thatching Leaves for roof thatching Leaves for roof thatching
<u>POACEAE</u> <i>Andropogon austro-caledonicum</i> <i>Imperatum</i> spp.	Herb Herb	Grass Grass	Stems for thatching Leaves for thatching
<u>RUBIACEAE</u> <i>Morinda</i> spp.	Lianes		Binding house posts
<u>SAPOTACEAE</u> <i>Manilkara dissecta</i> Baill.	Large rainforest tree	Buni	Centre poles for houses (?)

Compiled from Barrau (1956, 1958, 1962, 1980), Cherrier 1990 and Vieillard (1862).

TABLE A6.5: Trees used in canoe construction

Botanical Name	Common Name	Height & Diameter	Where Found
ANACARDIACEAE <i>Semecarpus atra</i> Vieillard		20 m 70 - 80 cm diam	Frequent in lowland formation but up 700 m; all soil types
ARALIACEAE <i>Schefflera gabriellae</i> Baillon	Ralia	30 m 80 cm diam	Forest , 600 m altitude on all soil types
ARAUCARICEAE <i>Agathis moorei</i> (Lin.) Masters	Kaori	30-40 m 1-2 m diam	100-800m altitude dense humid forest
<i>A. lanceolata</i> Lindley ex Warburg	Kaori	ditto	ditto
<i>Araucaria columnaris</i> (Fors.) Hooker	Pin Colonnaire	50-60 m 1 - 1.2 m diam.	littoral zone (calcareous) also in ultramafic terrain
ELAEOCARPACEAE <i>Elaeocarpus angustifolius</i> Blume	Cerisier Bleu	20 -25 m 80 - 1 m diam.	0 - 500m altitude dense forest
<i>Elaeocarpus</i> spp.			Juveniles for counter balance canoe
EUPHORBIACEAE <i>Aleurites moluccana</i> Willd	Bancoulier	20 m 80 cm diam	0 - 300 m altitude calcareous, schists
GUTTIFERAE <i>Montrouziera cauliflora</i> Planch. & Triana	Houp	30 m 1.5 m diam.	200 - 1100 m altitude; all soil types; dense forest
GYROCARPACEAE <i>Gyrocarpus americanus</i> Jacq.	bois à pirogues	> 15 m 1 m diam	lowland forest on alluvial soils of the north
HERNANDIACEAE <i>Hernandia cordigera</i> Nob	Bois Bleu	20 25 m 80 cm diam. ditto	0 - 500 m altitude dense forest, all soil types littoral forests
<i>H. nymphaeifolia</i> (K. Presl) Kubitski			
LEGUMINOSAE <i>Serianthes sachetae</i> Fosberg		up to 30 m 80 cm diam.	littoral forest & dense forest up to 500 m; all soils.
MALVACEAE <i>Hibiscus tiliaceous</i> L. (counter balance canoe)		small tree	dense thickets; wet lowland zones; around villages
NYCTAGINACEAE <i>Calpidia artensis</i> (Montr.) Heimerl		15 - 20 m 1 m diam	lowland forest
RUBIACEAE <i>Gardenisa aubryi</i> Vieillard. Resin from buds for corking canoes		Shrub	lowland and littoral zones
<i>G. oudiepe</i> Vieillard		Shrub	ditto
<i>G. urvillei</i> Montrouzier		Shrub	ditto

Compiled from Cherrier (1989).

Appendix 7: Authority list for species referred to in text.

PTERIDOPHYTES

Adiantaceae

Acrostichum aureum L.

Cyatheaceae

Cyathea vieillardii Mettenius

Dennstadiaceae

Pteridium esculentum (Forster) Cockayne

GYMNOSPERMS

Araucariaceae

Agathis ovata (C. Moore) Warburg

Araucaria columnaris (Forst. f.) Hook

ANGIOSPERMS

Anacardiaceae

Euroshinus obtusifolius Engl.

Apocynaceae

Cerbera manghas L.

Arecaceae

Cocos nucifera L.

Bignoniaceae

Dolichandrone spathacea (L. f.) K. Schum

Burseraceae

Canarium harveyi Seem.

C. indicum L.

C. oleiferum Baillon

Casuarinaceae

Casuarina collina Poisson

Clusiaceae

Montrouziera cauliflora Planch. & Triana.

Dioscoreaceae

Dioscorea alata L.

D. bulbifera L.

D. esculenta (Lour.) Burk.

D. pentaphylla L.

Ebenaceae

Diospyros fasciculosa (F. Muell.) F. Muell

Euphorbiaceae

Aleurites moluccana (L.) Wild

Drypetes deplanchei (Brong. & Gris) Merr.

Euphorbia kanalensis Boiss.

Flagellariaceae

Joinvillea elegans Brong. & Gris.

Flacourtiaceae

Homalium deplanchei (Vieill.) Warb.

Guttiferae

Calophyllum inophyllum L.

Mammea neurophylla (Schltr.) Kosterm.

Icacinaceae

Apodytes clusiifolia (Baillon) Villiers

Lecthydiaceae

Barringtonia asiatica (L.) Kurz.

Leguminosae

Acacia farnesiana (L.) Willd.

Acacia spirorbis Labill.

Liliaceae

Cordyline terminalis (L. Kunth.)

Malvaceae

Hibiscus manihot L.

H. tiliaceous L.

Meliaceae

Dysoxylum bijugum (Labill.) Seemann

Xylocarpus granatum Koen.

Moraceae

Artocarpus incisis

Musaceae

Musa discolor Hort.

M. paradisiaca Linn.

M. troglodytarum L.

Myrtaceae

- Arillastrum gummiferum* Panch.
- Melaleuca quinquenervia* (Cavanilles) S.T. Blake
- Psidium guajava* L.
- Syzigium densiflorum* Brong. & Gris

Oleaceae

- Olea paniculata* R. Br.

Poaceae

- Digitaria montana* Henrard
- Lepturus repens* (Forst. f.) R. Br.
- Lepturopetium kuniense* ?
- Saccharum officinarum* L.
- Spinifex sericus* ?
- Sporobolus virginicus* (L.) Kunth.
- Stenotaphrum micranthum* (Desv.) Hubb.
- Zoysia matrella* (L.) Merr.

Rhizophoraceae

- Avicennia marina* L. (Forsk.) Vierh.
- Brugeria gymnorhiza* (L.) Lam.

Rubiaceae

- Scyphiphora hydrophyllaceae* Gaertn. f.

Rutaceae

- Sarcomelicope leiocarpa* (P. Green) T. Hartley

Sapindaceae

- Arytera chartacea* Radlk.
- A. collina* (Pancher & Sébert) Radlk.
- Cupaniopsis globosa* Adema

Sapotaceae

- Manilkara dissecta* (L.) Dubard
- Mimusops elengi* L.
- Planchonella cinerea* (Pancher.) Royen

Sterculiaceae

- Acropogon bullatus* (Pancher & Sebert) Morat

Urticaceae

- Broussonetia papyrifera* (L.) Vent.

Verbenaceae

- Lantana camara* L.