Late Quaternary Marine and Freshwater Swamp Deposits of Northwestern Tasmania

By

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A thesis submitted to the Faculty of Science in fulfilment of the requirements for the degree of Doctor of Philosophy

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1981

STATEMENT OF AUTHOR

Except as stated herein this thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of my knowledge and belief, this thesis contains no copy of material previously published or written by another person, except when due reference is made in the text.

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ACKNOWLEDGEMENTS

The writer wishes to acknowledge the continuing interest, help and encouragement received from Dr. E.A. Colhoun, under whose supervision the research was carried out. The writer also wishes to express his indebtedness to Dr. W.G. Mook, Groningen University for undertaking radiocarbon dating and stable isotope analysis; the Geography Department of the University of Tasmania and the Australian Research Grants Committee for generous financial assistance; and the Tasmanian Department of Mines for technical assistance. In the field, helpful comments were received from Professor B.G. Thom, University of New South Wales; Dr. G. Singh, Australian National University; and Dr. P.S. Martin, University of Arizona. Assistance was gratefully received from Dr. P.G. Quilty, Macquarie University; Mrs. E. Turner, Tasmanian Museum; Mr. P. De Deckker, Australian National University; Mr. J.B. Smith, National Museum of Victoria; Mr. R. Ford, University of Tasmania; and Mr. N.K. Chick, University of Tasmania. Finally, the writer expresses his sincere thanks to Mr. R.D. Charlesworth for sample processing and Mrs. T.K.M. Hughes for typing the manuscript.

Abstract

A study of marine and freshwater swamp deposits and landforms in northwestern Tasmania reveals that profound palaeoenvironmental changes occurred during the late Quaternary as a consequence of eustatic sea level changes, tectonic and/or hydro-isostatic uplift, and palaeoclimatic changes.

Prograded bay sand barriers and lagoonal inlets constitute the most complex and extensively developed Holocene landforms and deposits on this coast. The barriers clearly depict marine transgression, followed by a major phase of barrier progradation and an episode of blowout and parabolic dune development. In the lagoonal inlets, the effects of strong tidal current action, halophytic vegetation, and wave and wind action have resulted in the development of distinctive depositional environments and landforms.

Pre-Holocene depositional marine landforms and sand deposits which locally contain a well-preserved fauna of mollusca and foraminifera, and fossil shore platforms covered with beach cobble deposits occur extensively in the area. These deposits occur from below sea level up to 15 to 20 m. The local and wider stratigraphic relationships of the marine material in relation to glacial, freshwater and aeolian deposits, and the ^{14}C dating of some of these deposits consistently point to a Last Interglacial age for the fossil marine features.

Oxygen isotope and chronostratigraphic studies elsewhere suggest that the maximum level attained by the sea during the Last Interglacial transgression was 5 to 10 m above present sea level. Although there is presently no direct evidence for or information on tectonic deformation or theoretically calculated data on hydro-isostatic deformation in northwestern Tasmania or elsewhere on the island, the higher levels recorded in this study suggest that such uplift and deformation occurred in the area during the late Quaternary.

Stratigraphic, sedimentary, palynologic, faunal, and conventional and isotopically enriched ^{14}C analysis of the swamp and lacustrine deposits formed under the influence of fluctuating artesian springs provides evidence from which a general palaeoenvironmental and palaeoclimatic record of approximately 100,000 years may be constructed.

During the Holocene Stage (10,000-0 BP) climate was warm and wet, and woody vegetation was dominant throughout the area. Locally, sand lunettes developed along lee shores of shallow lagoons. During the late Last Glacial Stage (25,000-10,000 BP) the climate became progressively drier and grassy open environments were more widespread. The driest part of this period occurred between ∿ 17,000 and 10,000 BP, when spring activity was very low and temperatures in western Tasmania were markedly reduced by highland glaciation. Predominantly wet conditions resulting from high precipitation and/or low evaporation rates occurred during the middle Last Glacial Stage (25,000-50,000 BP). The wettest part of this period occurred after about 35,000 BP during which the springs were very active, and extensive deposition of coarse river bed loads and alluvial fan gravels occurred elsewhere in the area. Considerably drier conditions occurred between approximately 55,000 and 45,000 BP during which woody vegetation was much more important than herbaceous vegetation and aquatic vegetation was virtually absent from the swamps. Prior to ∿ 55,000 BP, predominantly wet conditions prevailed on the swamps. These were periodically interrupted by relatively brief, drier phases during which woody scrub communities were somewhat more important and herbaceous and aquatic communities were less important than during the preceding and succeeding periods of the early Last Glacial Stage.

The direction of general climatic changes presented in this dissertation appears to be broadly sympathetic with climatic changes inferred from other southern Australian localities.

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Part I

INTRODUCTION

CHAPTER 1

INTRODUCTION AND BACKGROUND

1.1 AIMS

The aim of this dissertation is to describe the Late Quaternary marine and freshwater swamp deposits and associated landforms of the lowland plains and some of the nearby offshore islands of far northwestern Tasmania (Fig. 1). Particular emphasis is given to former sea level changes, the history of swamp development, to reconstructing the palaeogeographic environment and palaeoclimatic history, and to comparing the deductions and inferences arising therefrom with other relevant work.

1.2 STRUCTURE

The study consists of four parts. Part I, the Introduction, contains the aims, approach and Quaternary nomenclature, briefly reviews previous relevant research in the study area, and outlines the present environment of the coastal lowlands. Part II is a geomorphic and stratigraphic description of the Holocene and Pleistocene marine deposits, and of the erosional shoreline features. This part also contains an evaluation of evidence for higher pre-Holocene sea levels, and compares the results of this study with that of relevant research elsewhere in Tasmania, parts of mainland Australia, and further afield. Part III describes the lithostratigraphic and biostratigraphic records of the freshwater swamp deposits and evaluates their palaeoenvironmental and palaeoclimatic significance. The fourth part is a synthesis of the results of the study.

1.3 APPROACH

The project was commenced on a part-time basis in 1973, following a review of the literature and preliminary aerial photograph interpretation. Because the area consists of an assemblage of closely related depositional geomorphic units, initial investigation and reconnaissance was aimed at determining those features most worthy of detailed study. Holocene and Pleistocene marine landforms and deposits, and artesian spring and associated swamp deposits were extensively mapped and examined, and the sediments from the various environments were sampled for laboratory analysis. Laboratory procedures consisted primarily of grain size analysis and the determination of the composition of the sediments, and of systematic pollen analysis of the swamp deposits. Statistical methods were used where considered relevant. Details of the field and laboratory methods used are described in the appropriate sections.

Thirty one radiocarbon assays, a number of stable isotope and chemical analyses, and identifications of remains of extinct marsupials, fossil mollusca and foraminifera were obtained to facilitate the reconstruction of the palaeoenvironment and palaeoclimatic history of the area.

1.4 PREVIOUS WORK

Detailed geological description of the Smithton area was made by Nye *et al.* (1934) but the scant Quaternary morphostratigraphic content of their lengthy report was found to be frequently erroneous and of little relevance to the present study. The most relevant study of part of the lowland region was made by Gill and Banks (1956). This wide ranging study contains a general description of the artesian spring deposits at Mowbray and Pulbeena swamps, a review of the literature describing the palaeontology of extinct megafaunal remains found some forty years earlier during clearance and artificial drainage operations of the Mowbray Swamp area, and the occurrence of elevated fossiliferous marine sand deposits of Pleistocene age in the Mowbray Swamp-Christmas Hills area. Although Gill and Banks described some of the stratigraphic characteristics of the artesian spring deposits and associated swamp deposits, and obtained some radiocarbon assays, their interpretation of the data indicates that they did not fully recognize the palaeoenvironmental and palaeoclimatic significance of these deposits.

Understanding of the general stratigraphical relationships of some of the Pleistocene marine sand deposits was enhanced by percussion drilling logs contained in a Tasmanian Mines Department report which examines the groundwater potential of the area in general (Gulline, 1959). A preliminary study of the soils of the lowland sand plains was made by Hubble (1951). His observations were found to be accurate, and many of his tentative conclusions are substantiated by the writer's more detailed work within the sections of this thesis. Hubble (in Gill and Banks, 1956) also briefly commented on the soils of the Mowbray Swamp and Christmas Hills area. Finally, two recent palaeoenvironmental studies from adjacent areas are of significance to our present understanding of the environmental and climatic history of the region. A palynological study of an archaeological cave deposit on nearby Hunter Island was made by Hope (1978), and fossil alluvial fan deposits at Rocky Cape National Park have been described in some detail by Colhoun (1977a).

1.5 QUATERNARY NOMENCLATURE

Table 1 summarises the subdivisions of the late Quaternary referred to in this dissertation. The table is supplemented by the following explanatory comments:-

The problem of defining the Pleistocene/Holocene boundary has been discussed repeatedly in order to obtain international agreement on its position (Mercer, 1972). The Holocene sub-commission of the International Quaternary Union (INQUA) decided that the problem should be resolved in favour of a single date, and adopted an arbitrary date of 10,000 ^{14}C years at its Paris meeting in 1969. However, there has been considerable criticism of this choice, for example by Mercer (1972), and more recently by Watson and Wright (1980).

In view of the variety in types of stratigraphic units available for study (Hedberg, 1972), and the different thresholds and lag effects of geologic processes in response to climatic factors, Watson and Wright (1980) consider it unrealistic to select a single date as the basis for a world-wide, isochronous Pleistocene/Holocene boundary. They suggest the actual boundary is usually geographically time-transgressive and that this ought to be recognised by placing the boundary according to the best judgements available from the local stratigraphic record that reflects the termination of the Pleistocene.

TABLE 1. Subdivision of the Late Quaternary

			Approx. yrs BP
HOLOCENE			
			10,000
UPPER PLEISTOCENE	Last Glacial Stage	*Late*	25,000-10,000
		Middle	50,000-25,000
		Early	120,000-50,000
			120,000
	Last Interglacial Stage		
			130,000
MIDDLE PLEISTOCENE			

There is considerable recent geomorphological and palynological evidence to suggest that the arbitrary date of 10,000 BP for the Pleistocene/Holocene boundary would serve as a satisfactory general division for Tasmania. The boundary coincides closely with the final decay of glacial ice in the highland cirques and with the onset of rapid forest expansion and rising treelines in western Tasmania (Colhoun, 1975; Macphail and Jackson, 1978; Macphail, 1979).

The subdivision of the Last Glacial Stage can also be made on an arbitrary basis to form a chronologic framework with which radiometrically dated episodes of climatic change recorded from sediments can be compared. In view of present knowledge, such a subdivision is more convenient than any that might be based on lithostratigraphic, biostratigraphic or soil stratigraphic units. Such an arbitrary subdivision has served as a useful framework for stratigraphic correlation in the British Quaternary (Mitchell *et al.*, 1973).

In western Tasmania and at Lake Twynam in the Snowy Mountains region of southeastern Australia, there is radiometrically dated evidence which suggests that the maximum extension of ice during the late Last Glacial maximum occurred c. 18,000-20,000 BP (Colhoun, 1975; Costin, 1972). In addition, there is also evidence which suggests that the Last Glacial Stage was broadly tripartite in its climatic characteristics with cool interstadial conditions in the middle, separating the late cold phase from an early cold phase(s) (Colhoun, 1975; Bowler *et al.*, 1976; Kershaw, 1981).

There is some controversy on the time of the end of the Last Interglacial. This appears to stem largely from a lack of agreed definition of what an interglacial represents and the criteria used in determining where the boundary should be placed (Suggate, 1965, 1974). Marine evidence indicates that the most probable sequence of climatic variations between c. 130,000 and 70,000 years BP was of three warmer episodes (Sub-stages 5e, 5c and 5a of

Shackleton and Opdyke, 1973) separated by two colder episodes (Sub-stages 5b and 5d), but with the cold stages not being as cold as the coldest event of the late (i.e. post-25,000 BP) last glaciation maximum (Dansgaard and Duplessy, 1981). Recent terrestrial evidence points in the same direction (Woillard and Mook, 1982). Evidence seems also overwhelmingly in support for regarding only Sub-stage 5e as representative of the Last Interglacial on the basis of sea level having attained a position as high or higher than present sea level. In spite of interpretation and age dating problems of marine and terrestrial proxy data, the balance of evidence seems consistent enough to conclude that the warm (at least as warm as at present) Last Interglacial climate deteriorated rapidly and markedly some 120,000-115,000 years ago in mid and high latitudes, and that the period between about 115,000 and 75,000 years BP should be regarded as representing the early phases of the Last Glacial Stage (Dansgaard and Duplessy, 1981).

The Middle/Late Pleistocene boundary indicated follows the most recent recommendation of the INQUA Working Group on Major Subdivisions of the Pleistocene (Richmond, personal communication). The boundary corresponds with the major high sea level stand of the Last Interglacial (Sub-stage 5e, Shackleton and Opdyke, 1973; Termination II, Broecker and Van Donk, 1970), uranium series dated at approximately 130,000 years BP (e.g. Veeh, 1966; Land *et al.*, 1967; Steinen *et al.*, 1973; Bloom *et al.*, 1974).

CHAPTER 2

THE ENVIRONMENT

2.1 TASMANIA

Tasmania with its adjacent islands is a detached portion of the eastern highlands of the Australian landmass lying between approximately 39½° and 43½°S and between the Southern Ocean and the Tasman Sea (Fig. 1). Tasmania is a very mountainous island and very little of its land area lies close to sea level. The Western Highlands are a northwest-southeast trending mountain range which locally exceeds 1,500 m in elevation. The core of the island is the broad Central Plateau which is bordered to the east and north by a very prominent 500-1000 m high scarp. The Eastern Highlands are low coastal mountains 300-400 m high. Situated between the Central Plateau and the Eastern Highlands is the Midlands, the only extensive area of continuous inland plains. The most extensive continuous coastal plains are in the northeast and in the study area in the extreme northwest of the island.

The Western Highlands and western part of the North Coastal Lowlands are composed mainly of folded pre-Carboniferous rocks which have been uncovered as a result of stripping of the post-Carboniferous cover. Valleys have been excavated along the strike of the less resistant rocks leaving the more resistant

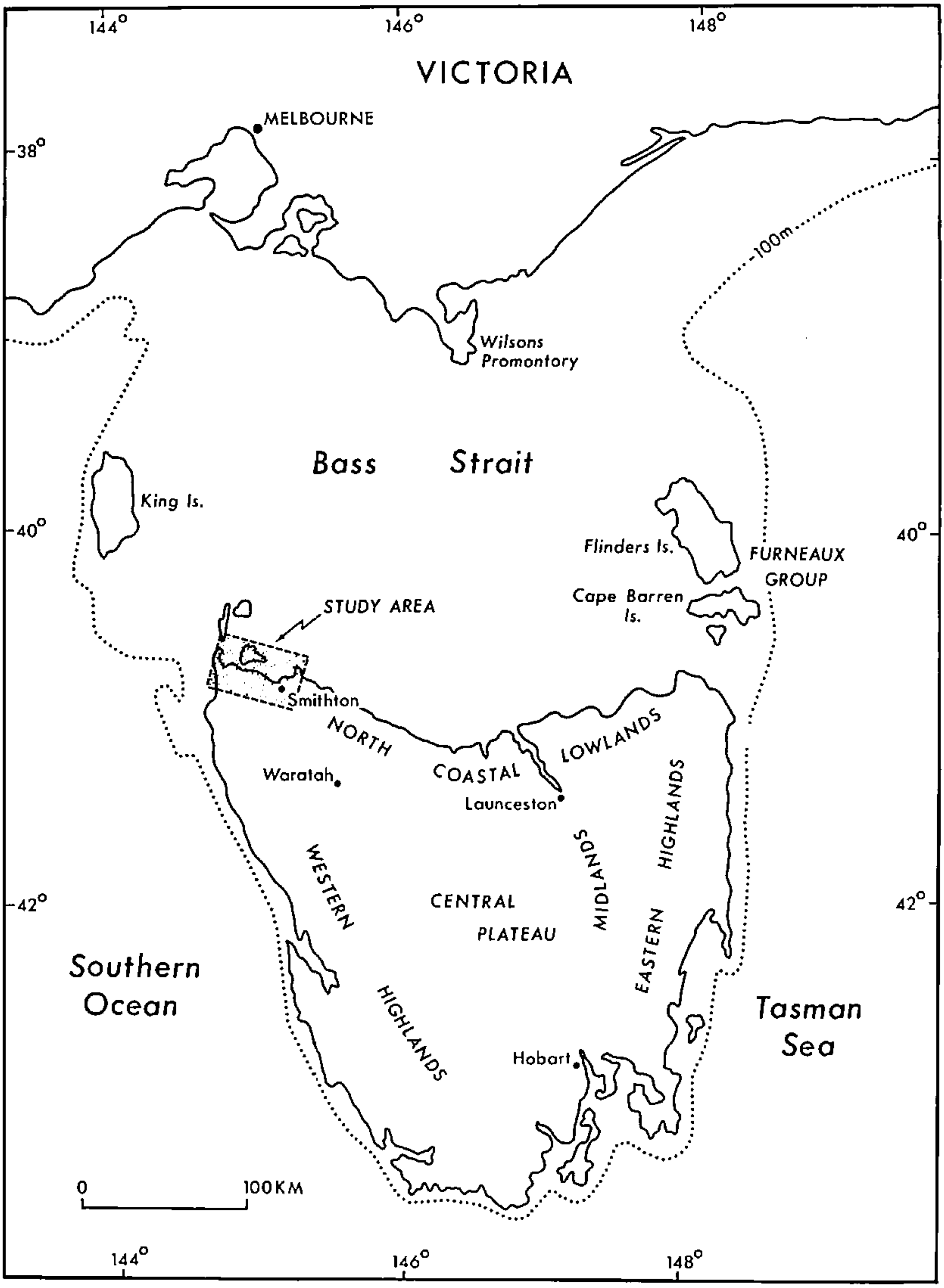


FIGURE 1. Physiographic regions of Tasmania and location of the study area.

rocks like quartzites and conglomerates to form the ridges. In the centre, east and southeast, the pre-Carboniferous rocks are covered by horizontal Permian and Triassic sediments. These sediments were intruded by large dolerite sills in the Jurassic and subsequently block faulted in late Cretaceous and early Tertiary times. In many places the resistant dolerite dominates the landscape in the form of plateau-like residuals. The scarps that bound the dolerite cappings are often related to fault trends and the valley axes are commonly related to both fault directions and major joint systems (Banks, 1965; Davies, 1965).

Consequent upon the island's diverse and rugged topographic structure is a complex pattern of local climates. Located in the westerly wind belt known as the "roaring forties" and dominated by southern oceanic airmasses, the island overall has a temperate marine climate. The alignment and elevation of the Western Highlands and Central Plateau intercept the west to east moving low pressure systems and create a pronounced rainshadow effect. The orographic ascent of the moisture bearing maritime airmasses brings abundant precipitation to the western half of the island which has a cool perhumid and humid climate. After shedding much of their moisture, the prevalent maritime airmasses are adiabatically warmed and dried on descending from the west and central high country to the inland plains and hills of eastern Tasmania, which for the most part has a dry to moist cool subhumid climate (Gentilli, 1972).

Within any one climatic zone the pattern of parent material largely determines the distribution of the island's soils. This is particularly so with the basic igneous rocks, the soils of which are distinct from those developed on more siliceous parent materials. Nearly all the soils are moderately to strongly leached and acid, and at high elevations consist predominantly of Podzolics. Moor Peats and Alpine Humus soils are common in extensive areas of impeded drainage such as on the Central Plateau. Strongly leached Krasnozoms are widespread on Tertiary basalts in the high rainfall areas of the northwest coastal regions but these may be largely relict soils. Black and Brown Earths and Prairie soils are prevalent on igneous rocks in the subhumid eastern half of the island, as are moderately leached Podzolic soils on siliceous sedimentary rocks. Groundwater Podzols and Podzols occur extensively on Pleistocene and Holocene marine and fluviatile deposits in the northeast and northwest (Nicolls and Dimmock, 1965).

The vegetation of Tasmania shows a marked contrast between the perhumid and humid west, characterized by temperate rainforest, and the subhumid east, covered by sclerophyll forest. The contrast is floristic as well as physiognomic. The plants in the Western Highlands tend to be "Antarctic" in association and display affinities with forms from New Zealand and Chile; those of the east, dominated by *Eucalyptus* spp. are "Australian" in relationship.

In broad terms, the vegetation consists of three major formations: rainforest, austral-montane shrub, and sclerophyll forest. Rainforest dominated by *Nothofagus cunninghamii* extends from sea level to over 1,000 m in the wet highlands. The austral-montane shrub consists mainly of Epacridaceous-Proteaceous species which occur at elevations over 1,000 m on the plateaus. Sclerophyll forest dominated by *Eucalyptus* spp. is distributed throughout the drier eastern half of the island. Complex ecotones resulting from variations in topography, edaphic conditions and fire frequency occur throughout the main formations. The most extensive are wet sclerophyll forest, sedgeland, moorland and coastal heath (Jackson, 1965).

2.2 THE STUDY AREA

2.2.1 Topography and drainage

The coastal lowland region of far northwestern Tasmania (Fig. 2) is characterized by very subdued relief. Most of the area consists of a number of broad, flat-floored basins which occupy extensive areas between Circular Head and Woolnorth Point. The basins are mantled with variable thicknesses of Quaternary alluvial, swamp peat, marl and fossiliferous marine sand deposits. The basins probably result from the fairly uniform resistance to erosion of the underlying Precambrian and Cambrian rocks; the more resistant parts of these systems occur above the level of the plains as ridges and hills. The Precambrian and Cambrian rocks have been exposed to erosion for a long period, probably from Devonian to Tertiary times, and consequently the hills seldom exceed 100 m in elevation, although exceptions of up to 250 m do occur. The highest topographical features of the area result from the preservation by Tertiary basaltic lavas which overlie the Precambrian and Cambrian rocks, the basalts occurring as cappings on isolated low hills and ridges or as more extensive plateau country. From the edges of the basalt plateaus and hills, the country slopes gently to the valley floors and coastal plains.

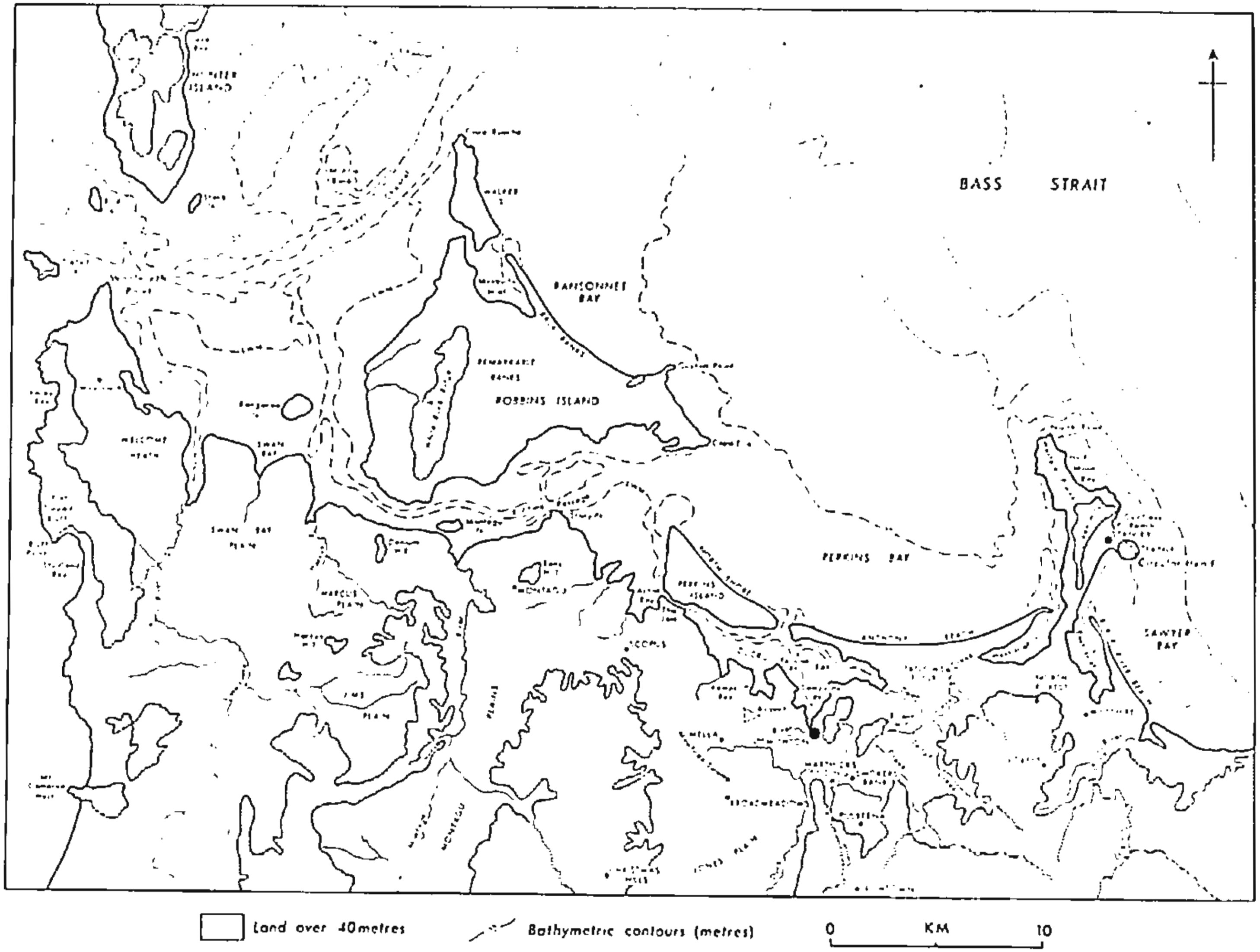


FIGURE 2. Localities mentioned.

The coast is characterized by low rocky headlands which alternate with extensive gently curved sandy bays that incorporate bayhead beaches, offshore islands and barrier beaches which partly enclose lagoonal inlets.

The Welcome River and its tributaries form the only important drainage system in the western part of the area. The river rises south of the study area on a basalt plateau and flows across the lowland sand plain to enter the sea through an estuary a few kilometres east of Woolnorth Point. The Montagu River traverses a broad, almost featureless sandy plain to reach the sea west of Montagu. Further east, the Duck River, its western tributaries and an intensive network of shallow drainage ditches remove surface water from Mowbray Swamp and the Broadmeadows area, and the low hills to the west. The main eastern tributaries of the Duck River drain the western and southern portions of the basalt plateau, the Irishtown valley, and the intervening country east of Mowbray Swamp. Flowing north along the eastern edge of Mowbray Swamp, the Duck River discharges into the Duck Bay estuary near Smithton. A number of smaller streams drain the extensive alluvial plain east of Smithton and discharge at the eastern end of Duck Bay. There are numerous small streams that flow eastward to Black River from the basalt plateau around Forest and several that flow northward into the lagoonal inlets on either side of the Circular Head Peninsula.

Many of the streams that drain the basalt plateau country emerge as springs either from beneath the basalt or from between the flows. Mineral springs occur in restricted areas on the lowland plains as at Mowbray Swamp and north of Irishtown. Most of these springs have built up low mounds of mineral deposits.

The overall gentle seaward slope (< 2°) of the coastal lowlands and the few major rivers which flow northward into Bass Strait facilitate the maintenance of very high groundwater levels on the plains which have strongly influenced the history of soil, vegetation and landform development.

2.2.2 Geology

The uplands of the region are composed of folded pre-Carboniferous rocks and Tertiary basalts (Fig. 3). The oldest rocks are Precambrian sediments which have undergone variable degrees of low grade regional metamorphism to quartzites, dolomites and cherts (Nye *et al.*, 1934; Gulline, 1959). The quartzites, which include various quartzite stages, and conglomerates occur mainly east and southeast of Smithton. The quartzite varies from thickly to thinly bedded, and because of fracturing it is generally very friable. The dolomites are extensively distributed. The thickness of the formation varies greatly, increasing from east to west and probably attaining its maximum thickness of ~ 500 m under Mowbray Swamp (Gulline, 1959). The formation shows several variations due to silicification and is made up of thick beds of dolomite, silicified oolitic dolomite and thickly bedded laminated cherts. The dolomites overlie the quartzites conformably.

Cambrian rocks are widely distributed throughout the area. Generally, outcrops are poor but exposures occur along the shoreline east of Smithton and near Montagu. The volcanic rock assemblage of this group, which consists mainly of lavas are more resistant to erosion than the sediments which consist

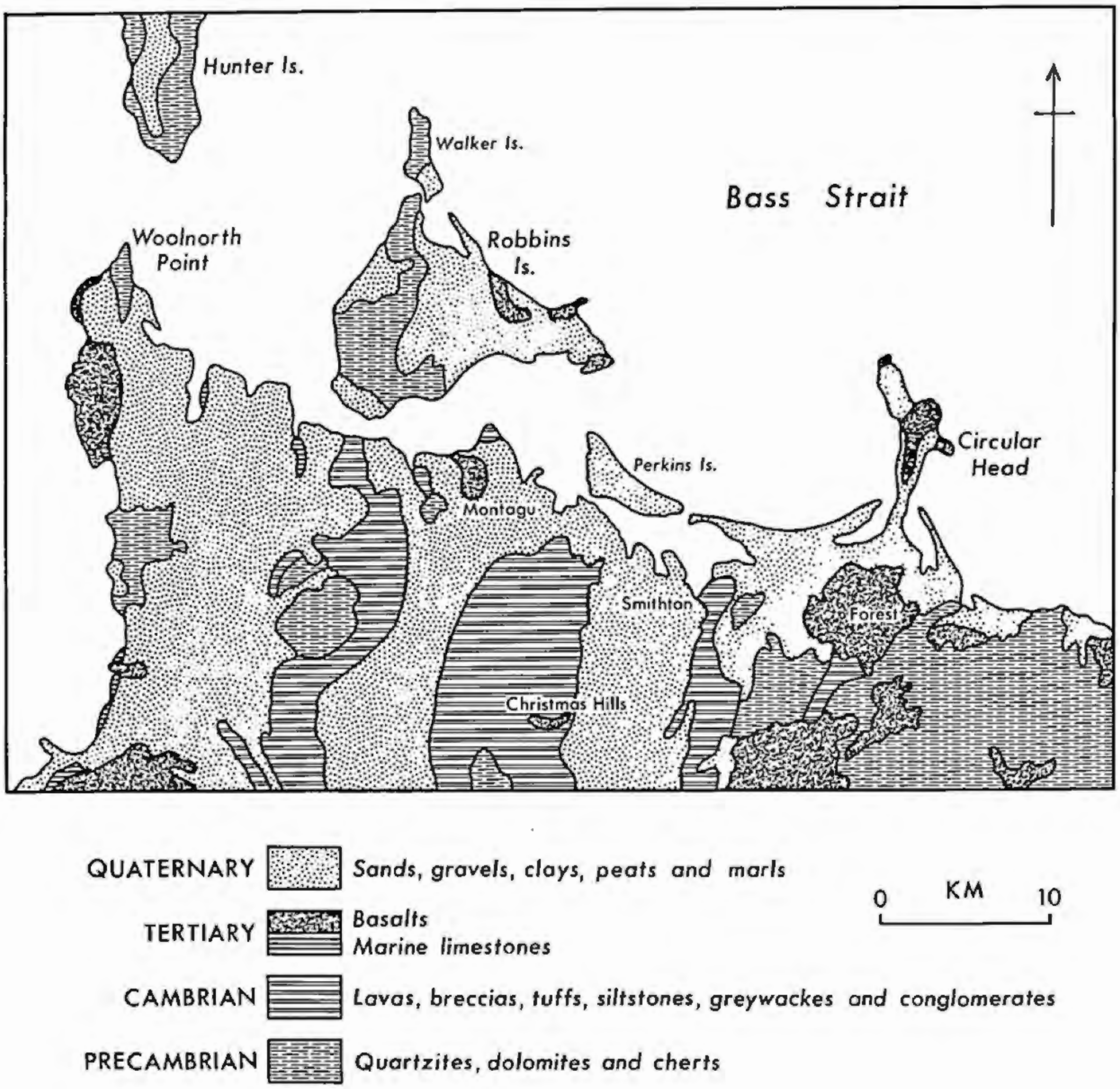


FIGURE 3. Geology.

Source: Geol. Survey of Tasm. Burnie Sheet SK 55-3 (1973) and King Is. Sheet SK 55-1 (1978).

mainly of siltstones, tuffs, breccias, greywackes and conglomerates. Hence, the sediments result in a very dissected topography while the volcanic rocks usually form the low ridges and prominent hills.

Tertiary marine limestone occurs only as small outcrops in the low lying parts of the area and in some localities can be seen to extend below sea level. The limestone varies from pure to sandy and contains a well-preserved Miocene molluscan and foraminiferal fauna (Hughes, 1957). The limestone overlies the Precambrian and Cambrian rocks unconformably and is overlain by Tertiary basalt and by Quaternary alluvial and marine sediments. The basalts occur extensively east of the Circular Head area. Flows are present from sea level up to 250 m which indicates that the basalt was extruded over the hills of the older rocks as well as into pre-existing valleys. "The Nut" at Stanley consists of coarse crystalline basaltic rock which is believed to be a remnant of a volcanic neck (Gill and Banks, 1956). As was briefly noted in the previous section, remnants of the basalt flows govern much of the present topography of the region.

Quaternary deposits have filled the low lying parts of the region. Marine and alluvial sands have been extensively deposited in the Smithton area where they unconformably overlie Precambrian and Cambrian rocks. Similar sand deposits occur extensively in the Montagu area, near Woolnorth, and on the nearby offshore islands. Marine cobble deposits occur extensively in the Circular Head area. Freshwater peats and marls disconformably overlie some of the alluvial and marine sand deposits.

The geological structure of the area is dominated by several major folds and strike aligned faults. The fold axes strike approximately northwest in the west of the region and northeast in the east, and plunge slightly in those directions. Overall the folding is very asymmetrical and open but a complete picture cannot be obtained because outcrops are few. From west of Smithton to the Montagu River the structure consists of a single shallow syncline cut off on each side by strike aligned faults. Minor folds are present on this syncline and these have the same axial trend. The gross structure appears to be similar east of Smithton except at the Black River where slight overturning occurs. The major folds are considered to have been initiated during the Precambrian but are believed to have become more pronounced during later orogenies. The minor folds are believed to have been developed mainly during the Tabberabberan Orogeny in Devonian times (Gulline, 1959; Spry and Banks, 1962). The age of the faults is uncertain as no evidence of sediments laid down between the Cambrian and the Tertiary remains. However, since the topography is still largely influenced by most of them, they are considered to be mainly of early Tertiary age (Gulline, 1959).

2.2.3 Climate

The climate of lowland northwestern Tasmania is characterized by moderately warm summers, cool winters and an uneven distribution of precipitation. Selected climatic data for the study area are summarized in table 2.

TABLE 2 Selected climatic data from Northwestern Tasmania

Station	Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Irishtown (61 m)	Precip. mm	50.6	53.8	53.8	97.3	122.9	135.8	154.4	145.5	115.5	113.5	87.9	75.2	1214.6
Smithton (9 m)	Mean Temp °C	16.1	16.9	15.5	13.4	11.2	9.6	9.0	9.3	10.4	11.7	13.1	14.7	12.6
	Precip. mm	47.0	51.8	54.1	85.9	105.7	119.6	138.9	130.0	102.6	104.1	82.8	66.8	1089.4
Stanley (11 m)	Mean Temp. °C	16.1	16.7	15.3	13.3	11.5	9.8	9.2	9.6	10.6	11.7	13.2	14.8	12.6
	Precip. mm	42.2	46.0	49.3	72.1	89.9	107.4	114.3	100.8	83.3	87.4	64.8	61.2	918.7
	Air Frost Days < 0°C						0.1	0.5	0.4	0.1	0.1			1.2
	Ground Frost Days < 2.2°C Screen Temp.				0.2	0.5	1.2	2.1	2.1	0.8	0.2			7.1
Waratah (624 m)	Mean Temp. °C	11.8	12.3	10.6	8.2	6.3	4.6	3.9	4.4	5.7	7.3	9.1	10.5	7.9
	Precip. mm	113.5	98.0	126.4	173.7	212.3	213.2	252.5	248.9	223.5	206.2	169.9	145.0	2203.4
	Air Frost Days < 0°C	0.2	0.2	0.4	2.2	4.6	7.6	10.6	10.8	7.8	4.4	1.6	0.4	50.8
	Ground Frost Days < 2.2°C Screen Temp.	2.3	2.2	3.2	7.3	11.8	15.2	19.5	19.8	15.4	12.8	7.6	4.8	121.9
Stanley	Wind Direction													
	Calm	1	1	2	4	7	8	7	6	2	2	1	1	3
	N-NNE	12	9	9	6	9	7	8	10	9	7	5	9	8
	NE-ENE	11	11	9	10	7	7	5	7	9	11	10	11	9
	E-ESE	17	17	19	12	9	12	10	13	17	15	16	17	15
	SE-SSE	4	4	4	4	1	3	3	3	2	2	3	3	3
	S-SSW	11	18	12	13	14	9	11	14	14	12	11	13	13
	SW-WSW	23	22	27	30	24	23	27	22	19	23	28	21	24
	W-WNW	15	12	13	12	13	12	12	12	14	18	19	16	14
	NW-NNW	6	6	5	9	16	19	17	13	14	10	7	9	11
	Wind Speed km/hr													
	0-10	36	34	38	46	49	52	48	49	43	32	27	32	40
	11-30	51	54	50	46	42	30	42	38	42	52	51	45	46
	31-50	11	11	10	5	8	7	7	10	12	12	17	21	11
	51-75	2	1	2	3	1	3	3	3	3	4	5	2	3
	> 75	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: Australian Bureau of Meteorology (1973)

The coastal lowland has a humid climate and the high plateau and mountain country to the south has a perhumid climate (Gentilli, 1972). There is a very steep precipitation gradient northwards from Waratah in the high plateau country towards Smithton on the coastal lowlands (Figs. 1 and 4A). In both zones precipitation occurs throughout the year with a marked winter maximum.

Mean temperatures vary from 16.9°C in February to 9.0°C in July near the coast which experiences very little frost and snow, and sharply decrease southwards towards Waratah which has a mean monthly temperature of 12.3°C in February and a minimum of 3.9°C in July. Here, at an elevation of 624 m, there are 51 air frosts and 122 ground frosts per year and frequent snowfalls in winter.

The greatest proportion of winds at all seasons are westerlies and are associated with both cyclonic and anticyclonic circulation patterns (Langford, 1965). At Stanley which is somewhat protected from direct westerly winds by the protruberance of The Nut, 62 percent of winds fall in the quadrant northwest to southwest. Northeasterly winds are more frequent in summer than in winter; and, for north to northwest winds, the reverse is true. The incidence of very high intensity winds and of calms is moderately low. Of the 9 a.m. and 3 p.m. winds considered at Stanley, 86 percent were less than 30 km/hr.

2.2.4 Soils

A number of distinctive soils occur in the area. The following general description of their main characteristics is based on the Great Soil Group Classification of Stephens (1962).

The soils of the region exhibit considerable variation in profile drainage characteristics. Freely and moderately well-drained soils occur chiefly on the steeper slopes and gently inclined surfaces of the prominent hills and ridges near the coast and higher upland areas to the east and south. Predominantly poorly drained soils occur extensively on the plains and offshore islands.

Moderately well-drained Yellow Podzolic soils with well-developed greyish A and yellowish often mottled B horizons occur on siliceous Precambrian and Cambrian rocks east of Smithton, west of Mowbray Swamp and on Montagu Plains. These soils remain largely uncleared of their natural vegetation but locally their use for agricultural purposes has increased in recent years. The most freely drained soils in the area are the Krasnozems which occur on the Tertiary basalts. They are deep, friable clay soils which generally show little differentiation of the distinctive red-brown profile into horizons. The depth of profile development and their occurrence beneath transgressive coastal dune sands of Pleistocene age in the Christmas Hills and North Forest areas demonstrates that these soils are of considerable age. As elsewhere in Tasmania, the Krasnozems are used for dairying and cash crop production.

Podzols and Groundwater Podzols are characteristic of the low-lying, poorly drained plains and nearby offshore islands. Strongly leached Podzols, usually several metres deep, occur on Pleistocene dune sands throughout the area. Shallow, moderately well-developed Podzols, generally less than one metre deep, occur on Holocene coastal dunes and beach ridges. Groundwater Podzols are typical of the Pleistocene marine and alluvial sand deposits. They are strongly leached and acid. The A_2 horizon is markedly bleached and is usually more than one metre thick. The brown to black $B_{2h,ir}$ horizon, which is usually very compact and several metres thick, contributes to the restriction of drainage in the Groundwater Podzols which are characteristically very wet in winter. Appreciable areas of these soils have been cleared of their natural vegetation and their drainage improved by the establishment of a network of shallow ditches.

Calcareous Coastal Sands and Terra Rossa soils occur in the westernmost part of the Welcome Heath area. Though small in area, these soils are quite conspicuous. They belong to systems of Holocene and Pleistocene dunes consisting of sand and shell fragments blown inland from west-facing beaches. Greyish to light yellowish shell sands with little development of a soil profile beyond slight surface leaching of shell fragments occupy the Holocene dunes near the coast. In contrast Terra Rossa soils with distinctive, loamy reddish-brown A and B horizons occur on subdued Pleistocene calcareous dunes further inland.

Highly organic soils which occupy areas of former swamp occur throughout the area. Peaty and marly Fen soils occur in association with alkaline artesian springs at Mowbray Swamp and in the Pulbeena-Marthicks Siding area. Peaty Acid Swamp soils locally occur on waterlogged alluvial deposits at Smokers Bank and Welcome Plains, and on artificially drained former salt marshes along the coast. On the uplands, acid Moor Podzol Peats occur in association with sedgelands and shallow peats occur on waterlogged sites.

2.2.5 Vegetation

Until recently, the nomenclature used to describe Australian plant communities was based on local terms of European and Aboriginal origin. Australian botanists now usually follow the simple and unambiguous classification devised by Specht (1970) in which structural forms are divided into height and crown density categories. However, the local terms are still widely used in Tasmania. In the following description of the major plant communities of far northwestern Tasmania Specht's structural terms are shown in brackets.

Five extensive general plant communities characterise the vegetation of the area in addition to cleared land (Fig. 4B). Temperate and scrub rainforests (Closed-forests) occur discontinuously on the plateau and mountains to the south. The rainforest is dominated by *Nothofagus cunninghamii* but includes *Phyllocladus aspleniifolius*, *Atherosperma moschatum* and *Eucryphia lucida*. However, due to a long history of firing much of the high ground is occupied by wet sclerophyll eucalyptus forests (Tall open-forests) of *E. obliqua*, *E. ovata*, *E. delegatensis*, *E. viminalis* and *E. nitida*. In addition occasional *P. aspleniifolius*, *A. moschatum*, and substantial areas of *Acacia melanoxylon* and *Acacia* spp. occur. The understorey consists of a thick stratum of low trees, shrubs and tree ferns which include *Melaleuca* spp., *Leptospermum* spp., *Monotoca* spp., *Phebalium squameum*, *Pomaderris apetala*, *Olearia* spp., *Bedfordia salicina* and *Dicksonia antarctica*. This forest extends northwards locally on areas of high ground to the coast but prior to land clearance was much more extensive.

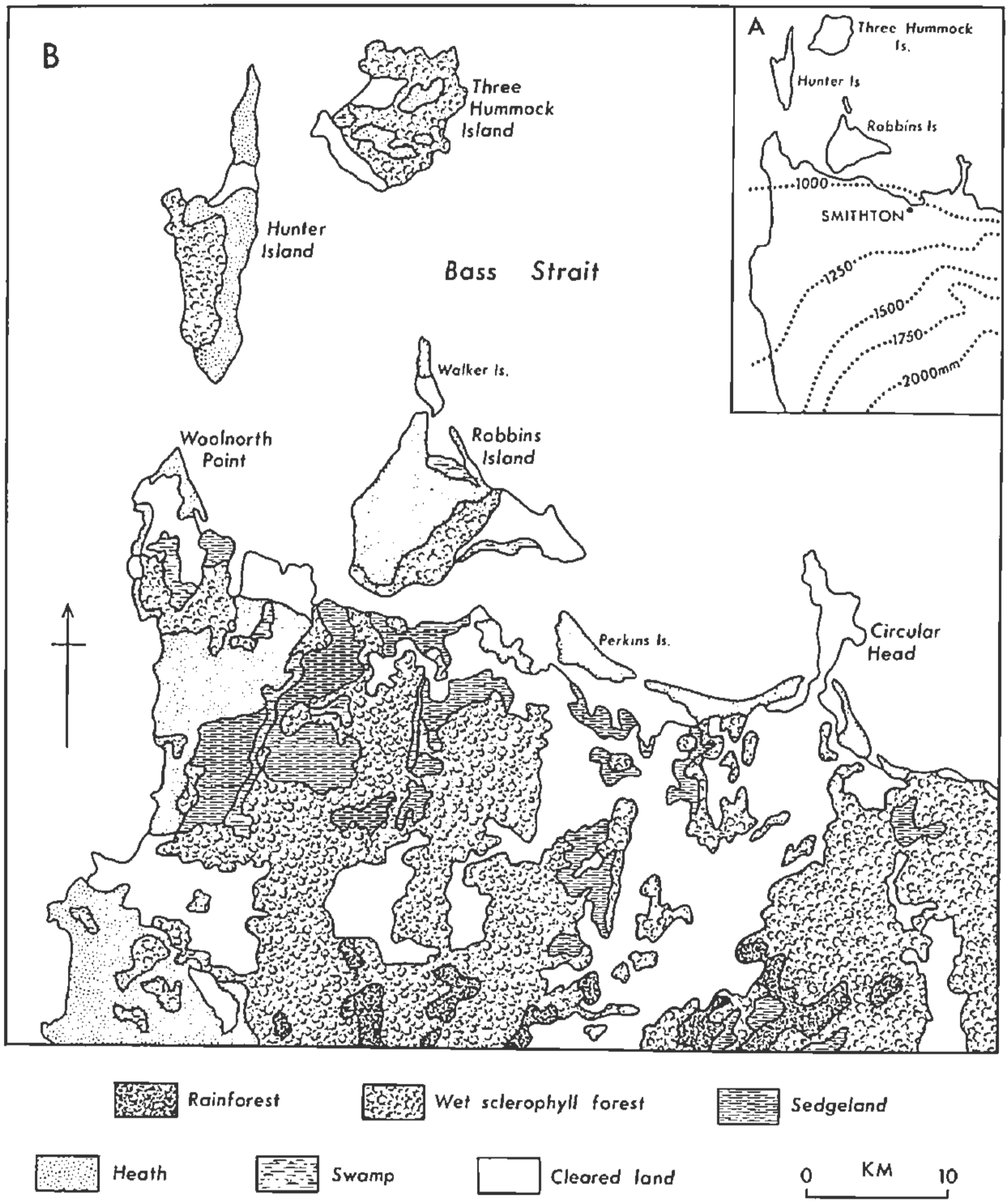


FIGURE 4A. Precipitation gradient.

4B. Vegetation (compiled from aerial photographs by S. Harris).

On the plateaus, mountains and locally on the sandy coastal plains extensive areas that have been frequently burnt over are dominated by the buttongrass *Gymnoschoenus sphaerocephalus*, *Lepidosperma* spp., and species of Restionaceae and Epacridaceae. These sedgelands (Closed-sedgeland) are distinct from the heathlands (Closed and Open-heath) of coastal areas which exhibit a shrub flora of *Leptospermum* spp., *Banksia marginata*, *Casuarina* spp., *Epacris* spp., and *Sprengelia incarnata*.

The freshwater swamps of the coastal lowlands were more extensive before land clearance and drainage. Those that remain are strongly dominated by closed swamp/shrub forest (Closed-scrub) of *Melaleuca* spp. and *Leptospermum* spp. Along the fringes of intertidal lagoonal inlets, salt marshes (Low shrubland) with *Salicornia* spp., *Arthrocnemum arbuscula* and *Juncus kraussii* occur.

Although temperate closed rainforest is the climax vegetation for most of this area, scrub rainforest, wet sclerophyll forest/woodland and swamp forest occur extensively as disclimax communities. The most important factor which has influenced forest history is fire, which through natural/cultural agency has increased the extent of wet sclerophyll forest/woodland at the expense of rainforest. Fire has also aided the maintenance of heathlands in exposed coastal areas, sedgelands in areas of impeded surface drainage, grassy areas within the forest, and *Melaleuca-Leptospermum* swamps.

PART II

MARINE LANDFORMS AND DEPOSITS

CHAPTER 3

HOLOCENE BARRIER SAND DEPOSITS

3.1 INTRODUCTION

The coast of northwestern Tasmania, in common with much of the remainder of the Australian coast facing Bass Strait, is a drowned embayment coast where rocky headlands alternate with extensive sandy bays that incorporate bayhead beaches and barrier beaches which partly enclose lagoonal inlets (Fig. 5). The size and configuration of individual bays and their distance apart are markedly influenced by the topography of the coast and immediate hinterland, and the presence of islands. Where the rocky uplands are close, the coastline is dominated by cliffs, shore platforms and small embayments with bayhead beaches, whereas the presence of lowlands signifies long, gently curved sandy bays.

The alignment and plan form of the sandy shores is primarily the result of the action of strongly refracted southwesterly swell which originates in storm centres in the Southern Ocean and approaches the coast from a northwesterly direction (Davies, 1960a). Most of the bays are swash aligned (Davies, 1972) and symmetrical in plan form. This persistent feature is due to the tendency of the beaches to adjust themselves

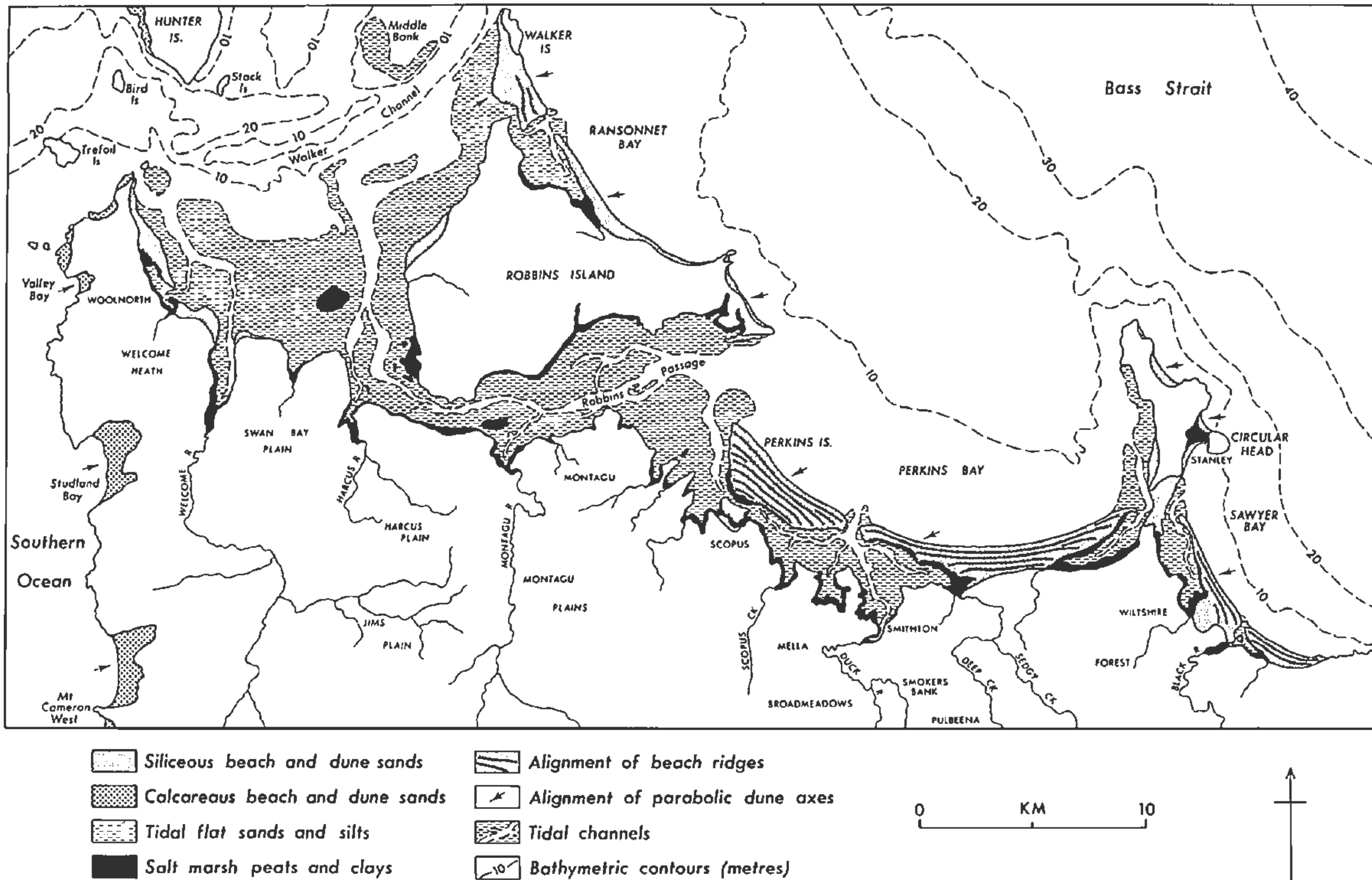


FIGURE 5. Distribution of Holocene marine deposits.

in outline to fit the wave fronts of the refracted dominant swell. Although southwesterly swell is the dominant wave regime affecting the northwest coast, swell entering Bass Strait from the east and local storms also periodically affect the coast.

No bay barriers or extensive beaches have developed west of Robbins Island because here strongly refracted swell is attenuated as it passes over extensive tracts of very shallow water.

3.2 BEACHES

Unlike much of the west coast where most of the beaches consist of calcareous sands, the beaches facing Bass Strait consist predominantly of fine siliceous sands. In the study area contemporary shingle and boulder beach deposits are few and where they occur are very restricted in extent. They often interdigitate with sandy beach deposits a short distance away from exposed headland situations and shore platforms from which they have been derived.

The backshore of the beaches consists of a line of dunes or, more commonly, a crumbling sand cliff in front of which there is sometimes a low berm. Such berms are either terrace, or ridge-like in form, and the outer face is frequently marked by a temporary nip. The inner part of the foreshore is sometimes marked by a series of cusps. The lower part of this zone slopes gradually into the lower foreshore which, depending on the prevailing wave conditions, at times exhibits ridges and runnels (Plate 1). Near lagoon entrances, the complex interaction of tidal

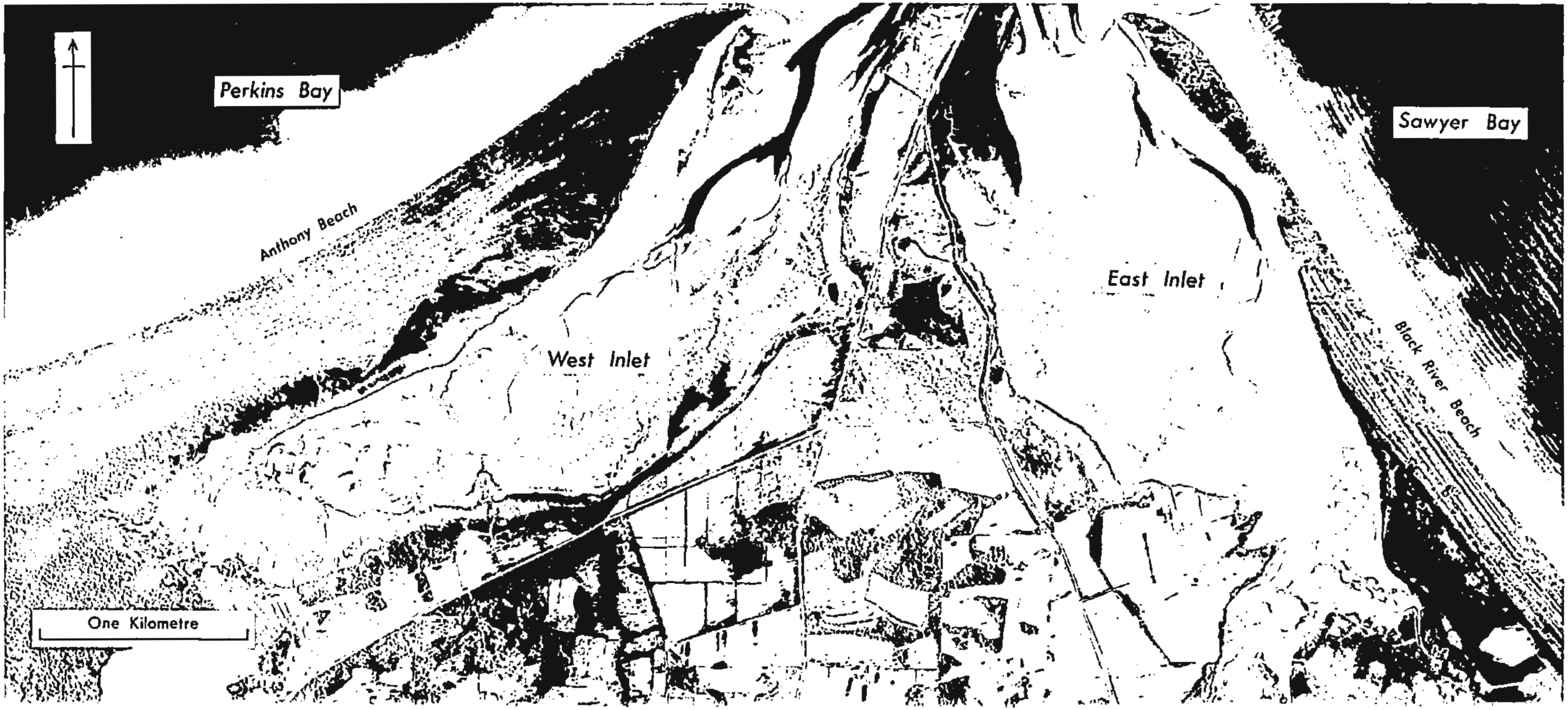


PLATE 1. Ridged Pleistocene cuspate foreland and Holocene bay barriers near North Forest.

currents and strongly refracted waves has resulted in wide beaches consisting of a low, intricate system of intertidal sand banks and channels.

The profiles of the beaches vary in response to wave action: long, low swell waves deliver sand to the shore and spilling breakers build up a convex swash bar or berm along the length of the beach. But during storms, steep, plunging breakers scour away sand from the beach, removing the berm and frequently cutting back the outer margin of the foredune. Sand eroded under such conditions is deposited in the form of a breakpoint bar which is sometimes visible during low tide in the breaker zone.

Owing to the remoteness of the field area and the lack of reliable wave data, a study of short-term changes in beach profile and related changes in sediment characteristics was not undertaken. However, visual observations suggest that a seasonal cycle of winter out and summer fill (Davies, 1957, 1972; King, 1959) is usual for the beaches of this area.

3.3 BEACH RIDGES AND PARALLEL DUNES

The mode of formation of parallel beach ridges has been described by a number of Australian and overseas workers. Davies (1957) was the first to outline a general hypothesis. According to Davies, parallel beach ridges originate as beach berms built during periods of beach fill. On them may grow halophytic vegetation which traps sand blown from the foreshore surface of the beach by onshore winds and raises the level of the ridge. After a period of beach erosion during which the incipient beach ridge is usually trimmed back, a new ridge may form in front of or against the first one, if there is an adequate sediment supply in the offshore area. This general hypothesis has been accepted with minor modifications by most Australian geomorphologists who have worked in a similar environment, for example Bird (1960, 1963), Jenkin (1968) and Wright (1970). However,Thom (1964, 1965), and Langford-Smith and Thom (1969) consider that further detailed systematic work is necessary before the hypothesis is fully substantiated.

Davies (1957) also postulated that height and spacing of beach ridges reflect rates of shoreline progradation. He points out that the extent to which sand accumulates on a ridge depends on the time it takes for a permanent new ridge to form to seaward and thus cut off the sediment supply. The longer it takes for such a new ridge to form, the higher and wider the older ridge will grow. In addition, as a greater proportion of its constituent sand becomes wind blown rather than wave deposited, so its form will gradually become more irregular. Hence, the final form of the ridge depends very largely on the rate of its formation. When ridges are built rapidly, they will be low, close together and very regular in profile. If, however, the rate of building is slower, they will be relatively high, further apart and more irregular in profile. Very high forms of this type are commonly referred to as parallel dunes of which the most important is usually the foredune.

The rate at which ridges are built depends largely upon the incidence of storm wave conditions, for over a long period of reduced storminess, ridge formation will be accelerated. However, other factors also have an important influence. These include eustatic sea level changes, particularly a rise in sea level, and variations in the rate of supply of sand from offshore (Davies, 1957; Bird, 1960).

There appear to be two, somewhat opposing views on the role of vegetation in the formation and preservation of sand beach ridges. Davies (1957) and Bird (1960) consider that the colonisation of vegetation at an early stage is essential, but Thom (1964) is of the opinion that, although it may influence the final form and assist their preservation, it does not play a significant role in their construction.

The writer's limited observations may be significant with regards to this problem. It was noted at a number of localities that wherever sand accumulation on the beach is colonized by plants, it occurs in a rather patchy manner. Along North Shore on Perkins Island, for example, patches of vegetation, consisting mainly of *Festuca littoralis* and introduced *Ammophila arenaria,* found to be growing on a discontinuous embryonic dune ridge, were obviously accumulating sand, while bare areas between were being deflated. As a result, the ridge had become very irregular in both plan and crestal form to the extent that its trend was locally barely recognizable. From this limited evidence it would appear that vegetation perhaps does not play as significant a role as envisaged by Davies (1957) and Bird (1960), and suggests that ridge preservation may depend more upon being protected from waves and excessive wave action by the building of new beach berms and ridges to seaward. Once ridges have been isolated from disturbing influences, conditions for the establishment and development of vegetation would be more favourable and afford better protection than the observed irregular colonisation along the exposed foreshore.

The extensively developed systems of beach ridges exhibit considerable spatial variations in amplitude and spacing which reflect local variations in exposure to wind and wave energy, and in offshore gradient. Owing to its sheltered position and the extensive very shallow sandy area offshore, shoreline progradation at Anthony Beach has resulted in the development of a plain up to 1.5 km wide, consisting of a large number of low (1-1.5 m), closely spaced (5-8 m) beach ridges fronted by a 4 to 5 m high composite dune on the seaward side. In contrast, the more exposed and deeper water facing narrower barriers, as for example at Black River Beach, exhibit fewer, higher (4-5 m) and more widely spaced (15-20 m) parallel dune ridges the pattern of which is locally interrupted by contemporary blowouts and parabolic dunes (Plate 1).

Although beach ridge systems appear very regular on aerial photographs, in the field, both amplitude and spacing of ridges within a system are variable enough to indicate that the rate of ridge formation has not been constant. In general terms, unmodified beach ridges are smooth and regular in form for considerable distances, and are of fairly uniform height over most of their length. In plan, the ridges are broadly curved. Minor changes in alignment occur and can be explained in terms of secular changes in the dominant wave direction as the barrier prograded seaward (Fig. 6). Adjacent to the positions of existing and former inlets, the ridges are often recurved, indicating that longshore drifting has played a part in their shaping. Truncation of ridges by migrating tidal channels is a common feature and has locally resulted in the development of narrow beaches and small areas of low, active transgressive dunes.

After periods of heavy rain, resulting in high groundwater tables, some of the swales that separate the ridges often contain

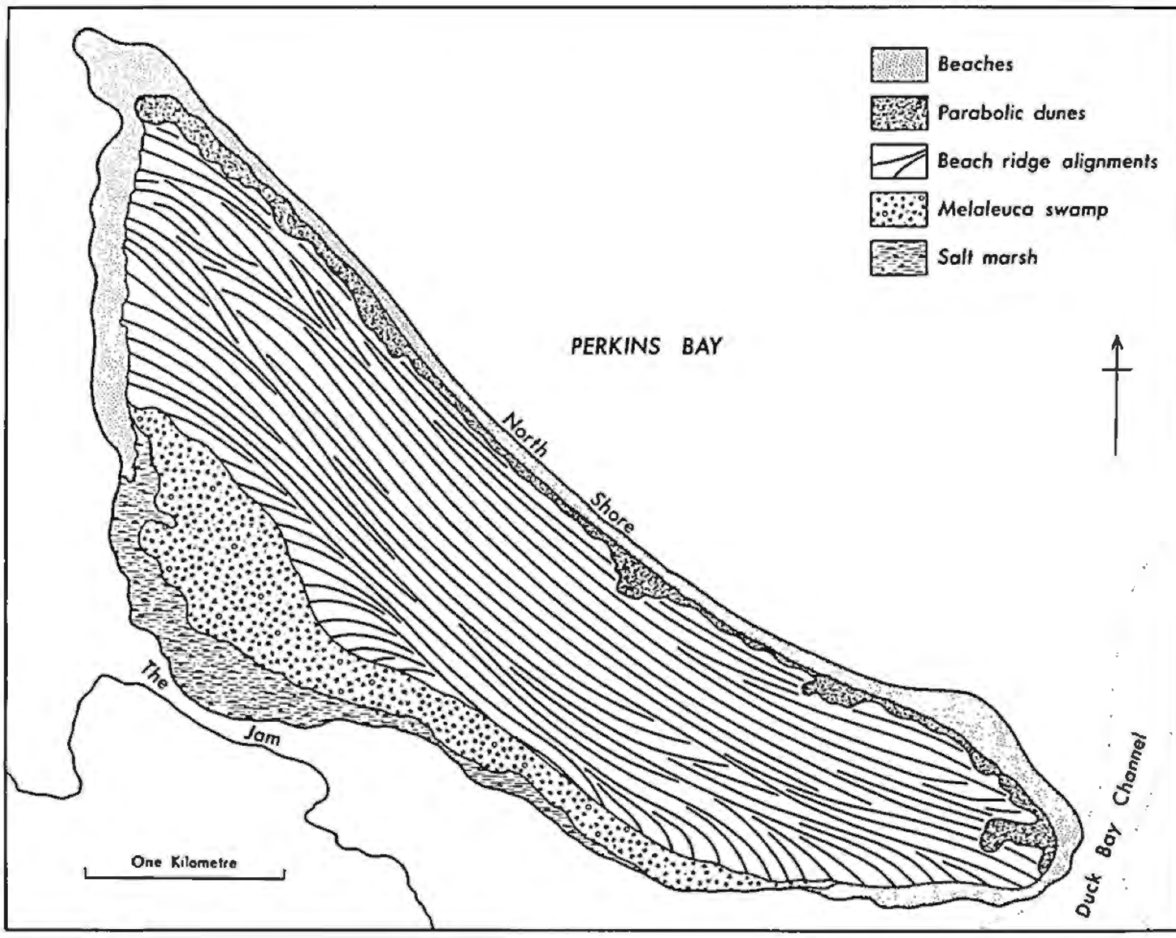


FIGURE 6. Beach ridge alignments, Perkins Island.

a shallow body of slowly flowing water which causes localized erosion of the ridges and infilling of the swales. Where drainage has been impeded development of a small thickness of sandy peat is a common feature of swales.

Internally the sands of beach ridges are indistinctly bedded as indicated by eroded sections at the western end of Perkins Island. At this locality, the upper 1 to 1.5 m of the outermost beach ridges has been affected by the relatively rapid development of a Podzol soil but the original aeolian bedding is still preserved by selective ferruginization (Plate 2). Shallow excavations at this locality showed that the sediments on which the beach ridge rests are either horizontally bedded or dip gently seawards at angles of less than 5°. The beds consist of fine quartz sand and coarse shell fragments. Very faint cross-bedding structures are common, often with quite steeply dipping laminae which show a tendency to be concave upwards. These basal beds are succeeded by distinctively bedded fine sands that contain very thin laminae which are almost entirely composed of small shell fragments and occasional small pelecepod valves. Most of the bedding is either horizontal or dips very gently seawards but it is often truncated by another series of beds which dips landwards at about 5 to 10°. Higher in the ridge, truncation appears to be rare and the beds tend to arch over in a smooth curve. Higher still, the bedding frequently becomes irregular with curving, undulating or straight foreset beds of fine sand. A fairly distinct break between the last two bedding sequences can sometimes be detected, but in most cases there is an imperceptible gradation, evidence of any break having been destroyed by soil forming processes.

PLATE 2. Detail of an eroded beach ridge at the western end of Perkins Island showing bedding and selective ferruginization.

The beach berms which are often present on the beaches in the area during the summer months have many features in common with the fossil beach ridges. They consist of smooth, elongate ridge or bench-like forms that frequently extend almost continuously along the entire length of the beaches. There is usually only one berm present but two have been observed on occasions on Anthony Beach. During low tide, sand is frequently blown onto the berm where it accumulates as miniature hummocky dunes on the crest and lee of the berm. During high tide levels the uprush of the waves washes over the berm and smooths it out homogenizing the wind blown and wave deposited sand fractions in the upper part of the beach berm. The low depression leeward of the berm usually forms an elongate trough in which sea water washing over the berm accumulates in a series of shallow pools. Such pools are drained when the tide goes out either by seepage through the sand and/or by flow along the trough and back to sea through a breach in the berm.

The digging of a number of shallow pits at Anthonys Beach revealed that the internal bedding structure of the berm and underlying beach is identical with that of the lower parts of the fossil beach ridges described above. The structure indicates that the lower parts of both deposits have formed as a result of periodic scouring and subsequent filling. Above the beach bedding, the bedding structures become progressively more continuous and usually contain shell fragments and pelecepod valves which have been spread and concentrated by the swash. Overlying the shelly sands the sediments are finer and contain less shell carbonate. Individual beds tend to be continuous over the slope of the berm but often the seaward dipping structures have been removed during a period of minor beach erosion. However, these are frequently replaced by subsequent beach accretion giving a low angle set of seaward dipping beds resting on the truncated landward dipping beds.

3.4 TRANSGRESSIVE DUNES

With the exception of the sheltered eastern half of Anthony Beach, parabolic dunes and blowouts partly interrupt the pattern of parallel beach ridges and dunes. Evidently, the parabolic dunes are secondary landforms which have developed mainly by partial rearrangement and displacement of beach ridges and parallel dunes. This is most clearly seen in the blowouts which have developed in the foredunes behind Anthony Beach and similar situations elsewhere in the area, through the excavation by wind of hollows in the seaward margin of frontal dunes where marine erosion has cut back an unvegetated, crumbling sand cliff. Blowouts of this type may become enlarged and begin to migrate through the primary dunes and ridges, undermine and overwhelm the vegetation, and eventually develop into U-shaped parabolic dunes.

Many of the parabolic dunes in the area are more or less stabilized by grasses, and scrub communities dominated by *Acacia sophorae* with *Banksia marginata*, but very active dunes, up to 30 m high, occur behind the relatively exposed beaches facing Ransonnet Bay (Fig. 7).

The alignments of the blowouts and parabolic dunes indicate that the dominant onshore sand transporting winds come from a northeasterly direction. As was noted previously

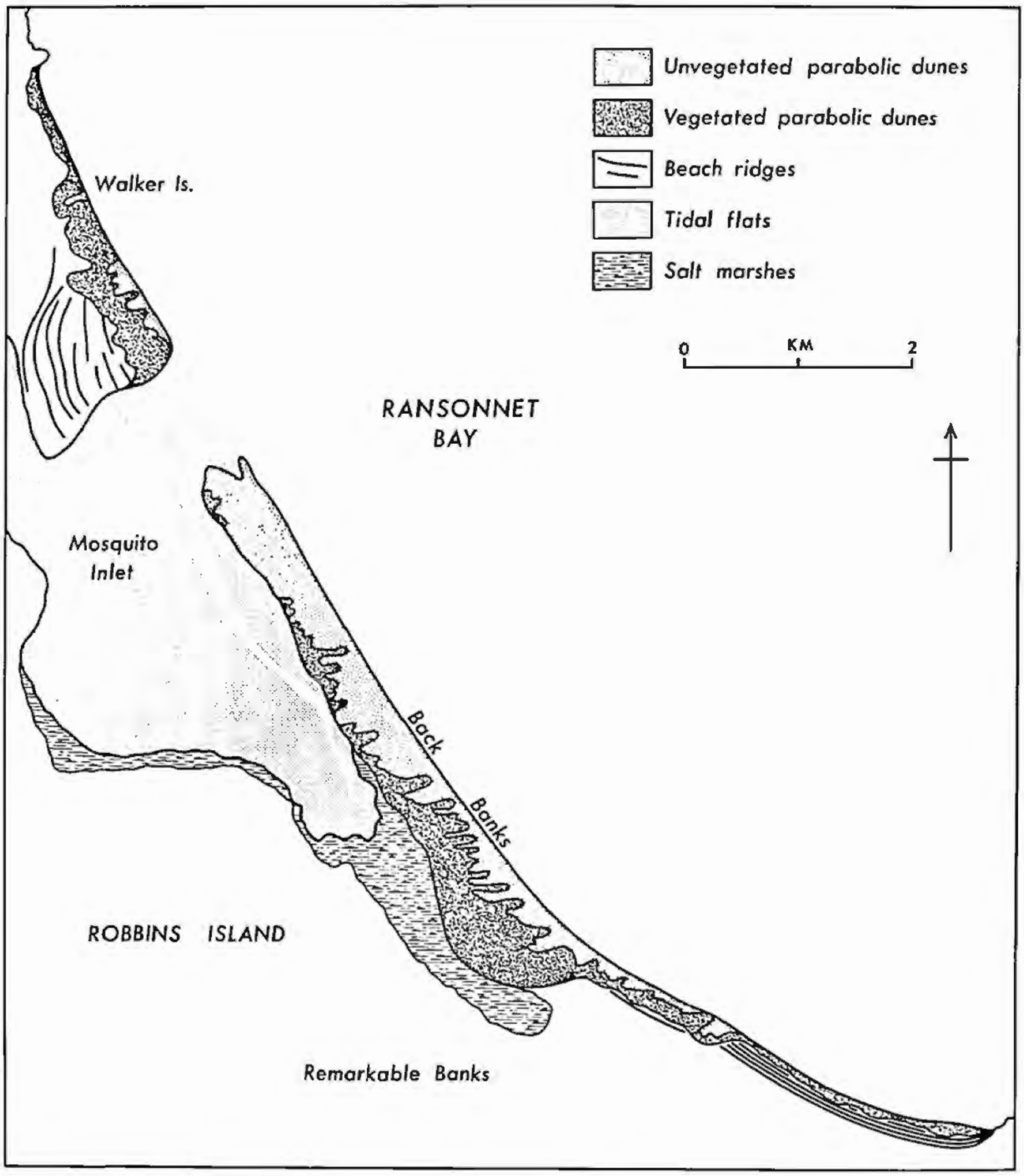


FIGURE 7. Parabolic dunes, Robbins and Walker islands (see also Plate 10).

(Chapter 2), onshore winds affect the area throughout the year but occur more frequently in summer than in winter.

Blowouts and parabolic dunes may also be initiated in a number of ways, where the vegetation cover which stabilized parallel dune ridges is damaged or destroyed as a result of direct or indirect human interference, particularly repeated burning. Even though this may have been a significant contributing factor, this cannot explain the partial rearrangement of the primary dune forms. Although beach berms and incipient beach ridges are periodically being built on the beaches, it was noted on a number of occasions that they rarely seem to survive for very long before being removed during periods of storm wave activity. The widespread evidence of foredune erosion (Plate 3), blowout and parabolic dune development indicates that conditions for beach ridge development and shoreline progradation appear no longer to exist. It should also be noted that this is an unprecedented event which is new in the recent geological history of the dune systems, for the older parallel ridges and dunes show no evidence of modification from the seaward side by secondary dune development.

Work by Davies (1957) and observations by the writer suggest that remobilization of sand is not only typical of the far northwest coast but also of other, if not all, prograded beach and barrier systems in Tasmania. Similarly, studies from New South Wales and Victoria have shown contemporary shoreline erosion and transgressive dune development to be the rule and progradation to be the exception (Bird, 1960; Langford-Smith and Thom, 1969; Thom, 1968, 1974; Thom *et al.*, 1978).

PLATE 3. Contemporary foredune erosion along Anthony Beach.

Recently, there have been several attempts to explain this apparently widespread contemporary phase of shoreline retrogradation in terms of changes in the frequency and magnitude of certain environmental factors. These include increased storminess which would affect wave climate (Davies, 1957), eustatic changes (Bird, 1960) particularly a rise in sea level (Schwartz, 1965), and reduced sediment supply (Thom, 1968; Langford-Smith and Thom, 1969; Davies, 1974). Although any of these factors could result in disequilibrium shoreline conditions, Thom (1974) in a general review of the beach erosion problem concluded that long-term observations are required before the various inferred causal relationships can be properly evaluated. More recently Thom (1978) re-examined the problem and tentatively presented the hypothesis that secular changes in the location, frequency and magnitude of extra-tropical cyclone activity in the Tasman Sea and resulting changes in the incidence of storm wave activity may be an important factor. However, he recognized that this may not represent the sole cause of change and that changes in the sediment budget and minor sea level oscillations may be significant auxiliary factors.

3.5 SEDIMENT ANALYSIS

3.5.1 Introduction

This aspect of the research project was not designed as an exhaustive treatment of the marine sand deposits but rather was directed towards broadly illustrating the grain size characteristics of the beach, beach ridge and parabolic dune sediments.

3.5.2 Field methods

In order to obtain an accurate estimation of the mean sediment size of beaches it is generally recommended to collect samples from each different zone, including backshore and foreshore areas (King, 1959). However, for the purpose of a general regional description sufficient information can usually be obtained from single samples collected from a comparable point, for example the mid-tide point as advocated by Bascom (1951). This approach was adopted and samples were collected on consecutive days approximately halfway along the main beaches from the surface few centimetres at Bascom's reference point. During the period of sampling in September, 1978, some of the beaches were cusped. In such places samples were taken from the cusp bays; this may have resulted in slightly finer mean diameters and lower carbonate values owing to the local sorting associated with beach cusp formation. Beach ridge and parabolic dune samples were collected from the same general localities by augering to a depth of 75 to 100 cm.

3.5.3 Laboratory methods

Air dried sediment samples were split with the aid of a mechanical sample splitter, and a sample of approximately 100 g of material was taken for analysis. The shell carbonate present in the samples was removed by leaching with 10% HCl prior to size analysis in order to enable more meaningful comparisons to be made with the Pleistocene marine sands (Chapter 5). Washed and even dried (105°C) samples were mechanically sieved for 15 minutes using a set of sieves of mesh sizes -1.0 ϕ to 4.0 ϕ at ½ ϕ intervals. Each fraction was weighed to the nearest 0.001 g on an air dampened Mettler balance and weights were calculated as percentages.

3.5.4 Statistical methods

Because of the variety of sediments to be examined in this study, the need to use a single method for comparative purposes, and the need to take the "tails" of the grain size distribution into account, the method used for determining mean grain size and sorting was that described by Folk and Ward (1957). Their statistical measures and terminology are summarized below:

Mean grain size -

$$M_z = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

Sorting (inclusive graphic standard deviation) -

$$\phi_1 = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

ϕ_1	0.35,	very well sorted
	0.35-0.50,	well sorted
	0.50-1.00,	moderately sorted
	1.00-2.00,	poorly sorted
	2.00-4.00,	very poorly sorted
	4.00,	extremely poorly sorted

The results of the grain size analysis and percentage shell carbonate determinations are presented in figure 8 and represent

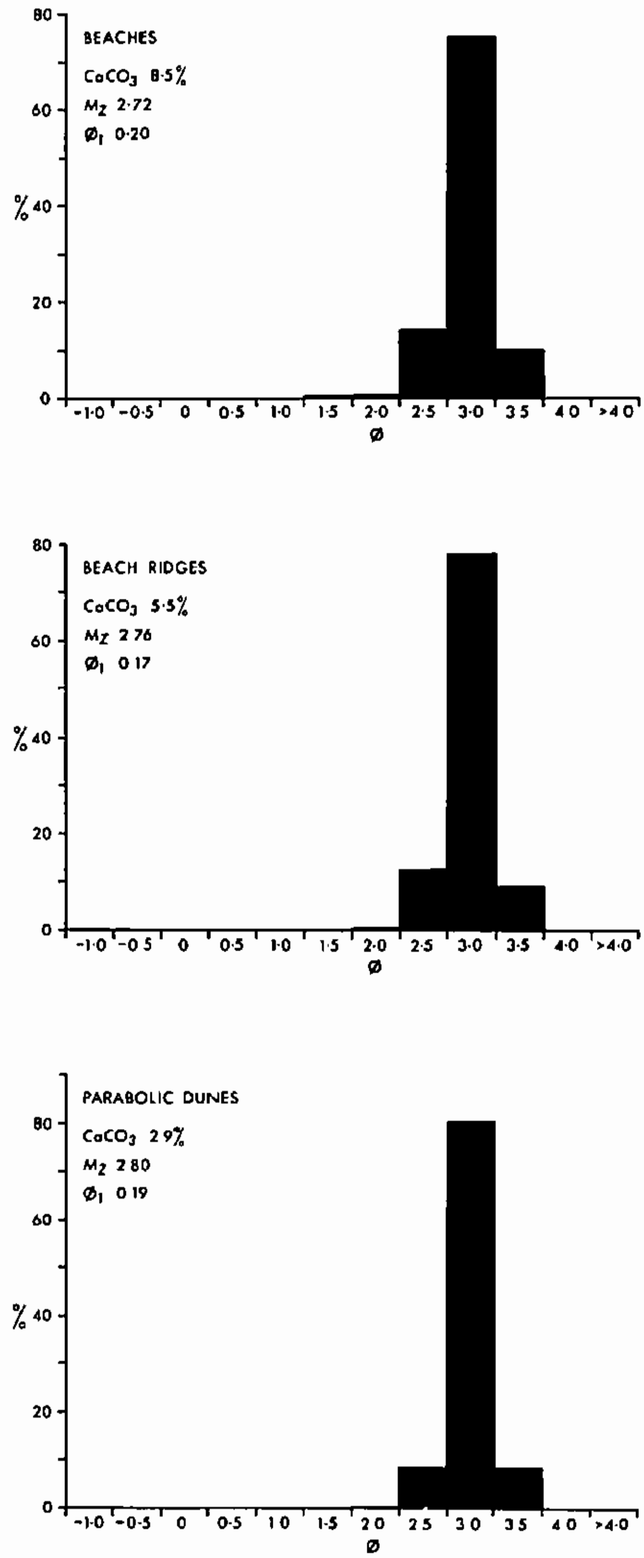


FIGURE 8. Grain size distribution of the barrier sands.

the average of five samples from the three major morphological units indicated.

3.5.5 The sediments

The barrier sediments consist of well-rounded quartz sands. The grain size characteristics show that all the sands are fine to very fine and very well sorted. While there is very little variation in the mechanical properties and carbonate content of the sands, some significant general trends are evident. The beach sands are slightly but significantly coarser (M_z 2.72) than the dune (M_z 2.80) and beach ridge sands (M_z 2.76). This reflects the selective removal of the finer fractions from the beach surface by onshore winds. The effects of aeolian processes also largely explain why the dune sands contain significantly less shell carbonate (2.9%) than the beach sands (8.5%). The intermediate carbonate values and grain size characteristics of the beach ridge sands supports the previously outlined field evidence and generally accepted views that both wind and wave processes are responsible for the development of these progradational shoreline features.

A number of systematic studies have shown that dune sands not only tend to be finer than beach sands but also that the former tend to be better sorted (Mason and Folk, 1958; Friedman, 1961; van de Geer, 1972). Although this study also shows that the dune sands are finer than the beach sands, the difference in the degree of sorting is not significant. However, since the beach sands contain a significant amount of very coarse shell material not found in the dune sands, the difference in mean grain size and sorting would undoubtedly have been more pronounced had the carbonate fraction been included in the mechanical size analysis.

3.6 SOIL DEVELOPMENT

Systematic augering of the beach ridges at Anthony Beach and inspection of the eroded sections at the western end of Perkins Island indicate that the soils of the Holocene barriers have been podzolised to a much lesser degree than the Pleistocene marine sands (Chapter 5). The present foredunes show no differentiation of soil profile horizons whatsoever. The beach ridges situated most to seaward exhibit weakly developed $B_{2h,ir}$ and B_{2ir} horizons overlain by a leached grey-white A_2 and grey-black A_1 horizons which together are up to about 1 m in thickness (Plate 4). Generally, the A horizon thickens landwards and the B horizon becomes progressively more pronounced (Plate 5) in the same direction. The B horizon is generally soft but in the innermost ridges, dark brown semi-compact nodules of humus-iron material are sometimes present.

Whilst the soil profiles show a marked succession across the beach ridges, pH values, determined with the aid of a C.S.I.R.O. Soil pH Testing Kit, are relatively uniform, varying from 4.5 at the surface to 5.5 at a depth of 1 m. These values contrast strongly with the present foredunes which have a pH of about 7.0. This is to be expected, however, because with the exception of the most recent foredunes, shell carbonate has been leached from above the water table throughout the beach ridge systems.

PLATE 4. Representative soil profile of seaward situated beach/dune ridges on Perkins Island.

PLATE 5. Innermost beach ridge on Perkins Island showing well-developed B_2 soil horizon.

3.7 BARRIER EVOLUTION

The morphological aspects of Australian prograded bay barrier systems have been described in considerable detail by a number of workers (Bird, 1961, 1973; Hails, 1968; Langford-Smith and Thom, 1969; Thom, 1965), but there have been very few morphostratigraphic studies of such systems. A recent, and notable exception is the well-documented study by Thom *et al.* (1978) which provides valuable data on the depositional history of some of the sand barriers in New South Wales. Although the extensively developed beach ridge plains of northwestern Tasmania offer excellent scope for similar chronological and palaeoenvironmental studies, this was not undertaken for this dissertation. Such a study is, however, currently in progress (Thom, personal communication).

The general morphological similarities of the prograded bay barrier systems in the study area with those described from the Australian mainland and in particular New South Wales (Thom *et al.*, 1978) strongly suggests that similar processes and synchronous events have been involved in their evolution. With this assumption in mind, the general evolution of the barrier systems in northwestern Tasmania can be briefly summarized as corresponding to the following sequence of events:

Global deglacial events which marked the close of the Last Glacial Stage resulted in the Holocene transgression (post 17,000 BP). As sea level rose, it transgressed across the Last Glacial subaerial landscape of the Bassian Plain, reworking some of the unconsolidated deposits and progressively displacing the sediments landward. Sea level is believed to have reached its approximate present position by about 6,000 BP (Thom and

Chappell, 1975). Following the end of the transgression, upward growing beaches developed within the limits of effective wave action to become the foundations for subsequent accretion of successive beach ridges and parallel dunes, generally normal to predominantly swash-wave induced sand transport and aeolian accumulation around sand binding vegetation. The relative regularity of the beach ridge patterns suggests that in the long term, shoreline progradation took place without major interruptions, as could result from sudden marked changes in the rate of onshore sediment supply, wave climate or sea level. As will be described in the next chapter, there is evidence to suggest that much of the sand that makes up the extensive barrier systems in the area was probably largely derived from a partial reworking of fossiliferous marine sand deposits of Pleistocene age, and that this resulted in a local superabundance of sand during and for sometime after the transgression. This evidence further suggests that the initial barriers probably came into existence in such a way as to partly anchor themselves on the relict Pleistocene marine sand deposits, and that an unconformity underlies the Holocene marine sequence at very shallow depth. This inference is supported by preliminary chronostratigraphic data from the barrier complex behind Anthony Beach where the Pleistocene unconformity has been encountered at 3 to 4 m depth (Thom, personal communication).

It has been postulated by some Australian geomorphologists that sea level, after reaching its uppermost transgression limit during mid-Holocene times, has been falling (e.g. Fairbridge, 1961; Gill and Hopley, 1972; Jennings, 1959, 1961; Jenkin, 1968; Hopley, 1980). A similar glacio-eustatic event was postulated for Tasmania by Davies (1958, 1959, 1961) who suggested that sea level was between 1 and 3 m above present sea level with the highest level represented in the northwest, and the lowest level in the southeast where he formally named it the Milford level. Davies further suggested that the elevational difference between the northwest and southeast might be explained in terms of slight tectonic tilting of the island. However, the problem of whether or not Tasmania experienced a slightly higher sea level during the mid-Holocene has been, and remains, a subject of considerable controversy. There is no known evidence for a higher Holocene sea level in the study area.

Chick (1971) in discussing the evidence for former higher sea levels around Ulverstone on the central northwest coast concluded that although a slightly elevated (1-1.5 m above HWM) shoreline feature occurs in this area, it lies well within the present upper limits of wave action. Similarly, van de Geer (1972) demonstrated that the Milford level at Marion Bay on the southeast coast as described by Davies (1959) does not provide convincing evidence for a higher mid-Holocene sea level. There are a few unpublished radiocarbon dates of some of the sites described by Davies (1959) that relate to the problem, and all of these are very much younger than the postulated higher sea level of 6,000 to 5,000 BP (Table 3). The radiocarbon dates suggest that the inner, higher parts of the Holocene surfaces above present HWM are non-synchronous and that progradation commenced at different times on different parts of the coast. However, much more systematic chronostratigraphic work is needed before this hypothesis can be substantiated.

Although disputed by some (e.g. Gill and Hopley, 1972; Hopley, 1980), there also appears to be no unequivocal evidence

TABLE 3 ^{14}C dates related to Holocene marine deposits in Tasmania

Location	Description	^{14}C age	Significance
Cremorne, South Arm Peninsula	Charcoal collected from marine sands at 1.2 m below the surface of the marine terrace; near the inner limit of deposition; 0.4 m below HWST; and on the western side of the Cremorne spit facing Pipe Clay Lagoon.	3620±80 BP GaK-650	The sample came from near the base of the wedge of marine sands and indicates that progradation of the terrace surface is probably of later age. (Davies, Stephens and van de Geer, 1966)*
Marion Bay, Southeastern Tasmania	Shells taken at 2 m depth and 0.6 m below HWST just east of the inner dune ridge at the southern end of the Marion Bay spit.	1890±90 BP GaK-2892	These dates indicate that the inside portion of the Marion Bay spit was formed by progradation from the core of the spit towards the lagoon between ~ 1900 BP and present. (Davies, Stephens and van de Geer, 1966)*
	Carbonized drift wood contained in shell bed 0.2 m above HWST on inner side of spit at Marion Bay.	390±90 BP GaK-647	
Snug, Southeastern Tasmania	Shells from marine sands at -1.6 m below HWST on the inner margin of the marine terrace at Snug. Surface elevation 1 m above HWST.	2760±120 BP GaK-649	These dates indicate that the marine terrace at Snug was formed by seaward progradation between ~ 3000 BP and present (Davies, Stephens and van de Geer, 1966)*
	Shells from marine sands at -0.6 m below HWST behind the low dunes on the outer part of the marine terrace at Snug. Surface elevation 0.6 m above HWST.	510±80 GaK-648	

* Sampling and dating done by Davies, Stephens and van de Geer: interpretations made by Colhoun (1976a) and van de Geer (1972).

for a recent higher sea level stand on the Australian mainland (e.g. Thom *et al.*, 1969, 1972; Belperio, 1979; Clarke *et al.*, 1979). Considerable controversy also exists over the ambiguity of some of the Victorian and Queensland field evidence used as an indicator of relative sea level movement (Thom *et al.*, 1972). It is believed by some Australian geomorphologists that the widely reported evidence of recent emergence on the Australian coast may be due to localized tectonic and/or hydro-isostatic responses, rather than glacio-eustatically induced changes in sea level (Thom and Chappell, 1975).

Chronological and geomorphological evidence from New South Wales, and geomorphological evidence from this study have shown that barrier progradation ceased some time ago and was replaced by a phase of shoreline modification, involving the large scale destruction of primary depositional landforms and the development of transgressive secondary dune forms. This apparently widespread event is believed to have commenced approximately 3,000 BP (Thom *et al.*, 1978), but as was noted, the causal factors involved are still unclear and require further systematic study before our understanding can be improved.

CHAPTER 4

LAGOONAL INLETS

4.1 INTRODUCTION

Largely protected from the direct effects of strongly refracted ocean swell waves by the bay barriers and extensive very shallow subtidal areas, the meso-tidal environments of the lagoonal inlets (tidal range approximately 2.5 m*) are constantly being modified by erosion and sedimentation. The effects of strong tidal current action, halophytic vegetation, and to a lesser degree wave and wind generated processes have resulted in the development of distinctive landforms and deposits.

4.2 SALT MARSHES

Situated above normal high tide levels, the salt marshes, which are thickly covered by halophytic vegetation and intricately dissected by a network of meandering creeks, occupy extensive areas around the shores of the lagoonal inlets (Fig. 5). The salt marshes are bordered by more extensive tidal flats which are

* Smithton Harbour Trust tidal data recorded in Duck Bay.

situated between the mean high tide and low tide levels. With the exception of the highest parts bordering the salt marshes, the tidal flats are generally devoid of vegetation and are dissected by a complex system of large tidal channels and tributary gullies.

For their optimum development, salt marshes require relatively sheltered situations from which strong wave action and tidal scour are largely excluded. This prerequisite largely explains their somewhat irregular distribution along the lagoonal shores, being most extensively developed in the heads and margins of the small embayments and estuaries, or as small, irregular patches on the higher parts of the tidal flats between the tidal channels.

The marshes exhibit a characteristic vegetation zonation which reflects effective control of the frequency of tidal submergence over the limits of the vertical distribution of the various halophytes (Chapman, 1960). The following three general vegetation zones can be identified on the fully developed marshes in the area:

(i) Lower marsh: *Salicornia quinqueflora* predominant with *Triglochin striata*.

(ii) Middle marsh: *Arthrocnemum arbuscula* predominant with *Salicornia quinqueflora*, *Triglochin striata*, *Samolus repens*, *Mimulus repens* and *Selliera radicans*.

(iii) Upper marsh: *Juncus kraussii* predominant with *Salicornia blackii*, *Samolus repens*, *Stipa stipoides* and *Hemichroa pentandra*.

> The uppermost part of this zone, which is seldom reached by the tides, passes into closed shrubland dominated by *Melaleuca ericifolia*.

An exception to the vegetation zonation described occurs in the very muddy upper reaches of the Duck River estuary near Smithton. Here, *Spartina townsendii* which was introduced into the area in 1956* is the dominant halophyte on the lower marshes and is succeeded by *Juncus kraussii* at higher tide levels. However, unlike the Tamar estuary in northern Tasmania where the introduction of *Spartina townsendii* has led to striking geomorphic changes (Phillips, 1975), its introduction in the Duck River estuary has not produced spectacular changes. Locally, die-back and subsequent erosion chiefly caused by cattle grazing and the dumping and burning of sawmill waste products is clearly evident.

The marshes are dissected by numerous, strongly meandering creeks that traverse the marsh surface in more or less random directions with only the major creeks flowing comparatively directly towards the tidal flats. Most of the marsh creeks which debouch onto the tidal flats are not continued over the tidal flats as ebb gullies, The drainage water generally disappears a short distance beyond the marsh edges by spreading out laterally over the unvegetated tidal flats and infiltrating the sands. Through-going creek-gully systems are found only where marsh creeks are very large in which case they are usually connected with a permanent terrestrial stream inland, or where the tidal flats are composed of sediments

* Smithton Harbour Trust records.

cohesive enough to maintain a channel without the aid of sediment binding vegetation, as for example in the muddy upper reaches of the Duck River estuary.

Where a meandering salt marsh creek leaves the marsh, the channel becomes wider and shallower, sinuosity decreases and the radii of curvature of the meanders increases dramatically. These changes in channel morphology indicate that the factors controlling channel form are different within the respective environments. On salt marshes, the sediment binding action of the dense vegetation and finer, more cohesive sediments play a predominant role (Pestrong, 1965), while on the tidal flats hydraulic flow phenomena determines the channel form (van Straaten, 1953; Jakobsen, 1962).

Whereas a part of the creek has been formed by lateral erosion after a considerable thickness of marsh sediment has already been built up, an important part has been present since the initial stages of marsh formation so that its depth is not so much the result of erosion but is largely due to the successive vertical growth of the marshes themselves (Chapman, 1960; Pestrong, 1965). When the marsh is flooded during periods of high tide, a considerable part of the sediments carried by the currents is filtered out and trapped by the dense vegetation cover: first the sand, then the finer fractions. In this way, a finely laminated deposit is usually formed, particularly along the banks of creeks because here the plants are the first to trap the suspended sediments when the water flows over the banks onto the marsh during high tides. In the Duck Bay area, this sedimentation process has locally resulted in the development of very low levées along the creeks and discontinuous marsh ridges along the seaward side of the marshes. The development of marsh ridges is hastened by waves which throw up material as they splash against the marsh cliff, as well as being aided by the accumulation of wind-borne fine sand derived from the tidal flats during periods of strong onshore winds and low tide levels.

Marsh ridges have been extensively developed along the relatively exposed inlet shores, as at Kangaroo Island southwest of Robbins Island. Here, parallel concentric marsh ridges have developed which are generally less than 50 cm high and consist of shelly, silty sand vegetated by *Juncus kraussii*. The intervening swales consist of peaty silts and clays covered by a dense mat of *Salicornia quinqueflora* and some isolated stands of *Arthrocnemum arbuscula*. Due to the sorting action of waves and currents, very shelly storm ridges and washover fans, sometimes partly vegetated by *Ammophila arenaria* and other halophytic grasses, have developed in front of *Juncus kraussii* salt marshes along parts of the exposed north-easterly facing lagoonal shores. Most ridges appear to be actively migrating across the marsh surface, the shelly sands being washed and blown over the marsh surface during strong wave and wind activity (Plate 6). East of The Jam and between Pelican Point and Sampsons Point, prolonged exposure to strong onshore winds has resulted in the development of a narrow strip of low (< 1.5 m), largely discontinuous hummocky dunes composed of fine sand. Locally, these low lagoon shore dunes have been subsequently eroded by meandering tidal channels and can sometimes be seen to overlie salt marsh peats and clays, as at The Jam where a thin and compressed silty salt marsh peat is overlain by up to 1 m of weakly podzolised dune sands (Plate 7).

PLATE 6. Washover fan east of The Jam. Note outcrop of salt marsh peat on the seaward side.

PLATE 7. Detail of eroded section at The Jam showing salt marsh peat overlain by lagoon shore dune sands.

PLATE 8. Cliffing of *Juncus kraussii* salt marsh at Duck Bay.

The salt marshes may pass gradually into the adjacent tidal flats but very frequently can be seen to terminate in low cliffs (Plate 8). Such marsh cliffs signify that at a given locality a period of sedimentation has been succeeded by a period of erosion. A gradual transition of salt marshes into tidal flats is generally only found in the very sheltered bay head positions and estuaries where the rate of sedimentation has largely exceeded the rate of wave erosion and current scour, as for example at Kemps Bay and Montagu Island.

On most of the marshes, cattle have partly destroyed the vegetation and have led to the development of salt pans. During periods of high tides and for some time thereafter, such areas usually retain water, and in summer, when evaporation is intense, the areas become hypersaline resulting in conditions at least temporarily adverse to the re-establishment of the halophytic vegetation.

4.3 TIDAL FLATS

In contrast to the salt marshes, the tidal flats are largely devoid of halophytic vegetation. Only in front of some of the salt marsh cliffs do irregular patches of *Salicornia quinqueflora* and *Spartina townsendii* occur. At lower levels, *Zostera* spp. can be found growing on slightly elevated silty areas separated by tidal channels and tributary gullies.

Owing to the sandy nature of most of the tidal flats in the area, the numerous gullies that dissect these areas disintegrate very easily and tend to become filled up with sand as soon as the ever changing current pattern of the tidal cycle no longer corresponds with the direction of their courses. Whereas gullies on the sandy lower tidal flats usually exhibit rather ill-defined braided courses, in contrast the gullies on the muddier upper tidal flats are more clearly defined and show a marked tendency towards the development of meanders. Such meanders are enlarged by lateral erosion and migrate slowly towards the main tidal channels. Since gullies on tidal flats are used by alternating currents from opposite directions this may seem paradoxical. However, detailed hydrological studies elsewhere have demonstrated that the ebb currents in the gullies are of far greater strength and of longer duration than those of the flood current so that the hydraulic geometry of the gullies approaches that of terrestrial streams (van Straaten, 1950, 1953; Jakobsen, 1962; Pestrong, 1965).

Perhaps the most outstanding geomorphological features of the tidal flats in the area are the very extensively developed large tidal channels which are morphologically very similar to those described from meso-tidal lagoonal inlets elsewhere, particularly northwestern Europe (van Veen, 1950; van Straaten, 1950; Robinson, 1960; Gierloff-Emden, 1961; Jakobsen, 1962). The distinction between small tributary gullies and the much larger tidal channels is, however, not merely a matter of dimension because very marked differences exist in both hydrological and morphological characteristics. Very detailed hydrologic studies by van Straaten (1953) and Jakobsen (1962) have demonstrated that unlike tributary gullies, the strength and duration of ebb and flood currents does not differ greatly in the major channels, however the conditions are often complicated by the development of separate ebb and flood channels (van Veen, 1950).

PLATE 9. Outcrop of Pleistocene humate-impregnated marine sand in a tidal channel at Duck Bay.

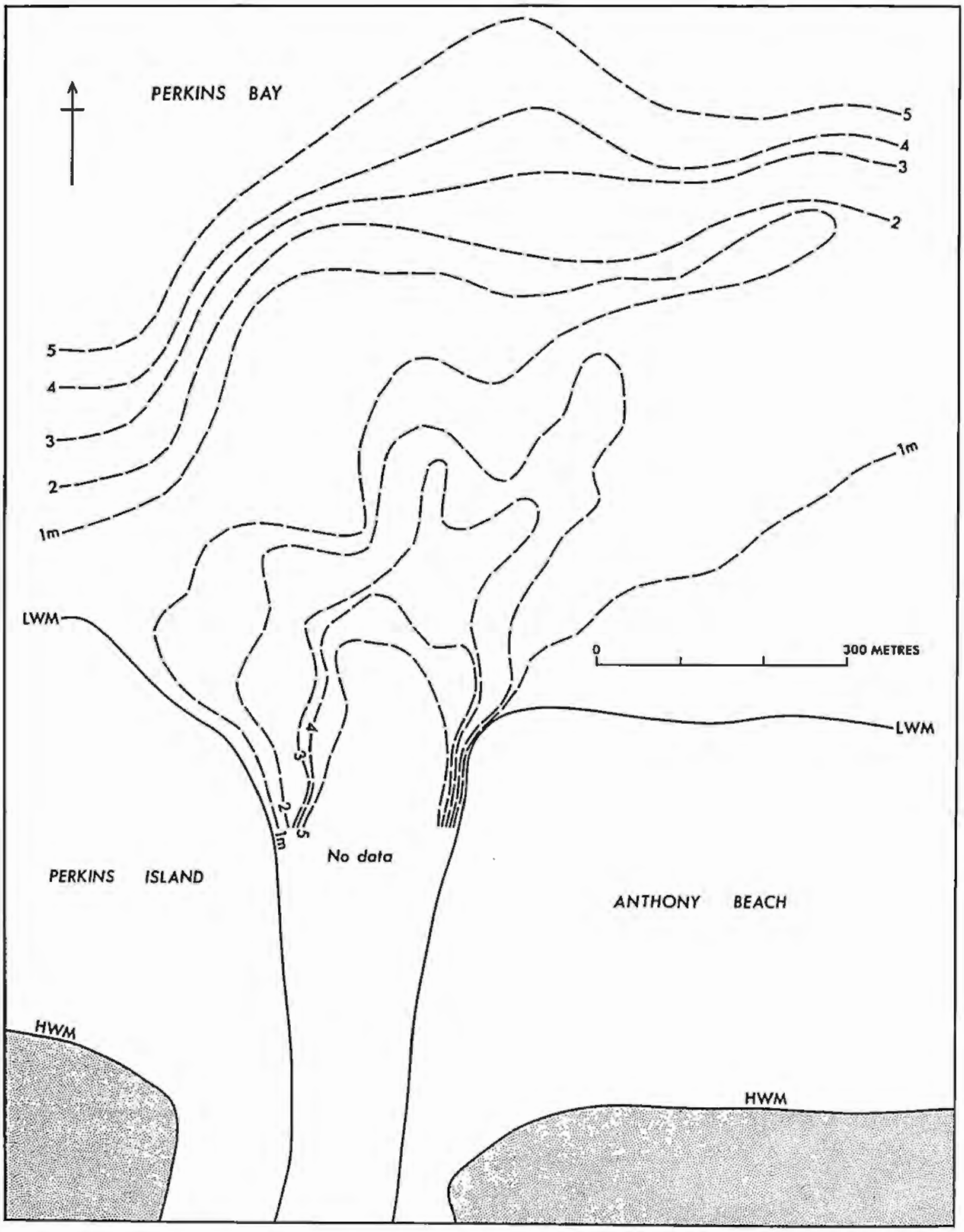


FIGURE 9. Sub-tidal ebb delta at the entrance to Duck Bay.
Source: Smithton Harbour Trust unpublished hydrographic data.

The floors of the channels, which usually exhibit very large transverse ripple marks, are mainly composed of recent and generally very shelly sediments formed in the channel environment itself, but in a few places erosion has uncovered very indurated outcrops of Pleistocene marine sands (Plate 9). Probing and digging in the Duck Bay area indicated that the Pleistocene sands locally underlie the lagoon sediments of the upper tidal flats at depths generally less than 1.5 m.

Anastomosing of some of the larger tidal channels has locally resulted in the formation of small isolated tidal flats completely surrounded by sub-tidal sand banks and channels. Such features are found a considerable distance offshore. The largest of these is Middle Bank which is situated west of Walker Island.

On the Bass Strait side of the narrow lagoon entrances, deltas have been formed as a result of the deposition from ebb currents flowing out to sea and the modifying influences of refracted swell waves. Their surfaces lie mostly below low tide level (Fig. 9).

4.4 SEDIMENT ANALYSIS

4.4.1 Introduction

Unlike beaches where single samples collected from a comparable point usually provides sufficient information for the purpose of general regional description of sediment characteristics, the inter-tidal inlet environments, however, are much too variable to permit such a simple and convenient sampling procedure to be adopted. As described in the previous sections, the lagoonal inlets of this area are characterized by three distinct depositional environments. For the purpose of this study, single samples were collected from the lower and upper tidal flats and the salt marshes in the Duck Bay, East Inlet and Swan Bay areas.

4.4.2 Laboratory methods

Prior to grain size analysis, carbonate content was determined by leaching with 10% HCl after drying the samples at 105°C, and combustable organic matter was determined on the residues by weight loss after combustion at 500°C for one hour. The grain size distribution of the sand fraction was determined at ½ ϕ intervals in the same manner as for the bay barrier sediments and the finer fraction was analysed at 1 ϕ intervals using the Bouyoucos hydrometer method (Bouyoucos, 1927, 1962). The results shown in the form of histograms in figure 10 suggest the average grain size characteristics of the sediments from the three main lagoonal inlet environments.

4.4.3 The sediments

By far the most important constituent of the lagoonal inlet deposits is fine, moderately well-rounded quartz sand. It is the dominant sediment in the channels and on the lower tidal flats. Muddy sediments are mainly encountered on the upper tidal flats, the salt marshes, and on the floors of gullies and

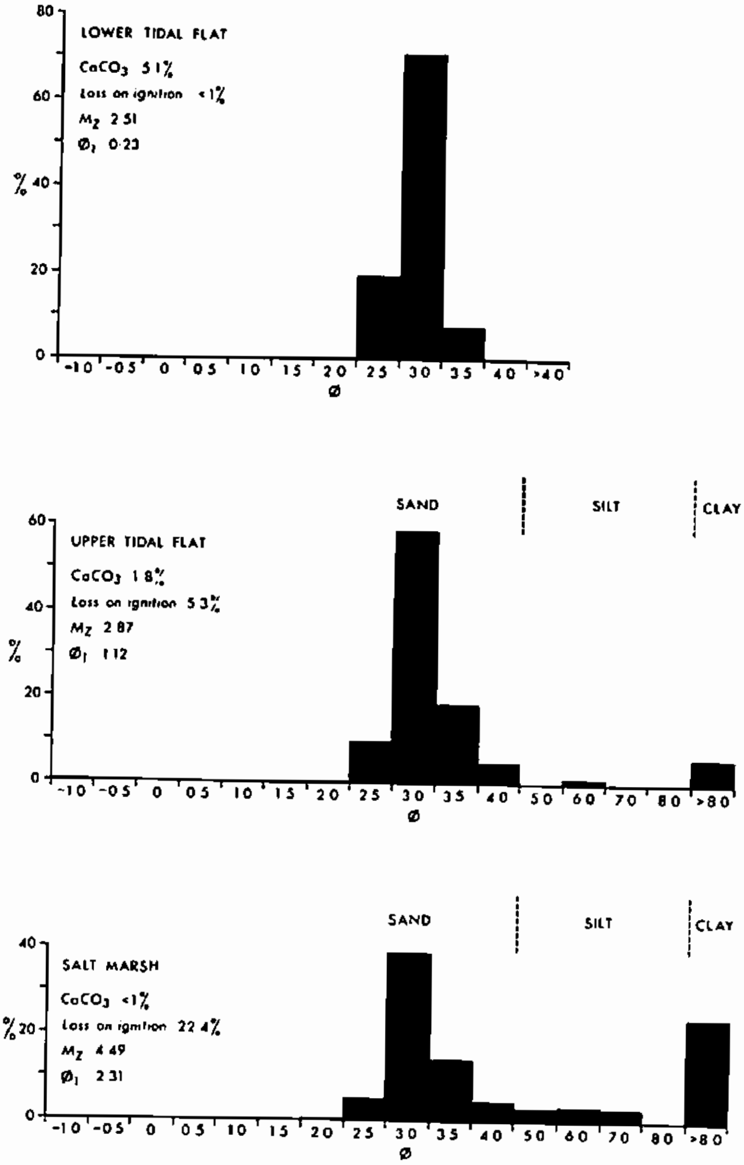


FIGURE 10. Grain size distribution of the lagoonal inlet sediments.

creeks. Minor accumulations of muddy sediments are usually also present in the troughs of ripple marks on the upper and lower tidal flats bordering the main channels. In these areas, the mud consists predominantly of faecal pellets and pseudo-faeces produced by molluscs and other burrowing intertidal organisms. Very shelly sands are found almost exclusively on the lower tidal flats near the lagoon entrances, and on the floors of the channels and larger gullies where localized concentrations of shell hash occur as a channel lag deposit. The very poor state of preservation of most of the shells suggests that they are probably largely of Pleistocene age and have been concentrated as a result of reworking from the underlying marine deposits.

The muddiest sediments of the area occur in the estuaries and in the heads of the many small lagoon embayments. Here, away from the effects of strong current and wave action suspended silt and clay carried into the lagoons by terrestrial streams is flocculated and precipitated by the electrolytic effect of sodium chloride in solution when sea water is encountered.

A notable feature of the sediments is that the mean grain size and percentage carbonate show a marked decrease shorewards (M_z 2.51-4.49; $CaCO_3$ 5-< 1%). This trend clearly reflects the diminishing current velocities in that direction. It is, however, not possible to fully understand the marked shoreward change in the degree of sorting (ϕ_1 0.23-2.31) and the bimodal nature of the upper tidal flat and salt marsh sediments without considering their structure. On the floors and banks of gullies and creeks, and over the surfaces of the upper tidal flats and salt marshes, the sediments tend to be made up of thin laminations which consist of fine sand and mud. The sands are the product of strong currents and waves, while the finer fractions have been laid down during the turn of the tides or other quiet water conditions favourable for the deposition of suspended silts and clays. Apart from the alternation with mud laminae, the sand fraction usually contains a certain amount of clayey material. This is mainly the result of the admixture of faecal pellets that are composed of mud but that behave granulometrically as sand grains.

4.5 SOIL DEVELOPMENT

Only the innermost salt marsh deposits which are seldom reached by normal tide levels exhibit the initial stages of Peaty Acid Swamp soil development. A representative example from the Duck Bay area is as follows:

A_1 0-30 cm Acid (pH 5.5) black fibrous sandy, clayey peat.

A_2 30-80 cm Dark grey to black clayey sand.

B_2 80-125 cm Grey and orange-brown mottled clayey sand with fossil burrowing casts and decomposed plant rootlets.

C 125-175 cm Wet grey fine sand with occasional clayey laminae, burrowing casts and *Zostera* spp.(?) rootlets. The C horizon overlies compact, humate impregnated marine sands.

The former lagoon environments are clearly evident in the profile of this young soil and the profile horizon differentiation is based more on lithological variations in the sediments than on the results of atmospherically and organically induced soil forming processes. The A horizon represents the salt marsh and the B horizon the upper tidal flat. The C horizon which overlies relict Pleistocene marine deposits represents the lower tidal flat and marks the initial stage of intertidal lagoon development.

4.6 LAGOONAL INLET EVOLUTION

The present environment and configuration of the lagoonal inlets is the outcome of a long and complex history of erosion and sedimentation. Their configuration has been largely determined by the evolution of the bay barrier system. The dominant tendency resulting from the initial development of the barrier system and its subsequent progradation and prolongation by accretion was a progressive change towards a very low wave energy environment in the embayments and estuaries, and the development of extensive sand flats dissected by a network of interconnected channels flowing out to sea through gaps in the barriers and sub-tidal ebb deltas maintained by strong tidal currents. There is substantial evidence which shows that much of the sand that makes up the tidal flats was derived from a reworking by migrating tidal channels of fossiliferous marine sands of Pleistocene age, and that an unconformity underlies the Holocene lagoon sequence at very shallow depth. As indicated in the previous chapter, a similar unconformity underlies the beach ridge complex behind Anthony Beach.

It is likely that the effects of environmental change caused by the development of prograding and prolongating beaches offshore towards the end of the Holocene transgression (~ 6,000 BP) were more or less immediately felt in the lagoons, and resulted in the progressive colonization of muddy areas by halophytic vegetation in sheltered embayments and estuaries. The barrier system is believed to have prograded to its present approximate extent during mid to late Holocene times (~ 6,000-3,000 BP) (Chapter 3), and it is envisaged that much of the present configuration of the lagoonal inlets developed during this time. However, as was noted, profound contemporary changes resulting from the effects of tidal current action, halophytic vegetation and wind and wave generated processes are clearly evident, and these are causing erosion of the shoreline locally.

CHAPTER 5

PLEISTOCENE BARRIER SAND DEPOSITS

5.1 INTRODUCTION

Much of the coastal plain between Circular Head and Woolnorth Point consists of a number of very extensive basins which are mantled by fossiliferous Pleistocene marine sand deposits that merge inland with alluvial deposits. Locally, the marine sand deposits have been blanketed by biochemically precipitated spring marl and peat swamp deposits. The marine deposits extend from below sea level up to 15 to 20 m and thus provide clear evidence that the area experienced a higher sea level phase in relation to the present in the not too distant past. In some of the embayments, the marine sand plains are surmounted by sequences of low, widely spaced degraded beach ridges the orientation of which suggests that shoreline alignments during the high sea level phase were comparable with the present.

The purpose of this chapter is to describe the morphological characteristics of the relict shoreline features and related landforms; to examine the stratigraphic relationships, faunal composition, sedimentary composition, and soil profile characteristics of the deposits.

5.2 FOSSIL BEACH RIDGES

Old beach ridges which represent former progradational shorelines are widely distributed in the area (Fig. 11). In most of the areas where Pleistocene marine sand deposits occur, however, land clearance and agricultural practices have extensively modified the surface of the plains and partly removed some of the ridge and swale systems. A somewhat different situation exists on the broad sand plain west and southwest of Smithton. In this area, the development of artesian spring marl and swamp peat deposits of Holocene and Last Glacial age (Chapter 9) have extensively blanketed much of the ridge and swale topography and fragments of ridges preserved by burial are now locally exposed in the drainage ditches.

Generally, the ridges and swales are not readily discernible on the ground, but are fairly clearly visible on aerial photographs even in areas where they are not clearly expressed topographically. In areas where ridge and swale lineations are clearly distinguishable, individual ridges vary in width from less than 75 m to over 200 m. In a longitudinal direction, the ridges are gently curved and parallel, but are often discontinuous as a result of dissection by small streams and modification by agricultural practices. As will be noted from figure 11, their alignment closely approximates that of the Holocene barrier ridges and beaches which demonstrates that the

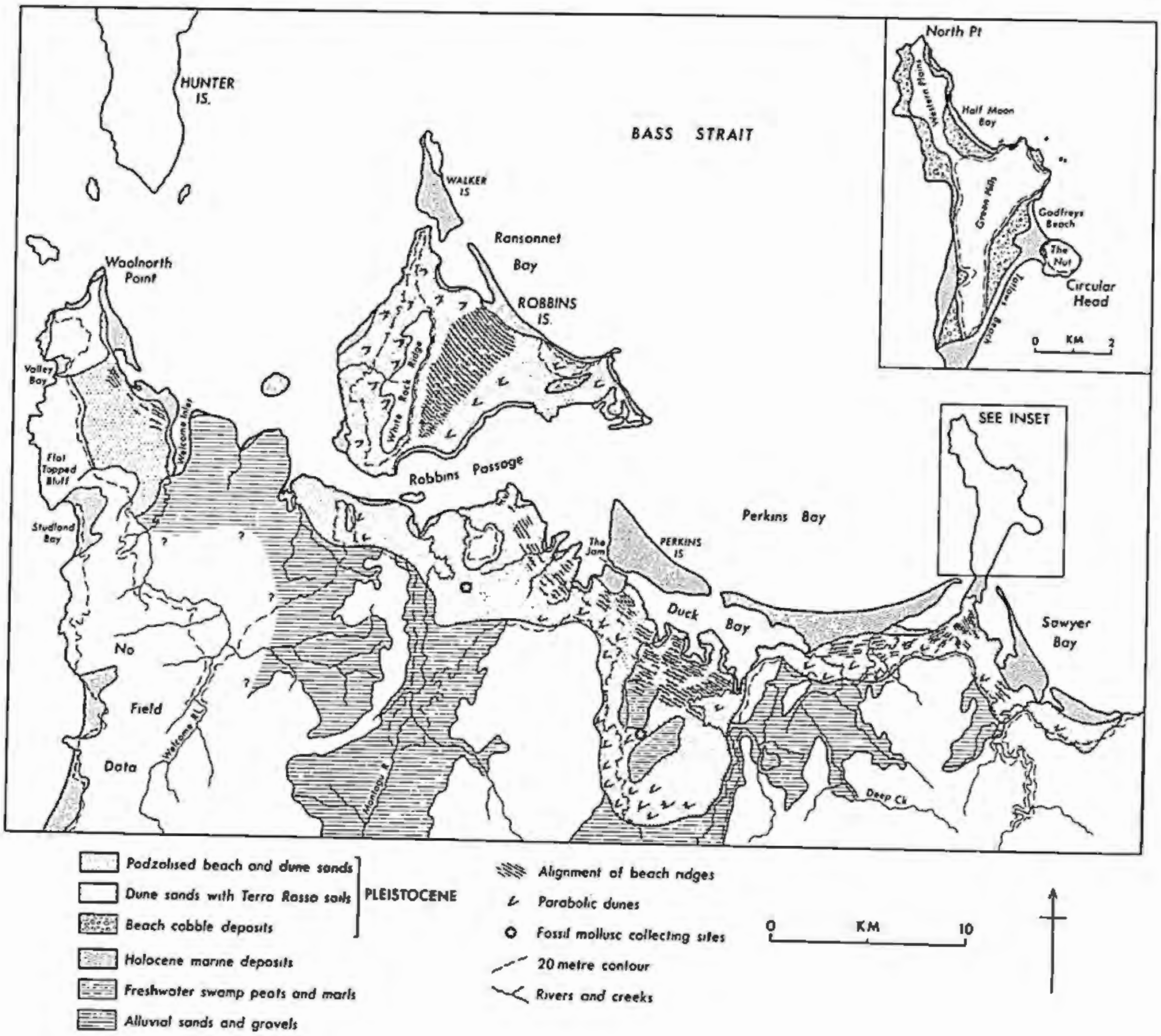


FIGURE 11. Distribution of Pleistocene marine deposits.

dominant wave regime must have been essentially the same as it is today in the not too distant past.

A marked difference in spacing exists between the Pleistocene and the Holocene ridges. Whereas the Holocene ridge spacing is generally less than 25 m, most of the Pleistocene ridges are spaced at intervals greater than 75 m. This suggests that rates of shoreline progradation during the Pleistocene were lower than during the mid to late Holocene phase of barrier progradation. Similar ridge spacing differences have been described from Last Interglacial age sand barrier systems in New South Wales (Thom, 1965; Langford-Smith and Thom, 1969).

In sharp contrast to the Holocene barrier and ridges, which have been little modified by degradational processes, the Pleistocene ridge systems show clear evidence of considerable degradation. This is well illustrated by the relatively undisturbed Pleistocene ridge and swale sequence at Remarkable Banks on Robbins Island (Plate 10). The island lies between 1 and 5 km offshore and is separated from the mainland by extensive tidal flats which are exposed during periods of low tide and the Robbins Passage tidal channel system. On the island an old wedge-shaped embayment which extends inland for approximately 9 km has been almost completely filled with marine sands and is surmounted by a system of low (75-150 cm) ridges that exhibit various degrees of preservation. Although most of the ridges show the characteristic wide spacing similar to the other Pleistocene ridges in the area, the northern part of the Remarkable Banks sequence locally exhibits discontinuous ridge spacing that is generally comparable with the Holocene barrier ridges of nearby

PLATE 10. Pleistocene beach/dune ridges at Remarkable Banks, Robbins Island.

Perkins Island and the parallel dune ridges at Black River to the east. Fragments of narrow (~ 25 m), and generally very low and degraded ridges occur within the wider swales between broad (75-150 m) ridges. Some of the broader ridges are evidently composite features because they can often be seen to divide laterally into two or more narrower ridges. A noteworthy feature of the swales, which show various degrees of infilling, is that they appear to have been largely preserved according to the degree to which they act as present day drainage channels. This is particularly well illustrated in localities where a number of swales have been captured by a single swale. In such instances, the captured swales do not continue below the point of capture, and below that point can often be seen to amalgamate into a single, broad, low, irregular hummock. Over much of the Remarkable Banks area erosion of the ridges, infilling and capture of the swales has been so intense that most of the more inland situated ridges have been reduced to very irregular fragmented structures some of which are surrounded by discontinuous shallow (< 1 m), oval-shaped bodies of standing water and densely vegetated swamps.

Although the ridge and swale topography in the area has lost much of its characteristic morphology and relief as a result of degradation, generally ridge and swale lineations remain quite pronounced. The relatively regular wide spacing of the broad relict ridges (Plate 11) suggests that they probably represent remnants of relatively high parallel frontal dunes which developed under conditions of relatively slow rates of shoreline progradation. However, the regularity of their pattern

PLATE 11. Detail of the Remarkable Banks beach/dune ridge and swale topography looking west.

indicates that the rate of onshore sand supply and colonization by sand binding halophytic vegetation of beach berms and incipient foredunes was sufficiently rapid to prevent blowout activity and the development of transgressive dunes.

There are a number of factors that influence the drainage characteristics of the Pleistocene barrier surface. These factors are best observed in the Remarkable Banks area. The most important appears to be the degree of Groundwater Podzol development, and its depth below the surface. The amount of runoff flowing at the surface depends ultimately on the depth of the water table. Over much of the Remarkable Banks area and in other localities where Pleistocene ridges occur, the water table usually coincides with the top of a very compact soil B horizon which is generally situated at a depth of less than 75 cm below the surface of the ridges. The compact soil B horizon is a result of cementation by humus and iron compounds over a long period. In the swales which locally contain a shallow permanent body of standing water thickly covered by *Restio tetraphyllus*, *Myriophyllum amphibium* and other aquatic and damp site freshwater species, the soil B horizon is overlain by up to 150 cm of black sandy peat and grey-black peaty sand.

5.3 FOSSIL TRANSGRESSIVE DUNES

A narrow fringe of predominantly northeasterly facing Pleistocene coastal parabolic dunes commonly occurs along the inland margins of the marine sand plains where they have locally transgressed onto the lower slopes of the surrounding hills and some distance across the alluvial deposits of the hinterland plains. Like the Pleistocene beach ridges, most of the dunes have lost much of their characteristic morphology and relief through various processes of degradation. However, in some localities their morphology remains quite pronounced. Low, smooth, whaleback ridges are not uncommon, and locally very degraded fragments of parabolic dune patterns can still be identified from aerial photographs and on the ground. All the dunes are fixed by vegetation and except in localities where sand is periodically being eroded by small ephemeral streams or is being quarried, no blowouts and secondary dunes develop in them.

Road and quarry exposures show that all the dunes consist of deeply leached white sand, in places several metres thick, overlying a very compact humus-bound B horizon which can also be several metres thick (Plate 12). Cross-bedding structures can sometimes be observed, as for example at a quarry site situated near Christmas Hills. At this locality, the transgressive dunes rise up to about 25 m above the marine sand plain from which they have been derived and can be seen to overlie a 75 to 100 cm thick fossil Krasnozem soil developed on the subjacent Tertiary basalt.

West of Welcome Heath in the far west of the study area a restricted irregular area of very subdued old dunes occurs. The dunes consist of calcareous aeolianite on which a well-developed Terra Rossa-type soil profile with nodular limestone inclusions has been formed (Plate 13). The shelly material that makes up these fossil dunes was originally blown inland from Pleistocene beaches situated on the exposed west coast that like their modern counterparts were much more calcareous than the beaches of the Bass Strait coast.

PLATE 12. Deeply podzolised Pleistocene dune sands exposed in a quarry at Christmas Hills.

PLATE 13. Terra Rossa-type soil developed on calcareous

Dune lakes, such as those described from King Island by Jennings (1957), do not occur in the area but small and shallow swampy ponds underlain by either compact humus-bound sandrock or by bedrock are a common feature of the subdued old dune fields. True dune lakes overlying Pleistocene marine deposits are, however, well developed outside the study area, as for example between Bluff Point and Mount Cameron on the west coast, and on Hunter and Three Hummock islands to the north.

Pleistocene calcareous parabolic cliff top dunes (Jennings, 1967) are not represented in the study area but occur on the west facing coasts of Hunter and Three Hummock islands. Aerial photographs indicate that these features are particularly well-developed along the northern west-facing shores of Hunter Island.

5.4 STRATIGRAPHIC RELATIONSHIPS

5.4.1 The Smithton area

The low lying embayment situated west and southwest of Smithton forms a sandy plain up to 7 km wide and extends over 10 km inland (Fig. 11). It has a very even surface and slopes towards Duck Bay with a gradient of 2 to 3 m/km. The plain is bounded to the south by an irregular fringe of degraded, low, coastal transgressive dunes which gradually merge inland at Jones Plain with extensive tracts of sandy and silty alluvial deposits at 20 to 40 m above sea level.

The eastern and western boundary of the plain is generally well-defined by a break of slope at 17 to 22 m above HWM at the foot of the surrounding hills which attain an elevation of 60 to 120 m and are composed mainly of Cambrian sedimentary and volcanic rocks (Nye *et al.*, 1934; Gulline, 1959). However, partial erosion and aeolian redeposition of marine sands against the lower parts of the hillslopes, and the movement of angular clastic deposits from the hillslopes onto the margins of the plain have masked the upper shoreline features.

With the exception of the Duck River which traverses the eastern margin of the former embayment, the plain is largely devoid of natural surface drainage. Because the fine sands of the plain are porous and the topography is not conducive to rapid runoff, the water table is high and swampy conditions prevail during the winter months. To facilitate drainage an extensive network of shallow drainage ditches has been dug over most of the plain.

Thin freshwater swamp deposits overlie the marine deposits extensively on the central and northwestern part of the plain. These deposits are best developed at Mowbray Swamp near Mella where they are associated with highly mineralised alkaline artesian springs (Chapter 8). The freshwater deposits associated with the springs consist of interbedded woody peats and biochemically precipitated marls and shell marls. Their composition and palaeoenvironmental significance will be discussed in chapters 9 and 10.

Attempts to determine the stratigraphy of the plain by hand augering were prevented below depths of 1.5 to 2.0 m by the presence of high groundwater tables and the widespread occurrence of massive humate-impregnated Groundwater Podzol B horizons. Fortunately, however, a number of water bores have penetrated through the sands. The percussion drilling records (Gulline, 1959) indicate that the floor of the embayment consists mainly of Precambrian dolomite which appears to be overlain along the western margins by discontinuous remnants of weathered Cambrian siltstone.

A levelled section of the approximate drilling sites of some of the water bores between Smithton and Christmas Hills shows that the dolomite floor appears to have a very even surface and that it, and the overlying marine sand and freshwater swamp deposits slope gently towards the sea (Fig. 12). The combined levelling and drilling data also show that the marine sands locally contain a thin basal sandy shell bed that can be traced inland up to an elevation of 13 m above HWM. Hand augering to a depth of about 2 m and the logs of nearby water bores suggest that the shelly sands probably do not occur above this elevation. However, further systematic drilling to bedrock is required to confirm this tentative conclusion.

Towards Christmas Hills, the sands thicken rapidly and gradually pass into a series of deeply podzolised parabolic dunes which, as mentioned previously, rise to a height of about 25 m above the general level of the plain and overlie fossil Krasnozem soils developed on Tertiary basalt.

Unfortunately, no sections that expose the entire thickness of the marine sands occur on the plain. However, the sand deposits are partially exposed in the numerous shallow drainage ditches at Mowbray Swamp and Broadmeadows Swamp. In these areas, thin bedding structures that dip seaward at angles of less than 4° have sometimes been preserved. At Mowbray Swamp the bedded sands contain occasional shell casts of *Fulvia* sp.,

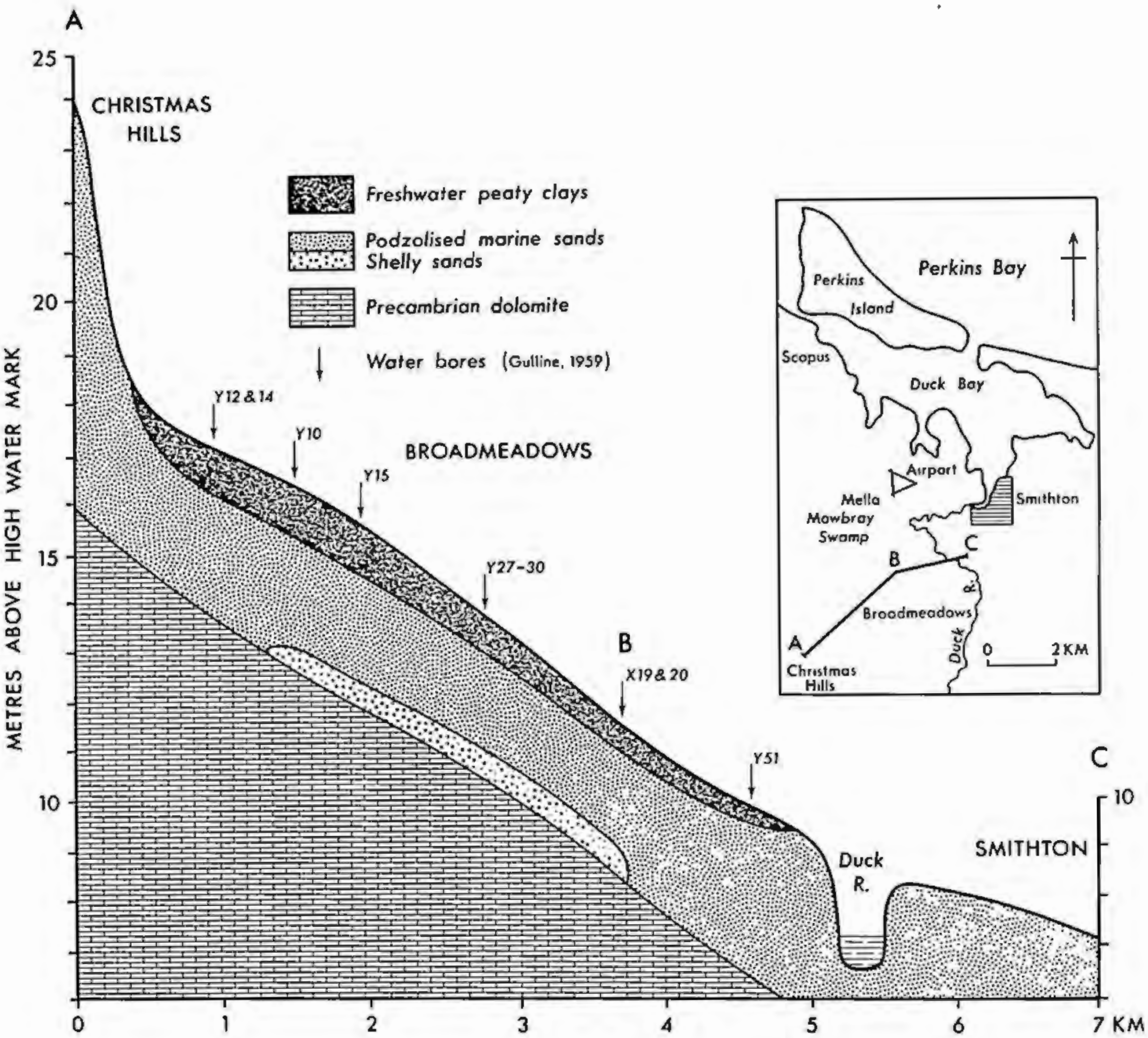


FIGURE 12. Cross-section of the Pleistocene marine sand deposits between Christmas Hills and Smithton.

Tucetilla sp. and small gastropods. Similar shell casts were also reported from this area by Gill and Banks (1956). No bioturbation structures were noted in the bedded sands which suggests that these sediments probably represent a beach facies (Reineck and Singh, 1975).

Along the lagoonal inlet shores of Duck Bay, wave erosion and tidal scour have caused widespread low cliffing and recession of the Pleistocene marine deposits. In front of such cliffed shores and along the banks of some of the large tidal channels, remnant outcrops of truncated Groundwater Podzol B horizons can be seen during periods of low tide. On the floors of the tidal channels, a lag deposit of partly decomposed and broken shells sometimes occurs. The very poor state of preservation of the shells suggests that these channel lag deposits result from the partial reworking of the Pleistocene marine sands by tidal scour.

In sections exposed in salt marsh creek banks, peaty marsh deposits locally overlie thinly bedded, compact dark-brown Pleistocene sands. Low, hummocky modern dunes have locally transgressed across the marsh and Pleistocene marine sand deposits. An example from The Jam area is shown in figure 13 which was constructed from augering and levelling data, and the drilling log of a nearby water bore (Gulline, 1959). The radiocarbon assay of 22,700 ± 1,100 BP (GaK-652) shown in the section was obtained from a sample of broken and largely decomposed shell hash which was collected by Professors J.L. Davies and N. Stephens, and the writer during an exploratory field trip in 1965. Although the sample dated considerably younger than the infinite age expected, it does, however, confirm a Pleistocene age for the

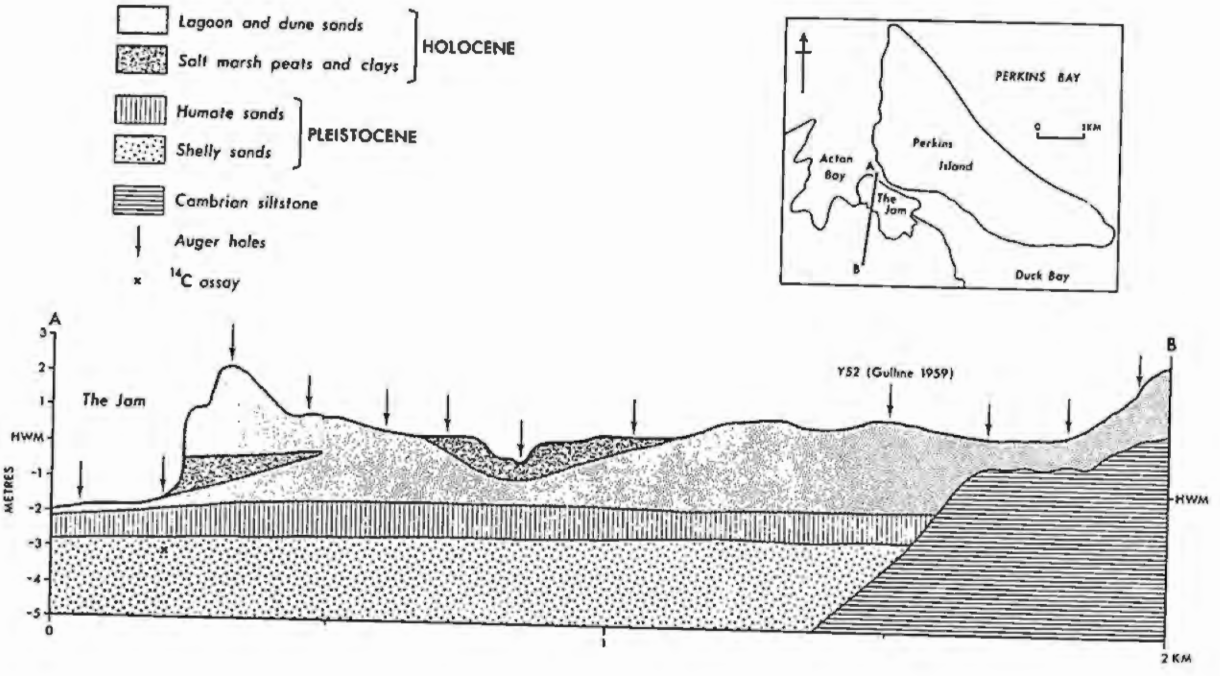


FIGURE 13. Cross-section of the Holocene and Pleistocene marine deposits at The Jam.

deposit. The younger than expected age obtained is almost certainly due to absorption of humic acids derived from the overlying humate-impregnated sands. Furthermore, it is also quite possible that the shells have been subjected to aragonite to calcite open system recrystallization. This process is known to occur commonly in marine carbonates that have been exposed to freshwater vadose conditions for a long period of time and causes changes in the carbon isotope composition of the shells (Chappell and Polach, 1972).

5.4.2 Robbins Island

Pleistocene marine sand deposits and associated transgressive aeolian deposits occur extensively on Robbins Island (Fig. 11). The marine deposits occur primarily in the Remarkable Banks area which, as was described in a previous section, consists of a sequence of degraded, widely spaced podzolised relict beach ridges and swales. Dumpy levelling revealed that the beach ridge plain rises gradually from 2.5 to 3.5 m above HWM at Mosquito Inlet to an elevation of 13 to 15 m above HWM some 9 km inland where it terminates abruptly against the rock surfaces of the old cliffline of White Rock Ridge and degraded transgressive dunes.

Attempts to penetrate the sand deposits of the plain by hand augering were prevented by the presence of a very compact Groundwater Podzol B horizon which is situated generally less than 75 cm below the surface, and by the very widespread occurrence of high water tables. Unfortunately, this area has not been drilled and there is therefore no stratigraphic information for this extensive embayment.

Along its western margin, the Remarkable Banks plain is bounded by an irregular line of cliffs of Precambrian quartzite which forms White Rock Ridge. The lower part of the cliffs is obscured by aeolian sand accumulations that rise a few metres above the level of the plain. Stabilized, subdued parabolic dunes which grade to hummocky sand sheets at higher elevations make up the surface forms on White Rock Ridge. Over most of the ridge the thickness of the aeolian sand cover does not appear to be very great and rock outcrops protrude through the sands in a number of places. Near the top of the ridge, dune outlines resembling traces of parabolic dune forms are clearly visible from aerial photographs and their alignments indicate that the sands were blown some distance onto the ridge from a predominantly southwesterly direction. Dune sections are exposed in a few places where ephemeral creeks have dissected the sand cover. The exposures show that the dunes are deeply podzolised.

The southern and eastern margins of the Remarkable Banks beach ridge plain terminates sharply against an extensive low lying and densely vegetated, poorly drained dune field. Aerial photographs indicate that the dunes, like those presently forming behind the nearby beaches, were blown inland from a northeasterly direction. Approximately 2 km southwest of Guyton Point, the old dunes appear to have transgressed over Tertiary basalt surfaces. In the same general area, sand covered basalt beach cobble deposits, which locally pass into very low amplitude ESE trending ridges occur. Levelling indicates that the cobble deposits occur at 9 to 12 m above HWM. However, because most of this part of the island is covered with a very dense shrub vegetation, it was not possible to determine the exact extent and altitudinal limits of the relict beach cobble deposits.

5.4.3 The Montagu area

The Montagu Plains embayment is situated approximately 12 km west of Smithton and forms part of an extensive low lying, almost featureless plain that slopes very gently towards the sea at Robbins Passage (Fig. 11). The plain is separated from the Smithton embayment at Scopus by a narrow undulating coastal plain that rises sharply to forested Cambrian siltstone hills inland. The former marine embayment is bounded to the south by extensive sandy and silty alluvial deposits, and by thin backwater peat swamp deposits. These deposits overlie Precambrian dolomite and Cambrian quartzite, outcrops of which locally protrude through the sediments. The inland limit of the marine deposits, which probably include some transgressive aeolian sands, has been traced up to 17 m above HWM.

The western boundary of the plain terminates against the slopes of low hills which attain an elevation of 60 m and are composed of Cambrian siltstones and deeply weathered volcanic rocks. The northeast facing lower slopes of the hills are blanketed by an unknown thickness of deeply podzolised dune sand that can be traced to an elevation of 18 to 25 m above HWM. In the north, the marine sands of the plain terminate in a low sandy cliff fronted by salt marshes at Robbins Passage, and against a series of up to 60 m high Tertiary basalt hills on which the village of Montagu is situated.

Although a number of water bores have been drilled in this area (Gulline, 1959), most were located on the low basalt hills around Montagu and on the Cambrian uplands to the east and west. Only four water bores were sited on the Montagu Plains but these were logged in an inconsistent manner and therefore provide only very general information on the stratigraphy and deposits of this area. However, the drilling records show that a 3 to 4 m thick marine sand sequence, which contains shells near the base, overlies a Tertiary marine limestone and a Cambrian siltstone basement. In the Montagu River, which traverses the western margin of the plain, the Tertiary limestone can be seen to unconformably overlie Precambrian dolomite. A few hundred metres east of the river a number of small outcrops of limestone and dolomite, which probably represent former intertidal reefs, protrude through the marine sands. In this area, the marine sands contain a rich and very well preserved fauna of mollusca and foraminifera the composition of which will be described and illustrated in a later section of this chapter. The top of the shell bed is situated at an elevation of 11.5 m above HWM in groundwater saturated sands at 1.0 to 1.5 m below the surface. The results of levelling, augering and probing in a landward direction indicates that the shelly sands probably do not occur at significantly higher elevations. However, because high groundwater conditions prevail throughout the year in this area and augering to depths greater than 1.5 m was not possible, this conclusion is tentative.

5.4.4 Woolnorth

This area which extends from Denium Hill west of Montagu to Woolnorth Point in the extreme west includes Harcus Plain, Swan Bay Plain and Woolnorth Heath (Fig. 11). This very extensive area is characterized by almost featureless, poorly drained plains consisting of deeply podzolised marine sand and fluviatile deposits. With the exception of the westernmost part of the Welcome Heath area where, as previously noted, subdued Pleistocene calcareous dunes on Precambrian quartzites occur, the area has a very even surface which gradually slopes towards the sea. The area is partly bounded to the south and east by a discontinuous fringe of transgressive Pleistocene coastal dunes composed almost entirely of fine quartz sands. The dune system gradually merges inland with alluvial sand deposits at Harcus Plain. The western margin of the coastal plain terminates abruptly at 16 to 21 m above HWM against the degraded slopes of an old sea cliff cut in Precambrian quartzites and Tertiary basalts. As in the Smithton and Montagu area, the lower parts of the cliff are obscured by hummocky aeolian sand accumulations and angular clastic slope deposits.

South of Flat Topped Bluff on the west coast, both active and fossil calcareous transgressive dunes occur. At Studland Bay, a very active, largely unvegetated parabolic dune has transgressed across the basalt coastal range and has extended some distance onto the Welcome Heath area. Although this remote area has not been investigated in any detail, the degree of soil profile development revealed by augering strongly suggests that the easternmost margins of the dune complex are of Pleistocene age and that it is probable that the older dune sands underlie the Holocene dune sands extensively on the uplands.

Except for the Welcome and Harcus rivers and their tributaries, the plains are largely devoid of natural surface drainage. Prior to the excavation of an intensive network of very shallow drainage ditches, high watertables and generally wet conditions prevailed throughout most of the year.

Little is known about the stratigraphy of the vast sand plains. Deep sections in the sediments are very few and attempts to auger through the sands were hindered by the occurrence of high groundwater levels and massive humate-impregnated Groundwater Podzol B soil horizons. Fortunately, however, four water bores have been struck in the Woolnorth area and the drilling logs (Gulline, 1959) show that the sands overlie Precambrian quartzites and Tertiary limestone at depths ranging from 4 to 10 m. Where the podzolised sands overlie the Tertiary limestone, a 1 to 1.5 m thick shell bed occurs at the base of the sands which presumably owes its preservation to alkaline groundwater conditions associated with the limestone. However, the shells were not retained by the drillers and there are therefore no data on the faunal composition of the deposits.

On the east bank of the Welcome Inlet, erosion during high river stages and wave activity during periods of high tides has extensively exposed the sediments of the Swan Bay Plain. A representative section of the exposed sediments is shown in figure 14 which is supplemented by the following description:

Unit 1 consists of moderately podzolized, very fine and well-sorted marine sands which form part of a narrow system of

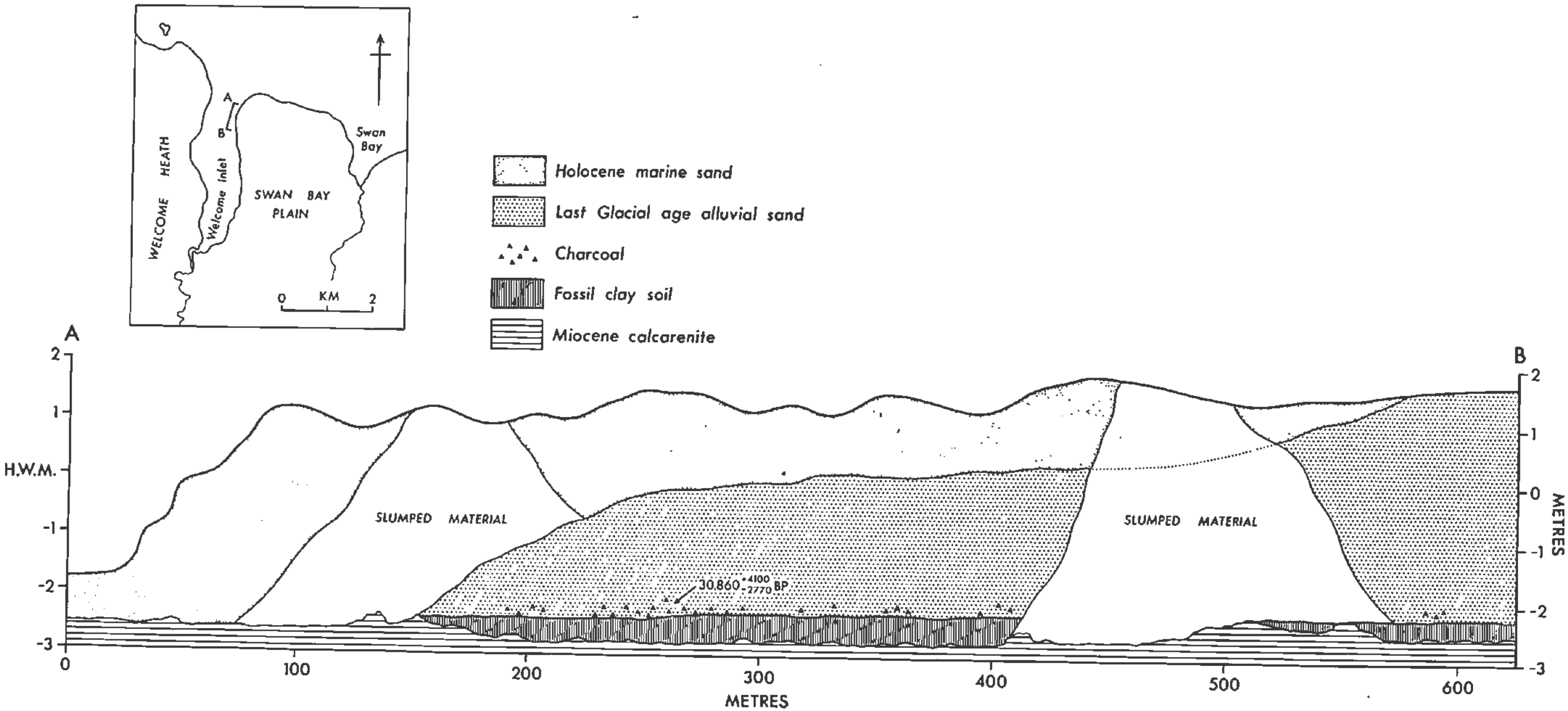


FIGURE 14. Cross-section of the sediments exposed along the east bank of Welcome Inlet.

low amplitude Holocene beach/dune ridges situated at 1.0 to 1.5 m above HWM. Low angle (3-5°) seaward dipping beds have been partly preserved in the predominantly soft, and thin (< 1 m) B soil horizon of this unit which also contains occasional shell casts and largely decomposed pelecepod valves consisting mainly of *Fulvia* sp.

Unit 2 consists of very compact, predominantly horizontally bedded podzolised alluvial sands. The sands are considerably coarser and less well-sorted than the overlying marine sands (Fig. 15) and consist almost entirely of angular quartzite fragments. The alluvial sands become progressively clayey with increasing depth and contain abundant charcoal fragments in the basal 20 cm of the sequence. A sample of the charcoal was assayed by radiocarbon at $30,860 \begin{smallmatrix} +\ 4100 \\ -\ 2770 \end{smallmatrix}$ years BP (GaK-5970). The bedded alluvial sequence increases rapidly in thickness in a landward direction where it contains occasional discontinuous thin lenses of fine angular gravel and rare, well-rounded quartzite pebbles (Plate 14).

The alluvial sands of Unit 2 are underlain by either horizontally bedded fossiliferous Tertiary marine limestone, or as in the figured section, by a 50 cm thick fossil clay soil with occasional Tertiary limestone inclusions. The soil passes gradually into indurated limestone. Outcrops of this basal unit also occur extensively on the intertidal estuarine sand flats and can be traced in an upstream direction for a distance of nearly 4 km (Plate 15). Similar, but much less well exposed and extensive sections of clay and Tertiary limestone, overlain by alluvial sands or estuarine salt marsh deposits, occur along the shores of the Harcus River estuary and at Swan Bay to

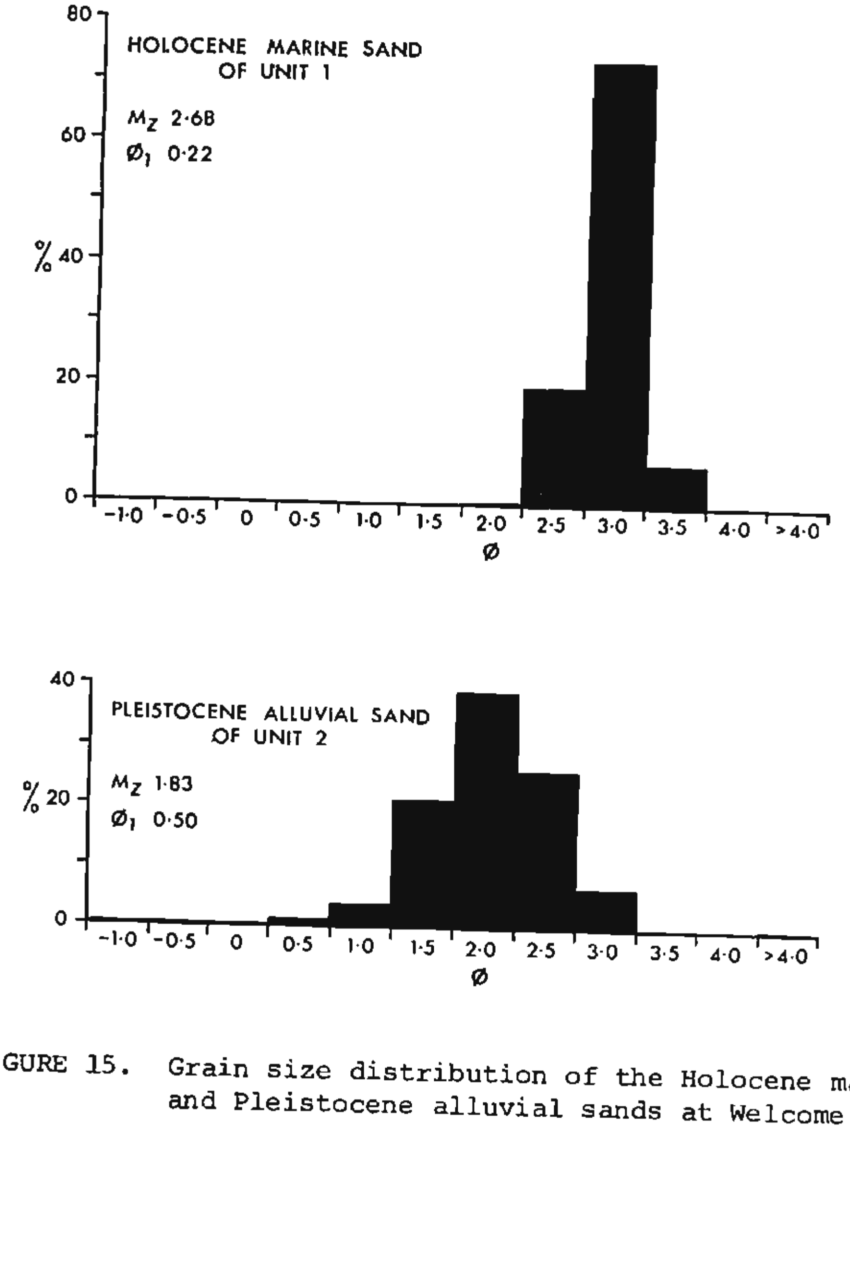


FIGURE 15. Grain size distribution of the Holocene marine and Pleistocene alluvial sands at Welcome Inlet.

PLATE 14. Last Glacial age bedded alluvial sands at Welcome Inlet.

PLATE 15. Fossiliferous Tertiary (Miocene) calcarenite exposed at low tide along the east bank of Welcome Inlet.

the east. Tertiary limestone also underlies the intertidal salt marshes on the west bank of the Welcome River estuary, and as suggested by the water bore data (Gulline, 1959) probably underlies the Pleistocene marine sand deposits at Welcome Heath extensively at depth.

The sequence of sediments outlined above indicates that the alluvial sequence of Unit 2 was deposited during the late Last Glacial Stage as a result of high river discharges that permitted large bed loads to be transported from the hinterland. The approximate extent of the alluvium as determined from widely spaced shallow auger holes and inspection of shallow drainage ditches shows that the sands are very widely distributed. The approximate maximum radiocarbon age of the alluvial sequence helps to explain the absence of Pleistocene marine sediments in the section at Welcome Inlet and nearby estuaries. It is assumed that the marine sands were eroded by river action during the late Glacial Stage. However, it is recognized that remnant Pleistocene marine deposits possibly underlie the alluvium a short distance away from the rivers. This possibility could not be tested with the available equipment.

The marine sands of Unit 1 probably represent the approximate landward limit of the Holocene marine transgression in this area. During this time, a number of low amplitude parallel beach dune ridges developed at the inner margin of the estuary prior to the development of the very extensive tidal flats and salt marshes that characterise this low wave energy environment at the present time.

5.4.5 The Deep Creek and Wiltshire areas

The low lying area between Smithton and Circular Head peninsula forms a continuous coastal sand plain that slopes towards the sea with a gradient of 5 to 15 m/km (Fig. 11). The plain is bounded to the south by a 1.0 to 1.5 km wide fringe of degraded and deeply podzolised parabolic dunes. Between Briant Hill and Tatlows Folly, the transgressive dunes merge inland with extensive, poorly drained tracts of alluvial sand deposits at 20 to 40 m above sea level. East of Tatlows Folly the coastal plain narrows and terminates against the steep slopes of the Tertiary basalt uplands, the lower parts of which are blanketed by an unknown thickness of deeply podzolised dune sand that can be traced to an approximate maximum elevation of 23 m above HWM, and can be seen to overlie thin fossil Krasnozem soils in roadside exposures in the North Forest area.

North of Tatlows Folly, the Pleistocene sand plain, which is partly surmounted by degraded beach ridges at 9 to 11 m above HWM, passes gradually into the back barrier slope of the Anthony Beach ridge and swale complex. As was noted in chapter 3, stratigraphic data from this area shows that the Pleistocene sands pass beneath the Holocene barrier at a very shallow depth. Between Tatlows Folly and Wiltshire the plain terminates in a 2 m high fossil sand cliff that is cut in the old ridged cuspate foreland of West and East inlets.

As elsewhere in the area, attempts to auger through the sands were hindered by the presence of compact Groundwater Podzol B horizons and high water tables. However, very recently a single hole was drilled by the Tasmanian Department of Mines on the plain in the Wiltshire area. Here, at an elevation of 20 m above approximate HWM at East Inlet, 7 m of podzolised dune sand overlies a 1 m thick bed of shelly sand underlain by a 30 cm thick remnant of a humic fossil soil on Cambrian greywackes. A sample of the soil was obtained by the writer for the purpose of pollen analysis. As will be described in more detail in chapter 10, the results show that the pollen assemblage may be interpreted to indicate that a wet sclerophyll forest occupied the site prior to the deposition of the marine sands.

5.5 FAUNA

Samples of shelly sand were obtained from the floors of 1.0 to 1.5 m deep pits excavated at Broadmeadows and Montagu. Unwashed bulk samples were submitted to Mrs. E. Turner of the Tasmanian Museum for identification of the molluscan fauna, and to Dr. P.G. Quilty of Macquarie University for listing of the foraminifera (Tables 4 and 5).

At both collecting sites, the top 10 to 15 cm of the sandy shell bed is situated within the zone of groundwater fluctuation and here most of the shells have been replaced by casts which are held together by a fine light grey sand matrix that has been firmly cemented by secondary carbonates derived from the solution of the shells. Below this zone, the permanently high groundwater table has aided the preservation of the fossils, most of which still exhibit their colour markings and intricate morphological features (Plate 16). Broken shells are few and most of the shells show very little evidence of post-mortem abrasion which suggests that they were not transported by waves and currents for more than relatively short distances before becoming incorporated in a prograding shoreline sequence.

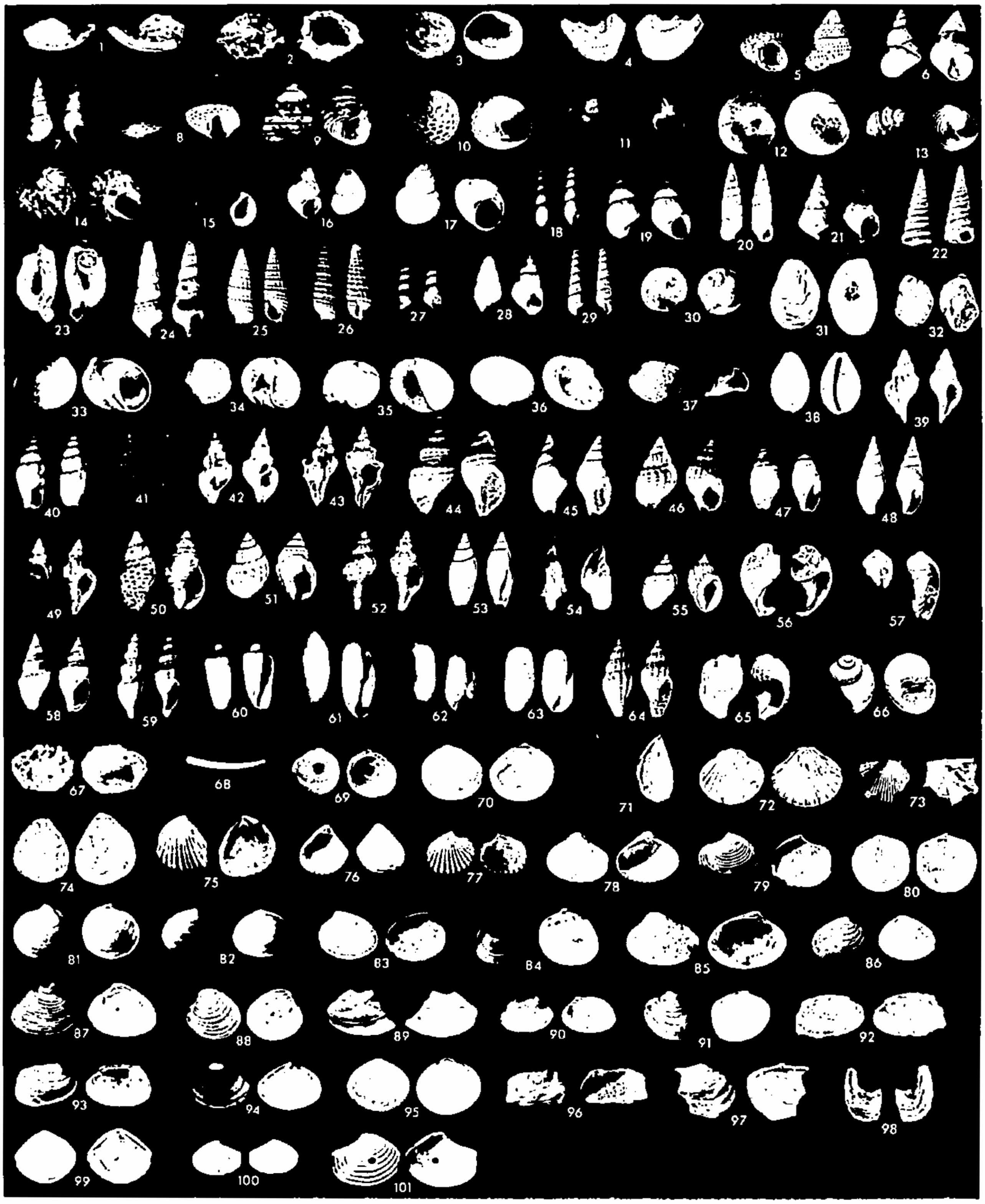


PLATE 16. Fossil mollusca.

TABLE 4 Fossil mollusca

	Broadmeadows	Montagu
1. *Notohaliotus ruber* Leach, 1814 (X0.13)		x
2. *Memitoma subemarginata* Blainville, 1819 (X0.9)		x
3. *Actinoleuca calamus* Crosse & Fischer, 1864 (X0.9)	x	x
4. *Amblychilepas nigrita* Sowerby, 1834 (X0.75)	x	
5. *Thalotia conica* Gray, 1827 (X0.6)	x	x
6. *Phasianotrochus rutilus* Adams, 1851 (X1.0)		x
7. *Bankivia fasciata* Menke, 1830 (X0.62)		x
8. *Calliostoma (australe?)* Broderip, 1835 (X0.6)		x
9. *Austrocochlea constricta* Lamarck, 1822 (X0.36)		x
10. *Austrocochlea concamerata* Wood, 1828 (X0.5)		x
11. *Austrocochlea odontis* Wood, 1828 (X0.5)		x
12. *Clanculus limbatus* Quoy & Gaimard, 1834 (0.51)		x
13. *Clanculus plebejus* Philippi, 1851 (X0.47)		x
14. *Subninella undulata* Solnader, 1786 (X0.23)		x
15. *Phasianella (australis?)* Gmelin, 1788 (X0.19)	x	x
16. *Notosetia nitens* Frauenfeld, 1867 (X0.5)	x	
17. *Notosetia simillima* May, 1915 (X0.66)	x	
18. *Pelecydium badius* Petterd, 1884 (X0.3)	x	
19. *Pisinna bicolor* Petterd, 1884 (X0.5)	x	
20. *Cacozeliana granaria* Kiener, 1842 (X0.66)	x	
21. *Hypotrochus monachus* Crosse & Fischer, 1864 (X0.6)	x	x
22. *Gazameda subsquamosa (tasmanica?)* Tate & May, 1900 (X0.5)		x
23. *Serpulorbis sipho* Lamarck, 1818 (X0.28)		x
24. *Zeacumatus diemenensis* Quoy & Gaimard, 1834 (X0.3)		x
25. *Notosinister festiva* Adams, 1851 (X0.9)	x	
26. *Notosinister pfeifferi* Crosse & Fischer, 1865 (X0.9	x	
27. *Melanella* sp. (X1.1)	x	
28. *Agatha metcalfei* Pritchard & Gatcliff, 1900 (X1.5)	x	
29. *Chemnitzia mariae* Tenison-Woods, 1876 (X1.6)	x	
30. *Sigapatella calyptraeformis* Lamarck, 1822 (X0.8)	x	x
31. *Zeacrypta immersa* Angas, 1865 (X0.41)		x
32. *Polinices conicus* Lamarck, 1822 (X0.26)	x	x
33. *Polinices sordidus* Swainson, 1821 (X0.28)		x
34. *Polinices aulacoglossa* Pilsbry & Vanatta, 1908 (X0.4)		x
35. *Sigaretotrema* sp. (X0.45)		x
36. *Ectosinum zonale* Quoy & Gaimard, 1833 (X0.62)		x
37. *Notocochlis stricta* Verco, 1909 (X0.75)		x
38. *Notocrypraea angustata* Gmelin, 1791 (X0.35)		x
39. *Bedeva paivae* Crosse, 1864 (X0.66)	x	
40. *Macrozafra atkinsoni* Tenison-Woods, 1875 (X0.5)	x	
41. *Cymatiella verrucosa* Reeve, 1844 (X0.33)		x
42. *Negyrina subdistorta* Lamarck, 1822 (X0.2)		x
43. *Pterynotus triformis* Reeve, 1845 (X0.18)		x
44. *Lepsiella vinosa* Lamarck, 1822 (X0.32)		x
45. *Pseudamycla miltostoma ?* Tenison-Woods, 1876 (X0.82)	x	x
46. *Tavanniotha optata* Gould, 1850 (X1.0)	x	
47. *Alocospira petterdi* Tate, 1893 (X0.7)	x	
48. *Dentimitrella* sp. (X0.5)		x
49. *Austrosipho grandis* Gray, 1839 (X0.11)		x

TABLE 4 (contd)

	Broadmeadows	Montagu
50. *Cominella lineolata* Lamarck, 1809 (X0.5)		x
51. *Parcanassa pauperata* Lamarck, 1822 (X0.9)		x
52. *Pleuroploca australasia* Perry, 1811 (X0.26)		x
53. *Cupidolivia numpha* Adams & Angas, 1863 (X1.0)		x
54. *Amorena undulata* Lamarck, 1804 (X0.15)		x
55. *Sydaphera granosa* Sowerby, 1832 (X0.33)		x
56. *Nevia spirata* Lamarck, 1822 (X0.5)		x
57. *Sinuginella pygmaeoides* Singleton, 1937 (X1.5)		x
58. *Epidirona quoyi* Reeve, 1843 (X1.0)		x
59. *Guraleus pictus* Adams & Angas, 1863 (X0.56)	x	x
60. *Retusa amphizosta* Watson, 1886 (X0.83)	x	
61. *Retusa apicina* Gould, 1859 (X1.0)	x	
62. *Cyclichnina atkinsoni* Tenison-Woods, 1875 (X1.0)	x	
63. *Cylichnina* sp. ? (1.0)	x	
64. *Mitraguraleus australis* Adams & Angas, 1863 (X0.5)		x
65. *Pervicacia bicolor* Angas, 1867 (X0.62)		x
66. *Salinator fragilis* Lamarck, 1822 (X0.8)		x
67. *Siphonaria diemenensis* Quoy & Gaimard, 1833 (X0.61)		x
68. *Cadulus vincentianus* Cotton & Godfrey, 1940 (X0.42)	x	
69. *Pronuncula decrorosa* Hedley, 1902 (X0.62)	x	
70. *Tucetilla striatularis* Lamarck, 1819 (X0.26)	x	x
71. *Mytilus planulatus* Lamarck, 1819 (X0.27)		
72. *Pecten meridionalis* Tate, 1886 (X0.15)		x
73. *Chlamys asperrimus* Lamarck, 1819 (X0.15)	x	x
74. *Ostrea angasi* Sowerby, 1871 (X0.15)	x	x
75. *Neotrigonia margaritacea* Lamarck, 1804 (X0.22)	x	x
76. *Cuna concentrica* Hedley, 1902 (X0.13)	x	
77. *Venericardia bimaculata* Deshayes, 1852 (X0.5)	x	x
78. *Cymamiomactra mactroides* Tate & May, 1900 (X0.25)	x	
79. *Myrtea botanica* Hedley, 1908 (X0.76)	x	x
80. *Divalucina cumingi* Adams & Angas, 1863 (X0.32)		x
81. *Wallucina assimilis* Angas, 1867 (X1.0)	x	
82. *Bornia trigonale* Tate, 1879 (X0.6)	x	
83. *Mysella donaciformis* Angas, 1878 (X0.6)	x	
84. *Fulvia tenuicostata* Lamarck, 1819 (X.18)	x	x
85. *Notocallista kingii* Gray, 1827 (X0.23)	x	x
86. *Chioneryx cardioides* Lamarck, 1818 (X0.77)	x	x
87. *Tawera gallinula* Lamarck, 1818 (X0.28)	x	x
88. *Placemen placida* Philippi, 1844 (X0.45)	x	x
89. *Callanaitis disjecta* Perry, 1811 (X0.35)		x
90. *Eumarica fumigata* Sowerby, 1853 (X0.18)	x	
91. *Katelysia peronii* Lamarck, 1818 (X0.28)	x	x
92. *Venerupis diemenensis* Quoy & Gaimard, 1835 (X0.39)		x
93. *Venerupis exotica* Lamarck, 1818 (X0.31)		x
94. *Donacilla erycinaea* Lamarck, 1818 (X0.33)	x	x
95. *Pseudarcopagia botanica* Hedley, 1917 (X0.5)		x
96. *Hiatella australis* Lamarck, 1818 (X0.7)		x
97. *Panope australis* Sowerby, 1833 (X0.23)		x
98. *Gari livida* Lamarck, 1818 (X0.2)	x	
99. *Myadora brevis* Sowerby, 1829 (X0.25)	x	x
100. *Myadora complexa* Iredale, 1924 (X0.33)	x	
101. *Myadora tasmanica* Tenison-Woods, 1875 (X0.5)		x

Since there is very little detailed knowledge of the present-day ecology of Tasmanian mollusca and foraminifera, only a very general assessment of the palaeoenvironment is possible. Perhaps the most significant characteristic of the fauna is that it does not contain extinct species.

The composition of the molluscan fauna is generally very similar to those now found in the shallow offshore areas of Bass Strait (May, 1923; Kershaw, 1958), and similar fossil assemblages commonly occur as a beach backwash deposit near low water mark along the shores of the open sandy embayments of the area. The composition of the Broadmeadows fauna is dominated by a great variety of subtidal pelecepods which suggests that the environment in which the organisms lived consisted of a quiet, shallow (20-30 m deep) open sandy bay environment, very similar to the present nearshore and offshore areas of Perkins Bay (Turner, personal communication). In contrast, the Montagu fauna contains a much greater number and variety of rock substrate species which suggests that the environment possibly consisted of a quiet sandy bay protected from strong wave action by intertidal and subtidal reefs. As was briefly noted in the previous section, a number of rock outcrops protrude through the marine sand deposits in the Montagu embayment and thus tends to support the general assessment of the environment in which the molluscs lived.

The foraminiferal fauna has much in common with the Bass Strait faunas in general and is normal for water depths of 10 to 50 m (Quilty, personal communication). It contains 15 to 20 percent planktonic forms, and brackish water benthonic species are relatively rare (< 5%). This strongly suggests that deposition occurred in open embayments from which estuarine fresh water influences were largely excluded.

TABLE 5 Fossil foraminifera

Benthonic species	Montagu	Broadmeadows
Elphidium crispum Linné 1758	x	x
Elphidium advenum Cushman 1922	x	x
Cibioides refulgens de Montfort 1808	x	
Cibioides lebatulus Walker & Jacob 1798	x	
Discorbis barkeri Mehan & Bhatt 1968	x	
Ammonia beccarii Linné 1767	x	x
Triloculina laevigata d'Orbigny 1878	x	x
Quinqueloculina lamarckiana d'Orbigny 1839	x	
Bulimina marginata d'Orbigny 1826	x	x

Planktonic species	Montagu	Broadmeadows
Globorotalia inflata d'Orbigny 1839	x	x
Globorotalia dutertrei subcretacea Lomnicki 1901	x	
Globigerina bulloides d'Orbigny 1826	x	x
Globigerinoides quadrilobatus immaturus Le Roy 1939	x	
Globigerinita glutinata Egger 1893	x	

Unlike the fossil evidence from similar Pleistocene sand deposits on King Island (Jennings, 1959), no warmer water planktonic foraminifera were noted. From this it may be tentatively concluded that sea water temperatures were probably very similar to those prevailing at the present time.

5.6 SEDIMENT ANALYSIS

5.6.1 Introduction

In order to broadly illustrate the physical characteristics of the Pleistocene marine sediments, representative samples were collected by augering at a uniform depth of 1 m in the Wiltshire, Smithton, Montagu and Woolnorth areas, and on Robbins Island. The grain size distribution of the samples was determined in the same manner as the Holocene marine sands described in chapter 3. Most of the samples contained small amounts of humic material. This was removed prior to mechanical sieving by boiling with H_2O_2. The results of the analysis and statistical treatment of the distribution data are presented in figure 16. The results are based on the average of five shell carbonate free samples from each of the three environments indicated.

5.6.2 The sediments

The Pleistocene marine sediments consist of moderately well-rounded quartz sands. The results of the size analysis show that the sands are medium-fine to very fine grained and very well-sorted. Both beach ridge and dune sands are slightly finer (M_z 2.90-2.98) and better sorted (ϕ_1 0.30) than the shelly

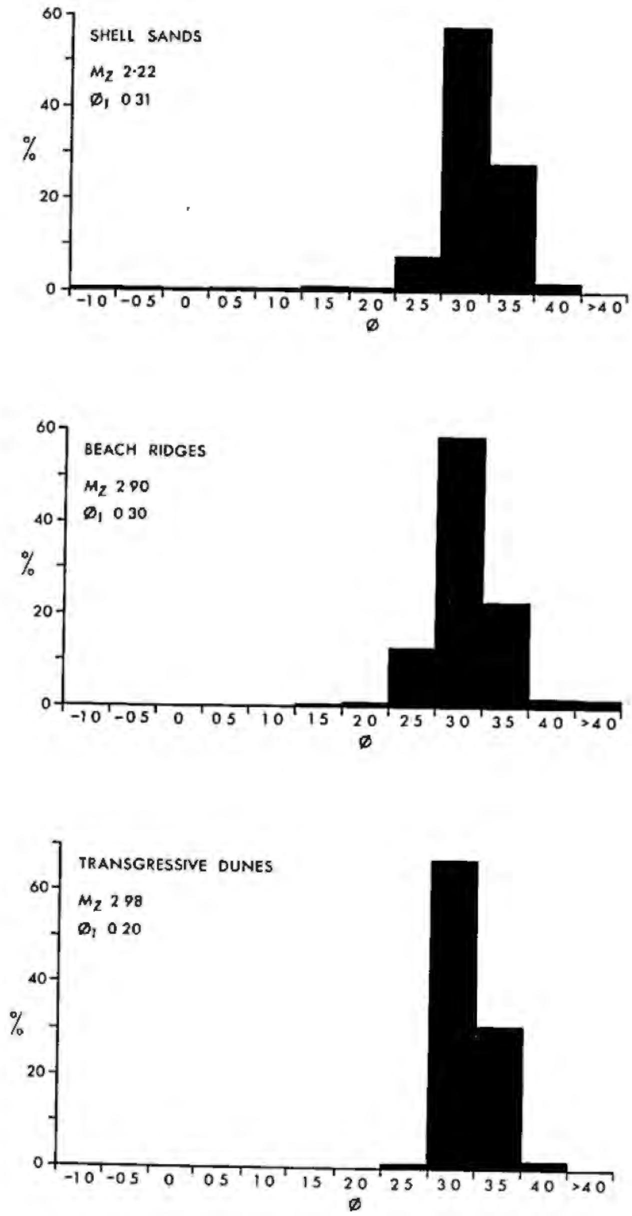


FIGURE 16. Grain size distribution of Pleistocene marine sands.

beach sands (M_z 2.22; ϕ_1 0.20). These minor differences reflect the selective remobilization of the finer sand fraction by onshore winds, a general trend that was also evident in the Holocene marine sands. Comparison with the Holocene barrier sands shows that the Pleistocene beach and beach ridge sands are slightly coarser and less well-sorted than the Holocene barrier sands, however, much more grain size data from both systems are required before the possible environmental significance of this apparent temporal variation can be evaluated.

Perhaps a more significant and noteworthy difference between the granulometric characteristics of the Pleistocene and Holocene marine sands is the consistent presence in the former of small amounts of material finer than 3.5 ϕ. Microscopic examination revealed that this fine fraction consists entirely of sub-rounded quartz fragments. It is not unlikely that the fine material is an inherent characteristic of the sediments and has been concentrated at depth as a result of illuviation. It is also possible, however, that it was introduced at the surface and illuviated, and is perhaps of aeolian origin. If this tentative inference is correct, this phase of aeolian activity must post-date the period of Pleistocene progradation, and in view of the fact that this fine material is virtually absent (< 0.2%) from the Holocene barrier sediments, it must pre-date the formation of the Holocene barrier systems. It is not unlikely that considerable aeolian remobilization of pre-Holocene sands was initiated by the Holocene transgression and that wind-borne particles derived from aeolian activity seawards of the present coast were carried inland and deposited over the lowlands. Alternatively, it is also possible that the fine material was derived as a result of deflation of parts of the Bassian sand plain or inland alluvial deposits during the late Last Glacial Stage (~ 22,000-11,000 BP) when the climate in northwestern Tasmania and elsewhere on the island was considerably drier than at present (Chapters 9 and 10).

5.6.3 Soil development

At elevations less than 20 m above present sea level, the soils of the plains have been derived primarily from siliceous marine sands. Similar soils also occur at higher elevations but only in very restricted areas where sand has been blown from the plains onto rock surfaces. With the exception of areas where alkaline peats, shell marls and biochemically precipitated marls blanket the marine sand deposits (Chapter 9), the lowland sand plains exhibit deeply podzolised and acid (pH 4.0-5.0) soil profiles that contain strongly developed humate-impregnated sand rock horizons which are in many respects very similar to those described from other coastal areas of Australia (Coaldrake, 1955; Langford-Smith and Thom, 1969; Jennings, 1959, 1961; Thom, 1965; Hails and Hoyt, 1968; Ward *et al.*, 1979).

As described by Coaldrake (1955) several different types of coastal sandrock occur in Australia, however, the most common has been formed by *in situ* cementation at groundwater level of loose sand by organic colloids and sesquioxides carried through the coastal sands by percolating rainwater. The sandrock formed in this way represents the illuvial B horizon of a Groundwater Podzol (Stephens, 1962). Such soils are also known as Humus

Podzol (Stace *et al.*, 1968) and bleached sands with pan (Northcote *et al.*, 1975).

The soils of the marine sand plains have been broadly described by Hubble (1951). His observations have been supplemented by the writer's observations of a number of sections exposed in drainage ditches on the plains and cliffed foreshore exposures in the Duck Bay area. A representative soil profile of the marine sand plains is as follows:

A_1	0-15 cm	Grey to dark grey sand with coarse organic matter in discrete particles.
A_2	15-150 cm	Light grey mottled sand with coarse fibrous sedge roots grading to light grey to white sand without plant roots at lower levels.
$B_{2h,ir}$	150-210 cm	Dark brown to black humate-cemented sand of varying hardness. Cliffed foreshore exposures in the Duck Bay area reveal that the humate-cemented sands continue to an unknown depth below sea level with frequent variations in hardness and locally overlie shelly sands.

The field observations also indicated that there is considerable spatial variation in both the depth below the surface and the degree of cementation of the $B_{2h,ir}$ horizons of the Groundwater Podzols in the area. Such variation appears to be due largely to local differences in the drainage characteristics of the sands, which are determined mostly by topography. Deep and freely drained

drained A horizons occur mainly in areas of higher relief such as dunes and some of the higher relict beach ridges on Robbins Island.

A number of foreshore sections in the Duck Bay area revealed that the contact between the A and B horizons frequently undulates and that the latter may be divided into multiple horizons. This indicates that the soil was formed under fluctuating groundwater table conditions.

Combustion of 5 sandrock samples at 500°C for one hour showed the humate content to range from 7 to 12 percent. There was very little ferric oxide residue which indicates that iron compounds play only a minor role as a cementing agent of the sandrock.

As was noted previously, the drainage status of the sand plains is generally very poor and surface water lies on the surface during the winter months, and occasionally extends well into the summer months, as in the Woolnorth-Swan Bay area and on Robbins Island. The few streams that cross the plains play an insignificant role in the removal of excess surface water. In cleared areas, however, much of the surface water is carried off by an extensive network of shallow drainage ditches. In localities where the water table is very close to the surface throughout the year, shallow swamps often occupy the swales of old beach ridges and localized depressions. The soil profiles developed in such areas differ from the example presented earlier in that a well developed leached light grey to white A_2 soil horizon is usually absent, and in that the surface 20 to 30 cm of the soil consists of very dark grey to black peaty matter with coarse, fibrous sedge(?) roots and very little sand.

Although groundwater podzolisation is the dominant soil forming trend on the plains, some of the larger old coastal parabolic dunes as at Christmas Hills display a Podzol soil profile which differs from the Groundwater Podzols in that the $B_{2h,ir}$ horizon is freely drained and oxidizing conditions are always present which causes induration of the B horizon.

A small area of Pleistocene subdued, very calcareous dunes forming alkaline (pH 8.0-9.0) Terra Rossa-type soils occurs west and north of the Woolnorth Estate homestead at Welcome Heath. The soils are well drained except for the depressions in the dunes where minor springs periodically occur. The dunes overlie Precambrian quartzites, outcrops of which protrude through the dune sands northwest of the homestead. A section exposed in a dune quarry (Plate 13) showed the following soil profile characteristics:

A	0-15 cm	Friable dark reddish-brown to brown loamy sand.
B	15-50 cm	Light red-brown friable sandy loam to sandy clay.
B/C	50-110 cm	Light brownish-yellow shelly sand with moderate secondary carbonate root casts and nodular inclusions.
C	110-460 cm	Pale yellow medium-fine shelly sand containing approximately 85 percent calcium carbonate.

As was noted on page 79, the shelly material that makes up these fossil dunes was blown inland from a Pleistocene beach at Valley Bay on the exposed west coast. Here, extensive, locally active calcareous parabolic dunes of Holocene age occur which like their Pleistocene counterparts are much more calcareous than the dunes presently forming along the Bass Strait coast. In contrast to the calcareous Pleistocene dunes, the Holocene calcareous dunes show little development of a soil profile beyond surface accumulation of organic matter and generally very slight leaching of the shell fragments which indicates that the Terra Rossa soils are of considerable age. A similar sharp contrast in the degree of soil development was noted by Dimmock (1957) on the west coast of Flinders Island. Terra Rossa soils also occur extensively on the Pleistocene dunes of western King Island (Jennings, 1959). Similar soils occur on the fringe of Pleistocene dune limestone plastered onto much of the coast of South Australia and Western Australia (Bauer, 1961), and on Pleistocene beach ridges in southeast South Australia (Blackburn *et al.*, 1965).

CHAPTER 6

PLEISTOCENE SHORE PLATFORMS AND BEACH COBBLE DEPOSITS

6.1 INTRODUCTION

Circular Head peninsula (Fig. 11) is a composite tombolo. The main part of the peninsula which is known as Green Hills consists of a 40 m high, almost flat-topped basalt ridge which is tied to the mainland by a Pleistocene fossil cobble beach overlain by a system of parallel dunes of Holocene age (Plate 17), and a Pleistocene cuspate foreland consisting of low degraded sand beach ridges.

Circular Head which is also known locally as The Nut (Plate 18) is the remains of a volcanic neck and consists of gigantic columns of coarse crystalline basaltic rock, 1.5 to 2 m in diameter, and rising to a height of 140 m above sea level. The columns are vertical and in places form high cliffs with a fringe of steeply sloping scree around their lowest parts. The Nut is tied to the basalt ridge of Green Hills by a Holocene tombolo which enclose an artificially drained and reclaimed marshy lagoon.

Holocene barrier sand spits occur on either side of the peninsula at North Forest and partly enclose extensive inlets

PLATE 17. Elevated Pleistocene beach cobble deposit overlain by Holocene dune sands between Tatlows Beach and Green Hills, Circular Head Peninsula.

PLATE 18. "The Nut" at Stanley joined to the main part of Circular Head Peninsula by a tombolo. The fence in the middle foreground marks the edge of the elevated shore platform at the northern headland of Godfreys Beach.

consisting of wide, sandy tidal flats fringed by salt marshes. The inlets are drained by a system of large tidal channels and creeks.

Elevated shore platforms covered with a veneer of rounded beach cobbles occur extensively in this area and provide further unequivocal evidence for a high pre-Holocene sea level. The elevations of the fossil marine features to be described in some detail below were obtained with the aid of a Dumpy level.

6.2 DISTRIBUTION, MORPHOLOGY AND STRATIGRAPHIC RELATIONSHIPS

At the northern headland of Godfreys Beach, a remnant of an elevated basalt shore platform occurs. Its seaward edge consists of a cliff which is situated 7 m above HWM. The platform slopes gradually inland to an elevation of 12 to 14 m above HWM where it terminates against the degraded slopes of Green Hills. Exposures along the seaward cliff show that the platform is covered by up to 70 cm of rounded basalt cobbles but the gravel veneer also includes occasional quartzite pebbles (Plate 19). A few hundred metres north along the cliff, a more extensive fossil shore platform occurs at about 9 m above a narrow modern wave-cut bench and extends back to nearly 15 m above HWM. This seaward sloping platform is also overlain by a thin veneer of well-rounded cobbles and pebbles. Rock stacks and islets which occur a few hundred metres offshore testify to the former further extension of this shore platform.

On the western side of Green Hills, further evidence of a high sea level is found. Here, the present shore is fronted by a wide sandy, and locally gravelly, beach the back of which is

PLATE 19. Detail of relict boulder and cobble beach capping the basalt shore platform at the northern headland of Godfreys Beach.

marked by low dunes that enclose a small marshy lagoon. From the lagoon, a platform rises sharply to 14 m above HWM over a distance of about 100 m and terminates against the steep slopes of the basalt ridge. This steeply seaward sloping platform, which runs along the whole western side of Green Hills, is covered by a 1 m thick cobble beach deposit which is overlain by a thin layer of soil and slope wash. A very similar situation exists all along the eastern side of Green Hills. Here, parallel Holocene coastal dunes have partly transgressed across an old seaward sloping platform which terminates in a well-marked cliff line at 13 to 15 m above HWM (Plate 20).

The Western Plains area forms a low lying extension of the peninsula. With the exception of the central part where two gently sloping basalt hills rise to about 40 m and very large angular basalt boulders protrude through the surface of the plain, the area is almost level. Approximately midway along Half Moon Bay the Western Plains terminate in a cliff about 6 m high (Plate 21). Exposures in the cliff face show that, as at Godfreys Beach, the platform is covered with a veneer of well-rounded beach cobbles and pebbles. The even surface of the platform and fossil cobble beach rises very gradually inshore to an elevation of 10 to 12 m above HWM and terminates against the previously mentioned low hills and basalt outcrops.

All along the northeastern, and also along a considerable extent of the southwestern shores of the Western Plains area, extensive cobble and pebble storm ridges have been built up to about 3 m above HWM during Holocene times. However, nowhere in the area is there evidence of modern beach materials having been

PLATE 20. Abandoned sea cliff and shore platform cut in basalt along eastern part of Green Hills.

PLATE 21. Frontal edge of Western Plains shore platform and boulder beach deposit at Half Moon Bay, Circular Head Peninsula.

thrown onto the fossil platforms at higher levels as a result of exceptional storm wave activity.

A number of largely obscured exposures of a cobble and pebble beach deposit at 9 to 13 m above HWM occur at Stanley and indicates that the village was partly built on a Pleistocene beach that formed in the lee of The Nut. Locally the deposit appears to be overlain by Holocene dune sands blown inland from Godfreys Beach.

6.3 SIGNIFICANCE OF THE SHORE PLATFORMS AND BEACH COBBLE DEPOSITS

There can be little doubt that the extensive and well-developed sea cliffs and wide seaward sloping (2°–5°) shore platforms covered by well-rounded beach cobble deposits in this area have resulted from a long period of wave activity during a Pleistocene high sea level stage. Although these relict marine landforms and deposits occur consistently up to about 15 m above HWM, uppermost shoreline features representing the maximum of the transgression have been masked by the movement of slope deposits from the steep hillsides onto the margins of the platforms. Because no suitable drilling equipment was available to the writer, precise upper marine limits could not be determined.

Since the fossil shoreline features occur in relatively exposed situations it may be argued that they do not necessarily indicate accurately the sea level with which they were associated, because it is recognized that wave action, particularly during severe storms, could abrade rock shores and deposit cobble beaches several metres above normal high water levels. However, as was briefly noted, contemporary cobble and pebble beach deposits in the area occur only 2 to 3 m above HWM. Assuming that at the time of the Pleistocene transgression wave intensities were not dissimilar to the present ones, the normal limit of wave processes is unlikely to have been more than 3 m above the prevailing mean sea level. It is likely, however, that the upper limit of effective wave action may have been somewhat higher in headland situations where wave energy was more intense than in the less exposed embayment locations.

None of the evidence considered here is radiometrically datable and the approximate age of the relict marine features is difficult to ascertain. However, since the fossil features occur at elevations very similar to the approximate upper limits of the more extensive marine sand deposits described in chapter 5 and are likewise locally overlain by marine sands of Holocene age, it is considered probable that they are of the same general age as the marine sand deposits. The apparently fine state of preservation of most of the beach cobbles suggests that they are probably not very old. Similarly, although the abandoned sea cliffs are somewhat degraded, they are well defined and suggest that they were cut in the not too distant past. The problem of determining the age of the relict marine landforms and deposits in northwestern Tasmania will be more fully considered in the following chapter.

CHAPTER 7

PLEISTOCENE SEA LEVELS

7.1 INTRODUCTION

The evidence described in the previous two chapters shows that there is clear erosional and depositional evidence in northwestern Tasmania that at some stage during the Pleistocene the sea stood approximately 15 m higher relative to present sea level. It is stressed that it is necessary to use the term relative in this context, as it is not clear whether the present position of the relict shorelines is the result of eustatic movement or tectonic movement, or a combination of both. The main aim of this chapter is to try and resolve this question. To achieve this it will be necessary to briefly review and evaluate the theories that have been put forward to explain the occurrence of emerged shorelines; and to compare the results of this study with that of other relevant research in Tasmania, and further afield.

7.2 BACKGROUND TO PLEISTOCENE SEA LEVEL CHANGES

During the first decades of this century, De Lamothe (1918), Baulig (1935), Daly (1943) and others postulated that most sea level oscillations and relict shorelines of the Quaternary were glacio-eustatic. They believed, correctly, that sea level oscillated in response to the waxing and waning of continental ice sheets. They proposed that there was a sequence of raised beaches along the shores of the western Mediterranean which could be related to different glacial events. This sequence consisted of five main terraces within the following limits: 90-100, 55-60, 28-30, 18-20 and 7-8 m (Guilcher, 1969). It was believed that this sequence recorded a series of oscillating sea levels, with maxima at progressively lower levels. For a time there was a tendency to correlate terraces discovered at these levels on other coasts with the Mediterranean sequence (see Zeuner, 1959), and to accept the correlation as evidence of the stability of the coast concerned. However, it is now recognized that the Mediterranean shoreline sequence has been affected by recent crustal movements, and thus can no longer be regarded as a means of obtaining precise values for the altitudes of Quaternary glacio-eustatic stillstands (Hey, 1978).

There are a number of objections that can be raised against the classic glacio-eustatic theory. It is obvious that this theory is not valid in all regions of the world, because not all regions have been stable during the Quaternary. It is also widely recognized, that in areas which received the load of ice caps during glaciations, isostatic movements occurred. Many of such areas have been studied in great detail in this respect, and the principles of isostatic recovery during and after ice retreat, resulting in tilted successive shorelines, have been clearly defined (e.g. Donner, 1965; Stephens and Synge, 1966;

Andrews, 1970). Other areas must also be excluded because they are either subsiding or are being uplifted at the present time (see Goudie, 1977, 191-192).

Orogenic activity is normally considered as being an essentially local factor of sea level change, and eustacy as being of world-wide nature. However, it is believed by some that local orogenic activity can have world-wide effects. This concept is commonly referred to as orogenic-eustacy. According to this concept, as postulated by Grasty (1967), large scale deformation and uplift of tectonically active areas could result in an increase of the area of the oceans and cause emergence of stable land masses. Over a long time period this process could be significant, though it probably cannot explain the relatively short amplitude sea level fluctuations of the Pleistocene. Nevertheless, it remains a possibility that the gradual fall in sea levels during the Pleistocene has been caused partly by this type of mechanism.

Recent developments in the field of global tectonics have added further complications to the classic glacio-eustatic theory of sea level change. According to current concepts, crustal plates grow along mid-ocean ridges and sink or override each other where they again come in contact. Changes in the rate of accretion at mid-ocean ridges will result in changes in the depth of the oceans, since uplift or subsidence of the ocean floor is a function of ridge activity. The concept that ridge activity may affect sea level has been postulated by a number of workers (e.g. Russell, 1968; Menard, 1969; Jacoby, 1972; Flemming and Roberts, 1973). As a result of recent developments in global tectonics and ocean floor spreading, Bloom (1971) has stressed the need for caution in accounting for changes in sea level in terms of changes in the proportion of water stored in glaciers. He estimates that as the ocean basins are widening at rates of up to 16 cm per year, the increase in volume of the oceans since the Last Interglacial Stage could accommodate about 6 percent of the returned meltwater, and that the Holocene shorelines would be about 8 metres lower than the interglacial shorelines of 100,000 years ago.

Also involving tectonic factors is the theory of hydro-isostacy. According to this theory, some continental shelves are out of phase in their adjustment to loading and unloading of water fed into or taken from the oceans by the growth and decay of ice masses. This hypothesis requires a lag response to load, so that the maximum downwarp of a shelf and adjacent coast is achieved sometime during the subsequent regressive sea level phase. The maximum upwarp of the next phase occurs after sea level has reached its minimum and is commencing its transgression. It is envisaged that the rate and amount of hydro-isostatic deformation would vary according to various factors. For instance, coasts adjacent to deep water would have their water load added early and close to shore during a transgression, whilst coasts which border shallow seas, such as Bass Strait, would have their load added late and, generally, far offshore. From this one would expect that the submergence would be roughly proportional to the proximity of deep water. This has tentatively been confirmed by the postglacial submergence histories of five eastern United States coastal sites (Bloom, 1967). Other factors which are believed to affect the degree of hydro-isostatic deformation are the local sub-crustal density, its dynamic viscosity, and the degree of isostatic adjustment achieved before loading or unloading began.

The concept that the earth's crust responds isostatically to changing ice and water loads is supported by recent quantitative studies (e.g. Walcott, 1972; Chappell, 1974; Clark *et al.*, 1978). These studies also indicate that the best place to observe the movement of sea level relative to the ocean basins is on the mid-oceanic islands, which are remote from plate boundaries, and move with the ocean floor in its response to changing water loads.

Until recently and almost without exception, eustatic sea level changes have been largely equated to recession and advances of Northern Hemisphere ice sheets. However, it is now believed by some that major changes in the amount of ice stored in Antarctica played an important role. The hypothesis referred to here postulates that large parts of the Antarctic ice sheet fluctuated out of phase with the Northern Hemisphere glaciations, and that periodically ice is discharged into the Southern Ocean causing a rapid rise of eustatic sea level. This controversial hypothesis was first formulated by Wilson (1964), and discussed by Hollin (1965, 1977, 1980), Mercer (1968), Denton *et al.* (1971), Flohn (1974) and Budd and McInnes (1978).

Although Wilson's hypothesis has considerable appeal, data from Southern Ocean deep sea cores argue strongly against major surges, but do not eliminate the possibility of smaller surges (Denton *et al.*, 1971, 298). However, very recent radiometrically controlled stable isotope and sea level data from New Guinea seems to unequivocally support Wilson's surge hypothesis (Aharon *et al.*, 1980). Furthermore, this study also points to the probability that an Antarctic ice surge may have initiated the Last Glaciation. From this it is clearly apparent that problems concerning the climatic and eustatic effects possibly caused by the dynamics of the Antarctic ice sheet require further detailed study.

Perhaps the most significant contribution to a better understanding of the magnitude of glacio-eustatic sea level changes has been provided by the results of oxygèn isotope studies of Pleistocene foraminiferal tests in deep-sea sediments. The original aim of oxygen isotope studies was to measure palaeotemperature (e.g. Epstein *et al.*, 1953; Emiliani, 1955, 1966). However, since 1955 the main development in work on Pleistocene deep-sea sediments has been the appreciation that variations in ocean ^{18}O content play a greater role than originally realized. During each glacial, isotopically light ice accumulated on the continents, leaving the oceans slightly enriched in ^{18}O. Consideration of the known isotopic composition of snow over the Antarctic ice sheet led Olauson (1965) to suggest that the effect on ocean composition was significantly greater than estimated by Emiliani (1955). Later Dansgaard and Tauber (1969) re-emphasised this point, and Shackleton (1967) confirmed it directly by making isotope analyses of benthonic foraminifera from deep water where the effects of temperature changes must have been minimal. The conclusion of Shackleton's study was that the main value of oxygen isotope sequences in Pleistocene deep-sea sediment cores lies in their direct and continuous record of ocean volume and hence sea level. More recently, valuable palaeo-sea level data has been obtained by this method. Based on an approximate equivalent of 0.1°/₀₀ isotope deviation to 10 m of sea level change, Shackleton and Opdyke (1973) have constructed a general sea level curve for the past 130 ka. This curve shows a remarkable agreement with the position of relative sea levels recorded from uranium series dated and oxygen isotope calibrated tectonically uplifted coral terrace shorelines in Barbados (Broecker *et al.*, 1968; Shackleton and Matthews, 1977; Fairbanks and Matthews, 1978), and New Guinea (Veeh and Chappell, 1970) and thus demonstrates convincingly that the method can give a reasonably clear record of glacio-eustatic sea level changes without the complicating effects of tectono-eustatism and hydro-isostatic adjustments due to changing loading factors.

7.3 INTERGLACIAL SEA LEVELS IN NORTHWESTERN TASMANIA

Since sea levels during glacial and interstadial episodes were well below present sea level (e.g. Broecker and Van Donk, 1970; Thom, 1973), it is clear that the relict marine landforms and deposits of northwestern Tasmania represent an interglacial sequence. Limited sub-surface data indicates that the deposits do not contain a stratigraphic break which suggests that they represent a single transgression. Shelly marine sands can be traced up to 13 m at Broadmeadows and 11 m at Montagu, and degraded sea cliffs and associated landforms and deposits occur consistently up to 15m above HWM in the Circular Head area. However, because the uppermost shoreline features have been masked by aeolian redeposition of marine sands and the movement of slope deposits it has not been possible to determine the maximum of the transgression in this region. The precise upper marine limits can only be determined with the aid of an extensive drilling programme and detailed sedimentological analysis of sub-surface samples. Because no suitable drilling equipment was available to the writer this could not be undertaken.

As was described in chapter 5, degraded, deeply podzolised transgressive coastal dunes are a common feature along the northeasterly facing innermost margins of the sand plains. Although some of these dunes may have begun to form before the innermost shorelines on the plain developed, it is not unlikely that they formed mainly during generally stable sea level conditions associated with the maximum of the transgression and perhaps reflect a period of diminishing sediment supply as a result of sea level stability, and/or variation in the frequency and magnitude of climatic factors.

Whereas there may have been a period of diminished sediment supply towards the end of the transgression, in contrast, the gradual altitudinal decline of the marine sand deposits substantially supports the hypothesis that excess sediment must have existed in the offshore reservoir during the regression, and that this material was continuously available for shoreward displacement and progradation. Furthermore, the parallel and regular nature of the relict ridge and swale topography demonstrates that the rate of shoreline progradation and subsequent stabilization by sand-binding vegetation was sufficiently rapid to prevent blowout and secondary transgressive dune formation on the plains. A warm, humid climate would have been conducive to the stabilization of beach ridges and parallel dunes by herbaceous and woody vegetation. In addition, the overall alignment of the fossil beach ridges clearly indicates that the dominant swell wave regime of that period was generally comparable with the present.

Other field evidence which unequivocally demonstrates a lengthy period of high sea level is provided by the erosional marine landforms in the Circular Head area. Although it is not possible to conclusively demonstrate that these features represent the same event as the more extensively developed marine sand deposits elsewhere in the area, there can be little doubt that the formation of the well-developed sea cliffs and seaward sloping shore platforms with beach cobble deposits which occur consistently up to an apparent limit of around 15 m above HWM have resulted from a prolonged period of marine processes at or about this altitude.

The presence of broad embayments, sloping gently seaward west of Smithton suggests that they would have been very favourable sites for the development and at least partial preservation of older interglacial marine landforms and deposits, but as was noted, available sub-surface data indicates that there is no stratigraphic break in the sand deposits. Moreover, despite extensive searching along the embayment margins, no remnants of older marine deposits were noted which suggests that the area has not experienced a higher Pleistocene sea level than the 13 to 15 m level indicated by the evidence described. However, since there has been no drilling in these areas and it therefore remains a possibility that remnants of older fringing marine deposits locally underlie the alluvial deposits which occupy extensive inland areas of the hill-foot zone at elevations of 20 to 30 m above sea level this conclusion is essentially tentative.

Depositional evidence for an approximately 40 m interglacial sea level in the study area was reported by Nye *et al.* (1934). The site described by these authors is situated in a small roadside section along the Old Stanley Road approximately 2 km east of Smithton and consists of a 50 cm thick, loosely cemented bed of well-rounded quartzite gravel which overlies an unknown thickness of compact, deeply podzolised alluvial sand (Plate 22). Examination of the section and surrounding area revealed that the gravel is not the result of marine erosion of the nearby Precambrian quartzite hills but appears to represent part of an extensive fluviatile sand and gravel sequence that is associated with a tributary of Coventry Creek. Similar sandy to gravelly deposits occur extensively at the same or slightly higher elevations on the plains to the east and the south where they mark the courses of present and former streams (Figs. 18 and 25).

None of the high sea level data can be radiometrically dated. Absolute age determination of the fossiliferous sand deposits by uranium series dating was not attempted because molluscs are known to acquire uranium post-mortem from the environment of fossilization. Since there is at present no means of determining at what stage in the diagenetic history secondary uranium enters fossil mollusca, it is not possible to assign reliable absolute ages to shells dated by this method (Kaufman *et al.*, 1971; Veeh, personal communication). The age of the marine deposits in question can therefore only be determined in relative terms by examining the stratigraphic relationships of the marine deposits in relation to overlying and associated deposits.

An approximate age of the marine deposits is indicated by the relative stratigraphic relationships at Mowbray Swamp west of Smithton. At this locality, the marine sands are extensively overlain by interstratified freshwater swamp peat and marl deposits

PLATE 22. Alluvial gravels and sands, Old Stanley Road.

which contain small tree root stumps in growth position. A number of conventional and isotopically enriched radiocarbon assays on peats and *in situ Leptospermum*(?) root stumps in this area indicate that the formation of the freshwater swamp deposits commenced sometime before 52,000 BP (Chapter 9). The biostratigraphic record of the swamp deposits and extrapolation of the radiocarbon data point to the high probability that the freshwater swamp deposits had begun to form by 85,000 BP (Chapter 9) which indicates a Last Interglacial age as the likely age for the underlying marine sands.

A Last Interglacial age is also suggested by the pollen content of the buried humic soil at Wiltshire described in chapter 5. As will be described in more detail in chapter 10, the pollen indicates that a temperate wet sclerophyll forest occupied this site sometime before the maximum of the marine transgression.

Substantial indirect evidence supporting the inferred Last Interglacial age for the Pleistocene marine deposits of northwestern Tasmania is provided by the deep-sea oxygen isotope records which if interpreted as representing a palaeo-ocean volume record, as suggested by Shackleton and Opdyke (1973), indicates that sea level during the maximum of the Last Interglacial transgression at approximately 130 ka was the highest in the last 800 ka, and that only twice during this long time interval did sea level attain the same or perhaps slightly exceed present sea level, at about 400 ka and 320 ka. From this it may be inferred that in relatively stable areas, relict shoreline features situated at significantly higher elevations than those constructed during the Holocene transgression must be either of Last Interglacial age or very much older. Although the morphological features of the interglacial shorelines in northwestern Tasmania are somewhat degraded as a result of various post-depositional processes, in general they are well defined thus suggesting a Last Interglacial age for all known pre-Holocene marine deposits in the area, rather than a very much older age. Moreover, if the marine deposits represent a pre-Last Interglacial high sea level stage one would expect to find interglacial marine and glacial age terrestrial deposits that precede the Last Interglacial to be found on them, but there is no evidence of such deposits.

7.4 EXTERNAL RELATIONSHIPS

7.4.1 Tasmania

Unequivocal evidence for former sea levels higher than present is not restricted to the far northwest coast of Tasmania. Erosional and depositional marine landforms which have been inferred to represent part of the Last Interglacial Stage occur extensively along all sectors of the Tasmanian coast and Bass Strait islands (Fig. 17), as recently discussed by van de Geer *et al.* (1979). In addition, there is some evidence to support the contention that shoreline features of pre-Last Interglacial age have locally been preserved.

Pleistocene marine landforms and deposits are widespread on King Island and these have been studied in considerable detail by Jennings (1959, 1961). In this area, bedrock surfaces at 69 m, and a boulder bed between 37 and 46 m which is believed to

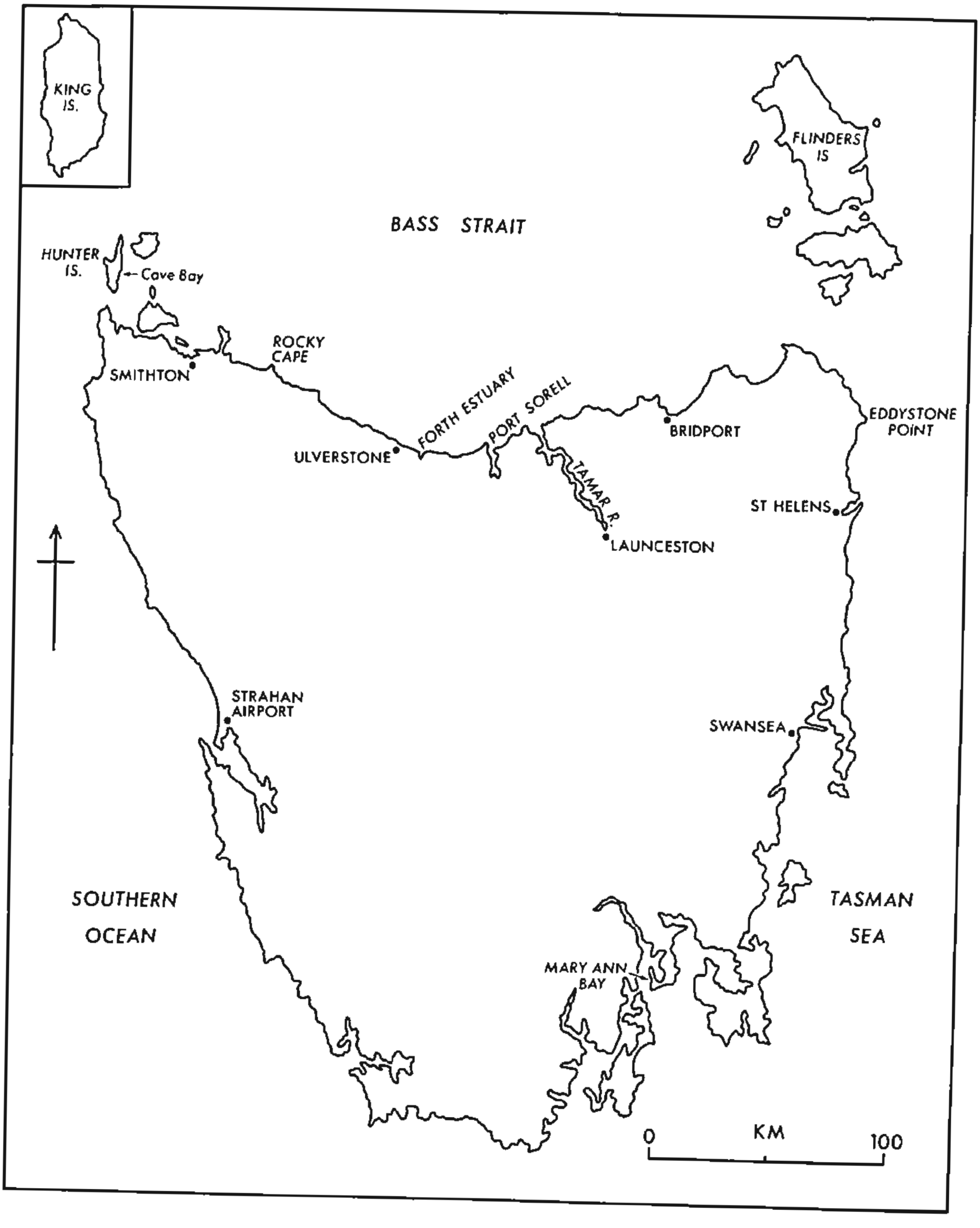


FIGURE 17. Localities of Pleistocene marine landforms and deposits in Tasmania.

represent a beach deposit, have been tentatively interpreted as evidence for Pleistocene sea level stands. Fossiliferous marine sand deposits occur very extensively on King Island from approximately 20 m to below present sea level and have been interpreted by Jennings (1959, 1961) as evidence for a falling sea level which he provisionally inferred belonged to the Last Interglacial Stage. Although Jennings referred to apparent halts at 12 to 15 m and 6 to 9 m, it is clear that he envisaged a more or less continuous and gradual regression.

Further evidence for high interglacial sea level stands in northwestern Tasmania is provided by the occurrence of fossil sea caves and associated archaeological deposits, as at Cave Bay on Hunter Island (Bowdler, 1974, 1975; Hope, 1978) and Rocky Cape National Park (Gill and Banks, 1956; Jones, 1965). The cave at Cave Bay is situated approximately 15 m above sea level in a prominent Precambrian quartzite cliff that forms part of the eastern coastline of Hunter Island. The presence of pollen and faunal remains in the cave deposit has enabled a detailed environmental history to be reconstructed. Radiocarbon dating of the cave fill sequence indicates that the site was intermittently occupied by aboriginal man from 23,000 BP during the late Last Glacial Stage and Holocene Stage. The elevation of the cave corresponds closely with the relict sea cliffs in the Circular Head area and thus points to the probability that the cave developed during the maximum of the Last Interglacial transgression. A Last Interglacial age has also been suggested for two sea caves at 11 and 15 m above sea level on King Island (Jennings, 1959; Goede *et al.*, 1979).

At Rocky Cape, two relict sea caves occur in Precambrian quartzite cliffs at 18 to 22 m (Edwards, 1941; Gill and Banks, 1956; Jones, 1965) and in the same general area interglacial shingle deposits occur at several levels up to 22 m above sea level (Colhoun, 1977a). The cave archaeological deposits have been radiocarbon dated to ~ 8,000 BP (Reber, 1965) and thus indicate that the caves must have formed sometime during the Pleistocene. Gill and Banks (1956) tentatively correlated their formation with the Pleistocene marine sand deposits west of Smithton. However, doubt on the validity of this correlation has been expressed by Jones (1965). He points out that remnants of a cemented beach deposit consisting of well-rounded cobbles in a sand matrix adheres to parts of the ceiling of one of the caves at 30 m above sea level, and suggests that these phenomena probably represent a higher pre-Last Interglacial sea level stand.

On the central northwest coast, some rock benches above 20 m and depositional shoreline features at lower elevations have been interpreted as representing former high sea level stands (Edwards, 1941). Near Ulverstone extensive depositional terraces and shorelines up to 14 m of probable Last Interglacial age and less clearly defined erosional marine features at higher elevations of 20 and 33 m have been described by Chick (1971). Further east, extensively developed marine terraces composed of fine sands and several large cobble beach ridges attain elevations up to 16 m above sea level near the mouth of the Forth estuary. These fossil marine landforms and deposits occur some distance north of an area that was extensively glaciated during the Penultimate Stage and the spatial and morphological relationships of the glacigenic and marine deposits indicates that the latter have been largely derived by reworking of fluvioglacial deposits during the Last Interglacial Stage (Colhoun, 1976b). Locally, some of the relict marine deposits have been reworked during the Holocene transgression and form the contemporary cobble beaches that characterise this part of the central northwest coast.

Recently, excavations at Royal Park in Launceston have uncovered a rich, well-preserved fossil mollusc fauna which includes the pelecepod *Anadara trapezia* Deshayes, 1840. *A. trapezia* is widely reported from marine deposits of Last Interglacial age in New South Wales and Victoria where it ranks virtually as a zone fossil as it is much less abundant in Holocene estuarine and lagoonal sediments. In Tasmania, *A. trapezia* has never been recorded from Holocene marine deposits. The remainder of the Royal Park fauna consists largely of species now living almost exclusively near the mouth of the Tamar estuary where freshwater influences are minimal. From this, Kershaw (personal communication) has tentatively concluded that the fauna probably represents a higher Pleistocene sea level stand.

Very extensive plains consisting of deeply podzolised marine sands and stratigraphically inferred to represent the Last Interglacial Stage, occur up to 30 m above sea level on the far northeast coast between Bridport and Eddystone Point (Bowden, 1978). In this area, marine features believed to be of pre-Last Interglacial age have also been preserved and occur at elevations of up to 69 m (Bowden, 1981). The marine sand plains of northeastern Tasmania decline gently seawards. A characteristic morphological feature of their surface is the widespread occurrence of well-developed WNW to ESE trending linear terrestrial sand dunes and multiple lunettes which have formed as a result of a partial reworking of the marine sands by prevalent westerly winds during late Last Glacial and early Holocene times.

Fossil marine landforms and deposits are well-represented on Flinders Island where bedrock surfaces between 61 and 77 m, shell carbonate-rich deposits at 30 to 37 m and at several elevations below 20 m have been interpreted as evidence for a number of high sea level stands during the Pleistocene (Kershaw and Sutherland, 1972).

Elevated remnants of marine deposits have been noted to occur at several localities along the east coast. In the St. Helens area possible erosional marine features at 24 to 26 m and Last Interglacial marine and estuarine deposits below 10 m have been reported by Sloane (1974). Shelly interglacial sands occur at Swansea but their altitudinal limits, distribution and faunal composition have not yet been determined in detail (Colhoun, personal communication).

Late Quaternary marine deposits are well-represented along the ria coastline of southeastern Tasmania, especially east of Hobart. Here around the margins of the Derwent River and Pitt Water estuarine marine terraces at elevations between 5 to 7 m have been described by Davies (1959). However, more recent investigations around the mouth of the Derwent estuary have shown that Pleistocene marine deposits occur at much higher elevations than recorded by Davies (1959) and extend up to a maximum of 22 m. The 22 m level is unequivocally established in a cliff section at Mary Ann Bay by an extensively exposed 5 m thick deposit of well-bedded, silty sands which contain a rich, and generally well-preserved estuarine mollusc fauna dominated by *Pecten meridionalis* Tate, 1891. This deposit has been tentatively inferred to represent the approximate maximum of the Last Interglacial transgression in southeastern Tasmania by Colhoun (1975).

A partly dissected but extensively well-preserved bedded beach sand and cobble deposit occurs at approximately 20 m between Ocean Beach and Strahan Airport on the west coast (Davies, 1960b). A recent preliminary study of this area has shown that the relict marine sands and gravels appear to have been largely reworked from Pleistocene glacigenic deposits during the Last Interglacial Stage (Banks *et al.*, 1977).

The available evidence thus indicates that there is good evidence that relict shoreline features of inferred Last Interglacial age occur extensively along the Tasmanian coastline at elevations of up to 15 to 22 m above present sea level, and that in the northeast and on Flinders Island similar features attain elevations of 30 to 37 m.

7.4.2 Last Interglacial sea level in southeastern Australia

A number of studies along the northern and central coast of New South Wales (Thom, 1965; Hails and Hoyt, 1968; Langford-Smith and Thom, 1969; Marshall and Thom, 1976), and western Victoria (Gill and Amin, 1975) have recorded the approximate limit of the Last Interglacial transgression at a height of up to 7 m above present sea level. The transgression limit in eastern Victoria and southeastern South Australia, on the other hand, has been shown to occur at elevations ranging from about 7 to 15 m. However, the Gippsland region of eastern Victoria and much of South Australia are known to have been affected by earth movements during the Pleistocene which has resulted in extensive warping and tilting of the interglacial marine terraces (e.g. Jenkin, 1968; Ward *et al.*, 1971; Cooke *et al.*, 1977; Sprigg, 1979).

When the evidence presented in this thesis is combined with the evidence cited in the literature it indicates that there is a very marked difference in height, relative to present sea level, of the landforms and deposits that indicate the approximate transgression limits of the Last Interglacial in Tasmania and New South Wales. The Tasmanian evidence is very much higher than that of New South Wales, where the evidence is considered to be characteristic of levels of eustatic sea level rise attained on stable coasts (Marshall and Thom, 1976).

7.4.3 Discussion and conclusion

Although disputed by some (e.g. Hollin, 1980), there is considerable chronostratigraphic evidence to indicate that the maximum of the Last Interglacial transgression did not exceed 10 m above present sea level. A Last Interglacial sea level maximum of between 2 to 7 m above present sea level is clearly indicated by the evidence from areas which due to their remoteness from plate boundaries are believed to have been tectonically stable for much of the Pleistocene, as for example, Florida (Broecker and Thurber, 1965), Bermuda (Land *et al.*, 1976), and various parts of the Pacific and Indian Oceans (Veeh, 1966). Hence, the highest elevations of the shorelines that formed between 120 and 130 ka in the above mentioned areas are becoming widely accepted as an approximate late Quaternary sea level datum (Chappell, 1974; Bloom *et al.*, 1974). Furthermore, this palaeo-sea level datum is also supported by the independently derived glacio-eustatic sea level curve inferred from the oxygen isotope composition of benthonic foraminifera in deep-sea sediments. This record shows that during the maximum of the Last Interglacial transgression sea level stood about 6 m higher than present and, as mentioned previously, this level was the highest for the past 800 ka (Shackleton and Opdyke, 1973). The evidence from 'stable' coastal areas and the deep-sea oxygen isotope record thus clearly demonstrates that the much higher elevations of the Last Interglacial marine deposits in northwestern Tasmania and elsewhere on the island cannot be solely attributed to glacio-eustatism but must largely reflect the effects of tectonic instability and/or responses to hydro-isostatic disequilibrium conditions of Tasmania and the Bass Strait region during late Quaternary times.

Although it has not been possible to establish precise uppermost marine limits in northwestern Tasmania, available field evidence indicates that relict Last Interglacial marine landforms and deposits occur up to at least 15 m above HWM. It seems, therefore, that uplift has raised the transgression limit (Stage 5e, Shackleton and Opdyke, 1973) by approximately 9 m over the last 125 thousand years. This would be a rate of around 0.07 m/ka assuming uplift has been uniform over that period.

There is sufficient consistent evidence to indicate that the Last Interglacial terminated abruptly at about 120 ka (Sub-stage 5e, Shackleton and Opdyke, 1973) and that sea level fell by perhaps as much as 60 m in a period of approximately 10,000 years (Bloom *et al.*, 1974; Steinen *et al.*, 1973; Aharon *et al.*, 1980), corresponding to a fast build-up of continental ice. The same situation appears to have occurred around 95 ka and 75 ka (Bloom *et al.*, 1974). The period of 115 to 75 ka is now widely considered to have been the early stages of the Last Glacial because during most of the time (Sub-stages 5c and 5a) the ice volume was intermediate, yet is estimated as having been 60% larger than today (Dansgaard and Duplessy, 1981).

In the light of this evidence, the apparent uppermost level of the marine deposits and associated landforms of northwestern Tasmania is tentatively correlated with the high Last Interglacial sea level stand recorded and dated at Barbados, New Guinea and elsewhere. The overall seaward slope of the deposits in the study area is interpreted as representing the early stages of the major regression that rapidly followed the termination of the Last Interglacial Stage shortly after 120 ka.

Although accurate transgression limits have not yet been established in most Tasmanian areas, available data suggest that the overall rate of uplift was perhaps greatest along the northeast coast. Here the rate of uplift appears to have been in the order of 0.21 m/ka (Bowden, 1981). The inferred uplift rate of northeastern Tasmania is more than adequate to explain the high marine levels encountered in the study area and elsewhere on the island.

Part III

SWAMP DEPOSITS

CHAPTER 8

ARTESIAN SPRINGS

8.1 INTRODUCTION

Artesian mineral springs and associated freshwater swamp deposits occur extensively on the low-lying marine and alluvial plains near Smithton. They are best developed at Pulbeena, Marthicks Siding, Mella, Broadmeadows, Christmas Hills, and near the mouth of Deep Creek (Fig. 2). At most of these localities, the springs have formed low mounds which vary from less than one to more than seven metres in elevation and are composed largely of biochemically precipitated marl and shell marl.

This chapter represents some of the hydraulic and chemical characteristics of the artesian springs.

8.2 CHARACTERISTICS OF THE ARTESIAN SPRINGS

8.2.1 Temperature

The spring waters in the area are several degrees warmer than would be expected from near-surface groundwater (Table 6). The higher temperatures are probably caused by the water rising quickly from considerable depths where the temperature is naturally higher. The process that probably operates is envisaged as follows. The water presumably attains temperature equilibrium with the aquifer rock at depth as it circulates in the region of normal geothermal heat flow. This water then flows to the surface through particular conduits rapidly enough so that it neither loses appreciable heat by conduction to near-surface cooler rocks and unconsolidated sediments nor mixes with cooler shallow circulating groundwater. In this case, the surface temperature of most of the spring water probably approaches that of water temperatures at the depth at which it was originally heated. On the other hand, if the heated water ascends slowly, losing heat by conduction or mixing with cool shallow groundwater, the surface temperature of the spring water would of course be expected to be well below its maximum temperature at depth.

The temperature below the surface normally increases by approximately 1°C for each 30 m increase in depth (Todd, 1959), and the temperature of near surface groundwater is usually 1-2°C above the mean annual air temperature which in the Smithton area is 12.6°C. Using the above figures and the measured spring water temperatures listed in table 6, the *minimum* depth from which the water could have come if normal geothermal heat flow was the cause of heating would be in the order of 100 m in the Pulbeena Swamp, Marthicks Siding and Christmas Hills areas, and about 160 m in the Mowbray Swamp area.

Groundwater is either of meteoric origin, i.e. derived from rainwater, or of juvenile origin. The latter refers to water which reaches the surface from a deep-seated heat source and is generally highly mineralized and thermal. Such juvenile thermal waters usually occur in volcanic areas or near areas where igneous bodies have been intruded beneath the surface and have not cooled to the extent of fitting into the normal temperature gradient. As there is presently no volcanic activity in northwestern Tasmania and the possibility of igneous intrusion occurring at shallow depth in this region seems most unlikely, the increase in water temperature cannot be attributed to a juvenile origin. A meteoric origin seems likely as the depth of penetration through the dolomite needed to attain the required temperatures is less than the known thickness of the strata.

8.2.2 Discharge

Because it was not practical to install weirs in the areas where free flowing springs occur, it is not possible to give an estimate of the volume of water that issues from the head of the springs. Observations suggest, however, that discharges remain fairly constant throughout the year, and it has been noted that even during drought conditions the springs and nearby water bores appear to be no less productive than at times of regular rainfall (Gulline, 1959).

8.2.3 Chemical composition

Chemical analyses of six spring water samples were made at the request of the writer by the Tasmanian Department of Mines Laboratory in Launceston. The results which are listed in table 6 show that the spring waters contain very high concentrations of dissolved solids, particularly calcium and magnesium ions.

Odourless gasses are emitted from all the springs. Although no analyses have been performed, the gas is probably rich

TABLE 6 Chemical composition of spring waters

	PULBEENA SWAMP		MOWBRAY SWAMP		MARTHICKS SIDING	CHRISTMAS HILLS
	Spring A 16.8°C	Spring B 17.4°C	Spring A 19.4°C	Spring B 19°C	17.1°C	17.2°C
pH	7.2	6.7	7.6	7.2	7.5	7.3
	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
HCO_3	900	1000	500	580	1850	520
Ca	105	115	80	80	220	80
Mg	100	105	42	42	220	40
Cl	53	56	56	56	53	56
Na	28	32	34	36	46	34
SO_4	14	9	< 5	8	8	< 5
SiO_2	7	5	< 5	5	9	7
K	1.8	1.8	2.5	3.3	9.4	1.9
Al	0.3	< 0.2	< 0.2	< 0.2	0.3	0.2
Fe	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Total dissolved solids	750	800	450	490	1390	470
Hardness as $CaCO_3$	670	720	375	375	1460	365

in carbon dioxide (CO_2) which could be derived from soil air. When rainwater, recharging the aquifer, passes through the soil zone it dissolves CO_2 from the soil atmosphere. As the percolating rainwater reaches the level of the heat source the CO_2 would be held in solution despite the higher temperature by the increased pressure, but on arrival back at the surface where the water experiences a pressure drop, a proportion of the CO_2 would come out of solution.

8.2.4 Stable isotope composition

In order to determine the origin of the thermal spring waters, ratios of the stable isotopes of oxygen and hydrogen were measured on four representative spring water samples from the Mowbray and Pulbeena areas, and a sample of meteoric water representing a single shower. These isotopes, being materials of the water molecule, have been shown to be particularly useful in determining the origin and history of groundwater, as recently discussed by Mook (1972).

The analyses were carried out by Dr. W.G. Mook at the Groningen University Isotope Physics Laboratory in the Netherlands.

Stable isotope ratios are reported in the δ notation. δ represents the deviation in parts per mill ($^{o}/_{oo}$) of the isotope ratio in a sample from that of the internationally adopted SMOW standard (Craig, 1957, 1961);

for oxygen (^{18}O):

$\delta^{18} = (^{18}O/^{16}O)$ sample/ $(^{18}O/^{16}O)$ SMOW-1;

for deuterium (^{2}H):

$\delta^{2} = (^{2}H/^{1}H)$ sample/ $(^{2}H/^{1}H)$ SMOW-1

Waters on the land surface are generally depleted in ^{18}O relative to SMOW, that is, their δ values are negative. This depletion occurs because the vapour pressure of water molecules containing the heavier isotopes is slightly less than of common water, $H_2{}^{16}O$. During evaporation and condensation in the hydrologic cycle, molecules containing heavier isotopes are concentrated in the liquid phase. As water evaporates from the ocean, the vapour is depleted in ^{18}O and the amount of depletion becomes greater as the temperature of evaporation decreases. Further isotopic fractionation takes place as water is condensed and re-evaporated during atmospheric transport. The amount of fractionation is inversely proportional to temperature, and also varies with altitude, latitude, and distance from the ocean (Dansgaard, 1964). From this it follows that the $\delta^{18}O$ value of meteoric groundwater should reflect that of precipitation of the catchment area. Groundwater isotope ratios can, however, be changed by chemical and isotope exchange reactions between the water and aquifer rock. Because the $\delta^{18}O$ value of rock forming minerals is strongly positive, reactions between rock and water will make the $\delta^{18}O$ values of the groundwater more positive. Such reactions are believed to occur only very slowly at temperatures below 150-200°C. Thus, anomalously positive $\delta^{18}O$ values may indicate that the groundwater has been exposed to very high temperatures (White *et al.*, 1973).

Another occurrence of deviations in $\delta^{18}O$ in groundwater from average precipitation is found if the precipitation has been subject to considerable evaporation before infiltration, as for example in shallow lakes or pools. As a consequence of the evaporation process, deviations from the linear relation between deuterium and the ^{18}O content of the water (Craig, 1961; Dansgaard, 1964) occur.

The results of the isotope analysis of water samples relative to the SMOW standard are listed in table 7. The deviations show that the $\delta^{18}O$ and $\delta^{2}H$ composition of the spring waters is very uniform and almost identical to that of the rainwater sample. The small difference between the mean O and H isotope value of the artesian spring water and precipitation ($\delta^{18}O$ -0.77°/₀₀; $\delta^{2}H$ -8.2°/₀₀) is considerably less than the seasonal differences normally found in meteoric waters of temperate regions (Dansgaard, 1964) and is therefore considered insignificant. The stable isotope data thus demonstrate that the water discharging from the slightly thermal artesian springs in the area is of meteoric origin and does not appear to have been subject to either significant evaporation prior to infiltration or isotopic and chemical exchange reactions resulting from very strong heating in the aquifer region.

TABLE 7 Stable isotope composition of spring waters

	$\delta^{18}O$ (°/$_{oo}$)	$\delta^{2}H$ (°/$_{oo}$)
Pulbeena Swamp		
Spring A	-4.80	-25.3
Spring B	-4.87	-24.2
Mowbray Swamp		
Spring A	-4.96	-24.7
Spring B	-4.95	-25.3
Precipitation		
Smithton (6/10/'79)	-4.12	-16.7

8.2.5 Age of the spring water

In this study it is assumed that the artesian water represents contemporary deep-seated groundwater which, as demonstrated by its oxygen and hydrogen isotope composition, is of meteoric origin. There is, however, a distinct possibility that the water has been in residence for a very long period of time before emerging at the surface. Possible future studies of the springs should perhaps try to resolve this question by attempting to isotopically date the waters with the aid of tritium and/or radiocarbon dating techniques (Mook, 1972). Since tritium has a relatively short half-life (12.3 years), and nearly all tritium present in the hydrosphere was injected within the last 30 years, the tritium content would indicate whether the groundwater was recharged more than about 20 years ago or more recently. Using this method, it is also frequently possible to use intermediate tritium values to estimate the proportions of young and old water in a mixed water body (Hobba *et al.*, 1979). Should the water be older than the effective tritium dating limit, its minimum age can be determined by conventional radiocarbon dating methods (Mook, 1972). Unfortunately the author did not have access to tritium dating and the financial resources for radiocarbon dating were concentrated on the organic deposits. Although it is not definitely established that the artesian water is not several decades or centuries old, a great age seems unlikely and for the present purpose the water is assumed to be approximately equivalent to contemporary water.

CHAPTER 9

FRESHWATER SWAMP DEPOSITS

9.1 INTRODUCTION

As was noted in the previous chapter, spring mounds are a characteristic feature of the low-lying plains. The spring mound marl deposits interdigitate with interbedded swamp peats which contain occasional small root stumps in growth position. The formation of interbedded swamp deposits has been primarily controlled by temporal fluctuations in spring activity. The freshwater swamp deposits overlie either Quaternary alluvial sands and gravels or fossiliferous marine sand deposits of Last Interglacial age.

A number of small circular inland lagoonal swamp deposits occur in the Smokers Bank area (Fig. 2). The swamp deposits are bound by low sand lunette ridges which were formed by lacustrine and aeolian processes prior to the development of the peat deposits on the floor of the lagoon.

This chapter presents the stratigraphy, composition and radiocarbon ages of the swamp deposits, and discusses their palaeoenvironmental and palaeoclimatic significance.

9.2 THE PULBEENA SWAMP DEPOSITS

9.2.1 Introduction

Pulbeena Swamp is located 4 km south of Smithton and forms part of a broad, almost featureless alluvial plain at about 30 m above sea level (Fig. 18). The floor of the swamp is underlain by Quaternary sands and gravels,and Precambrian dolomites. The plain is surrounded by a series of low hills which consist of Precambrian-Cambrian quartzites, cherts, and slates, and Tertiary basalts (Nye *et al.*, 1934; Gulline, 1959). The plain north of Pulbeena Swamp and most of the swamp itself is covered by artificially drained peaty soils. At the Pulbeena Limeworks, 5 km from Irishtown, a 5 m thick sequence of interbedded marl and peat deposits indicates that during the late Quaternary the central part of the spring-fed basin has alternated between a shallow lake when spring discharges were high and a swamp when spring discharges were reduced.

Attention was drawn to the Pulbeena deposits when in the course of thesis field work during 1974, a well preserved mandible and incisor of the extinct giant marsupial *Palorchestes azael* Owen 1874 was found in a quarry face at the Limeworks (Banks *et al.*, 1976). Preliminary stratigraphic and pollen analysis and ^{14}C dating which was undertaken to place the fossils in a palaeoenvironmental context revealed the need for more detailed study of the site; this was undertaken by Dr. E.A. Colhoun and the writer. The preliminary results of this study have recently been summarized (Colhoun *et al.*, 1977; Colhoun, 1978a, 1978b).

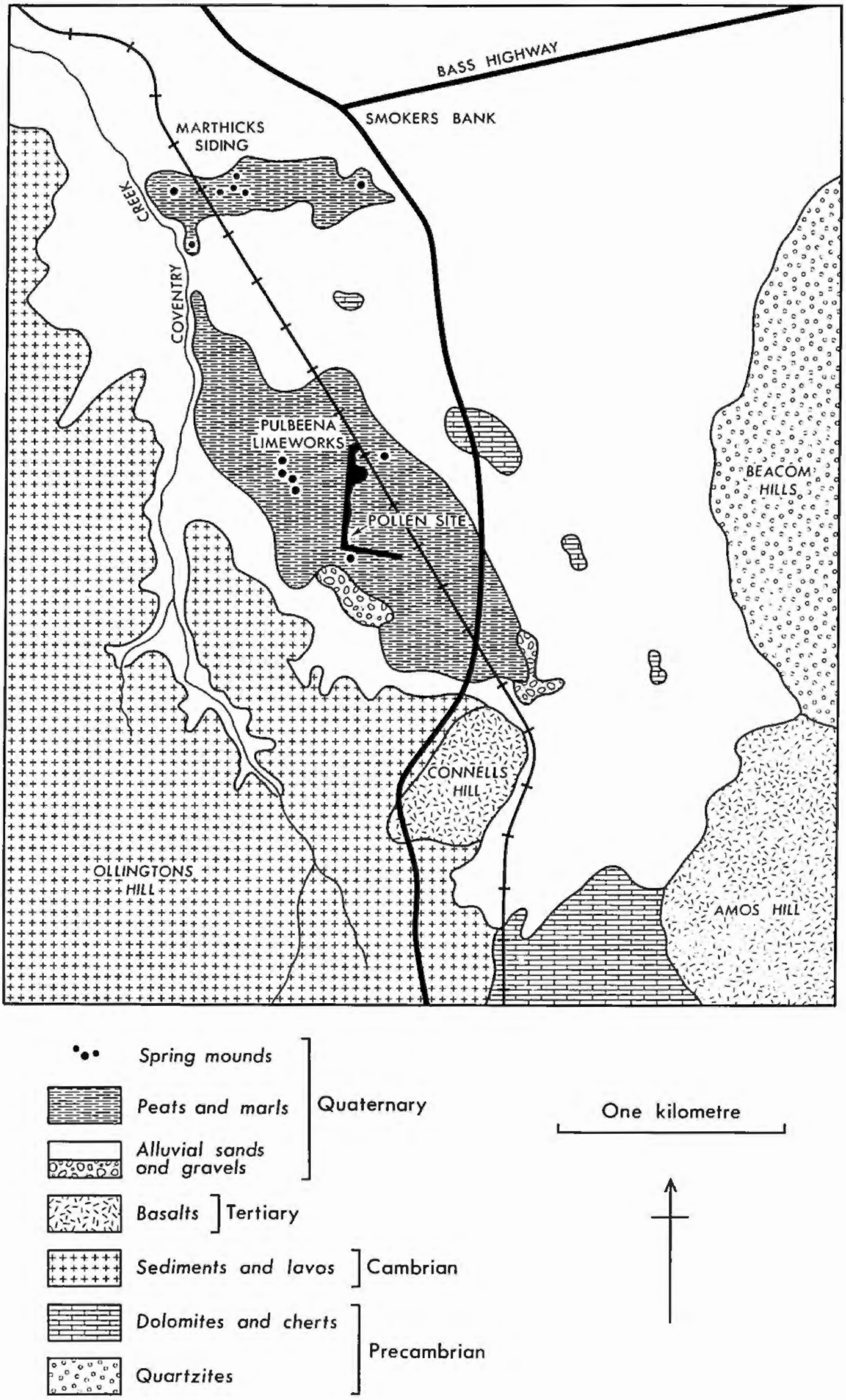


FIGURE 18. Spring mound and swamp deposits in the Pulbeena area.

9.9.2 Stratigraphy, dating and interpretation

The Pulbeena Limeworks quarry is situated near the centre of the swamp. Extensive exposures at this site show that the swamp surface is underlain by beds of calcareous biochemically precipitated marls and shell marls, and peaty marls with wood fragments and small tree root stumps in growth position. The sediments which are 2-5 m thick are mainly horizontally bedded. However, in the vicinity of active and dormant springs the beds are deformed and dip steeply towards the spring orifices.

Distinctive porous, tubular plant structures are a characteristic feature of some of the marl beds and indicate that photosynthesis by flowering plants and algae has played a significant role in influencing the processes of carbonate precipitation. Aquatic vegetation utilizes the CO_2 and the HCO_3^- contained in the bicarbonate spring waters. This raises the pH and causes precipitation of the carbonates once pH exceeds the value of about 9 (Reeves, 1968).

The stratigraphic record shown in figure 28 was recorded on the eastern side of the steeply inclined north trending quarry face at the Limeworks (Plate 23). This section is, however, only representative of the central and deepest part of the swamp and is not characteristic of the entire swamp. Considerable spatial variation in the thickness of individual beds and the deposit as a whole is clearly evident in the quarry exposures. The deposits thin rapidly away from the centre of the swamp where springs occur in close proximity and gradually grade into a 1.5 m thick, highly humified, peat bed along the outer margin of the swamp. The strong controlling influence of the springs on the stratigraphy is well illustrated by an extensively developed peat bed that occurs between approximately 50 and 100 cm depth over most of the central part of

PLATE 23. Section in the sequence of lake marls and swamp peats at the Pulbeena Limeworks quarry. The basal metre is obscured.

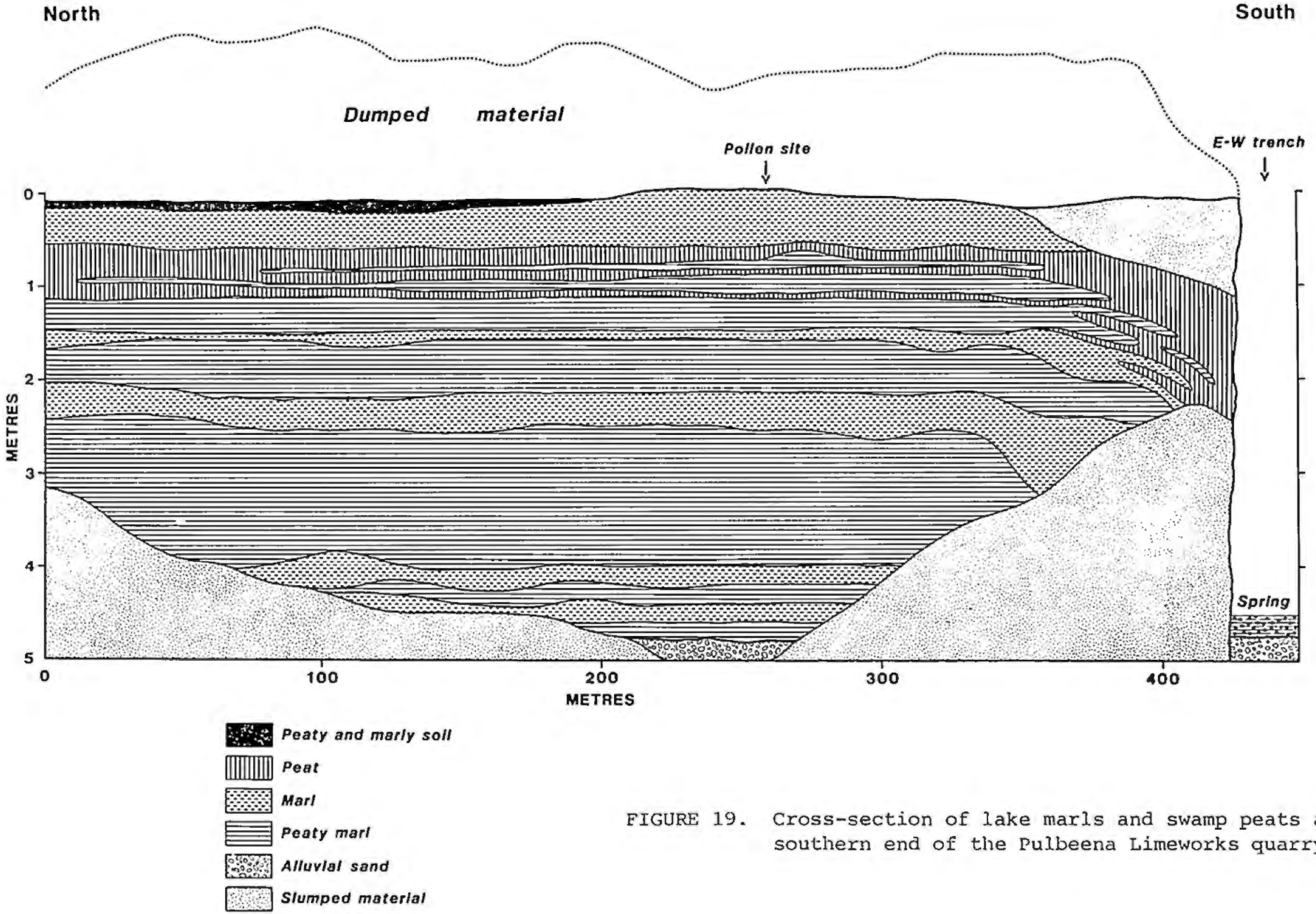


FIGURE 19. Cross-section of lake marls and swamp peats at southern end of the Pulbeena Limeworks quarry.

the swamp, but which becomes gradually divided into three quite distinct thinner beds separated by marl and peaty marl in the vicinity of spring orifices (Fig. 19). Similarly, complex stratigraphic relationships occur near the base of the sequence. Here, a number of low (< 1 m) dormant spring mounds, that formed on the alluvial plain during the early stages of spring activity, are separated by shallow depressions filled with highly compressed woody peats which grade laterally into peaty marl beds and finely laminated marls near the mound. Very similar lateral facies changes are evident throughout the sequence, but usually occur on a small scale. A characteristic feature of the marl and peaty marl beds is that they gradually become more peaty away from the springs. The strong overall controlling influence of the springs on the compositional characteristics of the sediments is schematically summarized in figure 20.

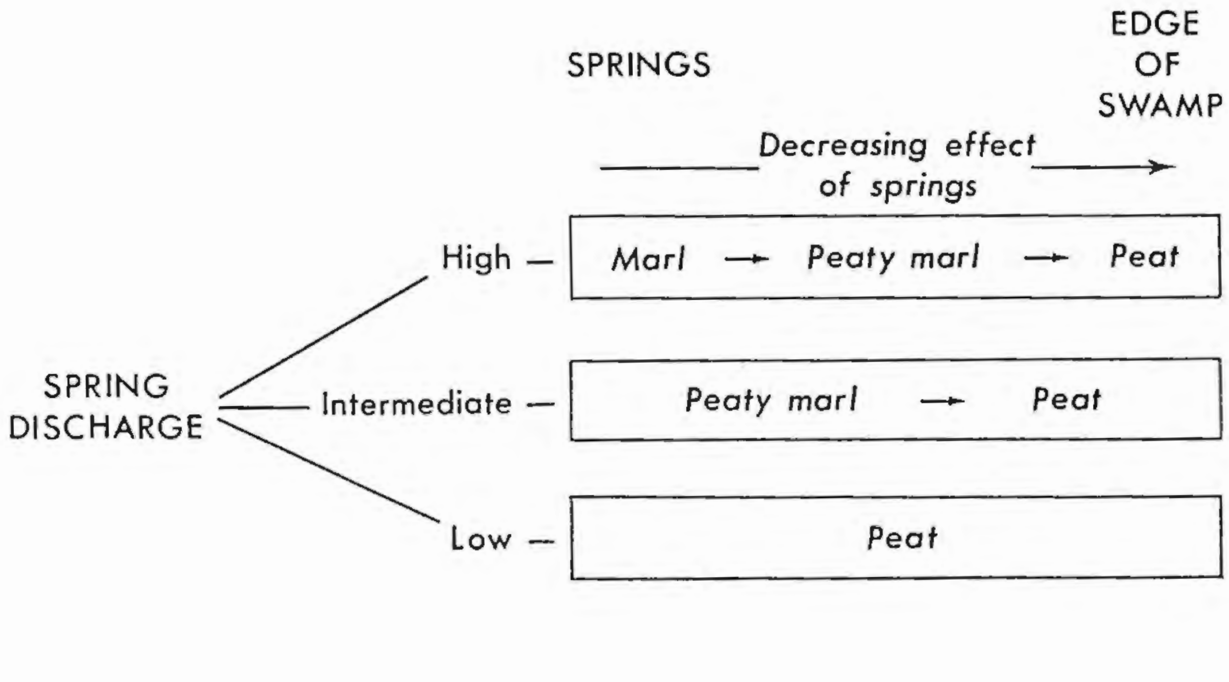


FIGURE 20. Schematic diagram of hydrology/sediment relationships at Pulbeena Swamp.

The section was sampled at 5 cm intervals and described in the field according to estimates of low (< 10%), moderate (10-20%), and high (> 20%) quantities of organic matter. Quantitative analysis of the composition was undertaken at 10 cm intervals on a portion of the collected samples. The percentage of carbonate was determined by leaching with HCl after drying the samples at 105°C, and organic matter was determined by weight loss after dry combustion at 500°C for one hour, leaving a siliceous silt and clay residue. The analysis shows (Fig. 28) that, with the exception of the distinct peat beds, the sediments are characterized by high values for carbonates (70-90%) and moderate values for organic matter (10-20%). Relatively high percentages of inorganic fractions occur near the base of the profile and represent slight erosion and redeposition of the underlying alluvial sands during the early stages of spring development. High values for inorganic fractions also occur at the surface (58%), probably reflecting agricultural practice, and between 90 and 115 cm depth (32%). The latter case can be explained by a reduction in the amount of dissolved carbonates reaching the surface during times of diminished spring activity, as could result from a climatically induced reduction in the rate of recharge of the aquifer budget causing clay and silts derived from shallow depths to become relatively more abundant in the precipitate.

Eleven samples have been assayed using conventional radiocarbon dating methods, and five samples have been assayed after having their ^{14}C activity increased by thermal isotope enrichment. Through thermal diffusion enrichment, the ^{14}C

detection limit is reduced to about 0.1°/₀₀ of modern activity. This makes it possible to extend the range of ^{14}C dating to about 75,000 years ago, provided sample contamination is much less than 0.1°/₀₀. Sample sizes of about 60 to 120 g of carbon are needed for the enrichment process. The carbon dioxide derived from sample combustion is reduced to carbon monoxide and enriched in Clusius-type thermal diffusion columns which transport the heavier ^{14}CO from a 120 litre top volume to an 8 litre bottom volume. The ^{14}C enrichment is calculated from the ^{18}O enrichment, which is determined by using a mass-spectrometer. Samples are pretreated with acid to remove carbonates, and with a hot alkali solution to remove humic acids and other components that may have been added after deposition of the wood or peat. The humic extract from these treatments is dated and its age compared with the cleaned material. When the humic extract is appreciably younger than the cleaned material, sample contamination is indicated (Grootes, 1978; Mook, personal communication). The results of the dating are given in table 8 and are shown on figure 28 where the enriched assays are in brackets. The ^{14}C assays have been corrected for $^{13}C/^{12}C$ and are based on a half life of 5568 years.

Prior to this study three conventional ^{14}C assays had been obtained from Pulbeena Swamp. A sample of wood from 230 cm depth and contiguous with a mandible of *Palorchestes azael* Owen 1874, had been assayed at 54,200 $^{+11,000}_{-\ 4,500}$ BP (GrN-7322) from approximately the present site. Samples of peat from between 62 and 80 cm depth, and shell marl from 170 cm depth in a pit approximately 200 m to the east had been assayed at 13,690 ± 550 BP and 27,900 ± 2,000 BP (Y-229-1 and Y-229-2) (Banks *et al.*, 1976; Gill and Banks, 1956; Barendsen *et al.*, 1957).

TABLE 8 Pulbeena Swamp radiocarbon dates

Depth (cm)	Material	GrN Lab. No.	^{14}C years BP
60	Humified peat	7881	11,370 ± 70
75	Humified peat	7688	14,980 ± 80
85	Humified peat	7882	16,590 ± 110
115	Humified peat	7689	22,130 ± 180
165	Charred root stump	7690	44,700 ± 1500
	" " "	9458	42,200 ± 800
200	Root stump	7691	48,400 $^{+1900}_{-1600}$
	" "	9459	53,400 $^{+3700}_{-2500}$
205-215	Root stump	8589	(42,700 ± 900)
	Humic extract	8636	(41,100 ± 800)
	Root stump	9438	41,450 ± 700
		9483	(42,620 ± 200)
255-265	Root stump	8526	(48,200 ± 250)
	Humic extract	8626	(47,500 ± 800)
320-330	Root stump	8754	(49,250 ± 300)
	Humic extract	8627	(47,600 $^{+1900}_{-1500}$)
*420-425	Peat in shell marl	9798	> 55,000
	" " " "	9905	(55,200 ± 500)
	Shell marl	9844	42,500 ± 1100)

* These assays were received after the pollen diagram had been photographed and therefore are not indicated in figure 28. Assay 9844 demonstrates that the shell marl has been considerably contaminated by younger carbonates and is thus unsuitable for ^{14}C dating.

The present dates appear to be accurate above 120 cm depth, below which assays approaching the limit of conventional radiocarbon dating remain stratigraphically consistent to 200 cm depth. However, whether or not they provide accurate age estimates is impossible to substantiate. Although assays made on standard and isotopically enriched samples at 210 cm are internally consistent they are not stratigraphically consistent with the assays from 165 cm and 200 cm which are as old, or older.

The dating problem is highlighted by the assays at 165 and 205-215 cm depths not showing significantly different ages even though they are separated by 45 cm of peaty marl and by older assays obtained from two separate root stumps at 200 cm. In addition, there is no statistically significant difference in age between the assays from 200, 260 and 325 cm depths. From this it would appear that the root stumps at 200 cm might have been derived from deeper horizons. However, this is unlikely, as the root stumps appeared to be in growth position. Also, it is difficult to envisage how waterlogged root stumps weighing in excess of 2 kg could have been mobilized by slowly flowing spring waters and deposited at a higher level. Further negative evidence for derivation is provided by the pollen record of the site. If considerable reworking of sediments had occurred in the lower part of the sequence, it would certainly have involved substantial redeposition of pollen which would have tended to homogenize the pollen spectra and not permit clear differentiation of pollen and biostratigraphic zones (Chapter 10). It might be argued that the lower part of the sequence was deposited very rapidly. Though it is probable that, due to the greater hydrostatic pressure of the springs, sedimentation was considerably more rapid than higher up in the sequence,where the hydraulic water pressure would have been less, it seems most unlikely that more than 2 m of well-stratified biochemically precipitated marls and peaty marls, containing distinct former swamp surface peats with root stumps in growth position, could have developed in less than 1000 years as suggested by the ^{14}C data. It seems equally unlikely that major changes in the artesian water budget, and by inference in the local precipitation and evaporation balance, would have occurred as rapidly. Finally, the ostracods also tend to suggest that no reworking of the deposits has occurred. In all samples, adults and juveniles were found together and left and right valves were present in about equal numbers,which indicates that no selective sorting of the ostracods has occurred. In addition, as most fragile shells belonging to species such as *Ilyodromus multifarius* n.sp., *Candona tecta* n.sp., *Candonopsis tenuis* Brady 1886, and *Darwinula* sp. were found to be perfectly intact in the samples, it is believed that little or no reworking of the sediments and ostracods has occurred (De Deckker, in preparation).

As was briefly noted, the diffusion isotope enrichment procedure makes it technically feasible to detect ^{14}C activities of less than 0.1% of the original sample activity. However, the measured age of a sample with such a low activity is critically dependent on sample contamination (Olsen, 1974). According to Stuiver *et al.* (1978), it takes only 0.1% contamination by younger carbon to double the ^{14}C activity of a 56,000 year old sample; a similar doubling is achieved for a 37,000 year old sample by adding 1% contamination. In both instances the measured sample age will be 5,600 years younger. These examples demonstrate that for each 19,000 year increase in age of a sample, contamination by the same amount of young carbon causes a ten times larger error. Although the ages of the humic extracts suggest that the samples have not been subject to obvious contamination, the lack of stratigraphic consistency and significant down-profile increase in age of the enriched assays clearly indicates that some form of trace contamination beyond the detection limits of the laboratory must be the cause of the age anomalies. Hence, the assays below 200 cm depth are rejected, and in view of the probable contamination problem, the simple mean of assays GrN-7691 and 9459 is taken as a minimum estimate of the possible age of the woody peat at 200 cm depth.

The sequence of sediments outlined in the stratigraphic column of figure 28 is generally characteristic of the central part of the swamp and is supplemented by the following description.

During the Holocene Stage, a distinct bed of yellow, biochemically precipitated marl with tubular plant stem cast structures was deposited between 40 and 60 cm depth and is overlain by shell marl between 20 and 40 cm. The change from biochemically precipitated marl to shell marl suggests that spring discharges were greater during the early-mid Holocene than either during late Holocene or late Last Glacial times. The surface 20 cm, which was partly removed at the site by quarry operations, is a plough layer.

The deposits between 60 and 115 cm consist predominantly of silt and clay-rich humified peat beds intercalated with laminated, biochemically precipitated marls and shelly, peaty marls. No wood fragments occur in these sediments which appear to have accumulated during a phase of low and fluctuating spring activity with an overall decrease upwards.

From 115 cm the sediments grade downward from peaty marls with shells to biochemically precipitated marls with occasional plant encrustation structures at 150 to 160 cm. A thin horizon consisting of peaty marl with small, well preserved root stumps in growth position occurs at 165 cm. It was noted that several of the root stumps were coated with charcoal, indicating that fire had burnt across this part of the swamp between about 42,000-44,000 BP.

Between 170 and 200 cm the sediments consist of peaty shell marls which overlie a horizon of root stumps in growth position and are underlain by a 40 cm thick compact bed of biochemically precipitated marl containing plant cast structures and occasional shells. From 260 to 400 cm the sediments consist mainly of peaty shell marl which contain root stumps at 260 and 325 cm. Below 400 cm there is a marked change to a bed of soft, structureless marl with shells which grades into finely laminated peaty marls between 420 and 440 cm. Predominantly shelly marls occur between 440 and 460 cm,and grade into a 20 cm thick bed of compact sandy, peaty marl that overlies the basal alluvial sands at 480 cm.

The alluvial sediments consist mainly of poorly sorted, subangular to angular quartzite and chert sands. The age of the alluvium is unknown but it is probably Quaternary.

The sequence of sediments outlined above indicates that the centre of the basin has alternated between shallow lake and swamp conditions in response to climatically induced variations in artesian water budget, and that these variations were most marked during the late Last Glacial and Holocene stages. Prior to the late Last Glacial Stage, alkaline lacustrine conditions predominated, but these were periodically interrupted by phases of reduced spring activity when shrubs and small trees encroached upon the swamp and formed peaty soils.

9.3 THE MOWBRAY SWAMP DEPOSITS

9.3.1 Introduction

Mowbray Swamp is situated 5 km west of Smithton at about 10 to 15 m above sea level (Fig. 21). The swamp is underlain by Last Interglacial shelly marine sands, Cambrian siltstones and Precambrian dolomites (Nye *et al.*, 1934; Gulline, 1959). Most of the swamp and the plain to the south is covered by peaty soils which have been artificially drained by an intensive network of drainage ditches. As at Pulbeena Swamp, the surface of Mowbray Swamp is extensively underlain by beds of biochemically precipitated calcareous marls and shell marls, and swamp peats containing wood fragments and occasional small tree root stumps in growth position.

Near Mella, spring mounds resembling small volcanoes are a characteristic morphological feature of the swamp topography (Plate 24). The mounds are up to 7 m high with low angle slope profiles between 5 to 10 degrees. They tend to be circular in form and in nearly all cases reveal collapsed summits near the spring orifices. A bubbling pool occurs on top of some of the mounds but, before artificial drainage, springs used to issue freely from the mounds, causing very swampy conditions to prevail

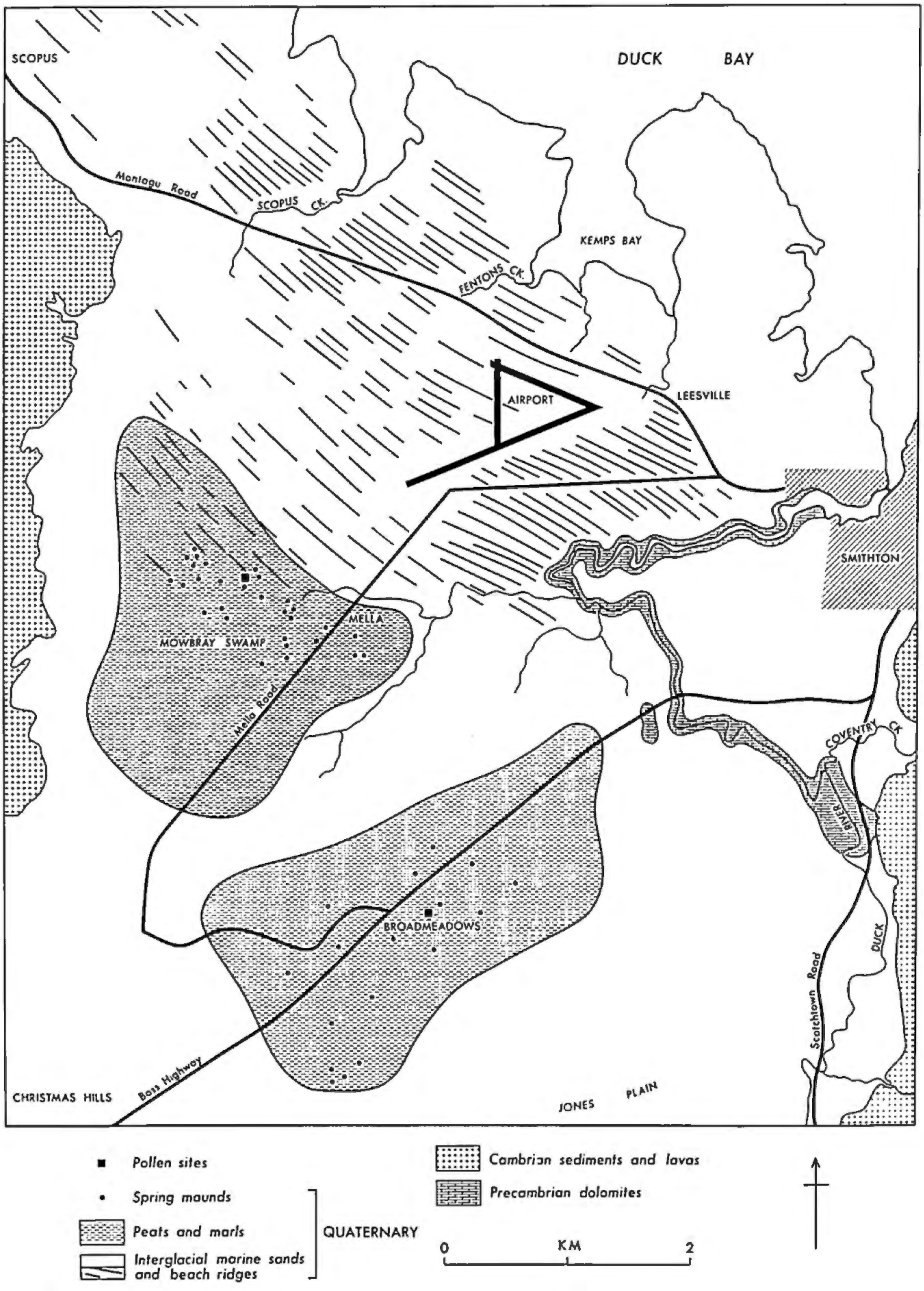


FIGURE 21. Spring mound and swamp deposits at Mowbray Swamp and Broadmeadows.

PLATE 24. Spring mound at Edward's farm, Mella.

PLATE 25. Drainage ditch section of spring mound at Mella showing interbedded peats and marls.

in the surrounding areas (Noetling, 1912). The greatest number of active and dormant mound springs occurs on the western part of the swamp. Here closely spaced springs have resulted in the development of composite forms consisting of a number of broad, 3 to 4 m high flat-topped mounds separated by shallow depressions that are frequently swampy, particularly during the winter months.

The composition of the spring mounds is revealed by a number of drainage ditch exposures which show that they consist of alternating beds of marl with interstratified woody peats (Plate 25) that dip radially outward parallel with the surface of the mound. The alternating beds indicate that the palaeohydrologic regime of the springs was highly variable.

9.3.2 Stratigraphy, dating and interpretation

The stratigraphic sequence shown in figure 29 was recorded in an almost completely enclosed shallow depression surrounded by artificially drained spring mounds on the property of Mr. R.I. Edward at Mella. The manually excavated section was described in the field and sampled at 2.5 cm for sediment and pollen analysis. The composition of the sediments was determined in the same manner as the Pulbeena Swamp sequence. The sediment analyses presented in figure 29 show that with the exception of the well-developed peat beds, the sediments are characterized by very high values for carbonates (70-90%) and low to moderate values for organic matter (5-20%). The highest values for inorganic fractions, consisting mainly of very fine quartz sands, occur near the base of the swamp deposit and represent a minor reworking of the underlying

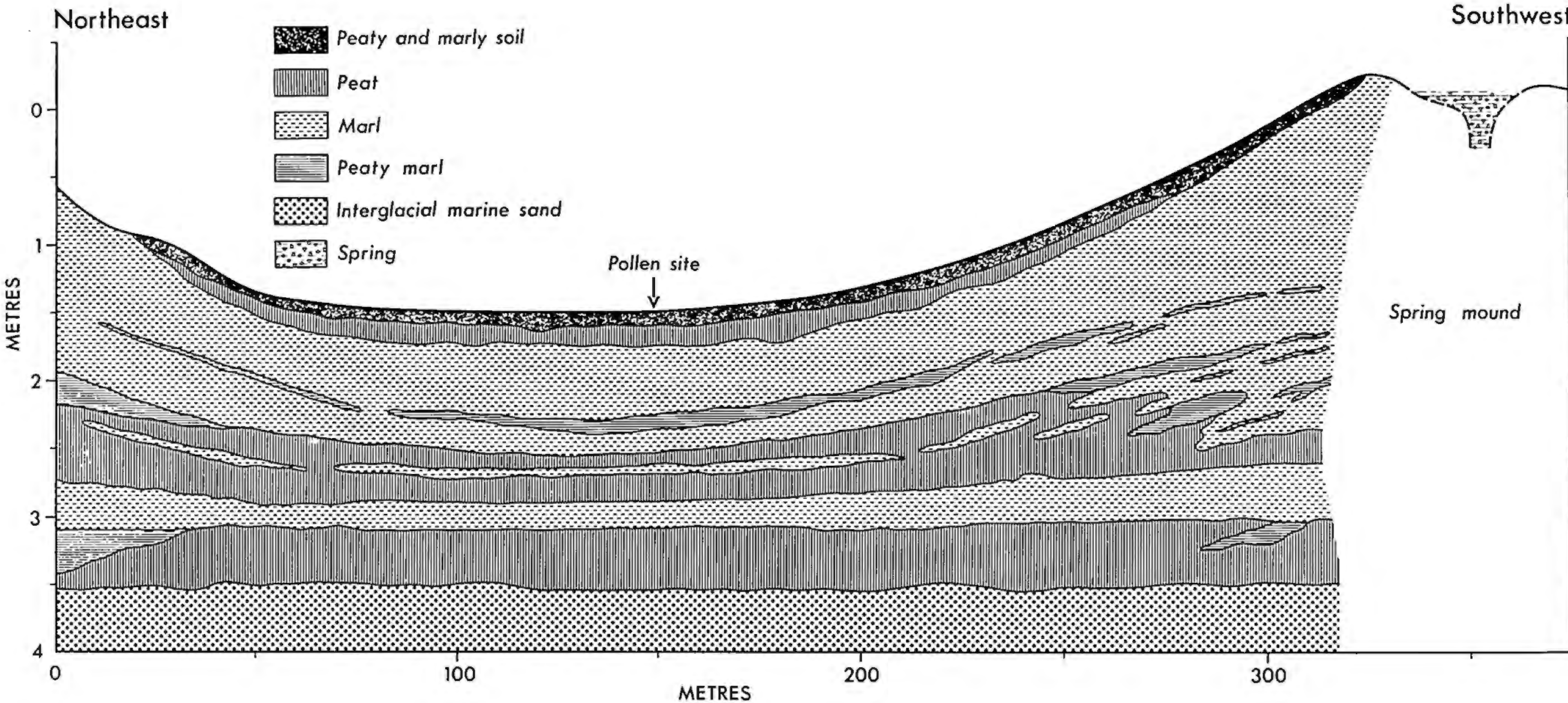


FIGURE 22. Cross-section of a spring mound and inter-mound depression at Mella.

marine sand deposits during the early history of spring development. Relatively high (39-45%) quantities of silt and clay are contained in the peat beds and probably reflect periods when spring activity was reduced in response to a reduction in the aquifer budget. The silt and clay fractions were probably mainly derived from weathered Cambrian siltstones which, as indicated by the water bore data, discontinuously overlie the Precambrian dolomites in this area (Gulline, 1959).

Systematic augering and exposures in the drainage ditches revealed that the alternations of peat and calcareous matter as recorded at the study site is characteristic of the spring mounds and surrounding areas (Fig. 22). The swamp deposits decrease very rapidly in thickness a short distance away from the springs and gradually grade into a less than 1 m thick humified peat bed over marine sands along the outermost margin of the swamp. As at Pulbeena Swamp, the strong controlling influence of the springs on the stratigraphy is clearly evident in drainage ditch exposures with marls and peaty marls gradually becoming more peaty away from the spring mounds. Over most of the swamp the deposits are less than 2 m thick. However, prior to drainage the deposits in the inter-mound depressions were at least 4 m thick (Noetling, 1912) which indicates that considerable compaction of the sediments has taken place as a result of drainage of the swamp.

Prior to the present study two ^{14}C assays were obtained by Gill and Banks (1956) from marl at 60 cm depth and peat at 60-120 cm depth at Mella. Both samples gave ^{14}C ages of > 37,760 BP (Y-148-1&2) (Barendsen *et al.*, 1957). More recently, a radiocarbon assay of $47,500 {+2700 \atop -2000}$ BP (GrN-7481) was obtained from an *in situ Leptospermum* (?) tree stump situated at 135 cm depth and approximately half way through a sectioned spring mound at Mella (Plate 26). This assay indicates that the initial formation of the Mowbray Swamp spring mound and swamp deposits dates back to the early part of the Last Glacial Stage (van de Geer *et al.*, 1979).

Three peat and wood samples and their humic extracts have been radiocarbon dated from this section at the Groningen University Isotope Physics Laboratory using conventional and thermal diffusion isotope enrichment techniques. The results are presented in figure 29 and table 9 where the enriched assays are shown in brackets. Due to the presence of numerous partly decomposed modern plant rootlets in the uppermost peat layer, radiocarbon dating of this shallow bed was not attempted. In view of the trace contamination problems encountered at Pulbeena Swamp and the similarity of environment at Mella, the assays at 120-130 cm depth probably also represent minimum ages.

The sequence of sediments outlined in figure 29 is supplemented by the following comments.

Although undated, lithostratigraphic correlation (Section 9.5) suggests that only the surface 10 cm of peaty marl of the soil horizon and biochemically precipitated marl belongs to the Holocene Stage. During what appears to represent all or part of the late Last Glacial Stage, a moderately humified clay-rich peat bed was deposited between 10 and 25 cm depth. The contrast in composition indicates that the springs were more active during the Holocene than during the late Last Glacial.

The deposits between 25 and 80 cm depth consist of biochemically precipitated marls with well-developed plant

PLATE 26. *Leptospermum* (?) root stump in growth position in a small spring mound at Mella. The root stump was radiocarbon dated at 47,500 $^{+\,2,700}_{-\,2,000}$ BP (GrN-7481).

TABLE 9 Mowbray Swamp radiocarbon dates

Depth (cm)	Material	GrN Lab. No.	^{14}C years BP
85	Root stump	8606	36,300 ± 700
	Humic extract	8646	34,100 ± 700
107.5-112.5	Humified peat	9341	$46,400 {}^{+1300}_{-1100}$
	Humic extract	9765	$45,200 {}^{+2600}_{-2000}$
120-130	Root stump	9342	> 52,000
	" "	9743	(52,220 ± 350)
	Humic extract	9767	$(51,300 {}^{+4400}_{-2800})$

occur in these sediments which appear to have accumulated over a period of 15,000 to 20,000 years under conditions of predominantly strong spring activity.

A thin bed consisting of peaty marl with small, well-preserved root stumps in growth position occurs between 80 and 90 cm depth, and overlies a 15 cm thick compact bed of biochemically precipitated marl with occasional freshwater shells. The woody and peaty marls indicate that spring activity was somewhat reduced around 36,000 BP which permitted small trees to encroach upon the swamp surface. Small semi-transparent mineral crystals are a characteristic feature of the woody bed and also occur in the lower peat beds. X-ray diffraction analysis revealed that the crystals are spring water precipitates and consist of the minerals Leonhardrite ($MgSO_4.4H_2O$) and Melanterite ($FeSO_4.7H_2O$) (Ford, personal communication).

From 115 to 140 cm the sediments consist of highly humified clay-rich woody peats which contain a thin layer of shell and biochemically precipitated marl that probably formed in response to a brief phase of increased spring discharge at approximately 48,000 BP.

At 140 cm, there is a marked change from woody peat to finely laminated, soft, shell marls and biochemically precipitated marls which at 160 cm overlie a compact bed of very fibrous peat which contains an horizon of well-preserved small *Leptospermum* (?) root stumps in growth position at 190 cm, and passes to sandy peat at 197.5 cm. The marine sediments which form the basal unit and consist of well-sorted, fine, quartz sands occur below 205 cm. The marine sands overlie Precambrian dolomite at depth.

The interbedded sequence of peats and marls outlined above indicates that, as at Pulbeena Swamp, climatically induced variations in the palaeohydrologic regime of the springs have had a marked effect on the characteristics of the sediments.

9.4 THE BROADMEADOWS SWAMP DEPOSITS

9.4.1 Introduction

Broadmeadows Swamp is situated 2 km northeast of Christmas Hills and 4 km southwest of Smithton at about 15 m above sea level (Fig. 21). The swamp deposits which have been artificially drained are up to 1 m thick and are underlain by shelly marine sands of Last Interglacial age which in turn are underlain by either weathered Cambrian siltstones and/or Precambrian dolomites (Nye *et al.*, 1934; Gulline, 1959). Low sandy rises resembling degraded interglacial beach/dune ridges occur discontinuously along the northwestern margin of the swamp and form a natural divide between this area and Mowbray Swamp.

The almost featureless swamp surface is locally interrupted by the occurrence of 0.5 to 1.5 m high spring mounds. Unlike the artesian spring deposits at Mowbray and Pulbeena swamps, the mounds and associated swamp deposits in this area consist of slightly acid (pH 6.5) clays and peaty clays which suggests that Cambrian siltstones are the aquifer rock in this area. All the mounds appear to be inactive at present. However, local residents reported that before the area was intensively tapped by water bores (Gulline, 1959) there was widespread leakage from the mounds causing swamp

PLATE 27. Study site at Broadmeadows showing clayey freshwater swamp peats overlying Pleistocene marine sands.

9.4.2 Stratigraphy, dating and interpretation

The sequence of sediments shown in figure 30 and plate 27 was recorded in a 110 cm deep excavation which was situated approximately 150 m from an inactive spring mound. The section was sampled at 5 cm intervals for sediment and pollen analysis. Organic content was determined by weight loss after drying a portion of the samples at 105°C followed by combustion at 500°C for an hour.

The loss-on-ignition curve of figure 30 shows that the predominantly clayey peat sediments are characterized by high values for organic matter, reaching a peak of 47 per cent at 95 cm depth. Very high values of silt and clay size residues (50-80%) characterize the upper 85 cm of the swamp deposit. The highest values for inorganic fractions (> 90%), consisting mainly of fine sands, occur near the base of the sequence and probably represent slight erosion and redeposition of the underlying marine deposits during the initial stages of spring activity in the area. The basal marine sediments consist of fine, well-sorted quartz sands which, as previously described in chapter 5, locally contain a well-preserved molluscan and foraminiferal fauna of Last Interglacial age.

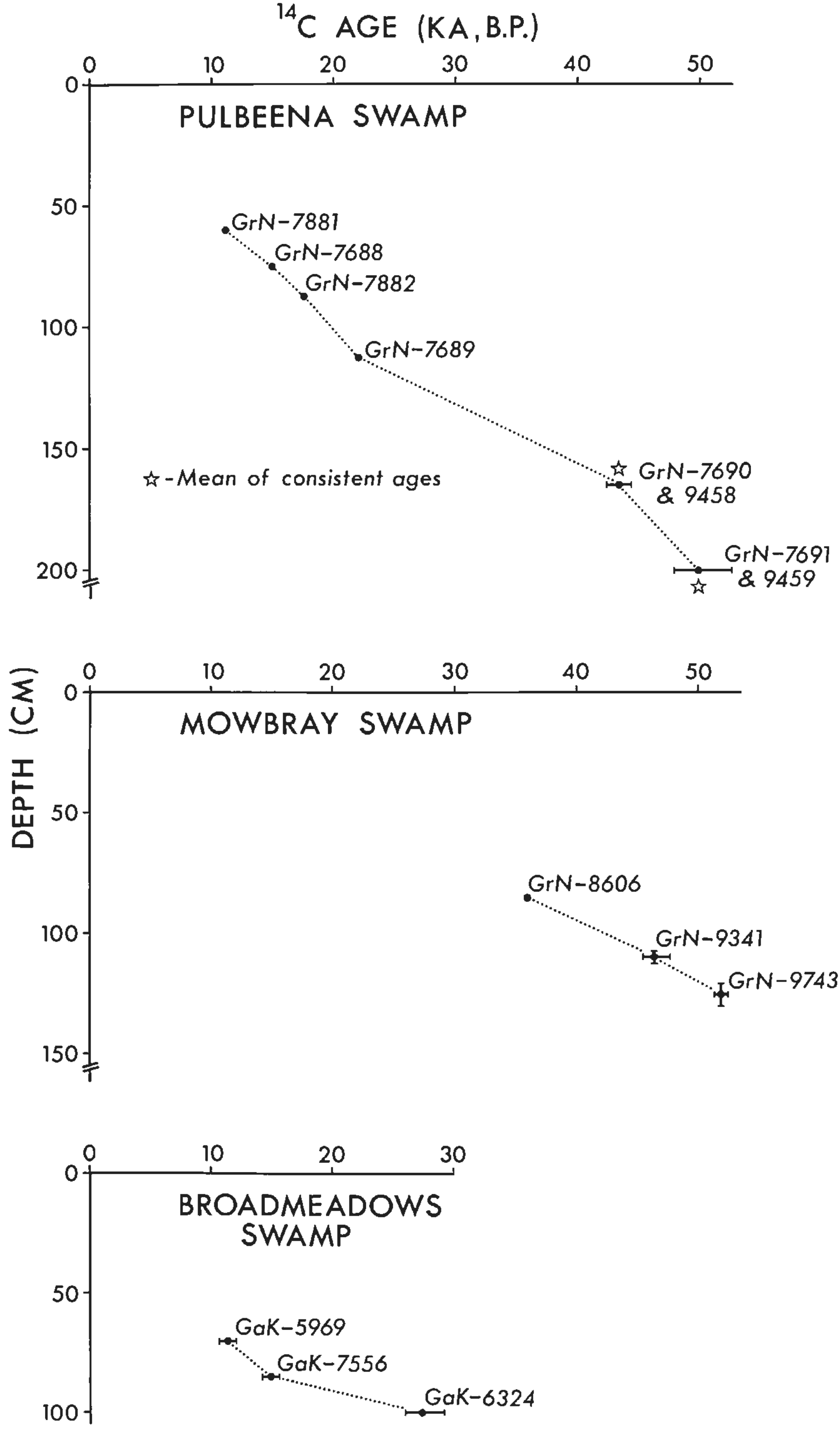
Three peat samples have been radiocarbon dated from the section at Gakushuin University, Tokyo (Fig. 30). Because modern, partly decomposed grass rootlets occur in abundance down to a depth of 60 cm, radiocarbon dating of the upper part of the sequence was not attempted. An assay of $27{,}600 \begin{smallmatrix} +\ 1700 \\ -\ 1430 \end{smallmatrix}$ BP (GaK-6324) was obtained from the base of the swamp deposits and suggests that spring activity in the area commenced around 30,000 years ago. A ^{14}C age of 15,000 ± 750 BP (GaK-7556) at 85 cm depth and low values for inorganic fractions between 85 and 95 cm suggests that spring discharges were very low between ∿ 27,000 and 15,000 BP. Higher values for inorganic fractions from 85 cm upwards, and a ^{14}C assay of 11,410 ± 770 BP (GaK-5969) at 70 cm depth, suggests that the springs gradually became more active after about 15,000 BP, and that the highest discharges occurred during the early to middle Holocene.

The inferred temporal variation in spring discharges outlined above appear to correspond well with those inferred from the Pulbeena and Mowbray Swamp deposits.

9.5 CORRELATION

9.5.1 Sedimentation rates

Time/depth curves (Fig. 23) and calculated facies sedimentation rates (Table 10) suggest that spring induced sediment accumulation rates have varied significantly. Although it is likely that sedimentation rates have varied in response to temporal variations in spring activity, there are, however, a number of reasons that render it unlikely that the calculated rates accurately reflect accumulation rates. As was briefly noted (Section 9.3.2) comments by Noetling (1912) indicate that at Mowbray Swamp considerable shrinkage of the deposits in the inter-mound depressions has taken place as a result of drainage of the swamp. Although there are no early records describing the pre-drainage thickness of the deposits at Pulbeena and Broadmeadows swamps, there can be little doubt that these sites have been similarly affected by drainage. In addition, there is evidence to indicate that the sediments have been considerably compacted by the weight



^{14}C AGE (KA, B.P.)
DEPTH (CM)
PULBEENA SWAMP
GrN-7881
GrN-7688
GrN-7882
GrN-7689
GrN-7690
& 9458
GrN-7691
& 9459
☆-Mean of consistent ages
MOWBRAY SWAMP
GrN-8606
GrN-9341
GrN-9743
BROADMEADOWS
SWAMP
GaK-5969
GaK-7556
GaK-6324
0
10
20
30
40
50
100
150
200

TABLE 10 Sedimentation rates

PULBEENA SWAMP

Depth interval (cm)	Sediment	^{14}C age interval (Ka)	Rate (cm/Ka)
0 - 60	Marl	11.4	5.3
60 - 75	Peat	3.6	4.2
85 - 115	Peat & peaty marl	5.5	5.5
115 - 165	Marl & peaty marl	21.4*	2.3
165 - 200	Peaty marl	$\geqslant$ 7.4*	$\leqslant$ 4.7

Approximate possible age at base** ∿ 107 Ka if constant accumulation rates of different sediment types is assumed.

MOWBRAY SWAMP

Depth interval (cm)	Sediment	^{14}C age interval (Ka)	Rate (cm/Ka)
0 - 85	Marl & peat	36.3	2.3
85 - 110	Marl	10.1	2.5
110 - 125	Peat	$\geqslant$ 5.8	$\leqslant$ 2.6

Approximate possible age at base** ∿ 82 Ka

BROADMEADOWS SWAMP

Depth interval (cm)	Sediment	^{14}C age interval (Ka)	Rate (cm/Ka)
0 - 70	Peaty clay	11.4	6.1
70 - 85	" "	3.7	4.0
85 - 100	Clayey peat	12.5	1.2

* Calculated from mean of two consistent ages at this level

** Calculated from mean of sedimentation rates listed above of the overburden. This is most clearly evident in the lower woody peat beds at Pulbeena Swamp and the basal woody peat bed at Mowbray Swamp. Here, the beds are very compact and flattened lateral branches of root stumps in growth position are a common feature. In calculating the sedimentation rates it was assumed that sediment accumulation, and by inference spring activity, has been a continuous process. However, the validity of this assumption is questionable. This is well illustrated by the evidence from Broadmeadows Swamp, where the ^{14}C data suggests that the nearby mound springs were mainly dormant between 27,000 and 15,000 BP. Furthermore, it is also considered unlikely that all the springs came into being at the same time. The presence of a number of dormant springs at Pulbeena and Mowbray swamps, and the considerable height range($< 1 - > 7$ m) of the mounds in the latter locality suggests that when mound springs have attained considerable height, new springs develop in the immediate surroundings in response to greater hydrostatic pressures which would seek to maintain minimum mound heights. The problems and uncertainties outlined above clearly indicate that the calculated sedimentation rates cannot be accepted at face value, and should not be used to extrapolate ages beyond radiocarbon dating control ($\sim$ 50,000 BP). Consequently, the possible basal ages of the sediments that can be calculated by assuming constant accumulation rates of different sediment types at Pulbeena and Mowbray swamps can only be regarded as approximate minimal ages.

9.5.2 Lithostratigraphic and chronostratigraphic correlation

The stratigraphy of the swamp deposits indicates that temporal variation in the strength of spring activity has had a marked effect on sediment composition. Marls are interpreted as representing periods of high spring discharges and peats conditions of reduced spring activity, with peaty marls having been formed between these two extreme hydrologic conditions. Further, the hydrologic changes are tentatively interpreted as a reflection of general climatically induced variations in the artesian water pressure/budget. If this inference is correct, then some degree of correlation of the main changes in the local hydrologic balance, as reflected in the sediments, should be evident between sites.

Figure 24 presents the probable lithostratigraphic and chronostratigraphic correlation, and gives a qualitative indication of the variations in the local palaeohydrologic balances at the three sites. The correlation diagram is supplemented by the following comments which serve to highlight some of the problems of correlation between the Pulbeena and Mowbray sequences.

The correlation of the uppermost marl bed at Pulbeena Swamp and the similar, but undated, lithofacies at Mowbray Swamp seems reasonably secure. However, direct correlation of the peat beds underlying the marls is problematical. This problem is compounded by the lack of radiometric dating for the upper part of the Mowbray Swamp sequence, and by the marked lateral stratigraphic variation in sediment type in the upper part of the Pulbeena Swamp sequence. As was noted, the study site at Pulbeena Limeworks was situated a short distance from depressed spring orifices. Here, three interbedded peats between 60 and 115 cm depth grade into a single peat a short distance from the study site. This bed could be traced continuously in trenches over at least 200 m towards the edge of the swamp and seems to reflect the gradually decreasing influence of the spring waters. In contrast, the stratigraphy at Mowbray Swamp

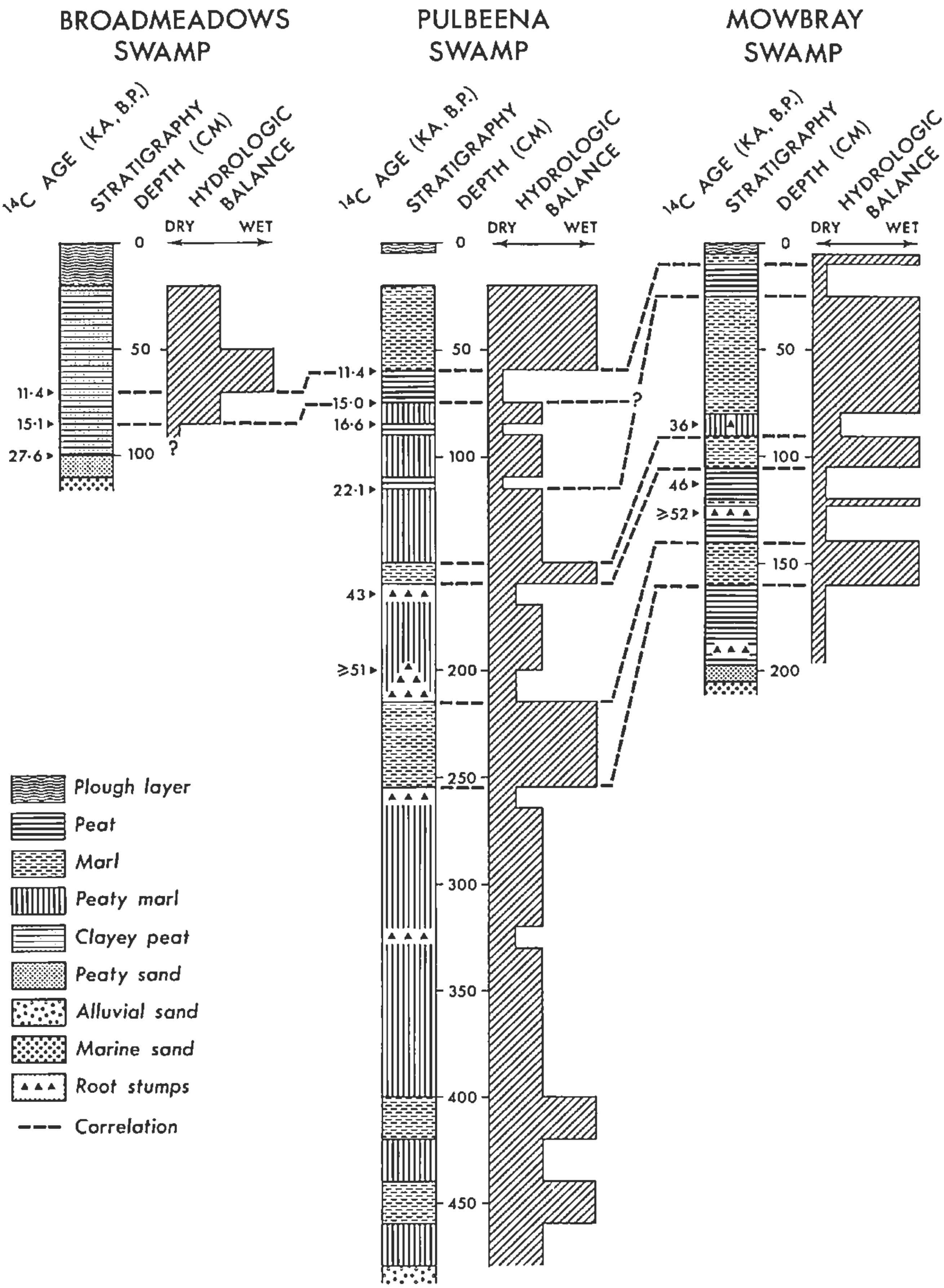


FIGURE 24. Lithostratigraphic and chronostratigraphic correlation of the artesian spring deposits, and inferred hydrologic balance.

was recorded in an inter-mound depression some 200 m away from the nearest mound springs, and therefore exhibits a simpler stratigraphy than the spring mounds. Hence, the local variations in spring controlled sedimentation indicates that the sequence of interbedded peats and peaty marls between 60 and 115 cm depth at Pulbeena Swamp are almost certainly the stratigraphic equivalent of the uppermost peat bed at Mowbray Swamp, even though the latter does not contain marl lenses indicative of periods of greater spring activity.

The ^{14}C data suggests that all or part of the very calcareous biochemically precipitated marl bed between 25 and 80 cm depth, and the underlying 10 cm thick woody and peaty marl bed at Mowbray Swamp formed about the same time (∿ 22,000-36,000 BP) as the peaty marl bed between 115 and 150 cm depth at Pulbeena Swamp. The differences in sediment type and the difference in hydrologic balance that they suggest highlights the difficulties of either perfect or wider correlation, where within site lithological variations may be as great or greater than between site variations. However, despite apparent differences in the magnitude of spring discharges, the suggested correlation seems likely because the direction of hydrologic change was the same, and both areas experienced predominantly higher spring discharges during the period between 22,000 and 11,000 BP.

The marls and ^{14}C assays show that both areas experienced high spring discharges between about 36,000 and 43,000 BP. Prior to this, the peat and peaty marl indicate that reduced discharges prevailed in both areas and appear to have commenced sometime before 52,000 BP. The marls indicate that local conditions were wet prior to this date, but when they commenced cannot be confidently ascertained from the data. Crude extrapolation of sedimentation rates suggests ∿ 65,000 BP as a possible date for the change from predominantly lower discharges and presumably drier conditions to higher discharges and wetter conditions at both sites. In view of the lack of radiometric dating control and the uncertainties surrounding age extrapolation, no further correlation is possible. However, it may be noted that lower discharges, and by inference drier conditions prevailed in both areas for a substantial period prior to the estimated age of 65,000 BP.

The ^{14}C assays indicate that the upper 70 cm of the peaty clays at Broadmeadows Swamp were deposited at the same time as the upper marl bed at Pulbeena Swamp. The inferred hydrologic conditions also correlate except that the loss-on-ignition data of Broadmeadows Swamp (Fig. 30) suggest that the springs became less active after the early/middle Holocene. Although not indicated in the correlation diagram, a similar change is apparent at Pulbeena Swamp where, as was noted in the description of the sediments, a change from shell marls to biochemically precipitated marls indicated that local conditions became marginally drier during the middle/late Holocene. The lithofacies and radiocarbon dates show that at both sites the springs were also less active between about 15,000 and 11,000 BP than during the early and middle Holocene. At Broadmeadows, the lowest spring discharges seem to have occurred between about 27,000 and 15,000 BP. This appears to be at variance with the evidence from Pulbeena Swamp where the sediments indicate that moderately high discharges occurred at least intermittently during this time. However, since the higher discharges recorded at Pulbeena Swamp are only evident near spring orifices, they are not characteristic of the whole central part of the swamp. Thus, as at Mowbray Swamp, this difference is probably more apparent than real. A possible contributing factor for the lack of perfect correlation may be that the basal part of the Broadmeadows sequence either contains a long hiatus or reflects extremely slow sedimentation. The hiatus seems to be due to temporary cessation of spring activity during an early stage of mound spring development in this area. The tremendous radiocarbon age difference in only 15 cm of highly organic sediments supports this interpretation.

Although the lithostratigraphic records from the swamp/lake deposits at Pulbeena Swamp, and mound spring and associated swamp deposits at Mowbray and Broadmeadows swamps appear largely to reflect local hydrologic conditions, the lithostratigraphic and chronostratigraphic correlation of these sites indicates that the direction of the main hydrologic changes are similar and approximately synchronous. Given this apparent regional parallelism, it is tentatively concluded that the broad-scale hydrologic changes recorded in the sediments reflect general climatically induced variations in the artesian water budget, and hence periods of wetter and drier climatic conditions.

9.6 THE SMOKERS BANK SWAMP DEPOSITS

9.6.1 Introduction

In contrast to the freshwater lacustrine and swamp deposits described in the preceding sections, the deposits and associated landforms presented in this section are not related to artesian spring activity but have resulted from lacustrine and aeolian processes that are not operative in the area at the present time.

A number of small, circular inland lagoonal swamps which are bounded by low sand lunette ridges along their northeastern margins occur on the western part of an old,

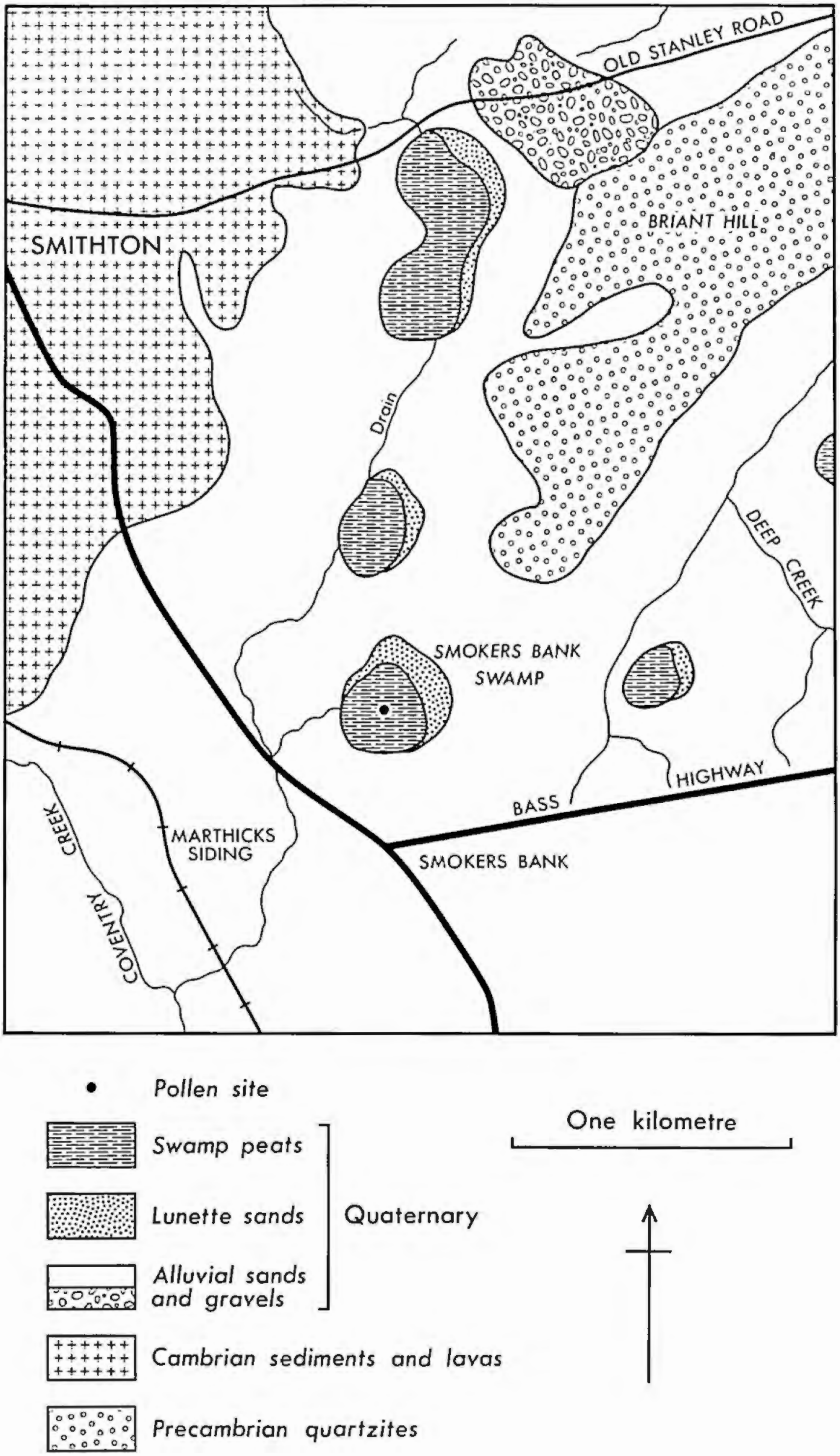


FIGURE 25. Lagoonal swamps and lunettes in the Smokers Bank area.

PLATE 28. Crest of sand lunette at Smokers Bank with swamp at left hand side of the photograph.

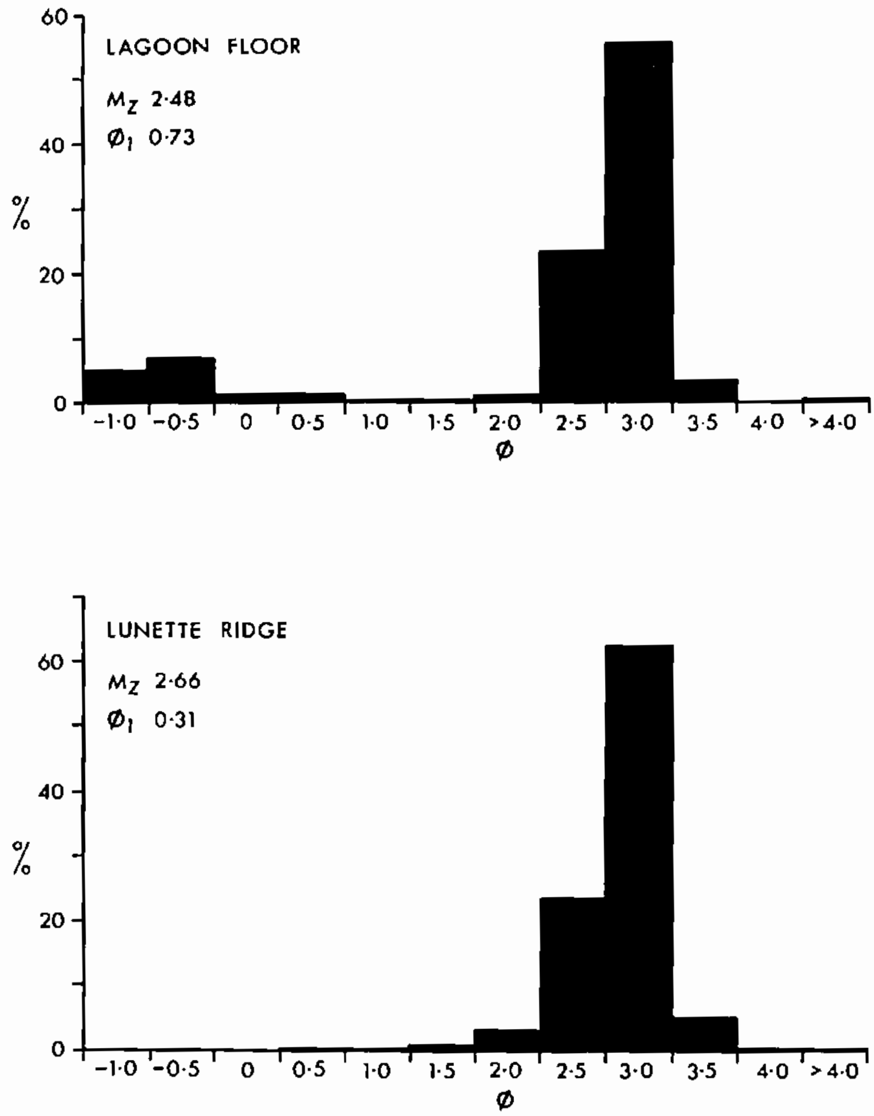


FIGURE 26. Grain size distribution of the Smokers Bank Swamp lagoon and lunette sands.

broad alluvial plain which is situated southwest of Smithton at about 30 m above sea level (Fig. 25). The shallow swampy basins are drained by the ephemeral tributaries of small creeks and a network of shallow drainage ditches.

Smokers Bank Swamp is located approximately 2 km southeast of Smithton and consists of a marshy depression which covers some 8 hectares. The swamp was formerly drained by a small outlet creek to the west but excess water is now carried off by a number of interconnected shallow ditches one of which runs approximately through the centre of the swamp. A 2.5 to 3.5 m high, vegetated, sand lunette occurs along the eastern margin of the swamp (Plate 28). A narrow, moderately well-developed fossil beach occurs in front of the lunette ridge and stands about 1 m above the centre of the swamp surface. The orientation of the beach indicates that it was formed by waves that were generated mainly by a west to southwesterly wind regime.

9.6.2 Stratigraphy and composition

Drainage ditch exposures show that the lagoonal swamp deposits are only 20 to 45 cm thick and consist mainly of acid (pH 5.5), sandy peats which are underlain by an unknown thickness of consolidated, moderately sorted alluvial sands (Fig. 26) consisting of sub-angular quartzite fragments and occasional small, poorly rounded pebbles. The age of the alluvium is unknown but it is probably late Quaternary. The fossil lunette ridge consists of well-sorted, medium-fine sands (Fig. 26).

9.6.3 Soil development

A number of auger holes indicated that the lunette ridge is entirely composed of fine sand and is characterized by a moderately well-developed podzol soil profile. The A_1 horizon is a light brownish-grey humic sand and is up to 20 cm thick. The A_2 horizon is 40 to 50 cm thick and consists of leached greyish-white sand. The $B_{2h,ir}$ horizon is 50 to 60 cm thick, is light brown in colour and is moderately indurated. The C horizon consists of wet pale grey-white sand.

9.6.4 Discussion and interpretation

Fossil terrestrial source-bordering aeolian landforms and associated features are not unique to the Smokers Bank area but have also been noted to occur leeward of river plain sources elsewhere in northwestern Tasmania (Colhoun, 1978a). Such landforms and deposits are, however, much more numerous and better developed on low ground in the drier eastern half of Tasmania (Colhoun, 1975). Detailed studies of some of these features in southeastern Tasmania have indicated that they appear to have developed in response to a major climatic change to greater aridity during the later part of the Last Glacial Stage (~ 20,000-10,000 BP) (Colhoun, 1975; Sigleo and Colhoun, 1975; Sigleo and Colhoun, in preparation). The inferred palaeoenvironmental conditions put forward in these studies correspond well with the evidence from mainland Australia where it has been demonstrated that a widespread phase of dune formation and lowering of lake levels occurred between about 22,000 and 14,000 BP (Bowler *et al.*, 1976).

The evidence from southeastern Tasmania and the Australian mainland led Bowden (1978) to the tentative conclusion that the very extensive source bordering aeolian landforms and deposits of the coastal region of northeastern Tasmania were also formed during the late Last Glacial period. However, a recently obtained radiocarbon assay on *in situ* wood overlain by several metres of podzolised, charcoal-rich lunette sands suggests that at least some of the inner ridges of the multiple lunettes in northeastern Tasmania developed after about 8,500 BP (Bowden, 1981). This radiocarbon assay also indicates that the palaeoenvironmental and palaeoclimatic history of Tasmanian fossil terrestrial aeolian landforms and deposits is probably considerably more complex than initially suggested by Colhoun (1975, 1978a), and that this problem needs to be more fully investigated in areas such as coastal northeastern Tasmania where it may be possible to increase the present state of knowledge by further stratigraphic studies and radiocarbon dating of multiple lunette sequences and associated aeolian and freshwater swamp deposits.

At Smokers Bank it is both difficult to date and evaluate the palaeoenvironmental and palaeoclimatic significance of the lagoonal swamp and sand lunette deposits. The fine sandy texture of the lunette suggests that the sediments have accumulated by saltation from a beach. Although there are sufficiently strong west to southwesterly winds to erode fine sands from lagoon beaches, there is, however, no beach to act as a source at present. Also, the peaty nature of the lagoonal swamp sediments indicates that a vegetated swamp occupied the lagoon for some time and that open water wave action and shoreward transport of sediments could not have occurred during this time. The lunette sands must therefore pre-date the development of the swamp peats and probably accumulated during times when somewhat higher and perhaps seasonally fluctuating water levels prevailed in the lagoon.

Since no suitable carbonaceous materials occur in association with the lunette sands and the shallow lagoon peat deposits are contaminated throughout by modern plant root materials, it has not been possible to use radiocarbon dating techniques to obtain an absolute age of the Smokers Bank deposits. Their age can therefore only be approximated on a relative basis using indicators such as the degree of soil development in the lunette and pollen analysis of the lagoon peats.

Although the degree of soil profile development is intimately related to local environmental factors, if used cautiously, soil profiles can provide a general indication of relative age. On this basis, the podzol soil profile developed in the Smokers Bank lunette contrasts very strongly with the very compact, deeply podzolised (> 3 m) Last Glacial age alluvial sands at Welcome Inlet (Chapter 5) but compares well with the moderate degree of podzolisation (< 1 m) observed in the innermost Holocene barrier beach ridges on Perkins Island (Chapter 3). These general comparisons point to the probability that the Smokers Bank deposits are of Holocene age. Further, the pollen record of the lagoonal swamp peat deposits (Chapter 10) indicates that the pollen profile is not likely to be older. If a Holocene age is accepted for these deposits, it seems likely that the lunette development occurred during the early to middle part of this period, when judging from the evidence provided by the artesian spring deposits at Pulbeena and Broadmeadows swamps, climate was moister than either during the preceding or succeeding periods.

9.7 FAUNA

The marly spring sediments and swamp peats at Pulbeena and Mowbray swamps contain a well-preserved molluscan fauna. Marl samples were found to contain an identical fauna consisting of many individuals of a few species of gastropods. These were identified by J.B. Smith of the National Museum in Victoria as:

Endodontidae,	*Trocholaoma spiceri* Petterd 1879
Planorbidae,	*Gyraulus* sp.
Planorbidae,	*Physastra* sp.
Succineidae,	*Austrosuccinea australis* Ferrusac 1821
Sphaeridae,	*Sphaerium tasmanicum* Tenison-Woods 1876

With the exception of *T. spiceri* which is a land snail, and *A. australis* which occupies marginal aquatic habitats, the other species live in still, or very slow moving, freshwater lakes. The assemblage is consistent with the interpretation of swamp, shallow lacustrine and pond environments as indicated by the sediments of the sites.

The Pulbeena and Mowbray swamp deposits contain abundant ostracods most of which require the presence of standing water and indicate a diversity of local habitats in a varied aquatic environment. A number of new fossil ostracod species have been recorded from the Pulbeena deposits. A detailed study of the ostracods by P. De Deckker (in preparation) has indicated that the variation in number generally parallels the line that separates the woody and the herbaceous taxa of the summary pollen diagrams (Figs. 28 and 29).

At Pulbeena Swamp there is a virtual absence of ostracods between 95 and 65 cm depth which indicates that the activity of the springs was reduced and drier conditions prevailed during late Last Glacial times (~ 18,000-10,000 BP), as was also inferred from the stratigraphy. Throughout the rest of the sequence, the greatest numbers of ostracods occur with the woody swamp taxa, Cyperaceae and aquatic taxa, and the lowest numbers occur in association with high Gramineae values. At Mowbray Swamp, the ostracods are almost exclusively associated with the marls and are either absent or occur only in very low numbers in the clayey peats which is consistent with the interpretation that the peat beds formed under conditions of greatly diminished spring activity. No gastropods or ostracods occur in the acid sediments at Broadmeadows and Smokers Bank swamps.

In recent years, important finds of remains of extinct marsupials have been taken from the dragline quarry face of the limeworks at Pulbeena. These include a mandible and incisor of *Palorchestes azael* Owen 1874 dated at 54,200 $^{+\ 11,000}_{-\ \ 4,500}$ BP (GrN-7322) (Banks *et al.*, 1976), and a nearly complete skeleton of *Macropus greyi* Waterhouse 1846 dated at 22,130 ± 180 BP (GrN-7689), as shown in figure 27. The latter has also been found in association with archaeological deposits dated at about 23,000 and 15,000 BP at Cave Bay Cave on Hunter Island, and in undated clayey spring mound deposits at Edith Creek (Horton and Murray, 1980). In addition, remains of emus (Dromornithidae, Aves) which became extinct in Tasmania early this century have been found at the Pulbeena Limeworks quarry (Murray, personal communication).

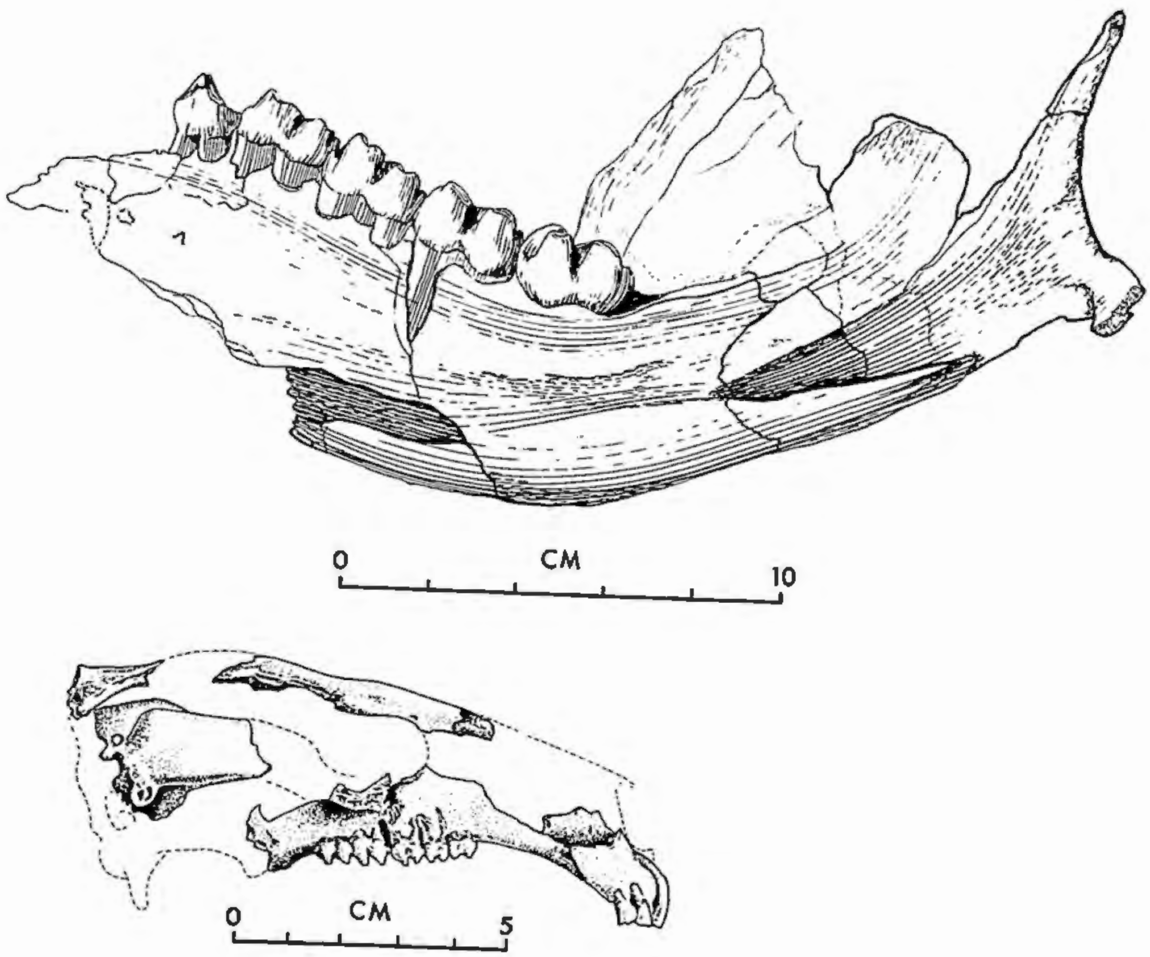


FIGURE 27. Extinct marsupials from the Limeworks quarry at Pulbeena. Right mandible of *Palorchestes azael* Owen 1874, dated at 54,200 $^{+\ 11,000}_{-\ \ 4,500}$ BP (GrN-7322) (after Banks *et al.*, 1976).

Reconstruction of the skull of *Macropus greyi* Waterhouse 1846, dated at 22,130 ± 180 BP (GrN-7689) (after Horton and Murray, 1980).

The earliest finds of remains of extinct marsupials in the area were made during the excavation of drainage ditches at Mowbray Swamp around 1910 (Noetling, 1912). According to the literature describing the finds (reviewed by Gill and Banks, 1956), the fossils appear to have been found near the base of the spring mound and associated swamp deposits and are therefore likely to date back to the early part of the Last Glacial Stage.

A very large bone deposit containing a very rich fauna which includes a number of extinct species has been reported from a small cave system 10 km southwest of Montagu (Murray and Goede, 1977). A uranium series date of 20,000 ± 4000 BP on a detrital speleothem associated with the deposit points to the probable survival in northwestern Tasmania of some extinct species of megafauna during the later part of the Last Glacial Stage (Goede *et al.*, 1978).

Detailed analyses of the freshwater molluscs, ostracods, and fossil marsupials were not objectives of this dissertation. However, the material found during the course of this study have been forwarded to the appropriate specialists whose work is not yet complete but who have made the identifications used in this brief section.

CHAPTER 10

POLLEN STUDIES

10.1 INTRODUCTION

As demonstrated in the previous chapter, temporal changes in the general relative hydrologic balance of the coastal lowlands are reflected in the lithostratigraphic records of the artesian spring deposits at Pulbeena, Mowbray, and Broadmeadows swamps, and also by the occurrence of a fossil sand lunette and associated lacustrine deposits at Smokers Bank. This chapter presents the results of systematic pollen analysis of these sites which was primarily undertaken to determine the possible relationships between inferred hydrologic balance and local vegetation responses.

10.2 PREVIOUS POLLEN STUDIES

Prior to the present study, nine samples were analysed from the lacustrine swamp deposits at Pulbeena Swamp for the purpose of placing the fossils of *Palorchestes azael* Owen 1874 in a stratigraphic and palaeoenvironmental context (Banks *et al.*, 1976). The preliminary analysis indicated that the sequence contained a long record of vegetation and hydrologic changes, and revealed the need for detailed pollen analysis of the site.

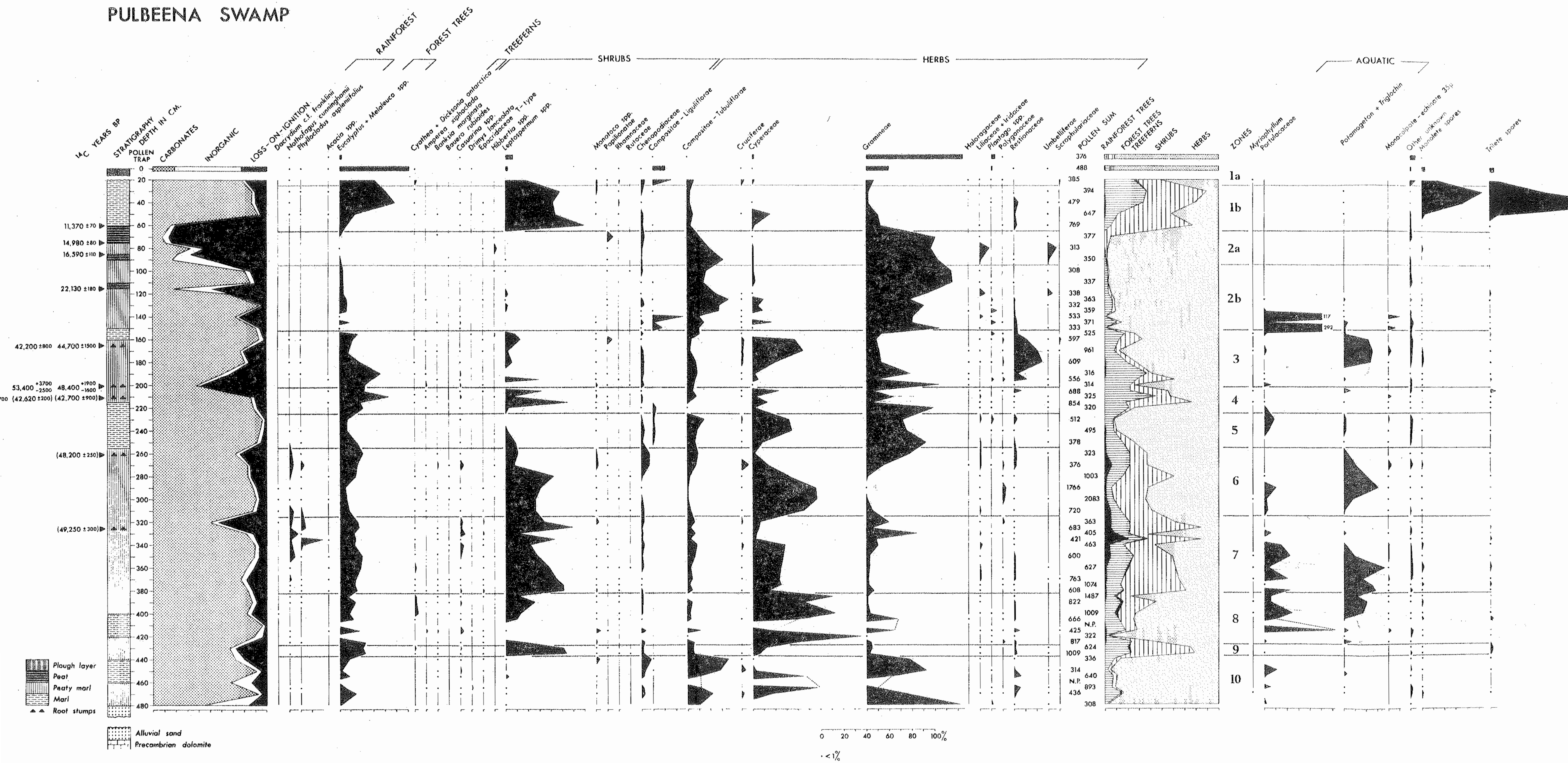
Preliminary pollen analysis of a few spring mound and swamp sediment samples from the Mowbray Swamp area was undertaken by Cookson (in Gill and Banks, 1956) who noted that a variety of common tree, shrub and herb taxa was represented but that the pollen content of the sediments was low.

10.3 METHODS AND PROBLEMS

The samples were processed by the techniques outlined by Faegri and Iversen (1975). The procedure involved successive treatments with 10% HCL, 10% KOH, 70% HF, and acetolysis solution. Some of the woody peat samples contained a high residual insoluble organic fraction. These samples were carefully bleached for up to half a minute with Cl before being stained and mounted in either glycerol or silicone oil which served as the media for studying the pollen on microscope slides. The pollen were counted using a Wild binocular microscope at 600 magnification and oil immersion was used whenever required. Pollen identifications were made with the aid of reference slides in the Geography and Botany departments of the University of Tasmania. The counts were based on a minimum sum of 300 grains of tree, shrub and herb pollen, plus the spores of the treefern *Dicksonia antarctica*. Aquatic pollen, monolete and trilete fern spores were counted outside the sum but are expressed as percentages of the sum. The presence of charcoal, algae and fungal spores was noted but no systematic counts were made. The taxonomic nomenclature is based on Curtis (1963, 1967), Curtis and Morris (1975), and Aston (1973).

The pollen in some samples was folded and broken, and in the alkaline spring deposits frequently somewhat corroded. Degradation was particularly common in the surface horizons which have been strongly affected by groundwater fluctuations and by burning. A more serious problem encountered was that at Pulbeena Swamp it was not possible to consistently differentiate *Melaleuca* spp. from *Eucalyptus* spp. pollen in slightly degraded condition although sufficiently well-preserved grains were observed to indicate that several species of each genus are present. Consequently, the values are combined in figure 28 but this has the disadvantage of merging a predominantly upland regional element viz. *Eucalyptus*, with the predominantly lowland swamp element *Melaleuca*. Both *Pediastrum* and *Botryococcus* are abundant in the marls at Pulbeena Swamp but these algae were generally too badly preserved to be systematically counted. Because of difficulties in consistently differentiating *Potamogeton* from *Triglochin* species at Pulbeena, the values are combined.

There are difficulties in determining whether certain pollen taxa belong to vegetation of the swamps or represent inputs from the vegetation of adjacent upland areas, as *Melaleuca*, *Acacia*, *Leptospermum*, *Monotoca*, Compositae, Cyperaceae, and Restionaceae could occur in abundance in either situation. This difficulty is increased because the surface of the swamps and much of the surrounding areas have been cleared of natural vegetation and are now cultivated, as is indicated by the high Gramineae values of the surface horizons. No contemporary spring controlled vegetation analogues occur elsewhere in the study area. Although there are a number of extensive swamps in the lowland area (Fig. 4B), these are either salt marsh/*Melaleuca* spp. coastal swamps or *Acacia melanoxylon* river swamps. It has therefore not been possible to undertake a representative surface pollen sample study to assess the pollen production and dispersal characteristics of the vegetation, and to determine the representativeness of the fossil pollen values in terms of contemporary vegetation or plant communities. In the absence of discriminating criteria it is judged from the rapidly changing values of many taxa that the bulk of the inputs were from the swamp surfaces and represent local vegetation changes that occurred in response to marked changes in the spring controlled hydrologic conditions. The pollen sum, therefore, necessarily includes all pollen taxa except for aquatics and fern taxa irrespective of whether there may or may not be a substantial pollen input from the upland regional vegetation. The only certain regional pollen component is the temperate rainforest taxa which by their values reflect increasing and decreasing distance of the pollen sources and variations in regional humidity. Because of the strong filtering effect that a dense canopy of *Melaleuca* forest and *Leptospermum* scrub might have on the regional pollen transport to the central parts of the swamps, it would be expected that distant rainforest and forest tree components from the adjacent uplands would be better represented during times when the swamp surfaces had a predominantly herbaceous vegetation. This is not the case, because the highest rainforest values tend to occur at the same time as the maximum development of tree and shrub taxa on or adjacent to the swamps, and the lowest values occur when woody taxa are poorly represented (e.g. Pulbeena Swamp Zone 2). Thus, although it has not been possible to differentiate local and regional pollen components, it is clear that the rainforest taxa covary with the local woody taxa from the swamps and that it is likely that other regional forest components would vary similarly.


PULBEENA SWAMP
RAINFOREST
FOREST TREES
TREEFERNS
SHRUBS
HERBS
AQUATIC
14C YEARS BP
STRATIGRAPHY
DEPTH IN CM.
POLLEN TRAP
CARBONATES
INORGANIC
LOSS-ON-IGNITION
POLLEN SUM
ZONES
Plough layer
Peat
Peaty marl
Marl
Root stumps
Alluvial sand
Precambrian dolomite
0 20 40 60 80 100%
· < 1%

10.4 PULBEENA SWAMP POLLEN DIAGRAM

10.4.1 Description

The pollen diagram (Fig. 28) is characterized by a relatively restricted number of taxa. It has been divided into ten local biostratigraphic zones on the basis of the predominance of herbaceous versus woody taxa for at least two horizons (Colhoun, personal communication). This recognises that single samples dominated by the superabundance of a single taxon of strictly local origin may deviate from the overall trend of pollen inputs to the deposit, and also recognizes that it is unlikely that any major ecological/hydrologic, and by inference climatic fluctuation will be recorded unless it endured for at least 1500-2000 years. Because of the limited resolving power of the analysis minor events may have been missed, but the aim was to differentiate the first order changes. The sediment variation, however, does not indicate that more information of a general nature would be gained from close resolution. The zonation was established assuming that there is a greater probability of the local pollen rain of a herbaceous vegetation being masked or diluted by an input of tree and shrub pollen from adjacent forest and scrub vegetation than *vice versa*. Because the profile as a whole is dominated by herbaceous vegetation it suggests predominantly open environments and the following arbitrary values were used to suggest differences in the quantity of tree and shrub vegetation present. Where the sum of woody taxa exceeds 50 percent it is considered that there was substantial tree and shrub vegetation; where herbaceous pollen exceeds 50 percent and pollen of woody taxa exceeds 25 percent, it is considered that stands of forest and scrub were probably discontinuous but formed a significant component of the vegetation; and where the sum of herbaceous pollen exceeds 75 percent the environment was considered to be essentially non-forested although no doubt sporadic stands of trees and shrubs were present locally. In addition cognisance was given to the changing values of rainforest and forest tree taxa in zoning the diagram. The pollen diagram is supplemented by the following description:-

Pollen Zone 10

This basal zone contains one horizon (460 cm) that is devoid of pollen. The remainder is characterized by an overwhelming abundance of herb pollen (91%) which consists of high values for Gramineae (41%), Compositae-tubuliflorae (20%) and Chenopodiaceae (3%), and peaks of Cyperaceae and Restionaceae at between 455 to 465 cm. The pollen of forest trees (7%) exceeds that of shrubs (2%) but woody taxa have low values and rainforest taxa and treeferns are virtually absent. There are small amounts of Portulacaceae and *Potamogeton* in the middle of the zone.

Pollen Zone 9

This is the thinnest zone in the sequence and it corresponds with a bed of very peaty marl. The pollen content consists predominantly of woody taxa (77%) and low values for herbs (23%). Shrubs (55%), especially *Leptospermum* are more important than the trees (22%) of *Eucalyptus-Melaleuca*. Gramineae, Compositae-tubuliflorae and Chenopodiaceae contribute most of the herbaceous pollen. Treeferns are present and include *Cyathea* and *Dicksonia* but aquatics are virtually absent.

Pollen Zone 8

The zone is characterized by substantial quantities of herbaceous pollen (68%) and moderate values for woody taxa (31%). However, very high values for Cyperaceae (55%) undoubtedly of local origin diminish the significance of the herbaceous pollen which otherwise consists of moderate values for Gramineae, Compositae-tubuliflorae and Chenopodiaceae, and increases the significance of woody taxa with relatively high values for *Eucalyptus-Melaleuca* (12%) and peaks for *Casuarina* and *Monotoca*. Traces of rainforest pollen are persistently present and treeferns attain a maximum that exceeds that of Zone 1 in the upper part of the diagram. Portulacaceae is abundant but fluctuates strongly and *Potamogeton* values are high in the upper part of the zone.

Pollen Zone 7

The zone is characterized by the predominance of woody taxa (63%) of which 42 percent are shrubs dominated by *Leptospermum* with subsidiary *Casuarina* and 16 percent forest trees of *Eucalyptus-Melaleuca*. The temperate rainforest species *Nothofagus cunninghamii* and *Phyllocladus aspleniifolius* reach their maximum values for any zone and together average over 5 percent. Herbaceous pollen values are lower (36%) than in either zone 6 or 8 but Gramineae, Compositae-tubuliflorae, Cyperaceae and Chenopodiaceae are consistently present. There are traces of treeferns and monolete fern spores are persistent. Portulacaceae fluctuates throughout the zone and *Potamogeton* decreases from high values at the base of the zone to less than 1 percent at the top.

Pollen Zone 6

During this zone herbaceous pollen (59%) only slightly exceed the pollen of woody taxa (42%) indicating that substantial quantities of forest trees (12%) and shrubs (27%) were present. The most important components are *Leptospermum* spp. with *Eucalyptus-Melaleuca* and some *Casuarina* and *Monotoca*. The pollen of rainforest species (3%) is consistently present and is more abundant than in Zone 1. The herbaceous pollen is dominated by Cyperaceae which averages 34 percent and is of local swamp/lake origin. Values of Gramineae and Compositae-tubuliflorae are very low but Chenopodiaceae are persistently present. The importance of a damp site and standing water are indicated by high values of Portulacaceae (3%) and *Potamogeton* (12%).

Pollen Zone 5

The zone is characterized by very high values of herbaceous taxa (86%) with Gramineae amounting to 40 percent, Compositae-tubuliflorae to 11 percent, and Cyperaceae to 26 percent. In addition Compositae-liguliflorae and Chenopodiaceae are frequent. The pollen values for forest trees (10%) consist mainly of *Eucalyptus-Melaleuca*, and the *Leptospermum* shrubs (40%) decline to zero in the upper part of the zone. Traces of rainforest species occur but there are no treeferns. Slight peaks of Portulacaceae and *Potamogeton* occur.

Pollen Zone 4

The zone is characterized by relatively high values for woody taxa (53%) in which pollen of forest trees constitutes 26 percent and pollen of shrubs 27 percent. *Eucalyptus* plus

Melaleuca dominates the tree-pollen and *Leptospermum* with *Casuarina* and *Monotoca* the shrub pollen. Rainforest pollen is almost absent but the treefern *D. antarctica* is present. Only traces of aquatic pollen of *Potamogeton* and *Myriophyllum*, and spores of ferns occur. The pollen of this horizon is associated with woody peat that contains tree stumps.

Pollen Zone 3

The zone is characterized by a predominance of herbaceous taxa (68%) but also contains substantial pollen of *Eucalyptus* plus *Melaleuca* forest (20%) and shrub (11%) taxa of *Leptospermum* and *Monotoca*, with traces of rainforest, treefern and fern taxa. The values of herbaceous and woody taxa fluctuate more in this zone than in either Zone 2 or Zone 4 but there is an overall upward decrease in woody taxa and increase in herbaceous taxa throughout the zone, a trend that is continued and emphasised in Zone 2. The aquatic pollen of *Potamogeton-Triglochin* is important.

Pollen Zone 2

The zone is characterized by very high values of Gramineae (56%), Compositae-tubuliflorae (21%) and herbs (total 95%), and very low values for forest trees (3%) and shrubs (2%) throughout the zone. Rainforest and treefern pollen is virtually absent, and values for damp site and aquatic taxa are extremely low except for the basal 20 cm. A division into subzones 2a and 2b is possible on the basis of the almost complete absence (< 1%) of tree pollen in the former and its significant occurrence (5%) in the latter.

Pollen Zone 1

This zone extends from 20 to 65 cm and includes the surface sample which exhibits the same pollen assemblage. The zone has been divided into two subzones on the basis of a decrease in woody taxa and an increase in herbaceous taxa at 20 cm. Subzone 1s represents the surface disturbance by agricultural practices which is indicated by high values of *Plantago lanceolata*, Compositae-liguliflorae probably *Taraxacum officinale*, and introduced grasses. Subzone 1b is characterized by low values for Gramineae and other herbs, and very high values for *Eucalyptus-Melaleuca* spp., and *Leptospermum* spp. A small component of rainforest taxa also occurs and includes *N. cunninghamii* and *P. aspleniifolius* as well as treefern spores. Abundant monolete and trilete spores and charcoal occur in the middle of the zone and may indicate the significant growth of ferns after partial destruction of the swamp vegetation by occasional fire. Aquatic pollen are rare but the presence of Cyperaceae and Restionaceae pollen indicates that damp surface conditions prevailed.

10.4.2 Interpretation

Although there are some problems of separating local from regional pollen types as discussed earlier, it is clear that there is a very high proportion of local components from a swamp-lake flora which was strongly influenced by changes in spring activity. The hydrologic changes are clearly reflected in the stratigraphy which integrates the relationships between hydrologic conditions and local vegetation responses.

Zone 10 represents the initial accumulation of materials on the swamp with a compressed bed of peaty marl including wood being overlain by biochemically precipitated marl with a low pollen content. The high values of Gramineae, Compositae and Cyperaceae point to a predominantly herbaceous vegetation during the initial stages of spring activity which flooded part of an old alluvial plain. The low values for aquatic taxa suggest that open water conditions were probably restricted to pools of standing water around spring orifices and that lake edge aquatic vegetation was not extensively developed.

Zone 9 is formed by a thin bed of peaty marl which coincides with high values of *Leptospermum* and moderate quantities of *Melaleuca-Eucalyptus*. Herbaceous and aquatic taxa are lower than in the succeeding Zone 8 which suggests that spring discharge was relatively low, as is also indicated by the composition of the sediments. Collectively, the pollen evidence indicates that a closed scrub or low swamp forest association occupied most of the site, and that open water conditions were virtually absent.

The sediments of Zone 8 indicate varying spring activity. The basal peaty marl was deposited under moderately low discharge conditions and is overlain by biochemically precipitated marl formed under higher discharge conditions. The peaty shell marls of the upper part of the zone indicate moderate discharge conditions similar to most of Zone 7. The swamp vegetation is predominantly herbaceous in the lower part of the zone with very large quantities of Cyperaceae and some Gramineae, and with very low quantities of woody taxa. However, woody taxa are considerably more important in the upper part of the zone where they are accompanied by trees of rainforest taxa, and *D. antarctica*. The occurrence of extensive open water conditions throughout this zone is indicated by the biochemically precipitated marl and the high values of *Potamogeton*. The sediments and vegetation indicate that a gradual change from moist to wet conditions occurred.

During Zone 7 the springs were moderately active and peaty shell marl was deposited extensively in the lake/swamp. In this zone the quantity of woody vegetation exceeds that of either Zone 8 or Zone 6. Although Cyperaceae is relatively reduced, the high values for Portulacaceae cf. *Claytonia australasica* and *Potamogeton* indicate that open water conditions prevailed locally on the swamp surface. A noteworthy feature of this zone is the presence of significant quantities of the rainforest taxa *N. cunninghamii* and *P. aspleniifolius*. These values are much higher than in any preceding or succeeding zone including the Holocene Stage. This demonstrates that the region had a densely forested environment and that the regional climate was moist to wet during this period, an interpretation that is supported by the swamp sediments. A distinct horizon of small root stumps in growth position occurs near the top of the zone and indicates a temporary period of reduced spring activity probably associated with a brief relatively dry phase.

Zone 6 was a period of moderate discharge when peaty shell marls accumulated. The swamp vegetation consisted of abundant *Leptospermum*, *Melaleuca* and some *Monotoca*. Cyperaceae is the major herb component and the high value for *Potamogeton* indicates the presence of open water and a high water table. That the regional climate was moist to wet is supported by the significant quantities of rainforest taxa. An horizon of small *in situ* root stumps near the top of this zone marks a period of reduced spring activity which like the similar horizon in Zone 7 may reflect a brief drier phase.

Zone 5 consists of biochemically precipitated marl deposited as a result of high spring activity. The high values for Gramineae, Compositae and Cyperaceae, and low values for woody swamp taxa point to a predominantly herbaceous vegetation. The pollen assemblage and values suggests that the swamp vegetation was broadly similar to that of Zone 10.

During Zone 4 the change from predominantly biochemically precipitated marl to a woody peat-marl indicates lowering of the groundwater and drying out of at least part of the swamp surface. The marked fluctuations of the dominant taxa may reflect relatively short term fluctuations in the discharge regime of the springs.

The peaty marl of Zone 3 indicates that generally moist conditions prevailed on the swamp surface as a result of moderately high spring activity. A marked horizon of small, charred root stumps occurs at 165 cm and indicates that the *Melaleuca-Leptospermum* vegetation on the swamp surface had been burned, from which it is inferred that a period of lower groundwater occurred near the top of the zone. The vegetation during this time was probably a mosaic which consisted of Cyperaceae and Restionaceae swamps with *Melaleuca* and *Leptospermum* scrub on slightly elevated sites away from the springs. The presence of shallow bodies of standing water is indicated by *Potamogeton*.

The sediments developed during Zone 2 indicate fluctuating groundwater conditions with an overall trend towards markedly lower spring activity during which peat beds, formed by herbaceous taxa, probably developed over the entire swamp surface. The general depression of groundwater level indicates a change from moister to drier climatic conditions after ∿ 36,000 BP. The maximum dryness occurred at 22,000 BP and between about 17,000 and 11,000 BP when, as described in chapter 9, there was a relatively high input of spring translocated silt and clay which supports the inferred substantial reduction in spring activity during this period.

The swamp surface was predominantly vegetated by grasses and other herbaceous taxa. Trees and shrubs were very few but were slightly more important during the earlier part of the zone when spring activity appears to have been greater. This is indicated by the abundance of Portulacaceae cf. *C. australasica*, and the very calcareous peaty marls. The pollen evidence indicates that the vegetation of the swamp surface and surrounding areas was dominated by herbaceous taxa, particularly grasses and composites, which suggest that markedly drier conditions prevailed. This interpretation is supported by the virtual absence of pollen of local woody swamp taxa and aquatics, and also by the total absence of rainforest pollen and treefern spores.

Zone 1 represents the Holocene Stage during which shell marl and biochemically precipitated marl were being successively formed. This shows that the strong spring activity and high groundwater level that prevailed during the early to middle Holocene was succeeded by slightly reduced spring discharges during the late Holocene, which suggests probable marginally drier conditions. During this time, the swamp surface was extensively vegetated mainly by a *Eucalyptus-Melaleuca-Leptospermum* swamp forest association similar to the pre-clearance vegetation. A notable feature of this zone is that although the springs were quite active, as indicated by the very calcareous nature of the sediments, the very low values of aquatic and damp site taxa indicates, however, that open water conditions were virtually absent. The possible palaeoclimatic significance of this observation will be discussed in section 10.9.1. Fern spores attain very high values during this zone and together with the presence of significant quantities of charcoal point to the probable influence of aboriginal firing on the vegetation of the area in the Holocene.

10.5 THE MOWBRAY SWAMP POLLEN DIAGRAMS

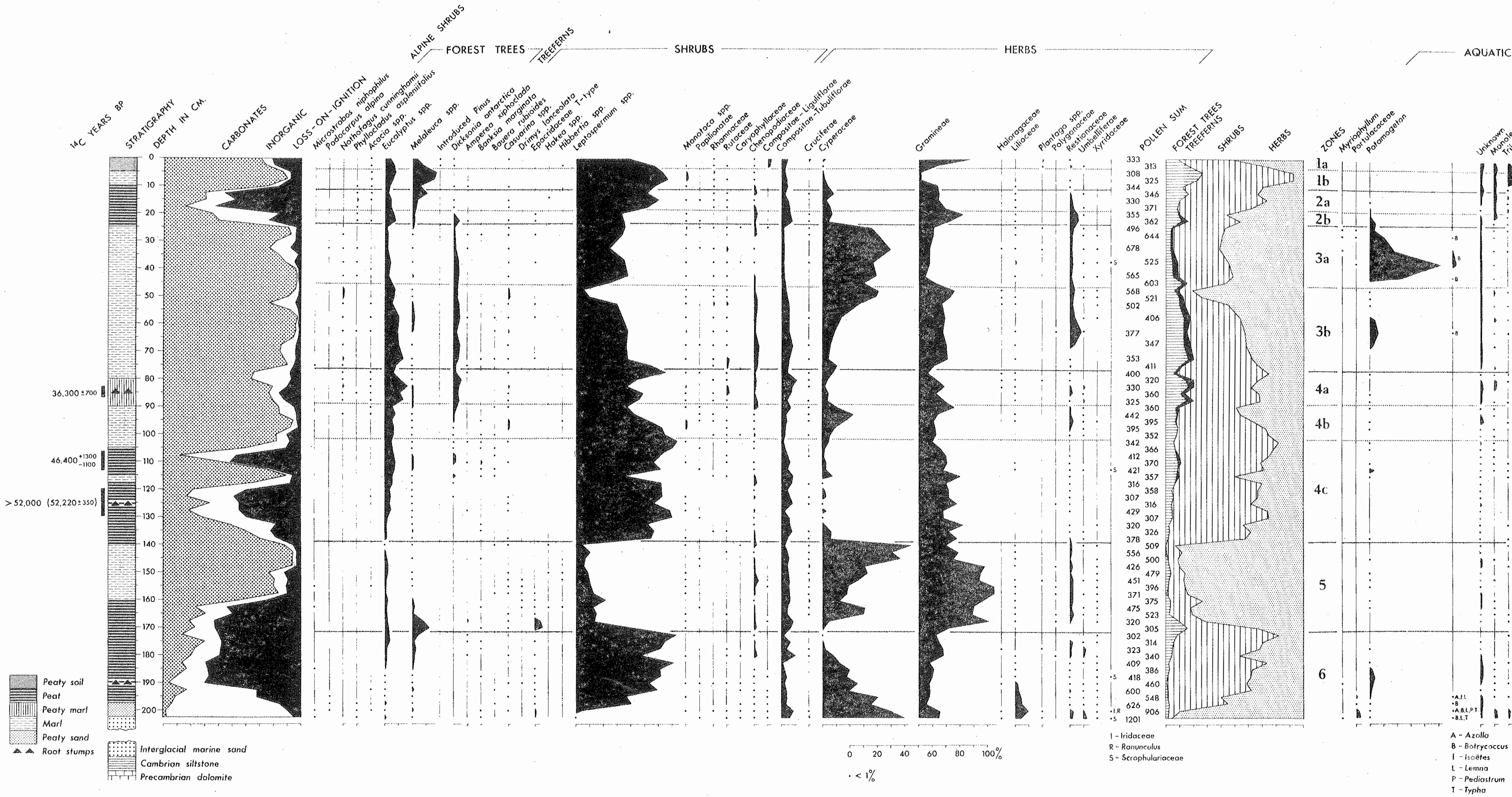
10.5.1 Description

The pollen diagram (Fig. 29) is characterized by a very restricted number of taxa. Marked changes in the frequency of the dominant taxa over at least two stratigraphic intervals served to identify six broad biostratigraphic zones, some of which can be divided into a number of distinctive subzones. The major characteristics of the zones are as follows:-

Pollen Zone 6

Except for the base of this zone, the pollen consists predominantly of *Leptospermum* spp. Only traces of other shrubs are present of which Epacridaceae T-type is the most persistent and attains the highest values. Forest tree pollen only occur in low quantities with *Eucalyptus* spp. and *Melaleuca* spp. attaining the highest values in the upper part of the zone, and temperate rainforest taxa occurring as background traces of less than 1 percent in the basal part of the zone. Cyperaceae values show a gradual but steep upward decrease from over 60 percent to less than 1 percent. Gramineae values, on the other hand, remain fairly constant throughout (5-17%). Significant amounts of Liliaceae pollen occur and attain a

MOWBRAY SWAMP



maximum of 10 percent near the base. In addition, traces of various other herbs occur, some of which attain their highest values near the base of the zone. Low but significant amounts of aquatic pollen and traces of algae are present which indicate that wet conditions were present at the site. Fern spores are few but are slightly more abundant in the basal few centimetres.

Pollen Zone 5

This zone is characterized by very high values for herbaceous taxa and very low values for forest tree and shrub taxa. Gramineae values are in excess of 40 percent throughout most of the zone but decline sharply in the upper levels where Cyperaceae is more abundant and reaches a peak of over 60 percent. A number of subsidiary herbs are consistently represented, the most important of which are Compositae-tubuliflorae, Chenopodiaceae, Restionaceae, Liliaceae, Xyridaceae, and occasional Umbelliferae. Both aquatics and fern spores are rare, and treefern spores are absent. *Eucalyptus* spp. are consistently represented by low values and *Melaleuca* spp. are important in the lower part of the zone where they attain a peak of 12 percent. Rainforest tree pollen are virtually absent. The shrub taxa is dominated by *Leptospermum* spp. but a variety of other shrub taxa are also consistently present in low amounts, the most important of which is Epacridaceae T-type which attains a small peak value of 7 percent at the base of the zone.

Pollen Zone 4

This zone is characterized by an abundance of woody taxa, consisting of up to 73 percent of *Leptospermum* spp.

and smaller amounts of *Eucalyptus* spp. (2-17%), *D. antarctica* (< 1-6%), plus traces of *Melaleuca* spp., *Acacia* spp. and *N. cunninghamii*. The herbaceous taxa consists of Gramineae (6-32%), Cyperaceae (< 1-22%), Compositae-tubuliflorae (2-11%), and lesser amounts of various other herbs. *Potamogeton* is represented by traces in the upper part of the zone but is virtually absent at lower levels. A division into three subzones is possible on the basis of significant minor changes in the frequency of the dominant taxa. Subzone 4c is characterized by high values for shrubs consisting predominantly of *Leptospermum* spp., and consistently very low values for Cyperaceae. In addition, temperate rainforest taxa are not represented. In subzone 4b, there is a marked decrease in *Leptospermum* spp. from 70 to less than 40 percent and slight increases in Gramineae, Cyperaceae, and in the upper part of the zone *D. antarctica*. Subzone 4a corresponds with a bed of peaty marl with small *Leptospermum* (?) root stumps in growth position. In this zone, the pollen of *Eucalyptus* spp., other forest trees and *D. antarctica* attain their highest values. Pollen of *Leptospermum* spp. is very abundant and attains a maximum of 67 percent of the sum at the top of the zone. Gramineae and Compositae-tubuliflorae pollen are present in significant amounts but the values for other herbaceous taxa are low.

Pollen Zone 3

This zone is characterized by widely ranging values for herbs (29-81%) and shrubs (9-56%). In addition, this zone also records the highest values for aquatic pollen and the alga *Botryococcus*. The latter was, however, very poorly preserved and is therefore almost certainly under-represented in figure 29. *Melaleuca* spp. are consistently low but other forest trees, in particular *Eucalyptus* spp. and *D. antarctica*, are well represented and attain significant values in the lower half of the zone. *N. cunninghamii* is consistently present with traces of *P. aspleniifolius* throughout the zone. Fern spores are rare. The zone can be divided into two fairly distinctive subzones. Subzone 3b is distinguished by significant quantities of *Eucalyptus* spp. as the main forest tree and by relatively high values of *D. antarctica*, Gramineae, Compositae and Chenopodiaceae. Although pollen of Cyperaceae increases strongly and *Potamogeton* is present in the middle of the zone these taxa are less abundant than in the overlying Subzone 3a. The pollen assemblage of Subzone 3b appears to reflect a transition from wet, swamp conditions to localised lacustrine conditions, a trend that reaches its peak in Zone 3a. Subzone 3a is characterized by a dominance of Cyperaceae and *Leptospermum* spp., and also contains much *Potamogeton*.

Pollen Zone 2

This zone is dominated by *Leptospermum* spp. (34-60%) and Gramineae (14-32%). Forest tree values are higher than in Subzone 3a and though exceeding 16 percent are lower than in Zone 1. Traces of *P. aspleniifolius* are present throughout the zone but no other rainforest taxa are represented. Damp site and aquatic pollen occur in low amounts with the latter being only significant in the lower part of the zone. Fern spores occur as traces only. The zone can be divided into two subzones on the basis that *Eucalyptus* spp., *D. antarctica*, Gramineae, Compositae-tubuliflorae, Restionaceae, and *Potamogeton* attain significantly higher values in Subzone 2b than in Subzone 2a, and that *Leptospermum* spp. and *Melaleuca* spp. are considerably more abundant in Subzone 2a than 2b.

Pollen Zone 1

This zone can be divided into subzones 1a and 1b on the basis of a marked decrease in forest tree and woody shrub taxa and an increase in herbaceous taxa. Subzone 1b is characterized by very low to moderate values for Gramineae (2-12%), generally low values for other herbs, very high values for *Leptospermum* spp. (59%) plus moderate values for *Melaleuca* spp. (13%), *Eucalyptus* spp. (6%), and traces of *Acacia* spp. Only traces of temperate rainforest taxa and *D. antarctica* occur. Pollen values for damp site taxa are very low and aquatics are not represented. Fern spores attain higher values than in any other zone and, as at Pulbeena Swamp, may reflect partial destruction of the swamp vegetation by occasional firing. In both spectra of Subzone 1a, agricultural disturbance of the swamp surface is indicated by the presence of introduced *Pinus*, significant values for Compositae-liguliflorae, probably *Taraxacum officinale*, traces of *Plantago lanceolata*, and very high values for Gramineae.

10.5.2 Interpretation

The pollen and sedimentary data demonstrate that as at Pulbeena Swamp, there is a general but consistent association of the local biostratigraphic zones and the lithostratigraphic units. This association clearly points to a strong influence on the local vegetation by the same factor that controlled the sedimentation, namely, the rate of effusion of bicarbonate-rich waters from the artesian springs.

Zone 6 represents the initial accumulation phase during which a thin bed of peaty sand was deposited. This was overlain by a compressed bed of fibrous peat that contains well-preserved small tree root stumps in growth position near the base. Crude extrapolation of sedimentation rates (Section 9.5.1) suggests that spring activity in the area probably commenced around ∿ 82,000 BP and that this zone therefore occurs within the early part of the Last Glacial Stage. During this early stage,minor erosion and redeposition of the marine sands by spring waters appears to have taken place. The high values for *Leptospermum* and Cyperaceae, plus a variety of damp site and aquatic taxa point to a predominantly shrub-sedge swamp vegetation which was locally interrupted by pools of standing water around the orifices of the springs. The upward decrease in the abundance of damp site elements and aquatics, and the overall increase in shrub taxa, grasses, Composites and Chenopods suggests that spring activity was progressively reduced.

Except for the basal 10 to 15 cm, the sediments of Zone 5 consist of finely laminated biochemically precipitated marls and shell marls, with the latter being the dominant sediment type in the lower half of the zone. The very calcareous nature of the sediments indicates that strong spring activity occurred. During this time, the vegetation was strongly dominated by herbaceous taxa which consisted mainly of Gramineae and Cyperaceae, with generally low values for woody shrub and forest taxa. The swamp vegetation probably consisted mainly of Cyperaceae and Restionaceae, plus occasional *Potamogeton*, all of which would have occupied damp areas and pools adjacent to the then very low and perhaps less numerous spring mounds. Woody shrubs are likely to have occupied somewhat drier sites some distance away from the mounds, with grasses and occasional forest trees in areas not affected by the springs. The overall upward increase of Cyperaceae, and corresponding decrease in *Leptospermum* and Gramineae suggests that the local conditions were somewhat wetter during the upper part of the zone. This interpretation is consistent with the minor changes in the composition of the sediments.

The sequence of interbedded sediments of Zone 4 indicates that spring activity was variable between approximately 55,000 and 35,000 BP. The main peat bed was deposited under low discharge conditions. However, these conditions were briefly interrupted by higher discharges shortly before about 46,000 BP when a thin bed of biochemically precipitated marl was deposited. The marls and peaty marls that characterize the upper part of the zone indicate a return to predominantly higher spring discharge conditions after 46,000 and before 36,000 BP. The swamp vegetation consisted predominantly of *Leptospermum* shrubs. Grasses, forest trees and other herbaceous taxa were also important and probably occupied drier areas away from the influence of the springs. Forest trees and treeferns as well as damp site elements and aquatics increased during Subzones 4b and 4a. Collectively, the dominant vegetation components suggest that during this time local conditions were probably marginally wetter than during Subzone 4c, as is also indicated by the composition of the sediments. Thus, the pollen and sediment data of Zone 4 indicate that there was a gradual change from relatively dry to generally wetter conditions during this part of the middle Last Glacial Stage.

The very calcareous marl deposits of Zone 3 indicate that during this time spring discharges were high and that very wet to lacustrine conditions occurred at the site between approximately 35,000 and 22,000 BP. The pollen evidence suggests that the swamp vegetation was probably a mosaic that consisted of areas of *Leptospermum* scrub and Cyperaceae swamps, with other woody and herbaceous taxa occupying slightly drier, elevated sites away from the direct influence of the springs. In shallow depressions around the mounds, pools of standing water contained abundant *Potamogeton* and *Botryococcus*. Forest trees, treeferns, and herbaceous taxa were more important, and damp site elements and aquatics much less important during the early part of the zone when local conditions appear to have been less wet than during the later part of the zone.

The inferred generally very wet conditions of Zone 3 are consistent with the evidence from the Last Glacial age fluviatile sequence at Welcome Inlet where, as previously described (Chapter 5), extensive aggradation occurred shortly after about 30,000 BP as a result of high river discharges and the deposition of sand and fine gravel bed loads.

The sediments developed during Zone 2 indicate predominantly low spring activity and groundwater levels during which a thin peat bed developed over the swamp surface. Lithostratigraphic correlation (Section 9.5.2) strongly points to the probability that this zone represents the late Last Glacial Stage (22,000-11,000 BP). As at Pulbeena Swamp, the high silt and clay content of the peat supports the inference that these sediments formed in response to substantially reduced spring discharges. During this time, the swamp surface was vegetated predominantly by shrubs, grasses and other herbaceous taxa. Although swamp forest trees appear to have been few, other forest trees were relatively important, particularly during the early part of the zone when the local condition seems to have been slightly wetter than at Pulbeena Swamp, as indicated by the presence of Cyperaceae, Restionaceae, and *Potamogeton*.

Lithostratigraphic correlation (Section 9.5.2) indicates that Zone 1 almost certainly represents the Holocene Stage during which a bed of biochemically precipitated marl was deposited as a result of high spring discharges from the nearby mound springs. The pattern of vegetation change during this time indicates that there was a marked overall increase in woody scrub and swamp forest taxa, a trend that reached its peak in the upper part of Subzone 1b. Throughout the Holocene Stage, the swamp surface appears to have been extensively vegetated mainly by a *Leptospermum-Melaleuca* damp swamp shrub-low forest association, with *Eucalyptus* forests probably occupying the drier margins of the swamp and the nearby hillsides.

10.6 THE BROADMEADOWS SWAMP POLLEN DIAGRAM

10.6.1 Description

The pollen diagram (Fig. 30) has been divided into two biostratigraphic zones on the basis of marked changes in the frequency of the dominant vegetation. As at Pulbeena and Mowbray swamps, the pollen diagram is characterised by a very restricted number of taxa, most of which are undoubtedly of local origin. The following description highlights the distinctive characteristics of the zones.

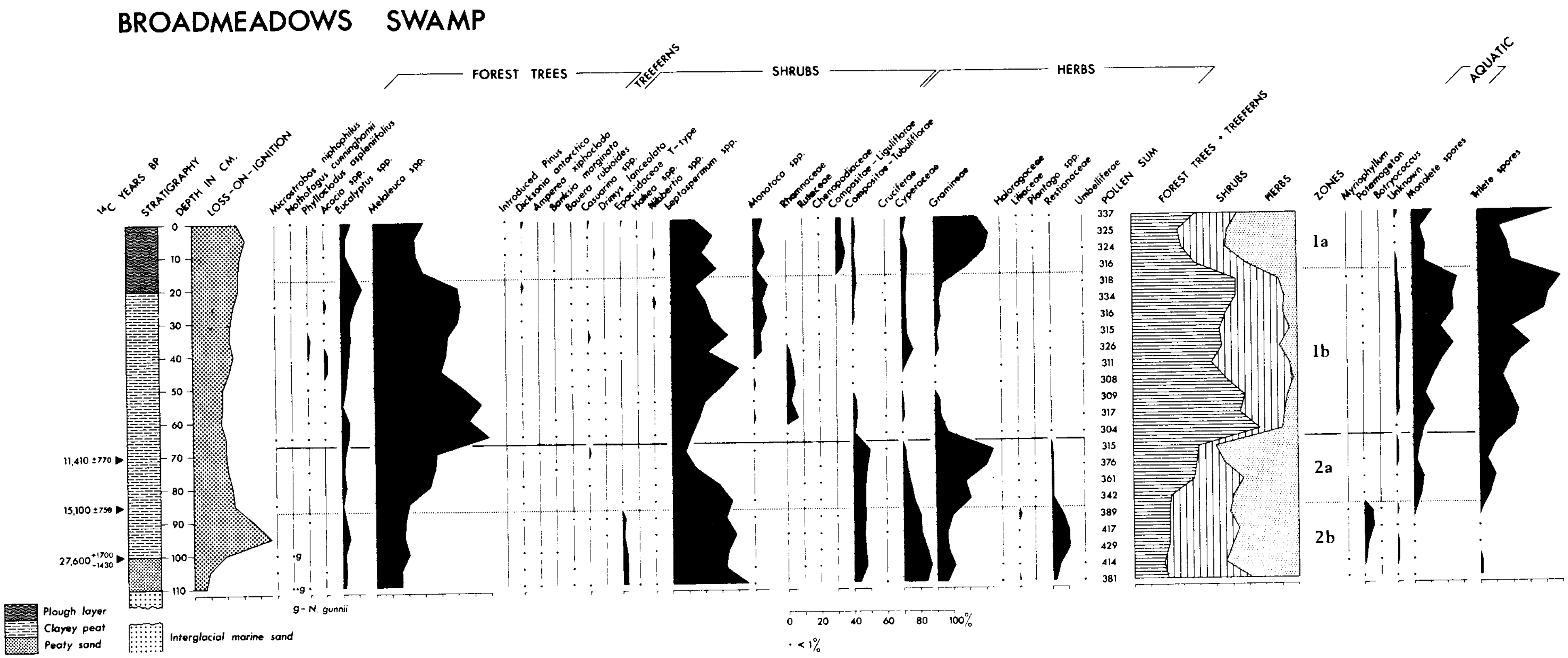


FIGURE 30. Broadmeadows Swamp pollen diagram.

Pollen Zone 2

In this zone the values for forest tree taxa are consistently lower and the values for herbaceous taxa higher than in Zone 1. Damp site and aquatic taxa are also important particularly in the lower part of the zone but fern spores are much less abundant than in Zone 1. A division into subzones 2a and 2b is possible on the basis of higher values for *Melaleuca* spp. and Gramineae pollen in the former, and higher values for *Leptospermum* spp., Epacridaceae T-type, Cyperaceae, Restionaceae and aquatic pollen in the latter.

Subzone 2b is characterized by moderately low values for *Melaleuca* spp. and *Eucalyptus* spp., and temperate rainforest taxa are represented only by trace values. *Leptospermum* spp. values are high and range from 33 to 46 percent. Epacridaceae T-type pollen values are significant in the lower part of the subzone. Gramineae values are consistently low (7-12%) with Compositae-tubuliflorae showing little variation. Cyperaceae and Restionaceae values are significant but both decline in importance upwards. *Potamogeton* is present in significant amounts and attains a peak in the upper part of the subzone. *Botryococcus* is also present but as at Mowbray Swamp it is almost certainly under-represented due to poor preservation. Fern spore values are very low.

Subzone 2a is characterized by a gradual increase in the values of *Melaleuca* spp. (21-38%) and Gramineae (22-35%), and a marked decline in the abundance of *Leptospermum* spp. (37-9%). *Eucalyptus* spp. values do not exceed 3 percent. Rainforest taxa and *D. antarctica* are represented by background trace values only. The values for damp site components are low throughout with Cyperaceae continuing the decline evident in Subzone 2b. Fern spore values fluctuate but do not exceed 10 percent.

Pollen Zone 1

This zone is divided into subzones on the basis of a decrease of woody taxa and an increase in herbaceous taxa at 20 cm depth. Subzone 1b is characterized by very low values for Gramineae and other herbaceous taxa (3-11%), and high values for forest trees (47-77%) and shrubs (14-47%). The woody taxa consists predominantly of *Melaleuca* spp. (41-70%) and *Leptospermum* spp. (13-40%). In addition, the shrubs of *Monotoca* spp. and Rhamnaceae are also important, with the former being most abundant in the upper part of the subzone and the latter attaining significant percentages in the lower part of the subzone. *Eucalyptus* spp. values are low except in the upper part of the subzone where they attain a peak value of 13 percent. *Acacia* spp. pollen is consistently present in small amounts. Various rainforest trees are represented by trace values, the most important of which is *P. aspleniifolius*. Treefern spore values are very low but other ferns attain very high values. Charcoal fragments are abundant throughout and reflect the effects of occasional fire on the swamp. Damp site elements are represented by low values and aquatic taxa occur as traces in the upper part of the zone. Subzone 1a represents surface disturbance by agricultural practices which is indicated by the presence of *Pinus*, introduced Compositae-liguliflorae,as well as by the high Gramineae values which reflect the extensive sown pastures that characterize this dairy farming district.

10.6.2 Interpretation

Zone 2 represents the late Last Glacial Stage during which peaty sands, peats and clayey peats were successively being formed. The composition of the sediments,as revealed by the loss-on-ignition data and the radiocarbon dating evidence show that during the early stages of spring activity sediment accumulation rates were very low as a result of low and/or long periods of dormancy of the mound springs. Also during this time the springs caused minor erosion and redeposition of the underlying interglacial marine sands occurred. The pollen evidence of Subzone 2b indicates that generally wet conditions prevailed on the swamp surface between about 30,000 and 15,000 BP. During this time, the swamp vegetation was probably a mosaic consisting of *Leptospermum-Melaleuca* damp scrub and low swamp forest that was locally interrupted by fairly extensive areas of Cyperaceae-Restionaceae sedgeland. Aquatic vegetation was dominated by *Potamogeton* occupying ponds adjacent to the springs. Away from the springs, the vegetation probably consisted of areas of heathland or grassland with occasional *Eucalyptus*. The pollen evidence of Subzone 2a which covers the period from about 15,000 to 11,000 BP indicates that during this time the swamp vegetation consisted mainly of a *Melaleuca-Leptospermum* damp low forest and scrub association. *Leptospermum* scrub appears to have been more important and perhaps covered larger areas during the early part of this subzone when somewhat drier conditions may have prevailed. Collectively, however, the frequencies of the various taxa indicate that the vegetation during this part of the late Last Glacial Stage was more open than during Subzone 2b or than during the Holocene.

Zone 1 represents the Holocene Stage during which nearly 70 cm of clayey peat was formed. This shows that strong spring activity and at least moist conditions prevailed. The loss-on-ignition curve of figure 30 suggests that spring discharges were slightly higher during the early to middle Holocene than during late Holocene times, a trend which was also evident in the alkaline spring deposits at Pulbeena Swamp. Throughout the Holocene Stage, the swamp was vegetated mainly by a *Melaleuca*-*Leptospermum* damp low forest-scrub association that was probably very similar to the pre-clearance vegetation. The near absence of aquatic vegetation and consistently low pollen inputs from damp site elements indicates, as at Pulbeena Swamp, that despite the high spring discharges lacustrine conditions did not develop. Possibly, the development of permanent water bodies was prohibited by high evaporation rates due to predominantly high temperatures. The extent to which the decrease of *Melaleuca* and Rhamnaceae and the increase in *Leptospermum* and *Monotoca* may reflect the impact of aboriginal man, as also suggested by the high spore values and presence of charcoal, and the extent to which it may represent a climatic deterioration cannot be established from the available data.

10.7 THE SMOKERS BANK SWAMP POLLEN DIAGRAM

10.7.1 Description

This section presents the pollen data from the inland lagoon swamp deposits at Smokers Bank (Chapter 9) and provides further palaeoenvironmental and palaeoclimatic data for this area. In addition, the pollen evidence is used to approximate the age for the swamp and associated sand lunette deposits described in the previous chapter.

The swamp deposits were analysed at 5 cm intervals to a depth of 35 cm (Fig. 31). Below this depth, pollen were found to be very rare. Most were broken and folded probably as a result of the partial remobilization of the underlying alluvial sands by wave activity during the initial high water stages in the lagoon when the lunette was being formed by the deflation of fine sand from the beach.

In recent years, the surface of the swamp has been cleared of all vegetation by burning and this has resulted in the removal of an unknown thickness of surface peat. The presence of numerous charred *Melaleuca* (?) root stumps at the surface indicates that prior to clearance operations a dense swamp forest association occupied the site. Presently, the site is used as a dumping ground for waste products from a nearby sawmill. The lowering of the swamp surface by burning has made this area prone to winter flooding and in some areas has led to the re-establishment of aquatic, damp site,and woody shrub vegetation most of which, however, is periodically destroyed as a result of the burning of mill waste products.

Although there are difficulties in determining whether certain pollen taxa belong to the local vegetation of the site or represent inputs from the vegetation of adjacent lowland or upland areas, it is judged that the abundant Restionaceae pollen mainly represents inputs from the swamp surface vegetation. Similarly, it is probable that in this swamp environment the bulk

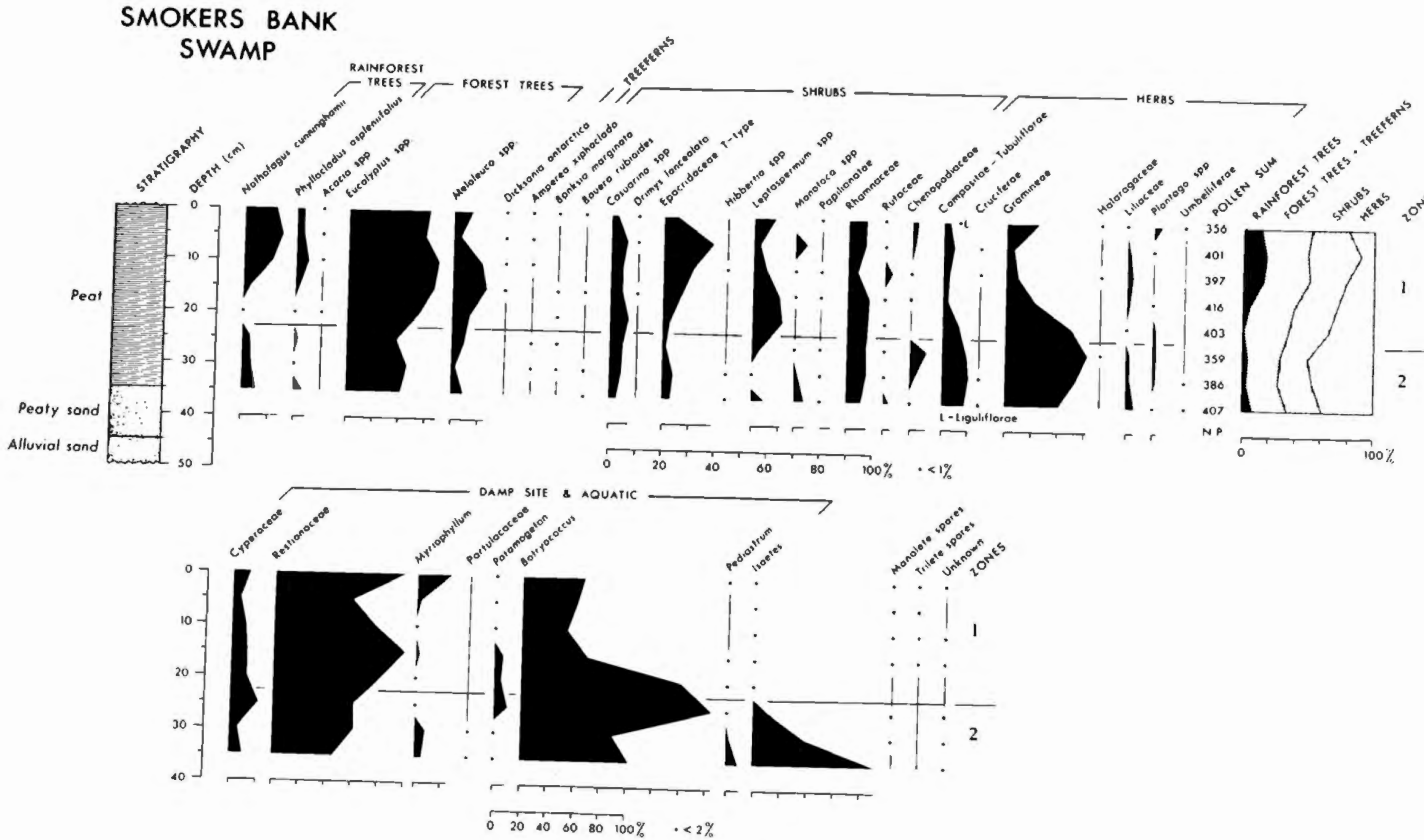


FIGURE 31. Smokers Bank Swamp pollen diagram.

of the Cyperaceae pollen was also locally derived. Hence, these taxa were counted outside the pollen sum together with the aquatic elements but their values are expressed as a percentage of the sum.

Pollen Zone 2

This zone is characterized by consistently high values of herbaceous taxa (40-50%), low values for temperate rainforest taxa (4-8%), and moderate values for other forest trees (24-26%) and shrub taxa (21-26%). The herbaceous taxa are dominated by Gramineae which increases from 20 percent near the base of the profile to 31 percent at 25 cm depth. Both Compositae-tubuliflorae and Chenopodiaceae show a significant upward increase with the latter attaining a peak value of 6 percent at the 25 cm level. A number of subsidiary herbs are present of which Liliaceae and *Plantago* spp. attain the highest values. The woody shrubs are dominated by Rhamnaceae and *Casuarina* spp. Epacridaceae pollen are significantly more abundant near the base of the profile, as are *Leptospermum* spp. and Rutaceae pollen. The forest tree component consists mainly of *Eucalyptus* spp. which is represented by values fluctuating around 20 percent. *Melaleuca* spp. values are fairly low but show an overall increase upwards. *D. antarctica* is not represented. Temperate rainforest trees are moderately well-represented with both *N. cunninghamii* and *P. aspleniifolius* being slightly more important at the base of the profile. The swamp vegetation appears to have been dominated by Restionaceae and Cyperaceae. However, the values of the former are significantly lower than in Zone 1 which probably reflects that a greater expanse of open and perhaps deeper water was present. This inference is supported by the much greater abundance of *Botryococcus*, *Pediastrum* and *Isoëtes*. Other aquatic components are represented by generally low values, with *Myriophyllum* being important near the base of the profile and *Potamogeton* in the upper part of the zone. Monolete fern spores occur as trace values but trilete spores are not represented.

Pollen Zone 1

This zone is characterized by a marked change in the woody versus herbaceous pollen ratios, indicating that during this time herbaceous vegetation was largely replaced by forest and shrub vegetation, a trend which appears to have commenced during Zone 2. The forest tree component is strongly dominated by *Eucalyptus* spp. which attains a maximum value of 34 percent at 10 cm. Rainforest tree values are also very significant with *N. cunninghamii* attaining a maximum of 14 percent and *P. aspleniifolius* 5 percent. However, both are represented by trace values only near the base of the zone. Spores of *D. antarctica* are present as background trace values of less than 1 percent. Woody shrubs are well represented throughout the zone with Epacridaceae T-type pollen attaining the highest values in the upper part of the zone and *Leptospermum* spp. pollen occurring abundantly in the lower part of the zone. In addition, both Rhamnaceae, mainly *P. apetala*, and *Casuarina* spp. attain significant values but show little variation in their respective frequencies. A number of subsidiary shrubs are represented of which only *Monotoca* spp. and Rutaceae attain locally significant values. The herbaceous taxa are dominated by Gramineae which, together with Compositae-tubuliflorae, show a marked upward decrease in values with the former accounting for 25 percent of the pollen sum near the base of the zone. The presence of small amounts of *Plantago lanceolata*, traces of Compositae-liguliflorae pollen, and a slightly greater abundance of Gramineae recorded at the surface horizon is interpreted as reflecting the effects of widespread agricultural practices in the surrounding area. As in Zone 2, the local swamp vegetation probably consisted mainly of Restionaceae which although showing a major fluctuation maintains very high values throughout the zone. Cyperaceae pollen values are consistently present in moderate amounts. *Myriophyllum* values show a sharp rise near the surface but are not important at lower levels where *Potamogeton* is more abundant. *Botryococcus* attains very high values near the base of the zone but declines sharply above the 20 cm level. *Pediastrum* and *Isoëtes* are represented by trace values. Both monolete and trilete spore values are low.

All the pollen spectra exhibit either a minor increase or decrease in value at the surface, the significance of which is difficult to evaluate, however, it is possible that these changes primarily reflect the disturbance of the ecosystem by the activities of man, as suggested by the evidence cited earlier for agricultural practices and the modification of the swamp surface.

10.7.2 Interpretation

The pollen evidence of Zone 2 clearly indicates that during this time woody vegetation was not very abundant in the area as a whole. There is some evidence to suggest that climate was moderately wet during the early part of the zone when woody taxa appear to have been slightly more abundant and a permanent water body occupied the lagoon. The scarcity and poor preservation of pollen at the base of the profile suggests that considerable remobilization of the alluvial sands occurred during this time as a result of waves and currents generated by strong west to southwesterly winds. The combined effects of these processes ultimately resulted in the progressive development of the lunette ridge.

The pollen assemblages of Zone 1 indicate that wooded environments dominated the landscape. During this time, wet sclerophyll forests probably occurred extensively on the nearby hills. The lowland vegetation is likely to have consisted of damp scrub or low forest and heath associations. The gradual overall increase in woody taxa at the expense of herbaceous taxa and in particular grasses appears to mark a transition from moderately open environments to predominantly closed, wooded upland and lowland environments. This probably reflects a change from moderately dry and possibly cool conditions to a predominantly warm and humid climate. During this time, the lagoonal swamp was probably almost completely vegetated which would have effectively prohibited the maintenance of the lagoon beach and accumulation of sands on the lunette ridge.

The tentative conclusion previously stated (Chapter 9) that the lagoonal swamp deposits are unlikely to be older than Holocene age appears to be reasonably well supported by the pollen record. Comparisons of the short and incomplete biostratigraphic record of this site with those of Pulbeena, Mowbray and Broadmeadows swamps suggest that the marked overall increase in forest and woody shrub taxa at the expense of herbaceous taxa probably occurred during early to middle Holocene times. Also, the expansion of woody taxa generally corresponds with a similar early to middle Holocene expansion of woodland elements elsewhere in Tasmania (Banks *et al.*, 1977; Macphail and Jackson, 1978; Macphail, 1979).

10.8 WILTSHIRE

In Chapter 5 brief reference was made to the Wiltshire area. In this area, a 30 cm thick remnant of a humic fossil soil occurs beneath shelly marine sand believed to be of Last Interglacial age. A sample of the soil was obtained from the Tasmanian Department of Mines for the purpose of pollen analysis. The results (Table 11) show that a wet sclerophyll forest association occupied the site either during the early part of the Last Interglacial Stage or during an earlier warm and humid interglacial or interstadial period. A noteworthy feature of the pollen record is the abundance of spores belonging to the treefern *Cyathea* - probably *C. cunninghamii*. Presently, *Cyathea* is relatively very rare in northwestern Tasmania and it is not abundant anywhere else in the State. Furthermore, to date it has not been recorded in significant amounts in Tasmanian Last Glacial and Holocene pollen sequences. It has, however, been recorded in great abundance in pollen-rich fluviatile swamp deposits of presumed Last Interglacial age (Colhoun, 1980). From this it may be tentatively concluded that *C. cunninghamii* treeferns were probably considerably more abundant in pre-Last Glacial times than they have been since.

TABLE 11 Pollen percentages from interglacial soil at Wiltshire

RAINFOREST TREES	*Nothofagus cunninghamii*	10.2
	Phyllocladus aspleniifolius	13.3
FOREST TREES	*Acacia* spp.	+
	Eucalyptus spp.	14.8
	Melaleuca spp.	+
TREEFERNS	*Cyathea cunninghamii*	33.8
	Dicksonia antarctica	14.8
SHRUBS	*Amperea xiphoclada*	+
	Bauera rubioides	+
	Drimys lanceolata	+
	Monotoca spp.	2.6
	Orites spp.	+
	Papilionateae	+
	Pittosporum bicolor	1.1
	Pomaderris apetala	3.0
	Richea sp.	+
	Rutaceae	1.5
HERBS	Caryophyllaceae	+
	Compositae-tubuliflorae*	+
	Cyperaceae	+
	Gramineae	+
	Polygonaceae	+
	Umbelliferae	+
	Pollen sum	540
	Monolete spores	14.8
	Trilete spores	1.8
	Unknown	1.3

+ < 1%

* Possibly shrubs in this assemblage

10.9 CORRELATION AND CONCLUSIONS

10.9.1 Northwestern Tasmania

Although the pollen records from the swamp/lake deposits at Pulbeena, Mowbray and Broadmeadows swamps very largely reflect changes in local vegetation communities, zonal pollen correlation of these complex sites indicates that most of the main changes between woody pollen/vegetation taxa and herbaceous pollen/vegetation taxa are approximately synchronous (Fig. 32 and Table 12), and can be consistently related to changes in the palaeohydrologic regime of the artesian springs as influenced by the precipitation/evaporation balance of the lowland region. However, in the absence of contemporary local vegetation/pollen analogue data, and detailed knowledge of the ecological and environmental requirements of taxa involved, only a broad and subjective climatic subdivision of the sequence of vegetation change is possible from a consideration of the inter-relationships between sediments and the proportion of woody versus herbaceous taxa in the local vegetation. The subdivision can be tentatively interpreted as corresponding with the following general changes in the regional hydrologic balance:

(1) Extrapolation of the radiocarbon data (Section 9.5.1) indicates that pollen zones 10-4 at Pulbeena Swamp and pollen zones 6, 5 and part of 4c at Mowbray Swamp represent part of the early Last Glacial Stage. Both sediments and pollen indicate that marked hydrologic changes occurred during this time, but that in the long term predominantly wet conditions prevailed with herbaceous taxa being dominant over forest trees and woody shrubs most of the time. The wettest conditions appear to have occurred during the onset of

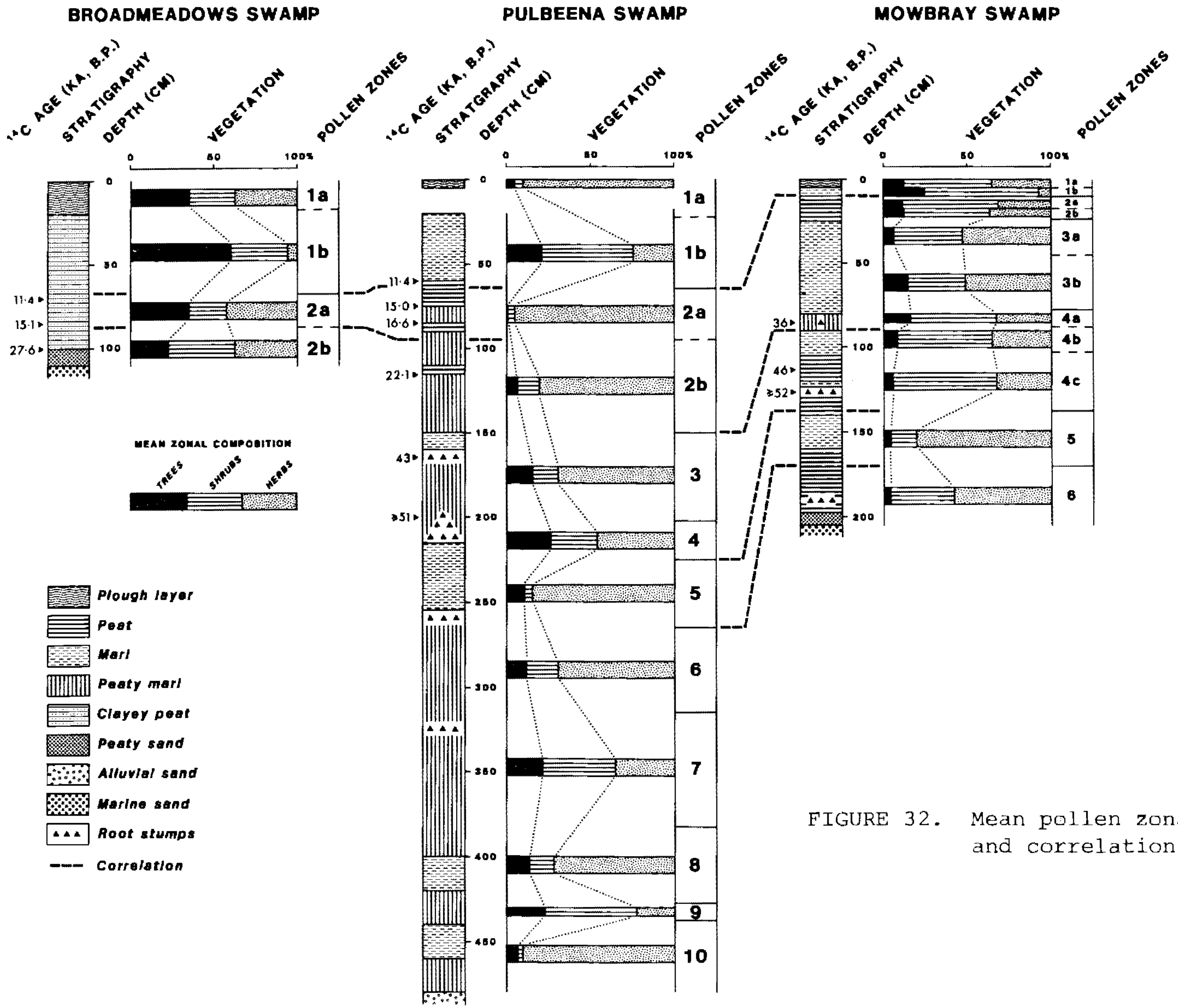


FIGURE 32. Mean pollen zonal compositio
and correlation.

TABLE 12 Pollen Zonal Correlation

Estimated years (Ka, B.P.)	PULBEENA SWAMP Zones	PULBEENA SWAMP Local vegetation	MOWBRAY SWAMP Zones	MOWBRAY SWAMP Local vegetation	BROADMEADOWS SWAMP Zones	BROADMEADOWS SWAMP Local vegetation
0	1a	Disturbed	1a	Disturbed	1a	Disturbed
	1b	Closed *Leptospermum-Melaleuca/ Eucalyptus* scrub forest	1b	Closed *Leptospermum-Melaleuca* scrub forest	1b	Closed *Melaleuca-Leptospermum* scrub forest
10	2a	Grassland	2a-b	*Leptospermum* scrub and grassland	2a	*Melaleuca-Leptospermum* scrub and grassland
20	2b	Grassland and localized scrub forest	3a	Cyperaceae-*Potamogeton* swamp and *Leptospermum* scrub	2b	*Leptospermum-Melaleuca* scrub forest and Cyperaceae-*Potamogeton* swamps
30		Portulacaecae swamps	3b	*Leptospermum-Eucalyptus* scrub and grassland, and localized swamps		(Onset of spring activity)
∿ 40	3	*Melaleuca/Eucalyptus-Leptospermum* scrub and Cyperaceae-Restionaceae-*Potamogeton/Triglochin* swamps	4a-c	*Leptospermum-Eucalyptus* scrub forest and grassland, with Cyperaceae swamps during Subzone b		
⩾ 51	4	*Leptospermum-Melaleuca/ Eucalyptus* scrub				
	5	Grassland and Cyperaceae swamps	5	Grassland and Cyperaceae swamps		
	6	*Leptospermum* scrub and Cyperaceae-*Potamogeton/Triglochin* swamps	6	*Leptospermum* scrub and Cyperaceae swamps (Onset of spring activity)		
	7	*Leptospermum-Melaleuca/Eucalyptus* scrub and Cyperaceae-Portulacaceae-*Potamogeton/Triglochin* swamps				
	8	Cyperaceae-Portulacaceae-*Potamogeton/Triglochin* swamps				
	9	*Leptospermum-Melaleuca/Eucalyptus* scrub forest				
	10	Grassland and Cyperaceae swamps (Onset of spring activity)				

spring activity at Pulbeena swamp (Zone 10) and sometime between approximately 65,000 and 55,000 BP (Pulbeena Zone 5 and Mowbray Swamp Zone 5). Relatively short-term drier conditions occurred during Pulbeena Swamp Zone 9 and the upper part of Zone 7 during which the springs were considerably less active and herbaceous taxa was partly replaced by woody taxa dominated by *Leptospermum* spp.

Available palaeontological and stratigraphic data indicates that now extinct giant marsupials were then present in the area (Gill and Banks, 1956; Banks *et al.*, 1976). The occurrence of their fossil remains in the artesian springs deposits suggests that the springs were used as watering places and that some of the animals probably perished as a result of becoming bogged in the soft waterlogged sediments.

(2) Both sediments and pollen indicate that between approximately 55,000 and 45,000 (Pulbeena Zone 4 and Mowbray Swamp Subzone 4c) conditions were considerably drier than during the preceding period. During this time, woody taxa dominate the pollen assemblages and indicate that swamp forest and scrub communities were much more important than herbaceous communities. Further, unlike the previous period, open water conditions were virtually absent, as indicated by the consistently low values for aquatic, Cyperaceae and Restionaceae pollen.

The inferred palaeoclimatic conditions appear to be at variance with the evidence from Blakes Opening in southern Tasmania (Colhoun and Goede, 1979). Here, pollen analysis and radiocarbon dating of organic-rich fluviatile backswamp deposits suggests that between approximately 55,000 and 45,000 BP the climate was considerably moister than during the preceding period.

(3) The lithostratigraphic and biostratigraphic records collectively indicate that predominantly moist to wet conditions prevailed between approximately 45,000 and 22,000 BP, with the wettest conditions occurring after 35,000 BP. During this long time period, herbaceous and aquatic vegetation progressively replaced the previously more abundant woody swamp vegetation.

Supporting evidence for the inferred generally wet conditions is provided by the evidence from Welcome Inlet where it has been demonstrated that extensive fluviatile deposition occurred after about 30,000 BP as a result of relatively high river discharges (Chapter 3). That wet conditions were not restricted to the swamps is also indicated by the chronostratigraphic evidence from Rocky Cape, where it has been demonstrated that extensive deposition of alluvial fan gravels accumulated between approximately 44,000 and 22,000 BP (Colhoun, 1977a).

(4) In contrast to the previous period, predominantly dry conditions prevailed between about 22,000 and 10,000 BP. During this time, which broadly represents the late Last Glacial Stage, spring activity was markedly reduced, as indicated by the high inorganic fraction of the peats and the near absence of aquatic taxa and ostracods. The pollen evidence from Pulbeena Swamp demonstrates that the reduction in spring discharges and associated lowering of the near surface groundwater table after about 22,000 BP had a marked effect upon the swamp vegetation and resulted in an almost complete replacement of the swamp forest tree and shrub vegetation by herbaceous vegetation consisting mainly of Gramineae and Compositae-tubuliflora. A similar, but much less marked replacement of woody taxa by grasses is also evident at Mowbray and Broadmeadows swamps.

That grassy open environments and relatively dry conditions were more widespread in northwestern Tasmania during the late Last Glacial Stage than during the preceding and succeeding period is indicated by the palynological evidence from Cave Bay on nearby Hunter Island where in combination with archaeological investigations by Bowdler (1974, 1975), Hope (1978) has shown that from about 23,000 BP until early in the Holocene Stage herbaceous taxa formed an important component of what was probably a lightly wooded *Eucalyptus*-savannah environment. In addition, there is evidence to suggest that grassland/steppe conditions occurred extensively in the southern part of the Midlands prior to about 9,500 BP (Macphail, 1975; Macphail and Jackson, 1978), and at Pipe Clay Lagoon in southeastern Tasmania after about 22,000 BP (Colhoun, 1977b).

(5) During the Holocene Stage (post 10,000 BP) woody swamp scrub and forest vegetation almost completely replaced the predominantly herbaceous vegetation of the late Last Glacial Stage on the swamp surfaces. This very marked rise in scrub and forest taxa generally corresponds with a well-documented similar expansion in both upland and lowland regions elsewhere in Tasmania (Hope, 1978; Macphail and Jackson, 1978; Macphail, 1979).

Marls and peaty clays accumulated as a result of high spring discharges. However, in contrast with periods of high spring discharges and marl deposition during the early and middle Last Glacial Stage, lacustrine conditions did not develop, as indicated by the virtual absence of aquatic pollen types and low values for the damp site elements Cyperaceae and Restionaceae. Possibly, this paradoxical situation reflects the effects of higher evaporation rates resulting from higher temperatures during the

Holocene. A possible corollary to this proposition is that the predominantly high artesian water budgets and wet surface conditions of the early and middle Last Glacial Stage perhaps resulted from low evaporation rates under cold conditions, rather than higher actual precipitation. As the available data is insufficient to resolve these important questions, it is difficult to compare the results of this study with the climatic changes inferred from other Australian palynological and hydrological studies.

The sediments at Pulbeena and Broadmeadows swamps indicate that spring activity was marginally greater during the early to middle part of this period than during the late Holocene which suggests that climate was perhaps slightly wetter during early to middle Holocene times. The abundance of charcoal and fern spores suggests that aboriginal man may have had a marked impact on the swamp ecosystem, particularly during the middle and late Holocene.

10.9.2 Possible wider palaeoclimatic significance of the artesian spring and freshwater swamp deposits

In Australia, long, time-controlled sediment sequences suitable for palaeoclimatic analysis are relatively rare. However, in recent years comprehensive results have emerged through studies of pollen and sediment analysis of cores obtained from lake basins. Because these studies are either from drier environments or from the humid tropics (Bowler *et al.*, 1976; Kershaw, 1981), detailed comparisons of the climatic changes cannot be made with the evidence from northwestern Tasmania. It is, however, possible and instructive to broadly compare the most important climatic changes inferred from the artesian spring deposits with those inferred from selected, well-dated, sediment sequences elsewhere in Australia.

At Lake Leake in South Australia, Dodson (1974a, 1975) has established a climatic sequence which dates back to about 50,000 years. During the period from 50,000 to 40,000 BP, *Eucalyptus* woodland with scrub understorey prevailed, but later developed into open *Eucalyptus* savannah in response to a change to predominantly drier conditions. The level of the lake rose and remained high between approximately 40,000 and 30,000 BP. During this time, aquatic vegetation was abundant in the lake, and the region maintained a *Eucalyptus* forest with a diverse understorey, indicating a period considerably wetter than preceded before. Marginally drier but oscillatory conditions prevailed from 30,000 until 26,000 BP, after which the lake dried and peat began to form in the basin. Subsequently, dry conditions characterized by open *Eucalyptus* savannah persisted from 26,000 to 11,000 BP. After about 10,000 BP the lake level rose in response to an increase in precipitation, with the wettest conditions occurring between 7,000 and 5,000 BP, after which conditions became drier. A similar pattern of climatic change was inferred by Dodson (1977) from nearby Wyrie Swamp. Here, the driest period of the last 50,000 years occurred during the late Last Glacial Stage (26,000-11,000 BP), during which the swamp dried out and only 30 cm of sediment accumulated over a period of 16,000 ^{14}C years. There is a good correlation of the general direction of climatic change between southeastern South Australia and northwestern Tasmania with relatively dry early to middle Last Glacial conditions changing to wetter conditions around 40,000 BP, and returning to drier conditions after 26,000 BP during the late Last Glacial Stage. The Holocene conditions are also broadly similar, with wet conditions during the early to middle part of this period. The increase in spring activity and associated expansion of swamp scrub and low forest in northwestern Tasmania, and a similar rapid forest expansion in lowland and upland areas elsewhere on the island after about 10,000 BP, not only agrees with Dodson's evidence from southeastern South Australia but also with the evidence obtained from pollen records from the eastern highlands of Victoria (Binder and Kershaw, 1978), Wilsons Promontory (Ladd, 1979), and Lake Bullenmerri in western Victoria (Dodson, 1979).

That the climate during the late Last Glacial period was drier than the preceding and succeeding period has also been demonstrated from sediment studies and pollen analysis at Lake Keilambete in western Victoria (Bowler and Hamada, 1971; Dodson, 1974b). This closely dated sequence shows that from about 30,000 until sometime after 20,000 BP the lake level remained at an intermediate level. However, the lake dried out around 18,000 BP and remained dry until about 10,000 BP when water level rose, reaching a maximum level at 6,500 BP.

In the upper 3 m of the long Lake George pollen sequence, Singh *et al.* (1979) have recorded a pattern of Last Glacial changes that appears to broadly parallel those inferred from northwestern Tasmania. At Lake George, open sclerophyll woodland, similar to that occurring in the area today, was the dominant vegetation during the Last Interglacial Stage and was replaced by herbfield-grassland associations considered to represent cold and dry conditions of the early part of the Last Glacial Stage. Singh *et al.* estimated this stage to have occurred between about 75,000 and 64,000 BP. However, since these age estimates are based on the approximate ages of the deep-sea oxygen isotope stages of Shackleton and Opdyke (1973), they represent possible approximate ages only. In the absence of radiometric dating control of inferred early Last Glacial climatic changes at Lake George and northwestern Tasmania, no useful comparisons can be made.

As in northwestern Tasmania and southeastern South Australia, overall moist to wet conditions accompanied by high water levels prevailed during the middle of the Last Glacial Stage. Woody shrubs and *Eucalyptus* dominated under cool temperate conditions until approximately 22,000 BP when herbland-grassland associations became the dominant vegetation in response to colder and drier conditions during the late Last Glacial Stage. Radiocarbon dating indicates that a transition to warmer and moister conditions occurred after 14,000 BP, and resulted in an expansion of forest vegetation consisting of wet sclerophyll elements during the early to middle Holocene, and dry sclerophyll elements during the late part of this period. According to Singh *et al.*, the change from wet to dry sclerophyll vegetation during the Holocene may in part have resulted from the influence of aboriginal man through his use of fire.

That the climate was considerably wetter during the middle of the Last Glacial Stage than during the succeeding period has also been unequivocally demonstrated in the now semi-arid part of New South Wales (Willandra Lakes; Lake Mungo). Here, after a long period of aridity possibly dating back to the Last Interglacial, the lakes rose to very high levels after about 45,000 BP, and remained high until 26,000 BP when levels fell and the first generation of clay dunes developed. The lakes remained at a low level for a further 8,000 to 9,000 years until final regional drying took place (Bowler, 1973, 1976; Bowler *et al.*, 1976).

At Lynch's Crater in the Atherton Tableland region of southern Queensland, Kershaw (1974, 1976, 1978) has outlined the broad pattern of vegetation changes and related them primarily to changes in precipitation. Kershaw's pollen diagram and extrapolation of the ^{14}C data shows that the angiosperm rainforest of the Last Interglacial Stage altered to moist rainforest with *Araucaria* between 79,000 and 76,000 BP, and that these changed to open sclerophyll forest or woodland at 38,000 ^{14}C years BP which persisted to 10,000 BP. After 10,000 BP, angiosperm rainforest developed again and precipitation was more abundant until 3,000 BP. After this period, a decrease in precipitation is indicated by the partial replacement of the angiosperm rainforest by sclerophyll forest taxa.

The evidence outlined above suggests that the onset of drier conditions during the Last Glacial Stage commenced much earlier in southern Queensland than in southern Australia and northwestern Tasmania. However, according to Kershaw (1981), the replacement of closed *Araucaria* forest by open sclerophyll forest or woodland around 38,000 BP at Lynch's Crater cannot be easily explained on climatic grounds alone. Although there is evidence of a reduction of precipitation at this time, the significant increase in the charcoal content of the core at this point indicates that fire, possibly encouraged by aboriginal man, was an important factor in replacing closed forest by open woodland in the Atherton Tableland region. Hence, no direct correlation with northwestern Tasmania is possible.

The southern Australian pollen and hydrologic sequences considered indicate that the general direction of middle and late Last Glacial and Holocene climatic changes compares reasonably well with the general sequence of major climatic changes suggested for northwestern Tasmania. However, since it has not been possible in the present study to objectively differentiate between responses to temperature and precipitation effects, the terms 'wetter' and 'drier' cannot be taken to define increased or reduced general precipitation regimes, though it may do so. However, until it becomes possible to derive a separate thermal and effective precipitation history for northwestern Tasmania, the suggested climatic significance of the artesian spring deposits is tentative.

PART IV

THE PALAEOGEOGRAPHIC ENVIRONMENT

CHAPTER 11

THE PALAEOGEOGRAPHIC ENVIRONMENT: A SYNTHESIS

11.1 INTRODUCTION

There are a number of problems in integrating the evidence of this study into a comprehensive local palaeogeographic model of late Quaternary environmental and climatic change. Although this dissertation sheds light on some of the more important questions concerning the origins and environmental significance of the late Quaternary marine and freshwater swamp deposits of the lowland region of far northwestern Tasmania, a number of important questions remain unanswered. Principally, a radiometrically controlled chronology has not as yet been established for the major geomorphic events associated with the development of the Holocene barrier system. Secondly, there are as yet insufficient absolute and relative chronostratigraphic data on the fluviatile and terrestrial aeolian landforms and deposits to fully resolve the time-stratigraphic position of these units. Thirdly, in the absence of discriminating criteria, it has not been possible to sensitively and objectively differentiate the responses to temperature and precipitation effects in the climatic interpretation of the artesian spring deposits. Hence, it is stressed that the inferred environmental and climatic significance of these deposits is equivocal. Finally, the internal composition and relative stratigraphic relationships of the Last Interglacial marine deposits has only been established in very broad outline and requires considerable further systematic field and laboratory analysis before their full history can be reconstructed. With these considerations in mind, the following description synthesizes the major events recorded in this study into a tentative and general late Quaternary palaeoenvironmental and palaeoclimatic sequence for the region.

11.2 SYNTHESIS

11.2.1 The Last Interglacial Stage (130,000-~120,000 BP)

The occurrence of high level fossiliferous marine sand and cobble deposits and associated relict shoreline features in northwestern Tasmania provides unequivocal evidence for a Quaternary sea level higher than the present level. The local and wider stratigraphic relationships of these deposits in relation to glacigenic, freshwater and aeolian deposits, and the radiocarbon dating of overlying freshwater swamp deposits strongly suggests that the marine deposits are of Last Interglacial age and probably developed within the period of approximately 130 ka and 120 ka (Stage 5e; Shackleton and Opdyke, 1973).

During the transgressive phase, low lying areas were inundated by a rising sea level that resulted from global deglacial events which marked the close of the Penultimate Glacial Stage. It is not possible to construe any local climatic inferences from the glacio-eustatic marine transgression. However, if maximum sea level was attained at or slightly after optimal climatic conditions, then the optimum appears to have been attained relatively early during the interglacial. The morphological effect of the transgression was the erosion of rocky headlands, the reworking of previously existing unconsolidated deposits and a progressive shoreward displacement of these sediments. Where the coastal profile was gentle and uninterrupted by bedrock rises, extensive filling of the broad, low-lying embayments west of Smithton occurred; where the offshore profile was relatively steep, as in the Circular Head area, cliffing of bedrock surfaces occurred and wide, seaward-sloping shore platforms and cobble beaches developed.

Field evidence suggests that barrier progradation was preceded by a phase of parabolic transgressive dune development. It is tentatively postulated that this phase probably occurred as a result of generally stable sea level conditions during the maximum of the transgression and perhaps reflects a period of diminished sediment supply as a result of sea level stability. A regressive progradational phase followed the maximum sea level stand. The presence of successively falling parallel beach ridges west of Smithton, on Robbins Island and elsewhere in the area indicates that shoreline progradation continued apparently uninterrupted as sea level fell to a position below present sea level (Stage 5d; Shackleton and Opdyke, 1973). The orientation of the beach ridges indicates that the dominant wave regime and shoreline alignment of that period was comparable with the present. The parallel and regular nature of the ridge systems indicates that the rate of shoreline progradation and the colonization by sand binding halophytic vegetation of beach berms, and incipient foredunes, was sufficiently rapid to prevent blowout activity and the development of secondary transgressive dune forms. A warm, humid climate comparable to the present would have been conducive to rapid stabilization of parallel beach ridges and dunes by herbaceous and woody vegetation associations.

The composition of the molluscan and foraminiferal faunas in the marine sand deposits at Broadmeadows and Montagu indicates that the environment in which the organisms lived consisted predominantly of shallow, open bay environments from which freshwater influences were largely excluded. The composition of the planktonic foraminiferal fauna suggests that sea water temperatures were probably generally comparable to those prevailing at the present time.

11.2.2 The Last Glacial Stage (∿ 120,000-10,000 BP)

Crude extrapolation of the radiocarbon data at Pulbeena and Mowbray swamps suggests that spring activity in these areas commenced sometime during the early part of the Last Glacial Stage Both swamp sediments and pollen indicate that marked hydrologic changes occurred during this time, but that in the long term the springs were very active and wet conditions prevailed most of the time as a result of high precipitation and/or low evaporation rates due to low temperatures. The sedimentary and pollen data also indicate that spring activity was markedly reduced in response to drier and perhaps warmer climatic conditions which appear to have commenced about 55,000 BP and lasted until 45,000 BP. During this time, woody taxa dominate the pollen assemblages and indicate that swamp forest and scrub communities were much more important on the swamps than herbaceous communities. In addition, unlike most of the previous period, open water conditions were virtually absent.

There is substantial evidence to suggest that predominantly wet conditions prevailed between approximately 45,000 and 22,000 BP, with the wettest conditions occurring after about 35,000 BP. Geomorphic, sedimentary and radiocarbon data indicate that erosion of Last Interglacial marine sand deposits and deposition of river bedloads occurred in the Swan Bay Plain area after about 30,000 BP. This wet phase is also evident at Mowbray Swamp. Here spring activity gradually increased after 36,000 BP which resulted in the accumulation of biochemically precipitated marls on and adjacent to the spring mounds. Generally wet conditions also occured at Pulbeena Swamp and at Broadmeadows Swamp, as indicated by the sediments and the pollen data. That wet conditions were of regional significance is further supported by the evidence at Rocky Cape. Here, over 12 m of unconsolidated alluvial fan deposits, derived from slope deposits in a small catchment overlie marine deposits of probable Last Interglacial age and very indurated fan deposits the age of which may precede the Last Interglacial Stage. Radiocarbon dating of wood and charcoal indicates that the unconsolidated alluvial fan gravels were deposited between about 44,000 and 22,000 BP, and that most were deposited between 33,000 and 22,000 BP (Colhoun, 1977a).

The lithostratigraphic and biostratigraphic data from the swamps demonstrate that the climate was drier between 22,000 and 10,000 BP than during the preceding and succeeding periods. During this time, spring activity was low and possibly ceased periodically as a result of a marked reduction in the rate of recharge of the artesian aquifers probably brought about by a substantial decrease in precipitation. The evidence from Pulbeena Swamp indicates that the driest period occurred after about 17,000 BP.

During the late Last Glacial maximum, sea level was at least 90 m below present sea level and Tasmania was connected to the Australian mainland. The effect of the lowering of sea level would have been to markedly increase the continentality of northwestern as well as eastern and midland Tasmania. The increased continentality would almost certainly have reinforced the overall temperature decrease during this time of highland glaciation, variably estimated at 5 to 8°C (Davies, 1967; Derbyshire, 1971; Colhoun, 1975), and would probably have increased the seasonal temperature range. It would probably also have reinforced the substantial decrease in precipitation indicated by this study, which has been widely recognized for Tasmania and southern Australia (Macphail, 1975; Colhoun, 1975; Hope, 1978; Galloway, 1965; Bowler *et al.*, 1976), and largely landlocked northwestern Tasmania would have experienced a high proportion of dry continental north to northwesterly airflows.

11.2.3 The Holocene Stage (10,000-0 BP)

The lithostratigraphic and biostratigraphic record of the swamps shows that there was a rapid return to wet conditions at the commencement of the Holocene Stage, and that this was accompanied by a rapid expansion of swamp forest tree and woody shrub vegetation. The compositional characteristics of the swamp sediments indicate that spring discharges were somewhat lower during the late Holocene suggesting that the climate was slightly less wet than during the early to mid Holocene period. A slightly wetter early to mid Holocene climate is also evident at Smokers Bank where it has been suggested that seasonally (?) high water levels occurred and resulted in the development of a low sand lunette ridge along the lee shore of a shallow lagoon.

The abundance of charcoal fragments and fern spores, and significant changes in the pollen spectra in the upper parts of the swamp sediments collectively suggest that aboriginal man may have had a marked impact on the swamp ecosystem from the mid Holocene period onwards. However, compared with the recent impact of European man, his effects were minor.

Although the present state of knowledge of the effects of the Holocene eustatic sea level rise in northwestern Tasmania is very limited, it is possible to identify three main stages of sand barrier evolution.

(i) The first stage corresponds with the post-glacial marine transgression which is believed to have commenced about 17,000 BP in southeastern Australia. During this time, Bass Strait was gradually innundated as a result of global deglacial events marking the close of the Last Glacial Stage. The morphologic effect of the transgression was the reworking of unconsolidated deposits and a progressive landward displacement of the sediments. In northwestern Tasmania, truncation of Podzol soils on fossiliferous marine deposits of Last Interglacial age occurred locally, and resulted in an abundance of sand being available for the development of barriers during and for some time after the transgression.

(ii) Sea level in eastern Australia attained its maximum about 6,000 BP. Although undated in the study area, a similar age is indicated by chronostratigraphic data from Laycocks Beach near Devonport. Here carbonized twigs and charcoal from the top of a shallow lagoon deposit overridden by shingle beach deposits have been radiocarbon dated to 5990 ± 260 BP (GaK-5618) and indicate that the Holocene transgression attained its maximum sometime after 5990 BP (Chick and Colhoun, personal communication). The dominant morphological tendency following the transgression in northwestern Tasmania was an onshore sediment transfer from nearshore environments to beach and foreshore zones, and the development of barriers consisting of successive beach ridges and parallel frontal dunes. The relative regularity of the beach ridge patterns suggests that in the long term shoreline progradation took place without major interruptions, as could result from substantial changes in the sediment budget, wave climate or sea level. Under the prevailing warm and humid climate, Podzol soil profiles developed on the beach ridges and parallel dunes as a result of rapid leaching of the porous moderately calcareous sands.

(iii) There is substantial field evidence to suggest that barrier shoreline progradation ceased in the area some time ago, and was replaced by a phase of shoreline modification involving the destruction of primary depositional landforms and redistribution of the sediments by onshore winds. The widespread foreshore erosion, blowout and transgressive dune development in the area clearly indicates that the conditions favourable for beach ridge development and barrier progradation no longer exist. Evidence from elsewhere in Australia suggests that such contemporary beach retrogradation and remobilization of sand is widespread but that, as in northwestern Tasmania, the causal factors involved are as yet unclear and therefore require further investigation.

The Holocene barrier systems have been deposited on the shallow coastal shelf in such a way as to partly enclose extensive lagoonal and estuarine inlets. Largely protected from the effects of refracted ocean swell, the inlets are being constantly modified by erosion and sedimentation. The effects of strong tidal current action and halophytic vegetation has resulted in the development of extensive sandy tidal flats which are fringed by muddy salt marshes.

The attempt made here to synthesize the geomorphic, stratigraphic and palynologic evidence into a sequence of late Quaternary palaeoenvironmental and palaeoclimatic changes in northwestern Tasmania clearly has limitations. What emerges is a broad outline which will almost certainly require modification as more data become available.

References

Aharon, P., Chappell, J. and Compston, W., 1980. Stable isotope and sea-level data from New Guinea supports Antarctic ice-surge theory of ice ages. *Nature*, 283, 649-651.

Andrews, J.T., 1970. A geomorphological study of post-glacial uplift with particular reference to Arctic Canada. *Inst. of British Geographers Special Publication No. 2.*

Aston, H.I., 1973. *Aquatic Plants of Australia.* Melbourne Univ. Press, 368 pp.

Australian Bureau of Meteorology, 1973. Climatic Survey of Northwest Tasmania. Region 1. *Govt. Publ.*, Canberra, 67 pp.

Banks, M.R., 1965. Geology and mineral deposits, pp. 12-18 in *Atlas of Tasmania*, J.L. Davies Ed., Hobart.

Banks, M.R., Colhoun, E.A. and van de Geer, G., 1976. Late Quaternary *Palorchestes azael* (Mammalia, Diprotodontidae) from northwestern Tasmania. *Alcheringa*, 1, 159-166.

Banks, M.R., Colhoun, E.A. and Chick, N.K., 1977. A reconnaissance of the geomorphology of central western Tasmania. In M.R. Banks and J.B. Kirkpatrick Eds., *Landscape and Man*, Roy. Soc. Tasm., Hobart, pp. 29-54.

Barendsen, G.W., Deevey, E.S. and Gralenski, L.J., 1957. Yale natural radiocarbon measurements III. *Science*, 126, 908-919.

Bascom, W.N., 1951. The relationship between sand size and beach face slope. *Trans. Am. Geoph. Union*, 32, 866-874.

Bauer, F.H., 1961. Chronic problems of terrace study in southern Australia. *Zeits. f. Geomorph.* Supplbd. 3, 57-72.

Baulig, H., 1935. The changing sea level. *Inst. Brit. Geographers*, 3, 46 pp.

Belperio, A.P., 1979. Negative evidence for a mid-Holocene high sea level along the coastal plain of the Great Barrier Reef Province. *Marine Geol.*, 32, M1-M9.

Binder, R. and Kershaw, A.P., 1978. A Late-Quaternary pollen diagram from the south-eastern highlands of Australia. *Search*, 9, 44-45.

Bird, E.C.F., 1960. The formation of sand beach ridges. *Austr. J. Sci.*, 22, 349-350.

__________, 1961. The coastal barriers of east Gippsland, Australia. *Geogr. J.*, 127, 460-468.

__________, 1963. The physiography of the Gippsland Lakes, Australia. *Zeits. f. Geomorph.*, 7, 233-245.

__________, 1973. Australian coastal barriers. In *Barrier Islands*, M.L. Schwartz Ed., pp. 410-426. Dowden, Hutchinson and Ross, Stroudsburg.

Blackburn, G., Bond, R.D. and Clarke, A.R.P., 1965. Soil development associated with stranded beach ridges in south-east South Australia. *CSIRO Soil Publication No. 22*, 65 pp.

Bloom, A.L., 1967. Pleistocene shorelines: a new test of isostacy. *Geol. Soc. Am. Bull.*, 78, 1477-1494.

__________, 1971. Glacio-eustatic and isostatic controls of sea level since the Last Glaciation. In *Late Cenozoic Glacial Ages*, K.K. Turekian Ed., pp. 355-380. Yale Univ. Press, New Haven, Conn.

Bloom, A.L., Broecker, W.S., Chappell, J., Matthews, R.K. and Mesolella, K.J., 1974. Quaternary sea level fluctuations on a tectonic coast: new $^{230}Th/^{234}U$ dates from the Huon Peninsula, New Guinea. *Quat. Res.*, 4, 185-205.

Bouyoucos, G.J., 1927. The hydrometer as a method for the mechanical analysis of soils. *Soil Sci.*, 23, 343-349.

_______________, 1962. Hydrometer method improved for making particle size analysis of soils. *J. Agron.*, 54, 464-465.

Bowden, A.R., 1978. Geomorphic perspective on shallow groundwater potential, coastal north-eastern Tasmania. *Austr. Water Resources Council Technical Paper* No. 36, 84 pp.

____________, 1981. *Coastal Sands of Northeastern Tasmania: Geomorphology and Groundwater Hydrology.* Ph.D. thesis, Dept. of Geography, University of Tasmania.

Bowdler, S., 1974. Pleistocene date for man in Tasmania. *Nature*, 252, 697-698.

___________, 1975. An account of an archaeological reconnaissance of Hunter's Isles, North-West Tasmania, 1973/4. *Rec. Q. Vict. Mus. Launceston*, No. 54, 22 pp.

Bowler, J.M., 1973. Clay dunes: their occurrence, formation and environmental significance. *Earth-Sci. Rev.*, 9, 315-338.

____________, 1976. Recent developments in reconstructing late Quaternary environments in Australia. In R.L. Kirk and A.G. Thorne Eds., *The Origin of the Australians.* Austr. Inst. Aborig. Studies, Canberra, pp. 55-77.

Bowler, J.M. and Hamada, T.T., 1971. Late Quaternary stratigraphy and radiocarbon chronology of water level fluctuations in Lake Keilambete, Victoria. *Nature*, 232, 330-332.

Bowler, J.M., Hope, G.S., Jennings, J.N., Singh, G. and Walker, D., 1976. Late Quaternary climates of Australia and New Guinea. *Quat. Res.*, 3, 359-394.

Broecker, W.S. and Thurber, D.L., 1965. Uranium-series dating of corals and oolites from Bahamian and Florida Key limestones. *Science*, 149, 58-60.

Broecker, W.S., Thurber, D.L., Goddard, J., Ku, T.L., Matthews, R.K. and Mesolella, K.J., 1968. Milankovitch hypothesis supported by precise dating of coral reefs and deep-sea sediments. *Science*, 159, 297-300.

Broecker, W.S. and van Donk, J., 1970. Insolation changes, ice volumes, and O^{18} records in deep sea cores. *Reviews, Geophysics and Space Research*, 8, 169-198.

Budd, W.F. and McInnes, B., 1978. In *Climatic Change and Variability*, A.B. Pittock *et al.* Eds., pp. 228-234. Cambridge Univ. Press.

Chapman, V.J., 1960. *Salt Marshes and Salt Deserts of the World.* Leonard Hill, London. 392 pp.

Chappell, J., 1974. Late Quaternary glacio- and hydro-isostacy on a layered earth. *Quat. Res.*, 4, 429-440.

Chappell, J. and Polach, H.A., 1972. Some effects of partial recrystallisation on ^{14}C dating Late Pleistocene corals and molluscs. *Quat. Res.*, 2, 244-252.

Chick, N.K., 1971. Fossil shorelines of the Ulverstone district, Tasmania. *Pap. Proc. Roy. Soc. Tasm.*, 105, 29-40.

Clark, J.A., Farrell, W.E. and Peltier, W.R., 1978. Global changes in Postglacial sea level: a numerical calculation. *Quat. Res.*, 9, 265-287.

Clarke, M.F., Wasson, R.J. and Williams, M.A.J., 1979. Point Stuart chenier and Holocene sea levels in northern Australia. *Search*, 10, 90-93.

Coaldrake, J.E., 1955. Fossil soil hardpans and coastal sandrock in southern Queensland. *Austr. J. Sci.*, 17, 132-133.

Colhoun, E.A., 1975. A Quaternary climatic curve for Tasmania. Paper at Australasian Conference on Climate and Climatic Change, Roy. Met. Soc. Monash Univ., December 1975, 40 pp.

______________, 1976a. Late Quaternary sea level changes: some Tasmanian evidence and problems. Unpublished address ANZAAS Quaternary Shorelines Committee, Hobart.

______________, 1976b. The glaciation of the lower Forth Valley northwestern Tasmania. *Austr. Geogr. Stud.*, 14, 83-102.

______________, 1977a. Late Quaternary fan gravels and slope deposits at Rocky Cape, northwestern Tasmania: their palaeoenvironmental significance. *Pap. Proc. Roy. Soc. Tasm.*, 111, 13-28.

______________, 1977b. A sequence of Late Quaternary deposits at Pipe Clay Lagoon, southeastern Tasmania. *Pap. Proc. Roy. Soc. Tasm.*, 111, 1-12.

______________, 1978a. The Late Quaternary environment of Tasmania as a backdrop to man's occupance. *Rec. Q. Vict. Mus. Launceston*, No. 61, 1-12.

______________, 1978b. Recent Quaternary and geomorphological studies in Tasmania. *Austr. Quat. Newsletter*, 12, 2-15.

______________, 1980. Quaternary fluviatile deposits from the Pieman dam site, western Tasmania. *Proc. Roy. Soc. Lond.*, B207, 355-384.

Colhoun, E.A., van de Geer, G. and Mook, W.G., 1977. Pulbeena Swamp northwestern Tasmania: stratigraphy and pollen analysis. *X INQUA Congress*, Birmingham. *Abstracts*, p. 91.

Colhoun, E.A. and Goede, A., 1979. The late Quaternary deposits of Blakes Opening and the middle Huon Valley, Tasmania. *Phil. Trans. Roy. Soc. Lond.*, 286, 371-395.

Cook, P.J., Colwell, J.B., Firman, J.B., Lindsay, J.M., Schwebel, D.A. and von der Borch, C.C., 1977. The late Cainnozoic sequence of south-east South Australia and Pleistocene sea level changes. *BMR J. Austr. Geol. & Geophys.*, 2, 81-88.

Costin, A.B., 1972. Carbon-14 dates from the Snowy Mountains area, southeastern Australia and their interpretation. *Quat. Res.*, 2, 579-590.

Craig, H., 1957. Isotope standards for carbon and oxygen and correction factors for mass-spectrometric analysis of carbon dioxide. *Geoch. et Cosmochim. Acta*, 12, 133-149.

__________, 1961. Isotopic variations in meteoric waters. *Science*, 133, 1833-1834.

Curtis, W.M., 1963, 1967. *The Student's Flora of Tasmania*, Parts 2 and 3. Govt. Printer, Tasmania.

Curtis, W.M. and Morris, D.I., 1975. *The Student's Flora of Tasmania*, Part 1, 2nd Edn. Govt. Printer, Tasmania.

Daly, R.A., 1943. *The Changing World of the Ice Age*. Yale Univ. Press, Newhaven, Conn. 271 pp.

Dansgaard, W., 1964. Stable isotopes in precipitation. *Tellus*, 16, 436-468.

Dansgaard, W. and Tauber, H., 1969. Glacial oxygen-18 content and Pleistocene ocean temperatures. *Science*, 166, 499-502.

Dansgaard, W. and Duplessy, J.C., 1981. The Eemian interglacial and its termination. *Boreas*, 10, 219-228.

Davies, J.L., 1957. The importance of cut and fill in the development of sand beach ridges. *Austr. J. Sci.*, 20, 105-111.

____________, 1958. Analysis of height variation in sand beach ridges. *Austr. J. Sci.*, 21, 51-52.

____________, 1959. Sea level change and shoreline development in southeastern Tasmania. *Pap. Proc. Roy. Soc. Tasm.*, 93, 89-95.

____________, 1960a. Beach alignment in southern Australia. *Austr. Geogr.*, 8, 42-44.

____________, 1960b. Quaternary strandlines in Tasmania. In summary of the Report of the ANZAAS Sections C and P Committees. *Austr. J. Sci.*, 23, 75.

____________, 1961. Tasmanian beach ridge systems in relation to sea level change. *Pap. Proc. Roy. Soc. Tasm.*, 95, 35-40.

____________, 1965. Landforms, pp. 19-25 in *Atlas of Tasmania*, J.L. Davies Ed., Hobart.

____________, 1967. Tasmanian landforms and Quaternary climates. Chapter 1 in *Landform Studies from Australia and New Guinea*, J.N. Jennings and J.A. Mabbutt Eds., A.N.U. Press, Canberra.

____________, 1972. *Geographical Variation in Coastal Development*, Oliver and Boyd, Edinburgh, 204 pp.

____________, 1974. The coastal sediment compartment. *Austr. Geogr. Stud.*, 12, 139-151.

De Lamothe, L., 1918. Les anciennes nappes alluviales et lignes de rivage du bassin de la Somme et leurs rappotts avec de la Méditerranée occidentale. *Bull. Soc. Géol. France*, 18, 3-58.

Denton, G.H., Armstrong, R.L. and Stuiver, M., 1971. The late Cenozoic history of Antarctica. In *Late Cenozoic glacial ages*, K.K. Turekian Ed., pp. 267-306. Yale Univ. Press, New Haven, Conn.

Derbyshire, E., 1971. A synoptic approach to the atmospheric circulation of the Last Glacial maximum in south-eastern Australia. *Palaeogeog., Palaeocl., Palaeoecol.*, 10, 103-124.

Dimmock, G.M., 1957. The soils of Flinders Island, Tasmania. *CSIRO Soils and Land Use Series* No. 23.

Dodson, J.R., 1974a. Vegetation history and water fluctuations at Lake Leake, southeastern South Australia. I. 10,000 BP to Present. *Austr. J. Bot.*, 22, 719-741.

___________, 1974b. Vegetation and climatic history near Lake Keilambete, western Victoria. *Austr. J. Bot.*, 22, 709-717.

___________, 1975. Vegetation history and water fluctuations at Lake Leake, south-eastern South Australia. II. 50,000 BP to 10,000 BP. *Austr. J. Bot.*, 23, 815-831.

___________, 1977. Late Quaternary palaeoecology of Wyrie Swamp, southeastern South Australia. *Quat. Res.*, 87, 97-114.

___________, 1979. Late Pleistocene vegetation and environments near Lake Bullenmerri, western Victoria. *Austr. J. Bot.*, 4, 419-427.

Donner, J.J., 1965. Shore-line diagrams in Finnish Quaternary research. *Baltica*, 2, 11-20.

Edwards, A.B., 1941. The north-west coast of Tasmania. *Proc. Roy. Soc. Vict.*, 53, 223-267.

Emiliani, C., 1955. Pleistocene temperatures. *J. Geol.*, 63, 538-578.

__________, 1966. Palaeotemperature analysis of Caribbean cores P 6304-8 and P 6304-9 and a generalized temperature curve for the last 425,000 years. *J. Geol.*, 74, 109-126.

Epstein, S., Buchsbaum, R., Lowenstam, H.A. and Urey, H.C., 1953. Revised carbonate-water isototic temperature scale. *Geol. Soc. Am. Bull.*, 64, 1315-1326.

Faegri, K. and Iversen, J., 1975. *Textbook of Pollen Analysis.* 3rd Edn. Blackwell, London, 295 pp.

Fairbanks, R.G. and Matthews, R.K., 1978. The marine oxygen isotope record in Pleistocene coral, Barbados, West Indies. *Quat. Res.*, 10, 181-196.

Fairbridge, R.W., 1961. Eustatic changes in sea-level. *Physics and Chemistry of the Earth*, 4, 99-185.

Flemming, N.C. and Roberts, D.G., 1973. Tectono-eustatic changes in sea level and sea floor spreading. *Nature*, 243, 19-22.

Flohn, H., 1974. Background of a geophysical model of the initiation of the next glaciation. *Quat. Res.*, 4, 385-404.

Folk, R.L. and Ward, W.C., 1957. Brazos River bar: a study in the significance of grain size parameters. *J. Sed. Petr.*, 27, 3-26.

Friedman, G.M., 1961. Distinction between dune, beach, and river sands from their textural characteristics. *J. Sed. Petr.*, 31, 514-529.

Galloway, R.W., 1965. Late Quaternary climates in Australia. *J. Geol.*, 73, 603-18.

Gentilli, J., 1972. *Australian Climatic Patterns*. Nelson, Melbourne. 285 pp.

Gierloff-Emden, H.G., 1961. *Luftbilt und Küstegeographie am Beispiel der deutschen Nordseeküste*. Selbstverlag des Institute für Ladeskunde, Bad Godesberg. 117 pp.

Gill, E.D. and Banks, M.R., 1956. Cainozoic history of Mowbray Swamp and other areas of northwestern Tasmania. *Rec. Q. Vict. Mus. Launceston*, N.S.6, 1-41.

Gill, E.D. and Hopley, D., 1972. Holocene sea levels in eastern Australia - a discussion. *Marine Geol.*, 12, 223-233.

Gill, E.D. and Amin, B.S., 1975. Interpretation of 7.5 and 4 metre Last Interglacial shore platforms in southeast Australia, *Search*, 6, 394-396.

Goede, A., Murray, P., and Harmon, R., 1978. Pleistocene man and megafauna in Tasmania: dated evidence from cave sites. *The Artefact*, 3, 139-149.

Goede, A., Harmon, R. and Kiernan, K., 1979. Sea caves of King Island. *Helictite*, 17, 51-64.

Goudie, A.S., 1977. *Environmental Change*. Clarendon Press, Oxford. 244 pp.

Grasty, R.L., 1967. Orogeny, a cause of world-wide regression of the seas. *Nature*, 216, 779.

Grootes, P.M., 1978. Carbon-14 time scale extended: comparison of chronologies. *Science*, 200, 11-15.

Guilcher, A., 1969. Pleistocene and Holocene sea level changes. *Earth-Sci. Rev.*, 5, 45-68.

Gulline, A.B., 1959. The underground water resources of the Smithton District. *Tasm. Dept. Mines Underground Water Supply Paper*, No. 5, 72 pp.

Hails, J.R., 1968. The late Quaternary of part of the mid-north coast, New South Wales. *Trans. Inst. Brit. Geogr.*, 44, 139-145.

Hails, J.R. and Hoyt, J.H., 1968. Barrier development on submerged coasts: problems of sea-level changes from a study of the Atlantic Coastal Plain of Georgia, U.S.A. and parts of the east Australian coast. *Zeits. f. Geomorph., Supplbd.*, 7, 24-55.

Hedberg, H.D. (ed.), 1972. Summary of an International Guide to the Stratigraphic Classification, Terminology and Usage. *Boreas*, 1, 213-239.

Hey, R.W., 1978. Horizontal Quaternary shorelines of the Mediterranean. *Quat. Res.*, 10, 197-203.

Hobba, W.A. Jr., Fisher, D.W., Pearson, F.J. Jr. and Chemerys, J.S., 1979. Hydrology and geochemistry of thermal springs of the Appalachians. *Geol. Surv. Prof. Paper,* 1044-E, 36 pp.

Hollin, J.T., 1965. Wilson's theory of ice ages. *Nature*, 208, 12-16.

____________, 1977. Thames interglacial sites, Ipswitchian sea levels and Antarctic ice surges. *Boreas*, 6, 33-52.

____________, 1980. Climate and sea level in isotope stage 5: an East Antarctic ice surge at ~ 95,000 BP? *Nature*, 183, 629-633.

Hope, G.S., 1978. The late Pleistocene and Holocene vegetational history of Hunter Island, north-western Tasmania. *Austr. J. Bot.*, 26, 493-514.

Hopley, D., 1980. Mid-Holocene high sea levels along the coastal plain of the Great Barrier Reef Province: a discussion. *Marine Geol.*, 35, M1-M9.

Horton, D.R. and Murray, P., 1980. The extinct Toolach Wallaby (*Macropus greyi*) from a spring mound in north western Tasmania. *Rec. Q. Vict. Mus., Launceston* (in press).

Hubble, G.D., 1951. A reconnaissance survey of the coastal heath country, north-west Tasmania. *CSIRO Division of Soils Report*, 10/51, Hobart, 24 pp.

Hughes, T.D., 1957. Limestones in Tasmania. *Tas. Dept. Mines Min. Resources Publ.* No. 10, 291 pp.

Jacoby, W.R., 1972. Plate theory, epeirogenesis and eustatic sea-level changes. *Tectophys.*, 15, 187-196.

Jackson, W.D., 1965. Vegetation, pp. 30-35 in *Atlas of Tasmania*, J.L. Davies Ed., Hobart.

Jakobsen, B., 1962. Morfologiske og hydrografiske undersøgelser af flod-og ebbeskår i tidevandsrender. *Geogr. Tidsskr.*, 61, 119-141.

Jenkin, J.J., 1968. The geomorphology and upper Cainozoic geology of S.E. Gippsland, Victoria. *Mem. Geol. Surv. Vict.*, 27, 144 pp.

Jennings, J.N., 1957. Coastal dune lakes as exemplified from King Island, Tasmania. *Geogr. Jour.*, 123, 60-70.

______________, 1959. The coastal geomorphology of King Island, Bass Strait, in relation to changes in the relative level of land and sea. *Rec. Q. Vict. Mus. Launceston* N.S.11, 1-39.

______________, 1961. Sea level changes in King Island, Bass Strait. *Zeits. f. Geomorph. Supplbd.*, 3, 80-84.

______________, 1967. Cliff-top dunes. *Austr. Geogr. Stud.*, 5, 40-49.

Jones, R., 1965. Observations on the geomorphology of a coastal cave near Wynyard, Tasmania. *Pap. Proc. Roy. Soc. Tasm.*, 99, 15-16.

Kaufman, A., Broecker, W.S., Ku, T.L. and Thurber, D.L., 1971. The status of U-series methods of mollusc dating. *Geoch. et Cosmochim. Acta*, 35, 1155-1183.

Kershaw, A.P., 1974. A long continuous pollen sequence from north-eastern Australia. *Nature*, 251, 222-223.

____________, 1976. A late Pleistocene and Holocene pollen diagram from Lynch's Crater, northeastern Queensland, Australia. *New Phytol.*, 77, 469-498.

____________, 1978. Record of last interglacial-glacial cycle from northeastern Queensland. *Nature*, 272, 159-161.

____________, 1981. Quaternary vegetation and environments. In A. Keats Ed., *Ecological Biogeography of Australia.* Junk, The Hague, pp. 83-101.

Kershaw, R.C., 1958. Tasmanian intertidal mollusca. *J. Malacol. Soc. Austr.*, 2, 58-100.

Kershaw, R.C. and Sutherland, F.L., 1972. Quaternary geomorphology of Flinders Island. *Rec. Q. Vict. Mus. Launceston.* N.S.43, 1-28.

King, C.A.M., 1959. *Beaches and Coasts.* Edward Arnold, London, 403 pp.

Ladd, P.G., 1979. A Holocene vegetation record from the eastern side of Wilsons Promontory, Victoria. *New Phytol.*, 82, 265-276.

Land, L.S., MacKenzie, T.F. and Gould, S.J., 1967. Pleistocene history of Bermuda. *Geol. Soc. Am. Bull.*, 78, 993.

Langford, J., 1965. Weather and climate, pp. 2-11 in *Atlas of Tasmania*, J.L. Davies Ed., Hobart.

Langford-Smith, T. and Thom, B.G., 1969. New South Wales coastal geomorphology. *J. Geol. Soc. Austr.*, 16, 572-580.

Macphail, M.K., 1975. Late Pleistocene environments in Tasmania. *Search*, 6, 295-300.

______________, 1979. Vegetation and climates in southern Tasmania since the Last Glaciation. *Quat. Res.*, 11, 306-41.

Macphail, M.K. and Jackson, W.D., 1978. The late Pleistocene and Holocene history of the Midlands of Tasmania: pollen evidence from Lake Tiberias. *Proc. Roy. Soc. Vict.*, 90, 287-300.

Marshall, J.F. and Thom, B.G., 1976. The sea level in the Last Interglacial. *Nature*, 263, 120-121.

Mason, C.C. and Folk, R.L., 1958. Differentiation of beach, dune and aeolian flat environments by size analysis, Mustang Island, Texas. *J. Sed. Petr.*, 28, 211-226.

May, W.L., 1923. *An illustrated index of Tasmanian shells.* Govt. Printer, Hobart.

Menard, H.W., 1969. Elevation and subsidence of oceanic crust. *Earth and Planet. Sci. Lett.*, 6, 275-284.

Mercer, J., 1968. Antarctic ice and Sangamon sea level. *International Union of Geodesy & Geophysics, Intern. Ass. of Scientific Hydrol. Publ.*, 79, 217-225.

______________, 1972. The lower boundary of the Holocene. *Quat. Res.*, 2, 15-24.

Mitchell, G.F., Penny, L.F., Shotten, F.W. and West, R.G., 1973. A correlation of Quaternary deposits in the British Isles. *Geol. Soc. Lond., Special Report No. 4*, 99 pp.

Mook, W.G., 1972. Application of natural isotopes in ground water hydrology. *Geol. en Mijnb.*, 51, 131-136.

Murray, P. and Goede, A., 1977. Pleistocene vertebrate remains from a cave near Montagu, N.W. Tasmania. *Rec. Q. Vic. Mus. Launceston.* No. 60, 30 p.

Nicolls, K.D. and Dimmock, G.M., 1965. Soils, pp. 27-29 in *Atlas of Tasmania*, J.L. Davies Ed., Hobart.

Noetling, F., 1912. The occurrence of gigantic marsupials in Tasmania. *Pap. Proc. Roy. Soc. Tasm.* for 1911, 124-133.

Northcote, K.H., Hubble, G.D., Isbell, R.F., Thompson, G.H. and Bettenay, E., 1975. *A Description of Australian Soils*. CSIRO Publ., Melbourne. 170 pp.

Nye, P.B., Finucane, K.H. and Blake, F., 1934. The Smithton district. *Geol. Survey Bull.*, No. 41, Tasm. Dept. Mines, Hobart. 120 pp.

Olausson, E., 1965. Evidence of climatic changes in deep-sea cores, with remarks on isotopic palaeotemperature analysis. *Prog. Ocenanogr.*, 3, 221-252.

Olsen, I.U., 1974. Some problems in connection with the evaluation of C14 dates. *Geol. Foren i Stockh. Forh.*, 96, 311-320.

Pestrong, R., 1965. The development of drainage patterns on tidal marshes. *Stanford Univ. Publ. Geol. Sciences*, 10, No. 2, 87 pp.

Phillips, A.W., 1975. The establishment of *Spartina* in the Tamar Estuary, Tasmania. *Pap. Proc. Roy. Soc. Tasm.*, 109, 65-75.

Reber, G., 1965. Aboriginal carbon dates from Tasmania. *Mankind*, 6, 264-268.

Reeves, C.C. Jr., 1968. *Introduction to Palaeolimnology*. Elsevier, Amsterdam. 228 pp.

Reineck, H.E. and Singh, I.B., 1975. *Depositional Sedimentary Environments*. Springer-Verlag, Berlin. 439 pp.

Robinson, A.H.W., 1960. Ebb-flood channel systems in sandy bays and estuaries. *Geography*, 45, 183-199.

Russell, K.L., 1968. Oceanic ridges and eustatic changes in sea level. *Nature*, 218, 861-862.

Schwartz, M.L., 1965. Laboratory study of sea level rise as a cause of shore erosion. *J. Geol.*, 73, 528-534.

Shackleton, N.J., 1967. Oxygen isotope analyses and Pleistocene temperatures re-assessed. *Nature*, 215, 15-17.

Shackleton, N.J. and Matthews, R.K., 1977. Oxygen isotope stratigraphy of late Pleistocene coral terraces in Barbados. *Nature*, 268, 618-620.

Shackleton, N.J. and Opdyke, N.D., 1973. Oxygen isotope and palaeomagnetic stratigraphy of Equatorial Pacific core V28-238: oxygen isotope temperatures and ice volumes on a 10^5 year and 10^6 year scale. *Quat. Res.*, 3, 39-55.

Sigleo, W.R. and Colhoun, E.A., 1975. Glacial age man in southeastern Tasmania: evidence from the Old Beach site. *Search*, 6, 300-302.

______________________________, Terrestrial dunes, man and late Quaternary environment in southern Tasmania (in prep.).

Singh, G., 1975. Late Quaternary vegetation and climatic oscillations at Lake George, N.S.W. Unpublished paper presented at *Australasian Conference on Climate and Climatic Change*. Monash University, 1975.

Singh, G., Kershaw, A.P. and Clark, R., 1981. Quaternary vegetation and fire history in Australia. In *Fire and the Australian Biota*, A.M. Gill, R.A. Groves and I.R. Noble Eds., Austr. Acad. Science, Canberra.

Sloane, D.J., 1974. *The Geomorphology of the George Bay area, St. Helens.* B.Sc. Honours thesis, Dept. of Geography, University of Tasmania.

Specht, R.L., 1970. Vegetation. In *The Australian Environment*, pp. 44-67, 4th Edn. G.W. Leeper Ed., CSIRO, Melbourne.

Sprigg, R.C., 1979. Stranded and submerged sea-beach systems of southeast South Australia and the aeolian desert cycle. *Sedim. Geol.*, 22, 53-96.

Spry, A. and Banks, M.R., 1962. The Geology of Tasmania. *J. Geol. Soc. Austr.*, 9, 107-362.

Stace, H.C.T., Hubble, G.D., Brewer, R., Northcote, K.H., Sleeman, J.R., Mulcahy, M.J. and Hallsworth, E.G., 1968. *A Handbook of Australian Soils.* Rellim Technical Publications, South Australia. 435 pp.

Steinen, R.P., Harrison, R.S. and Matthews, R.K., 1973. Eustatic low stand of sea level between 125,000 and 105,000 B.P.: evidence from the sub-surface of Barbados, West Indies. *Geol. Soc. Am. Bull.*, 84, 63-70.

Stephens, C.G., 1962. *A Manual of Australian Soils.* CSIRO Publ., Melbourne.

Stephens, N. and Synge, F.M., 1966. Pleistocene shorelines. In *Essays in Geomorphology*, G.H. Dury Ed., pp. 1-51. Hernemann, London.

Stuiver, M., Heusser, C.J. and Yang, I.C., 1978. North American glacial history extended to 75,000 years ago: The range of carbon-14 dating extended through isotope enrichment techniques. *Science*, 200, 16-21.

Suggate, R.P., 1965. The definition of "Interglacial". *J. Geol.*, 73, 619-626.

________, 1974. When did the Last Interglacial end? *Quat. Res.*, 4, 246-52.

Todd, D.K., 1959. *Groundwater Hydrology*. Wiley, New York. 536 pp.

Thom, B.G., 1964. Origin of sand beach ridges. *Austr. J. Sci.*, 26, 351.

________, 1965. Late Quaternary coastal morphology of the Port Stephens-Myall Lakes area, New South Wales. *Jour. Proc. Roy. Soc. N.S.W.*, 98, 23-36.

________, 1968. Coastal erosion in eastern Australia. *Aust. Geogr. Stud.*, 6, 90-93.

________, 1973. The dilemma of high interstadial sea levels during the Last Glaciation. *Progress in Geography*, 5, 170-246.

________, 1974. Coastal erosion in eastern Australia. *Search*, 5, 198-209.

________, 1978. Coastal sand deposition in southeast Australia during the Holocene. Chapter 9 in *Landform Evolution in Australia*. Davies, J.L. and Williams, M.A.J. Eds., ANU Press, Canberra.

Thom, B.G., Hails, J.R. and Martin, A.R.H., 1969. Radiocarbon evidence against higher postglacial sea levels in eastern Australia. *Marine Geol.*, 7, 161-168.

Thom, B.G., Hails, J.R., Martin, A.R.H. and Phipps, C.V.G., 1972. Postglacial sea levels in eastern Australia - a reply. *Marine Geol.*, 12, 233-242.

Thom, B.G. and Chappell, J., 1975. Holocene sea levels relative to Australia. *Search*, 6, 90-93.

Thom, B.G., Polach, H.A. and Bowman, G.M., 1978. Holocene age structure of coastal sand barriers in New South Wales. *Univ. of N.S.W. Faculty of Military Studies Publ.* 86 pp.

van de Geer, G., 1972. *Marion Bay Shoreline Morphology*, B.A. Hons. Thesis, Dept. of Geography, University of Tasmania.

van de Geer, G., Colhoun, E.A. and Bowden, A., 1979. Evidence and problems of Interglacial marine deposits in Tasmania. *Geol. en Mijnb.*, 58, 29-32.

van Straaten, L.M.J.U., 1950. Environment of formation and facies of the Wadden Sea sediments. *Tijdschr. Kon. Ned. Aardr. Gen.*, 67, 354-368.

______________________, 1953. Megaripples in the Dutch Wadden Sea and in the basin of Arcachon (France). *Geol. en Mijnb.*, 15, 1-11.

van Veen, J., 1950. Eb en vloedschaar systemen in the Nederlandse getijwateren. *Tijdschr. Kon. Ned. Aardr. Gen.*, 67, 303-325.

Veeh, H.H., 1966. Th^{230}/U^{238} and U^{234}/U^{238} ages of Pleistocene high sea level stand. *J. Geoph. Res.*, 71, 3379-3386.

Veeh, H.H. and Chappell, J., 1970. Astronomical theory of climatic change: support from New Guinea. *Science*, 167, 862-865.

Walcot, R.I., 1972. Past sea levels, eustacy and deformation of the earth. *Quat. Res.*, 2, 1-14.

Ward, W.R., Ross, P.J. and Colquhoun, D.J., 1971. Interglacial high sea levels - an absolute chronology derived from shoreline elevations. *Palaeogeogr., Palaeocl., Palaeoecol.*, 9, 77-99.

Watson, R.A. and Wright, H.E., 1980. The end of the Pleistocene: a general critique of chronostratigraphic classification. *Boreas*, 9, 153-163.

Ward, W.T., Little, I.P. and Thompson, C.H., 1979. Stratigraphy of two sandrocks at Rainbow Beach, Queensland, Australia, and a note on humate composition. *Palaeogeogr., Palaeocl., Palaeoecol.*, 26, 305-316.

White, D.E., Barnes, I. and O'Neil, J.R., 1973. Thermal and mineral waters of non-meteoric origin, California Coast Ranges. *Geol. Soc. Am. Bull.*, 84, 547-560.

Wilson, A.T., 1964. Origin of ice ages: an ice shelf theory for Pleistocene glaciation. *Nature*, 201, 147-149.

Woillard, G.M. and Mook, W.G., 1982. Carbon-14 dates at Grande Pile: Correlation of land and sea chronologies. *Science*, 215, 159-161.

Wright, L.D., 1970. The influence of sediment availability on patterns of beach ridge development in the vicinity of the Shoalhaven River Delta, N.S.W. *Austr. Geogr.*, 11, 336-348.

Zeuner, F.E., 1959. *The Pleistocene Period.* Hutchinson, London. 447 pp.

APPENDICES

APPENDIX I   Pulbeena Swamp Pollen Percentages

Depth (cm)	*Dacrydium* cf. *franklinii*	*Nothofagus cunninghamii*	*Phyllocladus aspleniifolius*	*Acacia* spp.	*Eucalyptus* + *Melaleuca* spp.	*Cyathea* + *Dicksonia antarctica*	*Amperea xiphoclada*	*Banksia marginata*	*Bauera rubioides*	*Casuarina* spp.	*Drimys lanceolata*	Epacridaceae T-type	*Hibbertia* spp.	*Leptospermum* spp.	*Monotoca* spp.	Papilionatae	Rhamnaceae	Rutaceae
Trap		+		+	+					+				6.6				
0		+	+	+	3.9	+				+	+			2.0	+		+	
20		+			24.9	1.8								18.7	1.6	+	1.0	
30		+	+	+	36.3	+				+				48.2	1.3		+	
40		1.3			33.2	+				+		+		42.0	+		1.0	
50		+	+	+	10.5	+		+		+	+	+		43.9	+		+	
60					6.1					+				70.2			+	
70								+								5.0		
80					+							+	2.2			+		
90					+									+		+		
100					2.9								+	+		+		+
110					2.7													
120					2.1									2.4				
125					4.4		+			+		+		+		+		
130					6.6									2.1		+		
135					4.2									1.1				
140					+					+								
145					6.2			8		1.1				2.4	+			
150					+					+								
155					13.9						+		1.0	8.6	+			
160		+	+		10.2	+						+		13.6	+	4.4		
170					6.8		+	+		+		+		2.1	+	+		
180		+	+		18.2	+				+				6.2	+			
190		+	+		35.4	+	+			1.3					+	+		
195				+	20.5			+		+				31.3	+		+	
200					22.0		1.0			1.0		+			1.6	+		+
205				+	16.0		+			+		+		33.1	+			
210					41.9	+	+	+		1.6			+	6.5	1.2	+		
215		+	+	+	13.8	+								56.7	+	+		
220					19.1		+			+				2.8	+	1.3		
230					7.6					+					+			
240		+	+		7.1									2.0	+			
250			+		14.3					+				9.0				
260		1.9	+		21.0			+		+				11.5	1.2	+		
270		3.5	2.7		14.9			1.1	+	2.9			+	8.0	1.9	+		
280		1.0	+	+	10.7	+	+		+				+	42.9	+	+	+	+
270	+	+	+		4.2	+		+	+	+		+		30.6	+		+	
300	+	+	+	+	5.9	+	+		+	+		+		26.9	+	+	+	+
310	+	3.3	1.1		7.6	+	+			+				26.3	+			+
320	+	2.2	3.3		14.9					1.9		1.1		34.7	2.5			
325		1.3	4.1		13.6	+		+		1.0	+			61.0				
330		7.7	+		11.9			+		4.2				11.1		+		
335		1.0	19.7	+	13.5	2.1		+		+		+		44.7	+	+		
340		2.2	1.5		12.1				+	2.8		+		22.5	+	+		
350		4.5	+	+	19.8	+		+		1.0	+	+	+	29.2	+	+		
360		+		+	17.7	1.4				+		+		39.1	+	+	+	+
370		1.4	+	+	13.6	+		+	+	+		+		45.6	+		+	
375		+	+		10.3	+		+		+		+		51.5	+	+	+	
380		+	+	+	13.7	+	+	+		1.2		1.3		51.5	1.3		+	
385		+	+		5.6	1.3		+		+		+		12.8	+		+	
390		+	+		12.8	1.7	+	+	+	1.0				26.0	+		+	
400	+				7.7	2.7		+	+	+	+			13.6	+		+	
405					10.2	+				+		+		10.5	+		+	
410									NO		POLLEN							
415		+		+	14.1		1.6	1.2		3.1	+	+		+	4.2	+		
420		+										+						
425		+	+		20.0			+		+		+		17.9	1.1			
430					16.0	+		+		1.0		+		51.0	+	+		
435		+			15.8	+		+		+		+		54.0	+		+	+
440					8.0			+		+		+		+	2.7			
450					1.6			+		1.0		+						
455					4.8			+		+				3.1	+			
460									NO		POLLEN							
465		+	+		5.5		+	+		+	1.3	+		+				
470					8.0					+				+	+			
480					1.3									+				

Depth (cm)	Chenopodiaceae	Compositae-Liguliflorae	Compositae-Tubuliflorae	Cruciferae	Cyperaceae	Gramineae	Haloragaceae	Liliaceae + Iradaceae	*Plantago* spp.	Polygonaceae	Restionaceae	Umbelliferae	Scrophulariaceae	Pollen sum	*Myriophyllum*	Portulacaceae	*Potamogeton* + *Triglochin*	Monocolpate-echinate	Unknown	Monolete spores	Trilete spores
Trap		+	+		1.3	85.1			2.9	+				376					5.1	+	
0	+	10.7		+	+	20.5			1.0		+	+		488					1.0	2.7	4.1
20	3.4	17.1	6.2	2.9	2.1	6.8	+	2.6	+	+			1.3	385	+				5.5	14.5	8.1
30	1.0	+	3.3			1.8	+					+		394			+		+	53.3	52.3
40	+		2.3		+	1.9			+			+		479	+		+		+	36.1	126.7
50	1.9		5.1	+	16.2	10.5					4.0	+	+	647			+		1.1	2.9	7.6
60	1.7	+	3.4		2.1	12.6		+		+	1.3	+		769					1.0	+	+
70	2.7		11.7		+	61.0		+			2.7	+		377					2.1	+	+
80	1.3		20.0		1.3	56.9		8.6				8.0		313					+	1.0	+
90	1.4		32.0		1.1	62.6		1.1			+	1.4		350					1.1		
100	1.6		16.9		1.0	74.7		+				+		308					1.3		
110	+	+	15.4		2.4	76.0		+	+		+	+		337					2.1	+	+
120	+		25.7	+	+	53.6		5.3				4.4		338					+	+	+
125	1.7	+	37.5	+	9.9	38.8			1.7		1.4			363		+	1.7		2.2	1.1	1.1
130	2.7		28.6		5.4	51.5			+		1.2	+		332			+		+	+	+
135	+	+	28.1	+	9.7	46.0	+		5.6		1.4			359		2.5	+		1.1	+	+
140	+	29.3	11.8	+		40.9		2.8	+		1.7			533		116.7	+	10.9	1.1	+	+
145	1.9	1.1	15.4	+	19.4	40.7			4.3	+	2.7			371		1.9	4.0	+	3.0	+	+
150	+	9.0	11.1	+	+	64.9		+			2.7	+		333		292.2	1.2	7.8	1.5	+	+
155	1.7		11.6	+		12.4			2.9	+	3.2			525	+	2.1	1.9		1.0	+	+
160	+		4.0	2.5	37.0	8.7		+	+	1.0	10.9	+		597			22.4		2.2	+	+
170	2.3		2.7	1.6	44.8	11.0	+	+		+	21.1	+	1.5	961	+	2.5	30.4	2.7	2.0	1.0	1.0
180	2.5		7.9	1.5	20.0	12.8	+	+	+	1.3	25.3		+	609			25,1	+	1.0	1.6	1.6
190	2.5		8.9	+	1.9	39.6	+			+	3.8			316		+			+	+	+
195	1.3		7.4	+	4.9	9.4	+		2.0	2.0	11.9	+		556		+	1.4	+	1.3	+	+
200	2.2		6.1		+	64.0	+				+	+		314		6.1			1.3	+	+
205	+		5.2	+	23.7	6.1		+		+	6.8			688	+		5.7		+	+	+
210	1.6		9.3	+	3.1	24.5		1.2			+	+		325				2.8	+		
215	1.3		1.9		13.0	5.6		+	+		+	+		854	+	+	+	+	+	+	+
220	+	3.1	+		1.6	60.0		+	+		+	+		320		1.9		+	2.3	+	+
230	1.4	1.0	15.6	1.0	32.2	31.8		1.4	2.0		3.1			512		9.4	2.2	1.4	2.0	+	+
240	2.8	2.0	9.3	+	35.4	36.4			+	+	+	+		495		4.2	2.2	+	1.3	+	+
250	1.6	1.3	7.1	+	9.3	52.9		1.1			1.1	+		378			+	+	+		
260	6.8		9.9		1.9	39.3		1.2		+	2.5	+		323		1.1	3.7		2.4	+	+
270	7.4		8.2	7.2	13.8	17.0	+	1.6	+	1.3	2.1			376			10.9	3.7	+	1.1	
280	1.5		2.5	+	32.0	1.4		+		+	+			1003		+	20.8	+	+	+	+
270	+		1.4	+	55.7	+		+		3.1	+			1766		10.4	30.7	+	+	+	+
300	1.2		1.2		56.8	1.1		+		2.5	+	+		2083	+	2.2	8.1	+	+	+	+
310	2.5		3.3	+	43.5	6.0		1.0			+			720		3.1	1.5	+	1.0	+	+
320	2.2		6.6	1.1	6.1	20.1		+		1.9	+			363			+		+		
325	1.0		2.9		4.8	5.1					+			683			+		1.2	+	1.5
330	1.7		6.7	1.0	3.7	46.7		1.2	+	+	+			405		6.2	2.5	+	1.2	+	+
335	1.0		3.3		2.4	8.8					+			421					+	+	1.4
340	2.4		8.6	1.9	28.3	10.6		2.2			+			463		15.3	2.1	1.1	1.1	1.7	+
350	1.2		6.7	+	26.7	3.5		+		+	1.2			600	+	23.3	9.8	1.5	1.5	+	+
360	1.9		3.0	+	25.2	3.5		1.0	+		1.0	+		627	+	4.1	35.7	+	2.2	1.9	1.1
370	+		4.6	+	23.6	2.0		1.2		+	1.3	+	+	763	+	20.4	17.7	1.0	2.1	+	+
375	+		2.5		25.6	2.3		+		+	+			1074		+	25.5	+	+	2.1	1.0
380	1.2		4.3	+	14.3	6.9		+			+			608		23.5	28.5	+	2.0	+	+
385	1.6				71.7	1.7		+			+			1487		6.1	12.2	+	+	+	+
390	1.7		4.3		46.0	1.6		+			1.0			822	+	6.0	20.0	+	+	1.0	
400	1.3		2.4		73.3	2.8		+	+	+	1.4			1009	+	25.5	17.5	+	+	+	+
405	+		3.6	+	4-.4	27.8	+			+	1.5			666		10.2	1.2	+	+	1.5	3.0
410																					
415	4.5		12.2		18.2	25.2		+	+	+	5.2		+	425		63.3	4.4	2.8	2.1	+	+
420			+		96.9	+			+		+			322			+		1.2	+	+
425	2.8		6.0		40.6	4.4			+	2.0	1.8			817		2.0	+	+	+		
430	1.6		5.6		11.2	5.3		+			1.0	+		624					+	+	2.2
435	2.0		6.1	+	6.3	3.7		+			2.2	+		1009		+			1.3	+	1.2
440	8.3	+	36.3	+	+	38.1					+			336					+	+	+
450	3.5	+	29.6	3.6	2.2	53.2		+	+		1.3	+	+	314		11.1		+	1.0	+	+
455	2.2		11.4		47.2	21.9					6.4			640		1.9	3.4		+		
460																					
465	2.2		11.8		59.5	10.2			+		6.0	+		893		3.1	+	+	1.8	+	
470	2.5		22.5	2.5	16.7	35.6		+	+	+	2.5	+		436	+		+		1.8	1.1	+
480			11.0			84.7			1.3		+	+		308		1.9			+		

+ indicates less than 1%

Depth (cm)	Microstrobos niphophilus	Podocarpus alpina	Nothofagus cunninghamii	Phyllocladus aspleniifolius	Acacia spp.	Eucalyptus spp.	Melaleuca spp.	Introduced Pinus	Dicksonia antarctica	Amperea xiphoclada	Banksia marginata	Bauera rubioides	Casuarina spp.	Drimys lanceolata	Epacridaceae T-type	Hakea spp.	Hibbertia spp.	Leptospermum spp.	Monotoca spp.	Papilionatae	Rhamnaceae	Rutaceae	Caryophyllaceae	Chenopodiaceae	Compositae-Liguliflorae	Compositae-Tubuliflorae	Cruciferae	Cyperaceae	Gramineae	Haloragaceae	Liliaceae	Plantago spp.	Polygonaceae	Restionaceae	Umbelliferae	Xyridaceae	Other herbs	Pollen Sum	Myriophyllum	Portulacaceae	Potamogeton	Other aquatics	Unknown	Monolete spores	Trilete spores
0					+	4.2	3.0	+	+				+					38.2			+			+	3.3	4.5	1.2	1.8	39.1			1.2		+				333					2.7	1.5	1.5
2.5					+	7.0	8.6	+	+								+	55.9	+		+	+		+	2.2	3.8		+	13.6			+		2.2	+			313					2.5	2.9	4.5
5.0					+	8.1	17.5											63.3	1.3		1.3			+		2.9		1.3	2.3									308					1.6	1.6	3.2
7.5					1.3	5.7	16.0											66.7	1.6		+	+		+		4.1		1.9	2.2					+				325					1.3	2.2	4.7
10.0				+	+	4.4	6.1			+	+		+					58.1	+		+			1.7		4.4		4.4	16.6		+			+				344					2.6	1.7	+
12.5				+	+	5.5	7.7			+								52.6			+	+		1.7		2.9	+	8.7	15.9		+			1.7	+			346					1.4	2.0	1.4
15.0				1.2	+	4.8	3.9		+				+			+		61.7	+	+		+		+		4.8		3.3	14.5		1.5			1.8				330			+		1.5	1.8	+
17.5				+		4.6	2.7		+				+					53.5			+	+		1.6		6.2		6.2	19.1		+			2.7			+	371			1.6		+	1.7	1.2
20.0				+		6.8	1.7		1.4				+		+			33.0	+					2.2		6.2	+	6.8	32.7		+			5.9	+		+	355			1.4		1.2	2.8	+
22.5				+		8.8	2.2		5.0	+					+			35.1	+	+				1.4		8.3	+	4.7	22.7		+			6.3				362		+	5.5		1.4	+	+
25.0						2.2	1.6		1.0				+					36.0	1.2	+	+	+	+	1.8	+	2.4	+	36.0	11.5		+	+		3.4	+			496	+		3.8		1.6	+	+
27.5			+			3.1	+		1.6	+	+		+		+			34.0	+			+		1.8		1.8	+	41.0	11.0		+			1.6	+	+		644	+	+	11.3	+	1.6	+	
32.5		+	+	+		2.5	+		1.9	+			+					24.9	+	+	+	1.6		+		2.5		50.5	9.3	+	+	+		2.0	+	+		678	+		18.1	+	1.2	+	+
37.5			+	+		4.6	+		4.0				+		+			35.3	+		+	+	+	+		1.9	+	37.0	8.4		1.5			3.0	+	+	+	525		+	53.0	2.6	1.5	+	
42.5			+	+	+	3.4	1.1		3.9				+					38.2	+		+	+		1.2		2.6		39.2	6.0		+			1.6	+	+		565			26.7	+	1.2	+	
45.0			1.2			5.9	+		3.7				1.2				+	25.3	+			+		1.6		3.7		31.5	13.0	+				3.4	+			603			+		1.2	+	+
47.5			1.2			8.0	+		2.9				1.8					10.2	+		+	+		2.6		4.4		38.6	23.4	+			+	3.7	+	+		568			+		1.0	1.3	1.6
52.5			+		+	6.0	1.0		4.4		+		+		+			30.5	+		+	1.0		2.8		5.8		26.9	16.7	+	+			2.4		+		502			+		1.4	+	+
57.5			+		+	10.8	2.0		4.7	+		+	+		+			33.8	+		+	+		2.0		5.7	+	14.0	19.0		+			4.2		+		406			4.2		1.5	2.2	+
62.5			+	+	+	9.8	1.3		3.2			+	1.3					38.3	1.0		+	+		1.6		5.8		8.7	17.5		+		+	8.7	+		+	377			6.6		1.1	+	+
67.5			+			11.2	+		5.2				+					37.6	+	+	+	+		3.7		8.6	+	5.8	20.5		+			2.6				347			2.3		1.4	+	
72.5			1.1			14.2	+		4.2		+	+	+					38.0	+		+	1.7		2.8		5.7	+	5.4	21.3		+			+				353					1.7		
75.0	+		+			8.8	+		1.9	+								53.5	+		+	1.2		2.9		5.6		10.9	11.4					1.2				411	+				1.0	1.0	
77.5					+	7.2	+		2.2	+			+					65.8	+	+		+		1.7		5.0	+	7.5	6.5		+			+				400	+		+		+	+	
80.0			+		+	12.5	+		5.9									45.0	+		+	+		1.9		11.6	+	4.4	13.4	+	+	+		+				320					1.5	2.2	+
82.5			1.2		+	17.3	1.2		4.5				1.2					38.9	+			1.2		1.5		8.2	+	1.8	18.8		+			1.2	1.5			330					2.1	1.8	
85.0			+		+	11.1	1.4		3.9				+					49.0	1.7		+	1.9		1.1		7.5		4.4	13.3					2.2	+			360			+		1.7		
87.5					+	13.8	1.5		4.3				+					46.3	+		+	+		2.8		4.3	+	3.7	18.5		+			+	1.2			325			+		1.2	+	+
90.0					+	6.1	1.4		3.0			+	+					38.5		+		+		3.0		6.9	+	11.4	25.8					1.2	+			360			+		+	+	
92.5			+		+	8.1	+		1.1									43.5	+	+	+			+		3.8	+	23.1	14.0		+			1.4				442					1.4	+	
95.0						6.3	+		1.3		+		1.0					52.9	+	+	+			+		4.5	+	16.5	11.1		+			2.8	+	+		395			+		2.5		+
97.5						7.6	1.6		+				1.0					62.5	+			+		+		3.3		9.4	11.9					1.0	+			395			+		+	+	
100.0						6.8	+		+		+	+						65.3	+		+	+	+	1.1		3.4	+	6.0	12.2					+	+			352					+	+	
102.5						5.5	+		+	+	+		+					74.0	+			+		+		1.7		5.3	10.5									342			+		1.2	+	
105.0						6.3	+		+		+	+						69.9	+	+				+		3.0		1.9	16.7				+					366			+		+	+	
107.5						7.1	1.0		1.9			+						62.5	+			+				4.5		1.4	20.2					+				412					+	+	
110.0						7.8	1.1		1.9	+	1.1		+					54.6	1.1			+		+		6.2	+	2.7	20.6		+			+		+		370			+		+		+
112.5						7.6	1.2		+		+							62.1	+	+				+		4.5		2.8	18.3					+	+		+	421			4.3		+	+	+
115.0						7.0	+		2.1		+	+						37.6	+		+	+		1.4		8.7		8.4	31.4		+			+				357			+		+		+
117.5						6.3	+		+									62.9	+							7.9	+	+	20.0					+				316					+		
120.0			+			3.9	+											62.1						2.2		5.0		2.2	22.4		+			+				358					1.0		
122.5					+	5.2	+		+				+					62.9						+		7.2	+	2.9	22.5					+				307					+		
125.0						4.1	+						+					56.8						1.6		8.5	+	+	27.9					+				316					1.6		
127.5						5.0				+			+					68.0	+							2.8		3.5	17.5					1.4				429					+		
130.0					+	3.6	1.3											70.4								5.6		+	18.3									307					+		
132.5						2.2	+				+							53.8						+		6.6		2.5	33.0					+		+		320					+		+
135.0						2.1	1.2				+							57.5			+	+		1.2		7.7	+	7.4	20.9					+	+			326					+		
137.5						2.1	+						+					54.6						1.6		4.8	+	6.1	27.8					1.3	+			378			+		+		+
140.0						+	+					+	+			+	+	5.3					+	2.0		3.3	+	64.9	20.0		+			1.7	+	+		509					+		+
142.5						1.1												10.4	+			+		+		4.7	+	50.5	29.2		+			1.8				556					+		
145.0						1.8	+				+							6.8	+	+				1.0		5.6	+	56.8	25.4		+			1.4		+		500			+		1.6	+	
147.5						3.0												6.3						1.2		4.9	1.2	31.4	48.5		+		+	2.1		+		426					1.2		+
150.0						3.1	+						+			+	+	9.4						1.2		5.4	+	32.6	44.6					1.9		+		479			+		+		
152.5						2.2	+						+	+		+		10.0						3.8		6.4	1.1	27.1	43.8		+	+		3.1	+	+		451			+		+	+	
155.0	+				+	1.5	+						+	+				10.9						1.1	+	5.8	+	19.4	55.5		+		+	3.0		+		396			+		+		
157.5						1.1						+	+	+	+			12.7						1.1		6.2	+	17.9	55.5		+		+	2.7	+	+		371					1.1		
160.0						2.7	1.1					+		+	+	+		21.7	+					+		6.9	1.1	13.4	47.4		+			2.7		+		375			+		1.1	+	+
162.5	+					1.5	1.7				+			+	+		+	13.3		+				1.5		5.5	+	31.2	40.1		+			1.5	+	+		475			+		1.0	+	+
165.0						1.9	1.2						+		+			14.9				+		1.4		5.7	+	29.6	39.4		+		+	3.3	+	+		523					+	+	
167.5						2.5	7.8			1.2			+		4.1			13.7						1.2	+	9.1		4.7	51.8		+		+	1.2		+		320					+		
170.0						3.7	12.2				+		+		6.1			43.3						2.4		6.8		1.4	22.5									305							
172.5						3.6	4.6			+								74.1	+					+		2.3		+	12.9							+		302							+
175.0						4.1	1.6			+	+				+			65.0	+					1.2		7.0		1.6	14.9		+			2.5	+	+		314					+		
177.5						2.2	2.8				+							62.1	+			+		1.5		4.3	+	2.6	18.3	+		+		1.7	2.2			323			+		+		
180.0						2.1	2.1			+			+		+			48.5				+	+	2.4		10.6	+	9.4	18.3		+		+	1.5	1.6	+		340					1.2		
182.5						1.2	1.2											71.9								1.7		13.5	8.2		+			+	+	+		409			+		1.4	+	+
185.0	+					1.6	1.2								+			61.7						+		2.8		20.0	11.4		+			+		+		386			2.1		2.1	+	
187.5						+	+				+				+			61.7			+			+	+	5.0		17.9	10.0		+			+		+	+	418			3.8		2.1	+	
190.0						+	+						+	+	+			53.8				+	+	+		3.2		26.7	8.2	+	2.1			+	+	+		460	+		2.8		1.3	+	+
192.5					+	+	1.0					+			+			59.9					+	+	+	4.1		20.3	8.6		2.8			1.0	+	+		600			1.5		+	+	
195.0		+				+	+						+		+			37.4	+					+	+	4.6		40.8	8.2		4.5			+	+	+		548		1.0	1.0	1.3	2.2	+	+
197.5		+		+		1.4	+					+			+			40.8					+	+	+	3.8		35.7	6.5		5.7			1.0	1.1	+		626		+	+	+	2.2		
200.0	+	+		+	+	+	1.4				+		+		1.1			5.4			+	+	+	+	+	9.2	+	48.3	15.6	+	10.3	+		2.9	1.4	+	+	906		2.4	+	2.1	1.8	1.8	1.4
202.5	+			+		1.4	+				+				1.1			+	+	+		+	+	1.0	+	6.6	1.2	59.9	15.0	+	4.8	+		2.5	3.5	+	+	1201	+	4.1	+	1.9	1.4	2.2	+

APPENDIX III Broadmeadows Swamp Pollen Percentages

Depth (cm)	*Microstrobos niphophilus*	*Nothofagus cunninghamii*	*Nothofagus gunnii*	*Phyllocladus asplenifolius*	*Acacia* spp.	*Eucalyptus* spp.	*Melaleuca* spp.	Introduced *Pinus*	*Dicksonia antarctica*	*Amperea xiphoclada*	*Banksia marginata*	*Bauera rubioides*	*Casuarina* spp.	*Drimys lanceolata*	Epacridaceae T-type	[illegible] spp.	*Hibbertia* spp.	*Leptospermum* spp.	[illegible] spp.	Rhamnaceae	Rutaceae	Chenopodiaceae
0		+			+	6.8	31.2	+	1.2				1.2		1.2			15.1	6.5			+
5						3.1	25.2	+					+			+		25.9	3.4			+
10		+			+	2.9	25.6	+	+								1.1	19.4	6.9			
15					+	7.9	29.9		+		+		+				+	27.8	1.9			+
20					+	12.9	50.8		1.1			+	+				+	15.1	8.5			
25	+	+			1.5	8.7	51.3		+			+	+				1.2	21.6	5.4			+
30				+	+	5.7	50.5		+			+	+		+			24.4	8.2	+		+
35				1.3	+	6.0	45.2		+				1.2		+		+	35.0	4.4	+		+
40				1.2	1.2	5.8	44.2					+	+		+			22.7	5.2	2.4	+	
45				+	1.9	4.5	41.3					+	+					39.7	+	4.2		+
50				+	+	2.6	54.1					+	+	+				32.5	1.3	5.6		
55					+	1.6	64.9		+				+	+		+	+	21.0		2.5		+
60				+	+	5.1	58.1				+		+					17.0	1.6	7.4		
65	+	+		+	+	3.7	70.4		+		+		+	+		+	+	12.7	+	+		
70						2.3	38.3		+	+			1.0	+				8.3	+			
75				+		1.9	37.3				+		+	+			+	14.4				+
80				+		2.5	34.1		+				+				+	28.6			+	+
85	+					1.5	21.4		+						+		+	36.4	+		+	+
90				+		2.8	19.0		+			+	+	+	1.8		+	33.4	+			+
95						4.3	18.2							+	1.4		+	39.2		+	+	+
100	+		+			1.6	19.4		+	+	+				3.2		+	34.6				+
105	+				+	2.2	15.9		+			+			3.6			33.1	+		+	+
110		+	+	+		1.8	16.0		+	+		+	+		3.1	+	+	45.9	+			

Depth (cm)	Compositae-Liguliflorae	Compositae-Tubuliflorae	Cruciferae	Cyperaceae	Gramineae	Haloragaceae	Liliaceae	*Plantago* spp.	Restionaceae	Umbelliferae	Pollen Sum	*Myriophyllum*	*Potamogeton*	*Botryococcus*	Unknown	Monolete spores	Trilete spores
0	3.8	1.5		3.6	25.6		+	+	+		337				1.9	13.4	44.0
5	3.7	2.1		1.2	33.0			+			325				+	5.5	13.5
10	5.8	1.1		4.0	30.7			+		+	324				+	12.0	18.2
15	4.1	2.2		3.8	20.6						316				1.2	7.6	20.0
20		2.2	+	2.8	5.0					+	318	+	+		1.6	26.7	50.5
25		1.2	+	3.0	2.7						334		+		2.1	24.0	42.0
30		1.6		3.2	3.2		+			+	316		+		2.5	24.3	39.7
35		+	+	3.2	1.2				+		315		+		3.2	17.5	20.0
40		+	+	7.0	2.1		+		+		326		+		2.1	32.2	29.8
45		+		1.9	+	+				+	311				1.9	17.1	19.6
50		+		+	+	+					308				1.3	12.1	15.1
55		2.0		1.2	2.9						309				1.2	8.2	19.0
60		2.6	+	1.6	3.8					+	317				1.9	13.5	24.4
65		1.7	+	+	8.3	+	+		+	+	304				+	7.3	22.0
70		10.2	+	2.0	35.7				1.3		315				1.0	4.3	10.2
75		9.0		3.0	30.7		+	+	1.2	+	376		+		1.1	2.4	5.3
80		8.0		4.7	18.3		+	+	1.0		361		+		+	6.4	10.2
85		8.1	+	7.0	21.4		+	+	1.7		342		+		+	5.0	6.7
90	+	9.2		10.0	10.0		1.5		7.4		389	+	5.4	+	1.2	1.9	2.0
95		8.0	+	11.0	6.7		+		10.5		417		6.0	+	+	+	+
100	+	9.7		14.5	6.8		+		10.5		429		2.3	+	1.4	+	+
105		10.1		17.1	11.4	+	+		5.5	+	414	+	1.4	+	1.7	+	1.6
110		4.8	+	13.7	6.3	+	1.1		3.7	+	381	+	+		+	+	1.5

\+ indicates less than 1%

APPENDIX IV Smokers Bank Swamp Pollen Percentages

Depth (cm)	*Nothofagus cunninghamii*	*Phyllocladus asplenifolius*	*Acacia* spp.	*Eucalyptus* spp.	*Melaleuca* spp.	*Dicksonia antarctica*	*Amperea xiphoclada*	*Banksia marginata*	*Bauera rubioides*	*Casuarina* spp.	*Drimys lanceolata*	Epacridaceae T-type	*Hibbertia* spp.	*Leptospermum* spp.	[illegible] spp	Papilionatae	Rhamnaceae	Rutaceae	Chenopodiaceae
0	12.2	2.5	+	31.3	6.9	+	+	+	+	2.2	+	6.2		7.2		+	6.9	+	2.2
5	14.4	3.1	+	29.8	2.6	+	+			6.1	+	18.4		2.6	4.1		6.7	+	1.0
10	11.2	4.6	+	34.6	10.8	+	+			4.6		11.2	+	3.0	+	+	3.6	3.0	+
15	3.2	1.6		33.6	12.1	+		+	+	4.5	+	7.0		9.9	+	+	8.3	+	+
20	+	+	+	27.4	6.6			+		7.5		2.6		11.6			7.9	+	2.0
25	2.4	1.4		19.2	4.8		+	+		5.3		1.4		3.4	+	+	7.2	+	6.2
30	3.5	+		23.0	1.7		+	+	+	4.7		4.1	+	+	1.2	+	7.6	+	1.7
35	5.2	2.8		21.9	4.5				+	2.8		2.8	+	4.5	3.9	+	5.6	2.2	+
40									NO		POLLEN								

Depth (cm)	Compositae-Liguliflorae	Compositae-Tubuliflorae	Cruciferae	Gramineae	Haloragaceae	Liliaceae	[illegible] spp	Umbelliferae	Pollen Sum	Cyperaceae	Restionaceae	*Myriophyllum*	Portulacaceae	*Potamogeton*	*Botryococcus*	*Pediastrum*	*Isoetes*	Monolete spores	Trilete spores	Unknown
0	+	2.5	+	11.9		+	1.2	+	356	12.8	102.0	26.0		+	44.8	+	1.9	1.9	1.7	1.9
5		4.1		2.6	+	1.5	+		401	6.1	59.5	3.0		+	41.7		1.0	1.6	1.6	1.5
10		2.3	+	4.3	+	2.0			397	9.9	78.1	+		+	35.2		+	1.3	1.9	2.0
15		2.2		11.5		1.2	+		410	12.1	101.1	2.2		7.3	50.0	+	1.2	+	1.6	2.5
20		6.6		24.7		+	1.2		403	12.9	82.6	+		4.9	125.0	+	+			1.9
25		9.2	+	30.[illegible]		1.[illegible]	1.4		359	22.6	62.5	+		9.2	149.2	+	8.2	+		1.4
30		10.0		27.7	+	1.7	1.2	+	386	5.9	62.1	8.2	+	+	71.4	3.2	35.3	+		1.7
35		8.4		20.2	+	2.8	+	+	407	9.0	45.6	6.7	+	1.1	82.6	8.4	93.4			2.2
40																				

\+ indicates less than 1%