THE GLACIAL HISTORY

OF THE

UPPER MERSEY VALLEY

by

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Submitted in fulfilment
of the requirements for the degree of

Master of Science

UNIVERSITY OF TASMANIA

HOBART

February, 1989

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Acknowledgements

Throughout the six years part time work and excess of 150 field days that this thesis took to complete many people have been of assistance and are gratefully acknowledged.

My family encouraged, assisted with many tasks and were understanding throughout. It would have been impossible to complete the task without the support of my wife Marie, my children, Louise and David, and my mother and father.

A number of colleagues, but mainly Mike Dunphy, Brian East, Darrell Fisher and Neville Grady, were very helpful either as assistants and company in the field or as proof readers for the manuscript.

The Hydro Electric Commission provided rainfall data, allowed the use of their map library and willingly copied maps for field use. The TSIT in particular the AV Centre, School of Architecture and School of Education lent facilities for the production of the manuscript. Figures 1, 3 and A2 were adapted from maps drawn by Dr G. van de Geer as part of the paper, Hannan and Colhoun (1987).

I also wish to express sincere appreciation for the help, careful supervision and friendship of my supervisor Prof E. H. Colhoun.

Declaration

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, and that, to the best of my knowledge and belief, the thesis contains no copy or paraphrase of material previously published or written by another person, except when due reference is made in the text of the thesis.

Signed DG Hannan

ABSTRACT

In the upper Mersey Valley there have been three and possibly four glaciations during the Pleistocene. From youngest to oldest they are named the Rowallan Glaciation, the Arm Glaciation, and the Croesus Glaciation. In addition sediment from a Tertiary glaciation and a Lower Palaeozoic glaciation have been recognised.

The Rowallan Glaciation covered the smallest area of the three Pleistocene glaciations. The glacier formed a reticulate system with the main source an icecap on the Central Plateau, and occupied an area of approximately 282 sq km. Major valleys were almost completely filled with ice and the glacier terminated in at least six ice lobes. In the region the Rowallan Glaciation covered an area of approximately 282 sq km. The lowest point reached was 390 m above sea level in the Mersey Valley and the equilibrium line altitude for the system was 1050 m, which indicates a snowline some 930 m below present and a drop in the average annual temperature of 6.2°C. The Rowallan Glaciation attained its maximum before or about 13,400 ± 600 yr BP and deglaciation was well advanced or complete by 9760 ± 720 yr BP.

The Arm Glacial system was larger in extent than the Rowallan Glaciation and at its maximum occupied an area of approximately 500 sq km. The lowest point reached was in the Mersey Valley at 330 m and it had an equilibrium line altitude of 950 m. This suggests a snowline 1030 m below present and a drop in the average annual temperature of 6.7°C. The age of the Arm Glaciation is not known but estimated to be in excess of 100,000 years BP.

The Croesus Glaciation is the oldest glaciation and had a very large extent, completely blanketing the upper Mersey Valley. It terminated far beyond the area of this study. The lowest altitude reached, the equilibrium line altitude and the estimated temperature drop during the glacial maximum are unknown. Some sediments of Croesus age show a reversed remanent detrital magnetism and thus have a minimum age of 730,000 years BP.

The Tertiary and upper Palaeozoic glaciations are postulated on the basis of scattered outcrops of lithified till in the region.

The Rowallan, Arm and Croesus glaciations of the upper Mersey Valley are tentatively correlated with other glaciations in Tasmania, namely the Margaret, Henty and Linda glaciations of the West Coast Ranges. The Rowallan Glaciation is also tentatively correlated with the glaciation of the Snowy Ranges on the mainland of Australia and with radiocarbon dated glaciations of New Zealand and Chile.

CHAPTER 1

THE UPPER MERSEY VALLEY AND ADJACENT AREAS: GEOGRAPHICAL BACKGROUND

LOCATION AND TOPOGRAPHY

The Mersey River[1] is located in Tasmania and Figure 1 shows the study area with reference to the rest of Tasmania.

The Mersey River is one of the longest rivers in Tasmania. It rises in Lake Meston at an altitude of 1050 m on the Central Plateau and flows generally northwards discharging into Bass Strait at Devonport on the northern coast of the state. The upper Mersey Valley is defined as that part which lies south of Liena. This thesis considers the section between Croesus Bridge and Cathedral Mountain, and the adjacent plateaux to the east and west (Figure A1).

The Central Plateau is a distinctive region of Tasmania with surface altitudes that vary from greater than 1100 m in the north to between 700 m and 800 m in the south. It occupies some 4500 square kilometres in the central northern part of the state. The upper Mersey Valley is located along the western edge of the Central Plateau which consists of steep-sided scarps below mountain peaks, or smaller plateaux areas that have been isolated by erosion. The peaks on the plateau immediately east of the Mersey River include Cathedral Mountain, Bishop Peak and Dean Bluff above Lees Paddocks in the southern parts; Clumner Bluff and Howells

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[1] Map References and Place Names
Throughout this thesis map references are given as six figure digits with the appropriate 1:25000 scale map (in brackets) published by the Lands Department, Tasmania. Place names used are listed alphabetically in Appendix A. Appendix A also contains a 1;25000 map reference and a Figure number indicating a map in Appendix A where each locality can be found.

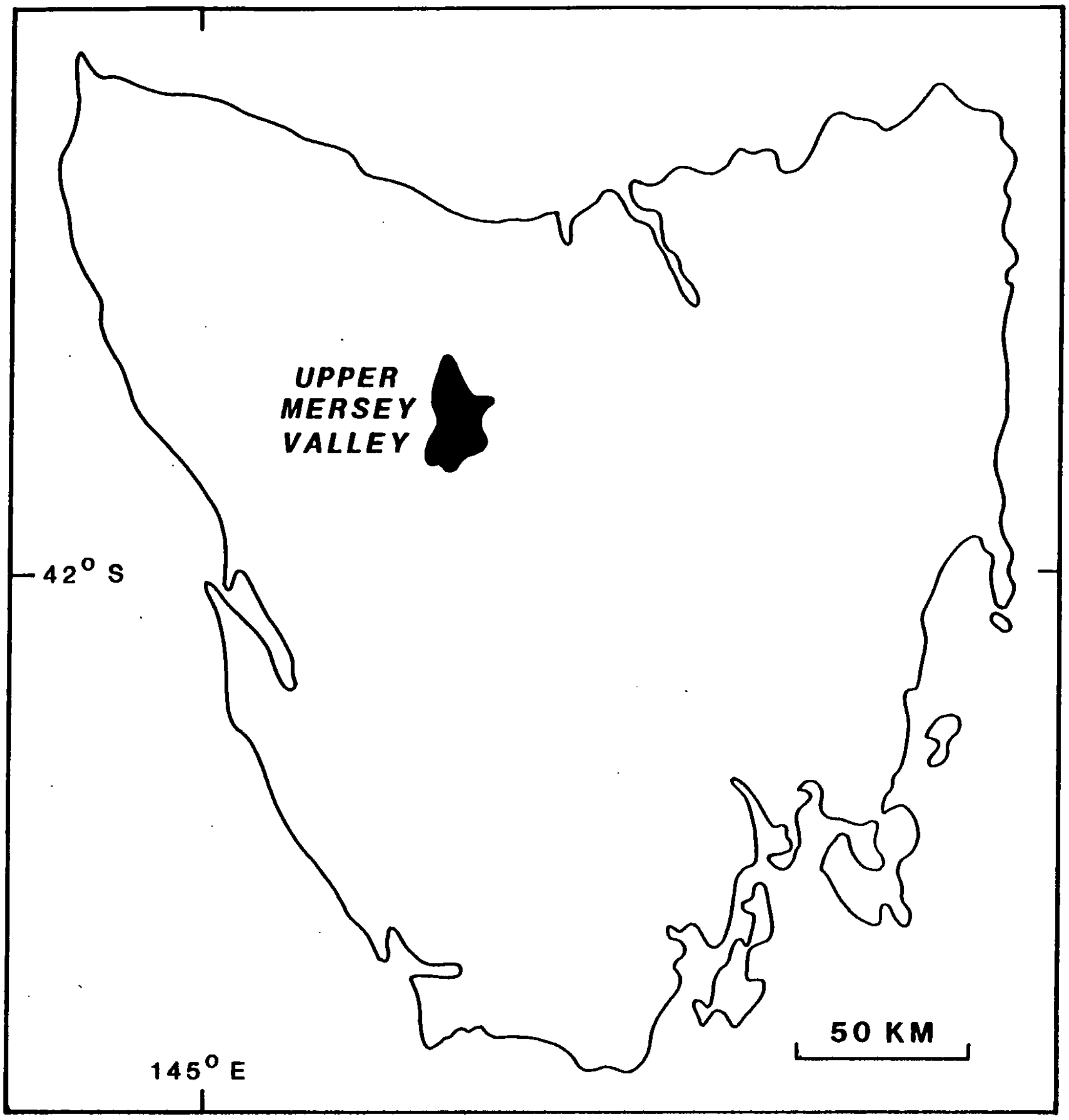

Figure 1: Location of the study area.

Bluff east of Lake Rowallan; and Western Bluff in the north. To the west of the Mersey, plateaux areas isolated by erosion include Mount Pillinger and February Plains, both with extensive areas at altitudes greater than 1100 m.

The western surface of the Central Plateau has been extensively glaciated and has been described as the 'Land of Ten Thousand Lakes' by Jennings and Ahmad (1957, p. 62). Lake Meston, a deep glacial lake, where the Mersey River rises is one of these lakes. The valley deepens west of Lake Meston and turns sharply northwards below Cathedral Mountain where the thalweg is steep, but lower down flat plains, such as Lees Paddocks and Steers Plain occur on its floor. Between the plain sections the river flows down rapids and there are at least three substantial waterfalls.

The upper Mersey River has a number of major tributaries that rise in the Central Plateau. They are the Fish River and the Fisher River, and some larger creeks which include Moses, Juno and Martha creeks. Fewer tributaries flow from the west but Wurragara Creek and the Arm River drain February Plains, and Gads Creek drains the Borradaile Plains.

THE LITHOLOGY AND GEOLOGICAL STRUCTURE OF THE UPPER MERSEY REGION

The solid geology of the area is summarised in Figure 2.

The Precambrian System

The oldest rocks in the region are of Precambrian age and are subdivided into three groups, the Howell Group, the Fisher Group and the Dove Group, by Jennings (1963, p. 32) on the basis of lithology. The rocks of each group are strongly deformed and are estimated to be more than 920 m thick. The Howell Group is exposed in the centre of the Mersey Valley from the confluence with the Fish River

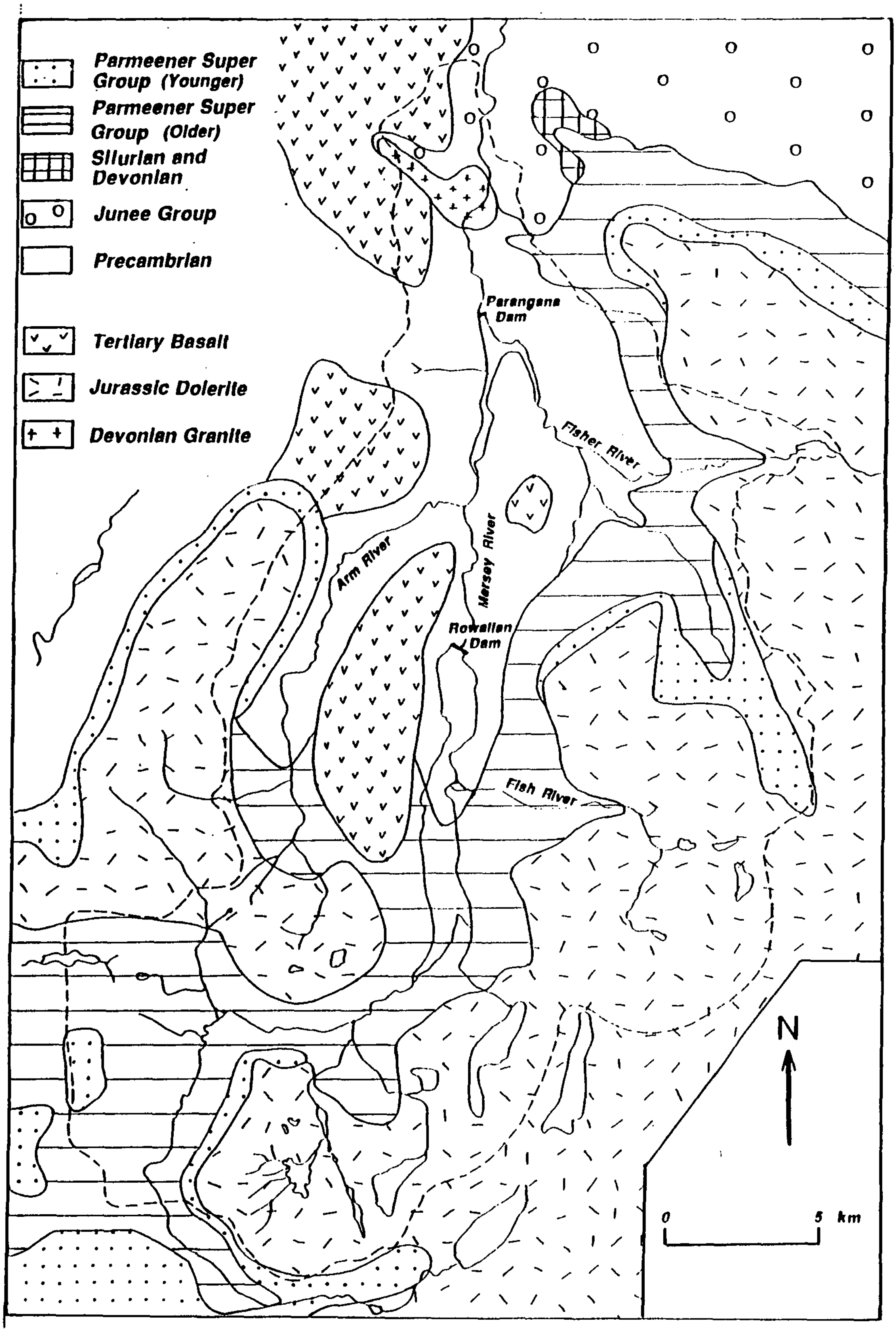

Figure 2: Solid geology of the upper Mersey Valley.

to Rowallan Dam, around the confluence with the Arm River and also in the upper Arm Valley. The Howell Group is composed of alternating units of quartzite and schist. The Fisher Group is found to outcrop in the lower Arm Valley, in the Mersey Valley near the junction with the Arm River and around Lake Parangana. The group consists of micaceous quartzites, with a schistose structure and minor interbedded quartz-muscovite schist. The Dove Group consists of quartz-sericite schist and garnetiferous quartz-sericite schist which is exposed in a 2 km-broad band in the centre of the Mersey Valley for approximately 3 km from the northern end of Lake Parangana.

The Ordovician System

Rocks of Ordovician age are termed the Junee Group in Tasmania and in the most northerly part of the region two members are represented by the Moina Sandstone and the Gordon Limestone (Jennings, 1963). Both units have been strongly folded and faulted, and several large synclines and anticlines are present in the district. The Moina Sandstone has a transitional boundary with the Gordon Limestone in the Mersey River, south of Liena, but in other places Jennings reports that the boundary is unconformable (1963, p. 57). The Moina Sandstone is some 250 m thick and consists largely of quartz sandstone with minor beds of shale, conglomerate and grit. The Gordon Limestone is responsible for the caves, such as Croesus Cave, which are located in the northern part of the region. Jennings (1963, p. 59) describes the limestone as hard, compact, generally massive and frequently stylolitic. It has prominent bedding planes and the dips are generally low in spite of the fact that it is strongly folded. The limestone is relatively pure although some shaley and sandy beds are present towards the top.

The Parmeener Super Group

The Parmeener Super Group is a sequence of rocks in Tasmania, of the Late Palaeozoic Era, in particular belonging to the upper Carboniferous, Permian, and Triassic Periods. It incorporates both marine and terrestrial sequences.

The Lower Parmeener Super Group

These rocks are mainly of upper Carboniferous and Permian age. They are extensively exposed in the central part of the Mersey Valley south of the Mersey-Fish River confluence. In contrast, the northern part of the region, in the Little Fisher Valley, around the slopes of Deception Point and on the Central Plateau has only isolated exposures. Elsewhere, particularly on the valley slopes, it is probable that most of the rocks are covered by till, talus and scree of Quaternary age. In the southern part of the Mersey Valley there are extensive exposures of Permian rocks. MacLeod, Jack and Threader (1961, p. 16) identify six subdivisons of these rocks as follows:

Top	Thickness (approx.)
Cygnet Coal Measures	100 m
Ferntree Group	200 m
Woodbridge Group	50 m
Mersey Group	25 m
Wallace River Group	160 m
Basal Conglomerate	12 m
Base	

The Basal Conglomerate is the only unit which does not outcrop continuously over the southern part of the region. The rocks of all the subdivisions are bedded horizontally or near-horizontally and are quite extensively faulted. The Basal Conglomerate is found exposed in the Mersey River north of the Fish River, near Steers Plain and below Cathedral Mountain. The clasts in the conglomerate are pebbles and boulders of rounded and sub-angular quartzite and schist. The Wallace River Group is made up of grey to dark grey mudstones with occasional grey sandstones and conglomerates. These rocks are of marine origin. The

Mersey Group consists of micaceous and arkosic quartz sandstones with thinner bands of carbonaceous shale. They have a terrestrial origin. The Woodbridge Group consist of extremely fossiliferous marine sandstones, siltstones and mudstones. The Ferntree Group consists of pebbly marine siltstones and mudstones, with occasional sandstones and conglomerates. These rocks are tough and well consolidated, and many of the frequently occurring waterfalls of the district are formed by them. The Cygnet Coal Measures consist of terrestrial sandstones and shales. Generally the Parmeener Super Group rocks are located on the valley slopes and scarps below the plateaux in the region. They can occasionally be seen either in the field or on aerial photograhs as resistant beds following the contours along the slopes.

Upper Parmeener Super Group

The upper Parmeener Super Group consist mainly of the Triassic rocks of the region. They are found to overlie the lower Parmeener Super Group System and hence the outcrop pattern for both is similar. Macleod and others (1961, p. 25) divide the system into three formations. 'Feldspathic' Sandstone occurs at the top and overlies the Ossa Formation which is above the Gould Formation. All three formations are lithologically similar in that they contain massive sandstones which are frequently coarse grained and cross-bedded, with minor siltstone lenses. They are of terrestrial origin representing mainly fluvial sedimentation.

The Quaternary System

The rocks of this system are the main topic of consideration in this thesis. Broadly, they consist of surface deposits of glacial and periglacial origin. They form incomplete mantles flanking the Central Plateau, Pillinger Plateau and Cathedral Plateau and also occur as thick deposits in the axes of valleys.

Igneous Rocks

There are three types of igneous rock represented in the region, Devonian granite, Jurassic dolerite and Tertiary basalt.

The Devonian granite occurs as a small stock north of Lake Parangana and has been called the Dalcoath Granite. Jennings describes it as "medium coarse grained, flesh-coloured rock with abundant glassy quartz crystals up to 5 mm across and altered feldspars 3-4 mm across and 10 mm long plus some altered biotite." (1963, p. 81)

Jurassic dolerite outcrops more widely than any other rock in the region. It occurs as horizontally-oriented sheets or sills intersecting the landscape at altitudes of 2000 m to 2800 m. It is a tough rock that has not been eroded extensively and underlies nearly all the plateaux. The dolerite is similar in composition to that which has been described elsewhere in Tasmania. It is a medium grained, dark grey basic rock with equal proportions of plagioclase and pyroxene and minor amounts of magnetite. In different locations the dolerite has been observed to have a variable grainsize and it is assumed that the differentiation processes which have been described in other parts of Tasmania (Walker, 1958; McDougall, 1958) have operated in this region. The dolerite is strongly faulted and jointed. These structural weaknesses are often reflected in the drainage and alignment of the glacial rock basin lakes.

Tertiary basalt occurs on Maggs Mountain, Borradaile Plains and Emu Plains. Spry (1958, p. 132) describes the basalt as varying in colour from grey to dark grey, but mainly light grey when weathered. Sutherland (1980, p. 185) gives detailed descriptions of many localities. He generally classifies them as aquagenic volcanics consisting of basaltic breccias, agglomerates and tuffs deposited in Oligocene-Miocene leads up to 150 m thick.

ACCESS TO THE REGION

The region in general has excellent access as major projects of the Forestry Commission and the Hydro Electric Commission (HEC) have resulted in well-formed roads being built. The main access to the upper Mersey Valley is by the Mersey Forestry road which is sealed as far south as the bridge over the Arm River. A gravel road extends from the Arm Bridge up the Mersey Valley as far as Jacksons Creek. Branches from this road allow access to Dublin Plains and the Little Fisher River. Commencing 30 m south of the Arm Bridge a gravel road loops around the upper Arm Valley and Maggs Mountain. In the Northern part of the Mersey Valley a sealed road leads to the Lemonthyme Power Station, with a minor gravel road branching off across Emu Plains and Borradaile Plains to link eventually with the main Mersey Forestry road 1 km north of the Arm Bridge. The northern part of the Central Plateau is reached by a well constructed gravel road that starts from the Mersey Forestry Road and also leads to the Fisher Power Station and Lake Mackenzie Dam.

Much of the southern part of the upper Mersey Valley is inaccessible by vehicle but numerous tracks, kept in good condition by the Lands Department and bushwalkers, allow relatively easy walking access. Well-formed tracks start from forestry roads and lead to Lees Paddocks, the Walls of Jerusalem, Chapter Lake, Lake Myrtle, Lake Adelaide and Mount Pillinger.

Outcrop of the Quaternary deposits throughout the region is very good. The numerous roads, tracks and streams sections together with occasional landslip scars, allow observations of many exposures. In addition, HEC and forestry earthworks, quarries, damsites and clearings allow exposures of sediments to be examined. On the rare occasions where the earthworks of the HEC have been covered, records of excavation and construction work are retained by the Geology Section of the HEC, Hobart, and are available for consultation on request.

CLIMATE

The only official station in the upper Mersey to record any aspect of climate is the rainfall station at Lake Mackenzie. An average annual rainfall of 1847 mm has been recorded (Bureau of Meteorology, 1980, p. 8). Records of the HEC (pers. comm.), also for Lake Mackenzie, indicate an average annual rainfall of 1922 mm. Other records obtained by the HEC indicate an average rainfall of 1265 mm for Rowallan Dam over a period of 8 years, 1982 mm at Borradaile Plains over 12 years and 1742 mm at Lake Myrtle, over 3 years. Other nearby stations manned by the Bureau of Meteorolgy are at Cradle Valley, which has an average annual rainfall of 2777 mm and Mole Creek where the average annual recording is 1120 mm. In summary the field area has a wet environment with precipitation values between 1600 mm and 2400 mm on the rainfall map (Figure 3) and with individual statistics varying from 1982 mm on the western plains to 1264 mm in the main Mersey Valley.

Temperature records are available only for Cradle Valley (914 m) with an average annual maximum of 10.9°C, an average annual minimum of 2.2°C and an annual average of 6.1°C. The January average is 10.8°C and the June average is 2.6°C and three winter months record minimum temperatures below 0°C. On average there are 52 days per year when snow is recorded, 206 days of light frost (<2°C air temperature) and 116 days per year of heavy frost (<0°C air temperature) (Bureau of Meteorology, 1979).

VEGETATION

Many vegetation types are identifiable in the region.

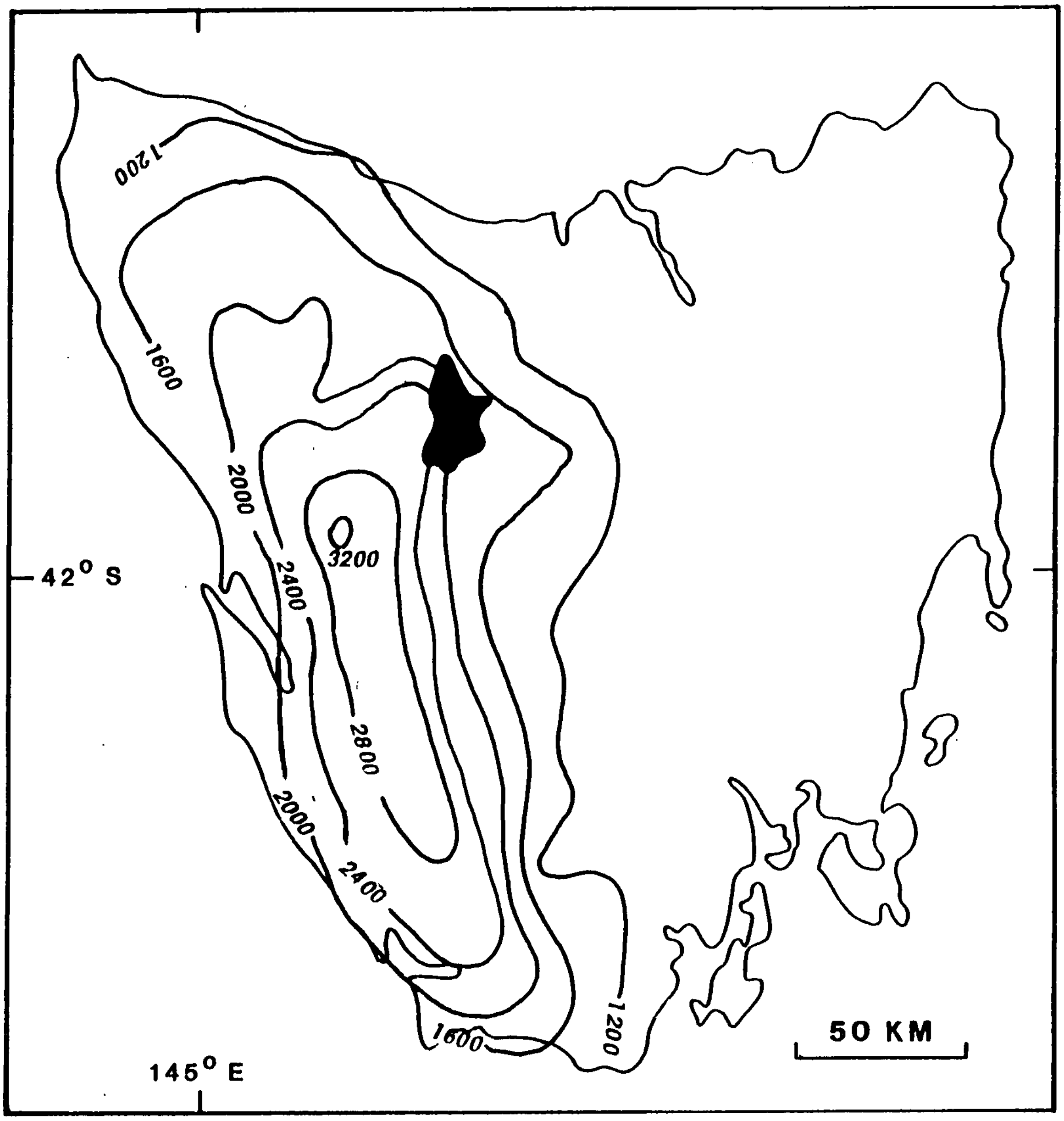

Figure 3: Rainfall map of part of western Tasmania showing isohyets which intersect the study area. Values are in mm. (Bureau of Meteorology, 1980)

In the valleys of the numerous rivers and creeks there is temperate rainforest. It is usually dominated by *Nothofagus cunninghamii* (myrtle), *Atherosperma moschatum* (sassafras) and *Phyllocladus aspleniifolius* (celery top pine), but at moderate altitudes (600 m to 900 m) and presumably wetter areas there can be fine stands of *Athrotaxis selaginoides* (King Billy pine) and *Diselma archeri* (cheshunt pine). At lower altitudes (below 700 m) understorey trees are located mainly in gullies and adjacent to streams, and include *Eucryphia lucida* (leatherwood), *Phebalium squameum, Telopea truncata* (waratah) and *Leptospermum lanigerum* . The ground cover is frequently dominated by *Dicksonia antarctica* (manfern) and other smaller ferns. The generally clear understorey is characteristic of Callidendrous rainforest which is well represented around the Central Plateau area (Forestry Commission, 1987, p. 32).

Sclerophyll forest dominated by *Eucalyptus dalrympleana, E. delegatensis, E. ovata* and *E. amygdalina* is present on the slopes above the valleys and extends to the plateau margins. Other canopy species found are *Acacia dealbata* (silver wattle), and occasionally *A. melanoxylon* (blackwood). Understorey and groundcover species common in the sclerophyll forest include *Dicksonia antarctica* (manfern), *Olearia argophylla, Pomaderris apetala* (dogwood), *Zieria arborescens* (stinkwood) and *Pultenaea juniperina* (prickly beauty).

Slopes below the plateaux can have local growths of shrubby plants such as *Hakea lissosperma* and *Olearia lirata,* where it is relatively wet and *Bedfordia linearis, Drimys lanceolata* (mountain pepper), *Coprosma nitida* and *Cyathodes parvifolia* in drier or well drained locations .

On the plateaux there are pockets of wet sclerophyll forest or groves of *Athrotaxis cupressoides* (pencil pine), *Diselma archeri* (cheshunt pine) and *Microstrobus niphophilus.* True montane vegetation is abundant on the plateaux and includes, *Eucalyptus coccifera* (snowgum), *Microcachrys tetragona* (creeping pine), *Richea* *scoparia, R. sprengelioides, Orites revoluta, Cyathodes straminea* (mountain berry), *Nothofagus gunnii* (tanglefoot) and *Boronia citriodora* (lemon scented boronia) as well as varieties of sedge and grass. The botanical names given follow Curtis (1956, 1963 and 1967)..

SOILS

Soils of the the region reflect to a large degree the parent rock from which they were formed. The list below summarises the major soil types of the region and the parent material from which they were derived:

SOIL	PARENT MATERIAL
Yellow brown gradational soils	Dolerite
Shallow brown soils often with stony profiles	Basalt
Sandy loams	Granite, upper Parmeener Group sandstones, glacifluvial outwash sand of the Rowallan Glaciation
Skeletal soils	Precambrian quartzites and schists, quartzite slope material
Red brown clay loams (often with stony horizons close to conglomerate or	Ordovician limestones

Quaternary sediments)	
Yellow podzolic soils	Lower Parmeener Super Group mudstones and sandstones
Loam or clay loams with shallow stony profiles	Till, scree and solifluction material

(Pinkard, 1980; Pemberton, 1986)

In conditions which favour the development of peat e.g. high altitude, lower temperature or waterlogging, organic soils are found. The Walls of Jerusalem around Lake Salome, Dublin Plains and Borradaile Plains are locations where organic soils are present.

FAUNA

The grassy plains which border the Mersey River are underlain by sandy soils derived from glacial outwash and make an ideal environment for the native fauna. The highlands and the plateaux also have prolific wildlife even though these areas are rocky and suffer a severe climate.

Both native monotremes, the platypus and the echnida, have been observed on numerous occasions. Judging by the number of platypus seen, the Mersey River in the vicinity of Lees Paddocks would appear to be a favourable environment for them. Of the larger marsupials, wombats are particularly abundant on the lower plains of the Mersey and its tributaries. Bennett's wallabies are plentiful and the eastern grey kangaroo is quite a common sight over the whole region. The smaller marsupials are more difficult to see, as they are not only nocturnal, but also live in the trees and are not easily disturbed by day. Nevertheless, brush tail possums, ringtail possums, pygmy possums, sugar gliders, bandicoots, potoroos and pademelons have all been seen and identified in the course of field work.

LAND USE

According to Binks (1980), in the early days of settlement of Tasmania a handful of explorers came though the region of the Central Plateau and upper Mersey River. By 1823 Curr and Fossey had explored the Mole Creek area and mapped a possible route to the northwest from Launceston, which became the Great Western Road in 1828. The need to provide an overland route from the southeast to the northwest had Jorgenson, in 1826, attempting to find a stock route from the Shannon River to Great Lake and then across to Valentines Peak. Jorgenson spent some two months trudging around the Central Plateau and apparently came as far west as the Walls of Jesusalem but was unsuccessful in finding a stock route.

The settlement of Chudleigh, in the 1850's, and later Mole Creek provided bases for trappers to visit the upper Mersey River. In the 1880's the other traditional land use of the Mersey Valley, the summer grazing for cattle commenced (Cubit, 1987, p. 3). The area was not used for forestry for some time as there were plenty of forests closer to settled land. The traditional pursuits can be traced through to the 1950's when the Forestry Commission and the HEC became actively engaged in the region. The Forestry Commission was logging the Maggs Mountain area and assessing the timber resources of the Fisher and Little Fisher Rivers in the late 1950's. In the 1960's the Fisher and Little Fisher areas were extensively logged and then resown. In the 1950's the HEC was investigated for damsites and eventually built three dams, Rowallan on the Mersey River above the Arm junction, Parangana on the Mersey below the Fisher junction and Lake Mackenzie on the Fisher River where it emerges from the lake.

Forestry operations are still actively pursued in the region but in recent times the area has been used increasingly for recreation purposes. Bushwalking is the predominant recreation pursuit, but also the Mersey River below Rowallan Dam has become a white water canoe run which can be varied in difficulty depending on how much water is released from the dam. The old Forestry Commission camp at the Arm River has been rebuilt into an Envronmental Centre for visiting school children. In keeping with this form of land use the Central Plateau Conservation area was proclaimed in 1978 and encompasses 40,000 ha on the western side of the plateau. The Walls of Jerusalem National Park was proclaimed in June 1981. At the same time part of the southern area of the Central Plateau Conservation Area was given upgraded status and added to the Cradle Mountain National Park (Lands Department, 1986)

In part, the recreational use of the area was responsible for the Commission of Inquiry into the Lemonthyne and Southern Forests as groups in the community were fearful that some of the unspoiled areas would suffer if forestry operations were extended. The findings of the commission are still not settled but it appears that the Forth River and part of Cathedral Mountain will achieve national park status. It is encouraging that not only did the Lemonthyme Commission pay special attention to the problems of formerly glaciated areas in Tasmania in their hearings and report, but also that the work of this thesis was able to be used as background for consideration in the resolution of the conflicting land use claims of the region. It has been rewarding to see the results of an essentially academic study applied to the resolution of current environmental problems.

CHAPTER 2

LITERATURE REVIEW, AIMS AND METHODOLOGY

A REVIEW OF PREVIOUS STUDIES OF GLACIATION IN THE UPPER MERSEY REGION

Published research on the glaciation of the upper Mersey River and the Central Plateau has a history which goes back to the last century and can be regarded as occurring in four stages, which are roughly chronological.

The first stage is the recognition of glaciation in the region, which depended on a series of miscellaneous observations made by various observers. Evidence of the Pleistocene glaciation in Tasmania was recognised first by Selwyn and Gould in 1860 (Banks, Colhoun and Hannan, 1987, p. 232).

Recognition of glacial action in the Central Plateau came much later when Johnston (1893, p. 92) in his landmark paper "The Glacier Epoch of Australasia" writes of the ability of the "great mountain plateau" (Central Plateau) to accumulate sufficient ice in the last period of astronomical "maximum eccentricity" to "supply its western alpine valleys with numerous ice streams or glaciers." He comes close to indicating that there could have been glaciers in the Mersey and Forth river valleys. That he had the opportunity to see this area is certain because in the same paper (1893, p. 94) he indicates that he visited the Western Highlands, including Gads Hill and Middlesex Plains. However, most attention in the paper is given to the evidence of glaciation on the West Coast Ranges.

It is interesting to note in passing that Johnston must have had a rapid change of mind since the publication of "The Geology of Tasmania" only five years earlier where he writes "the author is personally familiar with the various evidences of glaciation in Scotland at the higher and lower levels, and his knowledge of Tasmania is sufficiently wide to enable him to state with confidence that corresponding evidences in the latter place are entirely wanting within the Tertiary and later periods" (1888, p. 256).

Montgomery (1893, p. 161) observed "plain proof of ice action near East Mount Pelion" in a quartzite ridge with roches mountonnées close to the present bridge, where the Pelion Plains track crosses the Douglas River. A little later he states "The valley of the Forth has plainly been scooped out since the basalt was poured out, and as we have seen, at the head of this valley, the proofs of the presence of glaciers are very well marked" (1893, p.167). These localities are adjacent to the study area, but it appears that Montgomery concentrated his efforts on the west coast and did not traverse the upper Mersey River regions.

Reid (1919, p. 46) clearly asserts that the Central Plateau ice cap would have spilled ice into the Mersey and Forth valleys. He also refers to glacial erratics and moraines and describes boulder clay or till from the upper Forth Valley.

The second stage of development in the literature is centred on the model postulated by Lewis and based on the erosional effects of ice. Lewis (1932, p. 15) wrote a paper which in his own words was "to correct some errors which have worked confusion" with respect to the origin of the lakes in the Central Plateau. In the paper he claims that the upper levels of the plateau were subject to ice cap conditions during the Pleistocene ice age and that Lake Sorell, Arthurs Lake and Great Lake were all formed by glaciation. This is contrary to the opinion of Nye (1921, p. 18) who states that there is not the slightest evidence of any Quaternary glaciation to be found in spite of the fact that glacial evidence is common in the western part of the state. Lewis (1932, p. 30) indicates that he thought the ice cap was very large and inundated the Mersey and Forth Valleys, which were thought to have been produced by post glacial fluvial processes. In a later paper Lewis (1945) reviews glaciation over the whole state and postulates three periods of glaciation: the Malanna characterised by ice caps, the Yolande, characterised by valley glaciers and the Margaret characterised by cirque glaciers. The Malanna was regarded as the earliest and most extensive; the Margaret as the latest and least extensive.

The next stage is where the Lewis model is dismantled and a number of papers are responsible for its demise. Jennings and Ahmad (1957), in a paper describing the western part of the Central Plateau, suggest that contrary to Lewis there had been only one glacial event in the area. A map of the area showing the extent of the glaciation includes a major ice divide, as well as erosional zones, depositional zones and significant landforms. Jennings and Banks (1958) criticise the Lewis Model on a number of points and caution that the area influenced by glaciation as delimited by Lewis is too large. They suggest that future researchers should not simply graft areas on to the Lewis model without exercising extreme care. In the upper Mersey area a number of workers heeded the caution and fitted their observations into only one period of glaciation. Spry (1958) considered ice which spilled over from the Central Plateau into the Mersey River area and identified some sediments associated with the glaciation in the form of varves and moraines. In his paper he reconstructs the directions of ice flow from evidence of the river forms, moraines and varves. In a model reminiscent of that of Lewis he suggests that there were a number of phases of the one glaciation namely an early cirque phase, followed by an ice cap phase and a later valley glacier phase.

A change in methodology of reconstruction of glacial history appears in the literature in the late 1950's in which the researchers become more concerned with the glacial sediments and their extent rather than with the landforms of glacial erosion. Mather (1957), in an unpublished geological report on the Lake Mackenzie area for the HEC, maps till, talus and scree, and describes the occurrence of sand and outwash deposits in the region. He also indicates the presence of terminal moraines, rock basin lakes, moraine dammed lakes and "glacial deposits from which the finer grade material has been washed out." Ford (1960) identifies and maps the boundaries of till in the Little Fisher and Fisher Valleys. He also identifies the terminal moraines in the Little Fisher Valley and in the Dublin Bog area. Macleod and others (1961), and Jennings (1963), working for the Tasmanian Department of Mines produced Explanatory Reports for the Geological Map Series for the Du Cane and Middlesex Sheets respectively. These reports describe some of the glacial deposits. Macleod and others (1961, p. 27) summarise the body of information previously published and suggest ice directional movements from erosional landforms. They also (1961, p. 30) indicate the location of till and varved clay throughout the Du Cane area. Jennings (1963, p. 28) describes the glacial features of the Middlesex region and suggests that the Mersey glacier terminated at the Fisher River junction. Later in the paper (1963, p. 74) there is a brief description of glacial sediments of the Middlesex area. Derbyshire, Banks, Davies and Jennings (1965) conclude this stage of glacial studies when they summarise a number of the problems in reconstruction of the glacial history and in particular with the Lewis model of glaciation. The proposal reduced the area of proven glaciation which had been put forward by Lewis and was seen as a "factual statement of present knowledge of the glacial phenomena...." (Derbyshire and others, 1965, p. 2). As most of the evidence could be explained in terms of a single glaciation Derbyshire and others suggest that this would allow a 'fresh start' and would form a basis "for additional data as they become available" (1965, p. 3). Even at this stage they were aware of the stratigraphic evidence of Paterson (1965) for multiple glaciations in the Forth Valley.

The final stage identified in the literature is represented by studies which are based firmly on stratigraphy and mapping of the glacial sediment. Paterson (1965, 1966, 1967, 1969) and Paterson, Duigan and Joplin (1967) were the first to consider a glacial stratigraphy for the Mersey region. Paterson (1965) established that there were two glaciations in the area, when drilling for the Lemonthyme Power Station revealed a tillite underneath a surficial till. Paterson (1967, 1969) also described the glacial sediments which were found in the earthworks for the Parangana Dam and the Rowallan Dam in the Mersey Valley. He interpreted the stratigraphic information available at Parangana and suggested that there were two glacial advances and that the dam site was in the terminal zone of one of these advances. Derbyshire (1967, 1968, 1971, 1972, 1973), and Derbyshire and Peterson (1971) further emphasised the importance of sediments in the reconstruction of the glacial history of the Central Plateau region. Derbyshire (1967, 1968) mapped the extensive glacial sediments and periglacial sediments (1973), of the north west and central portions of Tasmania. From this evidence he formulated lithostratigraphical relationships for the area (Derbyshire, 1968, p. 39; Derbyshire and Peterson, 1971, p. 286). The suggestion was that the till at Rowallan Dam was younger than the till at Parangana Dam and it in turn was younger than the Lemonthyme tillite. Broadly three periods of glaciation were tentatively suggested. Kiernan (1983) used the thickness of weathering rinds on dolerite clasts in tills to suggest three stages of glaciation in Tasmania and specifically includes the Mersey and Forth valleys in the discussion. He also suggests tentative ages and correlations for the glaciations. Kiernan (1984) describes till, solifluction deposits, silt and gravel in the Mole Creek area and assigns the sediments to four chronostratigraphic formations on the basis of geographic locations, their compostion and degree of weathering. Colhoun (1985a) summarised the research of the West Coast Ranges of Tasmania and provided evidence for three periods of glaciation. Kiernan (1985) conducted detailed mapping in the Lake St Clair area which has boundaries impinging on the Mersey Valley. Hannan and Colhoun (1987) provide stratigraphic evidence for the existence of three periods of glaciation in the upper Mersey Valley. They formally name the three glaciations from youngest to oldest as Rowallan, Arm and Croesus, and provide descriptions of type sections for the basal till of each glaciation. This work is largely a product of this study which was published prior to completion of the thesis. It recognised that the three glaciations occurred during three glacial climatic stages at widely different times.

The Department of Arts, Sport, the Environment, Tourism and Territories in a report (1988) for the Commission of Inquiry into the Lemonthyme and Southern Forests reviews much of the information summarised above. Perhaps this can be regarded as a fifth stage in the review of the literature in that the research results are being applied to help solve a problem; namely how much of the area of the upper Mersey Valley (the Lemonthyme in the Commission's terminology) is of World Heritage value.

PROBLEMS ARISING FROM THE LITERATURE

Seven problems arise from a study of the literature:

1. Glacial landforms have been discussed in a number of papers in the literature (Jennings and Ahmad, 1957; Spry 1958; Ford, 1960; Derbyshire and others, 1965; Derbyshire, 1967, 1968). Discussion of the landforms in these papers, whilst technically accurate and wide ranging, is incomplete because the underpinning glacial framework is missing, or there is an assumption of a single period of glaciation.

2. There is no clear indication of the number of glacial events which affected the upper Mersey. Researchers reacting against the Lewis model of three glaciations suggested that only one could be identified in the region (Jennings and Ahmad, 1957; Spry, 1958; Ford, 1960). Paterson (1965) proposed two periods of glaciation and possibly three (1967, 1969) and Derbyshire and Peterson (1971) and Kiernan (1983) tentatively suggest three. The problem is further complicated by Kiernan (1985) who studied the Lake St Clair region to the south, and suggests three

glaciations with a distinct possibility of a fourth. On the West Coast Ranges Colhoun (1985) identifies three glaciations and Augustinus and Colhoun (1986) provide strong evidence for three glaciations with the possibility of four.

3. The areal extent of each period of glaciation has not been clearly identifed. Paterson (1967,1969) suggested that Parangana Dam was the terminus for a glacier. Other authors have identified end moraines without indicating the relative ages of the glaciers depositing them (Mather, 1957; Spry, 1957; Ford, 1960; Derbyshire and others, 1965; Derbyshire, 1967, 1968).

4. Glacial drift has been described by all authors referenced in the preceding literature review. Whilst many of these authors described the glacial drift in terms of till, glacifluvial outwash or glacilacustrine deposits, there has been little attempt to further classify or correlate the sediments, in particular the till.

5. Ice movement directions have been plotted by some of the authors. Jennings and Ahmad (1957) mapped the western part of the Central Plateau and showed ice movement directions and a major ice divide. Derbyshire, (1967, 1968) and Derbyshire and others (1965) also inferred ice movement directions from fabric analysis, striations and ice eroded surfaces. These authors assumed a single period of glaciation.

6. The problem of the ages of glaciations in the area has not been addressed. Stratigraphic information advanced by Paterson (1965, 1967, 1969) and Kiernan (1983) gave some indication of relative age. In other areas of Tasmania relative and absolute ages for the various glaciations have been reasonably well established (Colhoun, 1985b; Kiernan, 1985), with the onset of the last glaciation dated as approximately 25 ka BP, the maximum as 18 ka BP and deglaciation as 10 ka BP. Only tentative dates are suggested for older glaciations with the

penultimate glaciation is in the order of 140 to 170 ka BP and older glaciations in excess of 1 million years BP.

In the Mersey Valley there were only two radiocarbon dates reported in the literature prior to the commencement of this study. The first is 9,760 ±720 yr BP (Beta-4757) which is a basal date for an aboriginal rock shelter in Lees Paddocks (Lourandos, 1983, p. 30). The second of 10,840 ± 180 yr BP (Gak-785) is from peat in a depression in glacial drift on Borradaile Plains (Colhoun, 1985b, p. 46). These dates have both been suggested as approximate deglaciation dates for the area.

7. There has been no documented attempt to reconstruct the equilibrium line altitudes (ELA's) for the ice masses formed during the periods of glaciation or to deduce the depression of the temperature and the snowline which occurred.

AIMS OF THE STUDY AND METHODOLOGY

In broad terms this study aims to solve the problems listed above. The discussion that follows briefly expands on each problem and reviews the methodology used to achieve a solution. Details of specific methodologies is given in later sections where the solution to problems is discussed in greater detail.

1. A review of the landforms of the area is given in Chapter 3. As far as possible the review relates the landforms to the glacial events which produced them. Broadly the last glaciation, the Rowallan Glaciation was responsible for the sharply-defined landforms which appear in the areas closest to the ice sources. Immediately outside the zone influenced by the Rowallan Glaciation there are landforms resulting from the penultimate glaciation, the Arm Glaciation, which have been eroded and weathered to a greater degree. No significant landforms have been recorded which can be attributed to older glaciations .

Most of the area was covered on foot and the landforms identified were recorded on maps with a scale of 1:25000. Interpretation using maps and aerial photographs gave additional information which was added to the maps, both for areas investigated on the ground and for the very few areas which were not visited.

2. Three Pleistocene glaciations are postulated in the upper Mersey region with the possibility of a fourth. This problem is addressed in Chapter 4 and the discussion is in three parts. The first part deals with the stratigraphic relationships which have been established between sediments of the three glaciations. The second part is a statistical analysis of the thickness of weathering rinds of dolerite clasts contained in the tills of the three glaciations. The third part is a consideration of the geographic extent of the three glaciations.

Stratigraphic relationships between the three glaciations were established using normal stratigraphic principles. Field observations showed that at two locations Rowallan sediments were superimposed on Arm sediments. A similar relationship was established between Arm and Croesus sediments.

Once the statigraphic relationships had been established the analysis of the weathering rinds of the dolerite clasts could be related to the different glaciations. Sites were identified as belonging to each glaciation and the thicknesses of the weathering rinds on 50 medium grained, dolerite clasts were measured at each site. Extension of the number of sites produced a sufficiently large sample to permit a meaningful statistical analysis in three stages. The first stage is descriptive which permits each sample to be described and related to the normal distribution. The second stage is an analysis of variance which shows that differences occur between the samples from deposits attributed to the various glaciations. Apportioning the variance demonstrates which variables are responsible for observed differences. The third stage attempts to establish the number of populations which are represented in the total data and uses the Scheffé test and Fisher Least Squares Difference (LSD) test.

The geographic distribution of each of the glaciations follows from the stratigraphy and the weathering rind studies. All sites identified as belonging to either the Rowallan, Arm or Croesus glaciations were plotted on 1:25000 maps and a picture of the extent of each glaciation was established.

3. The areal extent of the Rowallan Glaciation is discussed in Chapter 5 whilst the extent of the Arm and Croesus glaciations is discussed in Chapter 6.

The extent of each glaciation was established from landform studies, stratigraphy, weathering rind analysis and geographic distribution, each of which has been discussed briefly above.

4. The discussion of the sediments associated with the Rowallan Glaciation is included in Chapter 5 and for the Arm and Croesus glaciations in Chapter 6.

Wherever sediments were found to outcrop, the physical characteristics were described. The description was based on observations of the structure, texture, including grainsize, and larger clastic constituents. If necessary a diagram or stratigraphic column was produced. The description also included the colour of the sediment, as it had been found in previous studies that more weathered sediments were more highly coloured (Kiernan, 1983; Colhoun, 1985). The revised Standard Soil Colour Chart was used. To record a colour for a sediment the moist sediment colour was compared with the closest colour on the chart and the number values were recorded. All colours were recorded in the field.

Clast analyses and fabric analyses were undertaken at stratigraphically or geographically significant sites. For a clast analysis 200 pebbles were broken open and the rock type identified. A bar chart was produced to depict the percentage of each rock type represented. In a fabric analysis the dip and orientation of 100 pebbles were measured, recorded and plotted on a Schmidt equal area stereographic net. The point density was counted with a Kalsbeck Counting Net and contoured at 2% intervals. The results of the fabric analysis were also analysed statistically.

A 2 kg sample was taken back to the laboratory from some locations for grain size analysis. The details of this technique are recorded in page 99

5. Ice movement directions are discussed for the Rowallan Glaciation in Chapter 5. The direction of ice movement for the older glaciations has not been discussed in detail for two reasons:

(i) Evidence for the Croesus Glaciation in the region is limited and the sediment which exists is extremely weathered. Any attempt to reconstruct the ice movement directions from such evidence would be extremely unreliable.

(ii) The ice movement directions for the Rowallan Glaciation have been mainly analysed in the source regions. It is assumed when the Arm Glaciation occupied this region, even though it occupied a greater area, the ice movement would have been similar. Outside the area occupied by the Rowallan Glaciation the Arm Glaciation is virtually enclosed in the valleys and ice movement is assumed to be been down-valley.

The ice movement directions for the Rowallan Glaciation orientations have been determined from roches moutonnées and related forms, striations and fabric analyses.

6. The age of the Rowallan Glaciation is considered in Chapter 5 and the ages of the Arm and Croesus glaciations are discussed in Chapter 6.

A number of radiocarbon dates have been obtained during this study. The most important dated sequence comes from Dublin Bog where cores were taken and and palynology was completed by Colhoun and van de Geer (Hill, Colhoun and van de Geer, 1988).

The thicknesses of weathering rinds is also used to give approximate minimum age estimates for the drift sheets.

A study, currently in progress by M. Pollington, on the remanent magnetism of fine grained sediment has also provided an indication of the ages of the glaciations.

7. Consideration of the probable climatic conditions that prevailed, during the Rowallan Glaciation is included in Chapter 5. An estimation of the climate during the Arm and Croesus glaciations is discussed in Chapter 6.

To reconstruct the ELA's for each of the Rowallan and Arm glaciations the extent of the ice was plotted on 1:25000 scale maps and the area measured. The assumed accumulation area ratio (AAR) is the ratio of the area above the equilibrium line to the area of the entire glacier and this ratio is taken as 0.6 (Porter, 1975; p. 35; Colhoun, 1985a, p. 45). Once the equilibrium line is calculated depression of the temperature and the snowline can be estimated and hence an indication of the climate during periods of glaciation is obtained.

There was insufficient evidence to calculate an equilibrium line altitude for ice during the Croesus Glaciation because the extent and form of the ice sheet and outlet glaciers is not known.

CHAPTER 3

LANDFORMS PRODUCED BY GLACIAL AND PERIGLACIAL PROCESSES

This chapter considers the landforms of the region in three parts. The erosional landforms and the depositional landforms which were formed by the three periods of glaciation comprise the first two parts. The third part is a discussion of the landforms which have resulted from periglacial processes and deglaciation, namely talus slopes, topples, blockfields, blockstreams and pressure release rifts.

LANDFORMS OF GLACIAL EROSION

The strongly emphasised landforms attributed to ice erosion during the Rowallan Glaciation are characterised by freshly scoured, little weathered rock surfaces which generally occur in topography almost devoid of weathering products or soil. The sparse vegetation of the highland areas grows mainly in joints of the rock, which is almost exclusively dolerite. By comparison the erosional landforms associated with the area of Arm Glaciation ice show a greater degree of weathering, soil development and vegetation cover but tree roots are still confined to joint planes. No landforms either erosional or depositional can be ascribed positively to ice of the Croesus Glaciation.

Roches moutonnées and related forms

Roches moutonnées are common in the upper Mersey region,particularly in the highland areas of the Central Plateau adjacent to Cathedral Mountain, the surrounds of Lake Myrtle, Zion Vale, Lake Thor and the head of the Fish River in the Walls of Jerusalem National Park. Here they are carved out of dolerite and vary in height from less than 2 m to 20 metres. Not all are developed in the classic form with an abraded stoss face and a plucked lee slope. Many whaleback forms occur which are "individual hillocks (that) tend to have smoothed rock surfaces on all sides, and are moulded into a shape which is longer than it is wide" (Sugden and John, 1976, p. 170). Why roches moutonnées developed in some situations and whaleback forms in others is not clear. In this region they develop in close proximity on dolerite which is apparently identical in texture and composition, and has the same frequency of joint pattern. Whilst no statistical information has been collected, it is evident that whaleback forms tend to be smaller than roches moutonnées and both forms occur in the valleys as well as the uplands. Between where the Fish River enters Lake Rowallan as an alluvial fan and the Rowallan Dam there is large outcrop of Precambrian Howell Group quartzite and schist (Jennings, 1963, p. 33) which has been moulded into spectacular roches moutonnées and whaleback forms. At Rowallan Dam there is rock bar which has been moulded strongly by ice. Downstream of the dam both forms are visible. Beyond the limits of the Rowallan Glaciation clearly differentiated ice moulded rock surfaces associated with the Arm Glaciation are present. Whaleback forms produced by ice of the Arm Glaciation are also extremely common in the upper Arm Valley.

These landforms indicate the general directions of ice movement when striations or other more reliable information is lacking. Although the form may be largely influenced by the last phase of ice movement across the area, it may owe part of its morphology to earlier phases of erosion by ice from similar sources.

Several of the plateau edges above steep scarps have characteristic concave reversed slopes towards the interior. These slopes appear to have been strongly eroded as the ice flowed towards the rising edge of the plateau. The summit of Mount Jerusalem is a typical example. Towards the west of Mount Jerusalem there is a steep scarp called the East Wall and towards the southeast the terrain slopes gradually to the near-horizontal surface of the Central Plateau. Similar profiles exist on Cathedral Mountain above Lees Paddocks, Clumner Bluff and Howells Bluff above Lake Rowallan and on Mount Pillinger west of the Mersey Valley. Examination of 1:25000 scale maps of the surrounding area indicates that the same effect occurs at a number of locations around the plateau edges of the Great Western Tiers. In contrast with the relatively smooth rising slope of ice erosion most of the scarp slopes have been modified subsequently by the operation of periglacial processes and mass movements which have resulted in the production of steepened scarps and thick scree mantles immediately below.

None of these forms was created solely by the Rowallan Glaciation. The Arm Glaciation may have been responsible for the features on Mount Jerusalem and Howells Bluff. If these landforms were formed in the way suggested above then the rest of those identified must have been produced by an earlier more extensive period of glaciation.

Ice eroded basin lakes

The ice sheet of the Rowallan Glaciation in the highland areas scooped out numerous rock hollows. These have subsequently been filled with water to become basin lakes. One of the best examples is Chalice Lake on the Cathedral Plateau. Figure 4 is an aerial photograph of Chalice Lake which shows how glacial erosion has stripped off any pre-existing surficial deposit and hollowed out the rock, making visible the close joint pattern in the dolerite. Chalice Lake is formed in the lowest part of the Cathedral Plateau and is the focus of a classic centripetal drainage pattern, formed by the creeks flowing from the surrounding high ground. The northeastern arm of Chalice Lake extends along a joint or fault-controlled valley for some 400 m which leads to the outlet stream that flows into Chapter Lake. Sugden and John (1976, p. 174) note that rock basins tend to be elongate and that often there is a lithological or structural reason for the direction of the elongation. Although most of Chalice Lake cannot be described as elongate, the northeastern

Figure 4: Aerial view of the irregularly-shaped Chalice Lake showing the glacially abraded surface and the centripetal drainage pattern. The steep-sided valley which bounds the eastern edge of the Cathedral Plateau runs from lower right to top left and Chapter Lake is visible in the upper centre part of the photograph.

Figure 5: The U-shaped Mersey Valley viewed from Cathedral Mountain with the flat-floored Lees Paddocks and the river meandering across them. The narrow plateau below Mount Pelion East is visible on the top left of the photograph. Mount Pillinger is in the background showing a 'reverse slope'.

arm follows a marked geological structure that intersects the elongate valley, in which Chapter Lake and Cloister Lagoon lie, at approximately 60°. The dolerite is strongly jointed and faulted and these many structures may account for the alignment of most of the lakes, even though neither joints nor faults have been included in the geological map sheet of the area (Macleod and others, 1961). Other noteable basin lakes of the highlands are Lake Louisa, Lake Adelaide, Lake Meston, Lake Myrtle, Lake Thor and Lake Tyre. All of these show some degree of elongation that is probably related to major structures in the dolerite or to preglacial lines of erosion.

Some basin lakes have associated moraines. Lake Myrtle which lies beneath Mount Rogoona occupies a hollow scooped out by ice and at the northwestern end the only outlet stream, Jacksons Creek, flows over till which is part of a moraine complex that blankets the shallow valley. Lake Adelaide, Cloister Lagoon, Lake Ayr and Reedy Lake are other examples of basin lakes which are dammed by moraine to some extent.

Numerous small tarns occur in the highland areas and there is a tendency for them to occur in clusters. One such cluster occupies a strip running southeast from Cathedral Mountain, where the main Mersey Glacier of the Rowallan Glaciation,spilled over the edge of the valley causing severe erosion. Other examples of clusters of tarns of Rowallan Glaciation age are found in the region around the head of the Fish River, Lake Thor, and in the area occupied by the Central Plateau ice cap, particularly southeast of Mount Jerusalem. Tarns which were probably formed by Arm Glaciation ice include the many small lakes which are called Solomon's Jewels in the Walls of Jerusalem National Park, the tarns on the southeastern corner of February Plains and along the eastern edge of the Clumner Plateau.

Cirques

There are only three landforms which can be described as cirques in the upper Mersey area: the hollow occupied by Lake Thor, the depression at the head of the Fish River and the hollow high on the northern banks of the Fish River below the Clumner Bluff plateau. There is doubt as to whether these landforms are true cirques, according to a definition proposed by the British Geomorphological Research Group which states "a cirque is a hollow, open downstream but bounded upstream by the crest of a steep slope ('headwall') which is arcuate in plan around a more gently sloping floor. It is glacial if the floor has been affected by glacial erosion while part of the headwall has developed subaerially, and a drainage divide was located sufficently close to the top of the headwall for little or none of the ice that fashioned the cirque to have flowed in from outside", (Evans and Cox, 1974, p. 151). There is doubt whether these 'cirques' meet the definition in respect of the last phrase as it is likely that ice coming from the Central Plateau icecap partly flowed over the headwalls. Such cirque-like forms have previously been termed overridden cirques (Derbyshire and others, 1965). Although they may have been overridden at maximum glaciation, in the later stages of the Rowallan Glaciation it is unlikely that ice would have moved over the headwall. Perhaps it is only during this time they can be considered to have functioned as cirque glaciers. The cirque below Clumner Bluff was not active during the Rowallan Glaciation and probably was part of the tributary glacier that flowed down the Fish River valley for most of the Arm Glaciation. The surface of Lake Thor lies at approximately 1200 m above sea level and the headwall rises to an altitude of 1280 m to the southeast and 1380 m to the northeast, which gives a rise of 80 m to 180 m. The floor of the Fish cirque has an altitude of 1177 m and tarns occur above the headwall at 1340 m, making a rise of 153 m. Both cirques face due west. The Clumner cirque faces south with the floor at an altitude of 1250 m and a headwall of 150 m rising to 1400 m.

Valleys and related forms

The main valley of the region is the Mersey Valley and within the boundaries of the Rowallan Glaciation it is clearly U-shaped. The Mersey Valley in the vicinity of Lees Paddocks is shown in Figure 5. The valley that contains Lake Ayr is also characteristically U-shaped. By comparison many of the other valleys, for example the valleys of Wurragara Creek and the Little Fisher River, which contained ice during the Rowallan Glaciation do not have a U-shaped cross profile.

Waterfalls and rapids, some formed as valley steps, are also common in the region. The Mersey between Lees Paddocks and Steers Plain has two large waterfalls, each of approximately 10 m descent. Where valleys are cut into the horizontally bedded Permian and Triassic strata they are more likely to develop waterfalls than those cut into dolerite, schist or quartzite. Moses Creek which was one of the main outlets for ice from the Chapter Lake region, flows over Parmeener Super Group rocks and has a number of rapids and waterfalls in its descent to the Mersey River. Other streams with waterfalls are Jacksons Creek, Fish River, Wurragara Creek and Reedy Creek. The Arm River above its junction with the Mersey descends a steep slope on which there are a number of waterfalls, outside the limits of the Rowallan Glaciation.

The Mersey Valley in the vicinity of Lake Parangana is within the terminal zone of Arm Glaciation ice, but beyond the terminus of Rowallan Glaciation ice, and is U-shaped. However, below the Parangana Dam the valley becomes decidedly V-shaped. Paterson (1969), during investigations for the dam site, used seismic velocities and drilling to delineate the channel form. He concluded that where the channel is cut into the bedrock, the shape varies sufficiently, from the dam crest to the dam toe, to indicate that a glacier terminated at this site. Field work for the present study uncovered till of the Arm Glaciation some 1.5 km below the toe of the dam, which suggests that the portion of the valley which is V-shaped was at least glaciated in part during the Arm Glaciation.

A hanging valley exists where the unnamed creek from Chalice Lake flows northeastwards into Chapter Lake. The part of the Cathedral Plateau glacier which moved along the valley now occupied by Cloister Lagoon and Chapter Lake overdeepened it to such an extent that the present tributary from Chalice Lake now joins at a different level. The two valleys meet in the near vertical 40 m-high Grail Falls (Figure 6).

Small scale erosional features

A number of authors have recorded that striations are not to be found on dolerite because it is easily weathered (Lewis, 1922, p. 21; Jennings and Ahmad, 1957, p. 57; Derbyshire, and others, 1965, p. 3). This is true of dolerite which has been exposed to the elements for a long time, but dolerite which has been protected in some way can retain striations. Lewis (1922, p. 21) was hopeful of finding striations where they had been "protected from weathering processes by clay or sand." Indeed it has been found that dolerite which has been protected by the water of a lake or tarn, by till, or even by an erratic will retain striations. In one instance in the upper Fish River at 408730 (Pillans Lake), removal of a large glacial boulder on a convex dolerite slope revealed striations. Similarly, abnormally low levels of water in tarns southeast of Cathedral Mountain have allowed striations to be observed. At lower altitudes where outcrops of Howell Group quartzite occur near the Rowallan Dam there are numerous striations on horizontal and vertical faces. At the southern end of Lake Rowallan, till covers outcrops of Permian mudstone in several localities. Careful removal of the till revealed striations on a smoothed, but undulating surface of Permian mudstone, even though the mudstone is fissile, closely jointed and shatters easily under a hammer blow (Figure 7). Striations attributable to ice of the Croesus Glaciation have been found in a quarry at 298756 (Rowallan). Permian siltstone smoothed by ice underlies a solifiucted till of Croesus age. This is discussed in detail on page 55. Only when the soliflucted till had been removed by hand were the striations revealed. A miniature 'crag and tail'

Figure 6: A small hanging valley at Grail Falls where the stream from Chalice Lake flows into the overdeepened valley which contains Chapter Lake. Ice moulded valley edges are also visible.

Figure 7: Glacial striations on mudstone lying beneath Rowallan Till. The smoothed surface of the mudstone is clearly visible and the blocky, fissile nature of the mudstone can be seen by the way it has broken on the left of the photograph.

is also present with the 'crag' a quartzite dropstone about 40 mm across. The tail is moulded in mudstone. (Figure 8)

Discussion of the significance of striations for ice movement direction is detailed in the section on ice movement direction for the Rowallan Glaciation on page 106.

Glacifluvial erosion features

Meltwater channels are the most common glacifluvial erosional feature observed and occur in great abundance in both highland areas and valleys. Most of the channels are fairly short (<200 m long) with floor widths of 2 m to 5 m and wall widths of approximately 50 m to 100 m. Some are cut extremely deeply into glacial drift. A good example from the Mersey Valley occurs below Lees Paddocks, where thick morainic deposits have been eroded by meltwater to form steep-sided, dry channels up to 40 m deep. The terrace surfaces of Reedy Creek and Wurragara Creek exhibit short, steep-sided, meltwater channels which commence suddenly in abrupt gully heads. Near the Fish River alluvial fan, meltwater channels have been cut into quartzite and schist up to 5 m deep. The landforms in the area west of Lake Louisa have also been modified by intense meltwater activity which has incised steep-sided trenches, usually controlled by joint direction in the dolerite basement.

A number of existing creeks probably owe their origin to meltwater activity associated with Rowallan Glaciation ice. The most obvious are the numerous streams flowing from areas of former intense meltwater activity around Lake Louisa and Lake Adelaide, and include Juno Creek and Stretcher Creek. These streams were initially formed when the Rowallan Glaciation was near its maximum and large volumes of meltwater were escaping from the plateau to lower levels. Many of these streams are cut into dolerite and the contemporary discharge makes them underfit streams. Other streams which started off as meltwater channels include the unnamed creek which flows into the wet area of Dublin Bog just north of the terminal moraine of the Rowallan Glaciation. It is possible that this stream

Figure 8: Miniature crag and tail in mudstone, lying underneath soliflucted Croesus Till. The smooth nature of the surface is apparent where it has been washed. Ice movement was generally in the same direction as the photograph was taken.

commenced to flow during the retreat stages of Arm Glaciation ice and was further developed during the Rowallan Glaciation. The unnamed tributary of the Douglas River flowing from the western end of Lake Ayr is another example. The twin branches in the headwaters of the Arm River are probably also the result of meltwater activity during the retreat of Arm Glaciation ice.

Waterfalls of the region have also been influenced by Rowallan age meltwater. A common feature, which extends beyond the Rowallan ice limits, occurs at the base of waterfalls and results in a channel form which is circular in plan, resembling a thermometer bulb. These features were formed as water eddies and turbulence of the very large volumes of meltwater swirled around the base of waterfalls, and cut the circular feature into rock. Waterfalls on larger streams may have two or three of these features, decreasing in size downstream. They are no longer actively forming because all occur above current flood levels and many are thickly vegetated with trees and shrubs of considerable size. All waterfalls observed and named on the 1:25000 Series Maps (Tasmanian Lands Department), such as Lewis Falls, Oxley Falls and Arm Falls, and the host of unnamed falls found on the steep slopes of the Mersey Valley display this characteristic relict 'thermometer bulb' channel form.

Nunataks

A number of the peaks of the region were free of ice during the Rowallan Glaciation. These include the mountains on the western edge of the Cathedral Plateau; Cathedral Mountain, Twin Spires, Bishop Peak, Curate Bluff, Dean Bluff and Premier Peak. In the Cradle Mountain National Park the peaks of Mount Ossa, Mount Pelion East and Mount Oakleigh would also have been nunataks. In the Central Plateau area Mount Rogoona and Mount Jerusalem can be considered nunataks even though there is doubt whether they were completely surrounded by ice during the Rowallan Glaciation maximum. Other major peaks in the Walls of Jerusalem area, for example the West Wall and the Temple had no ice of Rowallan age adjacent to them. February Plains, Mount Oakleigh to the south and Mount

Pillinger to the east of the Lake Ayr Valley were ice-free during the maximum of the Rowallan Glaciation.

During the Arm Glaciation most of the peaks named above may have been nunataks. The exact ice limits cannot be estimated with any certainty but based on a slight increase in the extent and thickness of the Arm Glaciation ice compared with Rowallan Glaciation ice, it is reasonable to assume that the ice would have been higher on all peaks. It is likely that ice would have flowed over the southern edge of February Plains. Also ice would have flowed from the Central Plateau into the Mersey Valley above Lees Paddocks leaving the line of peaks from Cathedral Mountain to Dean Bluff as small isolated nunataks. There is no evidence to suggest whether or not a greater thickness of ice on the Central Plateau would have covered Mount Jerusalem and the plateau above the West Wall during the maximum of the Arm Glaciation.

During the Croesus Glaciation it is estimated that all the peaks in the area would have been covered by ice. Perhaps some of the higher ground in the northern parts of the region, for example Western Bluff, may have remained above the ice but it is difficult to demonstrate the effects of such a glaciation with the incomplete field evidence available.

LANDFORMS OF GLACIAL DEPOSITION

End moraines, lateral and recessional moraines

End moraines are associated with each of the ice lobes of the Rowallan Glaciation. They occur at the Mersey-Arm confluence, Pillinger Bog, Dublin Bog, Lake Ayr and Reedy Lake, Little Fisher River, upper Arm River and North of Lake Adelaide (Figure 17). None of these end moraines exceeds 5 m in height. They are small compared with end moraines of the last glaciation in other parts of the state viz. the West Coast Ranges, where the Hamilton, Tyndall and Rolleston end moraines, are from 100 m to 300 m high (Colhoun, 1985b, p. 42); in the Snowy Ranges, in particular at Lake Skinner where the end moraine is approximately 60 m high; in the Arthur Ranges where moraines are up to 100 m high and at Mount Anne where moraines in excess of 200 m are present. Davies (1967, p.17) also made this observation and suggested that prolonged periglacial activity in the eastern part of the state, which was absent from the western part due to more intense and long periods of glaciation, redistributed the moraines. This explanation can be sustained no longer as it has been shown that deglaciation dates for the last glaciation are approximately contemporaneous around the state (Caine,1983; Colhoun, 1985a; Hannan and Colhoun, 1987) and therefore there was not a longer period of exposure to periglacial processes in the east than in the west, before land surfaces became stabilised by forest vegetation. The area of the glacier does not seem to be a factor as the Rowallan glacier had an area of 282 km^2, whilst the plateau glacier of the West Coast Ranges had an area of 91 km^2 (Colhoun, 1985, p. 44). The solution probably lies in the ice dynamics of glaciers occurring in the two regions. The present precipitation of the upper Mersey Valley is approximately 1800 mm, whereas at Queenstown, in the middle of the west coast of Tasmania, it is in excess of 2500 mm. Assuming that the hours of sunshine and evaporation were the same, (which is approximately the case at present) then the west coast glaciers would have been more dynamic, given that they were smaller in area than those on the Central Plateau. A more dynamic system would possibly mean a greater sediment load being transported more rapidly. It could also mean that the less active, and more extensive glaciers of the Central Plateau would have been more sensitive to climatic changes. Thus, they may not have been able to remain in any one position, for a sufficient period of time, to accumulate a moraine of reasonable size.

At an altitude of approximately 1100 m on the northern flank of the valley of Lake Ayr above the limits of Rowallan Glaciation ice a small lake is dammed by a moraine. The till in the moraine is not exposed and could not be examined. From the geographic pattern the moraine is assumed to be a termino-lateral moraine of the Arm Glaciation as it is estimated that ice of the Rowallan Glaciation maximum did not exceed an altitude of 1000 m in this area. Above the lake is a scarp of near vertical dolerite mantled with scree down to the lake edge.

Mather (1956, p. 16) and Derbyshire and others (1965) discuss the presence of moraines and moraine dammed lakes in the Lake Mackenzie area outside the area of study. The identification of till of Arm Glaciation age in the Fisher River and the HEC excavations makes it likely that these moraines are composed of similar material.

No end moraines which could be attributed to the Croesus Glaciation have been found in the area.

Extensive recessional moraines of the Rowallan Glaciation were formed after the retreat of the various ice lobes. The Mersey Valley and the Reedy Lake area in particular contain many recessional moraines of this age. The Mersey Forestry road, which runs along the eastern side of Lake Rowallan crosses numerous moraine ridges at angles of 30° to 40° to the maximum slope of the valley. Exposures in road cuttings show outcrops of basal till and meltout till, and less commonly gravels and sand. The walking track between Lees Paddocks and the Mersey forestry road contains many moraine ridges. High on the Mersey Valley slopes above Steers Plain two flat-topped, kame-type terraces, 20 m to 30 m broad occur. These may have been formed by the combined effects of deposition of detritus from the hillslopes, by deposition of moraine from the ice margin and by meltwater. The Fish River has a steep sided valley before its junction with the Mersey River, and has cut through till deposits up to 30 m thick. The deposits consist of basal till with a veneer of ablation till. The first part of the Walls of Jerusalem track, which commences above the Fish River crosses a number of arcuate lateral moraines of Rowallan age which curve across the upper slopes of the Fish Valley at 900 m to 1000 m altitude.

The broad valley from Lake Ayr, through Reedy Lake to Wurragara Creek is smothered in hummocky moraine left by the retreating ice of the Rowallan Glaciation. Numerous prominent, arcuate moraine ridges occur and appear to be arranged in steps towards Mount Pelion East to the south, and the Oakleigh Plateau to the north, indicating that the ice withdrew eastwards into the Mersey Valley towards the Lees Paddocks area. Between these moraine ridges are smaller moraine hummocks with evidence of outwash channels, infilled lakes and ponds being retained. Reedy Lake is itself a moraine-dammed lake with a prominent ridge around the western and southern sides, and hummocky moraine with lower relief on its other sides. Reedy Creek emerges from Reedy Lake on the eastern side and descends rapidly to Wurragara Creek. Immediately before the steep descent to Wurragara Creek it flows on Permian Mudstone revealing a thin veneer of ground moraine in the central part of the valley. Where the creek descends steeply into the valley it has cut into the thick till deposits of various recessional moraines.

Although outside the study area, the Mersey Valley between Junction Lake and Lake Meston has many similarities with the Lake Ayr-Reedy Lake region. There are numerous arcuate recessional moraine ridges with interspersed areas of hummocky moraine that have dammed lakes and ponds. The morphology of the complex not only suggests gradual recession of the ice front but also extensive meltwater activity during deposition of the sediments. The map of Jennings and Ahmad (1957) records extensive moraine development in this region.

To the north of Lake Adelaide and within 1500 m of the end moraine there are numerous recessional moraines.

Recessional moraines associated with the Arm Glaciation ice are not as obvious on the landscape but some poorly defined moraines extend across Dublin Plains. Spry (1958, p. 123) records on a map in his paper "vague end moraines" in the Arm Valley some 800 m downstream from the Arm Bridge at 300799 (Rowallan) but this study has not been able to confirm their existence. Recessional moraines of the Arm Glaciation age are visible in the valley of Wild Dog Creek in the Walls of Jerusalem National Park, where a number of incomplete arcuate ridges of till extend across the valley between the track leading to Herods Gate and the junction with Zion Creek.

Recessional moraines of the Croesus Glaciation have not been identified in this study.

Erratics and ice transported boulders

Glacially transported boulders, occasionally erratic, are generally widespread throughout the study area. In some places they are very large and in others very numerous. In the Mersey Valley below the Pillinger Plateau large angular dolerite boulders up to 10 m across are embedded in till and outwash sands and gravels. A similar ice-transported origin can be attributed to a number of extremely large boulders below the plateau edge near Clumner Bluff. One in particular at 361776 (Rowallan) is more than 8 m high and 15 m long and it could have fallen from the edge of Clumner Bluff on to the surface of the glacier and transported about 1 km. A different origin is suggested for boulders on the Cathedral Plateau above the edge of the Mersey Valley at 288612 (Cathedral). The large accumulations of boulders appear in hummocks and some are as large as 10 m across. It would appear that they were ripped off as the glacier rose above the edge of the valley and were deposited as a lateral moraine when the glacier lost momentum in the lee of Cathedral Mountain.

The region from Lake Loane, via Solomons Jewels to Wild Dog Creek and the unnamed valley to the west of George Howe's Lake, in the Walls of Jerusalem National Park, is one of the few upland areas of the region that was covered by ice during the Arm Glaciation and free of ice during the Rowallan Glaciation. Throughout this region there is widespread occurrence of ice-transported boulders many over 5 m across that resulted from the Arm Glaciation.

Dolerite erratics occur frequently in the drifts as far north as the Liena and Mole Creek areas where the underlying rock is mainly limestone. These erratics are presumed to be the result of the Croesus Glaciation.

Glacifluvial terraces and kame terraces

Retreat stages of ice of the Rowallan, Arm and Croesus glaciations are discussed in separate sections dealing with the individual deglaciations. Associated with all the identifiable retreat stages of the Rowallan Glaciation are well defined outwash terraces and small plains such as Lees Paddocks and Steers Plain. The area now occupied by the artificial Lake Rowallan contains an extensive outwash terrace which was known as Walters Marsh on maps published before the river was flooded. Similar outwash plains are present in the Arm Valley. They resulted from deposition of sediment by meltwater during the retreat of Arm Glaciation ice. For example, a large outwash plain occurs upstream of the final rapid descent of the Arm River into the Mersey. There are also similar smaller plains downstream from the junction with February Creek. The Dublin Plains area is also associated with outwash activity from the retreat stages of the Arm Glaciation. An extensive plain stretches from the Dublin Bog ice lobe of the Rowallan Glaciation almost to the Little Fisher River.

A kame terrace associated with the Rowallan Glaciation ice lobe at the Arm-Mersey confluence has been identified at a low altitude on the eastern side of the valley at 352833 (Borradaile). It is about 3 m broad and lies close to the break in slope.

PERIGLACIAL LANDFORMS AND DEPOSITS

Blockfields and blockstreams

Blockfields and blockstreams which are extensive spreads of coarse joint-determined boulders dislodged from the bedrock, have been found to occur just outside the area affected by ice of Rowallan Glaciation age. The main examples of blockfields and blockstreams are found on the plateaux of Cathedral Mountain, Mount Pillinger, Clumner Bluff and Lake Mackenzie. On the plateaux blockstreams occupy the central portions of the shallow valleys in a position which "mimics the drainage" in a similar way to those described by Caine (1983, p. 127). Where the blockstreams spill over the edge of the plateaux they do so from gaps along the edge of the plateau. The blockfields and blockstreams are usually vegetated to some degree but bare patches occur where the underlying sand and silt material has been washed away. Clasts composing the blockfields and blockstreams are exclusively dolerite and vary in size from the blockfields on the plateaux to the blockstreams spilling into the valleys. The plateau blockfields contain clasts up to a maximum of 3 m and a modal size of around 400 mm. Slopes on the surface of the plateau blockfields are low, varying from 2° to 5° with the overall surface uniform except for the irregularities between clasts. No longitudinal ridging was observed on blockfields or blockstreams of the plateau as reported by Caine (1983, p. 127). The blockstreams spilling over into the valleys contain coarser clasts with a maximum size of 7 m and a modal size of approximately 1 m. The slopes of the resulting screes can be up to 25° and some of these are cut by the Lake Mackenzie Road, which runs below the northern part of the Central Plateau. The stratigraphy of the blockfields is similar to that described by Caine (1983, p. 128) in that the upper 1 m to 1.5 m is composed of open blocks of dolerite with no interstitial fines, whilst at lower levels, in some localities, silt and sand can be found.

Topples

The presence of many large blocks which occur high on scree slopes suggests that dolerite columns have fallen or toppled (Caine, 1982, 1983) in the recent past. Caine (1982) describes toppling of blocks of dolerite as occurring by two mechanisms, cambering and slab failure. Cambering depends on the presence of a weaker layer of rock underneath the dolerite which collapses and is aided by close vertical joints in the dolerite (Caine, 1982, p. 137). The presence of horizontally bedded Permian and Triassic sandstone and mudstone outcrops at the base of vertically jointed dolerite is common in the Mersey Valley above the Rowallan Dam. In spite of this cambering has not been positively identified at any locality. Only one locality has been recognised where the possibility exists, and it occurs in a small cliff face at 335685 (Cathedral) where an outcrop of Permian mudstone is visible underlying a dolerite cliff. Large slabs of dolerite, largely intact, rest on the ground beneath the cliff. The difficulty with positive identification of cambering is that there are other mechanisms which could operate. In this case, for instance, the blocks could have fallen due to undercutting of the mudstones, maybe by meltwater of the Rowallan deglaciation. It is also possible that the topple could have resulted from pressure release on the cliff face due to melting of ice in the valley; a process that can be demonstsrated in this vicinity.

Slab failure occurs where a vertically jointed dolerite column develops shear cracks at the base and catastrophic failure occurs causing the block to fall (Caine, 1983, p. 138). A number of cliff faces in the region, particularly those on the eastern side of the valley above Lake Rowallan, are considered as sites where slab failure has occurred. Below Clumner Bluff long columns of dolerite have broken off the cliff face, but unlike the slab failures described at Ben Lomond by Caine (1982, 1983) the blocks have not remained intact after falling. They have disintegrated into very large boulders. One such boulder occurs at 361776 (Rowallan) and has been described as having been subsequently ice-transported in an earlier section. Although it is some 1.5 km from the cliff face it is regarded primarily as a product of slab failure. Below Howells Bluff the scree slopes are most likely to be the result of slab failure or perhaps due to undercutting by ice. On top of the bluff a number of the dolerite columns have tilted visibly from the edge of the scarp. Some have separated by as much as 1 m at the top with a tapering gap visible to 60 m depth.

There is evidence that toppling was associated with deglaciation. A section in the road cutting, beneath a site where toppling has been recognised at 335685 (Rowallan), reveals talus derived from the topples overlying a sequence consisting of 0.4 m of solifluction deposit, 0.8 m of gravel and 1.2 m of basal Rowallan Till. Topples have also been identified as partially filling the pressure release rifts. This is also regarded as a deglaciation phenomenon. Similarly topples are observed to fill a meltwater channel eroded during the Rowallan Glaciation maximum in the headwaters of Jacksons Creek. Caine (1983, p. 97) discusses toppling as being a deglaciation process on steep escarpments which have been overridden by glacial ice. None of the slopes described above were overridden by glacial ice, but glacial ice flowed past them for a considerable period of time and would have exerted pressures against the scarp faces. Release of this pressure due to deglaciation is a possible mechanism that could have contributed to the formation of the toppled masses of rock.

Talus slopes

Both within the former glaciated zone of the Rowallan Glaciation and outside it, talus commonly mantles the slopes beneath major scarps. The volume of material accumulated outside the glacial zone far exceeds that accumulated inside. Generally the talus slopes consist of single cones or aprons of blocks with no lateral interdigitation of talus cones from adjacent re-entrants in the scarp face. The inclination of the talus surface below the dolerite cliffs has been measured and is always less than 35°. Below Clumner Bluff the talus slopes vary from 23° to 28°; below Howells Bluff from 25° to 30°; below Cathedral Mountain from 25° to 32°; below Mount Rogoona from 21° to 28°; and below Mount Pillinger approximately 27°. The talus is composed of coarse angular dolerite particles with a modal size in the range of 2 m to 3 m. The largest clasts are aproximately 8 m across. The clasts generally increase in size with altitude on the talus slope. Occasionally large clasts are found to have travelled to the base of the talus slope. These clasts, which are probably fragments of dolerite columns, can be up to 15 m long and have probably toppled from the higher parts of the scarp face (Caine, 1983). More usually the clasts at the bottom of the talus slopes range in size from 2 m to 3 m.

In general, profiles found on the talus and topple deposits are slightly concave and this, together with the generally low angles of dip, suggests that movement of the screes continued for a period after initial deposition (Caine, 1983, p. 112). Certainly this is the case for Mount Rogoona where the talus shows fresh scarring towards the top and a low surface inclination of 20° is evident. A similar fresh scar appears below Cathedral Mountain. A talus cone fed by a blockstream, which commenced from the east of Mount Pillinger, and flowed south over the plateau edge at 285680 (Cathedral), is one of the few with a distinctive conical shape. Where the talus cone crosses the edge of the Mersey Valley it splays out and is superimposed on the till, gravel and sand deposited by ice and meltwater from the retreating Rowallan Glacier.

Solifluction deposits, stratified slope deposits and bedded screes

Paterson (1965, 1966, 1969) describes the extensive periglacial deposits found in the excavations for the Rowallan and Parangana dams. Pits dug adjacent to forestry roads 1 km to 2 km southeast of Rowallan Dam generally revealed a succession of 1.2 m of solifluction deposit overlying 1.8 m of poorly bedded gravels and boulders that dip towards the valley at approximately 15°, with bouldery till at the base (1965, p. 15). At the Parangana damsite Paterson describes a talus layer of maximum thickness of 9 m which overlies till and solifluction deposits that fills the valley to a depth of 45 m (1969, p. 57). Derbyshire (1973, p. 139) describes bedded screes on the slopes of the Mersey Valley in the vicinity of Parangana Dam. The screes are exposed in quarries where they have been excavated extensively for road gravel. The general stratigraphy reveals bedded angular quartzite fragments with the dip of the beds roughly parallel to the slope of the valley. The bedding of the screes is accentuated by a three characteristics as indicated below:

1. The colour of the matrix varies from grey (7.5Y, 4/1) to bright brown (7.5 YR, 5/8) to bright reddish brown (7.5YR, 5/8). The matrix which is present within a bed has a remarkably constant colour, and is the most noticeable characteristic that distinguishes between the beds.

2. The size of the clasts within a bed can also be constant. Some beds have most clasts within the range 30 mm to 40 mm and very few of a larger size. Others have up to 20% of clasts larger than 200 mm but also a modal size of 30 mm to 40 mm. The variation in clast size makes the appearance of the bed 'rougher' and contrasts with the uniform nature of beds with clasts of a similar size.

3. The amount of matrix contained within the clasts varies from bed to bed. Some beds have virtually no matrix, whilst other beds have 50% matrix and 50% of clasts, while others may be predominantly matrix.

The interface between beds is generally quite sharp and it dips in approximately the same direction as the surface. It seems that the dominant process to produce bedding is mass movement with deposits from higher on the slope sliding downhill and covering layers already emplaced lower down on the slope.

In the area around the Parangana Dam where these deposits are found, the surface slope varies from 30° to 40°. The bedded screes of the type described commence immediately below the scarps at the top of valley slope and extend down to beneath lake level.

Less extensive and thinner stratified slope deposits occur over quartzite on the north and west facing slopes of Maggs Mountain and on the valley slopes above the upper Arm River valley. Outside the Arm glacial limit on the flanks of Lemonthyme Hill, north of the Borradaile Plains there are extensive stratified slope deposits on quartzite bedrock. Stratified slope deposits appear to develop best on the closely jointed and fractured quartzites close to the glacial limits of the Rowallan and Arm Glaciations. They have also been developed on dolerite but are not as extensive nor as thick due largely to the more massive character of the dolerite.

Solifluction deposits occur extensively throughout the area of investigation. They vary in thickness from 0.2 m to 5 m in the upper Arm Valley where they mantle the slopes below February Plains and the southern portion of Maggs Mountain. They are also prevalent on the eastern side of the Mersey from Rowallan Dam to the Jacksons Creek-Moses Creek valley. There are two types of solifluction deposit. Firstly, there are the deposits which occur between the Arm and Rowallan ice limits which are thick deposits mantling the landscape, largely produced from the extensive deposits of Arm Till. The other type of solifluction deposits occurs inside the Rowallan ice limits. These are thin, generally in the order of 200 mm to 500 mm and are frequently found overlying Rowallan drift.

The thick solifuction deposits consist of derived till contained in a silty matrix. The clasts which are generally rounded can be up to 600 mm in length but are more usually in the range of 100 mm to 300 mm. The silty matrix is commonly coloured bright brown (7.5YR, 5/8). The thickest deposits occur on the slopes below February Plains where they have been exposed in sections of logging roads and are up to 5 m thick.

The solifluction deposits within the Rowallan Glaciation ice limits contain a higher proportion of angular clasts within a similar silty matrix which is coloured reddish brown (5YR, 4/6 to 4/8).

A solifluction deposit formed from Croesus Till has been identified in the upper Arm Valley. It occurs in two locations, one at a quarry site where it is approximately 2 m thick and is a dark reddish brown colour (5YR, 5/6) and the other in a section on a logging road 400 m east of the quarry. The significance of these deposits is discussed in more detail on page 55.

Pressure Release Fractures

A structural lineament, trending 45° in dolerite has been interpreted from aerial photographs above Steers Plain on the Mersey Valley. It is not included on the geological map of Jennings and others (1961). Occasionally it coincides with the cliffs at the top of the valley, but it also intersects a bulge in the edge of the valley where it has opened to form a 4 m-wide and 4 m-to 6 m-deep gully with near vertical sides as shown in Figure 9. Derbyshire (1973, p. 132) describes similar features from near Lake St Clair, and they are described by Kiernan (1985, p. 124) as rock crevasses and dilational trenches which parallel the steepened slope. The gully is continuous for approximately 350 m and ends on the northern side in a marshy plain and on the southern side in a small creek. Wet sclerophyll forest with thick, dark understorey makes mapping and photography difficult (Figure 9). However, on the western side above the gully there is at least one small fissure with reduced length and depth compared with the main gully. The fissure has a sigmoidal appearance which suggests a tensional origin, and the explanation offered for this feature is a pressure release fracture. Derbyshire (1973, p. 132) suggests that such fractures may have a periglacial origin. However, in the main valley adjacent to this location the glacier would have exerted considerable pressure on the valley slopes particularly with the injection of large volumes of ice from the Moses Creek-Jacksons Creek tributary on the other side. Withdrawal of both this ice and ice from the main valley would have greatly reduced the confining pressure acting on the valley wall. The release of this pressure would have facilitated dilation of the dolerite mass adjacent to the valley wall, particularly if it

Figure 9: Pressure release gully at the top of the Mersey Valley above Steers Plain. The width of the gully is approximately 5 m and boulders on the floor result from minor toppling.

Figure 10: Rowallan Till is superimposed on Arm Till. The matrix of the Rowallan Till is unweathered and is a greyish colour. The matrix of the Arm Till shows manganese staining and is weathered a reddish brown colour.

has been slightly undercut by ice or earlier erosion. On the other side of the valley a feature of similar origin, has been identified from aerial photographs, high on the valley edge at 338678 (Cathedral).

Present-day frost features

Field work for the study progressed throughout a number of winters, which allowed some observations of the effects of contemporary frost action. Frequently, in the early morning needle ice was observed to have lifted stones and soil particles off the ground by as much as 80 mm on bare slopes. The ice under the stones and soil particles normally melted during the clear and sunny days which followed the frosty nights. The development of the needle ice is restricted to unvegetated ground such as walking tracks, quarries and clearings made for timber loading. The lowest point at which needle ice was observed is 720 m but on bare soils it can be expected to occur at much lower levels.

Miniature stone nets formed by heaving and sorting are also found to be active in the area. They require a surface of mixed grain deposits. A number of gravel quarries from altitudes as low as 650 m in the Little Fisher Valley revealed miniature stone nets which usually occur in low-lying damp areas of the quarry floor where the moisture is prone to freezing.

Talus slopes in higher areas may still be active although at a much reduced rate, compared with during periods of cold climate. The only evidence for this is the occasional rock which is heard to fall, usually at night or in the early morning and the instability of the clasts, which in certain areas is such that walking releases a shower of loose boulders. It is assumed that as the clasts are still accumulating they are in unstable equilibrium and a small external force is all that is required to dislodge them.

CHAPTER 4

STRATIGRAPHIC RELATIONSHIPS BETWEEN THE ROWALLAN, ARM AND CROESUS GLACIATIONS

In the upper Mersey Valley, three distinct sequences of glacial drift have been recognised and have been named from youngest to oldest: the Rowallan Formation, the Arm Formation and the Croesus Formation. Differentiation of the drift sheets has been established, using stratigraphy, weathering characteristics of till, particularly the thickness of rinds on dolerite clasts, geographic distribution of the glacial drift and the nature and occurrence of glacial landforms.

The regional stratigraphy, the weathering characteristics of the sediment and the geographic distribution of the glacial drift each form a major heading in the discussion which follows.

REGIONAL STRATIGRAPHY

Although many sections were examined in road cuttings, quarries, stream channels, landslip scars, cliffs and drill cores, the relationships between the three glaciations can be established accurately by describing a few key sections.

The stratigraphic relationship between the Rowallan and Arm Glaciations

The most significant cutting is on a logging road south of February Creek, in the upper Arm Valley at 285743 (Rowallan), where an outcrop some 1.7 m thick occurs. This has been described by Hannan and Colhoun (1987, p. 40). A moderately compacted and weakly weathered till overlies a considerably more weathered till (Figure 10). Between the tills there is a clearly defined erosion surface and the

Table 1: Stratigraphic summary of the February Creek Section

	Thickness	Structure	Clast Description	Clast Weathering	Matrix Colour
Soil	10 to 20 mm	massive	small dolerite pebbles	not measured	not recorded
Solifluction deposit	140 mm to 150 mm	massive	angular dolerite	not measured	reddish brown (10YR, 4/4)
Rowallan Till	420 mm to 450 mm	blocky, massive	rounded dolerite with occasional clast of Arm Till	mean =0.4mm st dv =0.1mm max =0.9mm min =0.2mm	light brown (2.5YR,6/4)
Uncon-formity	---	undulating surface	---	---	---
Arm Till	410 mm (min)	sub-hoz, fissile planes	rounded dolerite	mean= 1.mm st dv =0.42mm max= 2.2mm min = 0.5 mm	reddish brown (5YR, 4/6)

upper till contains inclusions of the lower till. The characteristics of the units in the section are listed in Table 1 and the section is summarised in a stratigraphic column in Figure 11. The matrix and clasts of the lower Arm Till are noticeably more weathered with the intensity of weathering greater in the upper regions of the section. The more weathered region contains manganese staining around the dolerite clasts and the mean thickness of the weathering rinds on the dolerite shows a statistically significant difference from that in the overlying Rowallan Till ($t = 9.83$, $p \geq 0.0005$).

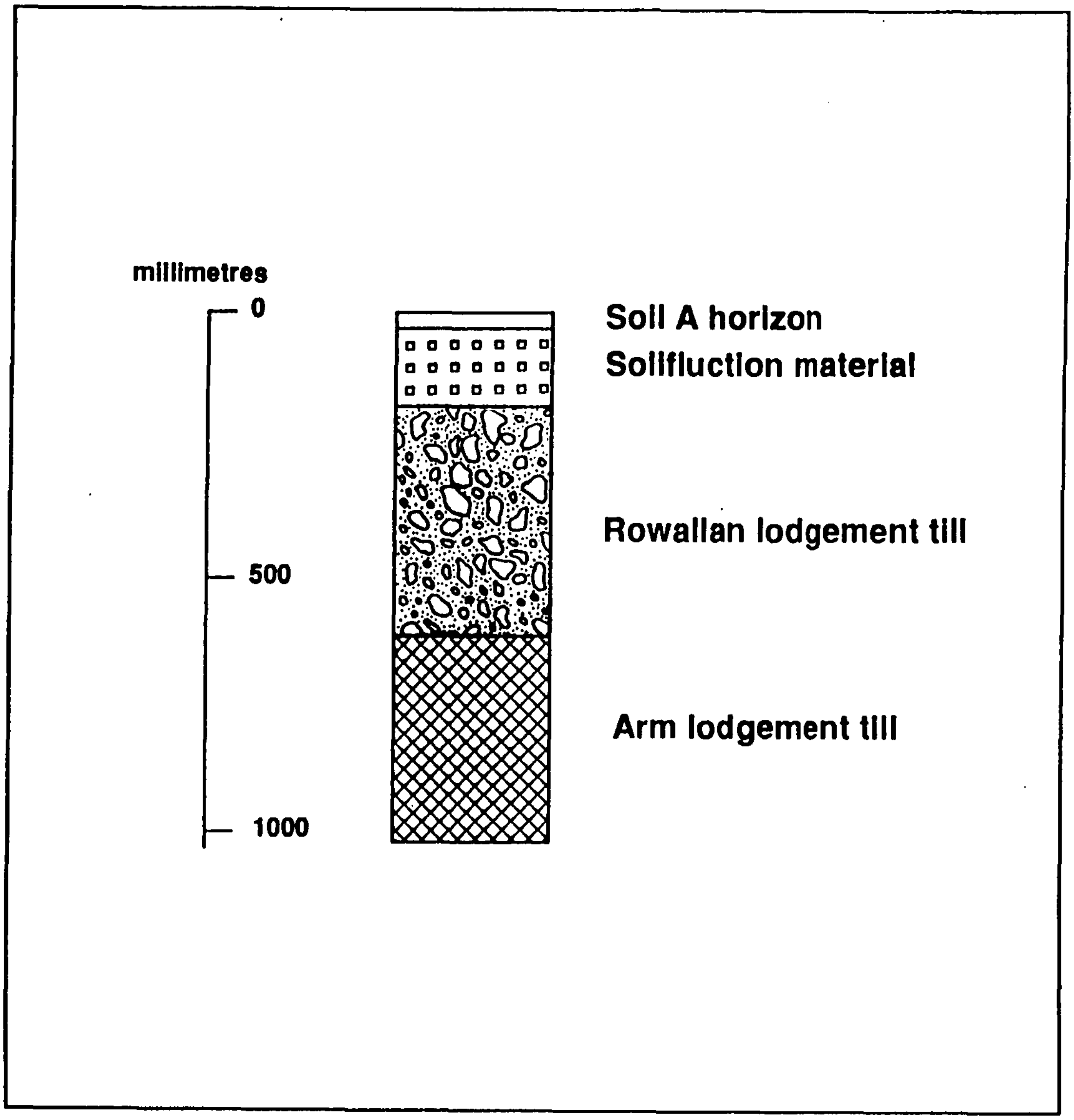

Figure 11: Stratigraphic column of the February Creek section showing Rowallan Till superimposed on Arm Till.

The lower till is the type section for Arm Till, and is discussed more fully in a later section (see page 126)

The importance of this section is that it demonstrates in clear stratigraphic terms that there were two periods of glaciation and that the Arm Glaciation is older than the Rowallan Glaciation. The section also allows close analysis and comparison of till characteristics, thereby creating a reference point for identification at other localities.

It is unusual to have two glacial tills preserved with one superimposed on the other, as the younger glaciation usually removes traces of the older glaciation. The locality described occurs at the terminus of a diffluent ice lobe of Rowallan age that flowed from the main glacier in the Mersey Valley and then crossed a low col of 740 m at 315740 (Rowallan) at the head of the Arm Valley. This section is preserved presumably because the diffluent glacier was melting rapidly and therefore had insufficient energy to completely erode the underlying Arm Till. It is clear that it eroded parts of the Arm Till as there is an erosion surface present and the Rowallan Till contains derived clasts of Arm Till.

Another section which illustrates the superposition of Rowallan glacial deposits on Arm glacial deposits occurs in a deep, vertically-sided gully which is part of the overspill channel just north of the toe of the Rowallan Dam. The section lies directly below a prominent rock bar which has been incorporated in part into the structure of the dam. The rock bar would have offered some protection for older sediments lying in its lee. In the section there is evidence of erosion surfaces, collapse structures, compaction due to overburden, washout channels, current bedding and surface weathering. The features all combine to present a complex array of glacial and glaciofluvial sediment and is shown diagrammatically in Figure 12 and in photographs in Figures 13 and 14.

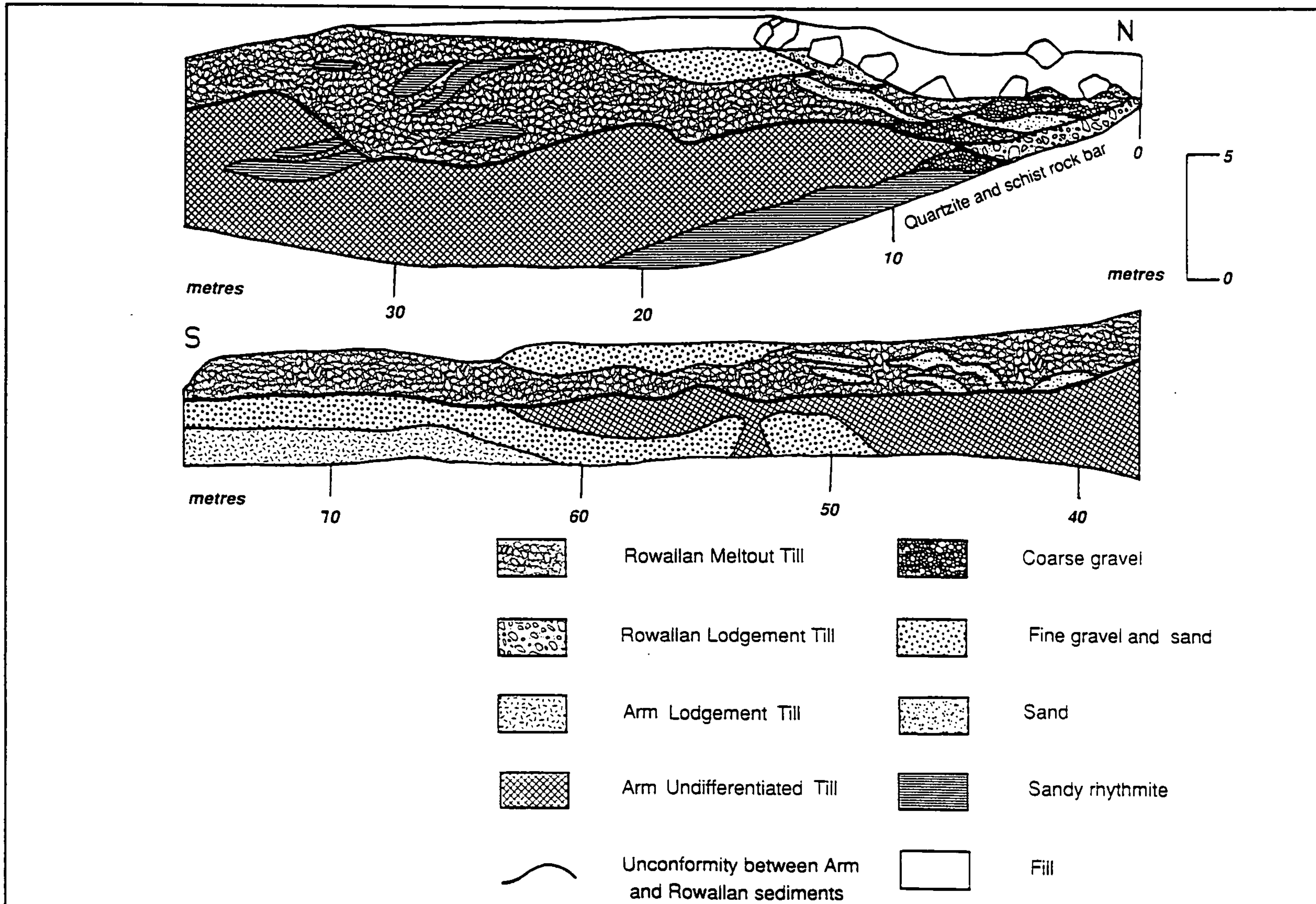

Figure 12: The section in the overspill channel of Rowallan Dam.

Figure 14: The Rowallan Dam section showing Arm age solifluctad till underneath Rowallan age till and glacifluvial sand and gravel. The iron pan appearance of the unconformity is clearly visible.

Figure 13: The sedimentary complex resting on the quartzite and schist rock bar below the Rowallan Dam. The unconformity between Arm and Rowallan age sediments is shown by the arrow. The two sticks are 5 m apart. The boulders at the top of the complex are fill.

The 80 m-long section is best observed on the eastern wall towards the northern end. An erosion surface occurs which is accentuated by an ironpan. It is overlain by 1.9 m of meltout till and 0.6 m of glacifluvial fine gravel and sand. The meltout till is relatively unweathered, is brown (10YR, 4/6) and contains clasts of dolerite, quartzite, schist and mudstone. It lacks the structure, texture and cohesiveness of a basal till deposit but has a pronounced horizontal alignment. The dolerite clasts are virtually unweathered (mean = 0.6 mm, standard deviation = 0.16 mm, minimum = 0.1 mm, maximum = 0.8 mm). The fine gravel and sand is also unweathered. The sand is well sorted, has occasional dolerite pebbles and is brown in colour (7.5YR, 4/6). It is identical to sand deposits which occur extensively beneath the river terraces along the banks of the Mersey River. Below the erosion surface there is approximately 1 m of weathered soliflucted till (undifferentiated till on Figure 12) overlying 0.7 m of fine gravel and sand, which in turn overlies 2 m of older lodgement till. By comparison the till below the erosion surface is quite weathered, bright brown in colour (7.5YR, 5/6) and contains clasts of dolerite, quartzite, schist and mudstone. The analysis of the dolerite clasts shows a greater degree of weathering than the overlying till (mean = 2.0 mm, standard deviation = 0.69 mm, minimum = 0.8 mm and a maximum = 3.9 mm). The lower sand rests unconformably on the till, shows a horizontal lamination and has a dark reddish-brown colour (2.5YR, 3/3). The erosion surface extends the length of the 80 m section and is accentuated in parts by the development of the crusty reddish brown ironpan. The surface undulates with an amplitude of approximately 2 m due to the collapse of the underlying sediment which is soliflucted meltout till, sand, gravel, rhythmically bedded silts and clays and basal till. In one place the lower undifferentiated till has collapsed to produce a wedge shaped structure of basal till in undifferentiated till. It is suggested that this feature is tectonic rather than periglacial in origin.

The western bank of the section also shows a complex sedimentary structure. It is not easy to interpret due to recent collapse, but it does not seem to add any information that was not seen in the well exposed eastern bank section.

This Rowallan section therefore, provides additional stratigraphic evidence for the relationship between the Rowallan and Arm glaciations and acts as an additional reference site for the comparison of Arm and Rowallan age sediments.

The stratigraphic relationship between the Arm and Croesus glaciations

Stratigraphic data from two related sections in the Arm Valley, discussed by Hannan and Colhoun (1987, p. 42), provide evidence for a glaciation older than the Arm Glaciation. Figure 15 and Table 2 summarise the situation.

A section on a disused logging road on the slopes of Maggs Mountain reveals a solifluction deposit exposed above Permian mudstone and underling Arm Till. This suggests that the solifluction deposit is older than Arm Glaciation age.

The other section is in a quarry, 400 m west, the same solifluction deposit rests on an ice-abraded surface of Permian mudstone. This suggests that the solifluction deposit is an old, soliflucted till. The ice-abraded features in the quarry section were exposed by shovelling the overburden solifluction material away from the surface then washing it carefully with water. Approximately 12 square metres of surface were exposed before abrasion features were visible. In this location the Permian bedrock is highly fissile, but where it is ice-abraded it appears indurated to a few millimetres below the surface which allows features to be preserved. A set of striations indicates a direction of ice flow towards 338°. A miniature crag and tail, with the crag a quartzite pebble and the tail made of moulded mudstone, is also present (Figure 8). It is some 250 mm long, and indicates an ice flow direction towards 323°. A similar feature from the Kakskielaklobb Peninsula where a hard

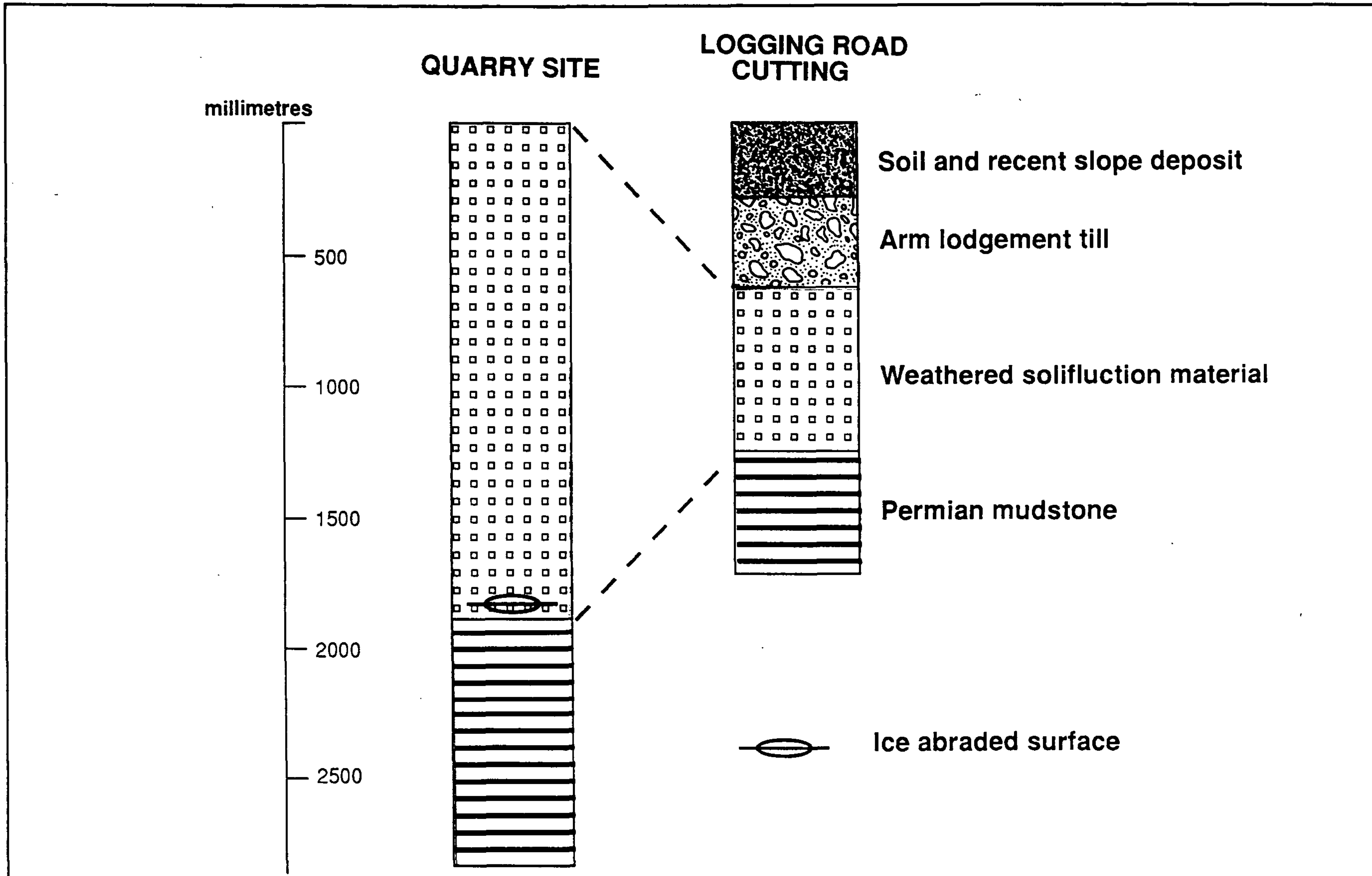

Figure 15: The quarry and logging road section in the upper Arm Valley which demonstrates the relationship between Arm Till and Croesus Till.

Table 2: Stratigraphic summary of the sections in the upper Arm Valley

	Thickness	Structure	Clast Composition	Clast Weathering	Matrix Colour
Logging Road Section					
Scree	50 mm	massive	quartzite and sandstone	not measured	not recorded
Younger solifluction material	300 mm	massive	sandstone, dolerite and mudstone	not measured	brown (7.5YR, 4/6)
Arm Till	350 mm	massive	sandstone, dolerite, mudstone and basalt	mean =3.4 mm st dv =0.93 mm max =5.6 mm min =1.2 mm	brown (7.5YR, 4/6)
Weathered solifluction material	600 mm	crumbly, massive	sandstone-76% dolerite-15% basalt-6% mudstone-2% quartzite-1%	mean =6.3 mm st dv =5.0 mm max =12.2mm min =3.6 mm	dark reddish brown (5YR, 3/6)
Mudstone	500 mm (min)	broken and crumbly	---	---	---
Quarry Section					
Weathered solifluction material	2 m (max)	non-coherent, massive	mudstone-49% dolerite-33% quartzite-9% sandstone-5% basalt-4%	mean =10.4mm st dv =2.69mm max =16.8 mm min =3.1 mm	dark reddish brown (5YR, 5/6)
Mudstone	6 m (min)	closely bedded, coherent	---	---	---

silicate knob had a 2 m tail of limestone bedrock, is described by Embleton and King (1968, p. 142).

The strength of the stratigraphic evidence depends on the two strongly weathered, older solifluction deposits being correlates. Geographically they are extremely close together and stratigraphically are superimposed on the same Permian mudstone. Clast analysis has similarities in that both contain mudstone, dolerite, sandstone and basalt. The difference between the sandstone and mudstone components is explained in terms of the regional geology; where sandstone is found on the slopes of the valley and mudstone on the lower flanks. The quarry is located some 50 m to 60 m vertically below the section of the logging road. In both deposits the dolerite pebbles are considerably more weathered than those in the Arm Till. There is some difference in the statistics for mean thickness of the dolerite weathering rinds between the two sites. The section in the disused logging road occurs on a reasonably steep slope. The dolerite pebbles found in this solifluction material were generally smaller than those which occur in the quarry. A number were completely weathered and thus only minimum rind thickness values could be obtained. It can also be argued that the rate of weathering on a flat surface is greater than that on a slope, since the water retention on the flatter site would be greater. It is therefore reasonable to suppose that the weathering rinds of the dolerite pebbles in the quarry should show higher mean values than on the slope.

These two sections indicate that an older till than the Arm Till is present in the district and that this till is extremely weathered. The older till is presumed to be the result of an earlier glaciation which has been called the Croesus Glaciation. The type section for till of this glaciation occurs near the Croesus Cave Reserve and is described in a later section (see page 132)

WEATHERING CHARACTERISTICS OF THE GLACIAL, GLACIFLUVIAL AND SOLIFLUCTION DEPOSITS

The weathering of the matrices of the tills

To record the extent of weathering in the matrices of tills three aspects were examined: the colour; the development of iron and manganese staining; and the general appearance, including structure.

The general characteristics of a till matrix, other than colour which is treated separately, are coherence, hardness and texture. The Rowallan Till is the least weathered till and in terms of the above criteria the matrix is coherent, reasonably hard and usually has a fine grained sandy and gritty texture. In localities dominated by Permian mudstone or Triassic sandstone clasts, the texture can be relatively even grained. The matrices of older tills have a tendency to be less coherent and considerably softer. The texture of the older tills is finer due to weathering of the particles in the matrices. The most common structure found in basal Rowallan Till is a fissility, which has a sub-horizontal orientation. Dreimanis (1976, p. 33) observes that "fissility, also called foliation, 'shear lenses', or 'laminated structure', is the most commonly mentioned structure of basal till and is particularly noticeable in silty tills." This fissility is also seen in some outcrops of Arm Till but has not been observed in the highly weathered Croesus Till.

In general it is found that the fresh till matrix, composed mainly of dolerite material, tends to be light brown and grey. Rowallan Till has colours in the range of brown (10YR, 4/4), dull yellowish brown (10YR, 5/3), grayish yellow brown (10YR, 6/2) and brownish gray (7.5YR, 6/1). With increased weathering the matrix becomes redder. Typically the matrix of Arm Till has colours in the range bright brown (7.5YR, 5/8); bright brown (7.5YR,4/6) and brown (7.5YR, 4/6). At the extremes of weathering the till matrix takes on a mottled appearance of deep red-brown and yellow. To note the colour of the matrices of older tills it is often necessary to record two colours. For example at the type section of Croesus Till the colour is recorded as bright reddish brown (5YR, 5/6) and dark reddish brown (5YR, 3/3), while at an other location dull reddish brown (2.5YR, 4/4) and bright reddish brown (5YR, 5/6) are recorded. The difference in colour with age is not a novel concept and has been discussed by Kelly and Baker (1966), who analysed orange zones within buff coloured till, and provided strong evidence that these were blocks of older till incorporated into the matrix of a younger till.

An unweathered till matrix shows no iron or manganese staining. A low intensity of manganese staining occurs in slighly weathered tills, and is concentrated around the moulds made in the matrix by clasts. Slight manganese staining is found in very few till of Rowallan age, but all tills of Arm age, which have been exposed to weathering have slight to intense manganese staining. Iron staining is found in the matrix of deeply weathered tills. Some of the deeply weathered tills of Arm age show signs of iron staining and most tills of the Croesus age are intensely iron stained

The thicknesses of dolerite clast weathering rinds in tills

Dolerite outcrops widely throughout the area and overall it is the most common clast in the tills, slope deposits and glacifluvial deposits. Dolerite is composed essentially of the minerals labradorite and augite, both of which weather fairly readily. The ophitic texture of dolerite has the effect of holding the weathered outer skin intact despite the chemical depletion of the mass and hence the weathering rind so formed remains reasonably coherent. The thickness of the weathering rind can be regarded as a function of time that is confounded by a number of other variables. Measurements of dolerite rind thickness in various glacial deposits, but mainly tills, were made for the purpose of trying to establish the relative ages of the deposits.

The measurement of dolerite weathering rind thickness as a relative dating technique has been used in Tasmania by Augustinus and Colhoun (1986), Kiernan (1983,1985), Caine (1983) and Colhoun (1976,1980,1985a). Overseas a number of different rock types have been measured for the same purpose. Gellatly (1984) and Chinn (1981) used sandstone clasts, Colman (1981) and Colman and Pierce (1981) used basalt and andesite clasts, Porter (1981) used volcanic clasts and Burke and Birkeland (1979) used granodiorite and monzonite clasts. In all cases the technique has been of use in establishing tentative relative ages, either in situations where there has been a lack of a framework provided by numerical ages or stratigraphy, or to support a framework established by numerical dating and stratigraphy.

Those who have used the technique have generally commented favourably on its usefulness. Porter (1981, p. 266) states "weathering rinds proved to be among the most useful of the weathering parameters". In their experimental study of the technique, Colman and Pierce (1981, p. 191) conclude that "weathering rinds have been shown to be an excellent indicator of relative age". In a review article on relative dating techniques, Brookes (1982, p. 191) reports that "the thickness of weathering rinds on boulders in glacial deposits has proved an effective discriminator of weathering intervals".

A basic assumption of the technique is that the clast used for measurement is free of weathering rind at the time of deposition. In deep sections of Rowallan Till and Arm Till it is possible to observe unweathered dolerite pebbles below the weathering front. With the Croesus Till no such outcrop has yet been seen but it is assumed that this till is no different in this respect from the Arm and Rowallan tills. The prime objective of the technique is to estimate the effect that time has on the thicknesses of weathering rinds and so it is important that confounding variables are identified and, if possible, controlled or at least noted so that their effect can be estimated. Colman and Pierce (1981, p. 4) discuss two groups of variables which can influence the formation or measurement of weathering rind thickness; environmental factors and sampling factors. Environmental factors include parent material, climate, vegetation, topography and time. Sampling factors include the selection of sites, collection of samples from the sites, procedures for measuring the selected samples and variance of the operator.

In the upper Mersey Valley, the standardisation of the parent material on dolerite was the easiest of the environmental factors to control. Dolerite intruded the area in the Jurassic Period as thick sills and feeder dykes. As cooling occurred from the edges of the intrusions, differentiation by fractionation and crystal settling produced different textures and grain size at various heights within the sill (McDougall, 1958, p. 52). To allow for the possibility that some of these textural variations could influence the rate of weathering, the standard parent material for measuring rinds was closely confined to medium grained dolerite.

The major climatic variable found by Colman and Pierce (1981, p. 14) was that increasing precipitation generally increased the thickness of weathering rinds on andesite. They also indicate that the effect of temperature on weathering rind development is largely unevaluated. In the upper Mersey Valley it is difficult to judge the climatic effect as the rainfall stations are spread far apart and the figures obtained are varied. The area falls within the 1600-2400 mm isohyets on the regional average annual rainfall map (Bureau of Meteorology, 1980, p. 2) although in the valley floors the value may be as low as 1200 mm. The two official meteorological stations closest to the region of investigation are Cradle Valley (2777 mm) and Lake Mackenzie (1847 mm). Specific rainfall data, for selected sites, recorded by the Hydro Electric Commission over periods ranging from 4 to 27 years (personal communication) have been previously discussed on page 10. However, the values are less than in the West Coast Ranges where Kiernan (1983,1985) made many of his measurements and are more comparable with Lake St Clair.

For the temperature variable the only figures available are for Cradle Valley with an annual maximum of 10.9°C, average annual minimum of 2.2°C. and an annual average of 6.3°C. From these data it would appear that the climatic variable is largely an uncontrolled one due to the lack of available data and rapid variation occurring over the area, where measurements of rind thicknesses were taken. In general, it has been found that the rind thickness in tills increases to the north. This is the direction of decreasing rainfall and possibly increasing temperature. If the results of Colman and Pierce (1981) are applied then the expectation would be that the thickness of weathering rinds would decrease to the north. Hence, it would seem that although the variable is uncontrolled its effect would be to reduce the magnitude of the measurements obtained in the northern regions, thereby reducing the general effect which has been obtained from the data.

The climatic history of the region could also be regarded as a possible variable to influence the degree of weathering. It is assumed that if the climate varied in the past it would not have had a regional pattern that is not greatly different from present. This would result in an exaggeration of the effect outlined above i.e. greater rainfall in the southern area for a longer period of time compared with the northern area and would have the effect of reducing weathering in the northern area.

The effects of topography include those of erosion and deposition. At some localities the effects of erosion were noticeable. For example, the weathering rinds for clasts from the partially stripped Arm Till underlying Rowallan Till at February Creek were significantly thinner than in other areas. Colman and Pierce (1981, p. 10) discuss a similar situation. The effect of deposition is less clear but where older sediments were found buried by later sediments no anomolous results were detected. A related phenomenon is that sediment below the weathering profile shows little to no weathering at all. This has been mentioned already with respect to the Arm and Rowallan tills. It is possible that further complications occur with outcrops on slopes being less weathered than similar outcrops lying on or near horizontal surfaces. Water runs off steep slopes more quickly than gentle slopes or flat surfaces. The sediment on the steep slope will be better drained than sediment on the lower slopes and valley floors. This may influence the rate of weathering and has been mentioned previously when comparing the weathering rinds on two deposits of soliflucted Croesus Till (see page 57).

Present vegetation covering the glacial sediments of the upper Mersey Valley is generally rainforest in the valleys, sclerophyll forest on the slopes and moorland in higher regions. Kiernan (1983, p. 201) sees fire history as a potentially uncontrolled variable which is related to vegetation. Whatever the vegetation history or fire history, it would seem reasonable to assume that in a continuous area of similar vegetation the effects on weathering rinds of dolerite would be relatively minor.

Kiernan (1983, p. 201) maintains that it is also possible that clast composition of the sediments can influence the rate of weathering. He thus sampled sites where dolerite clasts were 70% of the total clast analysis. This possibility was noted and taken into account in the evaluation of the results of the weathering data.

Sampling sites were selected first on stratigraphic grounds with measurements taken at significant stratigraphic locations. This allowed stratigraphic units to be "characterised" and the technique to be "calibrated". Sites which were geographically isolated and contained single units could then be included in the overall scheme. There was no attempt to use random procedures to select sites as in done by May and Dreimanis (1976, p. 100). At each site samples were collected as per Kiernan (1983, p. 201), from within, or as near as possible to, the soil B horizon, where the pebbles are generally most weathered and least likely to have been subject to reworking since deposition. The independence and randomness of sampling within a site is discussed below in the section on statistical procedures. In previous studies the number of samples collected varied. Chinn (1981) collected 50 samples; Colman and Pierce (1981), 30-60; Gellatly (1984),30-50; and Augustinus and Colhoun (1986), 20. In this study 50 samples were taken from each locality.

The procedure for measuring samples remained the same throughout the study. The yellow-orange to brown coloured weathering rinds on dolerite are discrete and contrast markedly with the dark grey of the unweathered rock. The rinds are coherent, tough and granular in younger weathered material, but softer and more clay-rich in older material. These properties allow them to be measured with relative ease in the field. Dolerite pebbles of greater than 20 mm were selected, from the zone of maximum weathering. These were split open with a crack hammer and the rind thicknesses measured with a vernier caliper. Some of the very large weathering rinds were recorded using a tape measure. For measurements up to 120 mm in thickness (the maximum measurement possible on the vernier calipers) the rind measurement was recorded to the nearest 0.1 mm and above 120 mm the measurement was made to the nearest 1 mm. The measurement of the rind was made perpendicular to as flat a face as possible on the pebble. No measurements were recorded from the zone around the fracture made in splitting the rock or from curves or concave depressions in pebbles as these zones tend to accumulate foreign material from the matrix of the sediment making the outer limit of the rind difficult to determine (Colman and Pierce, 1981, p. 8). Where there were markedly varied thicknesses visible on different parts of the same specimen it was deleted from the sample. Very few samples had to be discarded for this reason.

Chinn (1981, p. 39) discusses the difficulty with a diffuse inner boundary in the sandstones of the Torlesse Group of New Zealand. No such difficulty exists with dolerite as the reddish brown rind is clearly differentiated from the dark gray rock.

Statistical design and discussion of results

The statistical analysis is used to support the field evidence and to create hypotheses which allow the data to be explored with the possiblity of establishing further relationships. Such statistical relationships established from the data are useful but the geomorphic, stratigraphic and sedimentological data must remain as the primary evidence.

An important paper on the use and analysis of weathering rinds is that of Colman and Pierce (1981), where the weathering rinds on basalt and andesite from a number of areas in the United States are compared. Three sets of data from McCall, Lassen Peak (andesite) and Lassen Peak (basalt) were analysed intensively. The statistical design used by Colman and Pierce has formed the basis of the statistical analysis in this study.

All measurements of the thicknesses of weathering rinds in the upper Mersey Valley were recorded in the field and then transferred into a file in a Macintosh computer. Using the statistical package Statview each site comprised a separate record. Three types of statistical measure were calculated. A descriptive profile for each site, as well as describing the data, provides information for checking the samples for conformity with the underlying assumptions of the statistical tests. For example, to use parametric statistics requires that the data are recorded at interval level and should approximate a normal distribution. The second level of the statistical analysis is designed to make comparisons between the sites and is based on the analysis of variance technique. The third level is designed to give weight to the field evidence for the ages of the different deposits and uses the Scheffé test and Fisher Least Squares Difference (LSD) test.

For each site the descriptive statistics from the Statview package were calculated and include the mean, standard deviation, variance, maximum, minimum, range, skewness and kurtosis. The mean is commonly quoted and used as the characteristic descriptive measure in quantitative studies of the weathering rinds of rocks (Porter, 1975; Burke and Birkeland, 1979; Colman and Pierce, 1981; McGregor, 1981; Kiernan, 1983; Augustinus and Colhoun, 1986; Hannan and Colhoun, 1987). Less frequently the mode is used (Chinn, 1981; Brookes, 1982; Gellatly, 1984). All short descriptive statistics of weathering rind samples in this study quote the mean, standard deviation, maximum and minimum.

To satisfy the underlying asumptions of the statistical measures selected, the data must meet the general requirements for parametric statistics, and the specific requirements of analysis of variance. Parametric statistics require a normal distribution in the population being sampled and interval level data (Popham and Sirotnik, 1973, pp. 269-270). The data in this study conform to the requirements of interval level since they are measures of length. The normality of the data was checked in a number of ways. Each sample was subjected to a normality test using Chi square (Norcliffe, 1977, p. 65). Most of the samples can be considered normal at the 5% statistical level. Only one sample of Croesus Till and five samples of Rowallan Till cannot be considered as normal distributions at the 5% level. The problem of younger age material with thin weathering rinds not conforming to a normal distribution is described by Colman and Pierce (1981, p. 19). The skewness and kurtosis also suggest that most of the samples approximate to a normal distribution. Finally, histograms for the various site populations were plotted and the normality of the data was again demonstrated.

Edwards (1969, p. 145) states that the assumptions of the analysis of variance are fourfold: (1) the population distributions are normal; (2) the observations are independent and random; (3) the populations have the same variances; and (4) the populations have the same mean. He goes on to indicate that departures from normality and the equivalence of variances are relatively unimportant provided that the number of observations are relatively large and that the same number of observations is taken for each treatment group. Other authors indicate a similar stance (Keppel, 1973, p. 73; Popham and Sirotnik 1967, p. 238). It has already been indicated that there were 50 observations taken at each site in this study. This is regarded as a sufficient number as Silk (1979, p. 170) indicates that in comparison of means there should be more than 30 samples. That some of the data sets described in this study are not quite normal is not a serious violation of the assumptions. The requirement for homogeneity of means and variances is a problem, since the means and variances show a considerable variation. Transformation of the data is possible either by taking logarithms or using an inverse exponential (cube root or fourth root) of each observation. Both of these transformations were used to reduce variation of the mean and standard deviation in the data. Comparisons between raw data and transformed data are discussed below. The remaining assumption underlying the analysis of variance test is that the observations are independent and random.

The exact requirements of "random sampling" are difficult to envisage in some field situations. Given that sampling is limited to dolerite clasts taken from the soil B horizon is a considerable restriction in small outcrops. Andrews (1971, p. 11) discusses the procedure for sampling a site for till fabric analysis. He suggests that samples be taken from the whole area of the outcrop, including vertical faces and horizontal faces, and should include stones projecting out of the face as well as stones completely embedded. As far as possible this procedure was adopted and clasts were measured across the whole B soil horizon. The situation is the same as that described by Colman and Pierce (1981, p. 17): "although we would argue that little or no bias has been introduced by our procedures, they do preclude exact probability calculations for statistical tests. Neverthless, comparisons of the magnitudes of differences and amounts of variation are valid, especially because we believe that our sampling procedures introduced little bias into the data."

The statistical design is required to provide evidence that weathering rind samples from the various glaciations are significantly different. "The analysis of variance is a method of separating the total variance of a response into its separate components, corresponding to the sources of variation which can be identified." (Davies and Goldsmith, 1972, p. 123). A hierarchic (or nested) design of analysis of variance with three sources of variance, viz: age, site and observation was selected to show the amount of variation attributable to each source. This is virtually the same design as used by Colman and Pierce (1981). Variation due to errors in measurement are confined to the observation level; variations attributable to the site, which includes climate, vegetation, soil and topography are shown at the site level; and variations due to age are revealed at the age level of the hierarchy. The calculations follow the method outlined in Davies and Goldsmith (1972, p. 164). Calculations are made for raw data and data transformed both logarithmically and inverse exponentially.

The straight one-way analysis of variance of the means of all the samples, for both raw data and transformed data, shows that a significant difference exists at the <0.001 level. An analysis of variance test is employed as an overall screening method to see whether or not significant differences occur in the data. Since this is the case the next step is to indicate the sources of variation. In other words do these differences occur because of the measuring technique used, the differences in the environment between the sites or because of the different ages of the site-groupings? The nested analysis of variance test apportions variance to each of these nested groups. Table 3 summarises the results of this test.

The part of Table 3 based on raw data, allocates 43.4% of the variance among ages, with 35.6% among sites and 21.7% within sites. The allocation of variance among ages is low compared with the logarithmic and inverse exponential transformed data, which allocates 85.1% and 82.7% among ages and lesser amounts among sites and between sites. The most important point is that in all three calculations the majority of the variance is allocated among ages and that the result is statistically significant. This suggests that the most important variable is the

Table 3: Statistical summary of the weathering rind data analysis

SOURCE	SUM OF SQUARES	DEG. OF FREEDOM	MEAN SQUARE	LEVEL	UNIT SIZE	VARIANCE	% OF VARIANCE	F	P
Raw data, three ages of glaciation									
Among ages	65,156.3	2	32578.1	1	3	58.84	43.4	13.3	<< 0.01
Among sites	73,333.3	30	2444.4	2	33	48.32	35.6	85.3	<< 0.01
Within sites	46,324.9	1617	28.7	3	1650	28.65	21.1		
Raw data, four ages of glaciation									
Among ages	115,402.6	3	38467.5	1	4	107.79	71.0	48.3	<< 0.01
Among sites	23,087.0	29	796.1	2	33	15.35	10.1	27.8	<< 0.01
Within sites	46,324.9	1617	28.7	3	1650	28.65	18.9		
Logarithmic data, three ages of glaciation									
Among ages	2,544.5	2	1272.2	1	3	2.46	85.1	88.7	<< 0.01
Among sites	430.2	30	14.3	2	33	0.28	9.7	95.6	<< 0.01
Within sites	235.5	1617	0.2	3	1650	0.15	5.2		
Inverse exponential data, three ages of glaciation									
Among ages	248.8	2	124.4	1	3	0.24	82.7	65.5	<< 0.01
Among sites	57.5	30	1.9	2	33	0.04	12.5	136.9	<< 0.01
Within sites	23.1	1617	0.01	3	1650	0.01	4.8		
Inverse exponential data, four ages of glaciation									
Among ages	279.2	3	93.1	1	4	0.26	90.5	14.9	<< 0.01
Among sites	27.2	29	0.9	2	33	0.02	6.1	1.62	≈ 0.01
Within sites	23.1	1617	0.01	3	1650	0.01	4.7		

different age of the data. The discrepancy in the calculations using raw data and transformed data is due to a breach in assumptions of the analysis of variance. Two of the Croesus Glaciation sites have very much larger means and variances than other sites. The transformation of the data reduces the spread and hence the true picture is given in the transformed data calculations. To check this explanation the raw data was re-calculated in two different ways:

(i) The two "outliers" were taken to be part of an older glaciation and hence a different age; i.e. it was assumed that there were 4 ages of glaciation involved. The re-calculation produces an among ages variance of 71.0% for the raw data. This finding is repeated in the transformed data as well, where the allocation of variance rises to 87.2% in the logarithmic transformation and 90.5% in the inverse exponential transformation.

(ii) The calculation was performed without the two "outliers" in the raw data. i.e. they were ignored. The re-calculation produces an among ages variance of 81.5% for the raw data.

In summary, this level of the statistical analysis shows that there is a statistically significant difference between the various sites at which weathering rind measurements were made, and that approximately 80% of the variance of this difference is attributable to the different age-groupings of the data. The statistical probabilities for each of these differences is highly significant. For the table showing raw data only it is clear that the effect is masked by a statistical breach. Further, there is a suggestion that there may be a fourth period of glaciation involved, since the two highest means for the Croesus Glaciation are so much greater than at any other site. This glaciation would occur temporally between the Croesus Glaciation and the Arm Glaciation.

The final level of statistical analysis is to make comparisons between individual sites. The Scheffé test and Fisher LSD test are used for this purpose. The Scheffé test is used in multiple comparisons and involves comparing means of more than two groups (Keppel, 1973, p. 144). Means of all sites, where weathering rind observations were taken, are compared with each other. The Scheffé test was calculated for both raw data and logarithmically transformed data, with little variation in the results being noted. Figure 16 summarises the results of the Scheffé test comparisons for inverse exponential data. The axes of the table represent sites listed in rank order of their means. The symbols indicate whether a significant difference occurs at either the 5% or 1% level. The test is reasonably discriminatory as it accounts for 93% of the differences between Arm and Rowallan tills; 97% of the differences between Arm and Croesus tills and 100% of the differences between Rowallan and Croesus tills. It does include significant differences within till groups; 18% within samples of Rowallan Till, 38% within samples of Arm Till and 61% within samples of Croesus Till. It should be noted that some of the samples of Arm Till include those which were eroded by Rowallan age ice and consequently they may have had the zone of maximum weathering removed. The high number of significant results within the Croesus Till data reflects two facts. First that there is a large spread in the Croesus Till statistics; means vary from 6.3 mm to 50.8 mm, standard deviations from 2.02 mm to 24.46 mm, minima from 3.6 mm to 6 mm and maxima from 13.2 mm to 190 mm. Further the number of sites is six, which is much smaller than for other age groupings. This could account for the differences indicated by the Scheffé test but the previous suggestion that there could be more than one age represented in the Croesus data is again strongly indicated.

In the Fisher LSD test the means are listed in rank order and a comparison is made between successive pairs of means, from lowest to highest along the rank. Where two means are found to be statistically different then a 'statistical break' in the continuum is indicated at that point (Wall, 1986, p. 15.9). The Fisher LSD test was

X -- SIGNIFICANT AT THE 0.01 LEVEL

• -- SIGNIFICANT AT THE 0.001 LEVEL

	mean	rank order	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
ROWALLAN TILLS	0.2	(1)																																	
	0.2	(3)																																	
	0.2	(3)																																	
	0.3	(4)																																	
	0.3	(5)																																	
	0.4	(6)																																	
	0.5	(7)	•																																
	0.6	(8)	•	•	•	•																													
	0.7	(9)	X	X	X	X	•																												
	0.7	(10)	X	X	X	X	•																												
	0.9	(11)	X	X	X	X	X	•																											
ARM TILLS	1.1	(12)	X	X	X	X	X	X	•																										
	1.2	(13)	X	X	X	X	X	X	X	•	•																								
	1.5	(14)	X	X	X	X	X	X	X	X	X	•																							
	1.5	(15)	X	X	X	X	X	X	X	X	X	•																							
	1.7	(16)	X	X	X	X	X	X	X	X	X	X	•																						
	2.0	(17)	X	X	X	X	X	X	X	X	X	X	X	•																					
	2.1	(18)	X	X	X	X	X	X	X	X	X	X	X	•	•																				
	2.4	(19)	X	X	X	X	X	X	X	X	X	X	X	X	X	•																			
	2.5	(20)	X	X	X	X	X	X	X	X	X	X	X	X	X	•	•																		
	3.1	(21)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	•																	
	3.2	(22)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	•																
	3.3	(25)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	•																
	3.4	(24)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	•	•	•														
	4.2	(25)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	•														
	4.3	(26)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	•													
	4.5	(27)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	•	•	•	•									
CROESUS TILLS	6.3	(28)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	•	•	•						
	7.9	(29)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	•					
	10.1	(30)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					
	10.5	(31)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	•	•			
	21.5	(32)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
	50.8	(33)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	

ROWALLAN TILLS (1–11) | ARM TILLS (12–27) | CROESUS TILLS (28–33)

Figure 16: A summary of the statistically significant results obtained using the Scheffé Test.

Table 4: Results of the Fisher LSD Test showing the significant statistical breaks in weathering rind data

	Sample Mean and Rank Order	
ROWALLAN TILL	0.2 (1)	
	0.2 (3)	
	0.2 (3)	
	0.3 (4)	
	0.3 (5)	
	0.4 (6)	
	0.5 (7)	
	0.5 (8)	
		Statistical Break 1
	0.7 (9)	
	0.7 (10)	
	0.9 (11)	
		Statistical Break 2
ARM TILL	1.1 (12)	
	1.2 (13)	
		Statistical Break 3
	1.5 (14)	
	1.5 (15)	
	1.7 (16)	
	2.0 (17)	
	2.1 (18)	
	2.4 (19)	
	2.5 (20)	
	3.1 (21)	
	3.2 (22)	
	3.3 (23)	
	3.4 (24)	
		Statistical Break 4
	4.2 (25)	
	4.3 (26)	
	4.5 (27)	
		Statistical Break 5
CROESUS TILL	6.3 (28)	
		Statistical Break 6
	7.9 (29)	
		Statistical Break 7
	10.1 (30)	
		Statistical Break 8
	10.5 (31)	
		Statistical Break 9
	21.5 (32)	
		Statistical Break 10
	50.8 (33)	

calculated for both raw data and transformed data, and there is little difference between the results. For simplicity only the inverse exponential data is reproduced. Table 4 is a representation of the results of the statistic applied to inverse exponential data. Nine 'statistical breaks' are shown in the rank order indicated on the weathering rind analysis from the tills. Statistical Breaks 2 and 5 respectively, verify the stratigraphic field evidence which defined the difference between the Rowallan and Arm glaciations, and the Arm and Croesus glaciations. Statistical Break 1 separates the last three samples of the Rowallan Till in the rank order. These three tills are found at the top of valleys and, as with a number of tills in this situation, contain a higher proportion of angular clasts. It also suggests that this material may not have suffered the same degree of glacial attrition as did the clasts deposited from the glacier and exposed at lower altitudes in the valley. This being the case, it is possible that the tills at the top of the valleys contain material which was added to the glacial load, probably by mass movement. Such material may have already been weathered and the weathering rind may not have been completely removed by attrition. Statistical Break 3 indicates samples of Arm Till that were eroded by the Rowallan Glaciation and it is suggested that some of the till containing the more weathered clasts was removed. The rest of the 'breaks' cannot be simply explained. Statistical Break 4 isolates some of the Arm Tills in the northern part of the area, which are at a lower altitude. Statistical Breaks 6, 7, 8 and 9 clearly indicate the large differences which occur in weathering rinds of the samples of Croesus Till and highlight again the possibility of more than one glaciation older than the Arm Glaciation.

While the possiblility of a fourth glaciation is a reasonable expectation there is as yet no stratigraphic evidence that allows confirmation of such an event.

Weathering of glaciofluvial sediment

Other glacial deposits were examined for the purpose of establishing relative ages. Observations of the degree of weathering of solifluction deposits, rhythmites and glacifluvial deposits were made. Solifluction deposits as relative indicators of age pose a particular problem because it cannot be assumed that the matrices and clasts had the same degree of weathering when emplaced in their current situation. Throughout the area solifluction deposits have been derived from screes, dolerite outcrops by mass movement and till of the Croesus and Arm glaciations. Each of these deposits would have a different degree of weathering prior to becoming solifluction material.

Rhythmites associated with each of the three glaciations have been identified. Their weathering characteristics give some slight indication of differences in age. The least weathered rhythmites are sandy and were recovered from the cores in Dublin Bog and Pillinger Bog. These rhythmites are of Rowallan Glaciation age and are coloured olive grey (7.5GY, 5/1). They are totally unweathered. They are very flexible when saturated with water and are quite porous. In the Fish River gorge adjacent to the start of the Walls of Jerusalem track about 1.5 km upstream from the road bridge there are approximately 8 m of Rowallan age rhythmites exposed at the base of a 40 m-thick section. These are sandy in texture, slightly weathered and have a grayish olive colour (5Y , 5/2). They are flexible and contain little or no water, but are quite porous. The state of weathering of these rhythmites is comparable with the similar rhythmites of Rowallan age which are found in Wurragara Creek and the Lees Paddocks area.

By comparison the rhythmites exposed in the Arm Valley and deposited during the Arm Glaciation are considerably weathered and have a bright brown colour of (7.5YR, 5/6). They are very dry, quite brittle and are unable to take up much water. Rhythmites of the Croesus Glaciation are exposed at the Lemonthyne Dam and are Bright reddish brown (5YR, 5/6)

The weathering characteristics of two glacifluvial sand deposits can be directly compared in a section in the overspill channel section of the Rowallan Dam, where the sand of the Arm Glaciation is overlain by meltout till and sand of the Rowallan Glaciation. The Arm Glaciation sand is dark reddish brown (7.5YR, 5/6) and is well sorted with few pebbles. It has a reasonable coherence and high porosity and has the appearance of being weathered. By contrast the Rowallan age sand is bright yellowish brown (10YR, 5/8). It is non-coherent, friable and readily crumbles into its constituent grains.

Because of difficulties of pre-weathering in the solifluction deposit, paucity of occurrence of rhythmites and glacifluvial sediment none of these deposits were systematically analysed. The effort was put into analysis of the tills which always seemed to promise more reliable results.

GEOGRAPHIC EXTENT AND LOCATION OF THE GLACIAL SEDIMENTS

The characteristics of the three ages of glacial till from the Rowallan, Arm and Croesus glaciations were established at type sections and key exposures. Outcrops of till across the whole region could then be identified and plotted on maps of the Tasmanian Lands Department Series 1:25000. Numerous recent exposures of Rowallan Glaciation age deposits permitted detailed mapping of till and the related periglacial and glacifluvial sediments. By comparison Arm Glaciation age deposits have a more restricted area of outcrop. They have been removed in the highland areas by erosion and covered in many lower areas by later solifluction deposits formed both during the Rowallan Glaciation and the later part of the Arm Glaciation. Nevertheless the Arm Glaciation deposits are readily identifiable by their greater degree of weathering. Croesus Glacial age deposits are the most restricted. They occur in isolated outcrops, due to erosion and burial by deposits formed during two subsequent periods of glacial activity, and weathering and erosion at other times. Figure 17 shows the extent of the three glaciations. It is clear, for reasons expressed above, that reconstruction of the Rowallan Glaciation is the most detailed and Croesus the least detailed. The

Rowallan Glacial system has a reticulate form with the main source an icecap on the Central Plateau. The ice flowed into the main valleys of the upper Mersey Valley and terminated in a number of lobes. Immediately outside the Rowallan Glaciation ice limits, deposits belonging to the Arm Glaciation ice are readily identifiable. The Arm Till, particularly the portion of the matrix in the B soil horizon is less coherent and more highly coloured than for Rowallan Till and contains dolerite clasts with mean weathering rinds greater than 1 mm but less than 5 mm. The limits of the Arm Glaciation ice are not as clearly defined as those of Rowallan Glaciation ice, but the general extent has been established in the main valleys. Outside the Arm Glaciation ice limits the Croesus Glaciation deposits have been identified at only a few outcrops.

The distribution of the three glacial drift sheets adds weight to the overall argument that there were a minimum of three distinct glaciations with older glaciations being more widespread than recent ones. A fourth glaciation has been tentatively suggested from statistical analysis. The distribution of drift from which this glaciation is inferrred lies between the known occurrences of the Croesus and Arm tills. The statistical data are consistent with the inferred glaciation occurring between the Arm and Croesus glaciations.

CHAPTER 5

THE ROWALLAN GLACIATION

An icecap on the Central Plateau was the main source of ice during the Rowallan Glaciation. The ice formed a classic reticulate system of valley glaciers ending in well defined lobes. Throughout the upper Mersey region there is abundant evidence related to the Rowallan Glaciation. This evidence is the focus of this chapter. Six characteristics of the Rowallan Glaciation are discussed: the extent of the glaciation ice, the ice movement directions, the sedimentary deposits, deglaciation features, the age of the glaciation and the climate at the time of the glaciation. A section will be devoted to each of the six characteristics.

EXTENT OF ROWALLAN GLACIATION ICE

Rowallan Glaciation ice occupied some 282 km^2 of the upper Mersey Valley at its maximum extent. In order to facilitate the discussion of this complex glacial system three parts are considered: the ice extent and effects in the highland areas, in the valleys and at the terminal lobes.

The Rowallan Glaciation ice in the highland areas

The geology of the highland areas is dominated by dolerite which is frequently jointed in several directions. Highland areas eroded by Rowallan Glaciation ice have little to no soil cover and what vegetation is present frequently concentrates around joints in the dolerite, with large areas of bare rock between. The depositional zones of Rowallan Glaciation ice by contrast are well covered with a light brown soil which is capable of supporting a variety of vegetation. Both erosional zones and depositional zones are found in the highland areas, with the

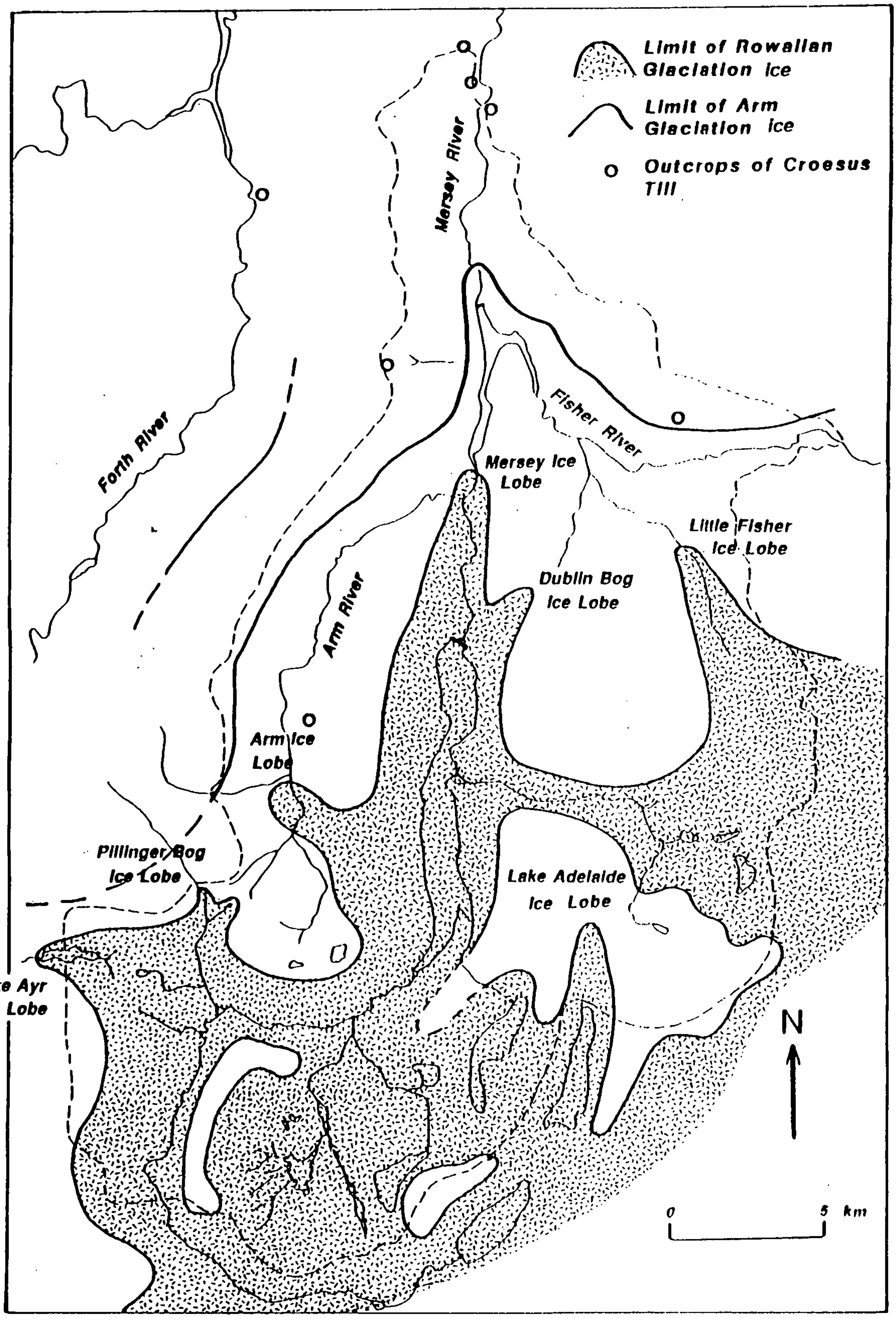

Figure 17: Extent of the three glaciations in the upper Mersey Valley.

erosional zones generally occurring at higher altitudes. For convenience of discussion of the extent of glaciation in the highland areas the region has been divided into six geographical areas; Cathedral Plateau, Mount Rogoona-Lake Myrtle area, Lake Louisa- Lake Adelaide area, Walls of Jerusalem area, Clumner Bluff-Deception Point Plateau and the Oakleigh Plateau.

The Cathedral Plateau

The eastern edge of the Mersey Valley above Lees Paddocks is formed by a linear scarp which rises to a maximum of 800 m above the river. There are a number of peaks discernable from Cathedral Mountain and Twin Spires in the south, via Bishop Peak in the centre to Curate Bluff, to Vicar Bluff and Dean Bluff in the north. These peaks form the western edge of an offshoot of the Central Plateau here named the Cathedral Plateau.

The Cathedral Plateau is somewhat dish-shaped and the mountains rise to heights of approximately 400 m above its centre. The central portion is dominated by the irregularly-shaped Chalice Lake (Figure 4). Drainage into Chalice Lake from the plateau is centripetal and only one stream, unnamed, flows out of the lake in a northeasterly direction, into Chapter Lake some 93 m below.

Ice of Rowallan age occupied the Cathedral Plateau but it was not sufficiently thick to cover Cathedral Mountain or any of the peaks above the Mersey River. Broadly this agrees with the findings of Derbyshire and others (1965) and Derbyshire (1968). Evidence of ice on the plateau occurs as isolated outcrops of Rowallan Till in small creeks and valleys. The central part of the plateau exhibits considerable ice scour, and Chalice Lake, an excellent example of a rock basin lake, occupies the central position along with numerous smaller lakes and tarns of similar origin. Countless roches moutonnées and whaleback forms are found with occasional glacial grooves and striations. Above the ice limits there is clear evidence of blockfields, blockstreams, screes and solifluction deposits which formed during the

Rowallan Glaciation. The extent of these features beyond the ice limits of the Rowallan Glaciation suggests the occurrence of periglacial action in the extraglacial area. Thick alpine soils have developed on the periglacial material in a number of places above the zone of ice action, for example, southeast of Dean Bluff. There is a gradation from the periglacial features above the ice limits on the plateau to the glacial features below. attempts to differentiate the boundary is a complex process as there is a prolific growth of alpine vegetation on the periglacial material. There are no outcrops of till near the interface and the limit of the ice was estimated by walking backward and forward from what was clearly glacial as judged by ice-eroded rock surfaces to what was clearly covered in boulders, debris and surficial deposits of periglacial origin. In this way the Rowallan maximum ice boundary was established to be just below 1280 m around Cathedral Mountain and 1230 m in the Dean Bluff-Premier Peak region.

Southeast of Cathedral Mountain there is a 3 km-long strip of small basin lakes which occupy the edge of the plateau immediately above the valley. In this region the glacier spilled over the top of the valley possibly because the valley is shallower here, with the floor as little as 350 m below the edge of the plateau. At the glacial maximum there would have been more than 500 m of ice above the valley floor. Derbyshire (1968) indicates this feature on a map as an overridden trough wall. Amongst the tarns there are a large number of ice transported boulders of dolerite.

The eastern edge of the Cathedral Plateau is delineated by a long, steep-sided flat-floored valley, resembling a miniature rift valley. It is occupied by a number of lakes at various altitudes. The most prominent are Cloister Lagoon (1038 m) in the south and Chapter Lake (1002 m) in the north. This valley feature appears to have a structural origin but Macleod and others (1961, p. 33), the only geological reference available, are equivocal and map it as being possibly fault or joint controlled. Present drainage of this valley is to the north. Ice of Rowallan Glaciation age, at its maximum extent totally submerged the valley with more than 300 m of ice which flowed northwards down the steep valley of Moses Creek. Some ice crossed the divide from Chapter Lake via the trough wall into Jacksons Creek. Sources of ice were from the east in the Chalice Lake area and from the west in the Lake Myrtle area. It is assumed from the directions indicated by roches moutonnées that ice moved along the valley to the north. Deep ice erosion along the valley containing Cloister Lagoon and Chapter Lake formed a hanging valley at Grail Falls above Chapter Lake (Figure 6).

Mount Rogoona-Lake Myrtle Area

Lake Myrtle lies at the foot of Mount Rogoona and is the source of Jacksons Creek. Like many lakes in the region it is a rock basin lake. Approximately 200 m of ice filled the hollow now occupied by Lake Myrtle, during the Rowallan Glaciation, but Mount Rogoona remained a nunatak throughout. Reconstruction of the ice extent was achieved using the same techniques employed on Cathedral Plateau and an upper limit of approximately 1220 m around the peak of Mount Rogoona was determined. Roches moutonnées indicate that the direction of ice movement was generally northwards, although some ice spilled to the northwest into Chapter Lake. Screes from the steep western face of Mount Rogoona form a continuous surface to the edge of Lake Myrtle. This suggests that scree accumulated on the steep face of Mount Rogoona above the ice margin in the Lake Myrtle hollow and that during deglaciation the scree moved to a lower level. Instability of screes on the face is further suggested by scalloped features high on scree beneath the mountain peak.

North of Lake Myrtle there is a flattish, bare dolerite surface with occasional roches moutonnées and small tarns, which descends steeply into a broad cirque-shaped valley occupied by Jacksons Creek to the northeast, Moses Creek to the west and a number of unnamed creeks in the centre. This broad valley represents a major spillover region for ice from the Central Plateau to the Mersey Valley and the main channel for ice moving from the Lake Myrtle - Mount Rogoona area to the Mersey Valley glacier.

On the evidence of thin outcrops of till in Jacksons Creek between Lake Myrtle and the top of the steep descent off the plateau, it appears that a small volume of ice moved along the present stream course. In the descent Jacksons Creek moves through a narrow steep-sided, rock-walled valley. The floor of the valley is filled with thick, coarse screes piled against the valley edges from where they were derived. The scree is so thick that Jacksons Creek, at this stage a rapidly flowing stream with considerable volume of water, flows underground for about 600 m. When it is flowing near the surface the noise of the creek resembles a swarm of angry bees, but for quite a considerable distance the creek is so far underground it cannot be heard at all (Figure 18). The depth of this scree suggests that if ice came through this narrow valley it was for a brief period only at the maximum of the Rowallan Glaciation. It is more likely that this steep-sided valley is the result of erosion by meltwater at the glacial maximum and in spite of the fact that periglacial activity in the form of toppling choked the valley with dolerite debris, Jacksons Creek continues to flow in its original channel.

Lake Louisa-Lake Adelaide Area

Lake Louisa (847 m) and Lake Adelaide (1055 m) occupy two parallel depressions on the western edge of the Central Plateau and are separated by a dissected ridge with crests rising to approximately 1100 m.

The drainage in the area is deranged. Streams flow into Lake Adelaide from the east, west and north. Less than 1km north of Lake Adelaide and about 20 m above that lake a stream in a deep valley flows west to Lake Rowallan. A single stream flows from Lake Adelaide in a westerly direction into Lake Louisa and another flows out from the southern end of Lake Adelaide (considered by some to be the source of the Mersey River). Streams flow into Lake Louisa from the south and east. Juno Creek is a fast flowing tributary of the Mersey system and is the only outlet stream.

Figure 18: The Jacksons Creek valley just before its steep descent from the Central Pateau. At this point the stream flows at a depth well below the surface. The thick scree deposits are mainly the result of toppling.

Figure 19: The Central Plateau viewed from Mount Jerusalem showing results of ice scour. The lack of soil and vegetation can be seen, as can numerous rock basin lakes.

There is little evidence of Rowallan age ice in the area around Lake Louisa. No till can be found around the edge of the lake or in Juno Creek, which is cut into dolerite. There is evidence of extensive meltwater activity east of Lake Louisa on the flattish surface in the vicinity of 345675 (Cathedral). No sediment is present but there is a confused aggregation of deep, steep-walled channels, which generally run parallel to the slope and in some cases appear to be structurally controlled. The nearest till outcrop to Lake Louisa was found to be an outcrop at an altitude of 900 m in the creek which flows from north of Lake Adelaide to the Mersey River. The structure and dip of this till indicate that it was deposited by ice from the main Mersey glacier rather than by ice coming off the plateau. Above Lake Louisa there are some well developed scree slopes which would suggest that the ice from the Rowallan Glaciation did not exceed an altitude of 1050 m in Lake Louisa. No ice flowed north from Lake Louisa during the Rowallan Glaciation. The conclusion is that very little ice, if indeed any, moved over the plateau edge from the Lake Louisa depression to the main Mersey glacier. In this case a small cirque-like ice mass may have occupied the Lake Louisa depression for most of the Rowallan Glaciation. Neither moraines nor outcrops of till produced by this glacier have been found and it can only be assumed that they are obscured by the abundant vegetation or the water of the lake or have been removed entirely by meltwater activity. However, the latter is thought to be unlikely.

Outcrops of the Rowallan Till are numerous around Lake Adelaide. They are found in the low bank of the northern foreshore of the lake, in creeks to the north of the lake and around the eastern edge of the lake. Hummocky moraines are found north of the lake and an end moraine exists at 382712 (Rowallan) just north of an area where bare rock surfaces underlie numerous ice transported dolerite boulders up to 2 m across. End moraines provide evidence that Rowallan ice occupied the flat plain north of Lake Adelaide. The ice could not have been very thick because extensive screes occur to the east, down to an altitude of 1200 m on higher ground which is part of the Walls of Jerusalem. At a point approximately 100 m south of the end moraine the maximum thickness of ice was 150 m.

At the Rowallan Glaciation ice limit it is possible, but unlikely, that ice spilled into the Mersey Valley north of Lake Adelaide. A moraine complex 800 m north of the lake indicates that for a significant period of the Rowallan Glaciation, ice was contained within 1 km of the lake. Here, extensive meltwater streams carved deep valleys in a westerly direction off the plateau. Ice spillover from Lake Adelaide to Lake Louisa would have occurred, mainly though a steep-sided channel at the northern end of the lake.

<u>The Walls of Jerusalem</u>

The Walls of Jerusalem National Park was proclaimed in 1981 and incorporates a large area from Deception Point in the north to Pine River in the south, and from the plateau edge near Clumner Bluff and Howells Bluff in the west to an irregular boundary some 5 kilometres east of Mount Jerusalem. The Walls of Jerusalem are nearly vertical dolerite scarps formed on the edges of mountains in the area, in particular the West Wall, south of Lake Salome; the East Wall, a scarp below Mount Jerusalem; and the Wailing Wall on the western edge of Jaffa Vale. The westward flowing Fish River is the main stream draining the northern part of the area, while the eastward flowing Pine River is the main river in the south.

There were two main sources of ice accumulation in the Walls of Jerusalem area during the Rowallan Glaciation. The first was the Central Plateau ice-cap having its greatest thickness east of a line connecting Mersey Crag and Mount Jerusalem. Jennings and Ahmed (1957) and Derbyshire (1968) describe a major ice divide occurring east of Mount Jerusalem. On the eastern side of the divide the main mass of ice generally moved southeasterly. Northwest of this divide small amounts of ice flowed northwesterly towards the Mersey Valley via the valleys of Zion Creek and the Little Fisher River. The second area of accumulation centred around two cirque-like landforms, one presently occupied by Lake Thor. The other occurs approximately one kilometre north at 450740 (Pillans Lake) in the headwaters of the Fish River. Ice from this second source area flowed into the main Mersey glacier via the Fish River valley. Rowallan age ice was absent from the area around the Temple, Jaffa Vale, Damascus Vale, Lake Salome, the West Wall, Wailing Wall and Mount Moriah. As indicated above, a relatively small amount of ice (considering the size of the icecap) flowed from the main icecap past the northern end of Mount Jerusalem. It moved in a general northeasterly direction, but a significant amount spilled down Zion Vale. The ice in Zion Vale was most likely less than 100 m thick as it did not overtop the low divide into the valley of Lake Salome, which is 110 m above the valley floor at Ephraims Gate. At the base of the valley the ice flowed through the Golden Gate and across the valley of Wild Dog Creek towards George Howe's Lakes with a small diffluent ice lobe extending up Wild Dog Creek. This connected with the main ice mass from the two 'cirques' in the Fish Valley. A substantial meltwater channel flowed through the unnamed creek which enters the Fish Valley close to Trappers Hut. The main mass of ice moved northeast through Lake Thor and the Fish Cirque with a substantial volume spilling into the Little Fisher Valley. Little, if any, ice of Rowallan age flowed west of Mersey Crag on the Clumner Plateau. The margin reached a height of approximately 1250 m before it was diverted westwards into the Fish Valley.

The Central Plateau icecap has left abundant evidence of its presence east of Mount Jerusalem (Figure19). An extensive sloping plain of smoothed, bare rock is present, with roches moutonnées indicating ice movement to the southeast. Little soil or vegetation exists and numerous depressions, many filled by lakes, ponds and marshes, are dotted across the landscape. On the northern slopes of Mount Jerusalem the bare slopes are occasionally striated, and give indication that ice also moved northwest and west from the main icecap. Screes accumulating underneath the East Wall are lower and thicker towards the south than in the north where they may have been trimmed by ice flowing from the Central Plateau.

The Temple, East Wall, West Wall, Mount Ophel and Zion Hill had no ice during the Rowallan Glaciation. Significant block stream development has occurred in the area known as the Gate of the Chain. There is a col between the Temple and Zion Hill, which would have been a main avenue for ice if it had flowed from the Central Plateau area into this region. Also extensive screes occur at the base of the 'walls' (Figure 20). These screes in the core of the Walls of Jerusalem National Park contrast with the relative dearth of scree within the limits of Rowallan age ice. The contrast suggests that the thick screes were developed over a long time and are unlikely to have been formed since the decay of the Rowallan ice. The valleys between these screes contain soils on thick deposits possibly derived from solifluction material. Around Lake Salome for instance there is up to 2 m of brown clay-rich material underlying poorly formed dark alpine soil. Such soil formation is not found in areas known to have been glaciated by Rowallan age ice. A similar situation exists in Jaffa Vale and along the northern shore of Lake Ball.

The Little Fisher River flows from the Central Plateau north of the Walls of Jerusalem National Park. Rowallan age ice spilled over from the central icecap and flowed about 5 kilometres down the valley to the moraines which are evidence of the Little Fisher ice lobe.

Clumner Bluff Deception Point Plateau

There is no evidence to suggest that ice of the Rowallan Glaciation was present on this plateau. The weathered nature of the landforms and presence of blockfields, blockstreams and scree contrast sharply with the ice smoothed landscape inside the Rowallan Glaceation limits.

The Oakleigh Plateau

Part of the Oakleigh Plateau encroaches into the area of investigation. There is no evidence that ice of the Rowallan Glaciation was present on the Oakleigh Plateau.

Figure 20: Part of the Walls of Jerusalem area which were unaffected by the Rowallan Glaciation. Note the thick scree at the base of the West Wall and the abundant vegetation compared with Figure 19.

The surface of the Oakleigh Plateau contrasts with the the surface of glaciated regions. The Oakleigh Plateau has low relief on which there has been considerable soil development. Limited exposures of the soil parent material reveal solifluction deposits. In the glaciated areas the topography consists of numerous small hills and valleys and there is a lack of soil development.

Extent and effects of Rowallan Glacial ice in the valleys

Five areas have been identified to aid discussion of this section. They are ordered from higher altitudes to lower altitudes as the Mersey Valley above Lees Paddocks, the Mersey Valley between Lees Paddocks and Steers Plain, Jacksons Creek and Moses Creek valleys, the Mersey around Lake Rowallan and the Fish River.

The Mersey Valley above Lees Paddocks

Ice moving down the Mersey Valley had as its source the Central Plateau and Cathedral Plateau. It is possible that some loss to the system occurred due to spillover through the Du Cane Gap and into the Narcissus River to the south. Kiernan (1983, p. 118) holds the same view and identifies the Du Cane Gap as a transfluence col through which ice escaped westwards from the Mersey Valley into the head of the Narcissus trough. No ice was lost from the Mersey system through the trough between Mount Ossa and Mount Massif. Kiernan (1985) states that the concavity of moraine ridges from the Mersey system suggest that there was no diffluence during the last glaciation.

At the maximum stage, ice filled the Mersey Valley in the vicinity of Lees Paddocks to the 1000 m contour, which would have given a depth of ice of more that 400 m adjacent to Bishop Peak. The evidence is based on till outcrops to a height of 900 m in the creek between Bishop Peak and Dean Bluff, and scree limits on Dean Bluff and Curate Bluff between 1000 m and 1100 m. On the other side of the valley the latero-terminal moraine related to the Lake Ayr lobe commences at about 1000 m on the flank of Mount Pelion East. On the sloping shelf east of Mount Pelion East, ice would have attained a maximum thickness of only 150 m and hence would not have been as active as the ice in the main part of the valley. This may account in part for the lack of penetration of Rowallan age ice into the Forth Valley via the Lake Ayr Valley. Diffluent ice moved up Wurragara Creek from the Lees Paddocks area and terminated in two lobes at Pillinger Bog (Figure 17).

The Mersey Valley between Lees Paddocks and Steers Plain

There is no evidence that ice overtopped the present valley to flow onto the Pillinger Plateau. Observations in all creeks flowing from the Pillinger Plateau including those rising in Lake Leonis and Lake McCoy, indicated that the highest outcrop of Rowallan Till was to be found at the top of the valley. Fabric analyses of the tills give a down-valley ice direction which suggests that the ice had attained a maximum altitude of 850 - 900 m with a depth of some 350 - 400 m in the centre of the valley. The iceflow was therefore constrained totally by the topography.

Jacksons Creek and Moses Creek

During most of the Rowallan Glaciation ice inundated the broad valley between Jacksons Creek and Moses Creek, and formed a major tributary of the Mersey glacier. The source of ice was the Central Plateau and the area around Lake Myrtle and Cathedral Plateau. At its maximum the ice would have been 350 m to 400 m thick.

The Mersey Valley around Lake Rowallan

Because of the volume of ice added to the main glacier in this region by the eastern tributaries of Moses Creek-Jacksons Creek valley, the Fisher River and possibly the Juno Creek valley, ice flowed over the western divide into the Arm River at a height of 850 m. Just north of the Fish River the eastern edge of the glacier may have been higher, as there is evidence of extreme meltwater activity around the 1000 m level at 269758 (Rowallan). The depth of ice adjacent to Howells Bluff was therefore approximately 450 m. This shows that though the glacier was close to its terminus and presumably melting, it maintained approximately the same height and thickness for nearly 10 km. From the Mersey-Fish confluence there was a rapid fall in the surface height of the glacier to approximately 750 m at Rowallan Dam and it terminated in another 5 km.

The Fish River

In the Fish Valley, in the creek below Trappers Hut, till is found up to 950 m and scree slopes are trimmed off just above this level at 980 - 1000 m. On the other side of the river the highest till outcrop is close to 1100 m in the creek which flows from Clumner Plateau. It seems possible, therefore, that ice was higher on the northern side of the Fish Valley than on the southern side.

The Ice lobes in the valley

The Rowallan glacier had seven terminal ice lobes as shown in Figure 17 at Pillinger Bog, the Lake Ayr area, Lake Adelaide, the upper Arm Valley, the Mersey-Arm confluence, Dublin Bog and the Little Fisher Valley.

The Pillinger Bog Ice Lobe

Pillinger Bog is a wet area at 273712 (Rowallan). It lies on the divide between two creeks, one of which flows northeast to become the east Arm River and the other southwest to Wurragara Creek.

During the maximum of the Rowallan Glaciation a small, bilobate, diffluent branch of the Mersey glacier terminated in this area. One lobe terminated in the valley of Wurragara Creek and was responsible for the deranged drainage in the vicinity of 204716 (Rowallan). The other lobe terminated just east of Pillinger Bog. Continuous outcrops of Rowallan Till can be traced from Wurragara Creek to the source of the unnamed tributary at Pillinger Bog. Dolerite clasts in till immediately below Pillinger Bog are more angular and more weathered than is normal for Rowallan Till. This might be expected at the terminus of a diffluent ice lobe that is moving upslope and would have incoporated scree and slope deposits that existed on the adjacent slopes. The short distance the clasts were transported to the terminal moraine and the reduced energy of the glacier would have limited the amount of attrition. The end moraine at the eastern end of Pillinger Bog represents a local limit for Rowallan age glacial ice, and the moraine has been breached by meltwater. A wet area 400 m east and 10 m below the end moraine was cored and trenched. The only sediments discovered were glacifluvial sands and gravels. Cores taken from Pillinger Bog produced between 0.5 m and 1.1 m of organic muds and rhythmic lake clays (Figure 21). The light grey rhythmites occur immediately above till, gravel and sand at the base of the section. The rhythmites are reasonably coarse with the minimum thickness of a couplet being approximately 1 mm. Should each couplet represent one year's sedimentation or less, then the glacier did not remain in this position for more than 40 years. The rapid retreat of the glacier from its terminal position is a feature apparent at other ice lobes in the other terminal ice lobes of the study.

The Lake Ayr Ice Lobe

The Lake Ayr Valley is broad and lies between the Oakleigh Plateau and Mount Pelion East. The eastern end of Lake Ayr is close to the drainage divide between the Mersey and the Forth River systems.

The terminus of the glacial ice in the Forth Valley has been independently established as close to the junction of the Forth River and Oakleigh Creek (Kiernan in the Department of Arts, Sport, the Environment, Tourism and Territories,1988, p. 241; Hannan,1987). This position is some 10 km upstream from the equivalent terminus on the Mersey River which indicates that the glacier occupying the Forth Valley was considerably smaller. If ice of the Rowallan Glaciation age moved through the Lake Ayr Valley into the Forth Valley it travelled approximately 11 km to the terminus, yet ice moving along the Mersey Valley from a similar location travelled 25 km to its terminus. The Mersey system was also fed by ice from the

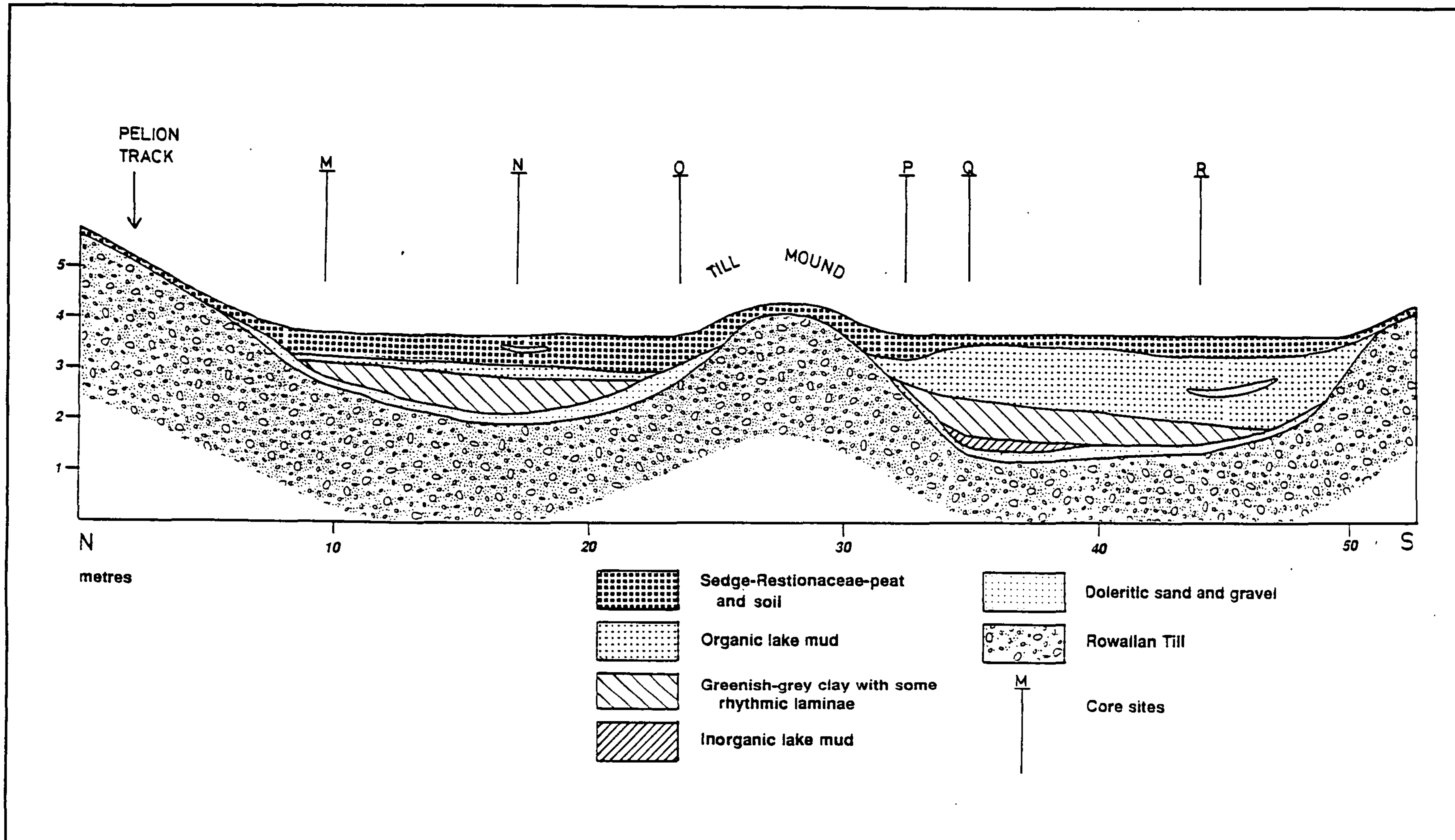

Figure 21: Pillinger Bog Section.

tributary glacier that flowed in the valleys of Moses Creek, Jacksons Creek and the Fish River. Only a small amount of ice, if any, seems to have moved from the Mersey system into the Forth system.

In the Lake Ayr valley there are a number of moraines most of which can be attributed to Rowallan age ice. The most obvious is a large arcuate moraine which commences near the 1000 m contour on Mount Pelion East, near the Rowallan ice limit in the Mersey Valley, and curves northwestwards to the 850 m contour west of Lake Ayr. A small creek with its source just north of the summit of the northern peak of Mount Pelion East follows the southern flank of the moraine. The rapid drop in altitude of the moraine on the northern slopes of Mount Pelion East suggests that there was little or no ice coming down the Douglas River to join the glacier at Lake Ayr. It is unlikely that ice from the Mersey system reached much further west than the end of Lake Ayr during the Rowallan Glaciation. Neither this moraine nor other prominent moraines can be traced continuously across the valley , but nevertheless discontinuous moraines occur on the steep northern slopes of the valley. The presence of numerous meltwater channels contained within the complex of moraine ridges on the northern slopes could suggest degradation by meltwater and slumping.

The plain to the west of Lake Ayr can be divided into a northern part which is hummocky moraine and a southern part which is dominantly outwash material. Whilst the hummocky moraine could be of Rowallan age, it is thought to be older since the small valley that contains the Oakleigh Track at 195708, (Will) was possibly ice-free during the Rowallan Glaciation. There is no evidence of till or moraines, and screes occupy the lower slopes of the shallow valley. The outwash on the plain west of Lake Ayr and the steep-sided channel in which the present Douglas River flows are both evidence for discharge of large volumes of glacial meltwater.

Other less prominent latero-terminal moraines occur close to Lake Ayr and mirror the outer moraine on the lower slopes above the southern edge of the lake. The eastern end of the valley in the vicinity of Reedy Lake contains a number of similar moraines which record the retreat of Rowallan ice towards the Mersey Valley. They are discussed in the section on deglaciation of Rowallan age ice on page 112.

The Lake Adelaide Ice Lobe

The Lake Adelaide ice lobe ended some 3.5 km north of Lake Adelaide where a hummocky surface of low relief indicates the terminal zone of the glacier at 382712 (Rowallan). Immediately south of the terminal moraine complex there are bare rock surfaces on which rest ice-transported boulders up to 2 m long.

The Upper Arm Ice Lobe

The ice lobe in the upper Arm Valley has been briefly discussed in the section on stratigraphy. Ice limits in this area were relatively easy to establish from numerous outcrops of till, solifluction and scree deposits in sections along roads and in quarries. Adjacent to this ice lobe, the maximum surface altitude of the glacier in the Mersey Valley reached approximately 850 m to 900 m. Ice entered the Arm Valley through the low divide west of the southern end of Lake Rowallan, and flowed approximately 4 km down the valley. At the divide the ice lobe would have been approximately 2 km wide and the ice would have been no more than 50 m thick, whereas the Mersey glacier at this point would have been almost 400 m thick. No definite end moraines have been observed in this area. However a number of till mounds occur close to the Arm Road at 293746 (Rowallan), and there is clear evidence of superposition of till of Rowallan age on older Arm age glacial deposits.

The Mersey River Ice Lobe

The terminal ice lobe of the main Mersey glacier ended approximately 1 km downstream from the Mersey-Arm confluence, where the glacier terminus would have become wedged between two quartzite knobs. This is termed Stage 1.

Beyond the terminus most of the outwash plain has been covered by the water of artificial Lake Parangana. The outwash plain slopes at approximately 7 m per km. It appears that the glacier did not remain in this situation for very long, as there is little till present and no obvious moraines, but receded to Stage 2, a line approximately 400 m above the Mersey-Arm confluence. Here an end moraine was developed, which is now incomplete since much of it has been removed by the HEC for road gravel. Fortunately, before excavation the area was mapped in detail as a potential campsite, using a contour interval of 5 feet at a scale of 1:1250. On the map the end moraine appears in its original form and unaffected parts have been identified and examined. For the terminus of a large glacier the end moraine is not impressive. Parts of it are breached by meltwater and subsequently the Mersey River, but the original arcuate form is visible. At its highest it is 4 m above the outwash plain and is composed of rounded pebbles, boulders, fine gravel and sand mainly of dolerite. In the river adjacent to the end moraine there is a small section which reveals 2 m of meltout till underneath 1 m of coarse well rounded gravel. The meltwater plain associated with this stage is fairly broad and falls approximately 10 m per km. On the eastern side of the meltwater plain there is a kame terrace.

Stage 3 of the glacier is 1.3 km south of the Mersey-Arm confluence where a thick moraine has been incised by meltwater. The Mersey River presently flows in a channel with a 30 m-high western bank, composed largely of till. The gravel terrace in front of this retreat stage is reasonably steep compared with other outwash plains as the river falls 25 m per kilometre.

Stage 4 occurred at the quartzite rock knoll on which the Rowallan Dam is constructed. The slope of this outwash plain is 9 m per km. Also associated with this stage are the extensive deposits (discussed on page 54) which occur around Rowallan Dam. During investigation for the damsite Paterson (1965, p. 117) records 27 m of till below the river level. The section in the overspill channel of the dam was discussed in Chapter 4 and the diagram of the section is shown on Figure 12.

It is possible that an intermediate stage occurred between Retreat Stages 3 and 4 some 900 m below the dam but HEC activities have removed most of what appears to have been an end moraine. Further retreat stages of the Rowallan Glaciation are discussed in a later section on deglaciation (see page 109).

<u>The Dublin Bog Ice Lobe</u>

Dublin Bog is a wet area in a broad valley about 2 km northeast of Rowallan Dam. It lies between two well-defined, arcuate end moraines which loop across the valley, approximately 1 km and 3 km from the dam. Ice of the Rowallan Glaciation spilled into this valley from the vicinity of the dam and terminated behind the outer moraine for a short period. In a creek bed on Dublin Road, 60 m above the surface of Dublin Bog, a 3 m outcrop of till is exposed in the outer moraine. The till is almost certainly Arm Till as the matrix is weathered, has a bright brown colour (7.5YR, 5/8) and has weathering rinds on dolerite clasts which are characteristic of Arm Till (mean = 2.5 mm; standard deviation = 0.63 mm; maximum = 3.8 mm and minimum = 1.1 mm). It is suggested that ice from the Rowallan Glacial maximum moved beyond the inner moraine in the centre of the valley (the present Dublin Bog) but did not override the outer moraine ridge, which contains some relict moraine material from the Arm Glaciation. The ice quickly retreated to the inner moraine as it did from the maximum (Stage 1) to Stage 2 in the Mersey Valley. A sequence of cores taken across Dublin Bog (Figure 23) to depths of >10 m is shown on Figure 22. Pollen analysed by Colhoun and van de Geer (see Hill, Colhoun and van de Geer, 1988) is discussed in a later section on page 117. At the base of the cores are rhythmites which lead Hannan and Colhoun (1987, p.44) to suggest that the ice retreated from this location within a few decades.

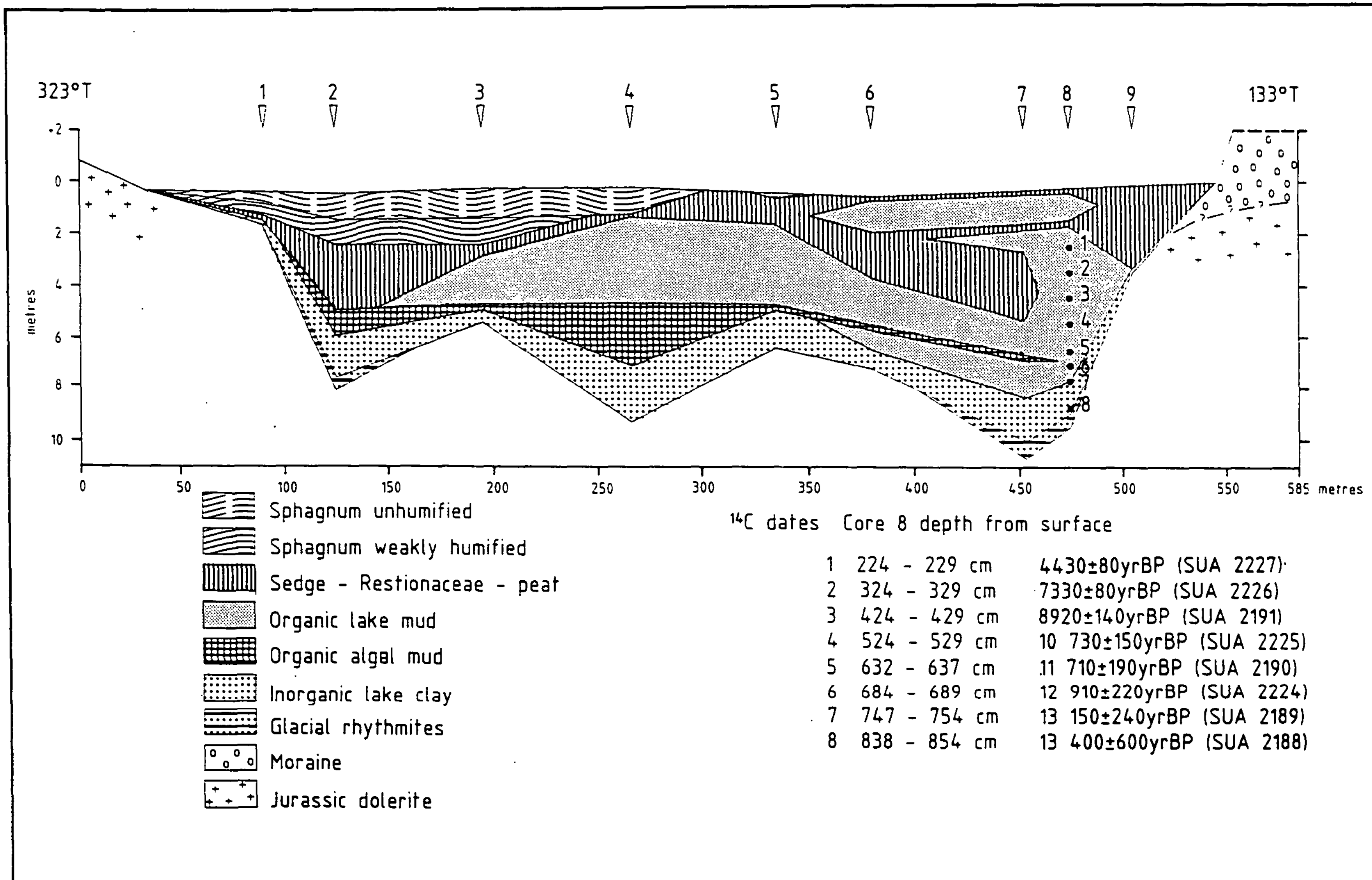

Figure 22: Dublin Bog Section (from Hill Colhoun and van de Geer, 1988).

Figure 23: The marshy near-horizontal surface of Dublin Bog stands out from the surrounding sclerophyll forest. Behind the largest eucalypt wet areas can be seen with sphagnum moss visible .

The Little Fisher Ice Lobe

A small ice lobe terminated in the Little Fisher at 412833 (Lake Mackenzie) during the Rowallan Glaciation maximum. Ford (1960) maps an area as "terminal moraines" in a similar locality. The glacier which was present here extended from east of Mersey Crag and flowed over the plateau edge. The moraines are indistinct and cannot be traced for longer than 30 m to 40 m across the valley.

SEDIMENTS ASSOCIATED WITH ROWALLAN GLACIATION ICE

Till

The term "till" has been used frequently in the preceding discussion, but so far there has been no attempt to discuss its definition and subdivision. This section aims at a closer scrutiny of the terminolgy and classification of till.

Dreimanis (1976a, p. 17) proposes that 'till' be the preferred name for glacial deposits in English and that 'moraine' be the preferred name in European languages. Both Dreimanis (1976a, p. 5 and 1982, p. 100) and Boulton (1980, p. 2) discuss the nomenclature of glacial deposits and the definition of till. Probably the best working definition is that "till is a sediment that has been transported and is subsequently deposited by or from glacier ice, with little or no sorting by water" (Dreimanis, 1982, p. 10). However, to avoid confusion the term moraine will be used here for the landform of a moraine ridge(s) unless specifically qualified as 'morainic deposits' which may include both till and ice contact stratified drift within the ridge.

Dreimanis (1982, p. 20) classifies glacial deposits as either subglacial or supraglacial tills, that may be of either primary or secondary origin. Subglacial primary tills include deformation till, lodgement till and meltout till. Subglacial secondary tills include undermelt tills and mass movement tills such as flow tills. Supraglacial primary tills are all meltout tills and include sublimation tills.

Supraglacial secondary tills are all mass movement tills and include flow tills. Several other classifications exist, e.g. Boulton (1980), but it is perhaps preferable to use one classification rather than parts of several when describing the glacial deposits of any particular region.

The classification and the identification of meltout till is problematic. The classification of Dreimanis summarised above indicates that meltout till can be formed in a subglacial position or in a supraglacial position. Drozdowski (1983, p. 119) states that the modern interpretation is that meltout tills are produced progressively from the top of debris-rich dead ice downwards and from the base up. Similar interpretations are indicated by McGown and Derbyshire (1977, p. 391), Haldorsen and Shaw (1982), Haldorsen (1983, p.145) and Eyles (1983, p. 47). In reviewing the problem of recognising meltout tills Haldorsen and Shaw (1982) use three criteria for their identification. These are:

(i) the presence of unlithified, sorted and stratified sediments within or interstratified with the till;

(ii) the presence of a statistically preferred orientation of stone axes closely related to ice-flow condition; and

(iii) a configuration of till with a recognizable textural or lithological property closely related to the configuration of englacial debris with the same property.

Haldorsen and Shaw (1982, p. 264) indicate that one of the difficultes in recognising meltout till comes from the fact that the dominant process in modern glacial environments is sediment flow. In contrast accumulation of true till either as meltout or lodgement, is minor. They pose the question as to what is sufficient evidence to identify a sediment as till and suggest that sufficiency exists when the evidence supports an interpretation above all other known relevant interpretations (1982, p. 261). This is the view which has been adopted in this study and meltout till has been identified on the basis of characteristics 1 and 2 mentioned immediately above.

Subglacial and supraglacial tills of Rowallan age have been identified in the upper Mersey Valley according to the criteria of Dreimanis (1982)

Subglacial till

This section considers the deformation and lodgement tills of the Rowallan Glaciation. Meltout till could not be differentiated into subglacial or supraglacial classifications and, as a consequence is discussed under the single heading of supraglacial till.

Deformation till was found where ice flowed down steep slopes on Permian siltstones. There are two clear exposures in the area, one at the Reedy Creek-Wurragara Creek junction and the other below Horeb Falls on Moses Creek. The section at Reedy Creek-Wurragara Creek junction is shown in Figure 24 with the deformation till outcrop at the base. The bedding of the till has a strike of 23° and a dip generally in the range of 10° to 15°, but up to 28°. The Permian rock is a fissile siltstone and is horizontally bedded but the interface between the till and the bedrock is relatively smooth, without any visible stepping. The siltstone was seen to be shattered into small angular pieces in the till close to the bedrock and thus has very little matrix. A similar outcrop of deformation till occurs over a siltstone, exposed in a road cutting in the upper Arm Valley at 289743, (Rowallan). There is a gradational boundary between the top of the fractured rock and the base of the angular fragmental deformation till.

Below Horeb Falls, a deformation till occurs on top of a well consolidated, coherent and possibly slightly metamorphosed calcareous siltstone and sandstone (Figure 25). The Permian rocks contain two sets of well developed joints at right angles to

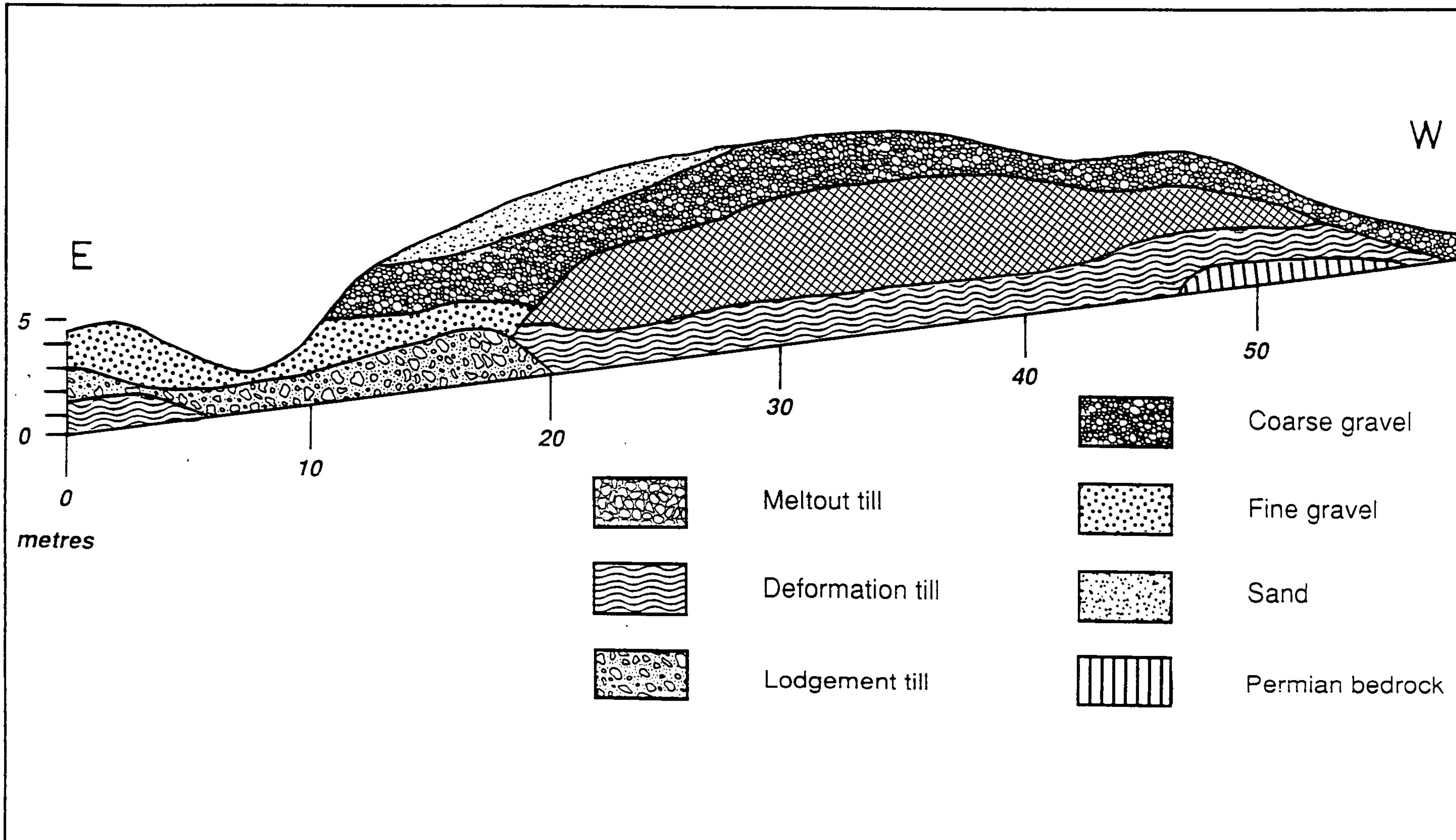

Figure 24: Section in the river bank at the confluence of Wurragara Creek and Reedy Creek, showing deformation till overlying Permian sediment.

Figure 25: Deformation till at Horeb Falls. The hammer is resting on the outcrop of Permian mudstone, which can be seen to be blocky as it is jointed at right angles. The block at the end of the stick has only moved a few millimetres.

Figure 26: Thick lodgement till in the Fish River valley with a veneer of ablation till at the top. A sub-horizontal lineation is visible withinin the till.

each other. The mudstone surface has been plucked quite severely with the resulting interface being stepped. In places it is possible to see where nearby rectangular blocks have been moved only a few millimetres from the bedrock, with the intervening space being filled by silty and occasionally sandy till matrix material. For a maximum of 1 m to 1.5 m above the bedrock the deformation till is clearly delineated. Permian sandstone and siltstone clasts dominate the till composition. Above the deformation till there is 5 m of lodgement till in which dolerite clasts predominate.

Lodgement till occurs widely in the upper Mersey Valley. At the type section for Rowallan Till, 500 m south of the Rowallan Dam at 352790 (Rowallan), Hannan and Colhoun (1987, p. 39) describe the till as a well-compacted grayish yellow brown till with a few horizons showing fissility. They also state that the till is seldom chemically altered below 1 m and that the rock clasts are entirely dolerite. Sieve analysis reveals the matrix to consist of 71% sand, 27% silt and 2% clay.

This is an apt description of lodgement till generally, throughout the upper Mersey Valley as it is coherent with clasts well cemented in the matrix. There are about equal proportions of clasts and matrix, and the clasts have a size range from small pebbles of 5 mm or less to boulders, which seldom exceed 2 m to 3 m across. In exposures where both lodgement till and meltout till are present the lodgement till nearly always has smaller clasts and will occur below the meltout till. The till is observed often to have a fissility or lamination, which is generally sub-horizontal but can dip up to 15° in a direction which approximates the ice movement direction. Usually the till is rather massive, but a weak blocky structure can be found. Exposures of lodgement till vary in thickness from less than 1 m to over 20 m. Thick exposures are found in the Fish Valley (25 m) (Figure 26), Moses Creek valley (14 m), Wurragara Creek valley (6 m) and at a number of places in the Mersey Valley.

The colour of the matrix of Rowallan lodgement till was recorded at a large number of sites and varies between being predominantly grey and yellow-brown. Most commonly the till was charted as brown (10 YR, 4/4) in the upper zones of the weathering profile. Where the till was completely fresh it was commonly a light brownish grey (7.5 YR, 7/1) or yellower, such as dull yellow brown (10YR, 5/3). Red hues are generally not found in the matrix of lodgement tills of the Rowallan Glaciation.

Clast analyses were made for a number of the lodgement till outcrops of the Rowallan Glaciation. In order to conduct a clast analysis 200 pebbles, greater than 150 mm diameter, were chosen at random from the exposure, broken open, identified and recorded. The analysis generally reflects the bedrock upstream of the exposure. The clast analyses allow the tills to be divided into 5 groups as follows:

(i) Tills containing 100% of dolerite clasts. These tills are located high on the edge of the valleys or on the plateaux regions.

(ii) Tills containing 75% of dolerite clasts and a minimum 95% of dolerite and mudstone . These tills are located in the middle of the valleys close to the dolerite boundary with Permian or Triassic rocks, for example in Wurragara Creek downstream of the gorge below February Plain and in the upper parts of the Jacksons Creek-Moses Creek valley.

(iii) Tills which have between 50% and 74% of dolerite clasts and the second most common clast mudstone. These tills are found in the middle of the main glacial arterial valleys in the vicinity of Lake Rowallan, for example in a lodgement till adjacent to Steers Plain and in the lower parts of the Jacksons Creek-Moses Creek valley.

(iv) Tills with less than 50% of dolerite and high to very high proportions of mustone and sandstone. Such tills are generally found at lower altitudes in the valley than the tills in category (ii) above, for example in the Mersey

Valley between Steers Plain and Lees Paddocks and the lower parts of Wurragara Creek.

(v) Tills with significant proportions of quartzite and schist. These tills occur below the Mersey - Fish confluence and reflect the outcrop of the Precambrian Howell Group metamorphics.

In general this classification of clast analysis follows from the higher to lower altitudes in the order of (i), (ii), (iv), (iii) and (v). Dolerite is the most common clast, partly because of its abundant exposure in the highland areas and partly because it is an extremely tough rock and survives entrainment for long distances. Mudstone is the second most common clast and is only found in till in the valleys, where the glacier exposed the Permian and Triassic bedrock. Sandstone is a minor clast only, except on rare occasions when found close to sandstone bedrock. Both sandstone and mudstone, but particularly sandstone, are prone to breaking up during transport and hence dominate the clast count only when close to these bedrock outcrops. Downstream the clasts of sandstone and mudstone are incorporated into the matrix. An additional complication to the pattern of observations is that in the lower parts of the Mersey Valley there were tributary glaciers entering the system, namely the Jacksons Creek-Moses Creek glacier and the Fish River glacier. These came directly from the highland areas, and therefore were charged with dolerite pebbles, which would have the effect of diluting the count of mudstone and sandstone clasts in the lower regions of the valley. Quartzite and schist are found as clasts in the Mersey Valley below Lake Rowallan where there are outcrops of the Howell Group quartzite and schist.

A number of the lodgement tills were subjected to particle size analysis. The samples taken from the field were ground by hand to break the matrix into its constituent parts. The sample was then split into halves until it was of a manageable size and the gravel fraction (> 2 mm) was removed. The gravel fraction and the matrix were weighed so that the percentage of gravel in the till could be calculated. After the matrix was air dried at 35°C for two days, it was weighed and wet sieved using Calgon as a dispersant. The coarse fraction was sieved through 1.0 mm, 0.5 mm, 0.25 mm 0.125 mm and 0.063 mm sieves and each fraction weighed. The fine fraction was analysed using pipette analysis. A small known volume (containing between 5 gm to 10 gm) of already dispersed till was made up to one litre in a measuring cylinder. The sample was left for a day to ensure that the clay did not flocculate. It was then stirred vigorously to distribute the silt and clay evenly throughout the column. Samples were taken at depths and times to correspond to Phi (Ø)diameters of 4.0, 5.0, 6.0,7.0, 8.0 and 9.0. according to Folk (1965). Calculations of the cumulative weight of sediment of the various grades were then plotted on graphs.

In general the lodgement tills appeared to contain a smaller percentage of gravel than the meltout tills. The amounts varied from 26.8% to 56.5%, and two samples, gathered close to deformation till, contained 61.9% and 61.3%. The lodgement tills of the area generally contain low percentages of clay. This is higher proportion than is found in meltout tills. The till with the highest clay fraction contains 4.1% clay and is found in close proximity to the Permian mudstones below Lees Paddocks. The till with the lowest percentage of clay is the highest altitude deposit of lodgement till in Leonis Creek and contains only 0.4% of clay.

No subglacial tills of secondary depositional character were recognised.

Supraglacial till

Meltout till was identified when it was interstratified with unlithified sand and gravel (Figure 27 and 28) or where the till fabric analysis was related to the general direction of ice flow in the region. For example the fabric analysis for a meltout till below Lees Paddocks at 288682 (Cathedral) had a strong orientation of 138°.

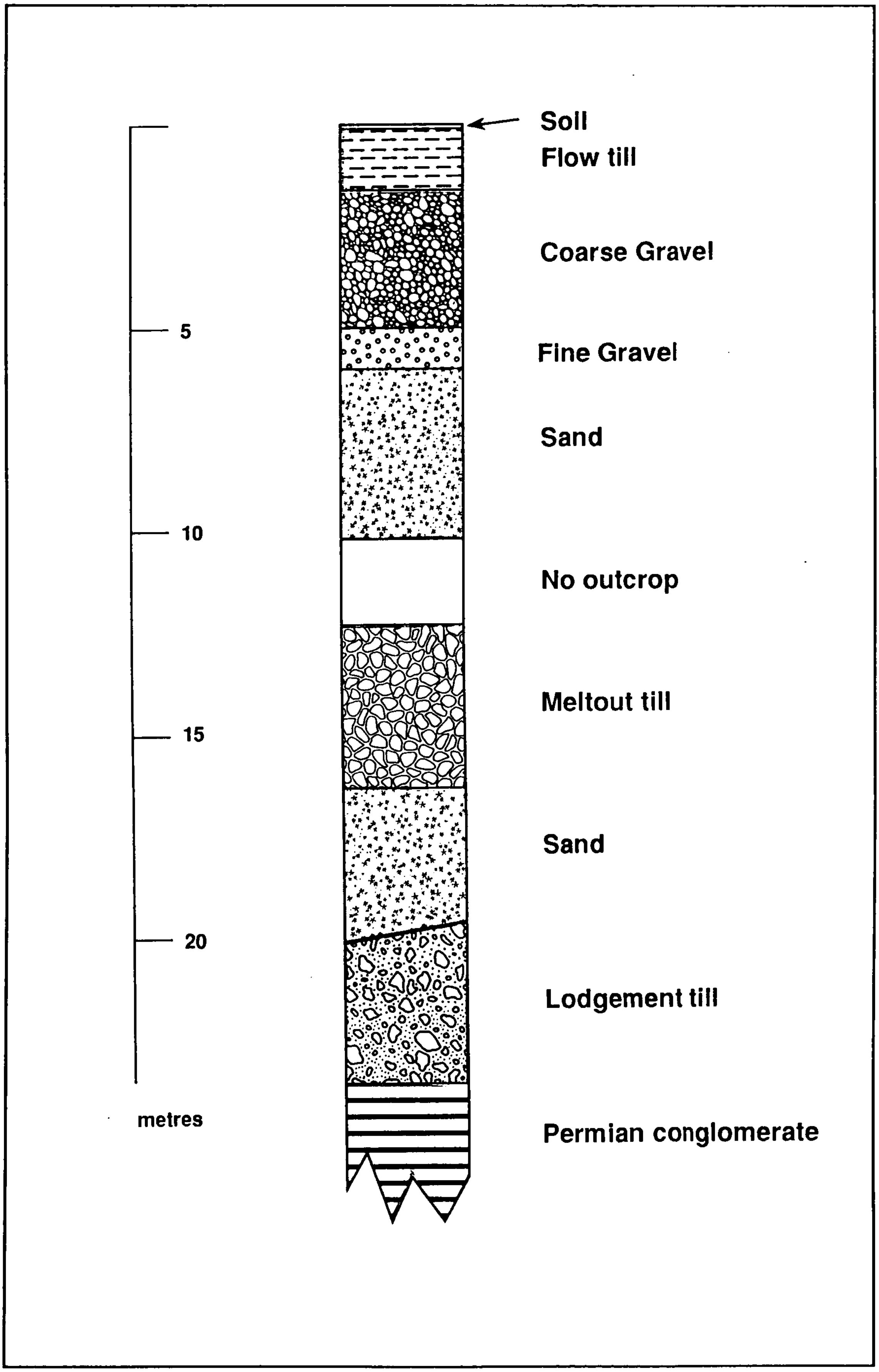

Figure 27: Stratigraphic column adjacent to Steers Plain at 319678 (Rowallan).

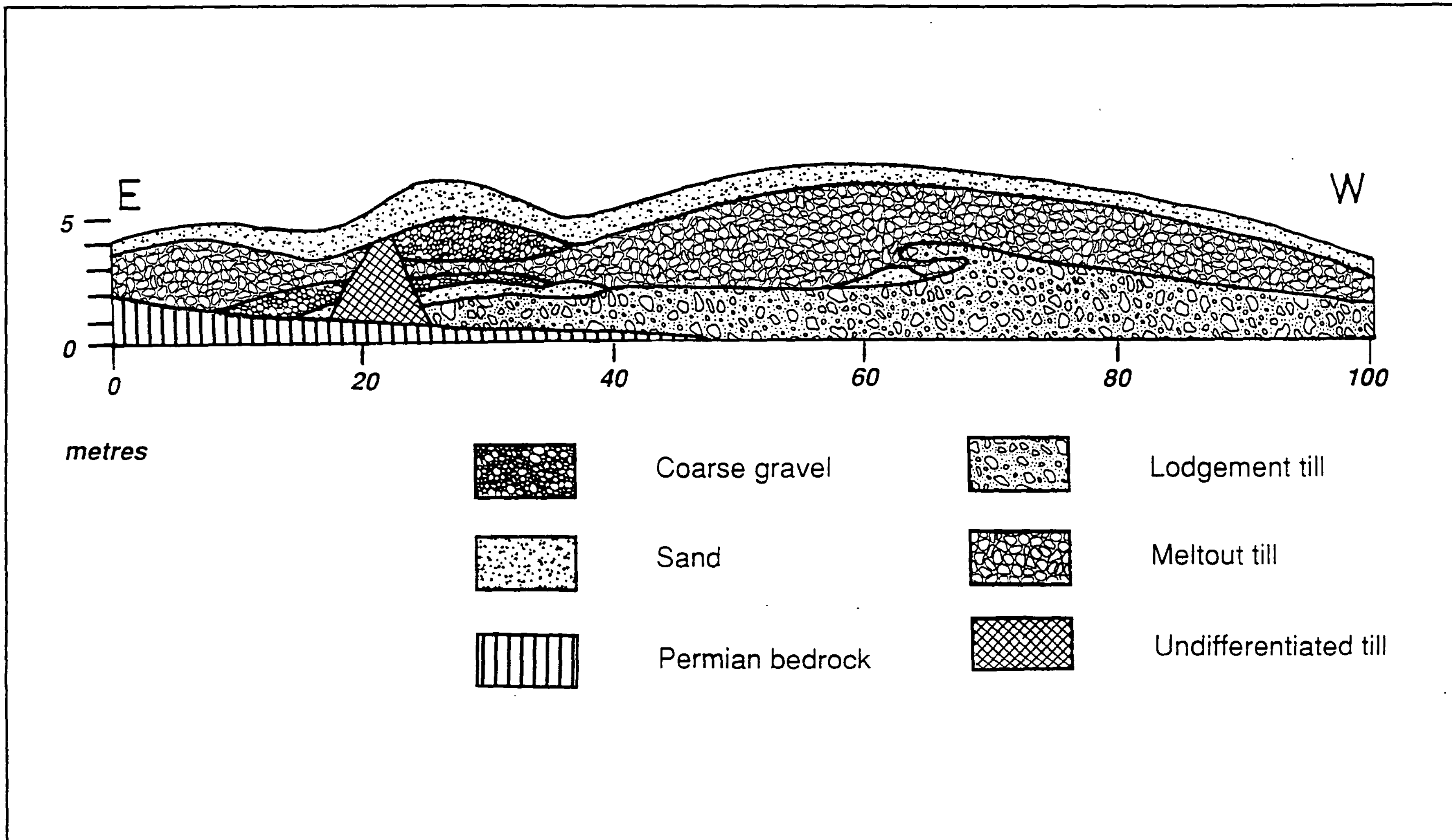

Figure 28: Stratigraphic section at 288682 (Cathedral) showing sand and gravel overlying lodgement till and underlying meltout till.

The matrix colour of meltout till can be categorised as brown and yellow brown. It lacks the grey colour of the lodgement till but seldom has any red component, except in rare circumstances, for example, when it has been in contact with water charged with organic material. Most commonly it was recorded as bright yellow brown (10 YR, 5/4) or as bright brown (7.5 YR, 5/8). Meltout till is not as coherent as the lodgement till and in hand specimen the matrix seems to contain a higher proportion of sand. Meltout till generally lacks structure with the exception of being very irregularly bedded. Exposures of meltout till occur over the area of the upper Mersey Valley and are usually found to overlie lodgement till. The maximum size of clast is larger than that found in lodgement till and the proportion of clasts to matrix is usually about 60%-70%.

Clast lithological analyses carried out on meltout tills produced similar results to those discussed above for lodgement till.

Particle size analysis of meltout tills indicated that some tills had high percentages of gravel. The highest was 70% for a till which was found in an outcrop above lodgement till and below a coarse gravel deposit (Figure 27). The clay fraction in the meltout tills was generally below 0.5%.

Although Dreimanis (1982, p. 20) separates meltout till from ablation till in his classification, in the field it is often difficult to separate the two. In the upper Mersey region, 1 m to 2 m of ablation till blanket much of the topography The ablation till is usually bright brown colour (10YR, 5/8) and it lacks structure, coherence and is composed of large rounded clasts usually of dolerite. The matrix is sandy and pebbly and has the appearance of being deposited in the presence of water.

A flow till was identified in an outcrop adjacent to Steers Plain at 319678 (Rowallan). It occurs on the top of a section (Figure 27) in a natural landslip, and is exposed laterally for approximately 20 m. The outcrop is part of the sediment accumulation from Stage 6 of the Rowallan deglaciation, which will be discussed in detail below. The flow till occurs in an outcrop close to the zone where the Jacksons Creek-Moses Creek glacier met the main Mersey glacier. The flow till overlies gravel, sand, meltout till and lodgement till. It is draped across the outwash gravel which outcrops immediately below. The main criteria for identifying it as flow till are as follows:

(i) The till rests on glacifluvial gravel with a sharp boundary between them. This is one of the situations in which flow tills may occur (Boulton, 1968, p. 410). The situation is also similar to that described by Hartshorn (1958, p. 479) who depicted flow tills of Massachusetts where they overlie sand and gravel with the fluvial material being undisturbed.

(ii) There is a difference in the fabric analysis of the lower lodgement till compared with that of the upper flow till. Of the three fabric diagrams completed for the lower lodgement till at different sites along the outcrop there are two dominant preferred directions, 15° and 42°. The four fabric diagrams for the upper till show many more preferred orientations, which are not represented as strongly since they are for the lodgement till. There are 4 equally preferred orientations in the four diagrams (approximately 38°, 47°, 76° and 330°). The fabric diagrams are reproduced in Figure 29. Although the characteristic of multiple fabric orientations is disputed as diagnostic by Kruger and Marcussen (1976, p. 61) it is advanced by Marcussen (1975, p.115) as being one of four criteria which allows for the recognition of flow tills.

(iii) The flow till is considerably harder than the lodgement till. The flow till has the consistency of concrete and because of this property the fabric analyses took about twice as long to complete. A flow till, by definition, must be fluid and capable of sliding under gravity. To do this requires a considerable volume of water must be contained within the sediment. Many of the clasts which the glacier would have gathered further up the valley and ground into the matrix are of a calcareous nature. These are mainly fossiliferous Permian siltstones and

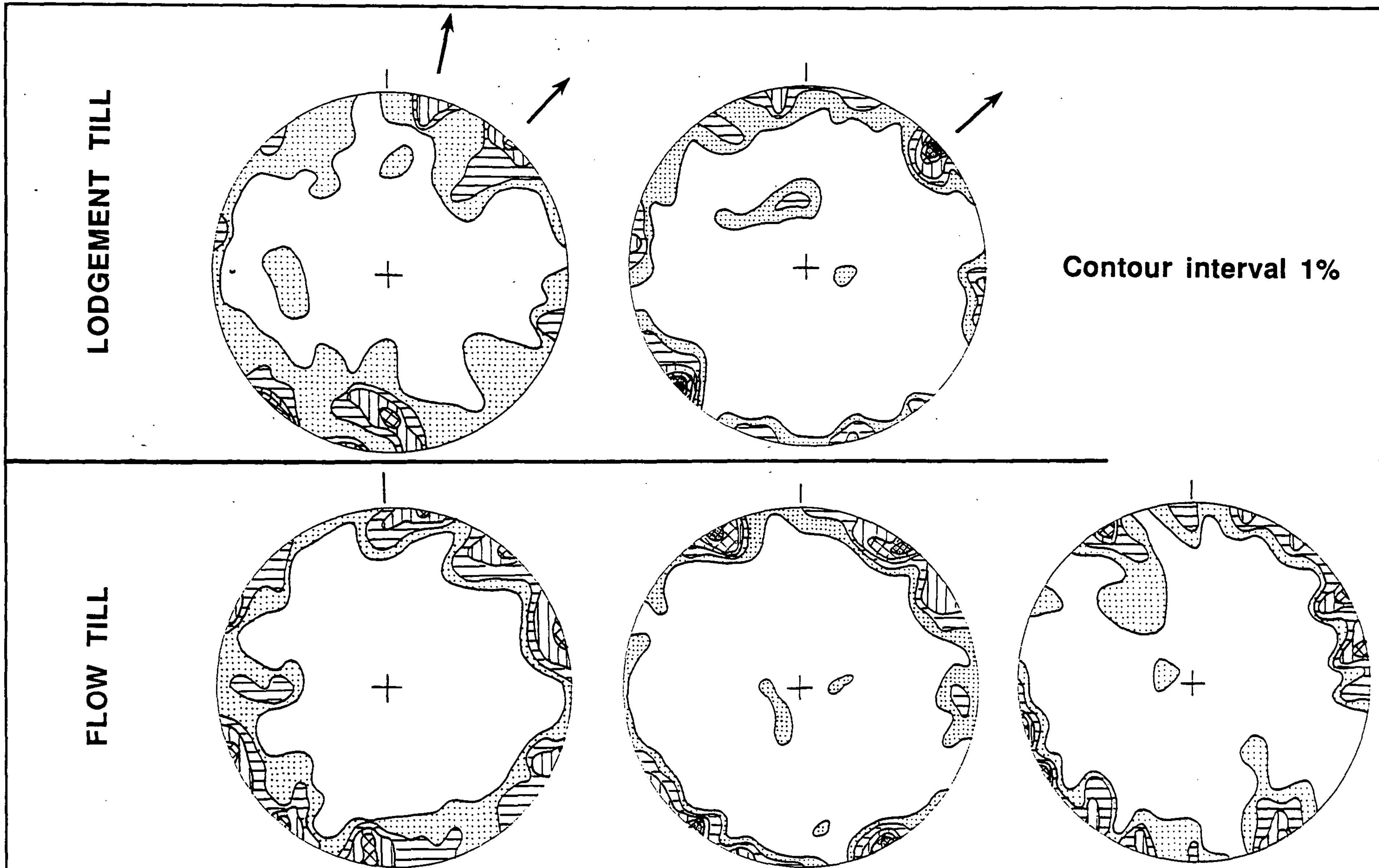

Figure 29: Comparison of fabric analyses of lodgement till and flow till at a section adjacent to Steers Plain at 319678 (Rowallan)

sandstones. The addition of copious water to such a clay rich calcareous sediment would have the effect of cementing it to a highly coherent state.

(iv) The till rests on a coarse roughly bedded gravel which has an uneven surface with the amplitude of undulations over the area of the outcrop approximately 2 m. The till has been draped across this and maintains orthogonal thickness.

(v) The results of the clast analyses of the two tills are different although the rocks represented are the same. In the flow till there is 11% sandstone, 6% quartzite, 23% mudstone and 60% dolerite. On the other hand the lodgement till has 1% sandstone, 3% quartzite, 42% mudstone and 55% dolerite. Particle size analysis of the flow till matrix showed that there is 90.2% sand, 8.4% silt and 1.4% clay, which is similar to lodgement tills of the area.

The conclusion is that the flow till has moved a short distance. The clast analysis suggests that it may have been deposited from ice perhaps from the tributary in Jacksons Creek-Moses Creek valley. If so, it is possible that the flow till could represent either redeposited lodgement till or a supraglacial flow till.

Glacifluvial and glacilacustrine deposits

In this section the glacifluvial deposits, mainly gravel and sand and lacustrine deposits, in the form of core samples and rhythmites, are discussed.

Abundant gravel is associated with the various retreat stages of the Rowallan Glaciation ice. Great variation in thickness and clast sizes occur in the gravel deposits throughout the area. The thickest gravels occur at identified retreat stages of the ice. For example, the island on Lake Rowallan at its southern end marks Stage 5 and contains 5 m to 8 m of gravel above the floor of the lake. These gravels are composed mainly of dolerite clasts ranging in size from less than 20 mm to 600 mm. A similar outcrop of gravel is found at Stage 6, as shown in Figure

27 , where a gravel bed of some 3.5 m outcrops above a till sequence and below a flow till.

Where clast analyses of gravels have been carried out they closely resemble the tills, particluarly the meltout tills in the immediate vicinity.

Sand deposits blanket the terraces, flood plains and the lower parts of the valleys of the main rivers and creeks. The sand is well washed and can be up to 3 m thick. Usually the sand is emplaced above the till and outwash gravel, but can be interbedded as is the case depicted in Figure 28. Holocene river gravels are found on top of the sand in localities where there are active creeks flowing. This is the case with the lower parts of Moses and McCoy creeks. Current bedding is sometimes visible in the sand as is the case in a logging track above Rowallan Dam, where a 500 mm exposure of sand dips from 3° to 5° and indicates a current direction of 3°. In the Fish River a large landslide of recent origin produced a thick section where a reverse graded sequence from rhythmites through to sand, gravel and till exists. The sand in this exposure shows many small-scale structures, such as normal faults, diapirs, current bedding, folds and slumps (see Figure 30). The deformational structures are the result of the overburden pressure from the till which has been deposited on top. The current bedding directions are inconclusive of the current direction at the time of deposition as there are two readings which indicate a current coming up the valley, one across the valley and one down the valley. The geographic distribution of the sand deposits in the lower parts of all the river valleys in the upper Mersey region indicate that the main sources of sand are the Permian and Triassic rocks of the region. In all creeks the outcrops of sand on the banks and terraces thin with increased altitude and cease quite abruptly. In Moses Creek no sand can be found above 750 m. Similarly in Jacksons Creek and Wurragara Creek there is no sand above 750 m and 860 m respectively. These heights correspond with steep gorge sections in these creeks, which is probably indicative of the base of the dolerite sheet.

Figure 30: Small faults in sandstone in a thick section in the Fish River valley. The faults are near vertical and are overlain by gravel and till.

Figure: 31 Rhythmite in the section in the Fish River valley. The rhythmites are folded by the overburden pressure. Compare with the sandstones in Figure 30.

In Wurragara Creek at 264696 (Cathedral), a 5 m-long outcrop shows 300 mm of fine silt at the base that is overlain by 300 mm of lodgement till, and 2.2 m of coarse meltout till and gravel. The clay-silt bed, at first sight, looked like a rhythmite but closer examination showed it to be very finely cross bedded, almost to an imbricate structure. Current directions all indicate a current from upstream. Presumably in this position the clay-silt bed is indicative of deposition by a subglacial stream.

Lake sediments were cored from Dublin Bog and Pillinger Bog. The cores at Dublin Bog (Figure 22) are composed of lake mud, clay, and towards the base silt and sand. The mud at the top of the core samples is peaty and contains organic material mainly fragments of *Sphagnum*, Restionaceae and charcoal. The colour of the mud is dark brown to medium brown and contains a high percentage of water. Organic algal mud is usually found underneath the organic mud. It is greenish brown to light yellowish brown in colour and indicates reasonably deep water. Immediately above the rhythmites and below the organic algal muds there are inorganic lake clays. These contain no observable sand, and are greenish gray to greenish brown in colour. They are laminated throughout and contain charcoal. The transition from the lake clay to the laminated silts and fine sands at the base of the cores is rapid.

At Pillinger Bog a similar situation exists in cores that are much shallower than at Dublin Bog (Figure 21). The top of the cores contains dark brown mud with abundant Restionaceae root material and occasional *Sphagnum* . Algal mud is missing from the sections and it is assumed that the water was not deep enough for this to develop. The inorganic lake clays contain much more water than they do at Dublin Bog. They are laminated and frequently contain charcoal fragments. At the base of the section there are bedded dolerite sands and fine gravels.

Rhythmites occur throughout the upper Mersey Valley and, except for one location in the Fish River valley, are usually less than 1 m thick. The Fish Valley exposure has some 6 m to 8 m of rhythmite (Figure 31) which grade upwards into sand and gravel. In the cores at both Dublin Bog and Pillinger Bog the rhythmites are unweathered and rich in clay. Colours vary in the range from light yellow brown to grey brown. The laminae vary in thickness from 1 mm to 5 mm. In other outcrops which have been exposed to weathering the rhythmites are similar except that they are browner in colour,which is due to the weathering and oxidation of the dolerite derived material in the sediment.

DIRECTIONS OF ICE MOVEMENT

The direction of ice movement of the Rowallan Gaciation has been established using roches moutonnées, whaleback forms, striations, grooves and till fabric analysis. A summary of the directions of ice flow of the Rowallan age ice is given in Figure 33.

Roches moutonnées and whaleback forms

Many of these landforms are present over the area. Not all are well formed and only those which have a clear orientation were used to estimate ice direction. In the field, orientations were measured using a prismatic compass. The results were adjusted for magnetic variation and plotted on the appropriate 1:25000 scale map. Caution in interpreting these landforms as indicators of ice direction was exercised as the landforms could have been formed in a previous period of glaciation. To what extent the ice may have moved in the same or different directions in former times is difficult to establish.

Striations and grooves

Striations were recorded on surfaces of rocks such as dolerite, quartzite and mudstone. A single record of a striation on mudstone was revealed after excavating a till outcrop overlying Permian mudstone at the southern end of Lake Rowallan (Figure 7). A few striations and grooves were recorded on dolerite (see for example Figure 32) where they had been protected from weathering by water, till or ice-transported boulders. Numerous striations were recorded in quartzite of the Howell Group in the vicinity of Rowallan Dam. Where striations were present it was common for there to be a number of directions to be indicated. In the field the range in orientation was recorded using a prismatic compass to ± 1°, and after results had been adjusted for magnetic variation they were plotted on a 1:25000 scale map.

Till fabric analysis

Fabric analyses were made at some 15 sites where there were outcrops of Rowallan Till. At the majority of sites the dominant clast in the till is dolerite, which over the whole area is well jointed, and readily breaks along joint planes. This produces clasts which are rectangular or sub-rectangular in shape and thus suitable for fabric analysis. Minor clasts which occur are Permian and Triassic sandstones and mudstones. The sandstones are either extremely rounded or disintegrate on removal from the section but the mudstones, particularly when metamorphosed, break into rectangular clasts that are also suitable for fabric analysis.

The methodology used in fabric analysis followed the recommendations of Andrews (1971). Sites were chosen where a reasonably thick outcrop (at least 0.5 m) of basal till was available. A site was selected to avoid large erratics which could have caused local variations in the ice flow direction. As far as possible the site was chosen so that an exposure could be cleaned and excavated to produce a horizontal area of 2 to 3 m^2. Pebbles were selected from the whole area excavated and were selected only if they were angular (not overly rounded) with the ratio of the a-axis : b-axis = 2 : 1 and between 30 mm and 100 mm long. Measurements of the dip and orientation of the a-axes of 100 pebbles were recorded. Dip was

Figure 32: Striations in dolerite on a moulded surface where the ice overtopped the edge of the Mersey Valley near Cathedral Mountain. The striations have been protected from erosion by water. Normally this feature would be under water but an exceptionally long dry spell of weather lowered the level of the lake by approximately 2 m.

measured with a clinometer and the orientation was measured with a compass with rotating bezel.

Cautions on technique from a number of sources were observed as fully as practical. Drake (1977b, p. 180) suggests that 100 pebbles should be selected and that strict adherence to the ratio of a-axes to b-axes be maintained in order to obtain valid results. Andrews (1979, p. 322) makes suggestions on excavating the site to remove the outer pebbles which may have been disturbed. He also gives directions for sampling a site and booking the results. Cornish (1979, p. 4) reviews the errors in field procedures which have been published in the literature.

The 100 data points were plotted on a Schmidt equal area stereographic net. The point density was counted with a Kalsbeck Counting Net and contoured at 1% intervals.

The problem of analysing till fabric data is discussed by a number of authors such as Ajne (1968), Harris, (1969), Stephens (1969), Robets and Mark (1970, 1971), Slaymaker and Church (1971), Andrews (1971), Mark, (1971, 1973, 1974), Ballantyne and Cornish (1979) and Westphal (1981). Discussion centres on which is the most reliable statistic to test goodness of fit in circular distributions. The statistics used in most of the studies in the literature are chi-square, Tukey chi-square and vector analysis such as eigenvalue techniques. In a comprehensive paper, Cornish (1979) reviews three-dimensional statistical analyses of till fabric data. He recommends that the most useful statistic is one proposed by Dale and Ballantyne (1980). The advantages of this statistic over the normally used chi-square or vector analysis are four-fold:

"(i) The tests are univariant with respect to the point of origin of measurements.

(ii) The tests do not assume a circular normal distribution.

(iii) There are no limitations on sample size.

(iv) Used in conjunction, the tests allow the the characteristics of the distribution to be identified, and the significance of 'sense' as well as orientation to be determined" (Dale and Ballantyne, 1980 p. 189).

Two statistics were calculated, A_n360 and A_n180. The purpose of these statistics is to test the strength and significance of sets of orientation measurements. Dale and Ballantyne (1980, p 189) indicate the usefulness of these statistics for till fabric analysis when they state "a sample with high values for both statistics would indicate that both orientation and inclination were significant. A high A_n360 value and a low A_n180 value would suggest that inclination alone was important and the converse, that only orientation was significant."

In all 15 sites sampled for basal Rowallan Till both A_n360 and A_n180 statistics were significant at the 0.001 level, indicating that both orientation and inclination are statistically significant. These directions have been plotted on Figure 33.

DEGLACIATION OF ROWALLAN GLACIATION ICE

Stages of Ice Retreat

Early stages of ice retreat have already been discussed in the section on valley ice lobes (see page 91) and it has already been suggested that there was rapid retreat from the terminal position of lobes at Dublin Bog, Pillinger Bog and the Mersey-Arm confluence.

There are obvious interpretation difficulties in relating landforms to stages of glaciation. The hummucky moraine, moraine ridges, outwash terraces and plains can be used to postulate an ice front which was in a steady-state position. Equally, however, the occurrence of these landforms could represent a readvance to a position after a rapid period of retreat during the general process of deglaciation. It

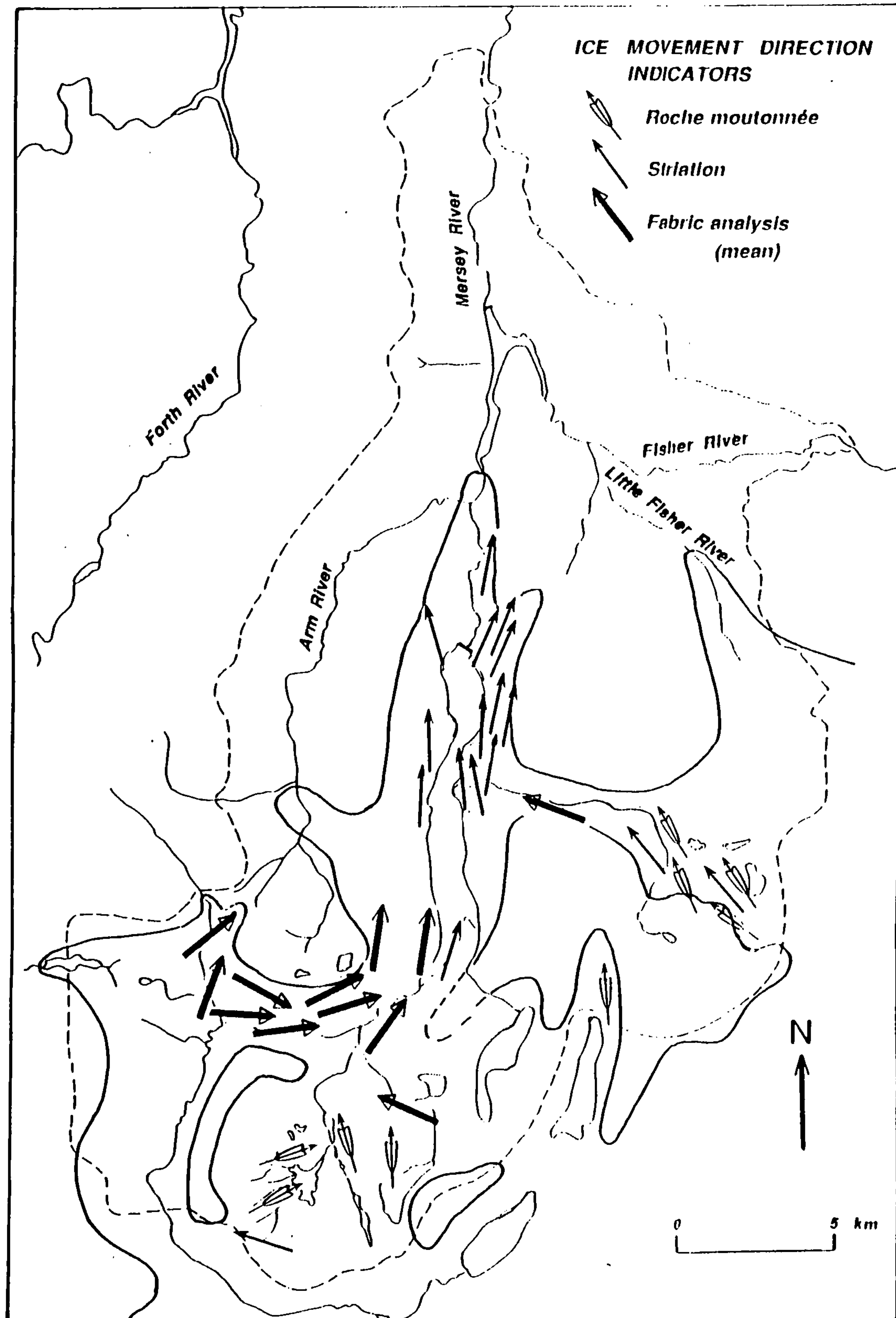

Figure 33: Ice flow directions for the Rowallan Glaciation.

is therefore difficult to use landforms to differentiate, with certainty, between a steady-state position and a readvance. The stance adopted has been to describe sequential positions on the landscape where the ice front remained for a period of time during the general deglaciation. These positions are identified as numbered 'Stages' beginning with Stage 1 for the maximum position at the terminal ice lobes.

The main Mersey Valley ice lobe is the only one where four stages of retreat can be detailed. Stage 1, the terminal stage, occupied a position 100 m below the Arm-Mersey confluence; Stage 2 is characterised by a dissected end moraine, 400 m above the Mersey-Arm confluence; Stage 3 has the steepest outwash terrace and occupies a position some 1.3 km above the Mersey-Arm confluence; and Stage 4 is the site of the Rowallan Dam where extensive till and glacifluvial deposits outcrop. Detailed examination of the middle part of the valley for 11 km above the dam is obscured by water, except at times of drought. During these periods it is possible to examine the southern end of the floor of Lake Rowallan. Maps published prior to the construction of the dam have been checked and no obvious stage was identifed.

Above the dam Stage 5 is identified by the HEC island at 342713 (Rowallan). It is entirely composed of coarse outwash gravel. The eastern side of the valley adjacent to this island also has extensive outcrops of glacifluvial sediment. A large end moraine occurs upstream and diverts the drainage of Juno Creek on the eastern flank and an unnamed creek on the western flank at 333708 (Rowallan). Presently both creeks follow the channel originally cut by meltwater in front of the moraine. Intensive meltwater activity, which has already been discussed, on the plateau west of Lake Louisa, may have contributed to the accumulation of these glacifluvial sediments.

Stage 6 occurs upstream of Steers Plain, where a hummocky moraine with irregular masses of boulders and pebbles is spread across the valley. These masses contrast sharply with the flat surface of the plain which is formed on a well-washed sand. High on the valley edge the creek which flows out of Lake McCoy cuts through thick moraines. Lower down this creek loses a considerable volume of water through percolation, presumably into the open structured meltout and ablation tills, gravels and sand deposited during this stage of retreat.

Stage 7 is the last clearly discernable stage and occurs just downstream of Lees Paddocks where a region of thick moraine has been incised by meltwater channels. One of the moraines, which may have a rock core, stands 120 m above the floor of the valley at 25679 (Cathedral) and is the largest and highest moraine yet to be identified in the region. Downstream from it are a number of meltwater channels flowing in apparently random directions. The height of the moraine suggests that the glacier remained at this point for some considerable time or that a significant readvance terminated at this location. The stream flowing from the Pillinger Plateau is diverted by the moraine and has a much-delayed junction with the Mersey River. This stream follows an outwash terrace which exists on the valley floor close to the northern flank of the valley beneath Pillinger Plateau. The terrace commences north of the dissected moraine and continues downstream for 600 m. At one point on the plain, drainage of the creek is so deranged, that it branches into two channels. The minor branch flows into a marsh dammed behind a moraine less than 200 m from the Mersey River, whilst the major branch takes the course indicated on the map (Cathedral).

Retreat from Stage 7 appears to have been extremely rapid as there are no discernable end moraines along the 4 km length of Lees Paddocks. It is possible that an additional stage occurred above Lees Paddocks in the vicinity of the rhythmite deposits at 256636 (Cathedral). When the glacier retreated from Stage 7 it seems that the retreat gained considerable momentum. Kiernan (1985, p. 480) states that in the later phases of glaciation, ice would have spilled off the western margin of the Traveller Range in only a few localities, and that the ice cover was generally less than 200 m thick. If this was the case, it is likely that the ice on the Traveller Range and the Mountains of Jupiter would be feeding the Mersey system no longer, but instead would be moving off in a southeasterly direction. The major collecting ground for glacial ice at Stage 7 would have been the Lake Meston area some 18 km from the northern end of Lees Paddocks. In effect, by this stage, the glacier had probably lost its 'critical mass' and further slight warming would have produced rapid retreat.

Retreat in the Lake Ayr region is evident by the many end moraines which cross the valley. Unfortunately these are incomplete and have been dissected by meltwater. Correlation with the main glacier in the Mersey Valley is therefore impossible. The irregular forms of these moraines are probably probably related in part to the fact that as the glacier retreated from the Lake Ayr-Reedy Lake region, meltwater would have been unable to escape to the west because the regional slope would have been towards the glacier. As a result, the meltwater would have been forced to flow towards the glacier. The numerous ponds, bogs and flat areas, representing silted ponds, reflect the quantity of water which was trapped in the dead ice moraine of this topographic re-entrant area during deglaciation.

There is no evidence for retreat stages in the Jacksons Creek - Moses Creek Valley, the Little Fisher Valley or the Fish River Valley.

Topples and solifluction deposits

Evidence that toppling was associated with deglaciation has been discussed previously (see page 44) with reference to a section in a road cutting, at 335685 (Rowallan), which reveals talus, derived from the topples, overlying a glacial sequence consisting of 0.4 m of solifluction slope deposit at the top, 0.8 m of gravel and 1.2 m of basal Rowallan Till. Caine (1983, p. 97) suggests that toppling is a deglaciation process on steep escarpments which have been overridden by glacial ice. It is certain that periglacial conditions were active in the deglaciation stages of the Rowallan Glaciation on the evidence of the superposition of detrital deposits on Rowallan glacial material. Talus overlies Rowallan Till at the top of the Mersey Valley below Lake McCoy where the till is light brown in colour, lacking in fines and contains more angular particles than other tills of a similar age. The talus is about 2 - 2.5 m thick. Solifluction deposits, which typify the region in the vicinity of Maggs Mountain, cover Rowallan Till in several localities. The maximum observed thickness of these deposits is 1.2 m, which is considerably less than the 5 m found lower in the valley beyond the Rowallan ice limits.

THE AGE OF THE ROWALLAN GLACIATION

The geographical extent, the stratigraphy and the weathering characteristics of the glacial sediments indicate that the Rowallan Glaciation was the youngest and least extensive glaciation of the upper Mersey Valley.

The age of the Rowallan Glaciation was estimated from a number of ^{14}C dates on charcoal and organic matter in the sediments.

In the Fish River Valley a small quarry, at an altitude of 720 m, reveals outcrops of glacifluvial sands and gravels overlying till. A lens in the bedded gravel contains charcoal fragments which were dated as >28,000 yr BP (SUA-1938). This location is at a lower altitude than the Rowallan maximum ice margin, which it is estimated, reached an altitude of between 1000 m and 1100 m. Clearly the date of >28,000 yr BP is too old for a retreat stage of the Rowallan Glaciation and either the charcoal must be derived from an older soil profile, which would have formed prior to the onset of glaciation, or the lateral moraine belongs to an earlier stage of glaciation. There is, therefore, no dated evidence from the region which defines the onset of the Rowallan or last glaciation which was estimated as about 25,000 years BP for the West Coast Ranges from pollen data (Colhoun and van de Geer, 1986).

The most continuous sequence, from which datable materials are available that succeeds the Rowallan Glaciation, occurs at Dubin Bog. The sequence contains a variety of lake clays and organic muds adjacent to the ice proximal slope of the end moraine. The lake sediments and organic muds obtained by cores have been dated by Hill, Colhoun and van de Geer (1988, p.108) as follows:

Sample	Material	Depth	Age (yr BP)
CORE 8			
SUA 2227	organic lake mud	2240-2290 mm	4,430± 80
SUA 2226	organic lake mud	3240-3290 mm	7,170 ±120
SUA 2191	organic lake mud	4240-4290 mm	8,920 ± 140
SUA 2225	organic lake mud	5240-5290 mm	10,730 ± 150
SUA 2190	organic lake mud	6320-6370 mm	11,710 ± 190
SUA 2224	organic lake mud	6840-6890 mm	12,910 ± 220
SUA 2189	organic lake mud	7470-7540 mm	13,150 ± 240
SUA 2188	diffuse charcoal in lake clay	8380-8540 mm	13,400 ± 600

Hannan and Colhoun (1987, p. 44) state that the clays containing the oldest date "overlie 440 mm of laminated clays and fine sands. The clay laminae vary from 1 mm to 5 mm in thickness and the sands from 5 mm to 30 mm. There are 31 clay and sand couplets and the basal 150 mm has a varved character. What periodicity of deposition each couplet represents is not known. The longest period likely is annual which suggest that the ice was present at Dublin Bog within a few decades of the basal ^{14}C age." The age of the glacial maximum therefore appears to differ from the West Coast where Kiernan (1983, p. 199) dates the last glaciation maximum as 18,800 ± 500 yr BP (ANU-2533) from wood in proglacial silts beneath outwash gravel near the confluence of the Dante Rivulet and the King River. Hannan and Colhoun (1987, p. 45) suggest that the difference could be related to a greater thickness and extent of ice in the Central Plateau compared with that of the West Coast system.

Three other sites of significance for the Rowallan deglaciation have been radiocarbon dated. The first is a basal radiocarbon date from an aboriginal rockshelter located near Ladder Creek on Lees Paddocks. This gives a date of 9,760 ± 720 (Beta-4757) (Lourandos, 1983, p. 39). The occupation of the rock shelter suggests that there was food available in the vicinity. Hence, it is likely that the Cathedral Plateau icecap had completely melted by this time. The second date comes from a core in an upland *Sphagnum* bog near the source of Zion Creek at 435706 (Pillans Lake). Three dates have been recorded by J. Whinam (pers comm) at 0.68 m - 0.72 m a date of 5,240 ± 140 yr BP (ANU-5793); at 1.59 m - 1.63 m a date of 7,350 ± 300 yr BP (ANU-5792) and at 2.00 m a date of 8,270 ± 270 yr BP(ANU-5794). Beneath the lowest date there is a sudden change to gley clay. This core was taken at an altitude of 1180 m and is close to the ice limits of the Rowallan Glaciation. The results show that vegetation was present approximately 8000 years BP in the Central Plateau area. The final date was obtained by J. A. Peterson of Monash University, from peat in a depression in glacial drift on Borradaile Plains and gives an age of 10,840 ±180 (Gak-785) (Colhoun, 1985b, p. 46) The accumulation of extensive peat on the plateau surface, even beyond the Rowallan ice limits, would tend to suggest that deglaciation was well advanced by this time. These dates are similar to those established in other parts of the state for the commencement of postglacial climatic warming (MacPhail, 1975; MacPhail and Peterson, 1975; Caine, 1983; Colhoun, 1985a ; van de Geer, Colhoun and Mook, 1986; Colhoun and van de Geer ,1986) which suggests that all ice had disappeared by 9500 years BP.

About 600 m upstream from the end of Lees Paddocks, Rowallan Till overlies an organic deposit which, from a brief palynological analysis, appears to be interglacial (Colhoun, pers comm). The deposit is rich in carbonised and mineralised wood and is presumably beyond the limits of radiocarbon dating. The site will be carefully sampled in the future for palynological investigation. (Figure 34)

CLIMATE DURING THE ROWALLAN GLACIATION

Taking the mean annual temperature of the nearest station, Cradle Valley (altitude 940 m), as 6.1°C (Bureau of Meteorology, 1980, p. 35), and a lapse rate of 0.65°C/100 m (Colhoun, 1985a p. 45) the present regional snowline is estimated to be at a height of 1878 m. To calculate the equilibrium line altitude (ELA) for the Rowallan Glaciation the method outlined by Porter (1975) was used. The ice limits of the Rowallan Glaciation were plotted on 1:25000 scale maps. An estimate was made of the location of the divide on the Central Plateau, between ice which flowed into the Mersey system and ice which flowed into other systems. Contour lines were constructed for the surface of the Rowallan Glacier. The assumed accumulation-area ratio (AAR) is the ratio of the area above the equilibrium line to the area of the entire glacier, and this ratio was taken to be 0.6 (Porter, 1975, p. 35; Colhoun, 1985a, p. 45). The total area of the Rowallan Glacier system was calculated to be 282 square kilometres. The lowest 113 square km (40%) of the area of the glacier was calculated by cumulatively adding the area occupied by successive 50 m elevations, starting from each of the lobes of the Rowallan Glaciation. In this way the ELA was calculated to be 1050 m. This figure is comparable with results obtained from other parts of the state. Colhoun (1985a, p. 45) obtained heights that varied from 835 m for the icecap, to 1000 m for a cirque glacier on Mount Darwin, for the Margaret Glaciation on the west coast of of Tasmania. Caine (1983, p. 59) calculated an ELA of 1400 m for the icecap phase of glaciation on Ben Lomond, whilst he obtained a figure of 1275 m for cirque glaciers. He (1983, p. 70) suggests later that the icecap phase was probably of penultimate glaciation age and the cirque phase of last glaciation age.

The figure calculated for the ELA can be transformed into a figure for the snowline by subracting 100 m (Caine, 1983, p. 58), which gives a snowline for the region, during the Rowallan Glaciation maximum, of 950 m. The comparison with the present snowline makes a difference of 950 m, which again is similar to snowlines calculated for other parts of the state. Caine (1983, p. 60) and Colhoun (1985a, p. 45) both quote a difference of approximately 1000 m between the snow lines of the present day and the last glaciation. Davies (1969, p. 4) postulated a rising snowline from west to east for the late Pleistocene glaciation of Tasmania. Interpreting his map suggests a snowline of 762 m (2500 feet) for the West Coast Ranges and 1219 m (4000 feet) for the Central Plateau region. The figures cited above indicate that the snowline probably did not rise as steeply as Davies predicted with figures of 735 m to 900 m on the West Coast Ranges; 950 m on the Central Plateau and 1175 m on Ben Lomond.

The present lapse rate is 0.65°C/100m (Colhoun, 1985, p. 45) and assuming no change since the Pleistocene then the average annual temperature in the area would be 6.2° C lower than at present. This would give an average annual temperature of -0.1° C at Cradle Valley.

Further indications of environmental conditions during the Rowallan Glaciation and the Holocene Stage in the region are obtained from Hill, Colhoun and van de Geer (1988, p. 129) in the pollen analysis of the cores taken from Dublin Bog. They analysed the pollen in the cores and subdivided them into 8 zones DB1 (youngest) to DB8 (oldest). Zone DB8 (inferred age from 13.6 ka to 13.4 ka) is dominated by herbs. The lack of *Isoetes* or *Botryococcus* indicates that nothing grew in the lake. The presence of carbon in the sediment suggests that there were frequent fires in the vicinity. In zone DB7 (inferred age 13.4 ka to 13.2 ka) the herbs still dominate but there is an appearance of alpine and subalpine vegetation including the ground level native pines *Microstrobus* and *Microcachrys* . During zone DB6 (13.3 ka to 12.9 ka) the vegetation became wet sclerophyll forest with the influx of *Eucalyptus* and *Pomaderris* . *Isoetes* , *Botryococcus* and Restionaceae were growing in the lake. The rise of the woody taxa during this period was rapid and occurred within 300 years. Zones DB5 (12.9 ka to 11.7 ka) and DB4 (11.7 ka to 10.3 ka) suggest a mild humid climate with the vegetation remaining wet sclerophyll forest dominated by eucalypts. The lake began to contract rapidly towards the end of DB4. During zones DB3 (10.3 ka to 8.4ka) and DB2 (8.4 ka to 3.36 ka) the lake continued to shrink to a swamp and towards the end of DB2 the concentration of eucalypt pollen commenced to fall. During DB1 (3.36 to present) *Eucalyptus* remained the dominant pollen taxon, but its concentration is greatly reduced and there is a reduction in the overall concentration of pollen. There is no suggestion of changing climatic conditions or vegetation type in the later stages but the lake was largely infilled and ceased to be a suitable site for pollen accumulation.

In summary there was a rapid transition from alpine and subalpine vegetation to wet sclerophyll forest after 13.2 ka and throughout most of the Holocene this forest was the regional vegetation type. It should be noted that this rapid transition of vegetation in the valley floors, which must be related to climatic warming, precedes the suggested age (9.5 ka) for all ice having melted from the upland by 3 ka. This data suggests that the 9.5 ka must be regarded as a minimum age and that most of the ice had probably disappeared somewhat earlier.

CHAPTER 6

THE ARM, CROESUS AND OLDER GLACIATIONS

Discussion of the characteristics of the Arm and Croesus glaciations will follow the format which was used for the Rowallan Glaciation.

THE ARM GLACIATION

There is much less evidence available to reconstruct the Arm Glaciation than there is to recontruct the geological history of the Rowallan Glaciation. Nevertheless, the discussion which follows outlines the evidence which has been gathered to recontruct the extent of ice, the associated sediments, the age and the climate operating in the upper Mersey Valley during the Arm Glaciation.

The extent of the Arm Glaciation

The extent the Arm Glaciation ice is shown on Figure 17. Fewer landforms can be positively attributed to the Arm Glaciation, than to the Rowallan Glaciation and the evidence for the ice limits relies on outcrops of sedimentary deposits, in particular till.

In order to analyse the extent of Arm Glaciation ice, four key areas will be discussed. The areas are the Mersey Valley, the Fisher and Little Fisher valleys, the Borradaile Plains and the Plateaux.

The Mersey Valley

Paterson (1966, 1969) maintained that the Parangana damsite was in the terminal zone of a glacier on the evidence of drilling which showed the channel profile of the

Mersey Valley to be narrow and V-shaped downstream and broader with truncated spurs upstream. It has previously been indicated that Parangana Dam may not be the terminus for Arm Glaciation ice. The evidence is related to an outcrop on the western bank of the Mersey River opposite the junction with Martha Creek. Here steeply dipping sequence of quartzite and schist is overlain by a diamictite. It is strongly suggested that the diamictite is till, because it contains rounded and unweathered dolerite boulders up to 0.8 m in size in a sandy and pebbly matrix. There does not appear to be a substantial silt or clay fraction in the matrix. The surface of the quartzite and schist lying directly underneath the deposit is extremely smooth, but where fluvial erosion has exposed the surface by removing the diamictite the surface is angular as the schistosity of the bedrock has facilitated severe erosion. It is suggested that the underlying schist was smoothed by ice action. The smooth nature of the schist beneath the diamictite is therefore not attributed to fluvial erosion, since present fluvial erosion tends to exaggerate the schistosity and break up the smooth surface. Considerable portions of the diamictite were removed and possible striations observed, but the structure and texture of the schist makes certain identification impossible. If this interpretation is correct then it implies that ice of the Arm Glaciation extended at least 1.6 km downstream of Parangana Dam, and the iceflow presumably followed the line of the pre-existing valley.

Arm Till has been described from the area around Parangana damsite and the Mersey - Fisher confluence by two authors (Paterson, 1965, 1966 and 1969, and Derbyshire, 1968). Paterson described in some detail the till and related deposits which were uncovered during the excavations for the dam. Derbyshire also had the advantage of seeing these excavations.

Till deposits visible now in the area of the damsite are restricted. An outcrop on the main Mersey Forestry road, 200 m above the bridge on the western side, occurs beneath thick slope deposits, and is a limited exposure. Similarly limited outcrops are visible in the overspill channel of the dam.

Above the dam on a disused access road there is a good exposure of Arm Till. This outcrop occurs at an altitude of 400 m which is some 60 m above the floor of the valley. A diagram of the exposure is shown in Figure 33. It reveals a complex of basal till, meltout till, flow till and glacifluvial sediment which will be discussed in detail in a later section on page 127. At the base of the section there is lodgement till and meltout till. The upper part of the section reveals an undifferentiated till overlying an erosion surface which occurs directly above gravel. These members are overlain by lodgement till and flow till. The occurrence of basal till overlying basal and meltout till raises the possibility of at least two local advances during the Arm Glaciation. Paterson (1966, p. 150) recorded 10 m of glacial sediment below the dam site and noted that there was a "pocket of periglacial solifluction material within the till" which also suggests more than one phase of cold climate. In a later paper (1969, p. 59) Paterson discusses the presence of an older and a younger till in a cut-off trench of the dam. It is unlikely that the older till is Croesus Till because he makes no mention of the state of weathering of the older till, yet indicates in a different section the presence of an extremely weathered till at the Mersey-Fisher junction "where dolerite boulders are almost completely decomposed."

It seems likely therefore, on the evidence obtained from the cutting above Parangana Dam and further evidence cited by Paterson, that the Arm Glaciation in this part of the valley consisted of more than one advance, and that the outermost ice limit was close to the confluence of Martha Creek with the Mersey River.

<u>The Fisher and Little Fisher valleys</u>

Ice of the Arm Glaciation flowed down the Little Fisher Valley and occupied a major part of the Fisher Valley above its junction with the Mersey Valley.

In the Little Fisher Valley downstream from the limit of the Rowallan Glaciation there are continuous thick outcrops of Arm Till to the junction of the Fisher River. The road above the Fisher Power Station exposes thick outcrops of Arm Till to an altitude of 600 m. On the road above this point there are only exposures of slope deposits found up to a height of 820 m where there is an outcrop of the very weathered Croesus Till. In the Fisher Valley upstream from the power station there are till outcrops that have been deposited mainly by ice that flowed from Dublin Plains and the Little Fisher Valley. It is suggested that only a small volume of ice, if any at all, flowed from the Central Plateau down the Fisher Valley at this time.

The Borradaile Plains Area

There is no evidence of Arm Glaciation ice completely covering the Borradaile Plains, but rather it seems to have been confined to the Mersey and Forth valleys and skirted around the southern edges of the plain.

Bare Hill road links the Mersey Forestry road to Borradaile Plains and contains continuous outcrops of Arm Till from the junction to an altitude of 700 m. Beyond this point there are outcrops of Tertiary basalt only in the road cuttings. Across the extent of the Borradaile Plains there are few rock outcrops except in quarries where excavation has been for road gravel. No substantial outcrop of Arm Till has been found anywhere on the Borradaile Plains. Small crumbly pieces of till material resembling Arm Till were found in the roots of upturned trees close to the top of the Mersey Valley near Gads Creek. On the southern part of the plain the landscape is dominated by quartzite slope deposits. In the northern part towards Emu Plains solifluction material composed mainly of basalt fragments, is usually all that can be seen near the surface. The only till found on Borradaile Plains is extremely weathered and most likely belongs to an older glaciation, probably the Croesus Glaciation.

On the newly constructed road to the Lemonthyne Forest which follows the top of the Forth Valley, in the vicinity of Sardine Creek, there are several outcrops of Arm Till that underlie solifluction deposits at altitudes in excess of 900 m.

From these observations the simplest explanation is that the ice of the Arm Glaciation was confined mainly within the major valleys of the Mersey, Forth and Arm and impinged marginally onto the Borradaile Plains. The field data imply that the Mersey, Forth and Arm valleys were almost completely filled with ice but still formed two major outlet glaciers from a central icecap. There is no evidence to indicate glaciation of either February Plains or Borradaile Plains at this time.

The Plateau Regions

Highland areas can be identified that are outside the zone affected by the Rowallan Glaciation but were influenced by the Arm Glaciation. The main areas are the eastern part of the Clumner Plateau, an area stretching from Solomon's Jewels to the Walls of Jerusalem, the Pillinger Plateau and a part of the Central Plateau around Lake Mackenzie.

The majority of the Clumner Plateau was not glaciated by ice during either the Rowallan or Arm glaciations. During the Rowallan Glaciation when ice was spilling off the plateau in the vicinity of Clumner Bluff there were two main glaciers one flowing through the Fish cirque and the other down the Little Fisher Valley. It is suggested that during the Arm Glaciation the ice would have occupied a greater area of the highland region and would have been thicker. This ice seems to have formed the ice-eroded rock surfaces and the basin lakes west of Mersey Crag on the Clumner Plateau. No till of any age has been found in this region.

The activity of Rowallan Glaciation ice has been described already for the area around the Walls of Jerusalem, and a number of ice-free areas identified including the area around Lake Loane, Solomons Jewels, the valley of Wild Dog Creek, Jaffa

Vale and the depression occupied by Lake Salome. It is suggested that most of these areas were covered with ice during the Arm Glaciation. Above the Rowallan Glaciation ice limits in Wild Dog Creek there are outcrops of till in the bank of the creek and arcuate moraines are present close to outwash and flood plain terraces of the creek. The area around Lake Salome and Jaffa Vale contains numerous outcrops of fine grained slope deposits, with occasional till, most likely Arm Till, underneath. The Solomons Jewels-Lake Loane area has an abundance of clearly defined glacial erosion features such as basin lakes, roches moutonnées and whaleback forms. There are also large numbers of dolerite ice-transported boulders and infrequent till outcrops. These are inferred to have been the result of Arm Glaciation activity. The lack of soil development in the region of Solomons Jewels is assumed to result from a combination of high altitude, slow weathering and the relative lack of glacial deposition.

The Pillinger Plateau is covered with scree and block fields, and it is understandable that no outcrop of till has been found. Below the Plateau in the headwaters of the Arm River there are numerous outcrops of Arm Till. Although there is no direct evidence it is likely that Arm Glaciation ice covered much of the Pillinger Plateau, but the peak of Mt Pillinger probably remained as a nunatak.

The northern part of the Central Plateau, around Lake Mackenzie, contains outcrops of till in the channel of the Fisher River. Similar till occurs extensively in excavations associated with the HEC dam and flume construction. The till outcrop in the Fisher River is approximately 1.2 m thick and is overlain by 2 m of solifluction material. The till is described by Mather (1956, p. 11) as a well-cemented till which is responsible for the rapids at this point. This same till was also found by Mather on the plateau in exploration test holes for the dam. The till in the river section is relatively unweathered and contains dolerite clasts only, which are generally rounded and have a maximum size of 1.2 m. Manganese staining is present, but the weathering on the dolerite clasts appears to be much less than is usually found in Arm Till. However, the pattern of distribution suggest that it is more likely to be Arm Till than either Rowallan or Croesus age tills. No measurements of the weathering on the dolerite clasts were taken as the till is covered with solifluction material and the soil B horizon does not extend into the till. The till has a dark reddish brown colour (5YR, 3/3). Other outcrops of the till are visible where the solifluction layer has been stripped off the surface around the pumping station overflow at 468874 (Lake Mackenzie) and its access road. In these outcrops the till is fissile and varies in colour from brown (7.5 YR, 4/4) when markedly weathered, to a mottled dull brown colour (7.5 YR, 5/4) in an less weathered state.

To the west of Lake Mackenzie at the end of the flume at 439874 (Lake Mackenzie) in a small creek and an adjacent quarry there are outcrops of an extremely weathered deposit which is probably a chemically decomposed dolerite. The exposure in the creek reveals corestones of parent material. The colour of the matrix is mottled and varies from (10 R, 4/8) to (10 R, 5/6) red. In the quarry no unweathered dolerite was found. The chemically weathered rock, can still be recognised as having had former corestones and the matrix between their ghost outlines has a mottled appeance, with the same red colour as that in the creek. Irregular veins of white clay cut across parts of the outcrop. In places the vein material is black and coarser in grainsize than the white clay material. The floor of the quarry reveals a polygonal structure of fine joints within the clay in spite of the fact that the site was visited after a long spell of wet weather. The weathered material lies underneath 2 m of dolerite slope material. The presence of this extremely weathered rock at several sites suggests that Arm Glaciation ice is not likely to have reached this point.

However there is evidence of Arm Glacial ice activity in the area east of Lake Mackenzie. There are records in the literature of moraines having been identified around a number of the lakes (Maher, 1956; Derbyshire and others, 1965). In the section on landforms (see page 37) it was indicated that there are no depositional landforms which can be positively attributed to glaciations older than the Arm Glaciation and on this basis it is reasonable to conclude that these moraines were probably formed during the Arm Glaciation. If this is the case then Arm Glaciation ice occupied such a large proportion of the Central Plateau that it seems likely that some ice may have spilled over the edge of the Great Western Tiers on the northern or Mole Creek side. This suggestion has not been followed up in this thesis but Kiernan (1984) records till north of the scarp.

Sediments of Arm Glaciation ice

Discussion of the sediments deposited by Arm Glaciation ice adopts the same format as used for the Rowallan Glaciation section.

Subglacial till

No certain deformation tills of Arm Glaciation age have been recognised in the area.

The type section for lodgement till of Arm Glaciation ice is exposed close to the terminus of the diffluent ice lobe of the Rowallan Glaciation that crossed the low col at the head of the Arm Valley from the Mersey Valley. The outcrop of Arm Till has been described by Hannan and Colhoun (1987, p.41). The till is a reddish brown colour (5YR, 4/6) and the structural appearance shows a pronounced sub-horizontal lineation and fissility, probably due to overburden pressure of the Rowallan age ice and debris. The clasts are composed entirely of dolerite, which is rather unusual for Arm Till. Perhaps as this is the most southerly and one of the highest exposures of Arm Till in the area, it reflects the dominance of dolerite outcrops on higher ground. To the north and lower down the Arm Valley there are outcrops of mudstone, sandstone, basalt and schist. The matrix at the type section has 57% sand, 42% silt and 0.7% clay. The matrix of the till shows obvious signs of weathering and there is clear manganese staining around the dolerite clasts. Dolerite weathering rinds were measured, and a range from 0.5 mm to 2.2 mm was

Figure 34: The organic deposit below Cathedral Mountain in the upper Mersey Valley. The rhythmic layering and the presence of abundant charcoal are clearly visible.

obtained with a mean of 1.1 mm and standard deviation of 0.5 mm. The weathering rind statistics show low when compared with the other measurements taken for Arm Till. This is to be expected as the superimposed Rowallan Till contains clasts of Arm Till, which indicates that some of the Arm Till, most likely the more weathered parts, was removed.

Lodgement till of Arm Glaciation iceis usually weathered for 1 m to 2 m from the surface. Commonly, the till shows manganese staining particularly around the clasts and some of the more intensely weathered tills show iron staining. The matrix colour of the weathered till generally shows only slight variation from brown (7.5YR, 4/6,) to bright brown or reddish brown (7.5YR, 5/8 or 7.5YR, 4/6). In one situation a till found above the Parangana Dam has an unusually strong reddish brown colour (2.5YR, 4/8), due to the schist clasts which weather a reddish colour.

One of the best sections where lodgement till of Arm Glaciation age is exposed in a cutting of an abandoned road on the east of Parangana Dam (Figure 35). The basal member consists of 3 m of relatively unweathered till of lodgement type. This grades into till which could be a deformation till, if judged by the large angular blocks of schist it contains near its base. It also contains dolerite clasts up to 0.5 m across. In the middle of the basal member is a sand lens which has sharp boundaries and which contains concretionary limonitic nodules up to 50 mm across. The maximum thickness of the sand is 1 m and in some places at the top there is a thin band of fine rhythmite. Above the sand the till is more weathered and contains well rounded dolerite boulders as the dominant clasts, ranging in size to 0.5 m maximum, but with a modal size of around 80 mm. Other clasts include rounded fragments of quartzite and schist. The matrix is pebbly and contains patches of intense manganese staining. Above this there is a gradational boundary to the second till member, which consists of 2 m to 3 m of very coarse meltout till. This member comprises weathered dolerite clasts up to 2 m across which are embedded in a pebbly manganese stained matrix. This till is overlain by a wedge-

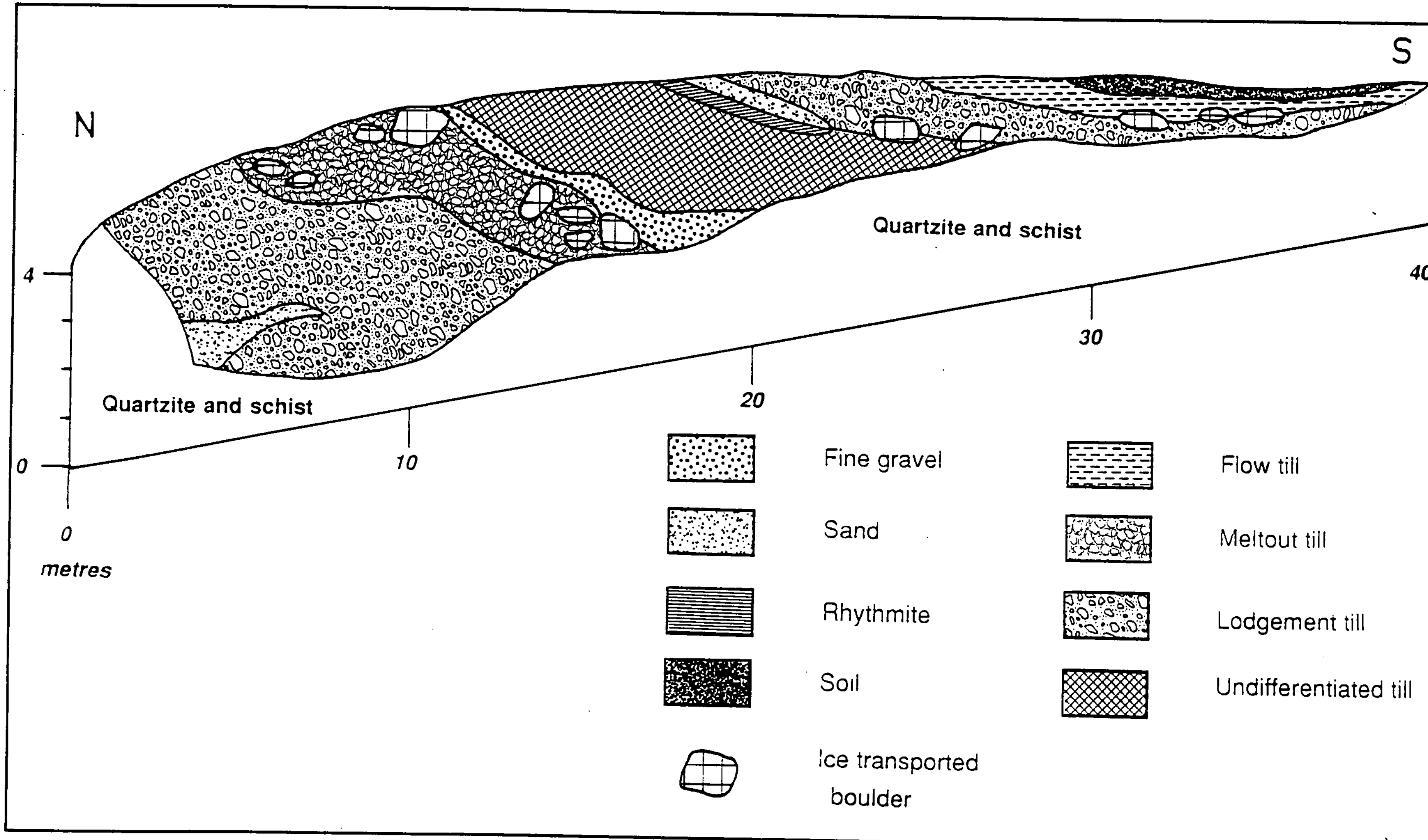

Figure 35: The section above Parangana Dam showing a complex of tills with flow till at the top of the sequence.

shaped, consolidated gravel bed, which in turn is overlain by the third till member; a 2 m to 3 m well compacted undifferentiated till composed mainly of well-rounded dolerite boulders and minor quartzite. This till has a horizontal attitude and appears to have been emplaced on a small erosion surface above the gravel bed. An analysis of the weathering rinds of this till produces statistics which are typical for the Arm Glaciation (mean = 4.22; standard deviation = 1.07; maximum = 6.7; and minimum 1.97). Small lenses of rhythmite and sand occur above this till. The fourth and fifth till members occur near the top of the section. The lower till member is lodgement till and has a characteristic reddish coloured matrix, and it is much more compact than the underlying tills. The clast composition of the till is quartzite 54%, dolerite 32%, schist 11% and basalt 3%. The top member of the section is a flow till that occurs beneath a pebbly soil and appears to truncate the underlying lodgement till. Some large dolerite clasts extend across the boundary between the two till members at the top of the section.

This section is valuable in that it shows the variety of till materials deposited by Arm Glaciation ice. The erosion surface and change in attitude between the second and third till members in the section have been taken to indicate a readvance in the region during Arm Glaciation times.

Weathering of the dolerite clasts of Arm Till has been discussed in detail Chapter 4. In general, both lodgement and meltout Arm Tills have mean dolerite weathering rind thicknesses between 1.1 mm and 4.5 mm, with the maximum thicknesses varying from 2.1 mm to 6.8 mm. The exception to this general picture is the till in the Lake Mackenzie area and the lower reaches of the LIttle Fisher River. In both cases the dolerite pebbles have little or no weathering on the clasts. This is anomolous as the matrix of both these tills is mottled and can show considerable manganese staining. But there is no doubt that they are more weathered and hence older than Rowallan age tills and a lot less weathered and younger than Croesus age tills.

Clast analysis of the lodgement tills of the Arm Glaciation generally show greater variation when compared with Rowallan Tills, because they are exposed at lower altitudes and the ice responsible for their deposition had the opportunity to erode a greater variety of rocks. Tills occurring in highland areas have 100% of dolerite clasts, as is the case at the type section and for tills around Lake Mackenzie. As with Rowallan Tills the dolerite is the most widespread clast, which reflects its durability and extensive outcrop.

The clast composition is highly sensitive to the local outcrop even where the prevailing country rock is limited. On top of Maggs Mountain, which is capped with basalt, there are tills with clasts compositions of 80% basalt and 10% dolerite. Lower in the Arm Valley the dilution of the basalt component is rapid, and a typical clast analysis just inside the quartzite boundary is quartzite 63%, dolerite 25% and basalt 12%. Downstream even further, near Parangana Dam and well within the Precambrian Howell Group a clast analysis of a lodgement till reveals quartzite 56%, dolerite 32%, schist 11% and basalt 2%.

No basal meltout tills or tills of secondary origin of Arm Glaciation age have been identified in the region.

Supraglacial till

Two classes of supraglacial till, meltout till and flow till, have been identified of Arm Glaciation age.

A typical meltout till has been described from the cutting above Lake Parangana. It is very coarse and intensely manganese stained with a pebbly matrix which varies in colour from yellow orange (10YR, 7/8) to light yellow orange (10YR, 8/4). Other meltout tills have been identified from the Dublin Plains area and the upper Arm Valley below February Plains, where they appear to have been soliflucted. A particularly weathered meltout till is visible in the overspill channel of the Rowallan

Dam. This till also appears to have been soliflucted, as a wedge-shaped structure is observable within it.

The only flow till which has been identified has already been mentioned as being exposed in the cutting above Lake Parangana (see page 127). This till is the top till in the section and is deduced to be a flow till for the following reasons:

(i) It truncates the till immediately beneath it.

(ii) There are a number of dolerite boulders which are exposed on the boundary between the two top till members. Their size is large compared with the clasts in the till beneath. When the glacier retreated they could have been lowered from the ice surface onto the till and covered later by the flow till as it moved into its present position.

(iii) The clast composition of the flow till is quite different from the till imediately below. The most significant difference is in the percentages of dolerite, quartzite and schist. The flow till has 2% dolerite, 91% quartzite and 6% schist whilst the till below has 54% quartzite, 32% dolerite, 11% schist and 3% basalt. The lodgement till contains a higher percentage of dolerite boulders derived from the plateau area than the flow till. The flow till on top of the section contains little dolerite and its clast compostion reflects the rock which is exposed in the immediate surroundings, a clast composition typical of supraglacial material.

Ablation tills which may have covered parts of the region after the retreat of Arm Glaciation ice have not been identified. Most likely they have been incorporated into slope deposits which were formed during the Rowallan Glaciation.

Glacifluvial and glacilacustrine deposits

Gravel and sand deposits of Arm Glaciation age have been recorded from the overspill section of the Rowallan Dam and the section above the Parangana Dam. Unlike the Rowallan Glaciation, glacifluvial deposits of Arm age are patchy and limited in outcrop.

Rhythmites associated with the Arm Glaciation occur in the small outcrops in the upper Arm River, and in the sections above Parangana Dam and below the Rowallan Dam. The rhythmites are generally reddish brown to bright brown in colour (5YR, 4/6 to 7.5YR, 5/6), often sandy and occur frequently in beds which have been disrupted.

Age of the Arm Glaciation

The Arm Glaciation is beyond the range of radiocarbon dating and no reliable quantitative age has been obtained. Hannan and Colhoun (1987) have estimated its age to be greater that 100,000 years by quantifying the thickness of the weathering rinds on dolerite clasts. Bearing in mind the following assumptions: that weathering rates are uniform with time, the average rind thickness is the most valuable parameter, dolerite rinds in the Rowallan tills commenced to weather some 13,500 years BP, then a minimum age of 70,000 years is suggested. Research by Burke and Birkeland (1979), Colman (1981), Colman and Pierce (1981) and Brookes (1982) have indicated that weathering rates become slower with time. It has also been shown that in other parts of Tasmania the last glacial maximum occurred around 18,000 years BP (Kiernan, 1983; Colhoun, 1985), the real age is therefore likely to be considerably greater, probably in excess of 100,000 years.

Climate during the Arm Glaciation

Using the same method as for the Rowallan Glaciation the area of the Arm Glaciation is calculated as approximately 500 km^2. The figure can be represented as a minimum estimate only, as the exact limits of the glaciation are not known at this stage. An estimate of the ELA is 950 m which is only 100 m lower than for the Rowallan Glaciation, yet the area occupied by the glacier is almost doubled. The snowline would have been at 850 m which gives a depression in temperature of 6.7°C and an average annual temperature at Cradle Valley of -0.6°C. These figures are very similar to calculations made by Colhoun (1985, p. 50) for the West Coast Ranges. He estimates that the ELA was at 740 m and the depression of the temperature was approximately 7°C below present. Comparing the penultimate glaciation and last glaciation for the West Coast Ranges the snowline was 100 m lower and the temperature 0.5°C lower. Caine (1983, p. 59) calculates an ELA for Ben Lomond of 1275 m for the penultimate glaciation which is some 125 m lower than the ELA for the last glaciation. In the upper Mersey Valley the snowline for the Arm Glaciation was 100 m below the snowline for the Rowallan Glaciation and the temperature was 0.5°C lower.

THE CROESUS GLACIATION

The extent and effects of Croesus Glaciation ice

The extent of Croesus Glaciation ice has been estimated from the till outcrops which are found in the valley beyond the known limits of deposits attributed to the Arm Glaciation.

Till deposited by Croesus Glaciation ice is extremely weathered and occurs in a few isolated outcrops in the most northern part of the region of investigation, immediately beyond the deposits of the Arm Glaciation. There are reports in the literature of very weathered tills occurring much further down the valley than the most northern outcrops examined in this study. Colhoun (1976, p. 97) reports till in the Mersey Valley as far down as Mole Creek and Chudleigh and suggests that a glacier extended to Dawsons Siding approximately 60 km downstream from Croesus Bridge. Kiernan (1984, p. 216) reports till of the same type as the Croesus Till in the Gog Range approximately 20 km downstream and suggests the terminus of the glacier would have occurred near Latrobe.

Clearly the exposures found in the vicinity of Croesus Bridge are a small representation of what was a very widespread glacial episode.

No landforms have been found that can be definitely attributed to the Croesus Glaciation.

Ice directions of this glaciation are also difficult to determine. The clasts in the tills are so weathered that it is not feasible to use fabric analysis techniques. Only one ice direction was obtained from striations on the eroded surface of Permian mudstone in a quarry in the upper Arm Valley, and the significance has been described in the initial section on stratigraphy (see page 55). As this site lies within the confines of a valley, the topography of which would have influenced the local ice flow, it has little value in the consideration of a wider pattern of regional glaciation.

Sediments of the Croesus Glaciation

Till

Outcrops of Croesus Till were extemely weathered and could not be classified in the same way as the tills of the Rowallan and Arm glaciations. The type section for Croesus Till has been described by Hannan and Colhoun and occurs in a cutting at 349985 (Liena) on a bend on the main Gowrie Park road about 1.5 km north of Croesus Bridge. The till has a mottled appearance due to deep weathering. It varies in colour from bright reddish brown (5YR, 5/6) to dark reddish brown (5YR, 3/6). Dolerite is the major clast component comprising 95%. Small pebbles of quartzite are the only other clasts represented, presumably derived from the abundant Permian mudstones in the immediate vicinity. The matrix is composed of 72% sand, 27% silt and 1% clay. It was expected that there would be a higher percentage of clay in the matrix as the deposit is deeply weathered. However the bulk of the matrix seems to be composed of crushed detritus from the sandstones and mudstones rather than from the weathering of dolerite clasts which must have lost most of their mass by chemical dissolution. Both the matrix and the dolerite particles are severely altered chemically. The depth of the cutting is approximately 5 m but the weathering penetrates to a depth well below this. The weathering rinds of the dolerite range from 6 mm to 190 mm with a mean of 50.8 mm and a standard deviation of 29.5 mm. These weathering data should be taken as a minimum value as many of the dolerite boulders were totally weathered. Hannan and Colhoun (1987, p.41) state that "the degree of chemical alteration of the dolerite clasts in the type Croesus Till section, unlike the Arm Till section, probably represent close to the maximum degree of chemical weathering...."

Glacifluvial and Glacilacustrine Deposits

No glacifluvial deposits of Croesus age have been found.

Rhythmites of Croesus age are found exposed in a cutting on the road adjacent to the penstock above the Lemonthyme Power Station. They are very weathered and occur at the base of the section below Croesus Till (Figure 36). The rhythmites are a minimum of 600 mm thick, have a reddish brown colour (5YR, 5/6).

Age of the Croesus Glaciation

The age of the Croesus Glaciation is problematic. The best evidence is given from palaeomagnetic studies conducted on the rhythmites above the Lemonthyme Power Station, have a reversed detrital remanent magnetism (DRM) (Pollington, 1988, pers. comm.) Sediments with DRM's that are consistently reversed must precede the Brunhes Chron in age and belong to the Matuyama Chron which has an upper age of approximately 730,000 years BP and a lower limit of around 2.5 million years (Tarling, 1983, p. 183; Opdyke, Glass, Hays and Foster, 1966). It is therefore indicated that the Croesus Glaciation tills have a minimum age of 730,000 years old and therefore are at least of early Pleistocene age.

Figure 36: Rhythmites underlying Croesus Till at the Lemonthyme Power station.

Climate during the Croesus Glaciation

The limits of the Croesus Glaciation go far beyond the limits of the region of study and the area of the glacier cannot yet be calculated. Because of this it is not possible to derive the former ELA or associated snowline and infer possible depression of temperature. All that can be maintained from the greater extent of ice is that conditions must have been more rigorous than during either the Arm or Rowallan glaciations.

TERTIARY GLACIATION

Evidence for a Tertiary Glaciation

Paterson (1965, p. 121) postulated two "glacial stages" from the occurrence of a lithified tillite underlying a till in the Lemonthyme Valley. In a later paper Paterson and others (1969, p. 221) reported the results of a pollen count of laminated carbonaceous clay, silt and sand which overlies the tillite. Among the pollen grains are representatives from Tertiary flora. Paterson and others (1967) were reticent to attribute a Tertiary origin to this sediment even although there was only slight evidence for a derived origin of the pollen. Colhoun (1975, p. 3) suggests that these deposits represent either a late Tertiary or early Pleistocene glacial climatic oscillation. In the lower Arm Valley an outcrop of a well consolidated diamictite occurs at 334839 (Borradaile), which has been described from this locality by Derbyshire (1968, p. 30) as a tillite. The clasts commonly have flat-iron shapes and micro-striations can be seen with the aid of a binocular microscope. These characteristics combined with the high degree of lithification show the diamictite to be a tillite.

The tillite is light grey in colour, is well lithified and is composed mainly of clasts of basalt and dolerite, but minor mudstone, quartzite and schist are also present. The clasts range in size up to 400 mm and are generally well rounded. The presence of Tertiary basalt and Jurassic dolerite are definite evidence of a post-Permian age and therefore cannot be attributed to the early Permian glaciations of Tasmania for which there is widespread evidence (see below). The well lithified nature of the tillite and its contents are sufficient to correlate it tentatively with the Lemonthyme Tillite. Although a Tertiary age seems likely there is currently insufficient evidence to assign an age within the Tertiary.

LATE PALAEOZOIC GLACIATION

Rocks belonging to the Parmeener Super Group outcrop widely in the southern parts of the upper Mersey Valley. In some localities there are outcrops of the basal diamictite. Exposures of this rock have been noted on the eastern bank of the Mersey River adjacent to Steers Plain, where the diamictite occurs beneath a lodgement till of Rowallan age. The rock is brownish in colour and is extremely coherent. It has no obvious structure and the clasts are composed entirely of quartzite and schist, with a modal size in the range of 6 mm-10 mm. This pebbly diamictite contrasts with a very coarse diamictite which occurs beneath Cathedral Mountain where the clasts range in size up to 1.5 m and are well rounded. At this location the rock is found to grade vertically and possibly laterally into a fossiliferous shale. The fossils are poorly preserved specimens of brachiopods and bryozoans. Banks (1978, 1981) and Banks and Clarke (1987, p. 4) indicate that almost everywhere in the state the basal glacigenic beds are overlain by a marine siltstone.

On the northernmost point of Maggs Mountain there is another outcrop of Late Palaeozoic diamictite. It occurs immediately above quartzite and schist bedrock, and contains angular pebbles and boulders of quartzite held in a tough siliceous matrix. The texture and mode of occurrence of this diamictite make it highly likely that it is a deformation till. The outcrop has presented problems to authors in the past. Spry (1958, p. 130) describes it as a fluviatile breccia of Tertiary age. Rawlings (1967, p.268) describes it as a sub-basaltic sediment and loosely categorises it 'grey billy'. Banks and Clarke (1987, p. 4) record bedded screes of this age in the Cradle Mountain area. Similar brecciated diamictites occur on the eastern side of Lake Parangana below the scree line on the slopes of the Central Plateau. However, it is not clear whether these are deformation tills or are coarse, completely lithified slope deposits and breccias of the Parmeener Super Group. The resolution of this problem is beyond the scope of this thesis but it is clear that the late Palaeozoic glaciation invaded an area with a topography of considerable relief.

In two areas, around the Little Fisher River and further north around Snake Creek there are a large number of gravel quarries, which contain rounded quartzite pebbles encased in a sandy matrix. There are no Jurassic dolerite or Tertiary basalt pebbles in the gravel. Where the gravels are undisturbed by earthworks they are horizontally bedded and contain beds of sand and pebbles. Quite often the sand layers are cross bedded. Both the gravel and sand are quite well lithified but are easily broken into their component parts when scraped with earthmoving machinery. The origin of these deposits is problematic, but the absence of dolerite and basalt would seem to suggest that they may belong to the Parmeener Super Group deposits. The unlithified nature of the deposits suggest that they are younger. Jennings (1963, p.74) describes Tertiary fluviatile gravels and breccias of a pre-basaltic age in the valleys of the district. They could have been formed during the Tertiary before extrusion of basalt, but this does not explain the absence of dolerite. Dolerite is an extremely common clast in all sediment of the district and it is difficult to imagine that these extensive deposits could have been deposited here without containing some dolerite.

Although the gravels have been suggested to be Tertiary fluvial deposits, the absence of dolerite is surprising and indicates that they might be outwash gravels associated with the late Palaeozoic glaciation. Such gravels are not unknown as Ford (1960, p. 27) describes a Permian conglomerate in the Fish River area which "breaks down readily to leave a loose scree of rounded quartzite pebbles on the ground surface."

CHAPTER 7

CONCLUSIONS

This chapter considers two broad aspects; firstly possible correlations of the glaciations in the upper Mersey Valley, with glaciations in Tasmania, mainland Australia and overseas, and secondly some concluding remarks on the findings of this research.

POSSIBLE CORRELATIONS WITH THE GLACIATIONS OF THE UPPER MERSEY REGION

Possible Correlations within Tasmania

This work in north-central Tasmania is one of several recent studies that have attempted to reconstruct the glacial history of a region in Tasmania, (e.g. Caine, 1983; Kiernan, 1985; Colhoun 1985a; Augustinus and Colhoun, 1986; Fitzsimmons, Colhoun and van de Geer, in press). It is valid to attempt to correlate within Tasmania to compare sequences of glaciation which have been described. There are difficulties in comparing regions and valleys that are not directly linked, and hence certain correlation is not yet possible. Rather a comparison of glacial sequences and conditions described in the literature with those outlined here for the upper Mersey Valley is made (see Table 5).

In the Lake St Clair area, to the south of the Mersey Valley Kiernan (1985) recognised three glaciations which would seem to correlate with the three in the upper Mersey Valley. A correlation between the Cynthia Bay drift sheet and the Rowallan Glaciation is likely as they are both the last glacial events in the region. Kiernan identified three drift sheets in the penultimate glaciation, and these are

Table 5: Summary of recent glacial studies in Tasmania

UPPER MERSEY VALLEY (Hannan and Colhoun 1987)	ST CLAIR REGION (Kiernan 1985)	KING VALLEY (Fitzsimmons in preparation)	WEST COAST RANGES (Colhoun 1985a)	PIEMAN-BOCO VALLEYS (Augustinus and Colhoun 1986)
Rowallan Glaciation	Cynthia Bay Drift	---	Margaret Glaciation	---
		Interglaciation		
Arm Glaciation	Beehive Drift Powers Creek Drift Clarence Drift	Bull Rvt Glacial Advance Blackwood Glacial Advance interstadial King Glacial Advance	Henty Glaciation (western region) Comstock Glaciation (eastern region)	Boco 1 Boco 2
??		Interglacial	---	---
		Governor Glacial Advance Fish Ck Glacial Advance Baxter Interstadial Traveller Ck Glacial Advance		
		Regency Interglacial		
Croesus Glaciation	Stonehaven Drift	Thureau Glacial Advance	Linda Glaciation	Bulgobac and Que
		Linda Palaeosol	Linda Palaeosol	
Lemonthyme Glaciation				

tentatively correlated with the Arm Glaciation in the upper Mersey Valley, which also may have had more than one advance. The oldest glaciation of the St Clair region is the Stonehaven Drift of the Franklin Valley. Correlation with the Croesus Glaciation is tentative as both are extremely old and contain sediments which are extremely weathered. Since all these deposits are intensely weathered and outcrop is limited there may well be more than one glaciation represented.

Recent work by Fitzsimmons (in Fitzsimmons, Colhoun and van de Geer, in press) in the King Valley has demonstrated three glaciations all older than the last glaciation. The interglacial between the last and penultimate glaciation is recognised on the basis of organic sequences at Langdon Creek and Smelters Creek. An organic sequence exists above Lees Paddocks in the upper Mersey Valley which underlies Rowallan Till. Close investigation of this deposit is required before any firm correlation can be made. Fitzsimmons subdivides the Henty Glaciation into three; the Bull River, Blackwood and the King glacial advances. These are tentatively correlated with the Arm Glaciation. There is no correlate in the upper Mersey Valley for the preceding Governor Glaciation of the King Valley, although there is a tentative suggestion from weathering rind evidence and geographic distribution, that a glaciation occurred temporally between the Arm and Croesus glaciations. The Thureau Glaciation of the King Valley is the oldest glaciation and the sediment is extremely weathered, hence a tentative correlation with the Croesus Glaciation is suggested.

The glaciations of the West Coast Ranges have been described by Colhoun (1985a). Correlating the Margaret Glaciation and the Rowallan Glaciation can be done with some degree of confidence as both are associated with organic material which has been radiocarbon dated. The Margaret Glaciation maximum has been dated as 18,800 ± 500 yr BP (ANU-2533) from wood found 100 mm above the base of outwash beyond the end moraine at Dante Rivulet. The Rowallan Glaciation maximum has been dated as 13,400 ± 600 (SUA-2188) from organic peat at the base of a proglacial lake dammed by the terminal moraine at Dublin Bog. The Henty Glaciation of the western part of the West Coast Ranges and the Comstock Glaciation of the eastern part is tentatively correlated with the Arm Glaciation of the upper Mersey Valley, as both are penultimate glaciations in each region. The Linda Glaciation as the oldest recognised on the West Coast Ranges and its deposits are strongly chemically weathered. It is tentatively correlated with the Croesus Glaciation.

In the upper Pieman and Boco valleys of the northern part of the west coast of Tasmania, Augustinus and Colhoun (1986) recognised three glaciations, all older than the last glaciation. The youngest are the Boco I and Boco II drifts of penultimate glaciation age which can be tentatively correlated with the Arm Glaciation. The Croesus Glaciation is tentatively correlated with the oldest glaciations of the Pieman and Boco valleys, the Bulgobac Drift and the Que Drift.

Caine (1983, p. 66) suggested two episides of glaciation on Ben Lomond in Northeastern Tasmania, a younger cirque phase and an older plateau phase. Dating of both glaciations is not definitive, but it seems that the period of cirque glaciation ended 10 ka years ago and a possibly commenced after 20 ka. This suggests a last glaciation age and would correlate it tentatively with the Rowallan Glaciation. The older plateau glaciation is possibly older tham 100ka and thus could be tentatively linked with the Arm Glaciation of the upper Mersey.

The evidence for two advances in the penultimate glaciation in the upper Pieman region and several ice advances during the penultimate glaciation of the St Clair and King Valley regions, it now seems certain that the penultimate glaciation in Tasmania had a number of stadia. There is also evidence that the penultimate glaciation in the upper Mersey Valley, the Arm Glaciation, had more than one advance.

Correlations with Mainland Australia

Only one phase of glaciation has been described from mainland Australia. This glaciation is represented by a number of small confluent valley glaciers with source cirques on the southeastern side of the Mount Kosciusko-Twynam ridge of the Snowy Mountains of southeastern Australia (Galloway, 1963). A radiocarbon date of 31,000 ± 2,300 (NZ 596) for wood fragments at the base of periglacial deposits is interpreted as the beginning of a widespread cooling-off period in the region (Costin, 1972, p. 582). From a 2 m section in the Kosciusko region, Martin (1985, p. 13) suggests that after 11,800 years there was a general amelioration of the climate. These dates suggest that the glaciation of the Mount Kosciusko region was equivalent to the Last Glaciation in Tasmania and hence can be correlated loosely with the Rowallan Glaciation.

Correlations with New Zealand and Chile

Precise correlation within Tasmania poses considerable problems. There are even more problems involved in comparing Tasmanian glaciations with overseas glaciations, but since Tasmania has a similar latitude to the South Island of New Zealand and Central Chile it is logical to look to these regions for some possible comparisons.

The glaciations in New Zealand from youngest to oldest are the Otiran Glaciation, Waimean Glaciation, Waimaungan Glaciation, Nemonan Glaciation, Porikan Glaciation and the Ross Glaciation (Suggate, 1985). Only radiocarbon dated sequences would appear to give clear evidence for possible correlation with the sequences in the upper Mersey Valley. Of the glaciations listed above the Otiran is the only glaciation which does not extend beyond the range of radiocarbon dating and hence is the only one to be considered in detail. The late Otiran glacial history has been subdivided by Suggate (1965) and Suggate and Moar (1970) as follows:

Before 22,300 - *c* 18,000 yr BP - Later Kumara-2 advance

c 18,000 - *c* 17,000 yr BP - Retreat of glaciers

c 17,000 - *c* 16,000 yr BP - Earlier Kumara-3 advance

c 16,000 - *c* 14,500 yr BP - Retreat of glaciers

c 14,500 - *c* 14,000 yr BP - Later Kumara-3 advance

*c*14,000yr BP - Major retreat of glaciers.

The transect of bore holes taken from the proglacial lake ponded behind the Rowallan terminal moraine at Dublin Bog, and shown in Figure 22 provides a series of dates, the oldest of which is 13,400 ± 600 yr BP (SUA - 2188). It is suggested that the Rowallan Glaciation can be tentatively correlated with the Otiran Glaciation in New Zealand and that the Kumara-3 advance may be a correlate of the Rowallan glacial maximum. This is further supported by the very rapid change from herbs to forest that occurred between 13.2 ka and 12.9 ka in the area around Dublin Bog (Hill, Colhoun and van de Geer, 1988, p. 129), suggesting a major retreat of glaciers occurring approximately contemporaneously with a similar event in New Zealand.

Correlation of older glaciations in New Zealand with those in the upper Mersey Valley is extremely tenuous, except to briefly indicate that the Arm Glaciation is tentatively dated as older than 100 ka and the Waimean Glaciation of New Zealand is tentatively dated as older than 130 ka (Burrows, 1979, p. 72). In the present state of knowledge it would be unwise to suggest any possible relationship between the Croesus and older New Zealand glacial episodes.

Pleistocene glaciations in Chile have been described by Mercer (1972, 1976, 1983), Laugenie and Mercer (1973), Heusser and Flint (1977) and Porter (1981). A summary of these papers is listed below.

Laugenie and Mercer (1973) Lago Llanquihue	Heusser and Flint (1977) Isla Chiloé	Porter (1981) Southern Lake District
Llanquihie	Llanquihie Glaciation	Llanquihie Drift
Casma	Intermediate Glaciation	Santa Maria Drift
Colegual	Fuerte San Antonio Glaciation	Rio Llico Drift
Rio Frio		Caracol Drift

Porter (1981, p. 282) examined critical sites for the three glaciation identified by Heusser and Flint (viz the Llanquihue, Intermediate and Fuerte San Antonio) and correlated them with the three younger glaciations of the Southern Lake District (viz the Llanquihue, Santa Maria and Rio Llico). The apparent absence of an older glaciation at Isla Chloé could reflect the absence of deep exposures in the area, but the fact that the Caracol Drift was not found beyond the limit of Rio Llico Drift on the mainland was also thought to be significant. Correlations with the Lago Llanquihue are problematic as a difference of interpretation for a key section, exists between Mercer and Porter, and for present purposes detailed discussion is not warranted.

Only the Llanquihue Glaciation has radiocarbon dated evidence associated with it. Hence, it is the only glaciation for which correlation with the upper Mersey Valley will be attempted. Porter (1981, p.275) subdivided the Llanquihue Drift into three units of stadial rank, Llanquihue I, II and III with the statement that "these are inferred to relate to at least three, or possibly four, episodes of glacier advance and (or) readvance, the ages of which are bracketed by radiocarbon dates." The

Llanquihue I advance has not as yet been closely dated and Porter (1981, p. 277) is equivocal suggesting that it could have occurred before 30 ka but also that an older suite of dates in the range of 40 ka to 58 ka could be minimum ages, making it possible that the drift is much older. The maximum of the Llanquihue II Drift is dated between 19 ka and 20 ka ago (Porter, 1981, p. 277). The Llanquihue III Drift is tentatively dated as 13 ka old with deglaciation well advanced by 12.8 ka (Mercer, 1983, p.122).

On this basis only Llanquihue II and III can be regarded as near equivalents with the Rowallan Glaciation in the upper Mersey Valley. The age of the Llanquihue III advance has similarities with the Rowallan Glaciation maximum in the Dublin Bog area where it is dated as before 13.4 ka and the further suggestion is made that deglaciation was well advanced by 12.9 ka. Another similarity exists in that Porter (1981, p. 285) calculates the Llanquihue snowline as being some 1000 m below the present, which is approximately the same figure as obtained for the Rowallan Glaciation. These comparisons could be fortuitous given the altitude difference between the Andes and the mountains of Tasmania even though they occur at the same latitudes.

CONCLUDING REMARKS

Seven problems arising from a survey of the literature were listed in Chapter 2. As the solution of these problems was the main aim of this study it seems appropriate to return to them at this stage and comment on the degree of resolution that this study has achieved.

The problems are given below as headings and the discussion relates to the degree to which they were resolved. The discussion also highlights the nature and direction which might be taken by future research in this area.

1. Glacial landforms had been discussed in a number of papers but acked an underpinning glacial framework.

Chapter 3 of this study identified the glacial landforms existing in the upper Mersey Valley. All the depositional landforms were attributed to either Rowallan or Arm glaciation ice with no landform identified which could definitely be related to the ice of the Croesus Glaciation. Outside the area of investigation, for example northeast of Mole Creek, erratics and possible moraines have been identified. As these are well beyond the limits of the Rowallan or Arm glaciations they must have been produced by an older glaciation, possibly the Croesus Glaciation. In order that the landforms of the Croesus Glaciation can be described there is a need for systematic field studies outside the known limits of the Arm Glaciation ice as presently defined by the Arm Till.

The area of study was approximately 500 sq km and most of it was covered in the course of fieldwork to produce a general overview of the glacial history of the region. The production of detailed landform maps for the whole area was not attempted as this task is regarded as a highly specific one, better accomplished by later workers with a smaller area of study. A particular area which could advance the knowledge of glaciation is the Lake Ayr Valley, where a complex array of landforms has been left behind by ice of the Rowallan and Arm Glaciations. This area is critical because it connects the Mersey and Forth valleys and would allow assessment of the quantity of ice that flowed into each valley during these glaciations. Similarly, the Walls of Jerusalem area has numerous landform complexes of the last two glaciations but it has been demonstrated that the core area was probably avoided by ice during the Rowallan Glaciation. More detailed mapping would, I feel, confirm this conclusively.

2. No clear indication of the number of glacial events affecting the upper Mersey had appeared in the literature.

This study provides clear evidence from a number of sources that there were three glaciations in the upper Mersey Valley, the Rowallan, Arm and Croesus. A fourth glaciation has been foreshadowed, which appears to occur temporally between the Arm and Croesus glaciations. Resolution of whether or not the fourth glaciation is a distinct glaciation or a phase of the Arm could possibly come from examination of the glacial history of the northern part of the Central Plateau.

Little systematic work has been conducted on the Central Plateau in recent years. It is thought that as the Central Plateau was the main source of past ice that possibly the evidence of the previous glacial limits could still remain intact in the northern and eastern parts. It was indicated in discussions of the extent of the Arm Glaciation that ice of this age could have flowed over the edge of the Great Western Tiers. The numerous creeks flowing northeast from the Great Western Tiers have the potential of providing stratigraphic evidence whether or not this assertion is valid.

The Forth Valley to the west could also be a region of potentially significant evidence on Pleistocene glaciations in the area, and would provide a link with the scenically attractive Cradle Mountain region where glacial erosion is much in evidence..

3. The areal extent of each period of glaciation has not been clearly identifed.

In this study the extent of the Rowallan Glaciation has been reconstructed with a high degree of accuracy. This partly reflects the quality and amount of evidence related to the Rowallan Glaciation which was uncovered, but also because the area of the Rowallan Glaciation occupies a large proportion of the study area. Indication of the extent of the Arm Glaciation is less detailed than the Rowallan

Glaciation because of poorer exposures and the relatively small area it occupied beyond the limits of Rowallan ice in the area of investigation. The Croesus Glaciation extends far beyond the area of investigation and detailed study in the middle reaches of the Mersey Valley will be needed to further resolve the extent of this glaciation.

4. Glacial drift, in particular the till has not been classified

The till classification of Dreimanis (1982) was used in an attempt to classify the sediment of the three glaciations. A number of difficulties were experienced in classifying all till deposits, particularly the meltout till. It was assumed that the till classification was comprehensive and all sediment identified as till should be capable of being classified. However, the evidence required to classify some of the till as meltout till was not available, e.g. it was not always found interstratified with meltwater sediment; or it was too time consuming, considering the number of outcrops that were examined over the 500 sq km study area, to produce fabric analyses for diagnositc purposes. Nevertheless in a large number of sites investigated, a number of the different classes of till were clearly identified viz. deformation till, lodgement till, meltout till and flow till.

In order to classify the till outcrops of the region, a number of intensive studies conducted over a smaller area would be useful. The detailed results could be applied more widely.

5. Ice movement directions had only been plotted by authors who had assumed a single period of glaciation

The ice movement directions for the Rowallan Glaciation have been established from roches moutonnées, whaleback forms, striations, grooves and till fabric analyses. The evidence obtained from both the highland areas and the valleys, gives a reasonable indication of the nature of flow of the Rowallan age ice (Figure 33).

The Arm Glaciation occupied only a small proportion of the valleys and an even smaller proportion of the highland areas beyond the limits of the Rowallan Glaciation. Though some pre-Rowallan striations and glacially smoothed rock surfaces were found no substantial effort was devoted to establishing Arm Glaciation ice directions as it was assumed that for the most part they would be down-valley outside the Rowallan ice limits. If a greater area of Arm Glaciation ice could be established by extending the area of investigation, it would be a worthwhile endeavour to reconstruct the regional ice movement directions.

The reconstruction of ice movement directions for the Croesus Glaciation is even more difficult due to the paucity of drift outcrop and lack of definite landforms. The apparent great age of this glaciation suggests that its extent will only be defined when the distribution of its deposits are known and details of local ice flow directions may not be obtained thoughout the region except in a general sense.

6. The ages of glaciations in the area had not been investigated

Information has been presented which suggests the age of each of the glaciations identified.

The approximate ages for the Rowallan Glaciation maximum and deglaciation has been reasonably well defined by a number of radiocarbon dates. No date has been obtained which gives an indication for the onset of the last cold period in the upper Mersey region. Intensive stratigraphic and palynogical study of the organic deposit underlying Rowallan Till at the southern end of Lees Paddocks may give an indication of the nature and age of part of the interglacial period between the Arm and Rowallan glaciations. The mineralised state of the wood in this deposit suggests that it is older than the limits of radiocarbon dating and hence is unlikely to give an indication of the onset of the Rowallan glaciation in the region.

The Arm and Croesus glaciations occurred beyond the limits of radiocarbon dating and with present dating techniques it is difficult to see how the age for each of these glaciations can be further refined. Thermoluminescence techniques or other similar new developments, such as beryllium dating, may be the only possible solutions. As yet such techniques have not been effectively used to date glacial deposits. It is unlikely that volcanic rocks will be found either interbedded or overlying the glacial deposits as the youngest dated volcanic rocks in Tasmania are in excess of 20 million years old; in the Great Lake region (Sutherland, Green and Wyatt, 1973), from the Hobart area (Sutherland, 1976, p. 111) and from south of Devonport (Cromer, 1980, p. 294). Thus potassium-argon dating does not seem to hold much promise.

7. No attempt has been made to reconstruct the ELA's or to deduce the depression of the temperature and the snowline for the glaciations

The ELA calculated for Rowallan Glaciation ice is based on measurements of the areal extent of the ice, which as indicated above was reconstructed with a high degree of accuracy. As such the calculation of the ELA is regarded as a reliable result within the limits of such calculations. The depression of the snowline and temperature are also regarded as reasonable estimates.

Calculations of the ELA for Arm Glaciation ice was based on the minimum extent that the ice could have occupied and can only be regarded as a good approximation. The depression of the snowline and the temperature, which were calculated from the ELA are also regarded as good approximations. Further study of the extent of the Arm Glaciation, particularly in the northern part of the Central Plateau, is needed in order to refine calculation of the ELA for the Arm Glaciation.

In order to arrive at an initial calculation of the ELA for ice during the Croesus Glaciation the areal extent of the former ice needs to be assessed in detail. This would require extensive fieldwork in the middle reaches of the Mersey Valley.

In conclusion it can be stated that the problems which were the focus of this investigation have been largely resolved. To some extent they have been replaced by a different set of problems to be solved by future work in the area. Perhaps the major claim of this study is that it has established a stratigraphic framework for the upper Mersey Valley, which will offer future workers a preliminary model with which they can compare their findings.

REFERENCES

Ajne, B. (1968), A simple test for uniformity of a circular distribution. *Biometrika*, 55(2), pp. 343-354.

Andrews, J.T. (1971), Techniques of till fabric analysis, *Technical Bulletin of the British Geomorphological Research Group,* 6, pp.1-43.

Andrews, J.T. Methods in the analysis of till fabrics, in Goldthwait, R.P. (Ed) (1979), *Till - a Symposium*, Ohio State University Press, pp. 321-327.

Augustinus, P. and Colhoun, E.A. (1986), Glacial history of the upper Pieman and Boco valleys, western Tasmania, *Australian Journal of Earth Sciences,* 33, pp. 181-191.

Ballantyne, C.K. and Cornish, R. (1979), Use of the chi-square test for the analysis of orientation data. *Journal of Sedimentary Petrology,* 49(3), pp. 713-776.

Banks, M.R. (1978), Reflections on a moonlit snowfield, *STATIC*, 78, pp. 24-33.

Banks, M.R., Late Palaeozoic tillites of Tasmania, in Hambrey, M.J. and Harland, W.B.(Ed) (1981), *Earth's Pre-Pleistocene Glacial Record,* Cambridge University Press, Cambridge, pp. 495-501.

Banks, M.R. and Ahmad, N. (1959), Notes on the Cainozoic history of western Tasmania - 'Malanna Glaciation', *Papers and Proceedings of the Royal Society of Tasmania,* 93, pp. 117-127.

Banks, M. R. and Clarke, M.J. (1987), Changes in the Geography of the Tasmanian Basin in the late Palaeozoic, in G.D. Mackenzie (ed.) *Gondwana Six: Stratigraphy, Sedimentology and Paleontology*, American Geophysical Union, Geophysical Monograph 41, pp. 1-14.

Banks, M. R., Colhoun, E. A. and Hannan, D. G. (1987), Early discoveries of the effect of ice action in Australia, *Journal of Glaciology,* 33 (114), pp. 231-235.

Binks, C. J. (1980), *Explorers of western Tasmania,* Mary Fisher Bookshop, Launceston.

Boulton, G.S. (1968), Flow tills and related deposits on some Vestspitsbergen glaciers, *Journal of Glaciology,* 7(51), pp. 391-412.

Boulton G.S. (1980), Classification of till, *Quaternary Newsletter,* 31, pp. 1-12.

Brookes, I.A. (1982), Dating methods of Pleistocene deposits and their problems VIII: Weathering, *Geoscience Canada,* 9(4), pp. 188-197.

Bureau of Meteorology, (1980), Climatic Survey of Tasmania, Region , Northern, Australian Government Publishing Service, Canberra, 64pp.

Burke, R.M. and Birkeland, P.W. (1979) Re-evaluation of multiparameter relative dating techniques and their application to the glacial sequence along the eastern escarpment of the Sierra Nevada, California, *Quaternary Research,*11, pp. 21-51.

Burrows, C.J. (1978) The Quaternary Ice Ages in New Zealand: A framework for biologists. *Mauri Ora,* 6, pp. 69-96.

Caine, N. (1982), Toppling failures from alpine cliffs on Ben Lomond,Tasmania, *Earth surface Processes,* 7, pp. 133-152.

Caine, N. (1983), The Mountains of northeastern Tasmania, Balkema, Rotterdam.

Chinn, J.J.H. (1981), Use of rock weathering-rind thickness for Holocene absolute age-dating in New Zealand, *Arctic and Alpine Research,* 13(1), pp. 33-45.

Colhoun, E.A. (1975), A Quaternary climatic curve for Tasmania. Royal Meteorological Society, *Australian Conference on Climatic and Climatic Change,* Monash University, pp. 1-40.

Colhoun, E.A. (1976), The glaciation of the lower Forth Valley, northwestern Tasmania, *Australian Geographical Studies,* 14, pp. 83-102.

Colhoun, E.A. (1980), Quaternary fluviatile deposits from the Pieman Dam site, western Tasmania, *Proceedings of the Royal Society of London,* B207, pp. 355-384.

Colhoun, E.A. (1984), Palaeoenvironmental report on Borradaile Plains Bog. *Unpublished Report,* University of Tasmania, 7pp.

Colhoun, E.A. (1985a), Glaciations of the West Coast of Tasmania. *Quaternary Research,* 24, pp. 39-59.

Colhoun, E.A. (1985b), Radiocarbon dates for Tasmania, 1956-1964, *Papers and Proceedings of the Royal Society of Tasmania,* 119, pp. 39-54.

Colhoun, E.A. and van de Geer, G. (1986), Holocene to middle last glaciation vegetation history at Tullarbine Dam, western Tasmania, *Proceedings of the Royal Society of London*, B227, pp. 177-207.

Colman, S.M. (1981), Rock-weathering rates as functions of time, *Quaternary Research,* 15, pp. 250-264.

Colman, S.M. and Pierce, K.L. (1981), Weathering rinds on andesite and basaltic stones as Quaternary age indicator, western United States. *Geological Survey Professional Paper,* 1210, 56 pp.

Cornish, R. (1979), The statistical analysis of till fabric data: A review. *Research Discussion Paper,*16, Department of Geography, University of Edinburgh, pp. 1-46.

Costin, A.B. (1972), Carbon-14 dates from the Snowy Mountains area, southeastern Australia and their interpretation, *Quaternary Research,* 2(4), pp.579-590.

Cromer, W.C. (1980), A late Eocene basalt date from northern Tasmania, *Search,* 11 (9), pp. 294-295.

Cubit, S. (1987), *Snarers and Cattlemen of the Mersey High Country,* Regal Press, Launceston.

Curtis, W. (1956), The Students Flora of Tasmania, Vol 1, Government Printer, Tasmania.

Curtis, W. (1963), The Students Flora of Tasmania, Vol 2, Government Printer, Tasmania.

Curtis, W. (1967), The Students Flora of Tasmania, Vol 3, Government Printer, Tasmania.

Dale, M.L. and Ballantyne, C.K. (1980), Two statistics for the analysis of orientation data in geography. *Professional Geographer,* 32(2), pp.184-191.

Davies, J.L. Tasmanian landforms and Quaternary climates, in Jennings, J. and Mabbutt, J.A. (Ed) (1967), Landform Studies from Australia and New Guinea. A.N.U. Press, Canberra, pp. 1-25.

Davies, J.L. (1969), *Landform of cold climates,* Australian National University Press, Canberra.

Davies, O.L. and Goldsmith, P.L. (1972), *Statistical Methods in Research and Production,* Oliver and Boyd, London.

Department of Arts, Sport, the Environment, Tourism and Territories, (1988), Report of the Commission of Inquiry into the Lemonthyme and Southern Forests, Australian Government Publishing Services, Canberra.

Derbyshire, E. D. (1967), Glacial geomorphology and climate of the montains of western Tasmania, *Unpublished PhD Thesis,* Monash University.

Derbyshire, E. D. (1968), Glacial map of NW - central Tasmania, *Geological Survey Record* 6, Tasmanian Department of Mines, Hobart.

Derbyshire, E. (1971), On the status and correlation of glacial episodes in southeastern Australia, *Search,* 2(8), pp. 285-288.

Derbyshire, E. (1972), Pleistocene glaciation of Tasmania: Review and Speculations, *Australian Geographical Studies,* 10, pp. 79-94.

Derbyshire, E. (1973), Periglaciatial phenomena in Tasmania. *Biuletyn Periglacjalny,* 22, pp. 133-148.

Derbyshire, E.D., Banks, M.R., Davies, J.L. and Jennings, J.N. (1965), A glacial map of Tasmania, *Royal Society of Tasmania Special Publication* 2.

Derbyshire, E. and Peterson, J.A. (1971), On the status and correlation of Pleistocene Glacial Episodes in southeastern Australia, *Australian Journal of Science,* 2(8), pp. 285-288.

Drake, L.D. (1977), Human factor in till fabric analysis, *Geology,* 5(3), pp. 180-184.

Dreimanis, A. (1976a), Terminology and classification of materials transported and deposited by glaciers, *Preprint of Paper presented at the Symposium of the Genesis of Till,* 1976, Stockholm.

Dreimanis, A., Tills: Their origins and properties, in Leggett, R.F. (Ed) (1976b), Glacial Till, *Special Publication of the Royal Society of Canada,* 12, pp.11-49.

Dreimanis, A. Till and tillite, in Fairbridge, R.W. and Bourgeois,J. (Ed.) (1978), *The Encyclopedia of Sedimentology,* Encyclopedia of Earth Science, 6, Dowden, Hutchins and Ross, Stroudsburg, pp. 805-810.

Dreimanis, A. (1982), Genetic classification of tills and criteria for their differentation: Progress report on activities 1977-1982, and definitions of glacigenic terms, *Unpublished Paper,* INQUA- Commission on Genesis and Lithology of Quaternary Deposits.

Drozdowski, E. Load deformations in meltout till and underlying laminated till: An example from northern Poland, in Evenson, E. E., Schluchter, Ch. and Rabassa, J. (Ed) (1983), *Tills and Related Deposits,* Balkema Rotterdam.

Edwards, A.L. (1969) *Statistical Analysis,* Holt Rinehart and Winston, New York.

Evans, I. S. and Cox, N. (1974), Geomorphology and the operational definition of cirques, *Area*, 6(2), pp. 150-153.

Eyles, N. Modern Icelandic glaciers as depositional models for 'hummocky moraine' in the Scottish Highlands, in Evenson, E. E., Schluchter, Ch. and Rabassa, J. (Ed) (1983), *Tills and Related Deposits,* Balkema Rotterdam.

Fitzsimmons, S. J., Colhoun, E. A. and van de Geer, G. (in press) Middle Pleistocene glacial stratigraphy at Baxter Rivulet, western Tasmania, Australia, *Palaeogeography, Palaeoclimatology and Palaeoecology.*

Folk, R.L. (1965), *Petrology of Sedimentary Rocks*, Hemphills, Austin Texas.

Ford, R.J. (1960), The geology of the Fisher River area. *Papers and Proceedings of the Royal Society of Tasmania,* 94, pp. 25-34.

Forestry Commission of Tasmania, (1987), *The Rainforests of Tasmania,* Tasmanian Government Printer, Hobart.

Galloway, R. W. (1963) Glaciation in the Snowy Mountains: a re-appraisal, *Proceedings of the Linnean Society of New South Wales,* 88(2), pp. 180-198.

Gellatly, A. F. (1984), The use of rock weathering-rind thickness to redate moraines in Mt Cook National Park, New Zealand, *Arctic and Alpine Research* ,1692) pp. 225 - 232.

Haldorsen, S. The enrichment of quartz in tills, in Evenson, E. E., Schluchter, Ch. and Rabassa, J. (Ed) (1983), *Tills and Related Deposits,* Balkema Rotterdam.

Haldorsen, S. and Shaw, J. (1982), The problem of recognising meltout till, *Boreas,* 11, pp. 261-177.

Hannan, D. G. (1987), Glacial values of protected areas, *Unpublished Consultants Report to the Commission of Inquiry for the Lemonthyme and Southern Forests,* 19pp.

Hannan, D.G. and Colhoun, E.A. (1987), The glacial stratigraphy of the upper Mersey Valley, *Australian Geographic Studies,* 25(2) pp. 36-46.

Harris, S.A. (1969), The meaning of till fabrics, *Canadian Geographer,* 13(4), pp. 317-337.

Harris, S.A., The nature and use of till fabrics, in Yatsu, E. and Falconer, A. (Ed) (1972), Research Methods in Pleistocene Geomorphology, *Proceedings 2nd. Guelph Symposium on Geomorphology,* 1971, Geoabstracts, Norwich, pp. 45-65.

Hartshorn, J.H.. (1958), Flowtill in southeastern Massachusetts, *Bulletin of the Geological Society of America,* 69, pp. 477-482.

Heusser, C. J. and Flint, R. F. (1977), Quaternary glaciation and environments of northern Isla Chiloé, Chile, *Geology,* 5, pp. 305-308.

Hill, R.S., Colhoun, E.A. and van de Geer, G. The Forth and Mersey Valley, in Colhoun, E.A. (1988), *Cainozoic Vegatation of Tasmania,* International Palynology Congress, Brisbane, University of Newcastle, pp. 102-131.

Jennings, I.B. (1963), Middlesex, *Geological Survey Explanatory Report,* Tasmanian Department of Mines, Hobart.

Jennings, J.N. and Ahmad, N., (1957), The Legacy of an ice cap, *The Australian Geographer,* 11(2), pp.62-75.

Jennings, J.N. and Banks, M.R. (1958), The Pleistocene glacial history of Tasmania, *Journal of Glaciology,* 13, pp. 298-303.

Johnson, R.M. (1888), *Geology of Tasmania,* Government Printer, Hobart.

Johnson, R.M. (1893), The Glacier Epoch in Australia, *Papers and Proceedings of the Royal Society of Tasmania ,* pp. 73-134.

Kelly, T.E. and Baker, C.H. (1966), Color variations within glacial till, east-central north Dakota - a preliminary investigation, *Journal of Sedimentary Petrology,* 36(1), pp. 75 - 80.

Keppel, G. (1984), *Design and Analysis: A Researchers Handbook,* Prentice Hall, New Jersey.

Kiernan, K. (1983), Weathering evidence for an additional glacial stage in Tasmania, Australian Geographical Studies, 21(2), pp. 197-220.

Kiernan, K. (1984), Land use and karst areas, forestry operations and the Mole Creek caves, *Australian Heritage Commisssion,* Canberra, pp. 213-233.

Kiernan, K.J. (1985), Late Cainozoic Glaciation and Mountain Geomorphology in the Central Highlands of Tasmania, *Unpublished PhD Thesis,* University of Tasmania.

Kruger, J. and Marcussen, I.B. (1976), Lodgement till and flow till: A discussion, *Boreas,* 5(2), pp. 61-63.

Lands Department of Tasmania, (1986), Walls of Jerusalem, *Map and Notes,* Government Printer, Hobart.

Laugenie, C. A. and Mercer, J. H. (1973), Southern Chile: A chronology of the last glaciation in *IX INQUA Congress Abstracts*, Christchurch, New Zealand, pp. 202-203.

Lewis, A.N. (1932) Note on the originof the Great Lake and other lakes on the Central Plateau, *Papers and Proceedings of the Royal Society of Tasmania,* pp. 15-38.

Lewis, A.N. (1945) Pleistocene glaciation in Tasmania, *Papers and Proceedings of the Royal Society of Tasmania,* pp. 41-56.

Lourandos, H. (1983) 10,000 years in the Tasmanian highlands, *Australian Archaeology,* 16, pp. 39-47.

Macleod, W.N., Jack, R.H. and Threader, V. M. (1961), *Du Cane,* Explanatory Report for One Mile Geological Map Series, Tasmanian Mines Department, Hobart.

Macphail, M. (1975), Late Pleistocene environments in Tasmania, *Search*, 6 (7), pp. 295-300

Macphail, M.K. and Peterson, J.A. (1975) New deglaciation dates from Tasmania, *Search*, 6(4), pp. 127-130.

Marcussen, I.B. (1975,) Distinguishing between lodgement till and flow till in Weichselian deposits, *Boreas*, 4, pp. 113-123.

Mark, D.M. (1971), Rotational vector procedure for the analysis of till fabrics. Geological Society of America Bulletin, 82, pp. 2661-2666.

Mark, D.M. (1973), Analysis of axial orientation data including till fabrics. *Geological Society of America Bulletin,* 84, pp.1 369-1374.

Mark, D.M. (1974) On the interpretation of till fabrics, *Geology*, 2, pp. 101-104.

Martin, A. R. H. Alpine vegetation and ^{14}C chronolgy, Kosciusko National Park, Australia, in Pillans, B. (Ed) (1985) *The Second Symposium of Results and Discussions Concerned with Late Quaternary Climatic History of Australia, New Zealand and Surrounding Seas,* Geology Department, Victoria University, Wellington.

Mather, R.P. (1957), Geological report on map square 4386, the Lake MacKenzie area, *Unpublished Report of the Hydro Electric Commission*, 24pp.

May, R.W. and Dreimanis, A. Compositional variability in tills, in Glacial Tills, (Ed.) Leggett, R.F. (1976), *Special Publication of the Rayal Society of Canada,* 12, pp. 99-120.

McDougall, I. A note on the petrography of the Great Lake dolerite sill, in Carey, S.W. (1958), *Dolerite a Symposium,* University of Tasmania, Hobart.

McGown, A. and Derbyshire, E. (1977), Genetic influences on the properties of tills, *Quaternary Journal of Engineering Geology,* 10, pp. 389-410.

McGregor, G.R. (1981), Weathering characteristics of late Pleistocene tills, *New Zealand Journal of Geology and Geophysics,* 24(1), pp. 107-123.

Mercer, J, (1972), Chilean glacial chronology 20,000 to 11,000 carbon -14 years ago: Some global comparisons, *Science*, 176, pp. 1118-1120.

Mercer, J. (1976), Glacial history of southernmost South America, *Quaternary Research,* 6, pp. 125-166.

Mercer, J.H. (1983,) Cenozoic glaciation in the southern hemisphere, *Annual Review of Earth and Planetary Sciences,* 11, pp. 99-132.

Montgomery, A. (1893), Glacial action in Tasmania, *Papers and Proceedings of the Royal Society of Tasmania,* pp. 159-169.

Norcliffe, G.B. (1977), *Inferential Statistics for Geographers,* Wiley, New York.

Nye, P.B. (1921), The underground water resources of the midlands Tasmania, *Underground Water Supply Bulletin No. 1,* Tasmanian Mines Department, Hobart.

Opdyke, N. D., Glass, B., Hays, J. D. and Foster, J. (1966), Paleomagnetic studies of Antacrtic deep sea cores, *Science*, 154, pp. 349-357.

Paterson, S.J., 1965, Pleistocene drift in the Mersey and Forth Valleys - probability of two glacial stages, *Papers and Proceedings of the Royal Society of Tasmania,* 99, pp. 115-124.

Paterson, S.J. (1966), Pleistocene deposits at Parangana Damsite in the Mersey Valley, *Papers and Proceedings of the Royal Society of Tasmania,* 100, pp. 147-153.

Paterson, S.J. (1967), Tertiary deep lead deposits in the Moina area, *Papers and Proceedings of the Royal Society of Tasmania,* 101, pp. 251-262.

Paterson, S.J., (1969,) Pleistocene deposits at Parangana Damsite in the Mersey Valley - results of excavation and construction drilling, *Papers and Proceedings of the Royal Society of Tasmania,* 103, pp. 57-61.

Paterson, S.J., Duigan, S.L. and Joplin, G.A. (1967), Notes on the Pleistocene deposits at Lemonthyne Creek in the Forth Valley, *Papers and Proceedings of the Royal Society of Tasmania,* 101, pp. 221-225.

Pemberton, M., (1986), *Land Systems of Tasmania, Region 5, Central Plateau,* Department of Agriculture, Tasmania.

Pinkard, G. J., (1980), *Land Systems of Tasmania, Region 3,* Department of Agriculture, Tasmania.

Popham, W.J. and Sirotnik, K.A. (1973), *Educational Statistics,* Harper and Rowe, New York.

Porter, S.C. (1975), Equilibrium-line altitudes of late Quaternary glaciers in the Southern Alps of New Zealand, *Quaternary Research,* 5 pp. 27-47.

Porter, S.C. (1981), Pleistocene glaciation in the Southern Lake District of Chile, *Quaternary Research,* 16, pp. 263-292.

Rawlings, G.E. (1967), Sub-basaltic sediments and metasediments of the Mersey-Forth area, *Papers and Proceedings of the Royal Society of Tasmania,* 101, pp. 267-273.

Reid, A.M. (1919), The Mount Pelion mineral district, *Geological Survey Bulletin 30,* Tasmanian Mines Department, Hobart.

Roberts, M.C. and Mark, D.M. (1970), The use of trend surfaces in till fabric analysis, *Canadian Journal of Earth Sciences,* 7, pp.1179-1184.

Roberts, M.C. and Mark, D.M. (1971), Use of trend surface analysis: Reply. *Canadian Journal of Earth Sciences,* 8, pp. 1167-1169.

Silk, J. (1979), *Statistical Concepts in Geography,* Allen and Unwin, Boston.

Slaymaker, H.O. and Church, M, The use of trend surface analysis in the interpretation of Quaternary deposits, in Yatsu, E. and Falconer, A. (Ed.) (1971), *Methods in Pleistocene Geomorphology,* Proceedings: 2nd Guelph Symposium on Geomorphology, Geoabstracts, Norwich, 1972, pp. 215-234.

Spry, A. (1958), The Precambrian rocks of Tasmania Part 3, Mersey- Forth area. *Papers and Proceedings of the Royal Society of Tasmania,* 92, pp.117-142.

Statview 512+ the Professional, Graphic, Statistics Utility, Brainpower inc, Calabasas, California.

Stephens, M.A. (1969), A goodness of fit stastic for the circle with some comparisons, *Biometrika*, 56(1), pp.161-168.

Sugden, D.E. and John, B.S. (1976), *Glaciers and Landscape A Geomorpholocial Approach,* Arnold London.

Suggate, R. P. (1965), Late Pleistocene geology of the northern part of the South Island of the South Island, New Zealand, *New Zealand Geological Survey Bulletin,* 77.

Suggate, R. P. (1985), The glacial sequence of North Westland, New Zealand, *New Zealand Geological Survey Record*, 7.

Suggate, R. P. and Moar, N. T. (1970), Revision of the chronology of the late Otira Glacial, *New Zealand Journal of Geology and Geophysics*, 13, pp. 742-746.

Sutherland, F.L. (1980), Aquagene volcanism in the Tasmanian Tertiary, in relation to coastal seas and river systems, *Papers and Proceedings of the Royal Society of Tasmania,* 114, pp. 178-199.

Sutherland, F.L. Volcanic rocks in Leaman, D. F. (1976), Hobart Sheet, *Explanatory Report of the Department of Mines,* Tasmania.

Sutherland, F. L., Green, D. C. and Wyatt, B. W. (1973), AGe of the Great Lake basalts, Tasmania inrelation to Australian Cainozoic volcanism, *Journal of the Geological Society of Australia,* 20, pp. 85-94.

Tarling, D. H. (1983), *Palaeomagnetism: Principles and Applications in Gelogy, Geophysics and Archaeology,* Chapman and Hall, London.

van de Geer, G., Colhoun, E.A. and Mook, W.G. (1986), Stratigraphy, pollen analysis and palaeoclimatic interpretation of Mowbray and Broadmeadows Swamps, northwestern Tasmania, *Australian Geographer*, 17, pp.121-133.

Wall, J (1986), *Statistical Data Analysis,* McGraw Hill, New York.

Walker, F. The causes of variation in dolerite intrusions, in Carey, S.W. (1958), *Dolerite a Symposium,* University of Tasmania, Hobart, pp.1-25.

Westphal, M. (1980/81), Analyse statistique de directions non orientées. *Pageoph*, 119, pp. 80-86.

APPENDIX A
PLACE NAMES USED IN THE TEXT

Place Name	Grid Reference (1:25000 Map)	Figure Number
Arm Falls	332839 (Borradaile)	A6
Arm River	320834 (Borradaile)	A2/A6
Arthurs Lake	950530 (Arthurs Lake)	A1
Bass Strait	480480 (Devonport)	A1
Bishop Peak	275643 (Cathedral)	A3
Borradaile Plains	315865 (Borradaile)	A2
Cathedral Mountain	264622 (Cathedral)	A2/A3
Central Plateau	520710 (Pillans Lake)	A2
Chalice Lake	297627 (Cathedral)	A3
Chapter Lake	304647 (Cathedral)	A3
Chudleigh	566991 (Mole Creek)	A1
Cloister Lagoon	315617 (Cathedral)	A3
Clumner Bluff	380768 (Rowallan)	A5/A6
Convent Hill	311603 (Cathedral)	A3
Cradle Valley	120897 (Cradle)	A1
Croesus Bridge	352969 (Liena)	A2
Curate Bluff	280654 (Cathedral)	A3
Damascus Vale	414687 (Lake Ada)	A4
Dawsons Siding	488303 (Latrobe)	A1
Dean Bluff	281663 (Cathedral)	A3
Deception Point	413807 (Lake Mackenzie)	A5
Devonport	455420 (Devonport)	A1
Douglas Creek	202689 (Cathedral)	A2
Du Cane Gap	254585 (Du Cane)	A2
Dublin Bog	367813 (Borradaile)	A5/A6
Dublin Plains	385838 (Borradaile)	A5/A6
East Wall	438601 (Pillans Lake)	A5
Emu Plains	320945 (Liena)	A2
Ephraims Gate	418608 (Pillans Lake)	A5
February Creek	273747 (Rowallan)	A2
February Plains	240760 (Rowallan)	A2
Fish River	385745 (Rowallan)	A2/A5/A6
Fisher River	440858 (Lake Mackenzie)	A2/A7
Fisher Power Station	390861 (Borradaile)	A7

Forth River	250855 (Borradaile)	A1/A2
Gads Creek	343887 (Borradaile)	A2
Gads Hill	299972 (Liena)	A3
Gate of the Chain	420701 (Pillans Lake)	A5
George Howes Lake	402734 (Pillans Lake)	A5
Gog Range	510042 (Gog)	A1
Golden Gate	413723 (Pillans Lake)	A5
Grail Falls	304639 (Cathedral)	A3
Great Lake	800600 (Split Rock)	A1
Great Western Tiers	505874 (Lake Mackenzie)	A1/A7
Horeb Falls	303654 (Cathedral)	A3
Howells Bluff	365732 (Rowallan)	A2/A5/A6
Jacksons Creek	321661 (Cathedral)	A2/A5
Jaffa Vale	425683 (Lake Ada)	A4
Junction Lake	323584 (Du Cane)	A4
Juno Creek	353688 (Cathedral)	A2
Lake Adelaide	657385 (Cathedral)	A4
Lake Ayr	220695 (Cathedral)	A2
Lake Ball	413673 (Ada)	A4
Lake Balmoral	511856 (Lake Mackenzie)	A7
Lake Bill	336657 (Cathedral)	A4
Lake Leonis	308697 (Cathedral)	A3
Lake Loane	381726 (Rowallan)	A5
Lake Louisa	360670 (Cathedral)	A4
Lake Mackenzie	490858 (Lake Mackenzie)	A7
Lake McCoy	295693 (Cathedral)	A3
Lake Meston	360610 (Cathedral)	A4
Lake Myrtle	325625 (Cathedral)	A4
Lake Parangana	355895 (Borradaile)	A2
Lake Rowallan	340730 (Rowallan)	A2/A4/A6
Lake Salome	411705 (Pillans Lake)	A5
Lake Sorell	140380 (Interlacken)	A1
Lake Thor	438723 (Pillans Lake)	A5
Lake Tyre	433708 (Pillans Lake)	A5
Latrobe	510344 (Latrobe)	A1
Lees Paddocks	267676 (Cathedral)	A3
Lemonthyme Hill	323904 (Liena)	A2
Lemothyme Pwr Station	282937 (Liena)	A2
Lewis Falls	312675 (Cathedral)	A3
Liena	355993 (Liena)	A2

Little Fisher River	392845 (Borradaile)	A5/A7
Mackenzie Dam	486854 (Lake Mackenzie)	A7
Maggs Mountain	326780 (Rowallan)	A6
Martha Creek	355919 (Liena)	A2
Mersey Crag	445753 (Pillans Lake)	A5
Mersey River	295674 (Cathedral)	A1/A2/A3/A4/A6
Middlesex Plains	165998 (Pencil Pine)	A1
Mole Creek	505989 (Mole Creek)	A1
Moses Creek	305661 (Cathedral)	A2
Mount Anne	529451 (Anne)	A1
Mount Jerusalem	437697 (Ada)	A5
Mount Massif	220602 (Cathedral)	A3
Mount Moriah	412679 (Lake Ada)	A4
Mount Oakleigh	205713 (Rowallan)	A2
Mount Ophel	412708 (Pillans Lake)	A5
Mount Ossa	198638 (Achilles)	A2
Mount Parmeener	475899 (Lake Mackenzie)	A7
Mount Pelion East	325655 (Cathedral)	A2/A3
Mount Pillinger	274702 (Rowallan)	A2/A3
Mount Rogoona	333619 (Cathedral)	A6
Oakleigh Creek	210743 (Will)	A2
Oxley Falls	306673 (Cathedral)	A3
Parangana Dam	352405 (Liena)	A2
Pelion Gap	217647 (Cathedral)	A2
Pelion Plains	207690 (Cathedral)	A2
Pillinger Bog	273712 (Rowallan)	A3
Pine River	428666 (Lake Ada)	A1
Premier Peak	296662 (Cathedral)	A3
Queenstown	805402 (Gormanston)	A1
Reedy Creek	255685 (Cathedral)	A3
Reedy Lake	246692 (Cathedral)	A3
Rowallan Dam	345797 (Rowallan)	A2
Sardine Creek	245837 (Borradaile)	A2
Sassafras Creek	420932 (Mole Creek)	A7
Shannon River	830410 (Wihareja)	A1
Snake Creek	292876 (Borradaile)	A7
Snowy Ranges	718462 (Neveda)	A1
Solomons Jewels	397721 (Rowallan)	A5
Steers Plain	319683 (Cathedral)	A4
Stretcher Creek	360719 (Rowallan)	A6

The Temple	423695 (Lake Ada)	A5
Traveller Range	255570 (Du Cane)	A3
Twin Spires	267628 (Cathedral)	A3
St. Valentines Peak	958208 (Guildford)	A1
Wailing Wall	413688 (Lake Ada)	A4
Walls of Jerusalem	420702 (Pillans Lake)	A4/A5
West Coast Ranges	830650 (Selina)	A1
West Wall	410696 (Lake Ada)	A5
Western Bluff	400930 (Mole Creek)	A7
Wild Dog Creek	405720 (Pillans Lake)	A5
Wurragara Creek	265690 (Cathedral)	A2
Vicar Bluff	281664 (Cathedral)	A3
Yeates Lagoon	471883 (Lake Mackenzie)	A7
Zion Creek	425715 (Pillans Lake)	A5
Zion Hill	422704 (Pillans Lake)	A5
Zion Vale	425715 (Pillans Lake)	A5

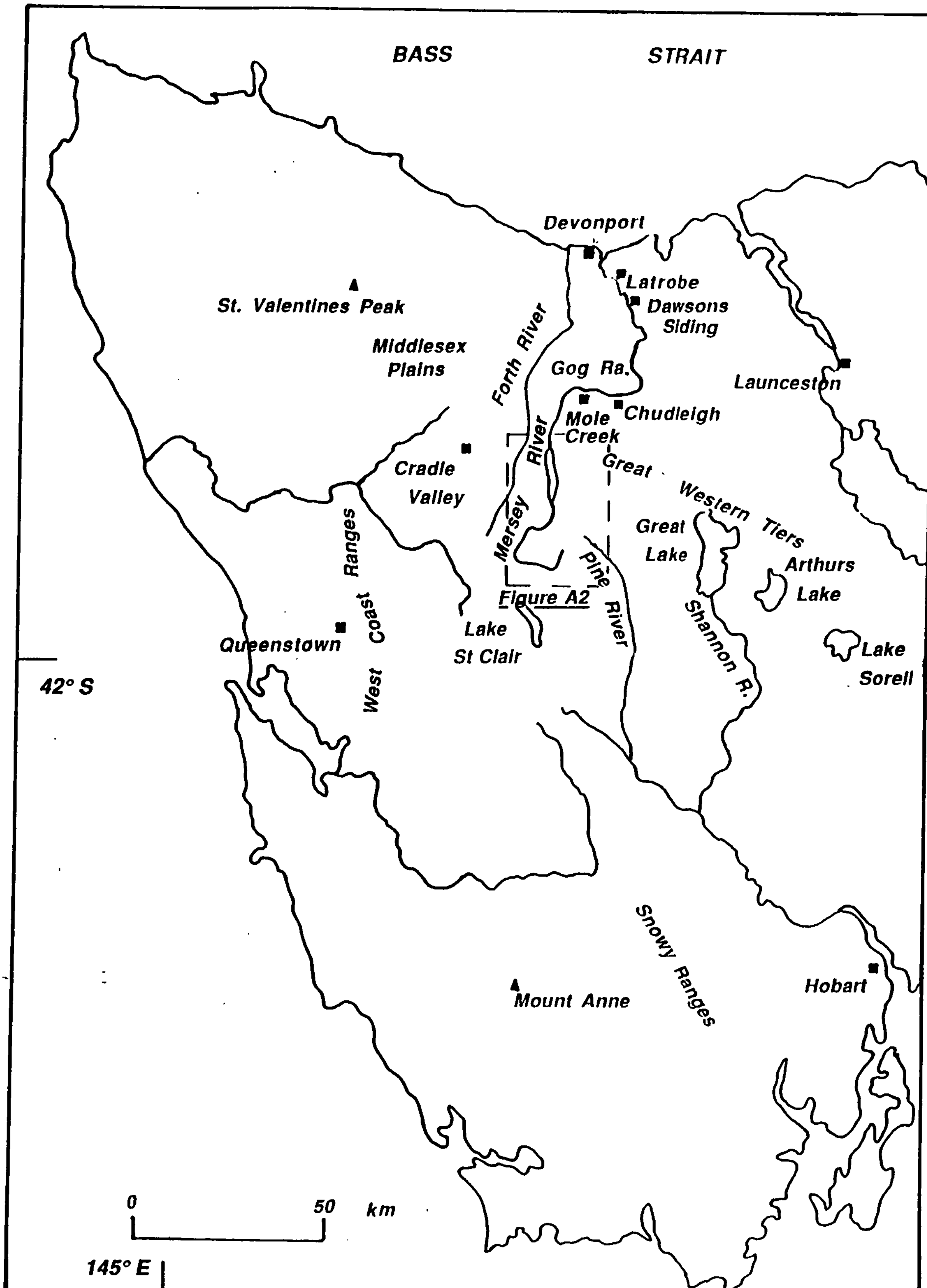

Figure A1: General locations in western and west-central Tasmania.

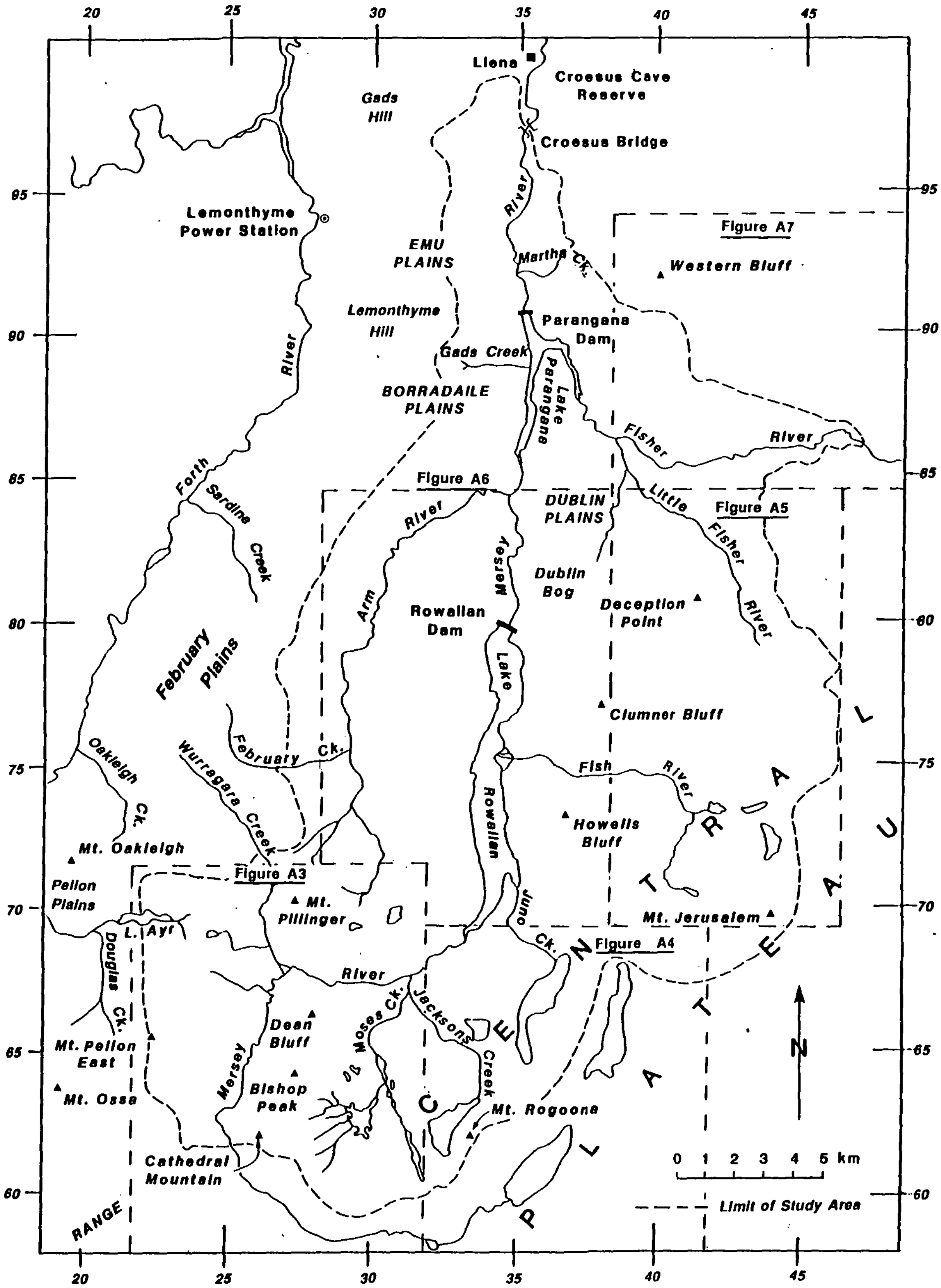

Figure A2: Locations in the study area.

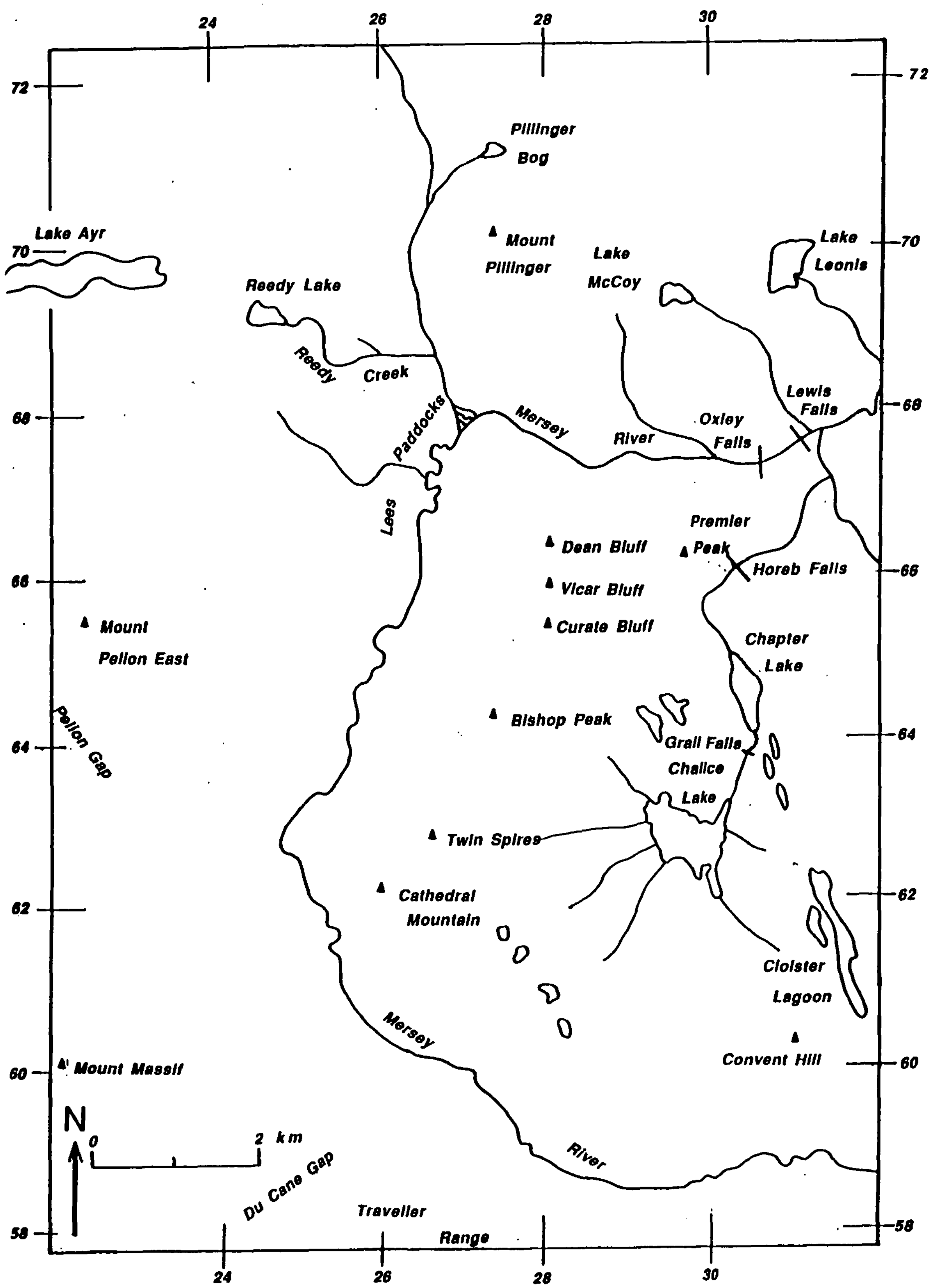

Figure A3: Locations in the Cathedral Mountain area.

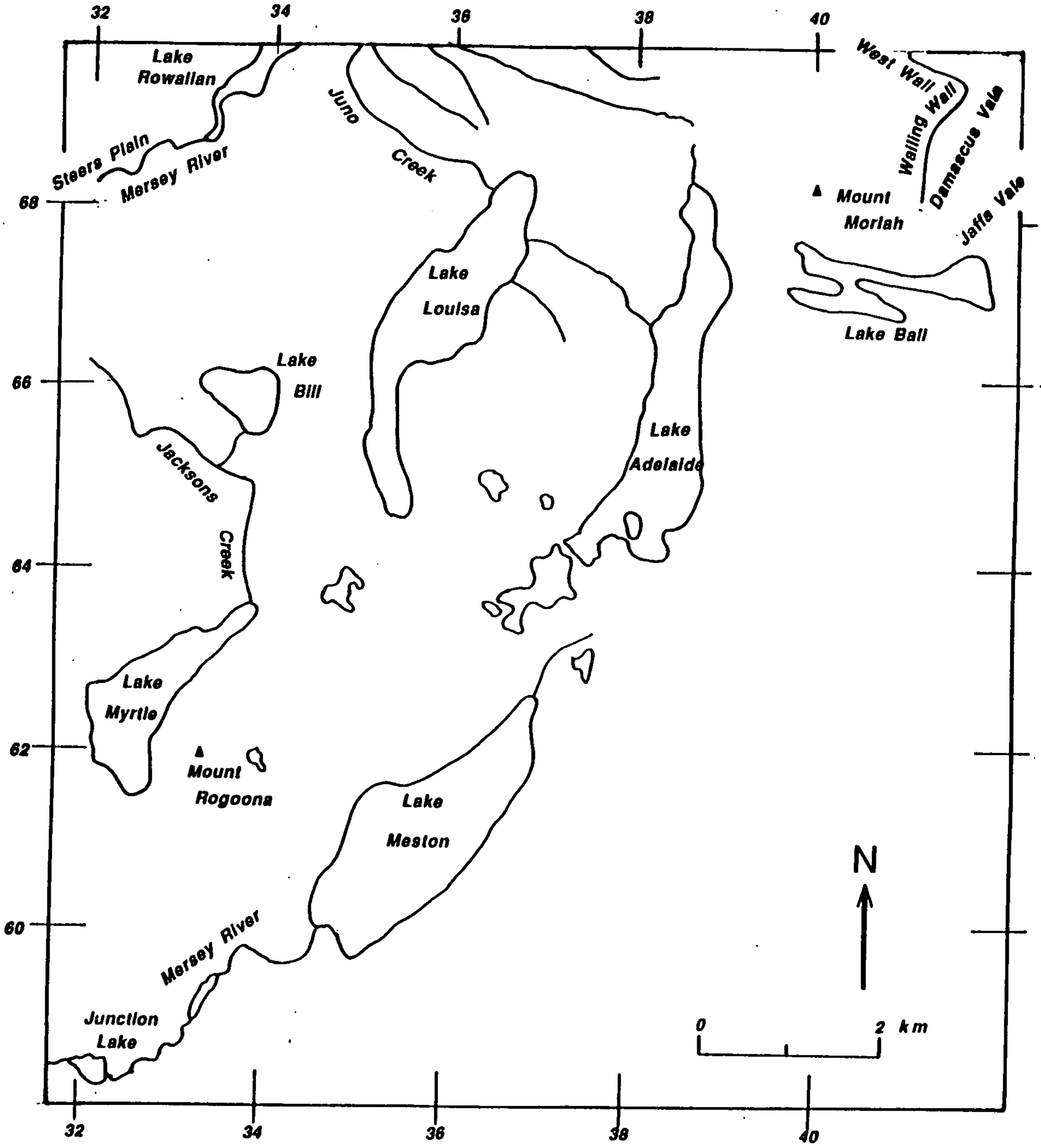

Figure A4: Locations in the Lake Myrtle area.

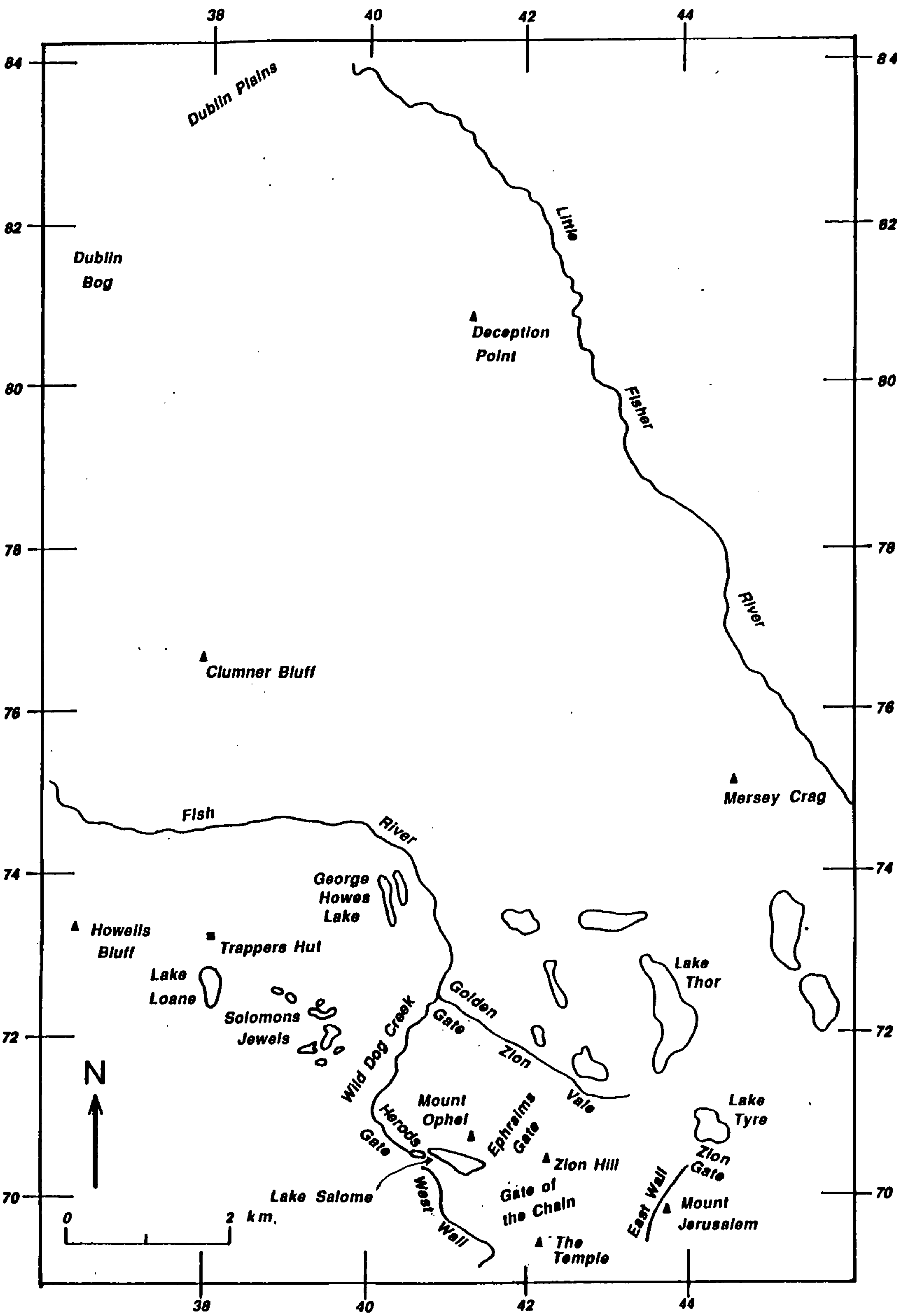

Figure A5: Locations in the Walls of Jerusalem area.

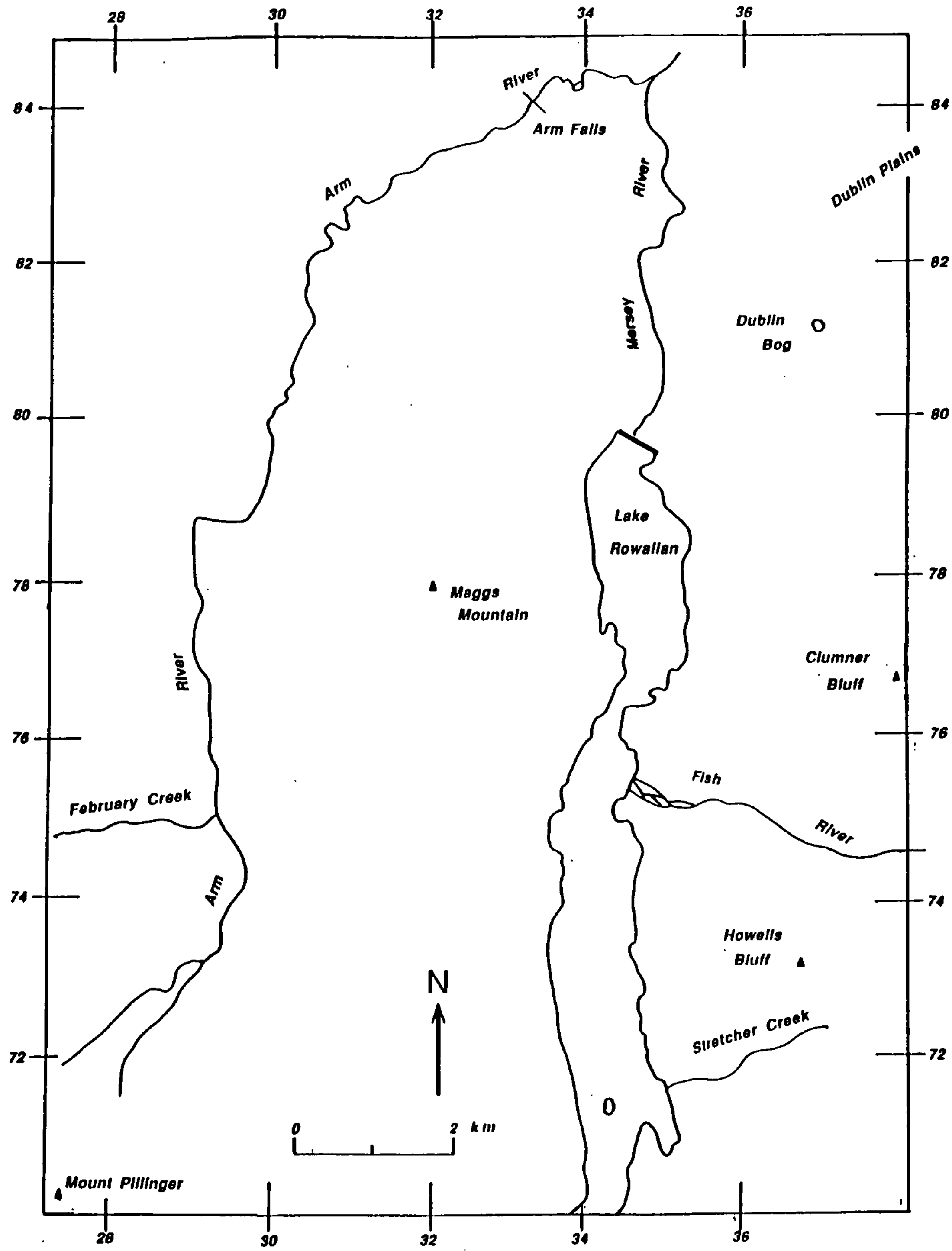

Figure A6: Locations in the Lake Rowallan area.

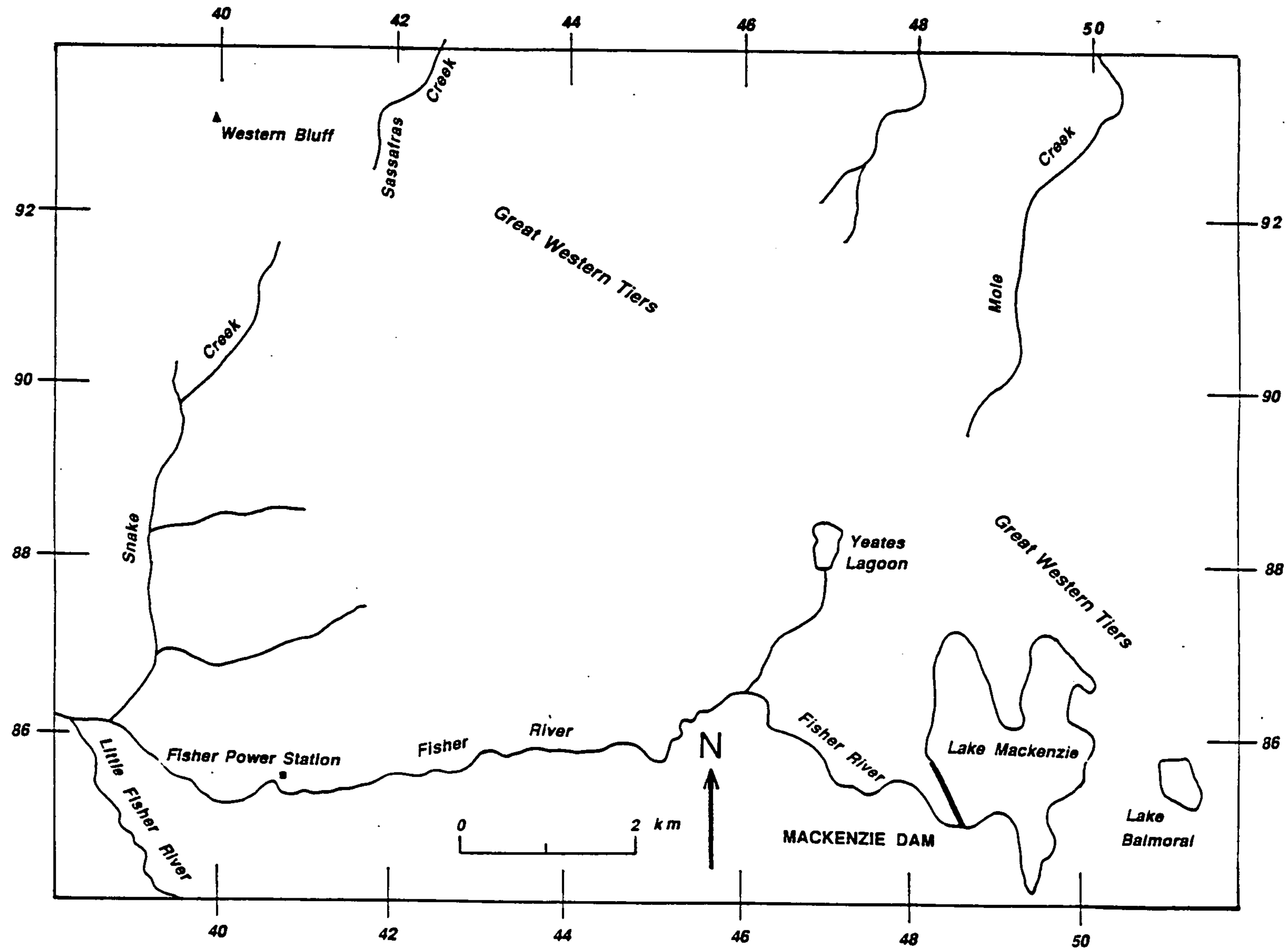

Figure A7: Locations in the Lake Mackenzie area.