TASMANIA

DEPARTMENT OF MINES

GEOLOGICAL SURVEY RECORD No. 6

GLACIAL MAP OF N.W. – CENTRAL TASMANIA

by

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Issued under the authority of
The Honourable ERIC ELLIOTT REECE, M.H.A.,
Minister for Mines for Tasmania

TASMANIA

1968

REGISTERED WITH G.P.O. FOR TRANSMISSION BY POST AS A BOOK

D. E. WILKINSON, Government Printer, Tasmania

28344

Price $0.50

PREFACE

In the published One Mile Geological Maps of the Mackintosh, Middlesex, Du Cane and St Clair Quadrangles the effects of Pleistocene glaciation have of necessity been only partially depicted in order that the solid geology may be more clearly indicated. However, through the work of many the region covered by these maps and the unpublished King William and Murchison Quadrangles is classic both throughout Australia and Overseas because of its modification by glaciation. It is, therefore, fitting that this report of the most recent work done in the region by geomorphology specialist, Mr. E. Derbyshire, be presented.

J. G. SYMONS, *Director of Mines.*

FRONTISPIECE.—View ENE from summit of Mt Rufus across terminal basin at South end of Lake St Clair to Southern (lower) point of western Central Plateau.

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INTRODUCTION

The Glacial Map of Northwest-Central Tasmania covers an area of about 1600 square miles along the western margins of the Central Plateau of Tasmania (but excluding the Plateau itself) between latitudes 41°30′ and 42°30′S and longitudes 145°50′ and 146°30′E. The map covers part of the area shown on the Mackintosh, Middlesex, Du Cane and St Clair Quadrangles of the One Mile Geological Map Series, and extends southward and westward on to the (unpublished) King William and Murchison Quadrangles.

The effects of Pleistocene glaciation in this area were first noted by the government geologist Charles Gould in the 1860's, but no details of these field observations were published by him. The period 1880-1900 saw the growth of a considerable body of field evidence of former glaciations. While much of this early work was centred upon the West Coast Range, parts of which were undergoing vigorous mineral exploration, the country between the Mackintosh River and Lake St Clair received some attention from government geologists and surveyors, notably Sprent (1887), Johnston (1894A, 1894B) and Montgomery (1894). While the smaller lakes of the Central Plateau and of the Cradle Mountain plateau were accepted as "almost *prima facie* evidence of glaciation" (Montgomery, *op. cit.*), the origin of the large lakes, including Lake St Clair, was already a contentious topic. The main conclusions of this early work were summarised by A. Penck in 1900 in an article which marked a growing overseas interest in the question of Tasmanian Pleistocene glaciation.

Field data, in general ancillary to hard rock and mineral exploration by government geologists (*e.g.* paper by Twelvetrees (1913) in which is noted glacial modification on and around Black Bluff) continued to accumulate in the period 1900-1922. Outstanding contributions during this time were made by Reid (1919) in the area between Barn Bluff and the middle reaches of the rivers Forth and Mersey, and by Benson (1917) in the Cradle Mountain district. This latter work included line soundings of Dove Lake and some neighbouring glacial rock basins. In an important paper published in 1925, Clemes firmly proposed the glacial erosional origin of the Lake St. Clair rock basin, although the theory had been tentatively put forward much earlier (Montgomery *op. cit.*; Officer, Balfour and Hogg, 1895).

In the 23 years from 1922 to 1945, A. N. Lewis published observations on the glacial geomorphology of a number of mountain areas in Tasmania, including parts of the central west (Lewis 1933, 1939, 1945). He attempted to resolve his discoveries into a chronological scheme which, however, depended unduly upon the views of Griffith Taylor and Edgworth David on the criteria indicating multiple glaciation. Accordingly, it has been rejected (see Jennings and Banks, 1958: Derbyshire, Banks, Davies and Jennings, 1965).

Recent work having a bearing on the glaciation of the region under review includes that of Jennings and Ahmad (1957), Macleod, Jack and Threader (1961), Jennings (1963) and Gulline (1965) on the Central Plateau and its western margins, Derbyshire (1963, 1965) on the Lake St Clair district, and Spry and Zimmerman

(1959) on points to the west of it, Jennings (1959) on the area about Cradle Mountain, and Spry (1958), Ford (1960), and Paterson (1965, 1966) on the Mersey and Forth valleys. Work reviewing Tasmanian glaciation and containing some reference to the Northwest-Central Tasmania includes Jennings and Banks (*op. cit.*), Davies (1962), Derbyshire, Banks, Davies and Jennings (*op. cit.*), and Derbyshire (1966).

The Glacial Map of Northwest-Central Tasmania is the outcome of a study of the glacial geology and geomorphology undertaken in the period 1960-1966. It represents over 150 days of field work and a similar length of time spent in aerial photo interpretation and plotting. A reliability diagram, indicating the relative importance of field and laboratory work over the region, is included in the Glacial Map (in pocket at back). In the first instance, the data for this district were assembled in map form during 1964 and 1965 for publication in the Glacial Map of Tasmania (Derbyshire, Banks, Davies and Jennings, 1965), at a scale of 1:250,000. The patterns shown over this present region (which is one of rapid transition climatically, morphologically, and geologically) proved so complex, however, that considerable generalisation of detail resulted, and publication at a larger scale was sought. It it hoped that the publication of the present Map at 1 inch: 2 miles, in providing some of this detail as well as additional field data and several amendments, will complement the Glacial Map of Tasmania and will be of use in association with the Middlesex, Du Cane and St Clair Quadrangles and the recently published Mackintosh Quadrangle of the One Mile Geological Map Series.

The map conventions follow closely those used in the Glacial Map of Tasmania, apart from modification necessitated by the absence of colour on the newer map. Reference should be made to the qualifications of the terms used in the legend which appear in the notes (pages 4-6) accompanying the Glacial Map of Tasmania.

I am indebted to the following friends and colleagues: J. N. Jennings, J. L. Davies and M. R. Banks (for much discussion, exchange of views and valuable co-operation), W. Paterson, J. G. Symons, A. Keller, J. Wilson and J. Stokes (for field and other assistance), J. L. Davies, Mrs. M. Peterson and J. Wilson (for a great deal of hospitality), K. Burns (for information on the Lake Windermere area), and W. Connell and D. Gallagher, rangers at Lake St Clair, for their co-operation. A particular debt is owed to J. A. Peterson for considerable support and immeasurable assistance is most phases of the work throughout the period.

My thanks are also due to the following institutions for assistance and co-operation: the Hydro-Electric Commission of Tasmania (especially S. J. Paterson, G. E. A. Hale, and G. Rawlings), the Departments of Geography and Geology in the University of Tasmania, the Department of Geography at Monash University, the Departments of Geology and Physics in the University of Keele (for X-ray diffractometry and electron microscopy respectively). the Surveyor-General and Secretary for Lands of Tasmania, and the Department of Mines of Tasmania (especially I. B. Jennings and E. Williams).

GENERAL STRUCTURE AND MORPHOLOGY

The general structure character of the region is well known (for details, see Jennings, 1959, 1963: Macleod, Jack and Threader, 1961: Gulline, 1965). The Precambrian basement is composed of strongly folded metasediments including schist, quartzite, phyllite, slate, and stretch-pebble conglomerate, together with limited outcrops of dolomite showing little or no metamorphism. The most extensive outcrops of the Precambrian basement occur in the southwest of the region (Alma, Franklin and Surprise River Valleys and the Loddon Range) and in the northwest where it forms a small but (in respect to glaciation) important plateau surface between 3000 and 4000 feet a.s.l. about Cradle Mountain and Barn Bluff. This faulted surface declines south and eastward, with a moderate relative relief, and is overlain unconformably by up to 2000 feet of sub-horizontal mudstone, siltstone, shale, sandstone and conglomerate of Permo-Triassic age. Into this series was intruded at various levels the Jurassic dolerite in the form of large sills (or cone-sheets: see Carey, 1958) usually exceeding 500 feet in thickness and over 2000 feet locally (Spry and Banks, 1962, page 337). Basalts of Tertiary age are extensive only in the north of the area, notably on Maggs Mountain, Borradaile Plains, Emu Plains, Gad's Hill, and Middlesex Plains where they underlie the tabular interfluves about the middle reaches of the Mersey and Forth rivers.

In lithological and structural terms, the region lies athwart the boundary between the pre-Permian fold province of the west and the fault-structure province underlain by Permian and younger rocks in the east (see Davies, 1965). This duality is expressed in the major landforms. The dolerite, which is resistant relative to the subjacent Permo-Triassic sediments stands out as a caprock and constitutes the outstanding bedrock element in the landscape. It underlies the surface of the Central Plateau and forms the summits of many mountains in the ranges left by the deep incision of rivers along the westerly front of the Plateau. These dolerite-capped mountains, stretching over some 25 miles between Cradle Mountain and Mt King William III, stand above valleys whose steep sides are made up of Precambrian rocks in the north and west, and Permo-Triassic sediments in the centre and south.

Relative relief is considerable, exceeding 2000 feet over wide areas and commonly exceeding 3000 feet. The boundary zone between the two great morphostructural provinces coincides west and southwest of Lake St Clair with the major watershed of Tasmania, the change being expressed in the asymmetry of the watershed (steep to the west, gentle to the east). North of the DuCane Range the watershed, now more symmetrical, runs northwestward through the Cradle Mountain plateau dividing west coast and Bass Strait drainage.

The general consistency of the relative relief in this region and immediately to the west suggests that while many of the finer details of the landscape are due to Pleistocene glaciation, the major forms are essentially due to the differential attack of humid temperate processes before the onset of the Pleistocene glaciations.

GLACIAL MORPHOLOGY

Glacial Erosion

This region of Tasmania possesses glacial erosional forms inherited from both montane and plateau-type glaciation. Cirques, over-ridden cirques, rock basins and glacial troughs, and some small-scale erosional features are shown on the Map.

CIRQUES

The widespread development of cirques, the typical landform of lightly to moderately glaciated mountains has resulted in the dissection of the upper slopes of most of the ranges to produce (in W. H. Hobbs' terminology) a "fretted upland". The growth of cirques on the eastern (leeward) slopes has given to these mountains a marked asymmetry, the concave glacial slopes of the east contrasting with the frequently little-modified western slopes, e.g., Loddon Range and Mt Hugel. The mean orientation of the cirques is somewhat south of east (115° within the main maximum between 110° and 120°), although there is wide departure from this mean in individual cases. Important secondary maxima occur at 150°-060°, 085°-090°, and 150°-160° (Figure 1).

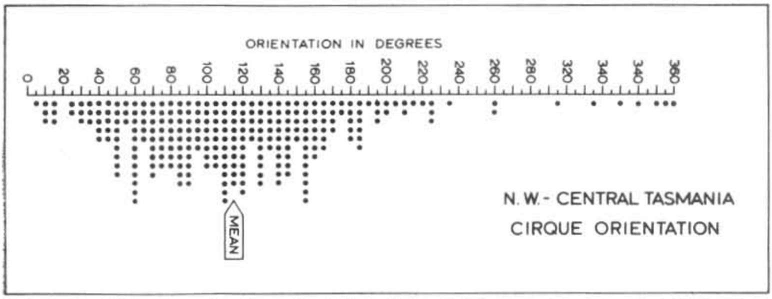

FIGURE 1.—Histogram showing orientation of the 265 cirques shown on the Glacial Map.

A major determinant of this orientation pattern is the general alignment of the mountain ranges. In the southern two-thirds of this region, many ridges run northwest to southeast in conformity with the northwest strike of the Precambrian basement and the larger faults in the post-Devonian rocks (*cf.* Gulline, *loc. cit.*). Relatively minor variations in ridge alignment may result in strong contrasts in cirque development. For example, the King William Range (summit 4500 feet a.s.l.), with an almost north to south alignment, has many cirques on its eastern slopes, the mean cirque orientation of 095°-100° reflecting the ridge alignment and the east to west valleys on the leeward side. In contrast Mt Olympus (summit 4746 feet a.s.l.), whose leeward slopes face northeast (030°), displays more limited cirque development. Nevertheless, some important cirques, such as the trough-end on Mt. Pelion West, face north of east as does the northernmost cirque in Tasmania (Black Bluff). The mean orientation of all cirques, including over-ridden cirques, on and about the Cradle Mountain—Barn Bluff Plateau is rather north of east (080°), the inter-quartile range being some 15° more northerly than that for the region as a whole. Given a westerly source of snowfall, the preponderance of structurally-guided southwest to northeast valleys in this area yields a mean cirque orientation about east-northeast.

Other important influences on the cirque distribution and orientation are the form of the mountain mass (ideally a ridge with a leeward bench below, upon which snowdrifts may accumulate, the main ridge thereby acting as a "snowfence": *cf.* Derbyshire, *in*

5 cm

*press**) and its location with respect to any "precipitation shadow" from adjacent mountains. The Wentworth Hills, which reach 4000 feet a.s.l., provide a good example. This range has a rather unfavourable alignment (northwest to southeast) and a plateau-like summit with no windward crest to serve as a snowfence. Moreover, it lies in the lee of the King William Range. All three factors have combined to provide a striking contrast between the severe glacial erosion of the latter range and the very slight modification of the Wentworth Hills which were affected during the last glaciation by cryonival rather than glacial processes.

Some 265 cirques are shown on the Map. In addition to the separately distinguished nivation cirques and over-ridden cirques, those mapped as glacial cirques include two types, namely discrete glacial cirques, and glacial valley-head cirques (trough-ends).

Nivation cirques are the product of perennial snow or firn patches. They are distinguished separately on the Map by the insertion of "N" within the cirque symbol. In terms of glaciation, these features are marginal and the mapping of them together with glacial cirques provides an indication of parts of the former transition zone from glacial to non-glacial environments (*e.g.* Mt. Hobhouse and Wentworth Hills). Well developed nivation cirques are few in this area. Examples of a variant form occur fairly commonly in western Tasmania. These are nivation-sharpened interfluves which may be termed "nivation crests": they include some features termed "elongate nivation cirques" elsewhere (Russell, 1933).

Discrete glacial cirques are common above 3500 feet. A threshhold may or may not be present. Cirques lacking thresholds are found on the steeper mountain slopes, many of the higher examples being relatively small, shallow, but very sharply defined and of almost perfect circular form. Some of these cirques are inset on the slopes of much larger cirques, *e.g.* the southernmost cirque on Mt Hugel within the Hugel Creek valley-head cirque (Plate 1). These small cirques owe their fresh form and inset character to a distinct phase when they were occupied by small glaciers or firn patches which were not tributary to any adjacent glaciers. This may have occurred in the last deglacial hemicycle (when ice would persist longest in these small but efficient drift-accumulation basins, *cf.* Jennings and Ahmad, *loc. cit.*), during a postglacial cool phase (neoglacial), or both. In the absence of a rock threshold, end moraine ridges have not formed in many cases, although lateral moraines may be very large and sharp-crested and contain a notable amount of protalus as in the NE-facing cirque on High Dome and the cirque on the southern slopes of Mt King William III. The glaciers which occupied some of these cirques were clearly transitional, at some stage, to small valley glaciers which were tributary to larger ice streams (*e.g.* southernmost cirque on Mt. Gell).

The high, discrete cirques of the region sometimes possess a well-developed rock threshold upon which may stand a substantial end moraine (Lake Enone and Lake Helen cirques on Mt. Olympus provide contrasting examples: see Derbyshire, *in press*). Other examples of this type include some of the higher cirques of the

* These relationships are common in this region, the "snowfence" being provided by the dolerite sill and the leeward bench occurring at its base on Permo-Triassic or Precambrian rocks. Due to the transgressive nature of the sill, the altitude of this break of slope is variable and results in many local variations (some of them considerable) in the altitude of cirque floors.

King William Range, and the cirques on Mt Ronald Cross and Black Bluff. The presence in many high discrete cirques of a single, large end moraine bounding a small, symmetrical rock basin suggests long periods of balanced glacial regimen, presumably coincident with the last pleniglacial.

A notable characteristic of the high, discrete cirques of North-west-Central Tasmania is their low depth: area ratio. Even some cirques with well developed rock basins have very low backwalls which have not been over-ridden by ice, *e.g.* the Lake Enone cirque. The accumulation of the ice which filled these cirques was clearly dependent on severe wind-drift accumulation. This was so substantial in some north-facing valley-heads as to offset the long exposure of the winter snow accumulation to the high summer sun. These facts of morphology and orientation suggest that, in glacial-meteorological terms, the cirque glaciers of central and northern Tasmania had as much in common with the sub-tropical glaciers of the present as with the temperate glaciers so intensively studied in northern Europe.

Larger cirques with thresholds are found in minor valley-heads at rather lower altitudes. They contain evidence, notably large outermost lateral moraines, indicating that at the period of maximum ice extension they partly overspilled their symmetrical rock basins to join other enlarged cirque glaciers on their lateral margins, and in many cases, the valley or piedmont ice below, e.g. southernmost cirque of King William I range (Plate 2). The well-marked end moraines on the thresholds mark an important retreatal stand of unknown duration.

Glacial valley-head cirques. Most of the trough-ends in this region lack a rock threshold. They include, for example, the great cirque on Mt. Pelion West (upper Forth glacier) and the Narcissus cirque (nearly 2000 feet deep and two miles across) at the head of the former St. Clair glacier. Some of the larger valley-heads possess rock thresholds marked by an elongate lake in the through-end. For example, Lake Marion occupies a shallow rock basin, 40 feet in depth. The best developed valley-head thresholds (King William Range, eastward of Mt. Gell in the Franklin River valley, and on the Cradle Mountain—Barn Bluff plateaux) are rather more complex in that they were associated with piedmont and plateau ice-sheets rather than with valley glaciers (see rock basins and glacial troughs page 17). The valley sections of these former glaciers, along which erosion was concentrated, were short but steep and narrow defiles in comparison with the trunk valleys without thresholds which, in general, have steeper longitudinal gradients and lower depth: width ratios.

Over-ridden cirques. Some cirques show evidence of having been over-ridden by ice, usually in the form of well-rounded and (on the Precambrian rocks) straited headwall crests. Over-ridden cirques occur most frequently on the plateau surfaces, *e.g.* Barn Bluff plateau, The Labyrinth, and the upper Franklin River valley. Their location and mean orientation, which is similar to neighbouring unmodified cirques, are consistent with the view that these cirques were initiated (or, if formed in an earlier glaciation, re-occupied) during the advancing hemicycle of the last regional glaciation (*cf.* Jennings and Ahmad, *loc. cit.*). While they have undergone some subsequent modification by periglacial solifluction, no evidence has been reported which indicates re-occupation by cirque glaciers or firn patches in postglacial time.

The volume and distribution of glacial rock basins provide an indication of variations in the severity of glacial erosion in the region. Four areas stand out in this respect, namely the Cradle Mountain and Barn Bluff plateaux, the upper Franklin River valley, the King William Range, and the Du Cane Range—Lake St Clair area.

The lakes on the Precambrian basement about Cradle Mountain and Barn Bluff vary from small lakes occupying hollows gouged out differently by the plateau ice-sheet, to substantial rock basins in cirques (*e.g.* Lake Will, approximately 90 feet deep*) over-ridden cirques (*e.g.* Crater Lake, approximately 200 feet deep) and over-ridden trough ends (*e.g.* Dove Lake, approximately 200 feet deep: Benson, 1917)). Lake Rodway, in the large, complex cirque on the lee-side of Cradle Mountain, is approximately 120 feet deep*.

The glacial rock basins of the upper Franklin River were among the earliest recognised in Tasmania. They range from a stepped series or chain of lakes on a "glacial stairway" (due east of Mt Gell) to small basins with the very broad and shallow head-water area. Distinctions are difficult here due to the effects of over-riding ice, for ice grew to form a small sheet in the headwater area and became a well developed reticular glacier system immediately downstream.

The outstanding examples of trough-end rock basins to be found in the area occur on the eastern flanks of the King William Range. Ice accumulated in the lee of this range to depths exceeding 1000 feet, the eastern slopes displaying evidence of some of the most severe glacial erosion of dolerite to be seen in Tasmania. Lake Rufus (Plate 3) less than three miles long is over 260 feet deep, while the smaller Lake Richmond (a fine trough-end rock basin) attains a depth of more than 110 feet. The sharp break of slope at the foot of the King William Range resulted in the coalescing of these substantial valley glaciers into a broad piedmont glacier, so that within one to three miles eastward of the summit of the range severe linear erosion by ice ceased abruptly. Eastwards of the rock basin lakes, the only large-scale evidence of former glaciation is depositional.

In the Du Cane—St Clair area, small rock basins occur on the plateau remnant of the Labyrinth both on the surface of the plateau and in over-ridden cirques on its northern margins. Lake St Clair occupies part of the largest glacial trough in Tasmania. Some nine miles long, the lake reaches approximately 530 feet in depth. It is made up of four distinct rock basins, the deepest occurring where the trough swings due south along the southeastern end of Mt Olympus. The bulk of this great lake basin is rock-girt, the moraines at the southern end probably not exceeding 100-120 feet judging from echo-profiles†. The trough has markedly asymmetrical cross-profiles, the deepest tract being along the foot of Mt. Olympus. This deep is narrow and straight and may mark the line of a long-suspected northwest-southeast fault (*cf.* Gulline, *loc. cit.*). The plan shape of Lake St. Clair reflects its origin due to convergence of four large ice streams from the Du Cane Range and, more important

* J. A. Peterson, personal communication.

† A detailed description of a bathymetrical survey of Lake St Clair, conducted by the writer in December, 1965, is in course of preparation.

in terms of ice volumes, a major flow of sheet ice from the adjacent Central Plateau notably about Mt Ida. At this point the lake both widens and deepens rapidly. With the emergence of the ice stream from the constriction provided by Mt Olympus on the west and the Central Plateau on the east, it spread out to form an expanded foot glacier which occupied and overspread the shallower but broader terminal basin at the southern end.

The considerable amount of valley widening and deepening effected by glacial erosion is obvious only in the source areas of the glaciers. Elsewhere, large scale signs of glacial erosion such as the catenary valley cross-profile are absent, a situation which in the past has led some workers to minimise glacial limits and others to invoke interglacial or postglacial rivers as the responsible agents. Many of the major glacial outlet valleys of Tasmania (*e.g.* Alma, Fury, Mersey, Forth, Fish and Fisher) have V-shaped cross profiles which suggest that the agents of modification include accumulation of glacial deposits within the valleys, postglacial river erosion of these deposits and of bedrock, and the frequently substantial accumulation of congeliturbate and talus on valley sides. This has been proved by excavations by the Hydro-Electric Commission in several Tasmanian valleys. (Paterson, 1965, 1966; Hale *in* Derbyshire, 1966).

SMALL SCALE EROSIONAL EFFECTS

To the cirques, rock basins and glacial troughs may be added the rather limited extent of "ice erosion surfaces". Small scale effects of ice abrasion and plucking, such as *roches moutonnées*, fluting, gouging and striation are best seen on the Precambrian rocks, notably about Dove Lake (Plate 4) and the rock bar north of Walter's Marsh in the Mersey River valley. The varying resistance of different members such as massive quartzite and contorted and strongly lineated mica and chlorite schists is reflected in the details of several glacial pavements in this northern area. While features attributable to glacial abrasion are extremely rare on the dolerite bedrock due to its weathering properties (although striation is moderately common on dolerite clasts in lodgment tills) its jointed structure is well suited to the development of *roche moutonnée* forms (*cf.* Jennings and Ahmad, *loc. cit.*). These are best seen on the eastern slopes of the King William Range, on The Labyrinth, and in the upper Franklin River valley. To these forms is owed a good deal of our knowledge of mean ice-flow directions on dolerite bedrock in the area mapped. As may be seen in the areas of Precambrian outcrop, the directions derived from *roches moutonnées* are consistent with those suggested by glacial striae and with the few till fabric orientations so far completed*.

GLACIAL DEPOSITIONAL LAND FORMS

Glacial deposits are widely distributed in this region, being generally thicker and least modified on gentler slopes including valley floors little modified by postglacial fluvial erosion. On steep slopes, glacial drift may be covered or mixed with varying thicknesses of talus in which broken dolerite columns are the major component.

* A series of till fabric measurements for several localities in this region will be published elsewhere.

The landforms of the glacial drift are predominantly of recessional origin and of frontal and lateral type. The most important in terms of former ice extent and movement are the end moraines which vary in size from the low, discontinuous and sometimes hummocky examples (*e.g.* northwest of Dove Lake) to substantial ridges some of which may be bedrock-cored.

A fine series of more than 80 end moraines can be followed from the middle reaches of the Navarre River to the southern shores of Lake St Clair and then, beyond the northern end of the lake, another series of more than 60 runs up the Narcissus River valley. These moraines have a relief which seldom exceeds 30 feet, yet several form unbroken ridges one to two miles in length. Exposures in some of these moraines reveal that they have a large content of bedded silt, sand and gravel capped by a superglacial till. The undisturbed upstream-dipping beds represent partially over-ridden outwash and bands of englacial debris (see page 20) laid down by moving ice undergoing slow, steady retreat. The regular spacing of the moraines over tracts 5½ miles long at both ends of Lake St Clair strengthens this conclusion and gives a good general indication of the course and regularity of contraction of the St Clair glacier and of its tributaries in the Marion and Pine Creek valleys. Immediately south and west of the Navarre River, however, the moraine ridges are of poor form, being broad and low and, locally, almost inundated by ice-melt deposits including glacifluvial gravels and ablation moraine. Equally clear evidence of contraction can be found at the eastern foot of the King William Range (Lake Rufus) and in two re-entrants on the west side of the Mersey River valley, namely at Kia-Ora Creek and at Campfire Creek at the foot of Falling Mountain. The westward convexities of the moraines at the latter location indicate the clearing of Du Cane Gap of glacier ice as the St Clair and Mersey glaciers separated during downwasting.

Hummocky moraines occur mainly in tributary valleys as well as on some plateau surfaces and within some high cirques, *e.g.* Hugel, Pine and Cuvier River valleys (linear to conical forms), some valleys in the King William Range (chaotic forms with very large boulders: Plate 5), Barn Bluff plateau (undulating forms), and the upper Hugel River valley (hummocks on plains of typical ablation till). They indicate thin, motionless ice.

Apart from one or two drumlinoid features near the head of the Franklin River, drift forms indicative of strong ice flow are limited to a few localised patches of lineated drift. The largest area of lineated drift is found in the great valley-head cirque between Acropolis and Falling Mountain, where individual ridges may be followed for over one mile. This ribbed drift has been attributed to late-glacial meltwater streams (MacLeod, Jack and Threader, *loc. cit.*) and to fluting beneath a large glacier moving by vigorous rotational slip (Derbyshire, 1963). It might also be argued that the ridges are akin to medial moraines which were let down during the last phase of the slow downwasting process already demonstrated for this area. The moulding of this symmetrically converging pattern of drift flutings on a surface with appreciable cross valley relief, such that the moraine ridges do not consistently follow the maximum gradient, constitutes an important obstacle to the meltwater hypothesis. However, in the absence of detailed ground studies of their morphology and deposits, the precise origin of the lineations remains debatable.

Plains of glacial outwash sand and gravel are closely associated with the retreatal moraine forms. They may underlie and locally overlie end moraines, the accumulation of glacifluvial gravel in intermorainal swales reducing the relative height of the ridges, especially on the distal side, the steep ice-contact face contrasting with gentle distal slopes made up of till and glacifluvial fill, *e.g.* the large end moraine ridges marking an important period of stability of both eastern and western lobes of the St Clair glacier, on the Traveller-Nive interfluve (3½ miles east-northeast of Derwent Bridge) and immediately east of the middle Navarre River (4½ miles southwest of Derwent Bridge) respectively. Outwash plains are rather small in the glacial valleys of the central area, and reach appreciable dimensions only in the more marginal valleys (*e.g.* Alma, Collingwood, middle Mersey and Forth) where they may show one and sometimes two low terrace surfaces. In postglacial times, the rivers appear to have cut their channels deeply into these fills, otherwise modifying them little. Substantial glacifluval fans are found at the mouths of some steep tributary valleys, the headwaters of which rise on high glaciated plateau surfaces (*e.g.* Fish River, Warragarra Creek, Commonwealth Creek) or within large cirques (*e.g.* Douglas Creek which flows north from the Mt. Ossa cirques). Incision by postglacial streams has revealed that the fans are composed predominantly of coarse to fine gravel, torrentially bedded, and including many boulders. Their freshness of form and content, and the presence of rhythmites in the lower strata of some of the fans, suggest that they started to accumulate when ice in the trunk valleys was rather thin, the bulk of their volume accumulating in ice-free reaches of trunk outlet valleys by meltwaters draining the adjacent plateau and mountain ice-masses which persisted longer.

GLACIAL SEDIMENTS

Glacial Till

Areally, the most important category of drift is the glacial till, the minimal proved extent of which may be gauged from the area shown on the Glacial Map as "ground moraine-undifferentiated". While fieldwork has established the presence of several types of till, mapping has not proceeded sufficiently to justify the differentiation on the Map. Three exposures of Pleistocene tillite are distinguished separately, however, because of their relevance to the important question of multiple glaciation.

The glacial tills of the region vary in their source rocks, consolidation, and state of weathering. Glacial drifts in which fragments of the Precambrian metamorphics predominate are usually rather poor in the silt-clay fraction, clasts are more angular, texture looser, and the degree of chemical weathering less than in the drifts with constitutions dominated by dolerite. The gravelly tills of the Cradle Mountain area provide good examples (Figure 2 and Table 1.)

The Permian and Triassic rocks are in general rather friable relative to the Precambrian rocks and the dolerite. Clasts of Permian mudstone and shale larger than pebble size are a relatively minor element in the glacial till, although Permo-Triassic material may make up a notable proportion of the sand and finer grades. Where the coarse sandstone and conglomerate members are well jointed, a blocky talus may develop and some such blocks have been preserved as superglacial erratics on end moraine surfaces (*e.g.* southwestern side of Lake St Clair).

	PEBBLE	GRAVEL			SAND		
		COARSE	MEDIUM	FINE	COARSE	MEDIUM	FINE
Lithology	Quartzite	Quartzite and Schist	Quartzite and Schist	Quartzite and Schist	50% Quartzite 50% Schist	70% Quartzite 30% Schist	90% Quartzite
Roundness	.3	.4-.5	.2-.5	.2-.5	.2-.5	.4	.4
Sphericity	.75	.79	.75	.49-.79	.57-.83	.65-.85	.65-.85

Commonly straited

TABLE 1.—Lithology, roundness and sphericity of fragments in gravelly surficial till of hummocky end moraine one mile NNW of Dove Lake.

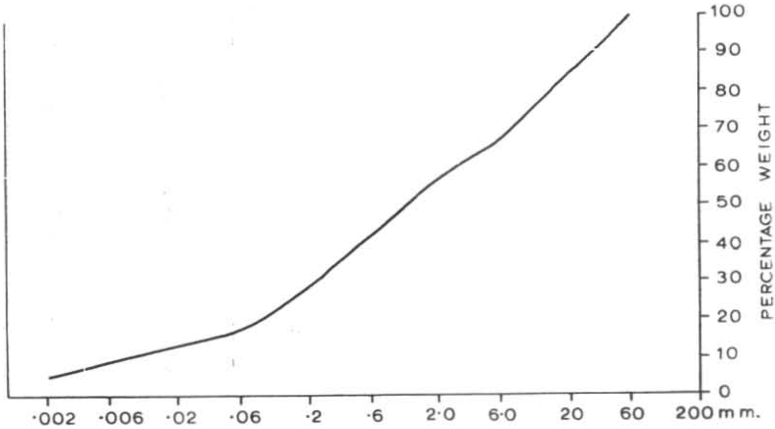

FIGURE 2.—Cumulative curve of fragments in gravelly surficial till of hummocky end moraine one mile NNW of Dove Lake.

Dolerite is the dominant constituent of the glacial drift over more than three-quarters of the area mapped. Being well jointed it is a prey to physical attack (including frost shatter, glacial plucking, and cambering and collapse on slopes oversteepened by glacial erosion: see Plate 6) as well as being susceptible to chemical weathering. Thus dolerite and its products may predominate in all grades of a till sample (*cf. Spry*, 1958) except the clay grade where, almost invariably, quartz is predominant. Chemical weathering subsequent to deposition has affected some dolerite till to depths of tens of feet.

The most notable drift member is the surficial till which covers many hundreds of square miles on the Central Plateau and the adjoining valleys and ranges to the west and south. In general, this loose to unconsolidated till is very bouldery and rather thin except locally. It has been affected by depogenic processes in post-glacial time such that in its upper layers the matrix is typically red-brown to yellow-red in colour (7.5 YR in the Hunsel Soil Colour book), massive in structure and with a silty clay texture. The included boulders, cobbles and pebbles, which are mainly of dolerite, are usually only slightly weathered, although individual dolerite clasts in the same exposure may vary in their degree of weathering. They may be a reflection of local variations in consolidation of the till and its relation to ground drainage, a different weathering condition before the entrainment of the fragments the glacier, or mineral grain size (for there is a tendency for fragments of fine-grained dolerite to be less weathered than the coarser-grained varieties). The rock fragments are sub-angular to well rounded, the degree of rounding being greater where a weathering rind is well developed. Most typically, this till occurs as a sheet of varying thickness with little topographical expression, such that it may be confused readily with the widespread congeliturbate mantle derived from weathered dolerite. The till may be distinguished by certain characteristics, notably its pebble orientation, the occasional quartzite pebble, and the presence of an appreciable amount of quartz in the clay fraction.

In contrast to the surficial till, the consolidated to toughly consolidated grey till of the region has been weathered down to only one to four feet below the ground surface. The shallow weathered zone is yellow to yellow-red in colour (10 YR 5/6 wet, 2.5 YR 7/4 dry), the platy structure deriving from the macro-fissility observable in the unweathered till. The grey till found at Rowallan dam-site on the Mersey River has been described by Spry (1958) and Paterson (1965), and may be taken as the type locality for northern Tasmania. It is tough, very well consolidated and practically watertight. Material between 25 and 2.5 cm. is generally sub-angular and consists of dolerite (65%), quartzite (30%), and mica schist (3%). Included clasts of dolerite are fresh to only slightly weathered, striae and glacial polish being present on some. The matrix, composed principally of quartz, mica and plagioclase with some chlorite is essentially unweathered, X-ray diffraction revealing only a small amount of clay mineral (kaolinite) in a sample taken 10 feet below the surface (Table 2).

Till with similar qualities also occurs in the Arm River valley (where it contains more basalt fragments), on the Mersey-Arm interfluve, and in the upper Fish River "ice spill-over" area (where the rock flour is rather poorer in quartz and mica than the till at Rowallan and richer in plagioclase and iron ore reflecting its closer proximity to the dolerite of the Central Plateau: Table 1, *cf.* samples 1 and 2). In the south, comparable till occurs on the proximal sides of the piedmont and moraines at the foot of the King William Range (*e.g.* southwest shores of Lake King William, where lodgment till rests on a pavement of Permian mudstones, the striae orientation (82°—92° true) indicating eastward advancing ice beyond the Lake Rufus trough), and widely near Lake St Clair where the percentage of dolerite clasts is higher (75—80%) and the contribution of the sedimentary rocks to the fines is greater than in the north. In the latter area, this till often contains appreciable amounts of sand and differs accordingly in its degree of consolidation and response to weathering. Even where it is markedly sandy, however, such as on and near the southern shores of Lake St Clair, it may be very poorly sorted (first and third quartiles spread of five Wentworth grades: see Figure 3) and, except in the medium and fine gravel grades, fragments are angular to sub-angular. Plagioclase with weathered mesostasis (49%) and quartz (41%) predominates in the medium sand fraction. This sandy till has retained its glacial fabric as well as the macro-fissility and other ice-pressure structures usually associated with lodgment till. As all exposures of this till in the south of the region are shallow, particles of dolerite show some signs of weathering. These limited exposures compare very closely with upper horizons of the Rowallan till if the differences in their source rocks, degree of compaction and pedogenic modification are kept in mind (Figure 3 and Table 2, samples 1-4). In the regularly spaced retreatal end moraines at both ends of Lake St Clair, the material is usually bedded, some individual bands being very well sorted and locally current bedded (Figure 4). These moraines were deposited by slow melting out of englacial bands rich in debris, especially sand and gravel, within ice-covered ridges partly insulated by a cover of englacial and superglacial moraine (Derbyshire, 1965; *cf.* Boulton, 1967), the grey clayey silt of the intervening swales accumulating by slopewash and tillflow at the same time. Near the outlet of Lake St Clair, the moraine ridges are composed almost entirely of massive to current-bedded grey-yellow to yellow

Sample	Location	Mineralogy of Fines					Weathering State of Dolerite Pebbles & Cobbles	Surface Form	Depth of Sample Below Surface (feet)	Remarks
		Clay Minerals				Non-Clay				
		14Å	10 - 14Å	10Å	7Å					
1. Rowallan grey till, loc. 1, o.s. 1	Rowallan dam-site, borrow pit area, Mersey River	chlorite	..	MUSCOVITE (very strong)	KAOLINITE (weak)	QUARTZ (very strong) PLAGIOCLASE (very strong)	fresh to very slightly altered	fresh	10	
2. Mersey—Fish 3, grey till	N. valley-side of Fish River at c. 2,400 ft. a.s.l.	chlorite (weak)	trace of randomly-interstratified mineral	muscovite	kaolinite (trace)	QUARTZ (strong) PLAGIOCLASE (strong)	fresh to very slightly altered	fresh	5	
3. St Clair gravelly lodgment till	Outlet canal, pumping station, Lake St Clair	..	unidentified mixed-layer mineral (very weak)	muscovite	..	QUARTZ (very strong) PLAGIOCLASE (strong)	fresh to very slightly altered	fresh	15	
4. K.W.R. 1/2 lodgment till (basal)	S.W. shore of Guelph Arm, Lake King William	..	montmorillonite/illite/chlorite (weak) randomly interstratified? montmorillonite/illite (trace)	muscovite	kaolinite (weak) ?dickite (weak)	QUARTZ (strong) PLAGIOCLASE (strong)	fresh to very slightly altered	(modified by artificial lake)	~3	
5. Parangana 2/1 till/?glacifluvial	Adjacent to Mersey Fisher R. confluence	montmorillonite (weak)	MONTMORILLONITE/ILLITE chlorite/vermiculite	illite	HALLOYSITE with kaolinite	quartz gibbsite	badly weathered to decomposed	degraded	10	free iron oxide abundant dominant minerals confirmed by electron microscopy

6. Lower Arm tillite (weathered zone)	¾ mile S.W. of Arm-Mersey confluence	chlorite (trace) montmorillonite or vermiculite	montmorillonite/illite randomly interstratified mineral (? mont./illite)	illite (weak)	KAOLINITE with halloysite	QUARTZ plagioclase (weak)	weathered to decomposed	degraded	6	"
7. K1 till	E. shore of Lake King William, 2 miles N. of Butler's Gorge	montmorillonite? (trace)	illite/vermiculite (weak)	illite (weak)	HALLOYSITE with kaolinite	QUARTZ gibbsite plagioclase (very weak)	badly weathered to decomposed	degraded	5	"
8. K 3/1 till	1½ miles N.W. of Mossy Marsh	..	montmorillonite/illite (weak) randomly-interstratified mineral ?mont/illite (weak)	illite (weak)	HALLOYSITE with kaolinite ?dickite (weak)	QUARTZ gibbsite plagioclase (very weak)	badly weathered to decomposed	degraded	5	"

TABLE 2—Mineralogy of fines, state of weathering of dolerite fragments and surface form of some morainic materials, N.W.—Central Tasmania.

Dominant Minerals in each Sample shown in Capitals sand in the manner of kame-moraines, thus reflecting the greater importance of englacial and superglacial meltwaters with increasing proximity to the Derwent outwash plain which was the main outlet for glacial drainage. In the medium grades, the sand is predominantly of quartz (52%) and slightly weathered plagioclase (29%). It is clean and very well sorted (Figure 5) to rather poorly sorted (Figure 6), but with a low to moderate roundness coefficient (.1-.4). Under the electron microscope, some of the quartz grains have a distinctively glacial surface texture (*cf.* Krinsley and Takahashi, 1962).

Some severely weathered till deposits are known from several limited exposures in the region, namely at and immediately south of the confluence of the Mersey and Fisher Rivers (Parangana Sugarloaf), on the eastern shore of Lake King William, and adjacent to the Tarraleah Highway between Butler's Gorge and Tarraleah.

The drift at the Mersey-Fisher confluence contains decomposed dolerite boulders to a depth of at least 15 feet below the present surface (Plate 7), while at the Parangana dam-site, 1500 yards downstream, the matrix of the drift is weathered at a depth of 85 feet below the surface (Paterson, 1966). The drift in these northern exposures is yellow-red in colour (10 YR and 7.5 YR ranges), heterogeneous, and gravelly in texture. It varies from poorly consolidated to cemented. The generally weak pebble orientation, a characteristic to be expected in this area of convergent ice streams and steep valley-side slopes, may indicate deposition as an ablation till, mixing by confluent glaciers, or (as the pebble orientation of the drift in the adit at Parangana dam-site indicates) subsequent modification by mass movement. This drift is locally stratified in the manner of many retreatal moraines, although the glacifluvial origin already suggested for some of it cannot be excluded entirely (*cf.* Paterson, 1966). Pebble counts of fragments with long axes between 0.2 and 25 cm. indicate a predominance of dolerite (60—70%) the remainder being quartzite and schist. The fine fraction is made up mainly of mixed layer minerals (montmorillonite/illite and chlorite/vermiculite) and halloysite with some illite, gibbsite and fine-grained quartz. The contrast with the Rowallan till is striking (Table 2, *cf.* samples 1 and 5).

Severe weathering of glacial till, as indicated by the degree of clay mineral development (notably the kaolinite family) and the state of decomposition of individual dolerite clasts, is known to exceed 10 feet in exposures between Lake King William and Mossy Marsh (two miles west-northwest of Tarraleah). This till, which overlies deeply weathered bedrock three miles SE of Butler's Gorge, is unstratified, heterogeneous, and consolidated to cemented. Rock fragments between 0.2 and 25cm are of dolerite (60—75%), quartzite (mean 25%) and sedimentary rocks (mainly siltstone: 5—15%). The dolerite fragments are well rounded due to the effects of weathering, but the quartzite is angular to subangular. The matrix, which is tougher than all fragments other than those of quartzite, has weathered to a yellow-red colour (7.5 and 10 YR ranges). It is very rich in free iron oxide and consists of quartz and clay minerals, notably halloysite. Gibbsite is also present (Table 2, samples 7 and 8). The till has retained its macro-fissility and moderate to strong pebble orientation, although its upper surface has been degraded and in at least one case (three miles west-northwest of Tarraleah) congeliturbate with slightly weathered fragments has moved across it.

A similarly weathered till rests on weathered dolerite bedrock in a shallow exposure near the dam of Laughing Jack Lagoon. Granules and pebbles are mainly of dolerite (80%), siltstone and sandstone (10%), and quartzite (5—10%). X-ray diffraction of the fines reveals a strong quartz peak, some gibbsite, and abundant clay mineral, notably halloysite with kaolinite and a mixed layer mineral

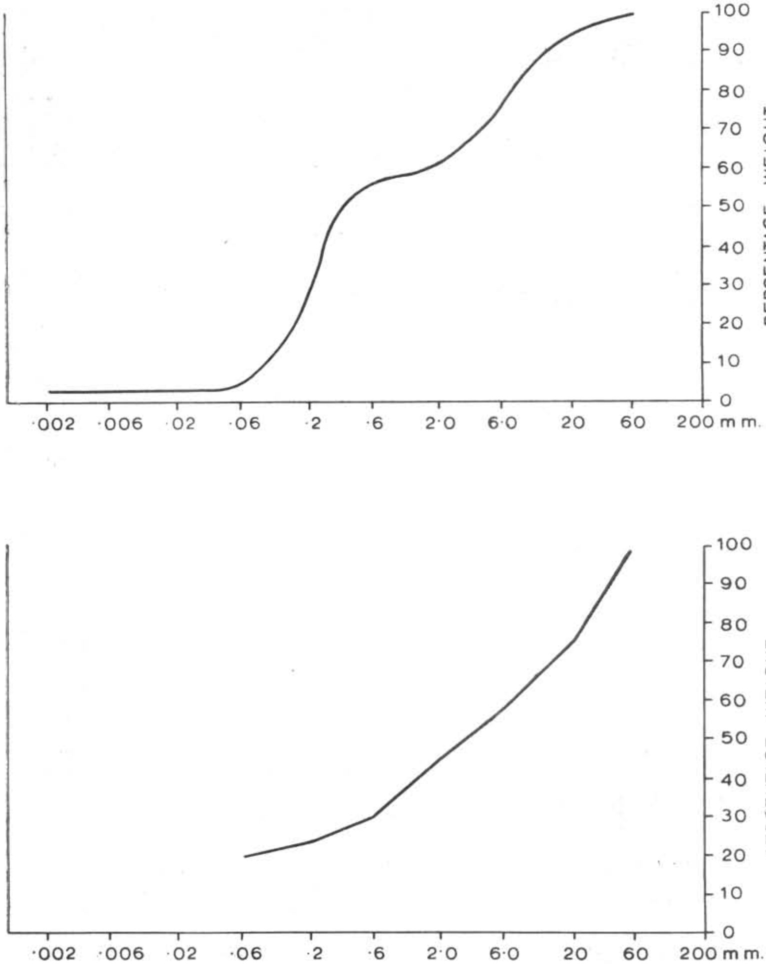

FIGURE 3.—Cumulative curves for (top) Lake St Clair lodgment till and (bottom) Rowallan lodgment till.

5 cm

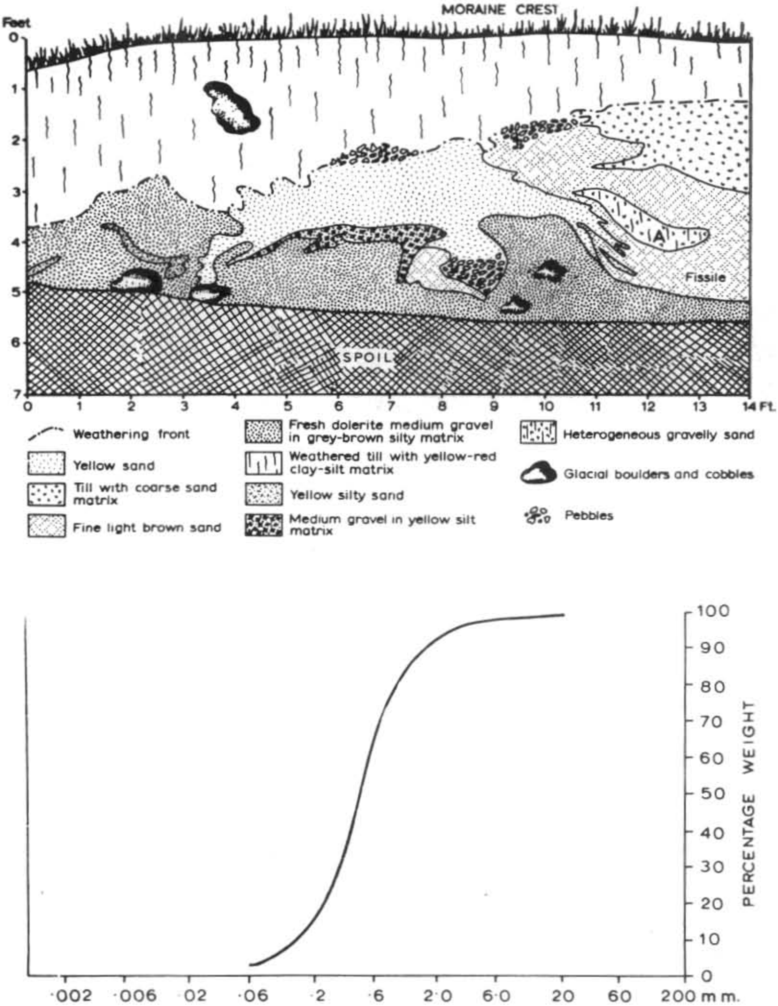

FIGURE 4.—(Top) Section in crest of retreatal end moraine, 400 yards SE of Cynthia Bay, Lake St Clair. (Bottom) Cumulative curve of gravelly sand at point "A" in section.

(? chlorite/vermiculite). The pebble orientation approximates the local slope (gradient approximately 12°), suggesting that the fabric of this till has been modified by mass movement.

In the Forth River valley about Lemonthyme Creek, unconsolidated till and outwash is underlain by 80 feet of hard, cemented tillite with a tensile strength rather greater than that of sandstone.

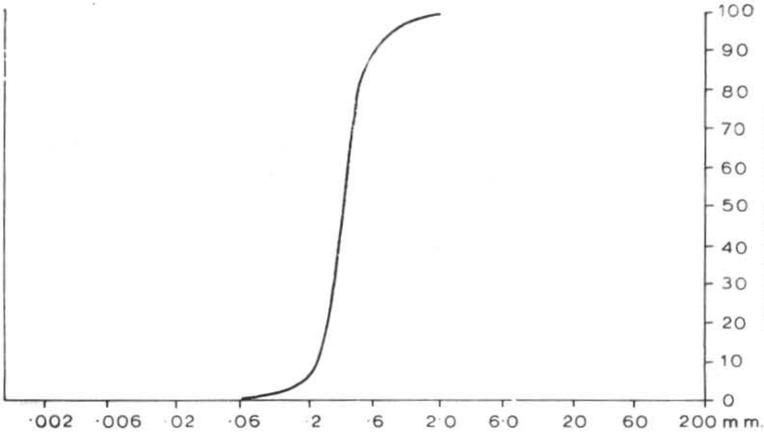

FIGURE 5.—Cumulative curve of sand from kame-moraine ridge near outlet of Lake St Clair.

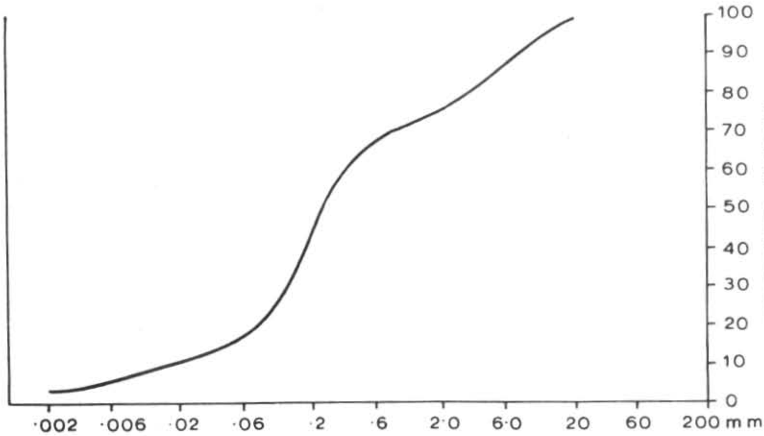

FIGURE 6.—Cumulative curve of washed layer in moraine from wall of canal at pumping station on SE shore of Lake St Clair.

It is grey to grey-blue in colour and essentially unweathered, except near its upper surface. Included fragments are of dolerite, Tertiary basalt, quartzite and schist. A full description is given in Paterson (1965). A similar tillite occurs at the surface in the upper Arm valley. Weathering has affected its upper surface almost to the limit of the shallow exposure ($2\frac{1}{2}$ feet). The decomposition of the included dolerite fragments, the toughness and weathering state of the matrix and the moderately good pebble orientation (suggesting in this case movement from somewhat south of east) closely compare with the weathered tills north and south of Butler's Gorge. The contrast in degree of weathering with the adjacent grey till is strong.

Tillite with rather more abundant basalt fragments outcrops in the lower Arm valley (Plate 8), its degraded surface being overlain by 10 feet of little-weathered loose gravel of probable glacifluvial origin. The tillite is hard, cemented and little affected by weathering even at shallow depth. The matrix was examined in thin section and was found to consist mainly of plagioclase and pyroxene. The abundant plagioclase fragments (up to 3mm in longest diameter) are fresh to slightly altered, and the pyroxene grains show marginal alteration in many cases. Quartzite is common, the fragments showing intergranular muscovite. Iron in the form of a brown or yellow weathering product is notable, especially within the many fragments of weathered mesostasis. The composition of fines from the weathered zone of this tillite is shown in Table 2.

Erratic boulders have been found well beyond the limits of glacial till. These include the large dolerite erratics on the surface of the Vale of Belvoir, near Lake Lea, rounded dolerite boulders weighing several tons beneath 20-40 feet of quartz-schist talus on the southwestern valley slopes 100 feet above the upper Collingwood River at 1500 feet a.s.l., and a variety of erratic pebbles and cobbles upon and within the soils of the Middlesex Plains about Daisy Dell. These erratics are slightly to severely weathered and may mark an early but brief maximal extension of the last regional glaciation. Alternatively, they may be the superglacial equivalent of the Lemonthyme basal tillite.

Glacifluvial Deposits

With the possible exception of parts of the drift at the Mersey-Fisher confluence, all the glacifluvial deposits of the region are fresh to only slightly weathered. Substantial accumulations occur only in the valleys of the west of the region, a thickness of 60 feet having been reported from the Franklin River valley (Gulline, *loc. cit.*). Elsewhere, exposures are limited to between 10 and 20 feet.

The deposits consist of unconsolidated, stratified silt, sand, gravel, pebbles and cobbles, with occasional boulders. Sorting is normal to very good (inter-quartile spread 3 to 1.5 Wentworth grades) in the sand and gravel grades. Current bedding is common. Some cobbly gravels forming the surface of outwash plains may be extremely poorly sorted, however, with the first and third quartiles spread over 5 Wentworth grades. Dolerite fragments, which predominate in all the gravel examined in the region, have moderate to high sphericity and roundness, but angularity increases sharply in the fine gravel and coarse sand grades. Quartz is usually predominant in the medium and fine sand, where rounding varies from moderate (quartz) to low (feldspars). Apart from local cementation, particularly within ferruginous nodular and vein-like concretions, the glacifluvial deposits are unconsolidated to loose, although they may be well compacted as at the northern end of Lake St Clair. They range in colour from yellow-grey (5 Y range) at depth to yellow-red (10 YR 5/6) and red-brown (5Y range) in shallow exposures. Some red-brown sand owes its colour to the presence of a thin layer of fines rich in free iron oxide which coats the sand grains (*e.g.* Derwent outwash plain, SE of Lake St Clair).

A borrow pit in the outwash plain below the Rowallan dam-site revealed the following succession:

Top—	*Thickness in feet*
Coarse, heterogeneous, poorly sorted cobbly gravel, weathered yellow in upper 1-2 feet	3
Fine gravel with pebbles, current bedded	2
Medium gravel, pebbly, coated with silt	3
Brown coarse to medium sand, current bedded	2
Silty-sandy fine gravel with pebbles	2
Finely bedded silt and fine sand	5
Base not Exposed	

Limited sections in glacifluvial sediments occur adjacent to low moraine ridges near the northern and southern shores of Lake St Clair. On the western bank of the Derwent River, immediately south of the weir at St Clair Lagoon, the following sequence was recorded:

Top—	*Thickness in feet*
Coarse, heterogeneous, poorly sorted sub-rounded to sub-angular bouldery to cobbly dolerite gravel, grey to grey-yellow	4½
Grey, moderately to poorly rounded sand and fine gravel with occasional large dolerite cobbles, rather poorly sorted at top, (inter-quartile spread 3.5 Wentworth grades), current bedded below	3
Water Level	

On the western bank of the Narcissus River, near its mouth, the following sequence was observed at low water stage:

Top—	*Thickness in inches*
Partly eroded modern peat marking land surface prior to raising of Lake level	2
Yellow sand with pebbles and roots	4
Coarse pebbly to cobbly gravel with sub-rounded fine to medium dolerite gravel layers, distinctly sandy in upper part	11
Coarse pebbly to cobbly sandy gravel with loose, very coarse dolerite gravel layers, well sorted: medium sand grade angular to sub-angular	12
Pebbly gravel with loose, coarse to medium dolerite gravel layers	6
Medium dolerite gravel with many pebbles	11
Fine dolerite gravel with few pebbles	9
Grey clay-silt lens, 3 inches long	2
Fine dolerite gravel with pebbles	4
Water Level	

On the Traveller-Clarence interfluve, three miles east-northeast of Derwent Bridge, the southern end of the large end moraine marking a major stillstand of the eastern lobe of the St Clair glacier is veneered with over six feet of well sorted to very well sorted yellow-red sand (first and third quartiles spread over 2.2 Wentworth grades) of low to moderate roundness, silt and thin clay layers. Current bedding indicates meltwater flow from the west (ice-proximal) side. The upper 1½ feet of the exposure is poorly sorted and contains many angular to sub-angular dolerite boulders and cobbles which appear to have been dropped from an ice front for they disturb the bedding in the underlying sand and silt.

Current bedding, truncation of beds, and local upstream apparent dips are characteristic of many of these glacifluvial deposits. Their frequently complex structure reflects a succession of depositional and erosional phases as the meltwaters, issuing sub-glacially from the terminal zone varied in course, discharge and load. The silt and fine sand, which are found at depths greater than eight feet in many exposures, show minor warping attributable to the weight of superincumbent ice and drift (Plate 9).

The presence of a coarse, poorly sorted, cobbly gravel on the surface of glacifluvial fills, is a general characteristic of the region. Some of this material has a sorting coefficient which is higher than that of some glacial till, although it is usually very poor in silt and clay and it lacks the distinctive pebble orientation of glacial till. These characteristics, and the sub-angular to sub-rounded form of the cobbles, indicating short transport, suggest that these surficial gravels originated as superglacial washed drift. They were laid down in the ice-contact portion of the outwash fill as the glacier thinned progressively. The moderate to low roundness values of the well sorted fine gravel and sand grades may also be attributable to very limited transport. This is to be expected in a region in which glacial outwash plains are very limited in extent, thickness, and number.

The sorted drift, including the surface layer of poorly sorted material, is intimately associated with the end moraines. In some localities (*e.g.* west bank of the Narcissus River), members of the glacifluvial suite can be traced from the small outwash plains into the bases of moraine ridges where they invariably assume an upstream dip (Plate 10). Such relationships are usually associated with the slow melting out of englacial debris in a proglacial environment where re-sorting of drift is very limited in the absence of large volumes of meltwater (*cf.* discussion of St Clair lodgment till page 26).

Glacilacustrine Deposits

Deposits laid down in ponded glacial meltwaters are known from limited exposures in valleys throughout the region. They occur in varying relationships to till both as massive deposits and as rhythmically graded beds (rhythmites).

The massive deposits rest upon the grey till, and beneath and locally upon the surficial till of loose texture. The deposits consist of unconsolidated, pliable clay-silt (silt greater than 75%), light grey in colour, with occasional sandy layers. They are composed mainly of quartz and mica, X-ray diffraction and electron microscopy revealing only a small proportion of clay mineral. Varying thicknesses of the grey clay-silt are found over a wide altitudinal range in minor undulations in the ground moraine, and underlying poorly drained, peat-covered plains (vegetation dominated by button grass—*Gymnoscheonus sphaerocephalus*) especially between end moraines and about hummocky moraines. These deposits are so widespread that only augered points with depths greater than six feet are shown on the Map. An excavation in a typical inter-morainal plain, half mile south of Cynthia Bay, revealed the following sequence:

Top—	*Thickness in inches*
Modern Peat	11
Root zone, including small angular dolerite and quartzite pebbles in grey, sandy silt matrix	11
Plastic grey clay-silt with sand and angular dolerite and quartzite pebbles	13
Homogeneous fine sand grading rapidly into plastic grey clay-silt, becoming more tenacious with depth	55

Base— Obstruction, probably glacial till stones.

In pedological terms, the material is a gley or humic gley indicative of poorly drained, chemically reducing conditions with only limited open water. The clay-silt may have accumulated in ill-drained undulations in the moraine surface rather in the manner of the so-called accretion-gleys of North America (Frye, Willman and Glass, 1960), although their unweathered condition, paucity of clay minerals and their inclusion in end moraines may favour a more rapid, proglacial process rather than the slow accumulation of partly weathered material envisaged for the American accretion-gleys. The combination, in one diffractogram of morainic material from near Cynthia Bay, of a strong quartz peak and a strong illite/montmorillonite peak in unoxidised material containing fresh dolerite granules suggests that the clay mineral in this case was not derived from *in situ* weathering but is the result of physical mixing (*cf.* Frye, Willman and Glass, *op. cit.*).

Rhythmites occur in the valleys of the Forth, Mersey, Arm and lower Fish Rivers and Warragarra Creek, and about the Traveller-Clarence interfluve.

A maximum thickness of 93 feet of rhythmites is interbedded with tillite at Lemonthyme Creek in the Forth River valley (Paterson 1965). They are consolidated but uncemented silt, in places appearing as graded units which vary considerably in thickness (0.5—10 cm). A thin section was prepared from an outcrop of these rhythmites, immediately north of the Lemonthyme Creek-Forth River confluence. The very abundant, rather randomly orientated muscovite is the most striking characteristic. Quartz was found to be fairly abundant, and the plagioclase to be in varying degrees of alteration. Pyroxene was occasionally recognisable within an amorphous iron-rich weathered groundmass. The silt is finely laminated but not obviously graded, and generally moderate-to fine-grained. The upper surface of the outcrop has been degraded.

Rhythmites with similar characteristics outcrop upslope of the lower Arm River tillite, where their degraded surface is overlain by fresh, washed drift and solifluction debris. In thin section, this fine-grained silt is laminated but not clearly graded. Quartz, altered plagioclase and pyroxene are predominant. Abundant plates of muscovite occur throughout, and lie generally sub-parallel to laminae.

Both of these glacilacustrine deposits are uniformly fine-grained and, in contrast to deposits to the south, show little evidence of graded bedding and contain no large erratic fragments. While their relationship to tillite, notably at Lemonthyme Creek, confirms their proglacial origin, it is evident that they were not laid down in juxtaposition to a rapidly wasting ice-front rich in englacial and superglacial debris. The uniformity of the grain size rather suggests rock flour, such as might be expected if deposition coincided with advancing or maximal phases of glaciation and limited liberation of sediment and meltwater.

One mile west of the Traveller-Clarence interfluve (three miles east-northeast of Derwent Bridge), a slightly weathered grey-yellow lodgment till is overlain by six feet of rhythmites, coarse and sandy at the base and containing many rafted erratics. These glacilacustrine beds are uncemented and stiffly plastic when newly exposed in moist condition. They harden rapidly on exposure (Plate 11) and crack in cuboid fashion on immersion but do not slake. All exposures seen are shallow and lie above the groundwater table, so that the rhythmites have been oxodized to a yellow or grey-yellow colour. Angular to sub-rounded cobbles are common in the upper part of the exposure where they disturb the underlying laminations. Cobbles and boulders are strewn over the surface. The silt appears to have been deposited in juxtaposition to an ice-front. At certain horizons, it constitutes a good series of graded beds, the yellow coarse laminae with abundant weathered material derived from the dolerite contrasting with the grey laminae of much finer material (? "winter" layer*) which is relatively fresh because of its higher content of fine-grained quartz. The upper laminations have been seriously disturbed by root action and an unknown thickness has been lost from the surface which is degradational. Three thin sections were prepared from three separate weathered outcrops of the rhythmites, 2½ 3 and 3¾ miles east-northeast of Derwent Bridge. All showed clear graded bedding. The coarse-grained laminae were found to consist mainly of plagioclase, pyroxene and quartz with occasional muscovite plates lying sub-parallel to the laminae. Small unaltered patches of pyroxene lie within large weathered patches of iron oxide. The plagioclase is often severely altered about the crystal margins. The fine-grained laminae consist of a rather cloudy amorphous iron-rich background with remnants of pyroxene, plagioclase and very occasional chlorite. Quartz is common but not very abundant. The fines were subjected to X-ray diffraction and were found to consist mainly of quartz and plagioclase with minor amounts of gibbsite and a mixed layer mineral (probably chlorite/montmorillonite/illite) and a trace of illite. This composition was confirmed by electron microscopy. Neither kaolinite nor halloysite were recognised. The shallow sample was well oxidized as indicated by the abundant free iron oxide present.

In the middle Arm River valley, the grey lodgment till is overlain by at least eight feet of grey to grey-yellow rhythmites. These are weakly consolidated and are composed almost entirely of fine silt

* If these units represent an annual sedimentation cycle (*i.e.* true varves), then the exposure represents approximately 300 years' accumulation. This would suggest, in turn, a prolonged period of stable ice-front.

(85%) and clay (15%), sand and granules being few and pebbles rare. On immersion, they break along the bedding planes. In thin section, the larger grains were found to be quartz and muscovite, the latter being abundant and lying sub-parallel to the laminations. The groundmass is of fine-grained quartz with slightly altered plagioclase and pyrixene and abundant fine spots of iron oxide. The deposit is finely laminated but not obviously graded, and fine-grained to very fine-grained. The sample was taken from that part of the exposure which is below the groundwater table for most of the year. This together with the higher quartz and muscovite content, accounts for their much fresher appearance in hand specimen than the Traveller-Clarence rhythmites. While texture and little-weathered condition compare more closely with the grey clay-silt than with the other rhythmites of the region, their composition, uniformly fine grain size† and finely laminated rather than graded character is typical of all the northern glacilacustrine deposits.

Deposition in quiet ponded-water conditions removed from any moraine-rich ice-fronts seems indicated. With sediments and melt-water derived from ice in the upper Arm River and the plateau surfaces about Mts Oakleigh and Pillinger, suitable depositional conditions may have been provided by an ice dam (Mersey glacier diffluent tongue) in the lower Arm valley, or by the presence of undulating moraine which has since been breached.

Laminated carbonaceous clay, silt and sand reach a thickness of 100 feet in a bore hole at Lemonthyme Creek. They rest on loose-textured gravelly till and are overlain by solifluction debris. They occupy a buried channel and appear to have been laid down close to the edge of the lower Forth glacier which ponded meltwaters in the Lemonthyme Creek valley. They are described fully by Paterson (1965) who ascribes them to the last regional glaciation.

Immediately downstream of the Lemonthyme area, in the limited exposure offered by a small creek bed, was found a well-cemented, finely-laminated grey mudstone which is tougher than all other Pleistocene rhythmites examined. It is extremely fine-grained, consisting mainly of quartz. Its relationship to other rhythmites in the Forth-Mersey area is unknown.

STRATIGRAPHY

By reason of contrasts in weathering, consolidation and texture, these glacigenic deposits constitute a lithological succession within which certain chronological divisions are evident. Recognition of the first of these divisions is due to Paterson (1965) who has proposed that the Lemonthyme tillite and interbedded rhythmites represent an earlier and distinct glacial stage from that represented by the gravelly Central Plateau till which rests upon it. The tillite exposures in the upper and lower Arm River valley are similar to the Lemonthyme tillite in content, texture and lithification, the latter characteristic clearly separating them from all other tills so far described in this region. In the absence of drilling and large-scale excavation, comparable deposits have not yet been recognised in the south. It may be that the substantial valley fills of the southwest of the region

† Granules, pebbles and cobbles are rare. One large pebble of sandstone was found in the rhythmites just above the water level of the Arm River. Its lower surface coincided with a bedding plane, the laminations below showing little sign of disturbance. The upper surface of the pebble was water-smoothed.

(notably in the valleys of the Alma-Collingwood and Canning Rivers) will prove to be composite both in character and in age as they have in the Forth and Mersey valleys.

The deeply weathered till deposits near the foot of Parangana Sugarloaf (Mersey-Fisher confluence) and in exposures between Lake King William and Tarraleah contrast so strikingly with adjacent surficial till that they are considered to be older (*cf.* Paterson, 1965). The upper surface of all these deposits is degradational, the southern exposures, while retaining a strong pebble orientation and macrofissility consistent with an origin due to lodgment, having lost most or all of their original surface form. While the widely separated weathered till deposits of Paragana and the King William East-Tarraleah area are all older than the Rowallan—St Clair till, it is not yet possible to demonstrate that they have chronostratigraphical equivalents. Nevertheless, it appears probable that at least some of these older till deposits represent the weathered zone of the basal tillite, as is the case in the Arm River valley (*cf.* samples 6 with samples 5, 7 and 8, Table 2). Others (*e.g.* east shore of Lake King William) may represent an early, more extensive phase of the last regional glaciation.

The remaining till of the region is fresh topographically and shows only superficial chemical weathering. The Rowallan till, resting on a pavement polished, striated and fluted by ice, has the texture, compaction and very consistent fabric of a typical *moraine de fond*, laid down by a thick, actively advancing ice-mass. Downstream it gives way to coarse, ice-contact stratified drift and a varied suite of equally unweathered glacifluvials, suggesting that it marks the last major extension of erosive glacial ice in the middle Mersey valley and adjacent Central Plateau. The deposition of similar till on the Mersey-Arm interfluve demands an ice thickness of at least 2000 feet over Walter's Marsh. In the south, the lodgment till on the southwest shores of Lake King William (laid down during the last major extension of the King William piedmont glacier) is comparable in its compaction and slightly weathered condition. The St. Clair till, although also a relatively unweathered lodgment till of the last major ice extension differs in that it was laid down by active but slowly wasting rather than by vigorously advancing ice, as indicated by its distinctive structures, more variable texture and compaction (and consequent variation in the weathering of the fines), and intimate relationship to glacifluvial outwash. In the absence of deep exposures, it is not known whether or not this retreatal lodgment till is underlain by the *moraine de fond* of the advancing ice.

The red-brown surficial till overlies the Rowallan and St. Clair lodgment till deposits in shallow exposures north and south of Lake St Clair, in the upper Hugel River valley, on the eastern slopes of the King William Range, the Arm-Mersey interfluve, and the upper Fish River valley. It is a common constituent in the upper parts of moraine ridges, and also occurs as a discontinuous cover on some glacifluvial deposits (notably in the proximal, ice-contact sections of small outwash plains). Locally, it may be represented by groups of large dolerite erratics with few fines, giving rise to some good examples of hummocky moraine, *e.g.* near Lake Rufus and west of Lake St Clair (Derbyshire, 1963, Figures 2 and 4). Its texture, distinctive morphology, moderate to weak pebble orientation, relative freshness of included fragments, and its situation above the Rowallan and St. Clair lodgment till favour the interpretation of this deposit as the superglacial and partly englacial till of the last regional ice cover, laid down during the deglacial hemicycle.

Upon and partly within the surficial till are found variable thicknesses of the massive grey clay-silt. The relationship of the clay-silt to the retreatal moraines is so clear (*e.g.* east of Derwent Bridge, in Pine Valley, and in the upper Cuvier valley), their constitution, colour and unweathered state so consistent, and their pollen content so abundant (N. Wace, personal communication), that they are ascribed to poorly-drained conditions perhaps with localised areas of shallow, ponded water which accompanied the retreat and dissolution of the last ice to occupy the valleys west of the Central Plateau.

Congeliturbate, bedded screes (*éboulis ordonnés*) and finer colluvium has encroached up the red-brown surficial till and the grey clay-silt. Depending on the locality, the congeliturbate may be any age from pleniglacial (contemporaneous solifluction of superglacial and released englacial debris, *cf.* Jennings and Ahmad, *loc. cit.*) to postglacial. The former case has been demonstrated in the Mersey valley (Paterson, 1966). Colluviation in postglacial times has been notable in some localities, the bedded screes of the Western Tiers and the Forth and Mersey River valleys having encroached upon congeliturbate of lateglacial to pleniglacial age. This may have occurred in middle postglacial time for a distinct phase of colluviation is known to have occurred near Lake Echo about 3000 yr. B.P. The occasional small protalus moraines of the higher discrete cirques and the small nivation hollows (Plate 6) may be correlative, in part at least, with this postglacial cool phase.

The application of a standard stratigraphical approach to Pleistocene glacial deposits encounters difficulties such as discontinuity and variability of beds and lack of distinctive organic remains which arise directly from the nature of the glaciation process (see Leighton, 1958). In western Tasmania, further handicaps are imposed by the inaccessibility, low frequency and shallowness of exposures outside the areas of dam construction. Accordingly, the lithostratigraphic subdivision of the glacial deposits here outlined must be regarded as preliminary.

The only good lithological evidence suggesting a distinct glaciation earlier than that which deposited the surficial drift has come from the borehole data of the Hydro-Electric Commision. On the dual basis of strong contrasts in weathering and degree of lithification, the subdivision of glacial deposits already proposed in the Forth and Mersey valleys by Paterson (1965, 1966) may be extended to include the till of the whole region, as follows:

Central Plateau till of loose texture	1– 45 ft.
Rowallan and St Clair lodgment till deposits	10–133 ft.
Tarraleah lodgment till	6 ft.
Parangana loose-textured till	50 ft.
Lemonthyme—	
Tillite and rhythmites	90 ft.
Basal tillite	60 ft.

The subdivision consists of two lodgment till deposits, one loose-textured till of superglacial and englacial origin, and a deeply-weathered till, loose-textured in the north but more consolidated in the south of the region. The Central Plateau and Rowallan—St Clair till deposits with their interbedded glacilacustrine and glacifluvial beds appear, on the grounds stated above, to be members of a single formation derived from the last regional ice cover. The Lemonthyme basal tillite and interbedded tillite and glacilacutsrine beds are regarded as members of one formation which may represent an earlier and distinct glacial stage. The status of the Parangana and Butler's Gorge—Tarraleah tills remains rather more problematical, however. In the absence of distinctive organic interstadial or interglacial deposits and of deep exposures in the south, it is not possible to say at that stage whether they constitute the weathered zone of the Lemonthyme tillite (and in part representing the superglacial and englacial till of the glacier which deposited it) or whether they owe their origin to an early but more extensive phase of the last regional glaciation*. The weathering characteristics and degradation of areas underlain by this till recall descriptions of, for example, pre-Weichselian drift in parts of western Europe (*e.g.* Woldstedt, 1954; Galon and Roszkowna, 1961), pre late-Wisconsinan drift in mid-western U.S.A. (Thornbury, 1964, page 220-226), and the Waimaunga drift of New Zealand (Gage, 1961).

All of the glacigenic deposits postdate the Tertiary basalts. A more precise indication of minimum age is possible only for the deposits of the last regional glaciation, and this only from a radiometric assay (26, 480± 800 yr. B.P.—see Gill, 1956) of relatively fresh deposits in the West Coast Range and a succession of colluvial deposits dated at between 30,400 and 2900 yr. B.P. on the eastern Central Plateau†. It is inferred that all deposits of this younger glaciation are less than 30,000 radiocarbon years old and older than the last glaciers to occupy the high discrete cirques to the west which persisted until *c.* 8720 yr. B.P. (Peterson, 1966). This glaciation, therefore, falls into the same time span as the late Weichselian glaciation of Europe and the Woodfordian phase of the Wisconsinan glaciation of the mid-western United States. The Lemonthyme tillite appears older in both fresh (lithified) and weathered exposures. Whether it is separated from the younger glacial deposits by an interglacial or merely an interstadial is not yet known.

Relationships between the major lithostratigraphic units and the regimes under which they accumulated are summarised in Table 3. The available evidence is such that chronostratigraphic equivalence of the proposed Rowallan and St Clair formations may be regarded as strongly presumptive if not absolute.

* There is some morphological evidence, in the form of distinct but somewhat degraded end moraines southwest of the Navarre River, that such an early more extensive phase occurred south of Lake St. Clair. Certainly, the outermost of the fresh morainal forms in this area (large end moraines indicative of a stable ice-front with a west lobe approximately along the line of the middle Navarre River and an east lobe on the Traveller-Clarence interfluve) are well within the drift-covered zone.

† A discussion of these dated deposits is in course of preparation.

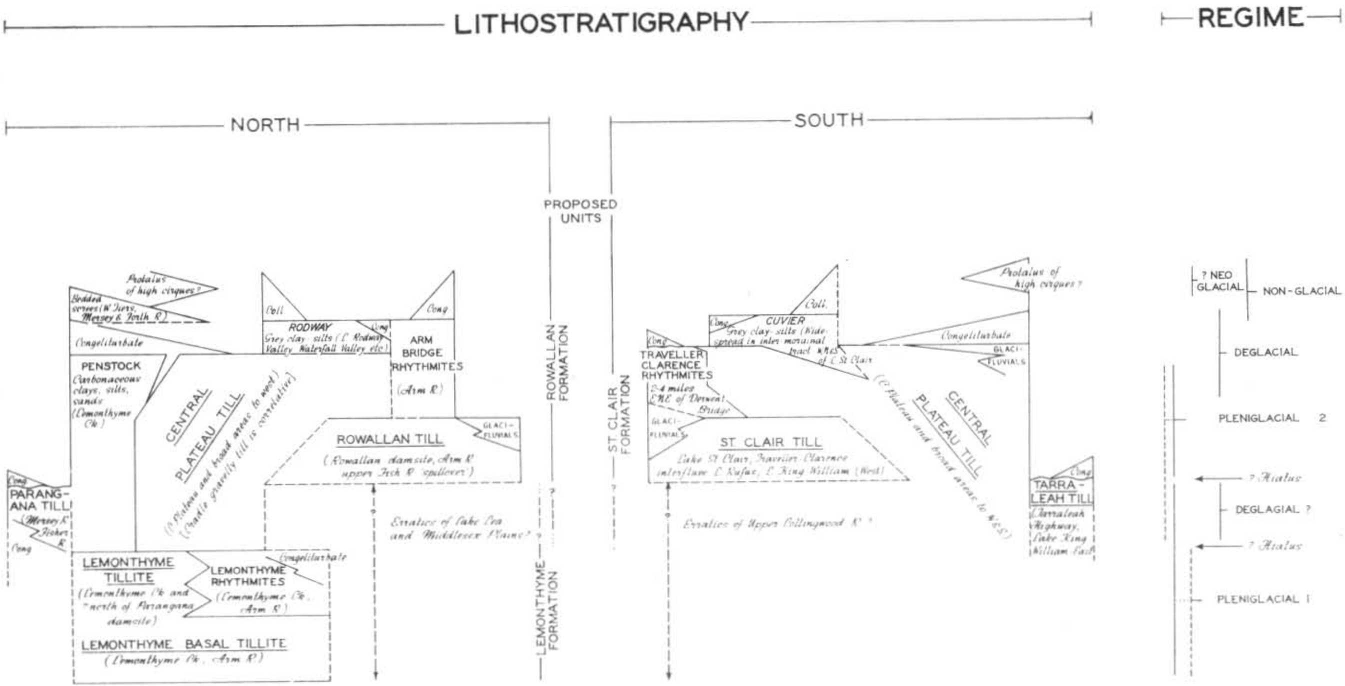

TABLE 3.—Lithostratigraphical relationships of Pleistocene glacial deposits of NW-Central Tasmania (schematic). Uncertain interfacial relationships are shown by broken lines. Wavy lines indicate degraded surfaces.

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Explanation of Plates

PLATE 1.

Shallow, sharply-defined cirque inset into slopes of valley-head cirque in lee of summit of Mt. Hugel. View N from Mt. Rufus summit.

PLATE 2.

Southernmost cirque of the King William I range, showing large outermost lateral moraine. View to N.

PLATE 3.

The ice-moulded southern wall of the Lake Rufus trough. Severe glacial over-deepening of this valley has left a small "half-dome" on the rim of the trough (centre). View SE.

PLATE 4.

Glacially-smoothed and striated surface of Precambrian quartzite beneath loose, gravelly till. One mile N of Dove Lake. The rod indicates magnetic N (right).

PLATE 5.

Chaotic ablation moraine with very large boulders, one half mile E of Lake George.

PLATE 6.

Cambering and large-scale collapse of masses of columnar dolerite adjacent to glacially-oversteepened headwall of Lake George trough (left), King William I range. The pond, which is c. 25 yards long, lies in a small nivation hollow which postdates the collapse.

PLATE 7.

Deeply weathered glacial deposit (Parangana 2/1) at confluence of Mersey and Fisher rivers. *Cf.* Table 1, sample 5.

PLATE 8.

Outcrop of lower Arm River tillite, near confluence of Arm and Mersey rivers. View to SW. Photo by J. A. Peterson.

PLATE 9.

Finely-bedded silt and very fine sand, somewhat contorted due to overlying drift and glacial ice. Silt and sand underlie one foot of current-bedded coarse sand and fine gravel and a five foot thick surface layer of very coarse, loosely-packed gravel in a silty sand matrix. Borrow-pit in outwash plain, one half mile downstream of Rowallan dam-site, Mersey River. December 11, 1965.

PLATE 10.

Northward (upglacier) dipping glacifluvial sand and gravel beneath crest of moraine ridge cut by Narcissus River, about one half mile N of northern shore of Lake St Clair. View S (downstream).

PLATE 11.

Rhythmites from outcrops 3 and 2½ miles ENE of Derwent Bridge. Both samples are five inches long.

5 cm

PLATE I.

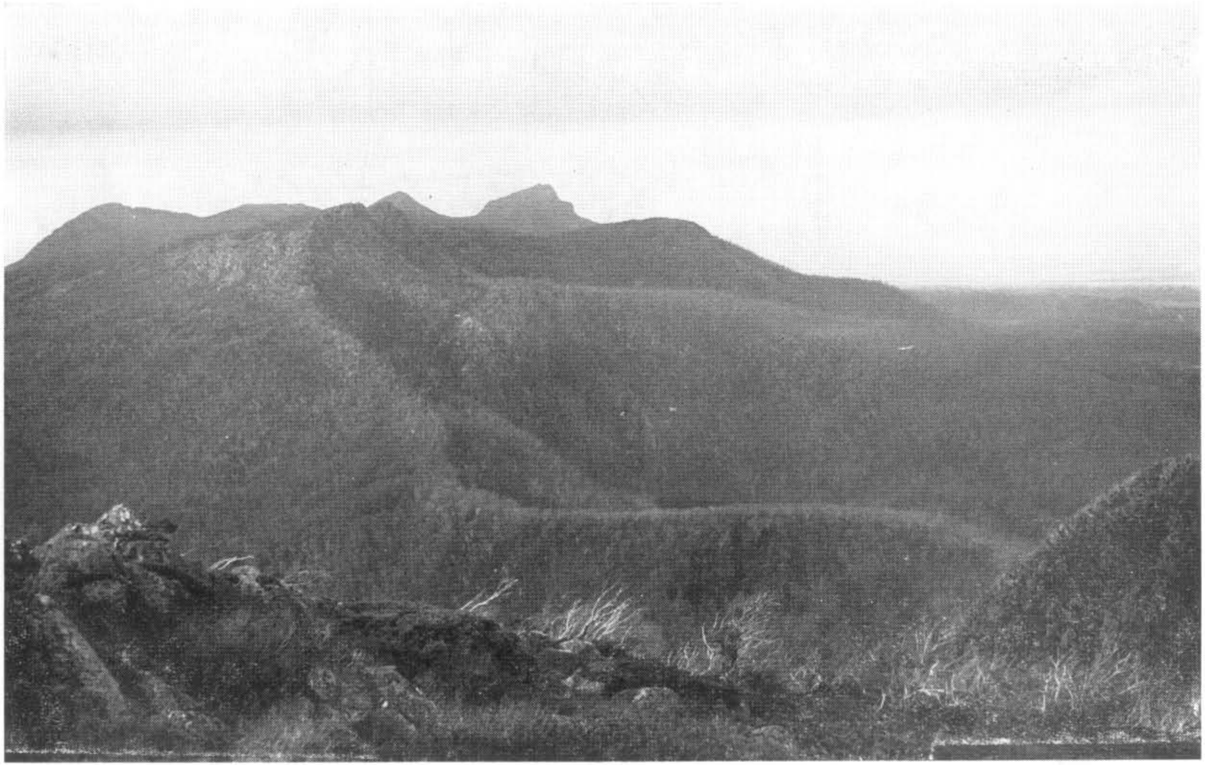

PLATE 2.

PLATE 3.

PLATE 4.

5 cm

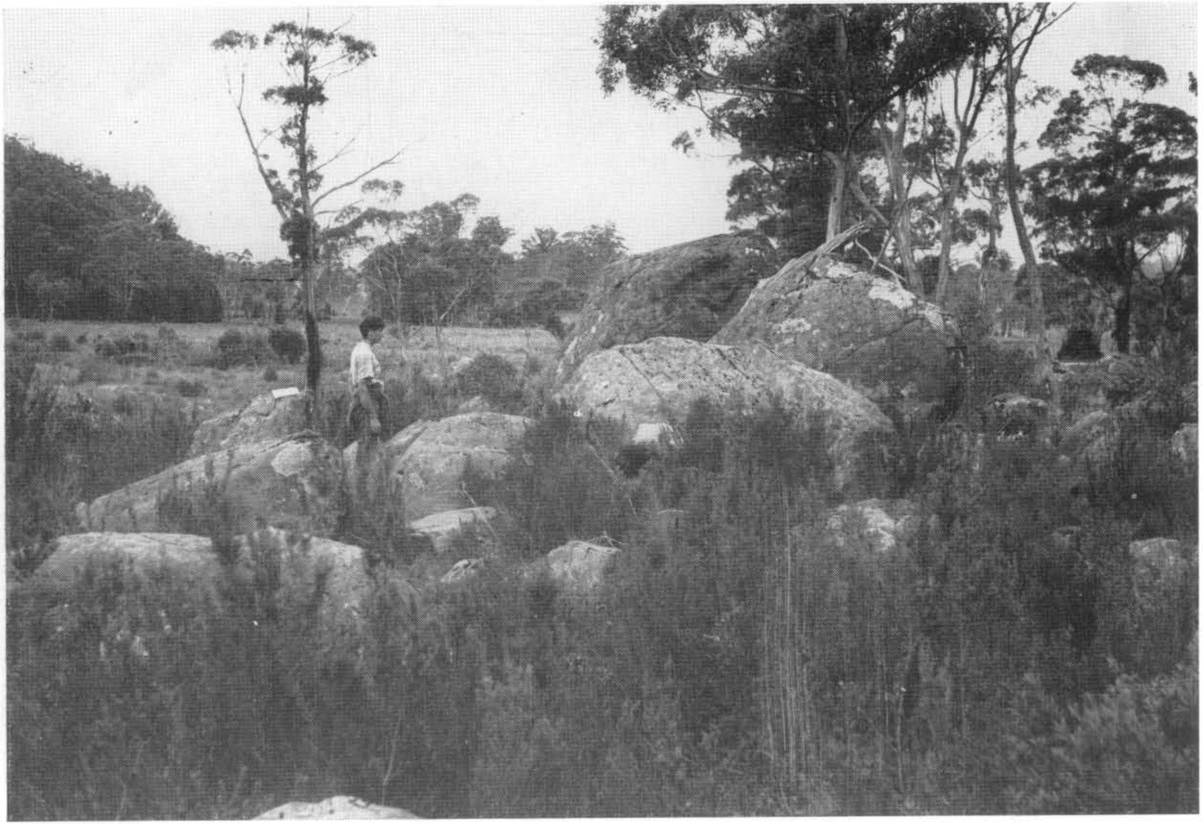

PLATE 5.

5 cm

PLATE 6.

5 cm

PLATE 7.

PLATE 8.

5 cm

PLATE 9.

5 cm

PLATE 10.

5 cm

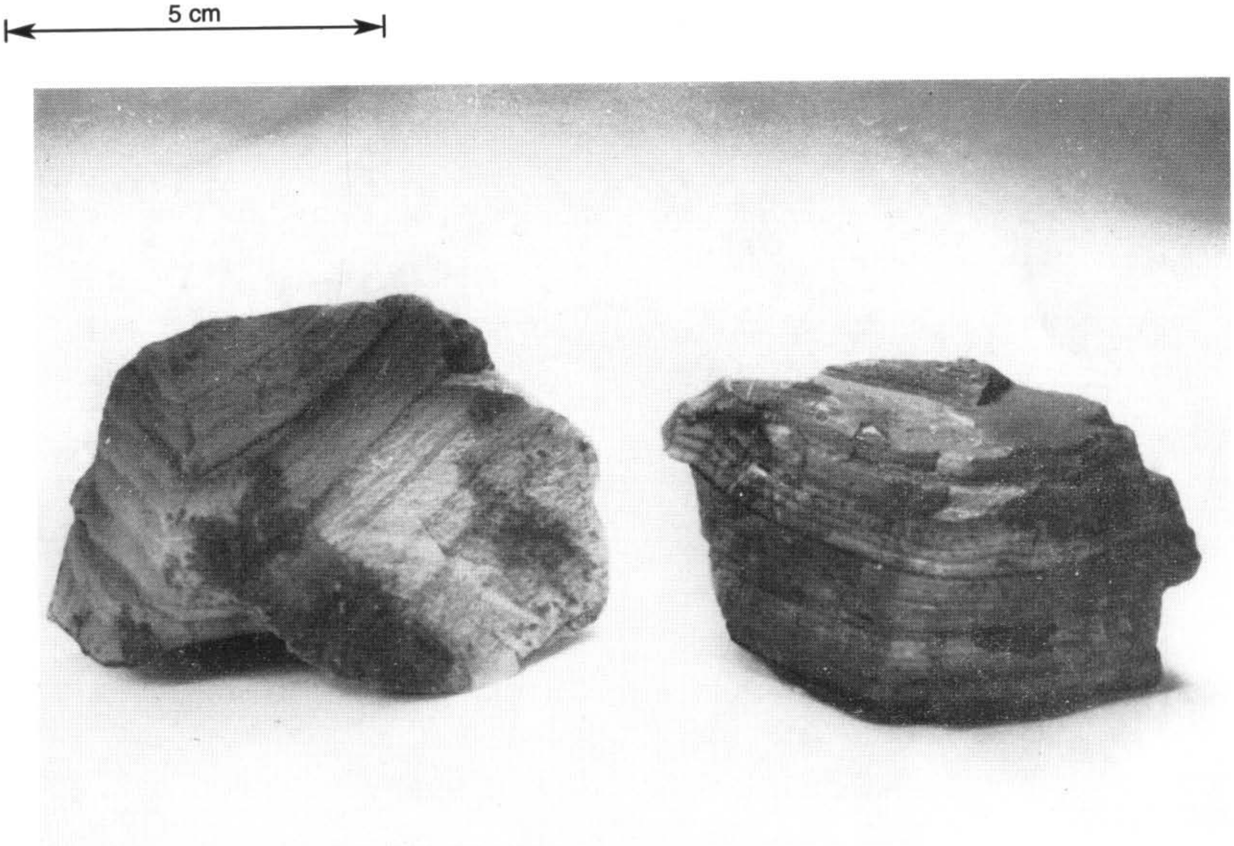

PLATE 11.


GLACIAL MAP of NORTHWEST – CENTRAL TASMANIA
by EDWARD DERBYSHIRE
Miles
5 cm
Compiled on the basis of field mapping, aerial photography and the literature to March 1966 by the author in the Department of Geography, Monash University, Clayton, Victoria, Australia
RELIABILITY DIAGRAM
First Order:
Detailed field study of sites and exposures
Detailed field study of landforms, including echo-sounding of lakes
Second Order:
Field study of landforms and surficial deposits, including reconnaissance surveys
Third Order:
Aerial photographic interpretation
LOCATION AND RELIEF
BLACK BLUFF 4393'
Lake Leo
River Forth
River Mersey
River Dove
River Fury
Campbell
Harrisons River
River Fisher
River Canning
South Eldon River
Franklin
Derwent River
Nive River
Gordon River
Denison River
LEGEND
ICE FLOW FEATURES
Lineated drift
Drumlins
Striae
Stone orientations (till fabrics)
ICE EROSION FEATURES
Cirques
Overridden cirques
Nivation cirques
Overridden trough walls and plateau edges
Glacially abraded valley steps
Rock basins
Glacial diffluence cols
Ice-eroded surfaces, direction of movement known
Ice-eroded surfaces, direction of movement uncertain
GLACIFLUVIAL FEATURES
Outwash deposits
GLACILACUSTRINE FEATURES
Lake deposits – massive
Lake deposits – rhythmically bedded
ICE DEPOSITIONAL FEATURES
Moraine ridges
Hummocky moraine
Ground moraine – undifferentiated
Tillite
Erratics beyond the limit of continuous drift (Probable movement indicated by line)
LOCAL LIMITS OF ICE ACTION
Drawn by Gary R.R. Swinton, 1966.