Pleistocene Glaciation in Tasmania

By

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PART I—TASMANIA: THE BACKGROUND

1. *Geographical*

Tasmania is one of the three marginal areas of the Southern Hemisphere which was affected by glaciation during the maximum phases of the Pleistocene Ice Age and which is now uncovered for study. No permanent snow fields now exist anywhere in Australia, but the southern extension now known as Tasmania was heavily glaciated at no distant date, while less extensive glaciation occurred about Mt. Kosciusko (7358 ft.) on the south-east of the Australian mainland.

Tasmania lies between 40-30° and 43-30° south latitude. It is an island by reason of the flooding of the low-lying connexion with Australia, now Bass Strait (maximum depth of 55 fathoms, but an isthmus would be created by rise in strand line of 180 ft.). It has an area of 26,000 square miles, somewhat bigger than Scotland and smaller than Ireland.

As an island, Tasmania escapes the continental conditions of mid-America, but it stands in the full force of the Westerly drift—the 'Roaring Forties'.

Snow at sea-level is rare. It is frequent in winter months at altitudes over 600 ft. and about one-fifth of the island, lying over 3500 ft. is covered with snow for about three months in an average year. Snow may fall on the mountains at any time, and winter drifts usually persist in a few spots till mid-summer. The present-day average temperature is remarkably equable—about 65° F. for summer and 50° F. for winter.

Tasmania is a region of violent contrasts. The higher mountain ranges towards the west often receive over 150 inches of rain a year. This is an area of temperate rain forest with a vegetable growth which defies cultivation and swallows up once prosperous mining towns in a generation. In the sheltered valleys of the centre and east, the rainfall drops to as little as 15 inches a year and arid conditions resembling those of the Australian mainland exist.

2. *Topographical*

Tasmania is a country of high relief, although not high altitude. Its highest mountain—Legge Tor, on Ben Lomond is only 5160 ft. above sea-level, but there are very few square miles of flat country anywhere. The island is really a highly dissected peneplain, the elevation of which has occurred in mutually separated blocks and in three or four time-phases.

All the western third—practically from the west coast to 147° east longitude—is in the rain-forest belt. This is mostly a sea of forest, equalling in impenetrability any tropical jungle, and largely of vegetation indigenous to the island. Out of this protrude serrated peaks of pink quartzite. At an elevation of 1500 ft. the forest gives place to a sub-alpine flora, in which beautiful flowering shrubs and native pines predominate. The main valleys at their lower levels are wide, glacial swamps covered by a peculiar sedge 'Button Grass' *(Gymnostachea spharrocephalus)*. The sides of the mountains are seamed with precipitous gorges and their peaks are ringed with mountain tarns of exquisite charm.

Eastward of this still little-known and practically unmapped region rises the rampart of the Central Plateau—a mass of dolerite, weathering to a red-brown colour, some 15,000 square miles in area resting on the older quartzites exposed to the west. The western edge of the plateau is cut by still deeper and wider gorges which enclose near their heads the finest of Tasmania's glacial lakes (Lake St. Clair is ten miles long and over 700 ft. deep). Isolated residuals, sometimes cirque-girt, mark the original extremity of the uplifted area and merge with the somewhat lower pink quartzite peaks of the extreme west. Green forest flows like a sea round them all. Further east again, the deep erosion channels disappear and the plateau surface becomes a stretch of windswept, ice-scraped upland dotted with innumerable pine-girt lakelets to the west, and long, narrow belts of summer pasture to the east. Near the centre are some large lakes, the most impressive being the Great Lake (60 square miles) occupying shallow rock basins. The average altitude of the plateau is 3300 ft., with the southern third about 1000 ft. lower, and with long ridges, particularly at the northern edge, rising to 4500 ft. Then, to the north and east, the plateau drops, by precipitous steps, to broad, mature river valleys of great fertility.

A smaller, but roughly similar plateau occupies the north-eastern sixth of the island. South-west of the Central Plateau are a large number of small plateaux, separated from the main uplifted area by broad still-stand areas largely modified by subsequent erosion, and stretching to the south coast. The south-eastern sixth of the island consists of a lower plateau averaging 1500 ft. in altitude and now dissected into a confusing jumble of rocky bush-covered hills and narrow valleys, sometimes stony gorges, sometimes fertile farm lands.

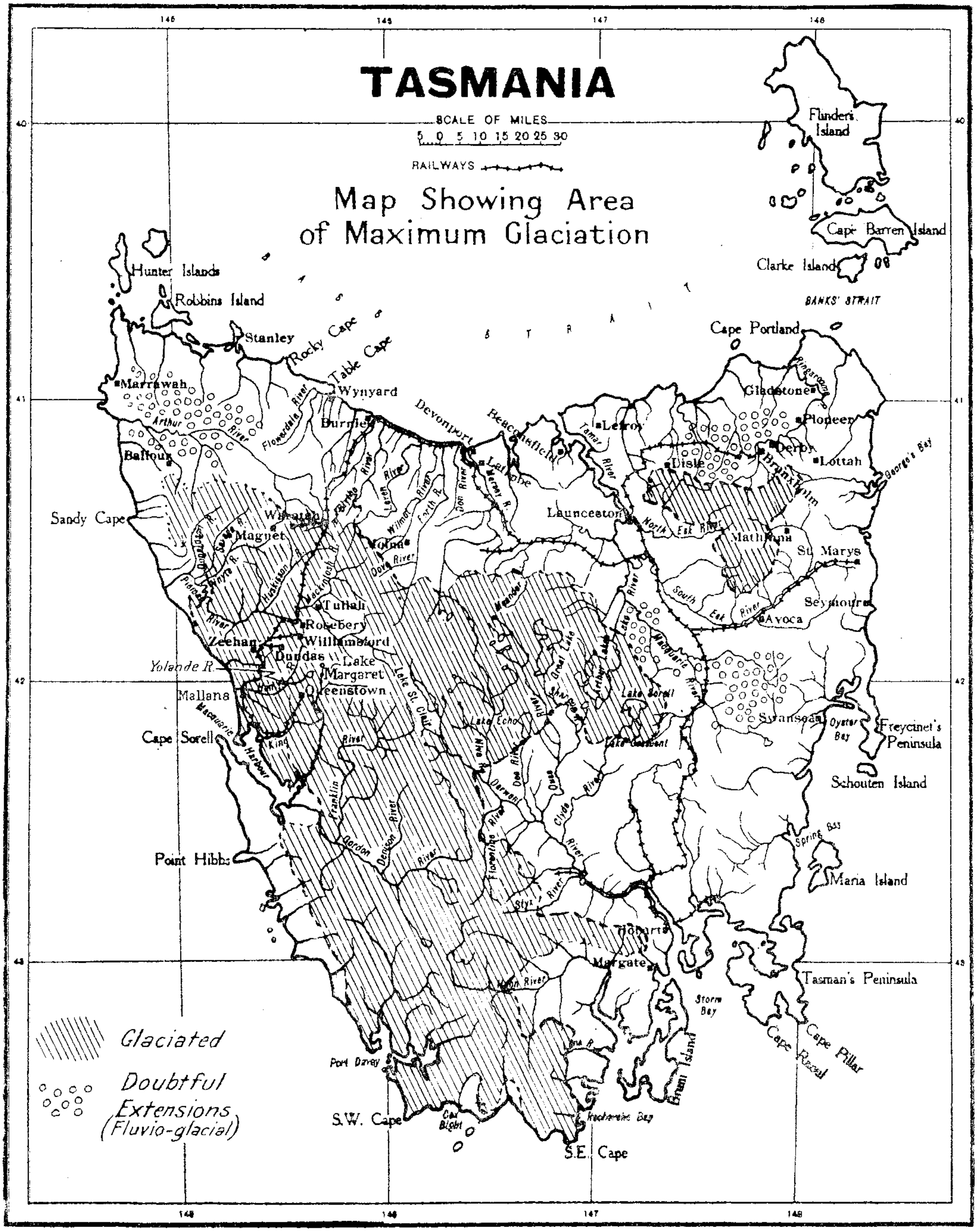
There has been much loss of territory by comparatively recent sinking. The east and west coasts are marked by jagged fault lines, and towards the south are often fringed by high cliffs. The south coast is a maze of deep indentations—the drowned heads of former valleys. The north coast is made by the flooding of Bass Strait and the drowning of the older waterways.

All the coast lands, except to the south-west and the lower reaches of the main rivers, are extremely fertile, carrying an agricultural population well above the average for Tasmania, and the source of much of Australia's supply of apples, hops, small berry fruits, oats and potatoes, butter and mutton. In general, most of the lower, long, flat coast lands and valleys closely resemble the richest parts of England, but most of the island is wider and more angular than the highlands of Scotland, plus a mantle of cold, wet jungle.

In addition to other advantages for the student, we may add that of accessibility. Hobart, the capital of the State, can be reached from Melbourne in three hours by daily air service and in twenty-four hours by ferry steamer and train. Queenstown, the site of the Mt. Lyell copper mine, is a prosperous centre right in the midst of the most heavily glaciated region and is only 100 miles by first-class road from Hobart, and Strahan, its port, on the west coast is only twenty-five miles further on. Tracks open up most of the best mountain resorts.

3. Geological

It is practically impossible to pass in a straight line for a mile anywhere in Tasmania without crossing a change of rock, and almost every geological epoch is represented to an extent that there can be few regions of similar area which can present so much of interest. This, however, has little bearing on glaciology.


TASMANIA
SCALE OF MILES
5 0 5 10 15 20 25 30
RAILWAYS
Map Showing Area
of Maximum Glaciation
Glaciated
Doubtful
Extensions
(Fluvio-glacial)
Hunter Islands
Robbins Island
Stanley
Rocky Cape
Table Cape
Wynyard
Burnie
Devonport
Beaconsfield
Latrobe
Launceston
Marrawah
Balfour
Sandy Cape
Waratah
Magnet
Tullah
Rosebery
Williamsford
Zeehan
Dundas
Lake Margaret
Queenstown
Mallana
Yolande R.
Cape Sorell
Macquarie Harbour
Point Hibbs
Port Davey
S.W. Cape
S.E. Cape
Hobart
Margate
Storm Bay
Bruni Island
Cape Raoul
Cape Pillar
Tasman's Peninsula
Maria Island
Schouten Island
Freycinet's Peninsula
Swansea
Avoca
Seymour
St Marys
Mathinna
Lottah
Derby
Pioneer
Gladstone
Branxholm
Lilydale
Lefroy
Cape Portland
Banks' Strait
Clarke Island
Cape Barren Island
Flinders Island
Lake Sorell
Great Lake
Lake Echo
Lake St. Clair
Franklin
Gordon
Denison River
Derwent
Huon River
Ouse
Clyde
Styx
North Esk River
South Esk River
Macquarie River
Tamar River
Mersey R.
Forth R.
Arthur River
Pieman
King

To avoid possible confusion in a reading of geological literature, it may be mentioned that Tasmanian mining fields are in the western and north-eastern areas, mostly in close association with glacial features, but this is quite a fortuitous coincidence arising from two separate factors.

The basal rocks are in part pre-Cambrian schists, followed by more widespread suites of Lower Palaeozoic strata of all types, highly crystallized by severe orogenic movements, accompanied by intrusions of granite and other plutonic rocks during late Silurian to early Carboniferous times. A major chain of folded mountains then formed was eroded to a peneplain, on which was deposited marine sediments of later Permian age and freshwater sandstones with coal measures extending into Mid-Triassic times. Then occurred the intrusion of sills of dolerite over most of Tasmania. These are often 2000 ft. thick and impart a distinctive character to all Tasmanian landscapes.

Another peneplaination was complete by Miocene times, and this was broken by a long-continued series of vertical uplifts. In the parts earlier affected erosion has exposed the Lower Palaeozoic rocks.

Long, narrow stretches of country were unaffected, and in these is to be found a suite of Pliocene-Pleistocene fluviatile deposits interstratified with extensive flows of basalt lavas which cover much of the country. The history of the Late Tertiary and Pleistocene periods has been unravelled from the data supplied by these deposits and basalts in relation to the topographic features and the superimposed glaciations.

4. Glaciology

Tasmania shows, to-day, a topography which in the south-western sixth of the island and throughout the western third over an altitude of about 2300 ft. has been in the main moulded by ice action. In the more favoured localities, three distinct ice invasions are clearly visible and the middle one of these can be divided into two phases. The southern, eastern and northern coast lines show very distinct evidence of three periods of higher sea-level and four of lower sea-level during the Pleistocene period.

The existence of Pleistocene glaciation has been recognized since 1849, and since the account published by R. M. Johnston in his Geology of Tasmania (1888) many descriptions have appeared. Most of the glaciological literature is to be found in the Papers and Proceedings of the Royal Society of Tasmania, with frequent incidental references in the Bulletins of the Geological Survey of Tasmania and the reports of the Glacial Committee in the Proceedings of the Australasian (now Australia and New Zealand) Association for the Advancement of Science.

Part II—Glacial Features and Associated Events

The absence of marine (and, for long intervals, even terrestrial) sediments due to the fact that, from the time of the dolerite intrusions (Jurassic or Cretaceous) to Pliocene times, Tasmania was a land surface, throws us back on erosion features as the only guide to chronology.(1) It appears clear that the mountain, plateau, and valley system was much as we now see it when the Pleistocene glacial period commenced. Prior to this, uplifts had occurred to give the main and more highly elevated features, but the movements did not conclude until well into the Pleistocene period.

(1) Marine transgression in southern Victoria in latest Oligocene-early Miocene times, extended to the northern coast of Tasmania in one area at least and gave us marine sandstones at Wynyard. These are rich in shell fossils, and have been correlated with the Janjukian-Miocene beds of Victoria.

Three subsequent events have proved to be of the highest importance in correlation of the glacial features with river terraces, &c., in unglaciated areas. These are—

(1) The deposition of distinct and widespread terrestrial series of sediments in the valleys formed as the result of the Mid-Miocene differential plateau uplifts.
(2) The covering of these deposits in places by flows of basaltic lavas which followed in the main the then existing valleys.
(3) Disruption of the basalt flows by continuance of the uplifts and the consequent erosion of new valleys and isolation of residual hills of river gravels protected by caps of resistant basalt.

The whole of this series of rocks and events has been termed by the present writer the *Launceston Stage*. Its importance lies in the fact that a second suite of gravels and basalts exists which is referable to a low-water phase during the Ice Age, and between the two occurred the first glacial phase. The glacial chronology has been worked out by a correlation of glacial features with two basaltic volcanic phases.

The Launceston Stage is distinctive—limestones, sandstones, and clays. Often very hard rocks are found beneath more recent river deposits in a number of places, both in the north and in the south of the island. The division of the Launceston Stage into two sub-stages is based on the occurrence, near Hobart, of two groups of beds referred to the Launceston Stage. The lowest beds which the present writer terms the Geilston Sub-stage contains a rich *Nothofagus* flora. Above this occur beds with a rich *Eucalyptus* flora, to which the name *Sandy Bay Sub-stage* has been assigned. Both of these occur near Hobart. The two may be relatively continuous. The small masses of these sediments preserved are almost always protected by overlying basalt, and show evidence of deposition at river valley level. There has been much elevation of the land since these Launceston Stage beds were deposited, but it is clear that at the time of their deposition sea-level was lower than it is to-day, because in some localties (for example, Penna, on the Tamar River) they extend below present sea-level, and yet they are clearly terrestrial deposits without a trace of marine organisms.

The volcanic phase which followed immediately cannot be dissociated from the uplifting movements. The more usual products were long, shallow lava streams which flowed down the existing valleys. Towards the north-west, some of these formed wide sheets of igenous rock. Near Waratah (Mt. Bischoff), lava flows overlying leaf beds of this stage stand at 700 ft. above sea-level. At the Great Lake basalt-filled valleys with some sub-basaltic river gravels still exist at an elevation of 3400 ft. It is not possible as yet to correlate these higher plateau basalts with the uplifts, but the present writer considers that, at least in the higher localities, the volcanic phase followed the commencement of the uplifts. Elsewhere, these older or higher basalts, which may be termed the Cremorne basalts (a name adopted by the present writer to distinguish the occurrence round Hobart) have been clearly broken by subsequent elevation and a 350-450 ft. uplift since the volcanic phase is in evidence almost everywhere. After the uplift, the older rivers were rejuvenated and eroded valleys in their previous deposits, cutting out the soft rock and leaving lines of hills or ridges where the basalt gave protection.

Towards the north-west (Waratah) area, the surface of the basalt is glaciated. The edge of the 2500 ft. plateau on which it lies is deeply eroded by river systems which show no sign of glaciation in their precipitous headwater sections, but contain glacial deposits at their lower levels. From this may be deduced that, since the glaciation of this area, river rejuvenation has occurred. Such an uplift—350 ft. appears to be the average of actual movement—is noticeable throughout Tasmania. It breaks across sedimentary rocks of the Launceston Stage at Evandale, has produced deep gorges on the north-west and east coasts, and is traceable through southern Tasmania. The famous Cataract Gorge in the City of Launceston is a result.

Professor David assigned the origin of many features on the west coast to a post-glacial isostatic recovery. Continuing observations from glaciated to non-glaciated areas, the present writer has traced the same elevation throughout Tasmania with little differentation assignable to post-glacial recovery. The glaciated areas at the maximum did not include one-third of the total area of the island. For this reason, some other cause must be sought. However, just here the uplift experienced by the whole of Tasmania is important as a correlating factor.

Tasmania has lost very considerable areas of land round all its coast-line by submergence. All the data at present available points to a date for this submergence roughly contemporaneous with this uplift just mentioned. This, again, is an important fact. The formation of Bass Strait cannot, in the writer's opinion, be assigned entirely to post-glacial flooding, because terraces attributable to high-water phases are found round its shores exactly as round the shores of other coasts. Post-glacial flooding obviously had a great effect on the location of the sea-shore and, perhaps, created a strait, but it is not sufficient to explain the formation of the lowlands in such sharp contrast with the neighbouring coastal peneplain which stands 350-450 ft. above sea-level right to the coast. Similar features are found down the east coast and round the south coast, modified in places because the uplift affected wide mature river valleys separated by hilly divides.

Malanna Glaciation

The first glacial phase occurred after the effusion of the older basalts. The present writer has termed it the Malanna glaciation after the location on the west coast where it was first identified as a separate phase by Loftus Hills (1914) and Sir Edgeworth David (1924). This glaciation was more extensive than the succeeding ones, although its remains are not so impressive as those left by the Yolande phase.

The Malanna glaciation is deducible from traces of moraines at a lower level than those of the second or Yolande glaciation and from definitely glacial valleys with rings of Yolande moraines extending round their upper reaches. It is difficult in many places to distinguish from the later glacial phase as the Yolande glaciers occupied and remodelled the cirques and valleys of the older glaciation. Although, in some instances, the courses of the two sets of glaciers were equally extensive, in most valleys the Malanna glaciers were much more extensive and sufficient evidence exists to fix the average extension of the Yolande glaciers down the Malanna glacial valleys.

The most useful key to the separation of the two phases is river erosion due to rejuvenation following the most recent uplift.

In general terms, ice reached the sea during Malannan times over most of south-western Tasmania—from Arthur Heads round to Recherche Bay. This ice came from the highlands to the eastward. Moraines and evidence of glacial erosion abound at sea-level in many places, but inland, the river valleys are for long stretches typical waterworn gorges. Higher again glacial features recur. Frequently low inter-valley divides are covered with morainal deposits and the valleys themselves, where ice flows would be expected, show no sign of glaciation. These water-cut gorges between the glacial features follow a defined line and occur 350-1200 ft. above sea-level. The evidence makes it clear that a rejuvenation by an uplift of about 350-450 ft. occurred subsequently to the Malanna glaciation. The eroded surfaces and deposits of the later Yolande glaciation are never cut in this way, and the tracks of these glaciers can be traced from cirque head to terminal moraine. This bare statement hardly conveys the full picture. The features resulting from water erosion are so clearly marked, consistent, and varied that there can be no escape from the conclusion that moraines now found at and near the west coast are the products of a glaciation earlier than the final development of the present topography.

In some localities near the edge of the higher plateaux, the Malanna glaciers filled valleys with ice 950 ft. thick, whose floor extended to 800 ft. above sea-level, while the Yolande glaciers have left a completely separate series of features on the mountain tops and did not descend below 2200 ft. The 'remains' of the Yolande glaciation are as clear and fresh as the day when the ice melted and are usually relatively free from vegetation. The Malanna glaciation is tattered with river erosion and can only be traced in scattered fragments. Very often the more impressive glaciated valleys are covered with deep soil supporting dense rain forest. For this reason, it is not possible always to see the topographical features, and their glacial characteristics can only be distinguished when a wide panorama is viewed from a mountain peak. This resulted in a long delay in observing this earlier glaciation—particularly when the neighbouring cirques and lakes of the Yolande glaciation were so distinct.

The most impressive feature of the Malanna glaciation is Port Davey, a glacial fiord, the only one in the Australian region—not in the same category as the fiords of Norway or New Zealand, but, nevertheless, a true example, with white cliffs rising to sharp tinds some 3200 ft. above the deep sinuous channels.

References to other localities in which glacial features assignable to this phase occur may be found in the writers 'Note on Pleistocene Glaciation Mt. Field to Mt. Strahan' and (with J. F. N. Murray) 'Glacial Features in the D'Entrecasteaux Valley'.

Malanna Low-water Phase

Great difficulty has been experienced in exactly fixing the relative position of the terraces representing the high-water phases and the troughs representing the low-water phases. The Launceston Stage is definitely pre-glacial and so are the associated high-level basalts. A trough reasonably correlated with the Malanna glaciation has been identified in the River Derwent and a later volcanic phase with an overlying terrace is also established beyond question, but the present writer has some doubt whether this lastmentioned terrace represents a high-water phase immediately preceding the Malanna glaciation or immediately following it. This difficulty is occasioned by the lack of data relating to the depth of later silts filling the Malanna troughs and the depth of the associated basalts below present sea-level. However, the basalts in places flowed down a trough below present sea-level in a way which would be impossible to-day, and the next deposits lie on top of them. There is no evidence at all of a pre-Malanna low-water phase. Unfortunately, Tasmania cannot be regarded as a stable land surface until Yolande times, but the balance of probabilities on present data are as here stated.

The Malanna glaciation was accompanied by a low-water phase remarkably approximating the similar feature in England. It is suspected in many places, but definitely proved in the estuary of the River Derwent, where a series of bores were sunk in the search for a rock foundation for a bridge. Diagrams are included in the writer's paper in Papers and Proceedings of the Royal Society of Tasmania, 1934 (1935), p. 80. Remarkable confirmation was obtained in 1938-39 when a bridge company erecting a bridge some two miles south of the locality of section B reproduced as above, acting in spite of the writer's published data struck the shoulder of the Malanna trough in the outer edge of an important abutment and were put to unexpected expense. The Malanna trough winds through the present estuary 150 ft. below present sea-level, tracing the course of the river during a period of low water. This trough is now nearly filled with river silt. It could not possibly have been eroded in this very hard dolerite and mudstone unless the strand line had been somewhat over 150 ft. lower than it is to-day.

Bridgewater Basalts

Somewhere towards the end of the low-water phase there was another volcanic phase. The river channels had been eroded and in a few places basalt lavas flowed down them. The lowest level reached by this basalt has not been ascertained. At Bridgewater it is 60 ft. below present sea-level. At Boyer, some five miles further up the Derwent, it has been bored to the same depth without finding the actual floor.

The Launceston Stage must have been deposited. Then river erosion cut for at least 400 ft. through the older river valleys partly filled by Cremorne basalts. As suggested, this was probably the result of some measure of uplift. Then occurred the low-water phase of the Malanna glaciation and the rivers cut channels another 150 ft. into solid rock—probably 100 ft. below the floor of the Launceston Stage deposits. After this, the second volcanic phase filled some of these troughs with basalt.

Millbrook Rise Stage(1)

The Malanna glaciation was followed by a high-water phase. River terraces were developed—or more probably river valleys were filled with sediments which subsequent erosion has left as terraces. The most typical feature is accumulation of very characteristic river gravels on top of the Bridgewater lower basalts.

These gravels extend on an average to about 150 ft. above sea-level.

There can be no doubt of the sequence low water phase-basalt-high water phase. The gravels on the basalt can be correlated with many other terraces round the coasts. They are particularly well developed at Bridgewater and Huonville.

These gravels are characterized in many places by predominant pebbles of Lower Palaeozoic quartzites, &c. This is significant, as the more recent terraces are predominantly of dolerite pebbles. There can be no question that in places the basalt flows caused lakes and otherwise interfered with the drainage, but wide valleys only partly filled with lava appeared to have been covered by water during the high-water phase to a width many times more extensive than the lava flows.

Yolande Glacial Phase

This glaciation is one of the most spectacular features of the western topography. Every mountain over 3600 ft. high and all the western third of Tasmania over 2200 ft. is heavily glaciated. The mountains and plateau residuals are seamed with cirques, the extremities of which often meet in comb ridges. Lakes occupy some portion of the majority, and typical U-shaped valleys stretch out towards the coastal plains. These are crossed at intervals by moraines. Briefly, every feature of mountain glaciation is to be found.

(1) Millbrook Rise is situated about one mile on the Hobart side of New Norfolk.

The Yolande glaciation was so recent that its characteristics have not been materially altered by erosion. The still more recent glaciation has not affected it. The present writer, speaking in very general terms, would say that the Malanna glaciation ended four times as long ago as the Yolande. The Yolande glaciation does not seem to have been as extensive as the Malanna, but towards the heads of the valleys its glaciers occupied the same cirques and, more or less, filled the same valley troughs. It thus largely obliterated the traces of the earlier glaciation which shows out from beneath the moraines of the Yolande phase only in a few favoured localities. The terrain of the Malanna glaciers has been weathered and new soil grows normal forests. In most places the track of the Yolande glaciers are as the ice left the countryside, largely devoid of soil and with swampy accumulations of clay in the undrained valleys. When in the winter snow covers the landscape, the track of the ancient glacier stands out with lifelike clarity.

The Yolande glaciation was not as extensive as the earlier phase. Often terminal moraines have been left half-way down the cirque sides. In other places, newer glacial valleys have been eroded within or on one side of the older one. The terminal limits of both are very confused and have not yet been satisfactorily differentiated in most places. This is due to the very narrow coastal belt invaded by both glaciations. In most places, terminal moraines of the Yolande phase obliterates observations of the Malanna phase.

The characteristic feature of the Yolande glaciation in the higher altitude is a paired arrangement of mountain lakes.(1) Almost everywhere the lakes, the majority of which are referable to the Yolande glaciation are arranged in pairs. There is usually 300 ft. difference in elevation between the higher and the lower, Sometimes one lake stands above the other up the valley, the longer axis of both and of the glacial valley in which they lie being in the same line, in other cases the lower lake occupies the bottom of the valley and the higher lake or lakes stand on the side empounded by a moraine marking the termination of a glacier which did not reach the valley floor. Sometimes, in complex cirques, there is a main lake at the lower level with a bouquet of smaller lakes occupying the ramifications of the cirque.(2)

From the remarkable regularity as to elevation of these pairs of lakes and the configuration of the valleys which all indicate an old, simple glacial valley further eroded by numerous glaciers which melted before reaching the older valley floor, the present writer concludes that the Yolande glaciation appeared in two distinct phases separated by an interglacial interval. The whole Yolande glaciation probably did not occupy a time interval anywhere approaching that of the Malanna. The present writer places the time interval from the onset of the earlier of the Yolande phase to the present day as less than the Malanna-Yolande interglacial period.

Yolande Low-water Phase

Associated with the Yolande glacial phase was a period of low sea-level. Basalts invaded the Malanna trough which had been filled with river sediments to a height of perhaps 150 ft. above present sea-level. Then came a new low-level phase, during which the Malanna-Yolande interglacial deposits were cut out. Where basalt had filled the valleys, the rivers sometimes excavated new channels alongside,

(1) Lakes Belton and Belcher, and Lakes Nicholls and Rayner in the National Park, and the Arthur Lakes in the midland area are examples.

(2) See sketch plan of Great Lake area, Pap. & Proc. Roy. Soc. Tas., 1932, 'Note on Origin of Great Lake and Other Lakes'; also sketch plan of Broad River valley, Pap. & Proc. Roy. Soc. Tas., 1921, 'Glacial Remains in the National Park'.

but more often swung from side to side, mostly in the older river deposits, but also cutting the basalt flows which now stand in narrow strips first on one side then on the other of the present valleys.

This newer trough was cut to approximately 60-80 ft. below present sea-level in a way, particularly where the frozen valley has been cut, which could not be done by the present rivers. Through the flooded estuaries, this old river channel winds. Its association with the basalt is very marked. Not only do the troughs in the main valleys show the lowering of the rivers, but this is a feature of all the small rivers and dry valleys near sea-level right round the coasts.

Ralph's Bay Stage

After the Yolande glacial stage with its accompanying low-water phase, there was a recovery of strand line resulting in raised beaches, which are to be seen all round the coast. The most outstanding examples are to be found round the shores of Ralph's Bay, south-east of Hobart. About this locality Darwin wrote: 'On the shore of Ralph Bay (opening into Storm Bay), I observed a continuous beach about 15 ft. above high-water mark clothed with vegetation, and by digging into it, pebbles encrusted with serpulae were found . . . ' (Geol. Observations, 2nd edition, 1876, p. 158.)

The only comment that can be made to this is that if Darwin had had longer in Tasmania he would not have confined his remarks to Ralph's Bay. The same features are to be found everywhere. Shore platforms run along the base of every cliff. This is so much a universal feature that, as a boy, I had never pictured the possibility of not being able to walk along the shore-line (the tide in southern Tasmania has only a rise and fall of 4 ft.) and these platforms are rarely submerged for far at high tide. They extend impartially in cliff faces, exposed to the heaviest seas, and these high in estuaries where waves never occur.

The raised beaches consist of compact, but unconsolidated, shell banks interlayered with sand. Sometimes they extend for half a mile from the present seashore and make very rich flats for growing vegetables, melons, and oats. They are extended inland as river terraces. In exposed beaches they are overlain by modern sand-dunes, and the two stages are clearly distinct. Beneath the Ralph's Bay stage lie tough ferrugineous clays at the bottom of the Cambridge or Millbrook Rise stage, and in some sections the three stages are clearly separable. The Ralph's Bay stage raised beaches are often 30 ft. thick, but exposures are not sufficiently frequent to determine the maximum, thickness.

Inland river terraces are to be found almost universally at about 15 ft. above the present river level. These are remarkably fertile and grow Australia's hop crops. This feature is too common to pass notice.

Margaret Glacial Phase

Subsequently to the Yolande glaciation there occurred a third (or fourth) glaciation. This was never as extensive as either the Yolande phases and only affected the tops of the mountains—the lowest levels are in general terms 3700 ft. in the centre and 2200 ft. on the west. All mountains of this altitude were affected, but the Margaret glaciers were small and seldom extended far from their cirque head. The largest observed by the present writer is in the type locality—Lake Margaret, where the glacier was about seven miles in length. Glaciers over one mile in length must have been rare. The most usual feature is rings or groups of small cirque high in the mountains, usually clustered round the top of the Yolande cirques (the conditions for ice production being similar during both phases).

These cirques are frequently occupied by tiny lakes of great beauty. They stand, on the average. 900-1200 ft. above the floor of the Yolande cirques. The walls of the Margaret cirques seldom stand more than 300 ft. high.

Small moraines are common. These are usually distinguishable as traversing country well above the névé and cirques of the Yolande glaciation.

Where accessible, the Margaret glaciation provides excellent examples of ice action, but, in general, they are high above all present roads and are difficult of access. In the type locality, Lake Margaret is a rock basin which forms an excellent reservoir. It is the site of an important power scheme. The original polished ice-scratched rock barrier has been raised by a concrete dam. Water from this is carried a short distance and dropped over the cirque wall of the Yolande glaciation into the Yolande valley. Elsewhere, many similar small hanging valleys attributable to the Margaret glaciation send their water cascading over the cliffs of the Yolande cirques.

It may be asked whether the Margaret phase was not a retreat feature of the Yolande glaciation. The only substantial evidence for two distinct glaciations is *(a)* the universality of the Margaret glaciation at its levels which connects Margaret cirques and tarns wherever they occur; *(b)* the degree of river erosion seen in a few localities between the deposition of the Yolande moraines and the Margaret moraines; *(c)* although in most cases evidence of Margaret glaciation is to be found in the upper levels of Yolande glacial valleys, it is not always so, and Margaret glaciers grew in places covered by Yolande névé. None of these arguments is conclusive. The present writer considers that the general appearance of freshness of deposits, etc., gives the impression that the Margaret glaciers existed at a period far closer to the present day than the time interval between the Yolande ice and the Margaret ice.

Margaret Low-water Phase

After the formation of the raised beaches and associated features a further low-water phase can be traced. Everywhere near sea-level the streams and rivers have cut a channel some 15-21 ft. below present sea-level, exposing sections of the Ralph's Bay stage terraces. This is almost universal. The evidence that this was made possible by lower sea-level and not by normal or flood erosion is shown by the fact that these small troughs and ditches have been flooded by subsequent rise in sea-level and a post-Margaret deposition is in rapid progress within the erosion features referable to this stage.

PART III—GLACIAL STUDIES IN TASMANIA

One of the most outstanding observations for a Tasmanian when reading accounts of glaciation in the northern hemisphere is the remarkable parallel between the features of glaciated landscapes here and those described in published accounts. Taking into consideration the very limited areas of flat land, the relatively small area of glaciation and the sharp relief, there seems to be no described glacial feature which cannot be found reproduced on some scale in Tasmania.

Take, for example, Hobbs' *Characteristics of Existing Glaciers:* Professor Hobbs' chapter on the 'Cirque and its Recession' is exactly confirmed in Tasmania. The present writer has developed the ideas set out in this paper from observations of cirques. Moraines are a dangerous framework, too liable to deformation by subsequent erosion and to being obscured by forest. Summer snow banks abound. (See Notes on La Perouse Range, Pap. & Proc. Roy. Soc. Tas., 1924 (1925), p. 38, for a description of a feature that is very common on all mountains.) The illustrations in Professor Hobbs' Plate II could have been taken in Tasmania, although, in general, this dolerite talus is broken in much larger blocks. These summer snow banks are the relicts of the Margaret glaciation, and are usually found near the upper edges of Margaret cirques which are always small and immature. See a typical example illustrated in Pap. & Proc. Roy. Soc. Tas., 1924 (1925), pl. VI, p. 18, fig. 2, and pl. V, fig. 1. These are trivial features compared with the main Yolande cirques, of which the Margaret cirques often form the upper branches. See examples illustrated in Pap. & Proc. Roy. Soc. Tas.. 1924 (1925), pl. IV and pl. VIII, and Pap. and Proc. Roy. Soc. Tas., 1921 (1922), pls XIII and XIV.

The quotation from Johnston quoted in Professor Hobbs' Ch. II on *High Level Sculpturing of the Upland* exactly describes the topography of many Tasmanian plateaux, although, in the majority, the process has extended to the removal of all or most of the pre-glacial surface with only high knife-edge divides remaining. Professor Hobbs' fig. 9 represents the average Tasmanian glaciated upland exactly. Fig. 10 could be a sketch, and fig. 12 a map, of several mountains in Tasmania.

In reference to Professor Hobbs' classification of the stages in the glacial dissection of an upland, pictures in his Ch. II and elaborated in his paper in Journ. of Geol., Vol. XXIX, No. 4, 1921, Tasmania echoes his views. Grooved uplands are very abundant, but the second stage, Early Fretted Uplands, are the most common topography. Horns with main and lateral comb ridges occur in the case of the higher mountains—see illustrations in Pap. & Proc. Roy. Soc. Tas., 1923 (1924), pls II, V, and VI, and 1924, pls III, VI, and VII. In some cases, rudimentary monuments have commenced to appear. See Pap. & Proc. Roy. Soc. Tas., 1924 (1925), pls VI and VIII. The present writer's observations are that glacial horns and monuments commence to make their appearance early in the Hobbs' second stage of Early Fretted Upland, and monuments are well developed by the time the glacial erosion is commencing the stage of Fretted Upland of maturity, In Tasmania, erosion has in no case reached Hobbs' third stage of full maturity, but in some of the more highly glaciated regions it was reaching that stage. It is relatively rare for glaciers to develop equally all round an upland plateau. The usual position is that one edge is highly dissected, with monuments appearing, high cols and occasional glacial horns, but the bulk of the plateau is only slightly affected.

At page 35 (1922 edition), Professer Hobbs says 'Deep glacier cut valleys available as highways and transecting high ranges are extremely rare'. This is the case in Tasmania, and explains much of the difficulty occasioned in opening up the glaciated western country.

Turning to Professor Hobbs' Ch. III 'Classification of Mountain Glaciers': Those of the Nivation type were extremely common in Tasmania. These are referable to the Margaret glaciation.

Ice Cap type have developed on the flat surface of the Central Plateau and were responsible for the Great Lake (see Lewis, 1932). The Piedmont type was represented in the south and west where short glaciers debouched on coastal plains (see Lewis and Murray, 1934). The glacier of the Yolande-Henty-Malanna type locality was also of this class.

Glaciers of the Dendritic or Valley types were by far the most numerous. It is difficult to distinguish which of the Tasmanian glaciers might be referred to the Inherited Basin or Radiating types rather than to the Dendritic type. Some may have occurred in places where their development was particularly favoured by pre-glacial topography, but the writer prefers to regard all such glaciers as local variations of the Valley type.

Glaciers of the Horseshoe type were very common. They occurred on all mountains and were the most usual feature of the Margaret glaciation. Professor Hobbs' Plate XIVA could illustrate many a Tasmanian mountain with winter snow. Plate XIVB resembles Linda Valley closely, although there is no ice now at Linda.

In his Ch. IV Professor Hobbs describes what he calls 'The Cascade Stairways and U Valleys'. Every word in these sections could have been written of the larger Yolande glacial valleys of western Tasmania. Rock bars are very common, and a great addition to the picturesqueness of the scenery. His Plate XVI could be exactly reproduced over thousands of square miles in Tasmania, and fig. 28 might represent a typical Tasmanian mountain top. The form shown in his fig. 30 is also common here. The W-pattern formed by glacial shearing on the side of the main valley of pre-glacial water-worn tributaries is a very distinctive feature.

Tasmania was not affected by a typical ice cap, but much of the level Central Plateau and the highly glaciated area round Port Davey shows local features as illustrated by Professor Hobbs in his chapter dealing with ice caps. His Plate XVIIB is reminiscent of the entrance to Port Davey, and his Plate XVIIIB is reproduced in minature in several places on the south-west coast of Tasmania.

Moraines cover much of western Tasmania, and the present writer finds Professor Hobbs' Ch. VI also exactly applicable. In most cases, the ultimate terminal moraines are now submerged and the lowest moraines of later glaciation have been removed by subsequent erosions, but in many valleys moraines stand out like railway embankments. The moraine at Lake St. Clair is some six miles long and 750 ft. in vertical thickness. Many impounded lakes occur. Professor Hobbs' fig. 44 is almost an exact reproduction of one of the most typical features in Tasmanian scenery. The Strahan terraces as described by David are 'Outwash Aprons' (Hobbs, p. 87) and similar features extend south to Cox Bight. Rock flows occur in all dolerite capped mountains. These have acquired the local name of 'Ploughed Fields'. A good example crosses the road to Mt. Wellington not ten miles from Hobart (see also Pap. & Proc. Roy. Soc. Tas., 1923 (1924), pl. VI, fig. 7), and other references in my papers.

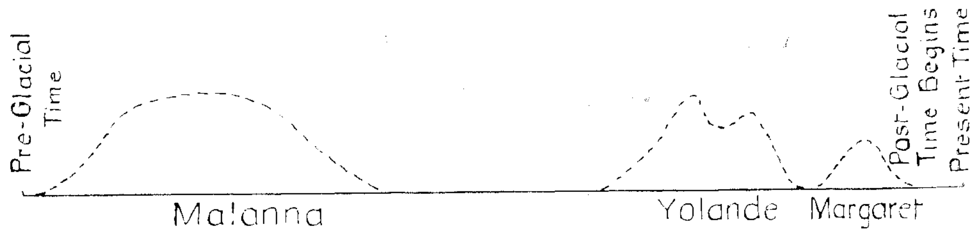
As has been stated, there are no comparisons in Tasmania with the continental ice sheets of higher latitudes, and the rest of Professor Hobbs book is unapplicable.

Turning now to a different problem—that of rise and fall of land and sea during the Pleistocene, we may take Daly's 'Changing World of the Ice Age', 1934—as a useful guide. Tasmania can provide little to advance knowledge of the rise and fall of land in the Pleistocene, except that change of strand line did occur. In the opinion of the present writer, the amount of ice at the maximum would be unlikely to amount to 4000 square miles (half island affected and only one-third of that area actually covered by ice). The maximum thickness I have ever observed would not be over 2200 ft. This would never have been true over the whole glaciated area, and probably 300 ft. would be a fair average over the whole 4000 square miles. This gives only a volume of 250 cubic miles. Even doubling this figure the weight of added ice would be trivial compared with the weight of the land—about 10,000 cubic miles.

There is no doubt that there was an Malanna-Yolande interglacial rise of land surface, but this affected all Tasmania more or less equally—whereas only one-third to one-half was covered by ice. This rise was greater (450 ft.) than the average thickness of ice. It was accompanied by considerable foundering of land round the coast—particularly in the south and probably in Bass Strait. The present writer therefore considers that these earth movements were not the result of accumulations of ice, at least over Tasmania or neighbouring waters.

Tasmania can provide no direct evidence *proving* that glacial epochs were contemporaneous in both hemispheres. There is, however, a remarkable parallel. This is particularly noticeable between the river terraces in the lower reaches of the Derwent and Huon Rivers which entered the sea some 40-60 miles from the nearest tributary glaciers and the River Thames in England, the lowest reaches of which were approximately similarly distant from the edge of the English ice sheet. Further, the evidence tends to the assumption that river terraces representing high sea-level alternated with the Tasmanian glaciations. If the hemispheres had had alternate ice invasions the effect of freezing in one hemisphere and melting in the other would have tended to cancel each other out or there would have had to be twice the development in one hemisphere (northern) than there was in the southern to account for development of river terraces in the southern.

Daly, fig. 22, the present writer would render this diagram for Tasmania as—



Figs 39A and B of Professor Daly's book are of great interest to a Tasmanian reader. Arch Island in D'Entrecasteaux Channel and Spectacle Island in Frederick Henry Bay provide elevated sea cut tunnels exactly similar to those shown in the plates, except that the Tasmanian examples are not as high above sea-level as that shown at Torghatten Island (15 ft. in Tasmania). The marine terrace occurs similarly. Fig. 39B is exactly like a photo of Remarkable Cave near Port Arthur. Figs 80 and 81, particularly the latter, could have been taken in many places round the east coast.

There is at present no sure basis for comparing the Tasmanian glaciations with the great ice sheets of Fennoscandia and North America, although many points in Professor Daly's books can be observed in miniature. Taking his formula and tables in his chapter on Earth's deformation and recoil, the amount of ice in Tasmania was so much smaller than the smallest example given by Professor Daly that the present writer considers it would be dangerous to attempt to extend these calculations to such small occurrences, and the field data in Tasmania emphasises that facts observed for large occurrences cannot be indefinitely extended downwards. However, when we turn to world-wide movements of sea-level we see a remarkable concordance between the Tasmanian shore line and features described in Professor Daly's chapter on High Sea Levels of the Pleistocene. (Compare Professor Daly's fig. 95 with Professor David's pl. XI in Pap. & Proc. Roy. Soc. Tas., 1923 (1924).)

One of the most outstanding features of Tasmanian glaciation, and a most baffling one which has caused much delay in the formulation of general descriptions, is the alternation in the same valley of glaciated and waterworn tracts. In some of the most splendid examples of glacial valleys, for example, the Gordon, King, and Pieman Rivers, there are enormous waterworn gorges between obviously glaciated stretches, and the ice which eroded the lower glacial valleys must by force of topography have passed through the waterworn portions of the valleys. The amount of post-glacial river erosion in some places has been very considerable. The gorge on the King River is 3000 ft. deep and about 10 miles long. It shows no signs of glaciation. This is only typical of most glacial valleys. The most probable explanation is that it is only the present surface features which show typical river erosion. The whole valley must once have been glaciated. In certain localities governed entirely by slope, post-glacial rivers and their tributaries have removed the superficial features of ice erosion and remodelled the details of the topography to a waterworn one. (Lewis, Aust. Geographer, 1936.)

An associated feature, and quite a common one, is that of two parallel valleys, the higher typically glaciated, the lower waterworn. In the type locality east of Malanna, the Henty River flows over morainic material, while some five miles farther south the Yolande flows in a gorge entirely waterworn and some 450 ft. deeper than the bed of the Henty. On the Central Plateau where the ice tongues were thinner and spread out over relatively flat country, marked gorges up to 120 ft. deep often run alongside the lines of the glacial tongues, so that moraines and glacial features occupy the low dividing ridges and the small valleys are waterworn.

It appears clear that in many places ice fed streams were at work before the ice disappeared. In the stage of retreat the ice remained for a very long time stationary and dwindling, protected the underlying landscape rather than eroding it, while near by a very active stream was engaged eroding back into the névé country far beyond the margin of the ice. Many lakes that have been drained in this way exist round the sides of many glacial valleys with waterworn troughs, what may be called hanging moraines. The most outstanding is the Gormanston moraine referred to in the present writer's paper 'A Record of Varved Shales from Tasmania'.

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