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A RECONNAISSANCE SURVEY OF THE GLACIATION OF MACQUARIE ISLAND

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(with three text figures and thirteen plates)

ABSTRACT

The paper reviews previous ideas on the glaciation of Macquarie Island and gives an account of glacial landforms observed during a brief visit in 1972. The field evidence indicates that Macquarie Island was not completely overridden in an easterly direction by an ice sheet which developed on a broad submarine shelf to the west as advocated by L.R. Blake (in Mawson 1943). Local plateau, valley and cirque glaciers accumulated in depressions, basins and valleys on the surface of the plateau and at their maximum extent occupied about 40% of the island. A migration of the Antarctic Convergence from 150 - 200 km south of the island to north of the island would depress sea level temperatures by 3-4^{o}C; an amount adequate to account for the modest glaciation of the plateau surface. The majority of plant and animal species probably immigrated prior to the last glaciation, which is of Wisconsin age, and survived in non-glaciated areas of the present island and adjacent shelf to the west.

INTRODUCTION

Different views have been expressed on the glaciation of Macquarie Island by Blake 1911-14 (in Mawson 1943), by Ivanac (1948), and by Gwynn 1949 (in Law and Burstall 1956). Blake considered that snow accumulated and an ice sheet developed on the broad shallow offshore shelf to the west of the island which was exposed by a lowering of world sea level. He envisaged that the horst-like ridge of the present Macquarie Island had been glaciated by an easterly movement of ice across the ridge from an axis of accumulation in the west during the late Pleistocene (see figure 1). Ivanac accepted that Macquarie Island had been almost totally glaciated by an ice sheet but considered that the main overriding ice moved from southwest to northeast and affected the plateau surface down to 125 m (400 feet) above sea level on the east coast. He suggested that this maximum stage of glaciation was succeeded by distinct stages when the ice cover on the ridge was almost continuous with glacier tongues reaching into the sea and finally be a stage of cirque glaciers. Gwynn questioned the theory that the ice sheet must have developed on the exposed shelf to the west or southwest of the present island. He suggested that the northern end of the island was glaciated during the last phase by ice which accumulated on the present plateau surface which forms the 200-300 m high backbone of the 34 km long island. Though it had previously been assumed that Macquarie Island was totally ice covered during the Pleistocene, Gwynn suggested that non-glaciated headlands and areas of shelf exposed by the lowering of sea level probably existed during the Pleistocene and in these non-glaciated areas some, if not many, species of the present flora and fauna could have survived.

In an attempt to assess the degree and pattern of recent glaciation the authors visited Macquarie Island with the Twenty Fifth A.N.A.R.E. Expedition which landed at Buckles Bay on the morning of Sunday, 19th November, 1972. The all too fleeting five and a half days of the changeover period were spent in making a reconnaissance survey of the glacial landforms and deposits in the northern and eastern parts of the island. The authors walked the main plateau track from A.N.A.R.E. Station via Finch Creek and Green Gorge to Lusitania Bay and returned via Green Gorge and Bauer Bay to A.N.A.R.E. Station. Place names used are shown on figure 1 and are those given on Macquarie Island map sheet, scale 1:50,000, First Edition, November 1971. Unnamed mountains are designated by spot heights or the highest enclosed contour.

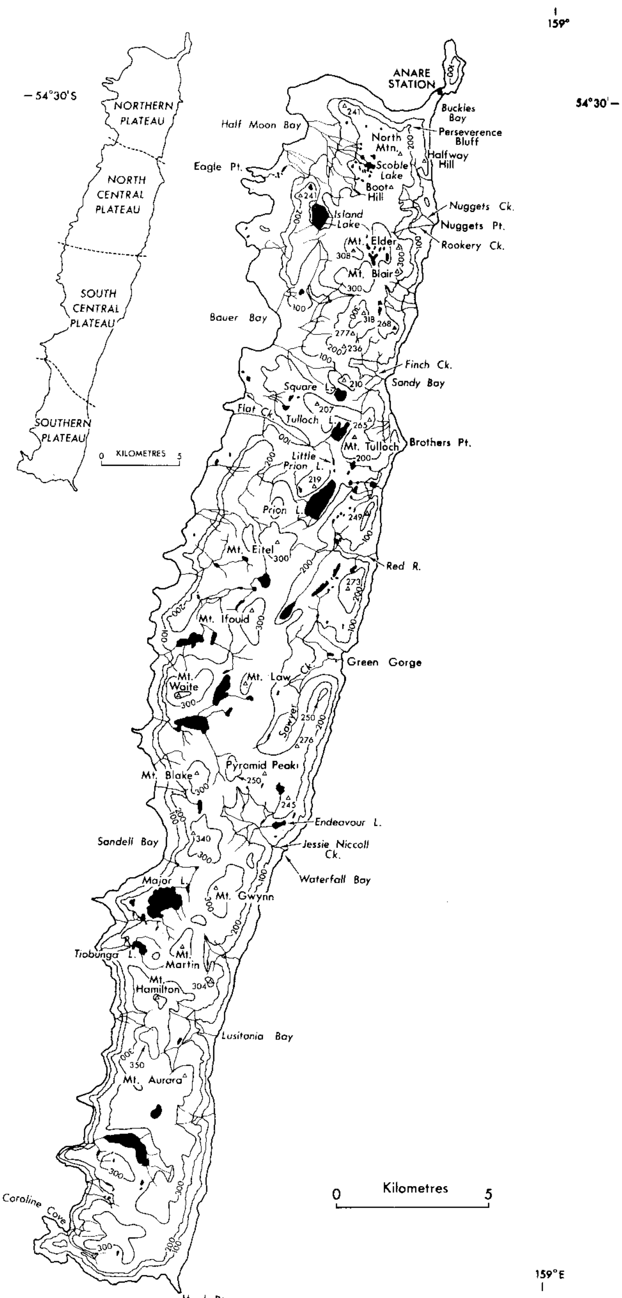

FIG.1. - Topographic map of Macquarie Island.

Though the main plateau track was generally followed, many minor detours were made to observe specific forms and deposits where features of interest were encountered. Unfortunately, time did not permit an exhaustive survey of the area traversed or a reconnaissance survey of the area south of Lusitania Bay and most of the west coast. The purpose of this report is to present our preliminary findings on parts of the northern and eastern areas of the plateau that forms Macquarie Island, to deduce the degree, pattern and character of the final glaciation and to suggest the main controlling factors. We acknowledge our indebtedness to A.N.A.R.E. for the privilege of the transport and facilities provided during our visit to Macquarie Island and hope that these first results may be succeeded by more detailed investigations on a future occasion. We also acknowledge our appreciation of the University of Tasmania for its support of this research project.

GLACIAL AND NONGLACIAL LANDFORMS

In any attempt to differentiate between areas which have been glaciated and areas which have escaped the effects of glacier ice in close juxtaposition, it is necessary to outline briefly the criteria which have been utilised to infer glaciation and the other criteria which indicate that certain areas may not have been glaciated. Blake (in Mawson 1943) recognised striae, roches moutonnées and many of the deep lakes and tarns as the products of glacial erosion on the plateau surface. He also recognised the presence of till deposits, end moraines and fluvioglacial deposits as the products of deposition by ice and its meltwaters. In addition he noted that many of the shallow lakes occupied hollows in the glacial drift rather than ice scoured rock basins. Ivanac's (1948) notes are extremely brief and add no factual records to the earlier work of Blake. Unfortunately, Gwynn's (1949) ideas are not discussed at length in Law and Burstall (1956) and he does not appear to have published his views on the glaciation of Macquarie Island elsewhere.

During the traverse made by the present authors, the presence of striae, glaciated outcrops, roches moutonnées, cirques, tarns and glacially deepened valleys with lakes was noted and indicated areas where glacial erosion occurred during the last glaciation. Glacial and fluvioglacial deposits include till, occasional perched blocks, glacial boulders and cobbles on the surface, end moraines, recessional and/or readvance moraines, lateral banks of glacial drift, kame terraces, outwash terraces, and those of former proglacial lakes. In addition the glaciated areas have experienced the erosive action of glacial meltwaters which have cut several varieties of meltwater channels deeply into bedrock during the stages of deglaciation. Though these forms and deposits are widespread on the northern and eastern parts of the plateau surface it soon became apparent that their distribution was not ubiquitous, that they occurred together in certain areas and were notably absent from the bare higher summits and ridges of the mountains and from some of the lower hills on the plateau surface. Also, most of the east coast margin to the plateau bears little direct trace of glaciation south of Finch Creek except at the valley and basin outlets where the cliff line is lower as at Red River, Green Gorge, Waterfall Bay, the unnamed basin ease of Mount Martin and Lusitania Bay. It also became apparent that the till cover was discontinuous on the plateau surface and that the distribution of glacial boulders and cobbles was not ubiquitous. Most of the thick deposits of till observed occurred on the floors of the larger valleys and as plugs in the minor valleys of the northeastern coastal slope.

Many of the mountain summits, high ridges and hill crests between the valley floors and the basins in the plateau surface which were occupied by ice show no trace of glacial erosion and lack landforms due to glacial deposition. The complete absence of cobbles and blocks bearing glacial striae or flat-iron faces from the surface of an area can be due to total removal by glacial scour but when the absence is accompanied by an absence of striated and smoothed bedrock surfaces and is further accompanied by the presence of intensely frost shattered crags, periglacial tors, very coarse block screes and block fields the inference is clear that these areas were not glaciated during the last glacial stage.

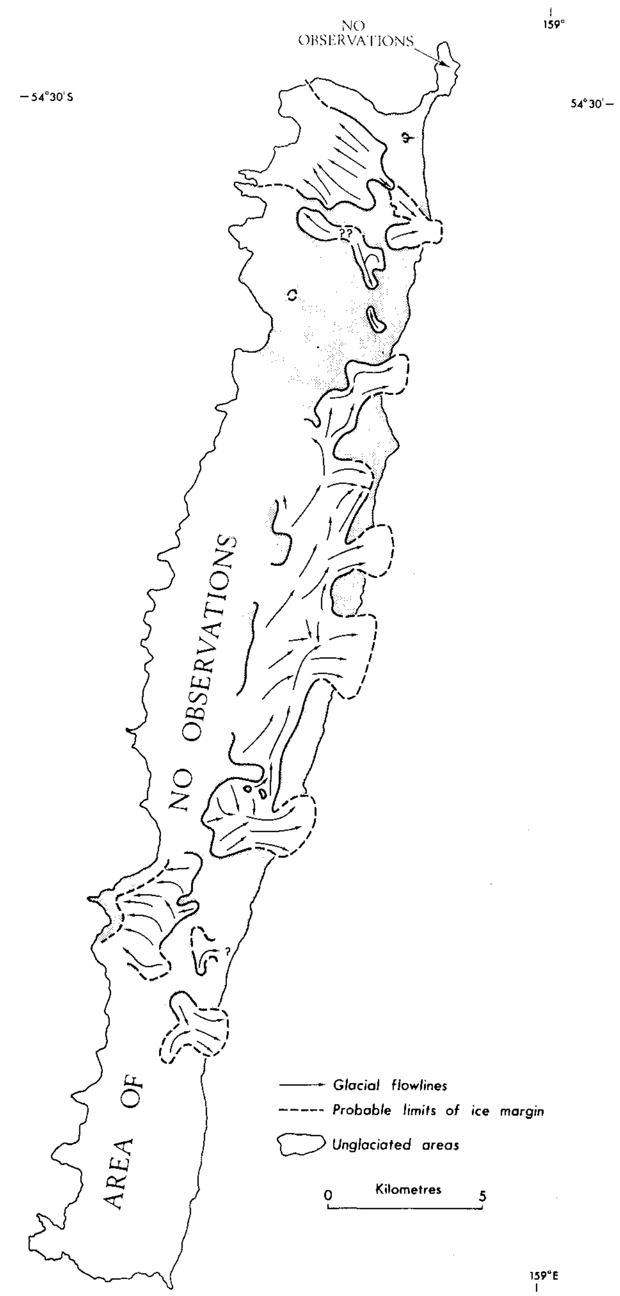

FIG. 2.- The extent of glacier ice on Macquarie Island during the Last Glaciation.

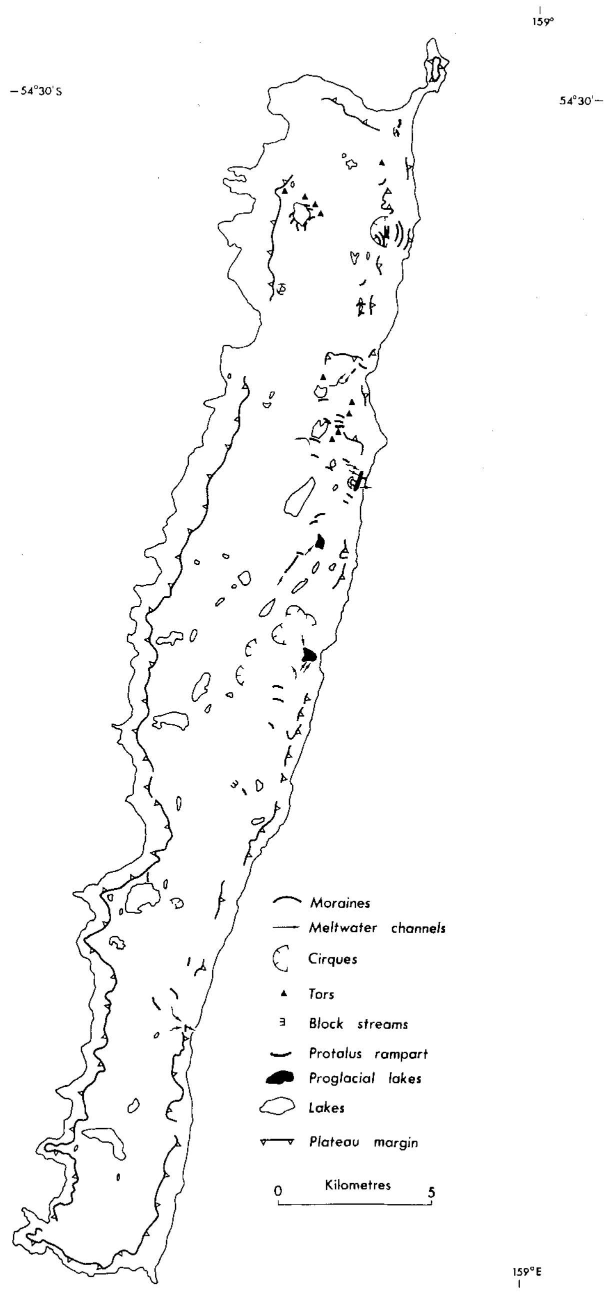

FIG. 3.- Glacial and fluvioglacial landforms of Macquarie Island.

The widespread development of solifluction deposits which occur mainly in the form of broad terraces and occasionally as lobes on steep slopes, and the presence of stone polygons and stone stripes cannot be used as indicators of non-glaciated areas on Macquarie as the present island lies in a humid periglacial environment and these forms occur in both the formerly glaciated and non-glaciated areas.

EVIDENCE FOR GLACIATION

For convenience the glacial and associated features observed will be described for three sub-regions which are defined as follows.

1. The Northern Plateau being the sub-region north of Stony Creek on the west coast and Finch Creek on the east coast.

2. The North Central Plateau being the sub-region that extends south of 1 to Green Gorge in the east and lies north of Mount Waite in the west.

3. The South Central Plateau being the sub-region that extends south from 2 to Lusitania Bay in the east and lies north of Mount Hamilton in the west. South of 3 the fourth sub-region, the Southern Plateau, was not visited.

The Northern Plateau

On the Northern Plateau clear evidence of glaciation exists between the rock basin lakes developed to the southwest of North Mountain, centred on Scoble Lake, and Island Lake (figure 2). Glacier ice also accumulated in Rookery Creek and moved downslope towards Nuggets Point. Cloud did not permit observation in Nuggets Creek where Blake, recorded a series of till deposits. There is every reason to believe that Nuggets Creek was occupied by ice of similar form to that in Rookery Creek. Ice also developed to the west of Mount Elder and Mount Blair, and north of the unnamed mountain which culminates in the spot height marked 268 m, 1.5 - 2.0 km north of Finch Creek.

The accumulation of a shallow dome of ice on the north western portion of the Northern Plateau is witnessed by the presence of many west-northwesterly oriented rock basin lakes in the area around Scoble Lake. Though some may be partially impounded by glacial deposits the larger lakes occupy rock depressions which are separated by low ridges that exhibit glacial surfaces, roches moutonnees and are sporadically mantled with thin soliflucted till which contains striated and smoothed cobbles and boulders. This ice moved westwards and northwestwards towards the coastal slope and Half Moon Bay and was probably between 50 m and 100 m thick. Owing to thick cloud and rain it was not possible to determine whether this shallow ice dome extended to the northern cliffline but it is suspected from the contrast of the degraded form of the fossil cliffline of the plateau edge north of Island Lake and the sharp steep undegraded cliffline to the plateau edge between the spot height of 241 m and Perseverence Bluff that all the ice moved westnorthwestwards and northwestwards and did not descend the northern slope. The northern margin of the ice dome probably thinned out just short of the northern cliff edge leaving a narrow non-glaciated cliff top strip.

Striated and faceted blocks of basalt and gabbro up to 25 cm in diameter were found in a small pile of rocks by the track on Perseverance Bluff at 200 m height. Despite this find Perseverance Bluff does not appear to have been glaciated during the last glacial stage as the rock pile resembles a small cairn and the blocks could have been carried from the Scoble Lake area by persons returning to A.N.A.R.E. Station from either Bauer Bay or Sandy Bay huts. No other evidence for ice was found on the crest of Perseverance Bluff though one small crescent-shaped ridge lying on a shelf to the southeast at about 130 m and tucked close into the base of the eastern slope resembled a protalus rampart form about the periphery of a snowpatch hollow (figure 3). Another small crescent-shaped ridge near the head of the gully to the south looked like a small moraine that bounded a small glacieret formed in the gully head. Closer inspection would be required to confirm the origin of these ridges.

The eastern margin of the ice dome did not cover North Mountain but thinned out against the western slope at about 250 m. Above this level large screes with joint determined blocks of 0.3 - 0.6 m diameter mantle the slope and appear to be stable under the present humid periglacial conditions. The rock outcrops on the summit ridge of North Mountain have been sculptured by intense and enduring frost weathering into summit crags and periglacial tors (plate 1). The dolerite of the scree blocks and tors is presently undergoing granular disintegration by the combined effects of chemical weathering and frost loosening of the particles. No till, glacial cobbles and boulders, or ice abraded rock surfaces, were encountered on the mountain and the sharp eastern cliff edge could not have been overrun by glacier ice or it would have been degraded by ice erosion. Snow which fell on the mountain would have been blown by westerly winds over this sharp edge and could have accumulated in the depression between North Mountain and Halfway Hill. The sharp eastern edge of North Mountain in probably a cirque headwall but low cloud precluded viewing this wall and the basin below. The gabbro rock and talus of North Mountain are presently being reduced in size to screes with particles of less than 20 cm diameter and granules by the combined effects of moderate frost shattering and chemical weathering of the surfaces. The large joint determined block screes are not being added to but are being reduced by these processes.

PLATE 1.- Small arcuate moraine ridge between Boot Hill and the southern spur of North Mountain. Note small tors on the summit of North Mountain and the sharp edge to the eastern plateau slope.

To the southwest and south of North Mountain ice from the Scoble Lake area extended as a glacier tongue between Boot Hill and North Mountain and may possibly have passed over the scarp edge into the head of Nuggets Creek (plate 1). A small moraine ridge 5-8 m high occurs on the margin of a shallow rock basin at 210-220 m height east of Boot Hill. This moraine may mark the limit of the ice tongue shown on figure 2 or a stage in the retreat of ice from Nuggets Creek.

South of Boot Hill and north of spot height 308 m the extent of glaciation was not clearly determined. Most of the area appears to have been ice free except perhaps for a northwesterly ice flow from the glacial lake area west of Mount Elder towards Island Lake. Island Lake occupies a shallow rock basin and was certainly glaciated by ice which originated in the hill basin to the southeast. The ice flowed northwestwards across the lake basin. Small tors on the ridge to the northeast and on the ridge to the northwest that culminates in spot height 241 m indicate that the thin ice probably did not merge with the shallow ice cap of Scoble Lake but was confined within the lake basin. Small amounts of meltwater may have flowed northwards through the low col between the ridges towards the cliff line but ice does not appear to have flowed through this col nor does it appear to have been thick enough to have surmounted the western edge of the lake basin as far as the plateau edge. Several stages of glacial retreat or readvance are depicted by the small latero-terminal moraine ridges composed chiefly of fluvioglacially washed sands and small gravels that occur on either side of the lake. Two moraine ridges were observed on the northern shore of the lake to the northwest of the sand bar. Three occur on the western shore of the lake and north of the sand bar.

The curvature of these moraines was controlled by the form of the Island Lake depression which must have been present prior to the last ice movement into the basin. Southeast of the sand bar more morainic hummocks were observed and were formed during the southwestward retreat of this ice lobe.

Blake noted that Rookery Creek had been glaciated and recorded till, outwash and end moraine deposits down to within 30 m above sea level at Nuggets Point. Our observations confirm that Rookery Creek was glaciated and from the top of the sharp headwall about six arcuate morainic ridges were seen to span the valley floor from about 200 m down to at least 50 m above sea level (plate 2). The highest ridge at about 200 m elevation appeared to be a coarse block moraine that was tucked in against the northeastern slope of Mount Elder. The next three ridges below this at about 150m, 120m and 100 m respectively appeared to be mainly composed of blocks. The lowest moraines were too distant and vegetated to determine their composition. The sharp bounding headwall is that of a low level cirque basin that has been engraved into the east facing coastal slope. The sharp break of slope in the rock between the plateau surface and the cirque headwall has not recently been overriden by an iceflow from the west or it would have been degraded and rounded off. The convex terminal curvature of the ice-distal sides of the moraines indicates that during the last glacial stage the ice developed within the amphitheatre-shaped valley of Rookery Creek and that the moraine ridges represent retreat/readvance stages during the general southwestward retreat of the cirque glacier. The plateau surface marked by spot height 321m to the west and Mount Elder to the south appears to have been ice free. Fresh screes occur on Mount Elder and on the headwall of Rookery Creek cirque.

PLATE 2.- Moraines on the northeastern coastal slope below the cirque of Rookery Creek.

Blake recorded erratics of enstatite-peridotite near sea level on the east coast at Nuggets Point and suggested that a train of these erratics extended across the island from Eagle Point in the west to Nuggets Point on the east and that this train of erratics indicated an easterly flow of the ice sheet. Recent mapping by Varne and Rubenach (1972), shows that in addition to the Eagle Point outcrop there are five other surface outcrops of serpentinised peridotite to the east of Island Lake from which the surface glacial cobbles could have been derived. Thus the geological evidence need not necessarily be interpreted as indicating an easterly ice flow across the island.

West of Mount Elder and east of the hill marked by spot height 308m is a group of nine small lakes. Several of the larger lakes lie in shallow rock basins. A shallow mass of ice, probably not more than 50m thick, accumulated in this small basin between the two hills. A tongue of ice may have flowed from the basin west-northwestwards towards Inland Lake, but the main flow pattern appears to have been from the lake basin at the foot of the western slope of Mount Elder by a semi-circular route to pass southeastwards through the col between Mount Blair and the unnamed hill to the west enclosed by the 300 m contour. A small moraine ridge spans the valley at 220-230 m height south of Mount Blair and possibly indicates the limit attained by the ice tongue which flowed through the col.

In the southeastern part of the Northern Plateau another small basin occurs east of the hill marked by spot height 318 m, north of the hill which culminates in spot height 268 m, and the eastern margin of the plateau. In this basin are four small lakes which are aligned along the axis of the shallow glacial trough that curves northwestwards from its source under the northern slope of the hill of 268 m height and terminates just above the plateau edge. The cirque glacier that developed in the south flowed as a glacier tongue along the rock scoured trough that contains the southern three lakes and terminated in a low moraine ridge which dams the most northerly lake and raised its water level slightly above that of the second lake. Another small arcuate moraine separates the second and third lake (not shown on the map). The convex curvature of the ice-distal slopes of these two moraines confirms the north-northwesterly ice flow.

No conclusive evidence was found for the development of glacier ice in the southwesterm part of the Northern Plateau to the south of Island Lake and west of the ridge marked by spot heights 318 m, 277 m and 236 m through a small lake perched in a shallow rock basin at 160-170 m above the western cliffs a kilometre northeast of Bauer Bay may occupy the site of a former perched cirque glacier. Heavy screes on the plateau margin southeast of Bauer Bay are stable and individual blocks have been grooved and polished by the wind. As on North Mountain it is thought that these screes were produced in an extraglacial area during the last cold stage.

The North Central Plateau

The glacier ice which affected Finch Creek valley moved northeastwards from the Square Lake and Tulloch Lake areas and passed seaward of the present coastline through the first major breach in the eastern plateau margin at Finch Creek and Sandy Bay. In the middle part of Finch Creek valley bedrock lies very close to the stream on the northern side but on the southern side thick surficial deposits occur in the deep postglacial V-shaped incision cut by the stream in the valley floor. At one locality above the moraine ridge on the southern side of the valley floor a section shows 1-2 m of soliflucted till resting directly on 4 m of till that overlies bedrock. The small moraine ridge is 5-7 m high and curves across the south side of the valley floor just southwest of the junction of Finch Creek and its lowest northern tributary. Down valley from this moraine the valley mouth is occupied by a broad terrace which despite the thick peat on its surface appears to decline seaward in the form of an outwash terrace developed when the ice stood at the moraine. On the northern side of the valley a ridge occurs beyond the margin of theterrace at a height of 50 m and may be the lateral moraine of the ice which extended seawards of the present coast. This suggests that at least two stages occurred during the retreat of ice from Finch Creek.

Near the mouth of Finch Creek the stream has cut down to expose 7-10 m of poorly to moderately sorted coarse sands and subangular gravels the bedding and morphometry of which is consistent with an interpretation of glacial outwash. The gravels are iron cemented near their base and contain rolled bones. The outwash deposits in turn rest on till and at the valley mouth on more than 1 m of laminated silts and fine sands which appear to be a proglacial meltwater deposit that accumulated in a shallow depression in the till surface. Basalt occurs in the stream bed.

Blake (in Mawson 1943) and Gill (in McEvey and Vestjens 1973) have indicated that three cycles of sedimentation were involved in the development of this valley mouth terrace deposit. Gill suggests that the deposits are not glacial outwash as suggested by Blake and on the basis of one ^{14}C date of 6,000 $\pm$ 120 yrs. B.P. (Gak-643) on Royal Penguin bones from a horizon 6 m above the creek mouth at sea level he concluded that the deposits are postglacial in age. Unfortunately we did not have time to investigate the stratigraphy of this site thoroughly. We consider that much of the deposit is probably of fluvioglacial origin and of late glacial age though some of the higher horizons may be of postglacial age. We also consider that caution is necessary in accepting the date of 6,000 $\pm$ 120 B.P. for the age of the Royal Penguin bones as the gravels are porous, are overlain by thick peat and contamination of this very brittle bone material is quite possible. Like Gill, we think that it would be worthwhile to date a series of bone samples from different levels within this valley mouth terrace and to make a full stratigraphic record of the site. Until this is done the origin and age of the deposits must remain problematic.

That the ice passed seawards is recorded by two occurrences of glacial striae engraved on a polished surface of basalt that crops out 50 m north of the mouth of Finch Creek. The striae are oriented towards 67^{o} and 72^{o}. Similar striae occur on ice polished basalt on the northern side of the first stream north of Finch Creek and are oriented towards 80^{o}. These striations indicate a flow along Finch Creek from west-southwest to east-northeast.

Glacier ice accumulated in the basin of Square Lake and flowed northeastwards into the valley of Finch Creek. The ice did not surmount the hill to the north marked by spot height 210 m as frost shattering has developed small tors on its crest and there is no trace of glacial smoothing above 170 m. At this level a distinct meltwater channel system has been developed cutting deeply into the rock of the southeastern spur (plate 3). As the meltwater channel approaches the southern tributaries of Finch Creek it bifurcates into several branches and is developed at several levels. Between the channel segments the rock outcrops have a water-washed and eroded appearance. The meltwater system was developed as the ice of Finch Creek withdrew to Square Lake during the deglaciation. A small moraine by the southeastern shore of Square Lake indicates that the ice retreat continued southwards towards Tulloch Lake. The hill marked 207m to the southwest of Square Lake was probably not glaciated and no direct evidence for the glaciation of Stony Creek was found. Thus the ice which occupied the col basin of Square Lake flowed northeastwards but does not appear to have flowed northwestwards.

PLATE 3. - Meltwater channel cut into rock at about 170 m height northeast of Square Lake.

The ice that flowed from Tulloch Lake northeast to Sandy Bay did not override Mount Tulloch or its northern spur marked by spot height 265 m. Mount Tulloch and the spur are crowned by tors and mantled with frost shattered rock. The ice does not appear to have more than half filled the valley that lies north of Mount Tulloch and did not rise above the 250 m contour. Thus at any point the ice was less than 100 m thick. During the retreat towards Tulloch Lake two cross-valley moraines were formed in the valley west of hill 265 m and a third small deposit occurs close to the foot of the northern slope of Mount Tulloch. It is probably a third moraine stage in the glacial retreat but could possibly be a late stage protalus rampart.

Tulloch Lake appears to be deep by comparison with Island Lake and Square Lake and has probably been considerably deepened by ice erosion. At its northeastern end a small hummocky area of moraine separates three small ponds from the main lake, while at its southern end thick moraine overlying rock perches the lake above the deep rock outlet that extends from Little Prion Lake to the head of the Flat Creek valley.

Little Prion Lake occupies a depression in the narrow rock trench that leads northwards from Prion Lake. This trench is the combined product of ice and meltwater erosion.

Just northeast of the outlet of Little Prion Lake a small ridge appears to be a moraine and represents a stage in the southward retreat of the ice flow. North of this a 20-25 m deep glacial meltwater channel has been cut into glacial deposits and bedrock and is continued westwards to Flat Creek (plate 4). This meltwater channel was probably developed after the ice front retreated from Tulloch Lake and while the ice tongue still blocked Little Prion Lake.

Prion Lake is a true rock basin formed by ice erosion. It is reported to be 35 m (110 feet) deep near its northern end (McGregor, 1953) and though Blake considered that it had been developed by strong ice plucking of joint planes during a west to east ice flow across the island the present authors consider that it was developed by the northeasterly flow of ice that accumulated within the leeward basin bounded by the high snowfence of Mount Eitel to the southwest, the hill enclosed by the 300 m contour to the west, and that marked by the spot height of 219 m to the northwest. This was also the view expressed by Gwynn. A small lake shore terrace has been formed at the eastern end of Prion Lake. This terrace is about 1 m above the water level and is probably due to the reworking of a morainic bar by wave action under the influence of strong southwesterly winds.

PLATE 4.- Floor of the meltwater channel that drained northwards from Little Prion Lake to Flat Creek.

In addition to the ice that flowed northwards from Prion Lake ice was deflected eastwards by Mount Tulloch towards the plateau margin south of Brothers Point. There are five shallow glacial lakes on the col south of Mount Tulloch and northeast of Prion Lake. A small moraine ridge divides the two in the northwest. Another small lateral moraine ridge occurs at about 200 m height on the southern slope of Mount Tulloch. From the northeastern lake a sinuous meltwater channel descends from about 180-140 m and has been incised deeply into the rock as it flowed eastwards into the northwestern part of a proglacial lake that was developed in a shallow valley above the edge of the plateau. This proglacial lake is now mainly filled with sediment but it appears to have been impounded initially in the northern part of the depression by ice. A moraine ridge occurs on the eastern margin of the lake floor and a small meltwater channel scars the western slope and probably conducted the meltwaters downslope along the ice margin at this stage. As there is no overflow channel cut in any col north of this moraine the lake meltwaters must have escaped subglacially over the plateau edge by the meltwater channel to the southeast of the moraine. After the ice margin had retreated southeastwards from this moraine the proglacial lake was extended southwards and the subglacial meltwater channel changed its function and operated as a lake overflow channel (plate 5).

West of and adjoining this former proglacial lake is a deep rock depression occupied by a lake. The depression has the form of an overridden cirque basin. It is suggested that a discrete low level cirque glacier was formed in it and deepened it early in the glaciation prior to its being overridden by ice from Prion Lake and the valley to the southwest at the maximum extent of glaciation. The ice which flowed northeastwards along this valley did not surmount the elongated hill marked by spot height 249 m but was confined to the west of it. Two stage moraines were deposited against the lower part of the hillslope at approximately 100 m and 150 m respectively as the ice front retreated across the col to the northern part of the Red River basin.

PLATE 5.- Part of the former lake bed 2 km south of Brothers Point showing outlet channel over the plateau edge to the east and two fragments of moraine ridges in the valley to the south.

Glacier ice accumulated under the lee of Mount Ifould and flowed northeastwards through the col between the elongate spur bounded by the 200 m contour east of Prion Lake and the plateau edge hill marked by 249 m, and eastwards at the mouth of the Red River basin. The lakes in the northern part of the Red River basin are mainly shallow lakes caused by an uneven distribution of morainic deposits on the rock floor. Two distinct arcs of moraine are shown on Figure 3 but more detailed observation would reveal considerable glacial deposits in this locality. The lakes on and below the 100 m contour at the confluence of the tributaries are mainly the remnants of a much larger lake which occupied this site and probably originated as a proglacial lake. The exit of the basin was seen to be choked with great thickness of glacial deposits above the plateau edge but detailed observations were not made. To the west the summit of Mount Eitel was probably ice free at the maximum glaciation. South of the former extensive proglacial lake the ice retreated southwestwards into the ice scoured Lake Ifould. Just northwest of the stream which leads from Mount Ifould and southwest of Mount Eitel there is a moraine at 150-160 m from which a meltwater channel drains along the course of the Red River. South of the moraine is a low kame terrace banked against the hillslope and this terrace is seen to originate from the outlet of a meltwater channel that leads across a rock spur to terminate at the moraine (plate 6). These features appear to represent the lateral and terminal forms developed by the ice and its meltwaters during a district retreat/readvance stage in the Red River basin. The chain of lakes to the east was not observed closely but the distinct alignment along a northeasterly curving line that merges with Lake Ifould suggests that the chain was mainly formed by glacial erosion accentuating a line of structural weakness. The mountain marked by spot height 273 m was ice free above 210 m but below this level thick glacial deposits are banked against the northwestern slope. The ice that developed in the cirque basins west of the Green Gorge basin probably just overflowed the col and connected with ice in the Red River basin. The two large cirque basins appear to have been approximately half filled with ice on their inner side and about one third filled with ice near their lips.

<u>The Southern Central Plateau</u>

Glacier ice accumulated in the Green Gorge basin in large cirque basins which occur on the lower slopes on the western side of the basin in the lee of Mount Ifould and Mount Law. The summits and upper ridges of Mount Ifould and Mount Law were probably ice free at the maximum

PLATE 6.- Low level kame terrace in the western part of the Red River Basin.

glaciation but glacier ice accumulated at several levels in the hollows on the steep leeward slopes. It would appear that here the distribution of ice, snowfields, bare rock ridges and summits was essentially of alpine character with ice and snow in the hollows at all levels on the slopes and that these were separated by sharp ridges which experienced strong frost action while the main glacier occupied the basin below. This ice was confluent with ice which flowed northeastwards along Sawyer Creek and developed at its head in the lee of Pyramid Peak and the two mountains enclosed by the 250 m contour to the west and northwest. The ice in Sawyer Creek and the ice of the Green Gorge basin both extended seawards of the present coastline at Green Gorge. This ice appears not to have exceeded 150 m in thickness inland and was probably about 100 m thick when it crossed the present coast. Though it was probably some of the thickest ice on Macquarie Island during the last glacial stage and caused considerable erosion it still was not thick enough to submerge any part of the crest of the narrow coastal ridge that extends from spot height 276 m east of the head of Sawyer Creek to the area enclosed by the 250 m contour south of Green Gorge which exhibits a few small tors.

At Green Gorge the seaward passage of the ice strongly eroded the rock barrier at the basin mouth and fragmented it into a series of disconnected glacial crags. Behind the crags the floor of a formerly extensive lake is filled with sediment and peat (plate 7). The lake was probably first developed as a proglacial lake during the deglaciation and the distinct cliffs which bound its western and southwestern margin may be spurs truncated by the ice. However, the level of the lake floor is so low (about 12-13 m above H.W.S.T.) that it is just possible that it may have been invaded by the sea passing between the glacial crags at its mouth at the height of the Post Glacial marine transgression. If so, the steep ice truncated cliffs west and southwest of the lake may have been accentuated in places by being retrimmed by wave erosion. Since the lake basin forms a good trap it should contain a very full postglacial sediment sequence.

A small meltwater channel occurs on the northern slope leading down to the former lake. Two former parallel submarginal meltwater channels occur between 40 and 100 m height on the northwestern flank of the spur south of Green Gorge (plate 8). These channels are steep V-shaped gorges which are incised 10-12 m into rock, are peat lined, and are either dry or carry underfit streams. A third occurs between 150 m and 100 m height slightly further south. This channel curves obliquely downslope towards the valley axis. The floor of Sawyer Creek is filled with thick glacial deposits that are peat covered. The large moraine ridges span the valley floor at approximately the 100 m contour and slightly north of the junction of the two headwater streams. These two moraines overlie rock and are associated with steep gorge sections of Sawyer Creek which were probably cut by glacial meltwaters during the final deglaciation. These moraines, and a third cross-valley moraine near the head of the eastern headwater tributary, mark stages of retreat/readvance during the general southwestward retreat of ice towards Pyramid Peak.

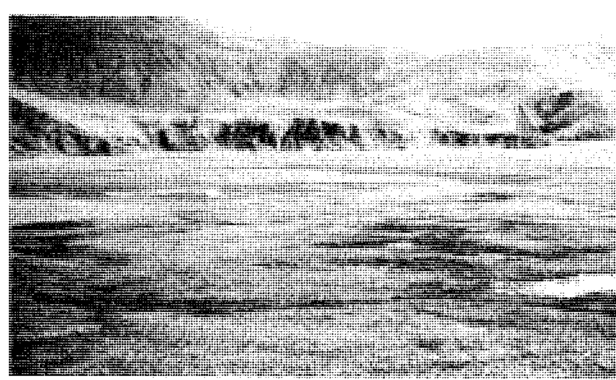

PLATE 7.- Postglacial lake bed west of Green Gorge showing steep bounding cliffs and low level cirque basins on the slopes of Mount Ifould.

Glacier ice accumulated in the basin of Jessie Niccol Creek, flowed centripetally towards the centre of the basin and eastwards towards the eastern edge of the plateau between Waterfall Bay and Endeavour Lake.

PLATE 8.- Intake of one of the submarginal meltwater channels on the hillslope southwest of Green Gorge.

The ice was probably between 100m and 150m thick and while it filled most of the basin it did not engulf the surrounding summits. Glacial cobbles and thin morainic deposits occur on the basin floor. The plateau edge spur north of Endeavour Lake marked by spot height 245 m appears to have remained as a nunatak area. Thin ice must have passed northwards via the col north of Pyramid Peak into Sawyer Creek, and, in doing so, eroded the lake basin. Morainic debris occurs around and north of the lake but the summit of Pyramid Peak and the mountain to the west enclosed by the 250 m contour were not submerged and the upper limit of ice action may be represented by a bank of lateral moraine at about 240 m on the southwestern slope. An adjacent hill a short distance west-northwest has a frost shattered summit and exhibits two very coarse block streams on its southeastern slope. The block streams appear to be stable at present. The area above the 300 m contour on the southwest, the high col leading to Major Lake, and Mount Gwynn to the south also appear to have been ice free during the last glacial stage. From the foregoing description it may be concluded that the Jessie Niccol Creek basin operated virtually as an independent collecting ground for snow and ice during the last glacial stage and its only connection with other ice was through the Pyramid Lake col to Sawyer Creek. The accumulation was facilitated by the moderately high snowfence which extends from Mount Blake in the northwest to the mountain in the southwest which culminates in spot height 340 m on the western edge of the plateau.

The platform occupied by Major and Tiobunga lakes to the west of Mount Gwynn and Mount Martin was glaciated by a shallow dome of ice similar to that which developed around Scoble Lake on the Northern Plateau. The Major-Tiobunga lake platform is exposed to the full force of the westerly and northwesterly winds. The shallow form of the ice cap was probably controlled mainly by the topography and partly be the deflation of snow from the ice surface and its transport across the high cols between Mount Hamilton and Mount Martin to the Lusitania Creek basin, between Mount Martin and Mount Gwynn to the basin in the lee of Mount Martin, and northwest of Mount Gwynn to the Jessie Niccol Creek Basin. Almost the entire area of this platform below the 250 m contour was glaciated but there is little trace of glaciation above 280 m except for a small cirque basin on the southwestern slopes of Mount Gwynn which was occupied by ice that merged with the Major Lake ice.

Ice occupied the two small lake basins north of Major Lake and was about 70-80 m thick. In the northern lake basin ice flowed directly westwards to the plateau edge. In the second lake basin ice flowed north-westwards and then westwards to the plateau edge. During the ice recession moraines were deposited on the northern shore of Major Lake. These moraines were not visited but the position of the largest is shown on figure 3. A small peak east of Major Lake and south of the second lake basin remained above the ice surface and has a strongly frost shattered crest. The ice that accumulated on the lower western slopes of Mount Martin flowed northwest into Major Lake and then westward to the plateau edge where it probably terminated in an ice fall. It eroded the rock basin of Major Lake and was probably slightly over 100 m thick. The lakes west and south of Major Lake occur either in ice scoured rock depressions or in hollows in the thick glacial deposits which occur on the shores of and around Major Lake.

Tiobunga Lake was glaciated by ice which developed in the valley between Mount Martin and Mount Hamilton and flowed northwestwards and westwards to the plateau edge. Lack of time and thick cloud prevented further observation in this area.

Glacier ice developed on the floor of the basin to the east of Mount Martin which acted as a snowfence. The summit of Mount Martin was not glaciated and there does not appear to have been any connection between the ice of this basin and that of either Major Lake or Lusitania Creek. A lateral moraine occurs east of the small lake in the southern part of the basin from which the main ice flow was northward towards the centre of the basin and then eastward to the margin of the plateau (plate 9).

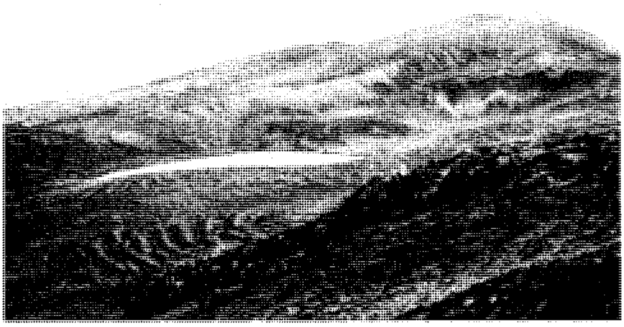

PLATE 9. - Lateral moraine and glacial lake basin in the southern part of the basin east of Mount Martin. Note the extensive solifluction terraces.

Mount Hamilton, the mountain to the south enclosed by the 350 m contour and Mount Aurora formed the snowfence which caused the development of glacier ice in the Lusitania Creek basin. This basin appears to have been glaciated by two short glaciers that were developed in the northwestern and southwestern branches of the valley and merged below the spur marked by the 250 m contour in the western part of the basin. The ice did not connect with any other basin and appears to have only half filled the basin probably being slightly more than 100 m thick. The glaciers flowed southeast and northeast before merging to flow eastwards to beyond the present coastline in Lusitania Bay. Three banks of lateral moraine occur between 250 m and 270 m on the southern slope of the hill marked by spot height 304 m (plate 10). These appear to mark the upper lateral limit of glaciation. A similar lateral moraine descends obliquely southeastwards across the eastern spur of Mount Hamilton from about 300 m to 250 m. It is an obvious ice margin limit above which large talus blocks have fallen from the steep eastern slope of the ice free summit of Mount Hamilton.

PLATE 10. - Banks of lateral moraine at 250-270 m on the northern side of the Lusitania Creek valley.

A V-shaped meltwater gorge occurs at the mouth of the Lusitania Creek and has been cut 20-30 m deep into the rock of the plateau edge (plate 11). To the south of the gorge entrance there is a small ridge of moraine which indicates a stage in the glacial retreat during which the gorge carried proglacial meltwaters seaward. It is unlikely that such a deep gorge could have been initiated proglacially without the development of a large proglacial lake on the floor of the basin of Lusitania Creek.

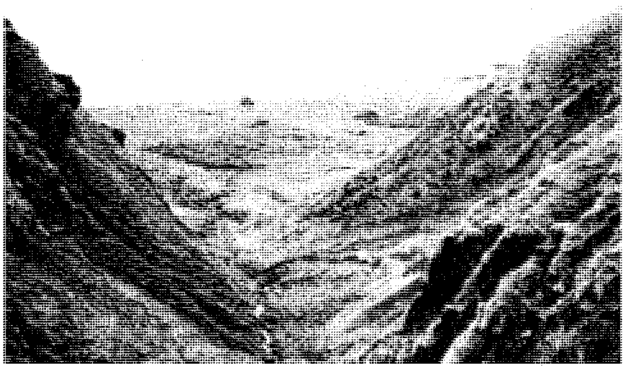

PLATE 11. - Meltwater gorge at the mouth of Lusitania Creek valley.

There is no evidence of such a lake and it is probable that the meltwater gorge was initiated subglacially during an earlier stage of the glaciation when the Lusitania ice extended a short distance seaward of the present coastline. Evidence for the development of considerable meltwater in the Lusitania Creek basin is supported by the development of a deep submarginal channel cut into the rock of the hill slope to the south at about 80 m to 100 m (plate 12). This channel trends along the contour before it turns through a right angle to plunge downslope. This suggests that the marginal meltwaters found a subglacial or englacial route to the ice margin stage marked by the moraine at the head of the proglacial metlwater gorge.

The course of the northern tributary stream of Lusitania Creek is inherited from a former meltwater channel the course of which can be clearly seen in the profile between 100 m and 130 m height where a sinuous channel has been incised 15-20 m into the rock (plate 13). The present stream is markedly underfit. Thus the ice retreated southwestwards and northwestwards in the Lusitania Creek basin and the meltwater streams generated during the retreat cut deep rock channels into the basin floor and lower hill slopes.

The Southern Plateau sub-region to the south of Mount Hamilton and Mount Aurora was nct visited.

THE PATTERN OF GLACIATION AND DEGLACIATION

Despite the fact that only two thirds of the island was viewed during the changeover period and accepting that an incomplete record was made of the landforms and deposits produced by glaciation within this area, nevertheless sufficient detail was observed to make a preliminary assessment of the extent of ice development, the pattern of ice movements and the nature of the deglaciation (figures 2 and 3).

Though it is possible that Macquarie Island was more extensively glaciated prior to the last glacial stage as suggested by Blake and accepted by Ivanac no record of an older glaciation or glaciation at higher levels was found and the record of the last glacial stage indicates that not more than 40% of the area of the island was glaciated at that time. The development of snowfields and glaciers occurred selectively in the basins and valleys on the eastern side of the plateau to the leeward of the high mountains in the centre of the plateau which acted as barriers to the prevailing northwesterly and westerly winds.

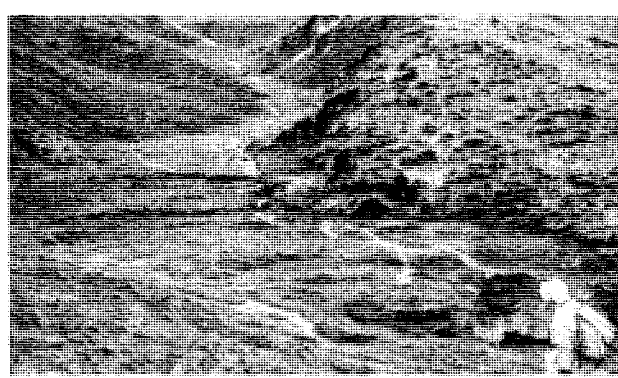

PLATE 12. - Submarginal meltwater channel on the southeastern slope of Lusitania Creek valley showing the abrupt change in direction as the water that flowed along or close to the ice margin turned downslope beneath or into the ice.

These snowfences partially protected the snow that was blown over their crests into the eastern basins and valleys from being blows off the plateau into the sea. As the basins occupied by Square Lake, Tulloch Lake, Prion Lake, Ifould Lake and the Red River, Green Gorge and Sawyer Creek, Jessie Niccol Creek, the basin east of Mount Martin and Lusitania Creek, were erosionally fashioned prior to the last glacial stage the flow of the shallow ice masses within them was primarily controlled by the form of the preexisting topography. Where there was a direct easterly outlet at a valley mouth or over the plateau edge as at Lusitania Bay, Waterfall Bay, Green Gorge, Red River and south of Brothers Point the ice flowed eastwards to the sea, but where there was a barrier ridge on the plateau edge as east of Sawyer Creek, Ifould, Prion and Tulloch lakes the ice was deflected northwestwards along the trend of the old valleys before turning seawards at breaks in the plateau margin. Where low cols occurred between adjacent valleys and basins thin ice connected across the cols as at Pyramid Lake, at the col between the Green Gorge and Red River basins, between the latter and the valley leading to the cliff edge two kilometres south of Brothers Point, between Prion Lake and Tulloch Lake, and from Tulloch Lake to Finch Creek. In all cases the ice flowed in a northeasterly or northerly direction across the cols. No ice moved southwards across a col in the eastern part of the island. This pattern does not necessarily imply that most of the snow and hail came from the southwest, but merely reflects the nature of development of the pre-last glacial topography which has a distinct northeasterly erosional trend which is at least partly related to geologic structures. The controlling influence of the pre-last glacial topography on the ice masses was accentuated by the dominance of westerly winds and moist airstreams which when forced to rise over the plateau condensed and fell mainly as snow.

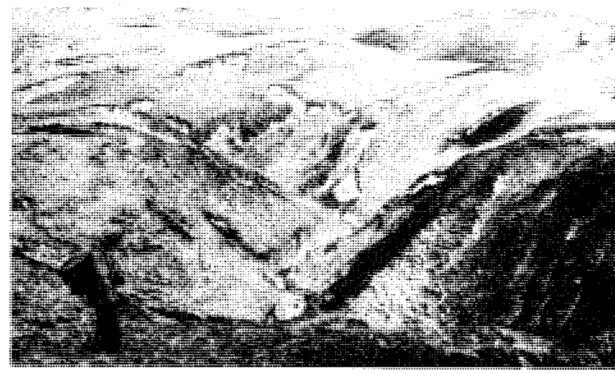

PLATE 13.- Middle section of Lusitania Creek showing present stream occupying a sinuous meltwater gorge.

The glacial retreat in each of the eastern basins and valleys occurred in a westerly and southwesterly direction. The cross-valley moraine ridges indicate that several distinct readvance/retreat stages occurred during the general deglaciation. The development of meltwater channels and gorges in and at the exit of several of the basins and valleys indicates that considerable meltwaters were generated during the deglaciation and that processes of fluvioglacial erosion affected the landscape. The absence of such channels from the mountains of the main watershed of the plateau and the eastern coastal ridges indicates that they projected above the ice surface throughout the last glacial stage.

Where the plateau surface is open to the west and is backed by high mountains to the east as at Scoble Lake and Major Lake, shallow ice caps formed from which the ice flowed westwards to the plateau margin. The moraine ridges observed in these areas also indicate that several stages were involved in the easterly retreat of these ice masses during deglaciation.

In the northeast, where basins were not developed inland from the coast, low-level cirque glaciers developed in a perched position on the plateau margin. Such a cirque glacier was certainly developed in Rookery Creek and another was probably developed in Nuggets Creek. To the north a small cirque glacier and large snowpatch may have been developed southeast of Perseverance Bluff. An overridden cirque was developed near the plateau edge two kilometres south of Brothers Point. The presence of these cirques and snowpatch areas on the plateau edge is primarily due to Perseverance Bluff, North Mountain and Mount Elder being located adjacent to the plateau edge and acting as snowfences which permitted accumulation of snow and ice in the leeward hollows below. The many moraines in Rookery Creek indicate that the ice retreated in several stages westwards toward the cirque headwall.

The development of cirque basins on the eastern slopes of Mount Law and Mount Ifould occurred in a similar way to that of Rookery Creek but their occurrence on the western side of the Green Gorge basin is due to the location of the high snowfences in the centre of the plateau rather than at the coast.

CONCLUSIONS

Blake (1943) and Ivanac (1948) indicated that a total glaciation of Macquarie Island had taken place during the last glacial stage from an ice axis that had developed on exposed sea floor to the west or southwest of the island. Ivanac suggested that this stage of total glaciation was succeeded by later distinct stages when valley glaciers and cirque glaciers were present. The present survey shows conclusively that there was not a total inundation of Macquarie Island by ice during the last glacial stage, that there was not a hypothetical ice axis developed to the west and southwest of the island, and that glacier ice accumulated selectively in basins, valleys, hollows and on broad shelves on the main plateau surface as first surmised by Gwynn (in Law and Burstall, 1956) but demonstrated in more detail here. The locations of the centres of ice development were determined by the combined effects of wind drifting of snow and hail and the pre-last glacial topography of the island. The pattern of the ice movements during the hemicycles of glaciation and deglaciation was controlled by the topography.

There is no reason to believe that distinct consecutive phases of valley and cirque glaciation succeeded the waning of a total ice sheet cover. Small ice caps, valley and cirque glaciers developed synchronously in different locations and at different levels on the plateau surface, on the mountain slopes that rise above the surface and on its northwestern coastal margin. Where one ice mass impinged upon another they became confluent as in the western part of the Green Gorge basin, or the larger ice mass overrode the smaller mass as in the case of the overridden cirque two kilometres south of Brothers Point. Similarly plateau ice caps, basin, valley and cirque glaciers melted contemporaneously and though several distinct retreat/readvance stages can be recognised in each valley the stages do not relate to different morphological forms of ice mass being present at different times.

The conclusion that some 60 percent of the present area of Macquarie Island was not glaciated during the last glaciation is inevitable, not to mention the much greater area which may have been exposed on the shallow shelf to the west of the island during the last major lowering of sea level. This conclusion indicates the strong possibility that most of the endemic and subantarctic species of circumpolar distribution in the flora of Macquarie Island could have arrived prior to the last glacial stage and could have survived the colder conditions in close proximity to their present location. The immigration of all the species by long distance dispersal on migratory birds during postglacial time as advocated by Taylor (1955) need not be substantiated. Similarly penguins, albatrosses, skuas, sea elephants and seals probably predate the last glaciation of the island and lived, nested and bred on the non-glaciated portions of the present island and its shelf extensions during the last glaciation.

As Macquarie Island has no glacier ice or perennial snowbanks today the most likely condition that caused the cooling of climate during the last glacial stage would have been a shift of the Antarctic Convergence from its present position 150-200 kilometres south to north of the island. This would have given Macquarie Island a position relative to the Antarctic Convergence similar to that of Heard Island today and would have been sufficient to depress the mean temperature at sea level by 3-4°C. With the present amount of precipitation of slightly greater than 1000 mm per annum this temperature decrease would have been sufficient to produce the very modest degree of glaciation that occurred on the plateau surface.

There is at present no evidence from Macquarie Island to indicate the age of the last glaciation but there is also no reason to believe that it did not occur synchronously with the last glaciation of Northwestern Europe, North America and the last major advance of ice in Antarctica which latter would have been associated with the northward migration of the Antarctic Convergence. The morphologic character of the glacial landforms and deposits and the freshly incised character of the meltwater channels would also support a Weichselian/Wisconsin age for the glaciation.

REFERENCES

Blake, L.R., 1911-14: See Mawson, D., 1943.

Gill, E.D., 1973: See McEvey, A.R., and Vestjens, W.J.M., 1973.

Gwynn, A.M., 1949: See Law, P.G.; and Burstall, T., 1956.

Ivanac, J.P., 1948: Geological Observations on Macquarie Island. *Comm. of Australia, Department of National Development, Bureau of Mineral Resources, Geology and Geophysics Records* 1948/39, 1-4.

Law, P.G. and Burstall, T., 1956: Macquarie Island. *A.N.A.R.E. Interim Report,* 14, 48pp.

McEvey, A.R., and Vestjens, W.J.M., 1973: Fossil Penguin Bones from Macquarie Island, with appendix by E.D. Gill. *Proc. R. Soc. Vict., 86,* 2, 151-173.

McGregor, P.M., 1953: Report on the Sounding of Prion Lake, Macquarie Island, March 1953, Australia. *Comm. of Australia, Department of National Development, Bureau of Mineral Resources, Geology and Geophysics Records* 1953, No. 110.

Mawson, D., 1943: Macquarie Island: its Geography and Geology. *Australasian Antarctic Expedition 1911-14, Scientific Reports* Series A, 5, 194pp.

Taylor, B.W., 1955: The Flora, Vegetation and Soils of Macquarie Island. *A.N.A.R.E. Reports* Series B, 2, 192pp.

Varne, R., and Rubenach, M.J., 1972: Geology of Macquarie Island and its relationship to oceanic crust. *Antarctic Research Series of the American Geophysical Union,* 19, 251-266.