LANDFORMS OF AEOLIAN, TECTONIC AND MARINE ORIGIN IN THE BAUER BAY-SANDY BAY REGION OF SUBANTARCTIC MACQUARIE ISLAND

by D.A. Adamson, P.M. Selkirk and E.A. Colhoun

(with seven text-figures and twelve plates)

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Aeolian landforms on Macquarie Island, in the Southern Ocean, occur above 100 m on the plateau between Bauer Bay and Sandy Bay. An extensive sand sheet, at least 6000 to 7000 years old, is wind and water eroded to produce blow-outs with bare troughs and vegetated elevated margins. Sand moved eastwards before the prevailing winds. Wind-polished bedrock on the western edge of the plateau is a relict feature. Wind-polishing of bedrock occurs today near sea level at the head of Bauer Bay.

The area is tectonically active. No evidence of former glacial activity was observed. Topographic features in this area, previously regarded as glacial, are attributed to faulting.

Tectonic uplift and sea-level changes are invoked to explain the formation and age of the broad and gently sloping raised marine terrace around much of the western and northern coasts. This explanation also sets constraints on the ages of the sand sheet and the cobble beach at about 100 m on the plateau east of Bauer Bay.

Key Words: tectonic activity, fault movement, aeolian landforms, marine landforms, Macquarie Island.

INTRODUCTION

Macquarie Island (54°37′S, 158°53′E) is the highest point on the Macquarie Ridge, part of the tectonically active boundary between the Pacific and Australian plates. The plates are moving northwards at different rates with some convergence. The island is in a zone of frequent earthquakes (Jones & McCue, this volume), crustal shortening (Williamson, this volume), block faulting (Duncan & Varne, this volume), and relatively rapid uplift (Colhoun & Goede 1973, Selkirk *et al.* 1983). Macquarie Island is seamed by scores of active normal faults, many represented by youthful scarps.

At 54°S, Macquarie Island is in the path of high latitude cyclones. At the meteorological station near sea level, annual average wind speed is 8.3 ms^{-1}, annual precipitation about 900 mm, annual mean temperature 4.8°C and mean temperature for the coolest month (July) 3.3°C. Most of the island is between 100 and 300 m elevation. Snow can fall at any time but lies only briefly.

Hamilton (1926) reported that the only sand area on the island occurred on the east coast at its northern end, immediately south of the junction between the isthmus and the main island. Taylor (1955) noted the abundant sand at the head of Bauer Bay. Other areas of sand accumulation occur, particularly on the plateau on the western side of the island. The present paper describes and puts age constraints on an extensive plateau sand sheet east of Bauer Bay.

There is a long-standing and still active controversy over glaciation on the island during the last global glacial period, about 15 to 25 thousand years ago, when world sea level was some 100 to 140 m lower than today. Crohn (1986) maintains that glaciation affected most or all of the present plateau surface, whereas Ledingham & Peterson (1984) consider that many features previously ascribed to glaciation are better explained by tectonic activity, particularly as beach cobbles occur at high altitudes in supposedly glaciated areas. The present paper supports and develops Ledingham and Peterson's view that faulting is responsible for landforms previously interpreted as glacial.

A raised marine terrace (Blake *in* Mawson 1943, Colhoun & Goede 1973) extends along the northern two-thirds of the west coast of the island — a gently sloping platform rising to about 15 m a.s.l., up to 1 km wide and mantled by peat and mire. It extends from the shoreline (tidal range about 1 m; Bye, pers. comm.) to the base of the steep slopes or cliffs which bound the plateau. Elsewhere along the coast, except in the far southeast near Hurd Point, steep slopes and cliffs rise to the high plateau directly from the ocean or from a narrow rocky shore.

This paper describes landforms in the area near Bauer Bay and Sandy Bay, where there is interplay of past and present aeolian, tectonic, fluvial and marine processes. An extensive sand-sheet, containing terrestrial peats of mid to early Holocene age and now being dissected by water and wind erosion, occurs at over 100 m a.s.l. Near sea level, present-day aeolian processes are also active. Recent faulting has affected drainage, particularly on the eastern side of the region. Finally we propose a model for the formation and age of the broad marine-cut platform on the western coast by relating it to global sea-level changes, uplift rates and dated deposits.

AEOLIAN LANDFORMS

Sand Sheet

Between Bauer Bay and Sandy Bay, a low col, at about 100 to 150 m altitude, separates higher plateau surfaces to the north from those to the south (fig. 1). On the northern side of Stony Creek is an extensive thin sand sheet (dated at least 6000 to 7000 years old from interbedded peats) which mantles the plateau surface at between 100 and 200 m altitude (figs 2 and 3). The sand extends across the col and around the flanks of Hill 236 to spill over into the head of the Finch Creek valley (fig. 4). (Note that unnamed hills are referred to by their spot heights in metres on the 1:50,000 Macquarie Island map, first edition, 1971, NMP/68/025, Division of National Mapping, Canberra, Australia.) The full extent of this sand to the east of Bauer Bay has not been traced on the ground, but it occurs north of a line from Stony Creek, across the col between Hill 210 and Hill 236 to Finch Creek. The sand deposit is dissected by wind and water erosion to form blow-outs, gullies and bare surfaces flanked by low sandy scarps (fig. 2). Layers of peat and iron-cemented sand are exposed in the scarps and on bare surfaces. Cobbles of an undated beach (Beach 5 of Ledingham & Peterson 1984) occur on the largest bare-eroded surface.

Plates 1, 2 and 3 (see figs 1 to 5 for all plate locations) show the general topography of the sandy area west of the col. Plate 1 shows the view northnorthwest across Stony Creek valley to the sand-mantled plateau and hill slope where blow-outs and gullies are visible. Plate 2 shows the view westnorthwest down the incised valley of Stony Creek with its obvious valley-in-valley form. On the northern 10° to 20° slopes of the valley, linear blow-outs (see arrow) occur with their long axes oriented roughly parallel to the contours. The 25° to 40° southern slopes are deeply gullied and free of sand. Plate shows the view from the site of the dated peat deposit (fig. 2) on the sand-mantled plateau, across the hidden, deep valley of Stony Creek to the gullies on its southern side. The general concordance of plateau surfaces north and south of Stony Creek is obvious. The distribution of sand on the plateau south of Stony Creek has not been investigated, but a cobble and sandy beach has been recorded there (Ledingham & Peterson 1984, Beach 7).

Blow-outs

Blow-outs have not been described previously from Macquarie Island. They are trough-shaped elongated hollows formed by wind eroding a pre-existing sand deposit, the sand blown from the trough accumulating downwind and to the side of the trough in a blow-out dune (Whittow 1984). Figures 2 and 3 show that the long axes of the blow-outs are parallel to the dominant and strong west to northwest winds. The slight northwards rotation of the blow-outs on the lower slopes, near Stony Creek (fig. 2, plate 2 arrow), compared with those on the plateau above, matches precisely the orientation of the valley and is accounted for by winds channelled up the valley. Small blow-outs on the eastern edge of figure 2 show slight but definite divergence due to wind flow around a ridge.

Figure 3 shows several blow-outs on a 10° south-facing slope, mantled by sand and dissected by drainage lines. Cross-sections (AF, GL) of the blow-out in the centre of the diagram show the convex shape of the sandy body (BE, HK), inset into which is a trough V-shaped in plan view with an east-pointing apex. Its sandy floor (CD, IJ) is flanked to north and south by steep edges. At the eastern end of the blow-out (east of IJ) the sandy trough changes to a sandy tongue roughly coincident with the dune surface. Plate 4 shows the sandy trough in the foreground, widening westwards. In Plate 5, a person stands where the deeply inset trough, sloping westwards behind the person, changes into an eastward-sloping sandy tongue roughly level with the surface of the convex blow-out dune.

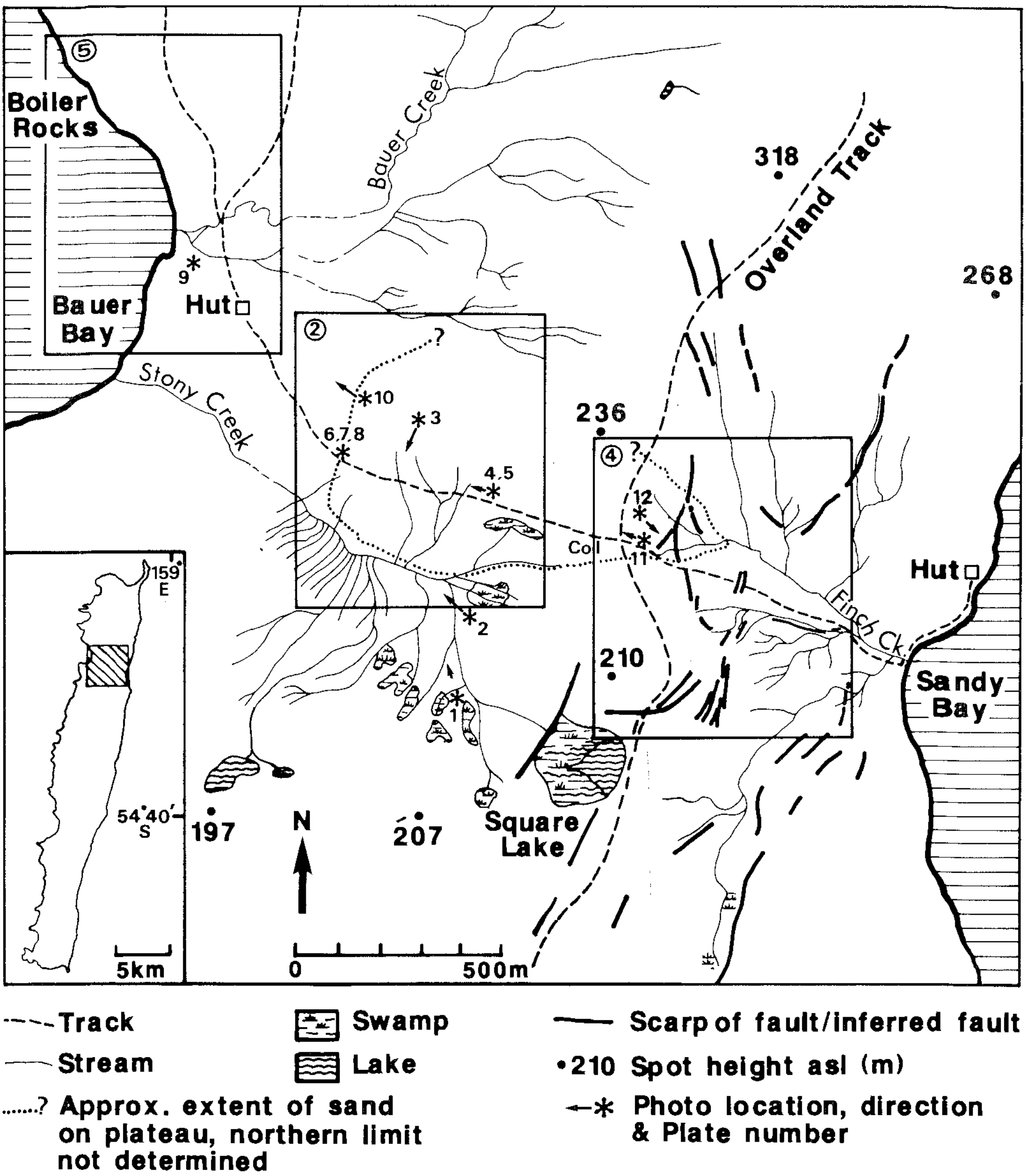

Fig. 1 — The Bauer Bay–Sandy Bay region of Macquarie Island showing the location of larger scale maps (figs 2, 4 and 5). Information for the maps was derived from: 1:50,000 map Australia, Macquarie Island, first edition, November 1971, Division of National Mapping, Canberra; from 1976 air photos; and from field work. The drainage pattern differs substantially from that shown on the published 1:50,000 map.

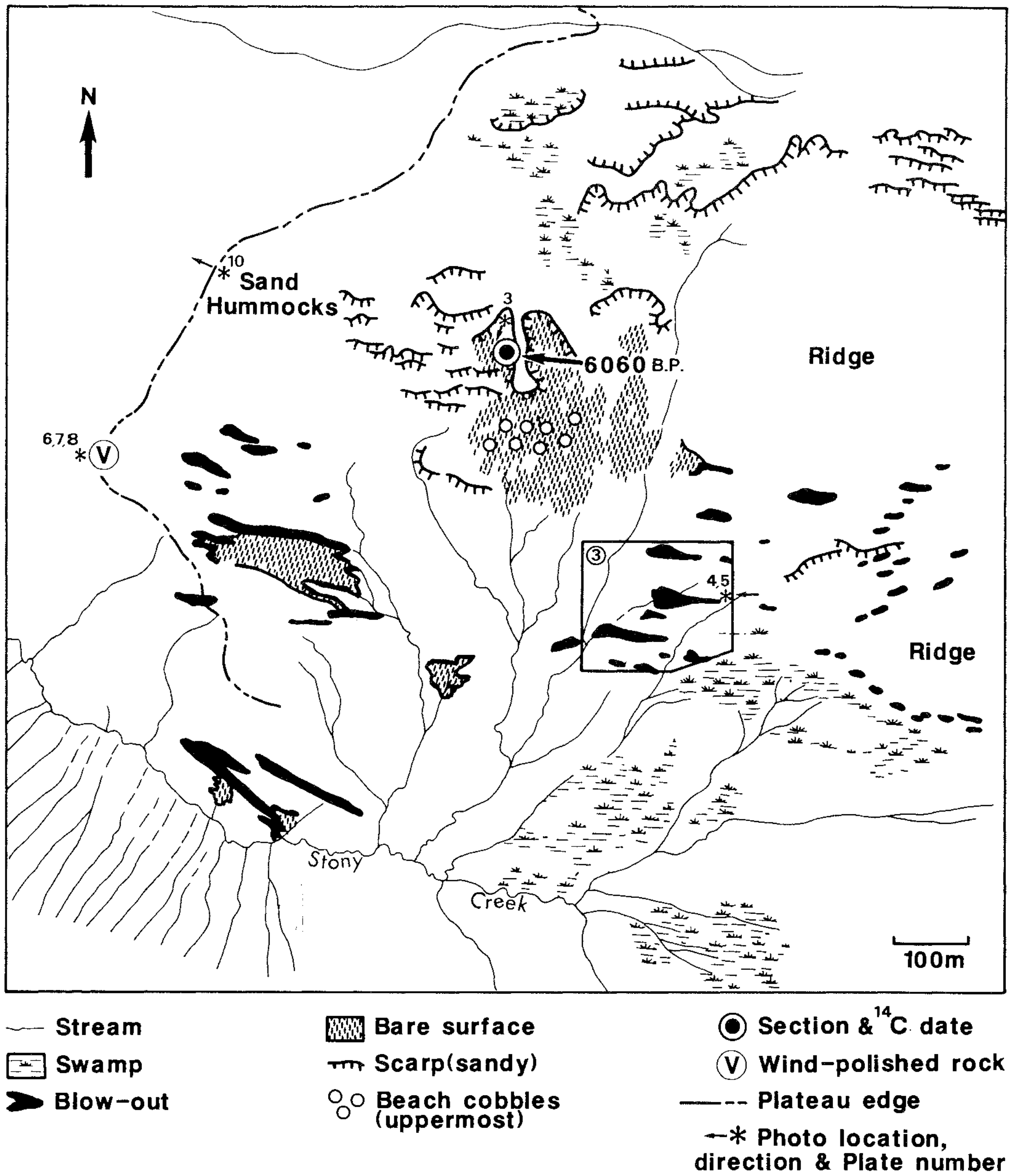

Fig. 2 — Part of the sand sheet on the plateau north of Stony Creek. Location of figure 3 is shown. The dated terrestrial peat (Beta 20167: 6060 ± 70 B.P.) occurred as a basal band 30 mm thick, 2.78 m below the surface of the sand sheet and overlying angular cobbles and weathered bedrock.

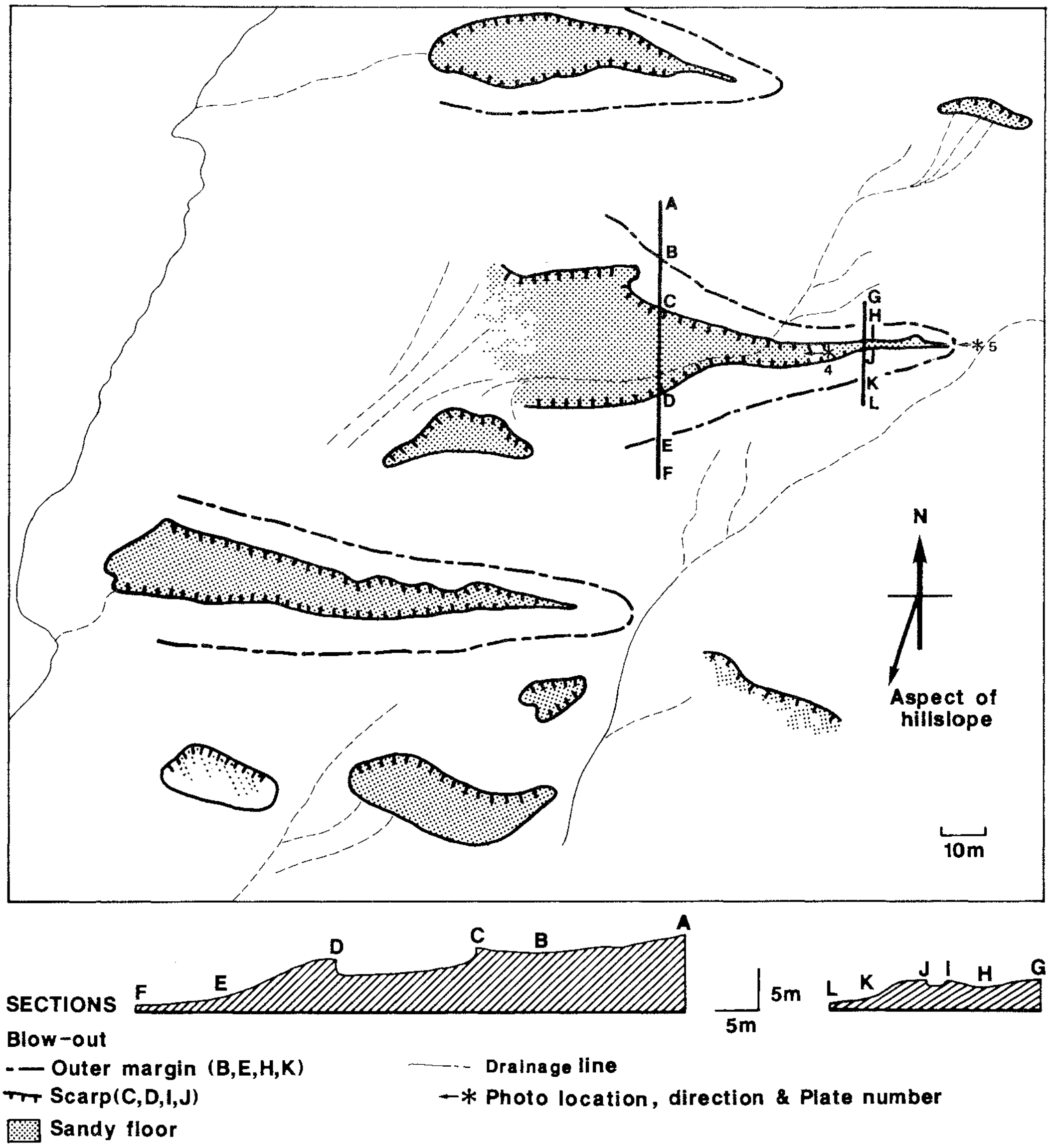

Fig. 3 — Detailed plan and sections of blow-outs on the sand sheet at about 100 m altitude on the plateau north of Stony Creek.

Starting from the wide western end, the sandy floor of the blow-out slopes very gently up towards the east, but as the V narrows the slope steepens slightly to reach a broad crest (close to the position of IJ in fig. 3 and the person in plate 5). To the east of this crest the slope falls gently towards the tip of the bare sandy tongue (plate 5) at the eastern end of the blow-out dune. The dominant and severe westerly winds accelerating into the funnel of the V-shaped trough presumably pick up sand from the gently rising western two-thirds of the trough and drop it to the east of the crest on the gentle downslope. The rising western (windward) side of the longitudinal trough is a wind erosion zone but the eastern (lee) slope is a depositional zone. So long as the sand supply is adequate, and while water erosion does not carry too much sand downhill, the blow-out trough and dune move slowly downwind towards the east, the trough progressively eating into, and blowing forward, its own dune.

The blow-outs are oriented approximately across the hillslope and, because of their convex transverse profile, pond or divert drainage (fig. 3, B and H). Ponding on the upslope side of blow-outs results in seepage of water into their troughs. Between transects AF and GL, a drainage line has broken through the blow-out dune, so that the trough westwards has become a minor creek. The floors of blow-outs also intercept subsurface water moving downslope along relatively impervious surfaces of weathered bedrock, buried peat or layers of iron-cemented sand. Consequently the floors and sides of troughs are often saturated with water, as shown in plate 4 and in plate 5 beyond the person. Water flow and seepage probably contribute to the development of blow-outs by transporting sand from the steeper sides and slopes of the trough to the gentler slopes of the floor. Borowka (1980) found that wind around 15 to 20 ms^{-1}, even for brief periods, is effective at moving sand from wet, cold (2°–6° C) surfaces, and that changes in air viscosity and density at low temperatures increase the effectiveness of cold air in moving sand. Conditions described by Borowka are similar to those on Macquarie Island. Jungerius *et al.* (1981) also noted that rain had little effect on wind erosion in blow-outs in Holland, possibly because strong winds desiccate the surface of wet sand quickly so that the effect of precipitation is short-lived.

The flanks of the blow-out are well vegetated. Only the incised trough (CD, IJ) and the narrow sandy tongue east of IJ are bare or sparsely vegetated (plates 4 and 5). Sparse colonisation is visible in the background in plate 4, at the broad

PLATE 1

Stony Creek valley looking northnorthwest to the sand-mantled plateau and hill slope (much of which is shown in fig. 2). Part of the marine terrace north of Bauer Bay is visible on the coast. The beach marked by rounded cobbles (Beach 5 of Ledingham & Peterson 1984) is shown by the large horizontal arrowhead; the eastern edge of the blow-outs mapped in figures 2 and 3, by the small horizontal arrow; the location of the dated peat (Beta 20167: 6060 $^{-1}$ 70 B.P.) near the base of the sand sheet, by the small vertical arrowhead; the wind-polished bedrock (fig. 2 and plates 6, 7 and 8), by the large vertical arrow. Locations of all plates are shown on the relevant figures.

PLATE 2

Stony Creek valley looking westnorthwest. Linear blow-outs occur on the northern (right-hand) slope, one at low level is marked by the vertical arrow. The arrowhead marks the crest of the steep southern slope, also marked on plate 3.

PLATE 3

Looking southwards across the deeply incised valley of Stony Creek, most of which is hidden. The arrowhead shows the same location marked in plate 2. The surface and base of the sand sheet is marked by two horizontal white arrows. Dated peat (Beta 20167: 6060 $^{-1}$ 70 B.P.) was excavated at this site from the base of the sand sheet. Beneath the sand sheet is a strew of angular cobbles and weathered bedrock.

western part of the trough where the sand supply has been depleted. Plate 5 shows a narrow rim of *Acaena magellanica* adjacent to the bare sand, its stolons growing onto the sandy surface. *Luzula crinita* and *Pleurophyllum hookeri* occur with *Acaena magellanica* to form a complete cover of vegetation over the rest of the blow-out dune. The vegetated eastern end of the blow-out (the deposition zone) traps sand and builds up its convex surface as fast as sand is blown from the west (the erosional zone), plant growth roughly keeping pace with sand supply. The eastern advancing tip of the dune is about 500 mm above the adjacent surface. Build-up and advance of the blow-out dune will cease when sand supply declines. In the wet environment of the island, plant growth is rapid, so that no leeward slip-slope of bare sand develops, as might occur in drier, warmer environments. Once the sand grains are blown from the trough of the

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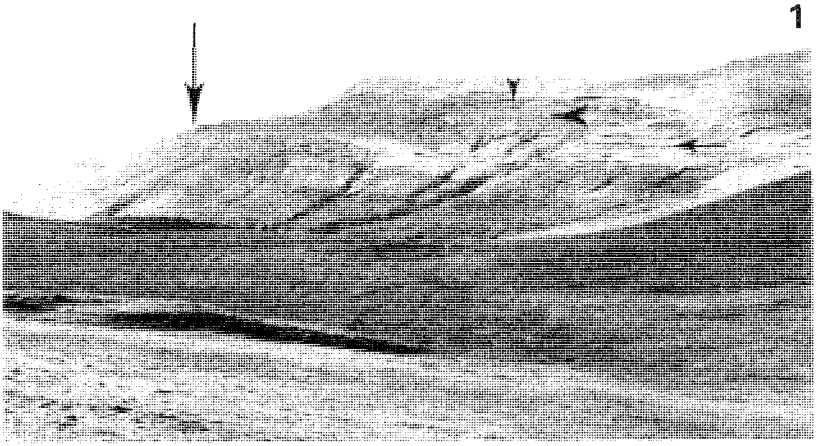

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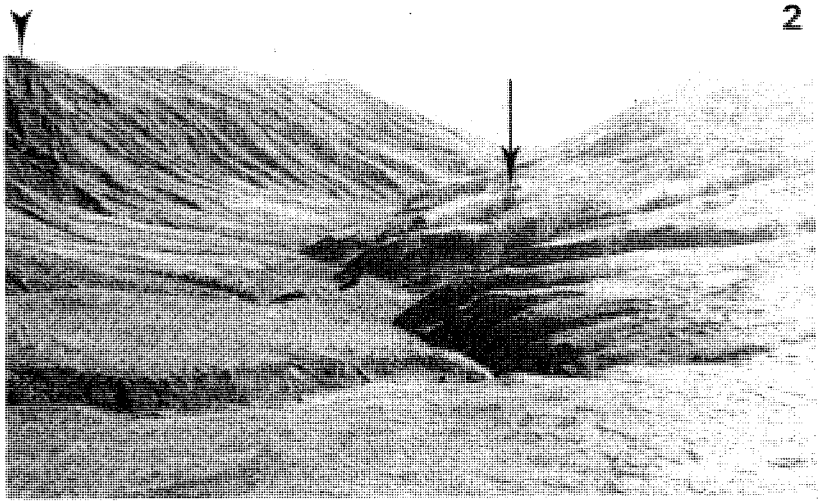

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erosional zone, they are trapped where they fall by the vegetation in the accumulation zone. At the leeward (eastern) end of the blow-out, instead of a slip-slope of bare sand, there is a broad convex apron or lobe of accreting vegetated sand.

Deepening of the trough of the blow-out is limited by the depth of poorly consolidated sand. When a resistant surface of any sort is reached, the trough widens rather than deepens. Wind acceleration is less than it would be in a narrow trough, water erosion becomes relatively more important than wind erosion, and the possibility of plant colonisation of the now more stable surface increases (plate 4, background). By this stage, the most active part of the blow-out is further east. Several blow-outs may coalesce. A bare area in figure 2 (about 300 m west of the location of fig. 3) probably represents such an area, with much of the sand washed down towards Stony Creek. Near the cobble beach, the broad area bare of vegetation, bounded by sandy scarps, probably resulted from a long period of aeolian reworking of the sand deposit and sand removal by sheet and gully erosion.

Bedrock Polished and Grooved by Wind

Colhoun & Goede (1974) first recorded wind-polished and grooved rocks at the plateau margin above Bauer Bay. These bedrock exposures occur at about 100 m a.s.l. beside the Bauer Bay–Sandy Bay walking track, a few metres below the ridge/plateau crest at the top of the steep climb out of Bauer Bay, about 500 m southeast of the hut (figs 1 and 2). The polished surfaces of these rocks are fully exposed to the prevailing west to west-northwest wind. Plates 6, 7 and 8 show that wind-driven sand is not active at the site today, nor was it in the recent past, because ventifacted surfaces are colonised by large lichen colonies up to 250 mm in diameter and by moss clumps which encroach on the polished surfaces for over 100 mm (plate 8). The linear wind-eroded grooves are 40 to 120 mm in length, up to 25 mm wide and about 10 mm deep (plate 7) attesting to the severe erosive effect of blown sand. Similar erosional marks in the form of elongated pits on wind-polished rock are common in polar sandy deserts of Antarctica (Selby 1977, Pickard 1982, Adamson & Pickard 1986). The linear grooves visible in plates 6 and 7 are oriented at 310°, parallel to the present prevailing wind, leading to the conclusion that the dominant wind direction has not altered since their formation.

Wind-polished rock also occurs a couple of metres above sea level, about 100 m inland from the present high tide limit, on the sandy plain in Bauer Bay (plates 9 and 10, figs 1 and 5). This contemporary polish is less well developed than on the fine-grained rock at high altitude, because the rock near sea level is coarse-grained and may have been exposed to wind for a relatively short time. Ventifact formation on this sand plain confirms the ability of strong winds to move sand from normally wet surfaces in the moist cold environment of Macquarie Island and illustrates one situation in which wind-polish by blown sand can occur.

Sand Hummocks

Mounds of sand up to 1 m tall, covered by dense *Acaena magellanica*, form a hummocky landscape below bare slopes in the headwaters of Finch Creek (plate 11, fig. 4). Hummocks vegetated by *Poa foliosa* occur near the plateau edge overlooking Bauer Bay (fig. 2). In the case of hummocks covered by *Acaena*, the plant's ability to trap sand blown from adjacent unvegetated surfaces accounts for hummock growth. Juxtaposition of bare erosional and depositional surfaces is particularly clear near the intersection of the Overland and Bauer Bay–Sandy Bay tracks (fig. 4). Sand moved across the plateau from the west cascades eastwards down 15° slopes into the upper valley of Finch Creek (plates 11 and 12). Mobile sand is either washed into the upper tributaries or blown into, and trapped by, the dense vegetation.

Radiocarbon dated peat (Beta 20159: 5680 ± 80 B.P. or 6575 ± 225 B.P. when calibrated following Klein *et al.* (1982), from 6.52 m below the base of the modern vegetation, see arrow in plate 12 and fig. 4) at the base of the hummocky sand sheet shows that sand transgressed the site at least 6500 years ago. Since then sand has been supplied to and stripped from the slope by wind and water erosion, with periods of stability as shown by a date of 3230 ± 90 B.P. on peat at a depth of 3.88 to 3.91 m (Beta 20160). At present the site is being eroded by water and wind, revealing the stratigraphy of the interbedded peats and sands.

Residual sand hummocks also occur on the sandy plain near sea level in Bauer Bay (fig. 5) and on the plateau where sandy scarps mark remnants of a formerly more complete surface (fig. 2).

On the plateau edge above Bauer Bay, and draped for a short distance down the steep slope below, is a sand deposit with a form reminiscent of a climbing dune. Alternatively, it may be a relic of a more extensive mantle of sand on the steep seaward slopes leading up to the plateau. This dune-like feature is adjacent to an area of hummocky sand

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PLATE 4

Blow-out. The person is near location D in figure 3. Free water on the sandy surface of the trough within the blow-out is shining. Sparse revegetation is visible in the wide western part of the trough in the middle distance. The vegetation most clearly visible is Pleurophyllum hookerii *(white arrow) and* Acaena magellanica *(black arrow).*

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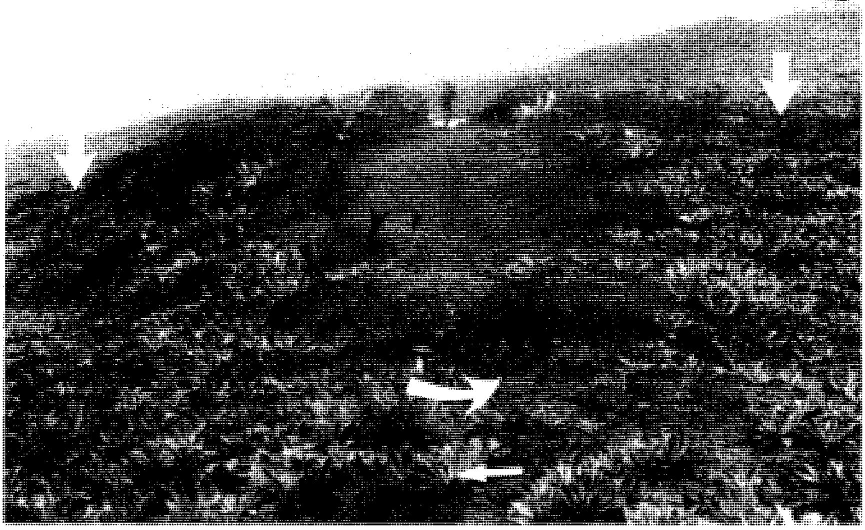

PLATE 5

Blow-out viewed from beyond its eastern end, looking westwards. The person is a few metres west of IJ in figure 3. The approximate positions of H and K in figure 3 are shown by broad white arrows. The small arrowhead points to Acaena magellanica *colonising bare sand, the large arrowhead to mixed* Luzula crinita *and* Acaena, *and the small white arrow to* Pleurophyllum hookeri. *The curved white arrow indicates the eastern advancing tip of the blow-out.*

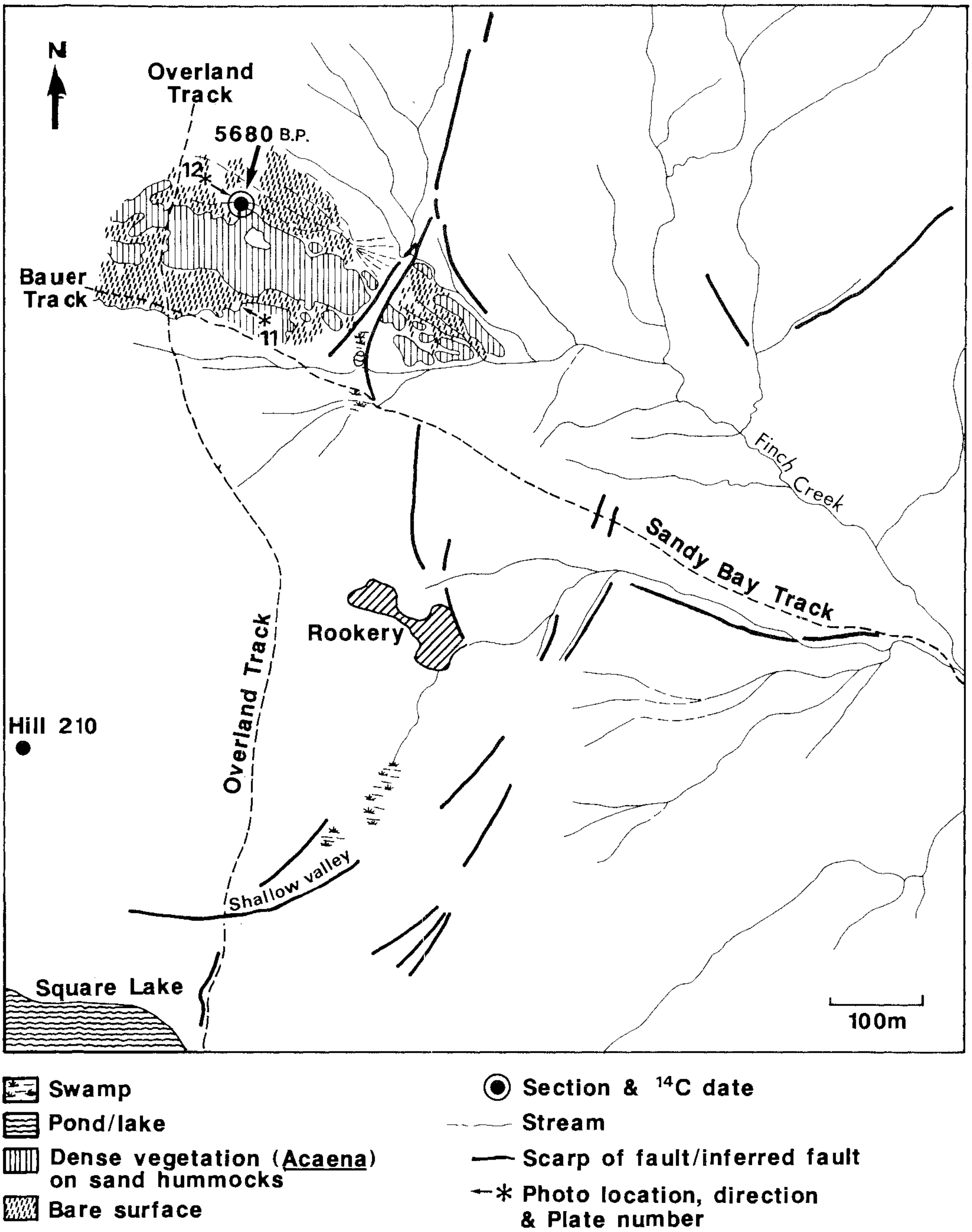

Fig. 4 — Sand and fault scarp distribution in the upper part of Finch Creek on the eastern side of the island. The dated peat (Beta 20159: 5680 ± 80 B.P.) occurred beneath 6.52 m of sand transported from upslope (west), probably mainly by wind action.

PLATE 6

Wind-polished rock surface to the left (westnorth-west) of the ridge, to the right there is no polish. The pocket knife in plates 6, 7 and 8 is 80 mm long. Arrow shows present dominant wind direction. Location of plates 6, 7 and 8 is shown in figure 2.

PLATE 7

Same site as plate 6, showing wind-eroded linear grooves and the polished rock surface. The pointed end of each groove (small arrows) is downwind. Present dominant wind direction is parallel to the long axis of the grooves.

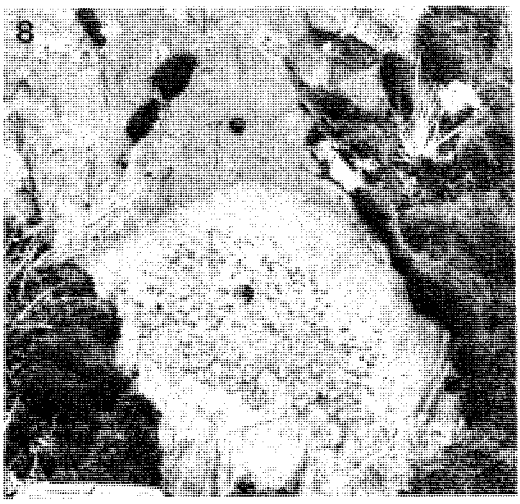

PLATE 8

Lichen and moss growing over the wind-polished surface of the rock.

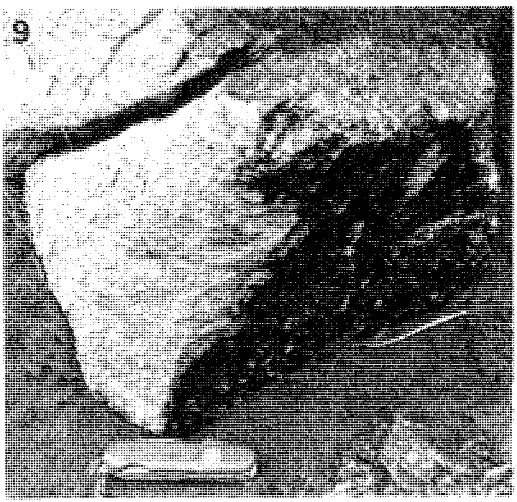

PLATE 9

Wind-polished surface on the windward (left) side of rock about 100 m from the present shore in Bauer Bay. Location shown in figure 5. Knife 80 mm long.

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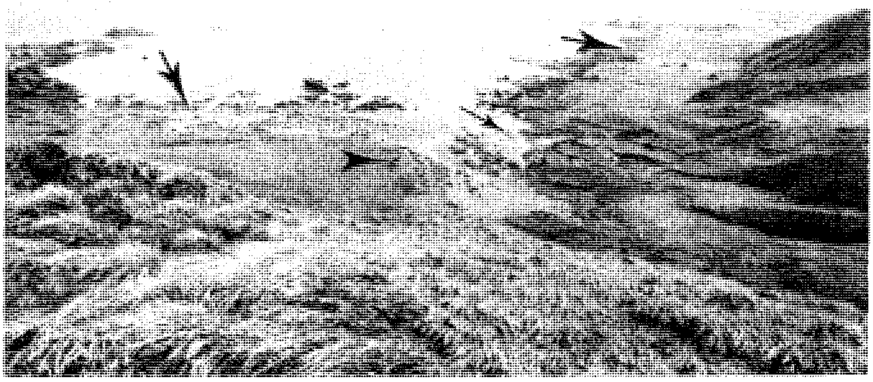

PLATE 10

The view westwards over Bauer Bay and the marine terrace from the sand hummock area at the edge of the plateau (fig. 2). Bauer Bay hut (arrowhead), the wind-polished rocks (small arrow), and the approximately north and south limits of figure 5 (large arrows) are indicated.

vegetated by *Poa foliosa* on the plateau (fig. 2, location of plate 10), and lies about 300 m northnortheast along the plateau edge from the ventifacted rocks. This area merits thorough investigation.

TECTONIC LANDFORMS

Faulting has affected landforms on Macquarie Island (Ledingham & Peterson 1984). The Bauer Bay–Sandy Bay region is crossed by a major, possibly faulted, geological contact between basalt and pillow lavas to the south and intrusive rocks to the north (Varne & Rubenach 1972, Christodoulou *et al.* 1984, Crohn 1986). The eastern half of the region shown in figure 1 contains numerous curving linear scarps ranging from one to many metres in height, which we interpret as fault scarps. They traverse the undulating topography, sometimes conforming to the orientation of topographic features such as streams or valleys, but also crossing hillsides, ridges and valleys to disrupt pre-existing topography. Sets of scarps often have coherent orientations over several kilometres. Some of these are undoubtedly young fault scarps with oversteepened, poorly vegetated slopes. Exposures of fault planes and breccia occasionally occur in gullies cut into these scarps.

Most scarps of faults and inferred faults shown in figures 1 and 4 are not oriented in the direction of the major lithological contact crossing the island between Bauer and Sandy Bays, suggesting that this major geological boundary has not been active in the recent past. Recent fault movement has occurred most commonly in a north-northwest to northeast direction in this part of the island.

The curving scarp that is crossed by the Overland Track just northeast of Square Lake and southeast of Hill 210 forms the southern side of a shallow valley leading down to the uppermost royal penguin rookery and into a branch of Finch Creek. Two further traces of this lineament curve northward and cross the ridge occupied by the Sandy Bay Track. Here the lineaments are expressed as slight but distinct notches on the ridge crest. The continuity of these lineaments is clear on aerial photographs. These may be interpreted as fault scarps, and the shallow valley as fault-bounded. Colhoun & Goede (1974, plate 3) interpreted this valley as a meltwater channel cut into the rock of the southeastern spur of Hill 210 during retreat of ice from the Finch Creek valley to Square Lake. Ledingham & Peterson (1984, p.230) thought that a small corrie glacier may have existed in this area, one of the very few areas on Macquarie Island where they considered that glaciation may have occurred. The present authors prefer a tectonic explanation for this lineament, because of the apparent continuity from the wall of the shallow valley to the notches in the ridge referred to above

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PLATE 11

Sand hummocks (location fig. 4) vegetated by Acaena magellanica. *The person is standing in a narrow trough between adjacent hummocks. Sand blown from the west (background) accumulates on the hummocks, or overwhelms the vegetation (right-hand foreground).*

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PLATE 12

An eroded sand deposit in the headwaters of Finch Creek, looking eastsoutheast into Sandy Bay. Buried sandy peat horizons with undulating surfaces are visible in the exposure. A radiocarbon date of 5680 ± 80 B. P. (Beta 20159) was obtained from near the base of the sand (arrow), 6.52 m below the present vegetation.

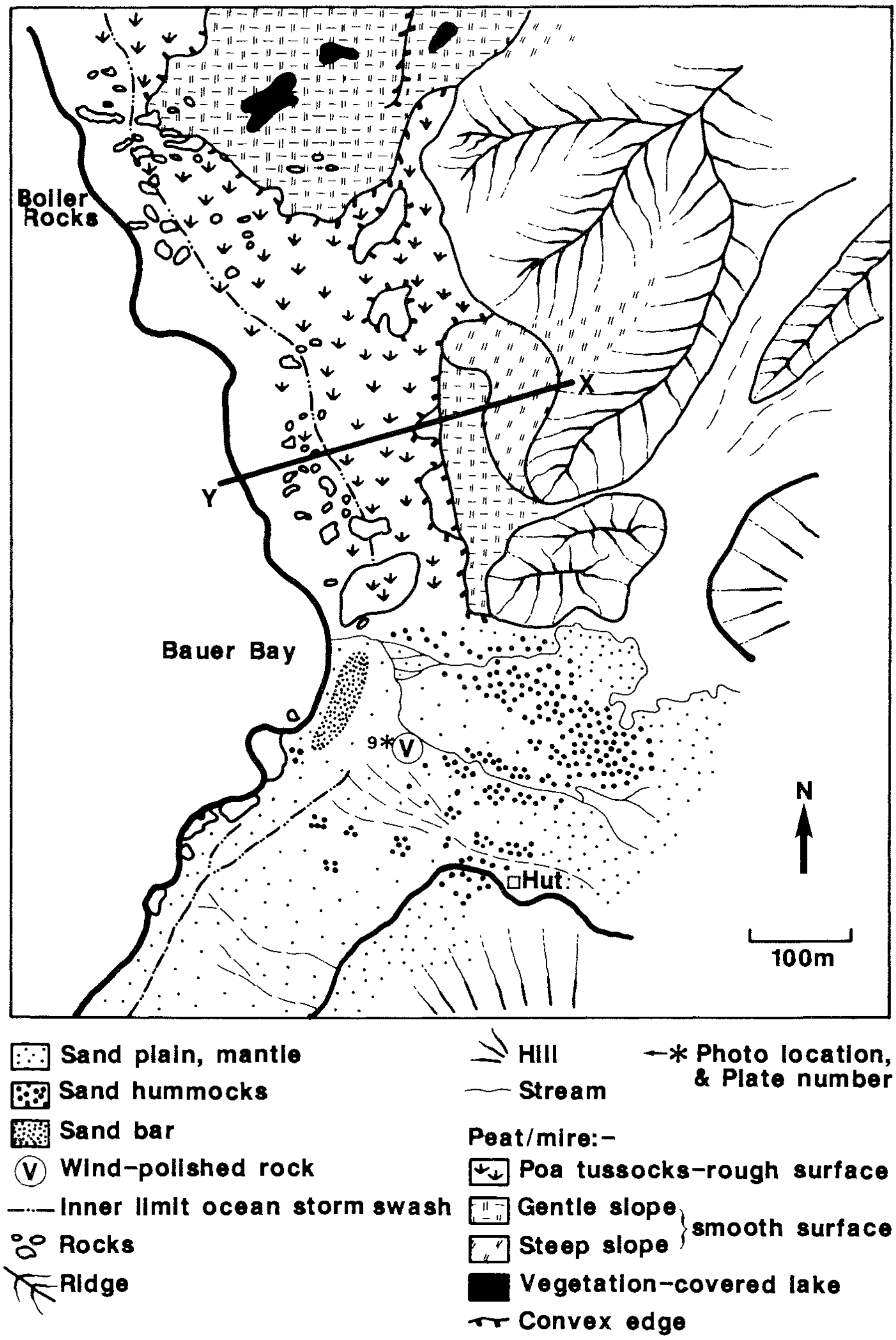

Fig. 5 — The raised marine terrace at Bauer bay, mantled by sand and mire. Section XY is figure 6.

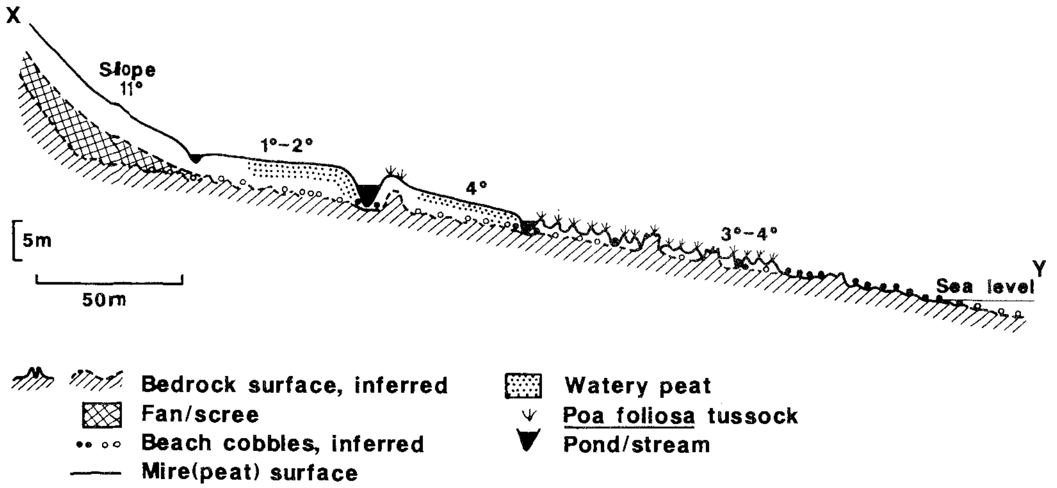

Fig. 6 — Section XY (fig. 5).

(fig. 4), and conclude that landforms in this area show evidence of tectonic activity not glaciation.

This is particularly obvious near the head of Finch Creek, where displacement along minor fault scarps disrupts drainage and sand distribution (fig. 4). There is minor ponding and swamp formation between the faults, and disruption of drainage and sand accumulation upslope and below them. Slightly offset faults continue southwards as low scarps, one forming the eastern edge of the royal penguin rookery.

MARINE LANDFORMS

On the northwest coast of the island, a terrace or platform up to 1 km wide rises gently, at slopes of 2° to 4°, from the shoreline to about 15 m a.s.l. (figs 5 and 6, plate 10). The platform is backed by steep slopes or cliffs at the plateau margin. It is mantled by rounded cobbles which can be located most easily where drainage channels and ponds prevent thick peat accumulation. The terrace is also dotted with numerous rock stacks. It is inferred that wave action in the past cut the platform, rounded the cobbles which mantle it, etched the stacks, and formed the steep slopes and cliffs by eroding their bases. The broad, gently-sloping platform and the steep slopes at its back are landforms of coastal erosion.

The steep slopes have been modified by water erosion and earthquakes to produce fan and scree deposits mantling the inner edge of the platform (fig. 6). At the head of Bauer Bay, the platform is covered by sand, now being redistributed by wind and water erosion. Here Colhoun & Goede (1973) determined the altitude of a former upper marine limit as 9 m above present sea level. The less sheltered conditions away from the head of the bay may help account for the slightly higher limit now estimated at transect XY (figs 5 and 6). Away from Bauer Bay, cover on the terrace is a complex mosaic of ponds, drainage channels and various types of mire. Vegetation on the platform includes wet tussock grassland of *Poa foliosa*, forming rough hummocky surfaces over large areas, particularly near the shore. Elsewhere the vegetation has a smoother surface covered by a wide range of plant communities, depending on hydrology, from relatively well-drained herbfield to water-saturated quaking bogs and vegetation-filled ponds (figs 5 and 6; Taylor 1955, fig. 6). Plant alliances and associations on the marine terrace have been described by Taylor (1955).

THE AGE AND ORIGIN OF LANDFORMS

Global sea-level fluctuations and uplift of the island are two independent processes which set constraints on the development and age of Macquarie Island landforms. Global sea-level fluctuations are well known in general terms (Chappell 1983). Radiocarbon dating of uplifted deposits that were once near sea level gives estimates of Holocene uplift rates for the island (Colhoun & Goede 1973, Selkirk *et al.* 1983, Bergstrom 1986).

For the main island, radiocarbon dating gives estimates ranging from 1.5 to 6 mma^{-1}. The authors of this paper find the lower end of the published range of rates for uplift of the main island more plausible in the light of field observations in 1986–87. A second method of estimating uplift rate depends upon measuring the present altitude above sea level of wave-cut features that were being formed when the sea reached its present high level, about 6000 to 7000 years ago. The landward edge of the rock-cut marine terrace north of Bauer Bay is estimated to be between 10 and 20 m a.s.l. (fig. 6). Colhoun & Goede (1973) measured an upper marine limit in the sandy area at the head of Bauer Bay of 9 m. Altitudes between 10 and 20 m give uplift rates between 1.7 and 3.3 mma^{-1}. For the purposes of this discussion two values, 3 mma^{-1} and 4.5 mma^{-1} (Colhoun & Goede's (1973) maximum rate), are arbitrarily selected.

Figure 7 superimposes average uplift rates for the island, assuming no tilting, of 4.5 and 3 mma^{-1} upon the global sea-level curve for the late Quaternary (Chappell 1983). It focusses on two main locations, the landward edge of the marine-cut rock terrace at between 10 and 20 m altitude, and the sand sheet on the plateau at between 100 and 120 m altitude.

The relation between sea-level rise and island uplift could explain the genesis of the broad, gently-sloping coastal terrace. For much of the time between 15 000-16 000 and 7000-8000 years ago sea level rose faster than the land by at least 10 mma^{-1} (fig. 7). The result may have been prolonged and extremely vigorous marine erosion of the coast of the already elevated island, reflected by unusually rapid coastal cliff retreat, dispersal of the collapsed debris by wave action, and the planation of a bedrock terrace with a slope determined by the rate of gain of sea over land and the resistance of the bedrock to erosion. The measured seaward slope of the terrace ranges from about 1.5° to 4°. The width of the terrace depended on the duration (some 8000 years) of vigorous erosion by the rapidly rising sea. The base of the existing steep slopes and cliffs marks the end of terrace formation which occurred when sea level stabilised 6000 to 7000 years ago, but the land kept rising. The full width of the terrace can be estimated from the length of time when it was presumed to be forming (about 8000 years), the gain of sea over land during that time (about 10 mma^{-1}), and the terrace's slope (between 1.5° and 4°). These values predict widths between about 1000 and 3000 m. The width now exposed above sea level north of Bauer Bay ranges from about 200 to 1500 m. The model proposed, therefore, predicts that the terrace extends offshore, at the same slope as onshore, for between two and five times its onshore width. Its seaward edge probably lies between 70 and 120 m below present sea level. The few soundings northwest of the island are consistent with these predictions, but detailed soundings, which the authors hope to carry out in the future, would provide a simple test of the model.

According to this model, during the period when sea level was rising rapidly relative to the land, a strip of high plateau equal to the width of the terrace was destroyed by the sea continually eroding the base of the retreating plateau. In this way, former lakes on the plateau were destroyed, explaining the presence of fragmentary terminal Pleistocene and early Holocene lake deposits, now exposed at the top of the cliffs, and steep slopes flanking the plateau (Selkirk, Selkirk, Bergstrom & Adamson, this volume). Valleys such as that of Stony Creek were also deepened. A problem with this model is that it requires very high rates of cliff retreat of between 100 and 400 mm per annum. A combination of steady net submergence, fault-fractured and crushed rock, and the extremely high wave energy on a west-facing coast at 54°S may make this possible.

Debris from rapidly retreating cliffs would have been effectively reworked by wave action. While much would have been lost into deep water, long-shore drift and local wave action would have delivered copious sand to the Bauer Bay region where the prograding sea pushed it landwards into Bauer Bay. The sand sheet on the plateau between Bauer Bay and the head of Finch Creek and the wind-polished rocks at about 100 m altitude on the plateau edge may have originated in the early Holocene, if the volume and rate of sand arriving onshore was sufficient to overwhelm vegetation and allow sand to climb onto the plateau. The age of about 7000 years ago on peat beneath the sand sheet (Beta 20167) is consistent with this suggestion. Alternatively the high-level sand may derive from an earlier period about 40 000 years ago, or earlier, during emergence of this upper part of the island from the sea (fig. 7). Radiocarbon dates obtained from peats buried in or below these sands do not yet distinguish between these two possibilities because of possible reworking of the sand deposit, but the cobble beach below the sand (Beach 5 of Ledingham & Peterson 1984) almost certainly dates from the earlier period. Research in this interesting area may further resolve the age and origin of the sand sheet. What is plain from the dated peats included in the sands is that the sand was present and being reworked eastwards from between 6000 and 7000 years ago to the present.

The presence of the broad, partly emerged marine terrace along the northwestern coast implies relatively uniform uplift since formation of the

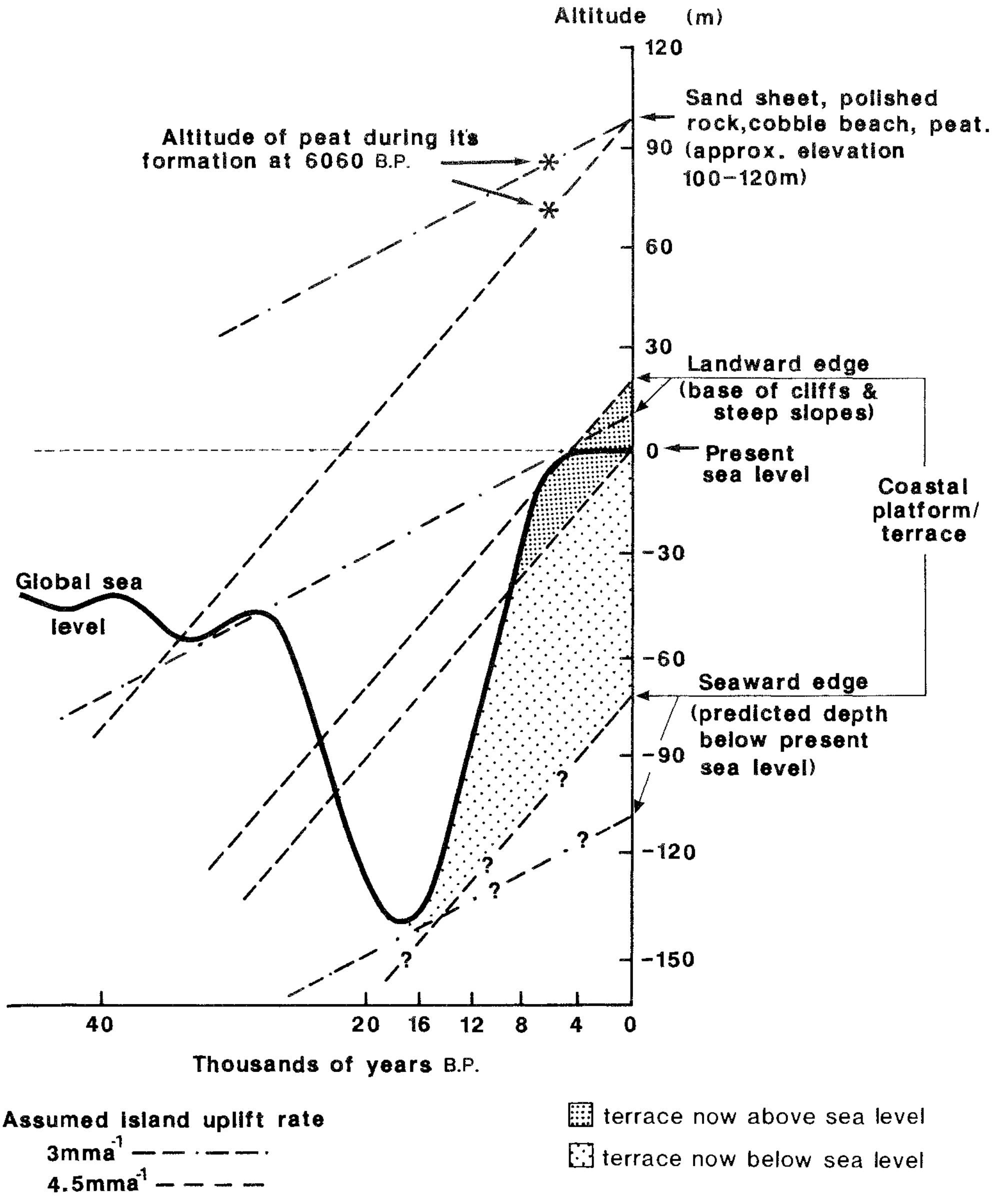

Fig. 7 — The relation between time, global sea level and the level of the land north of Bauer Bay during the terminal Pleistocene and Holocene. The sea-level curve is highly simplified. Stippling shows the terrace cut by marine erosion; an uplift rate of 4.5 mma and an upper limit of former marine erosion of 20 m above present sea level are assumed. Alternative time lines for the terrace are shown assuming values of 3 mma^{-1} and 10 m. Two estimates of the altitude of the dated peat (Beta 20167) on the plateau north of Stony Creek at the time of its formation are also shown. With the uplift rates adopted, the cobble beach would have been at sea level about 40 000 years ago or earlier.

terrace began about 16 000 years ago, according to the model we presently favour. As the exposed landward fringe of the terrace is preserved undisrupted, differential vertical movement along faults must have been minor during and since its formation. The absence of a broad raised terrace on the east coast implies more active differential vertical movement on faults, the absence of steady uplift during the period when sea level was rising rapidly, slight tilting of the island downwards to the east, or a combination of these processes. Fault movement on the island parallel and close to the east coast is active today. The major western faulted margin of the island block must lie west of the marine terrace.

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