GLACIOLOGICAL OBSERVATIONS AT ADMIRALTY BAY, KING GEORGE ISLAND, IN 1957–58

By H. M. Noble

ABSTRACT. Two glaciers on King George Island, South Shetland Islands, are described. One is a tidal glacier of the outlet valley type (Stenhouse Glacier) and the other is a small cirque glacier (Flagstaff Glacier) close to it. Measurements of accumulation and ablation during 1957–58 are given together with an outline of the prevailing meteorological conditions. Tentative budgets for both glaciers are put forward, and a few general conclusions concerning the state of these two glaciers are drawn from the available data.

KING GEORGE ISLAND, the largest of the South Shetland Islands group, is 80 km. long and 30 km. wide with its major axis in an east-north-east direction. Most of the island is covered by an ice dome rising to 600 m. above sea-level. The northern coast is a uniform arc fringed with ice cliffs and occasional offshore reefs, which contrasts strongly with the jutting capes and deep inlets of the south coast. The largest of these inlets is Admiralty Bay which is divided at its head by a relatively ice-free promontory about 3 km. long, known as Keller Peninsula.

Since 1948 meteorological observations have been made at a site on the east coast of Keller Peninsula as part of the scientific programme of the Falkland Islands Dependencies Survey. In 1957 King George Island was selected as one of the localities for additional glaciological observations in connection with the International Geophysical Year, and it is with these that this report is concerned.

WEATHER

The South Shetland Islands lie directly in the path of a series of westerly depressions, which bring high winds and heavy precipitation. Thawing can occur at sea-level throughout the year and at any altitude in summer. The maximum temperatures for each month are remarkably constant at about +4° C. In contrast with this, the minimum monthly temperatures drop sharply during the winter and are usually associated in winter with periods of cold, calm weather and bright sunshine. Court (1951) has described the area as one where "anticyclonic lobes or cells form during moderate or low index conditions". During these spells katabatic winds commonly discharge from areas shielded from direct sunlight.

Another important feature is the frequent formation of rime on the ice cap. This usually occurs during the passage of a depression. Maling (1948), referring to Signy Island where conditions are similar, has pointed out that rime, forming above the cloud base, not only adds appreciably to accumulation but also covers steep rock outcrops where snow cannot collect and therefore increases the albedo of the region, which in turn retards ablation.

THE FORMER EXTENT OF GLACIERS

Extending upwards for 30 m. from the present surface of Stenhouse Glacier there is a zone of relatively lichen-free rock. Rock outcrops at sea-level bear striations which run parallel to the shore. This would indicate that at one time the massive glaciers at the head of Admiralty Bay extended down either side of Keller Peninsula, and this is further supported by the overdeepening of the bay. The presence of a raised beach less than 10 m. above sea-level suggests a general reduction of the ice cover.

GLACIOLOGICAL OBSERVATIONS

Observations were made on two glaciers situated close to the British station at Admiralty Bay (Fig. 1) during the period 3 March 1957 to 31 March 1958. The glaciers chosen for investigation were:

i. Stenhouse Glacier.

ii. Flagstaff Glacier.

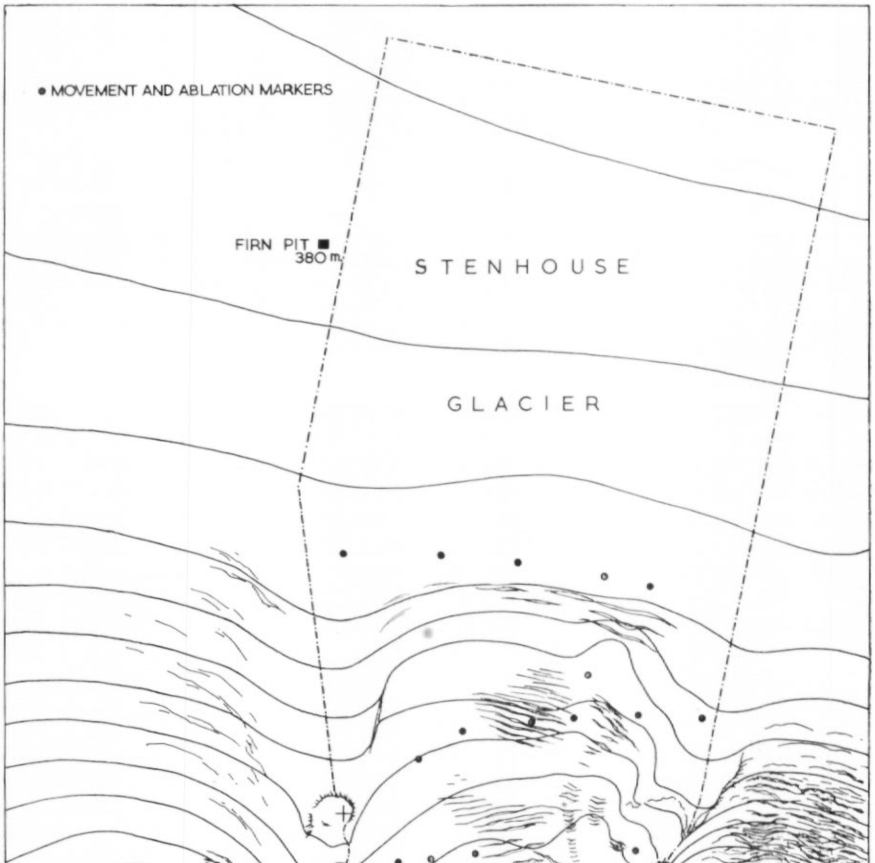

Fig. 1. Sketch map of the northern Admiralty Bay area, King George Island, showing the positions of Stenhouse and Flagstaff Glaciers, and the sites of marker stakes on Stenhouse Glacier. Form lines are at approximately 30 m. intervals. The stippled areas are exposed rock and scree.

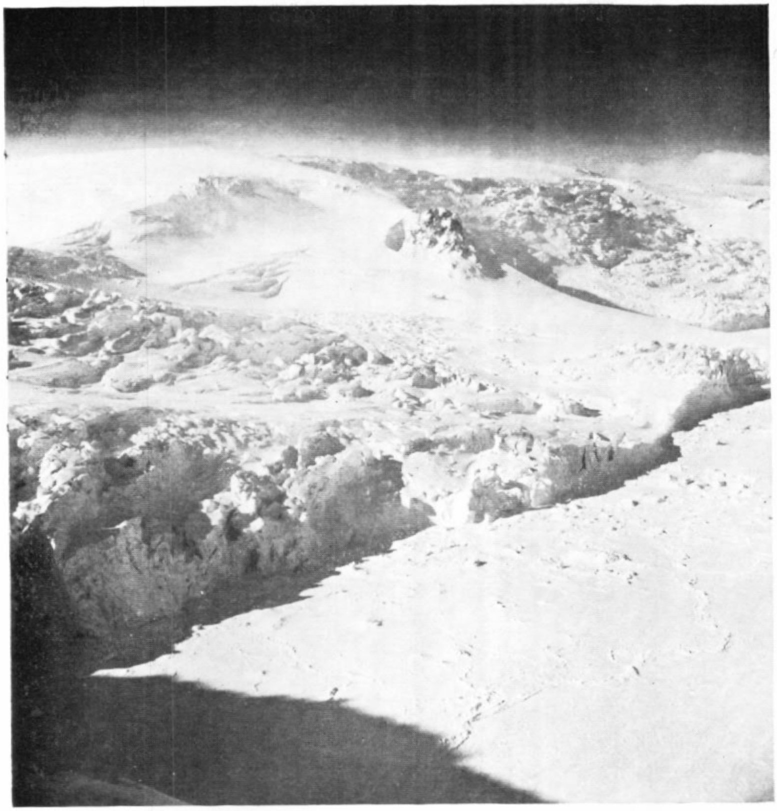

Fig. 2. View of the snout and lower parts of Stenhouse Glacier from the northern end of Keller Peninsula. 3 October 1957.

Stenhouse Glacier

Stenhouse Glacier (Figs. 1 and 2) is of the "outlet valley" type (Ahlmann, 1948); for the purposes of study it can be conveniently subdivided into two parts:

i. The "ice field", which is an ill-defined area lying between 450 and 600 m. above sea-level and estimated to be 4×10^6 m.$^2 \pm 20$ per cent in size.

ii. The "outlet valley", which breaks away from the main ice cap at a height of 450 m. and flows in a stream 1·5 km. wide and 2·0 km. long to debouch into Visca Anchorage in Admiralty Bay immediately to the east of Keller Peninsula. It is highly crevassed and fast flowing. The ice cliff which forms its termination stands in deep water and is of irregular height.

The average angle of slope in the lower part of the glacier is 12° and, because of its southerly aspect, this results in the sun's rays having a very high angle of incidence (minimum 50°). For many months the glacier receives no direct sunlight at all, and consequently the firn line is lower than might have been expected.

1. *Accumulation*

i. Stakes, which were drilled into the ice or firn to a depth of 1 m., were used to record both accumulation and ablation over the budget year. The greatest value for accumulation, 2·0 m. of snow (1·2 m. of water), was recorded in the area of the glacier below the "step" where the lower part of the glacier breaks away from the ice cap. A large proportion of this was due to the deposition of drift snow swept down from the ice cap.

ii. A pit was dug at an approximate height of 380 m. on the ice cap in June 1957. The maximum depth reached was 10 m. Annual layering was difficult to recognize, because of the profusion of ice layers resulting from random thaws and rime formation, but a tentative interpretation based on grain-size variation was made, and this is shown in Fig. 3.

iii. Rime formation occurred frequently on the ice cap but not at sea-level. No way was found for measuring accurately the density of the ice layers caused by this rime and as a result the average density of the various snow layers must be higher than the figures given in Fig. 3.

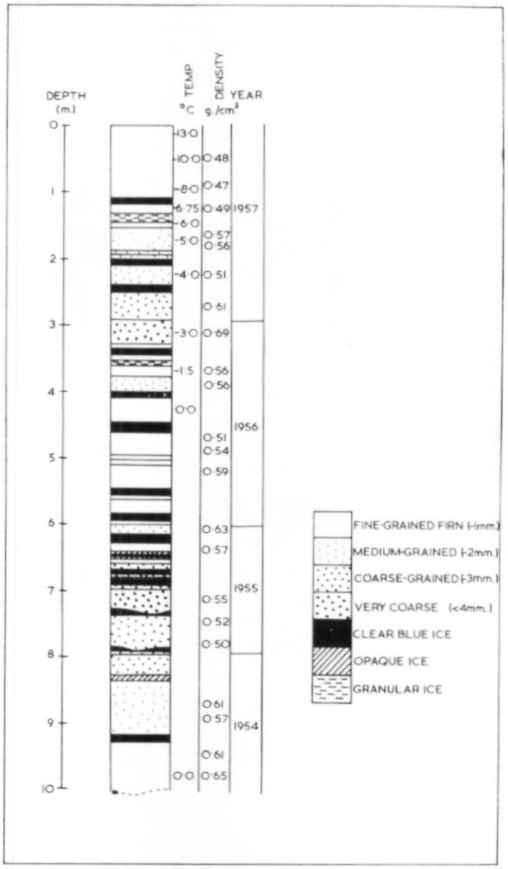

Fig. 3. Profile of a firn pit dug on Stenhouse Glacier at a height of 380 m. a.s.l. on 21–26 June 1957.

Re-freezing of melt water. Sverdrup (1935) has shown that the disappearance of the "cold wave" from the surface regions of firn is largely due to the latent heat released by the re-freezing of melt water. It is assumed in this case that the obliteration of the "cold wave" as it existed on 14 November 1957 was due entirely to this.

Assuming the density of firn is 0·5 g./cm.³ at 0–4 m. depth, 0·6 g./cm.³ at 4–5 m. depth and the specific heat of ice is 0·48 (Sverdrup, 1935), then the quantity of melt water which re-froze and therefore should be added to the accumulation (as measured in other ways) is 0·04 m. of water.

Method of measuring the density of firn. Square blocks were cut from the side of a pit with a bread-knife, measured with a hand rule and weighed on a spring balance. The resultant error was calculated at ±10 per cent.

2. *Ablation*

Melting. It was difficult to determine the mass of ice removed from the surface of the glacier by melt and sublimation processes, because the ablation zone was highly crevassed and dangerous. Stakes placed here rapidly became inaccessible and finally dropped over the terminal ice cliff. However, one stake placed in slow-moving ice 69 m. above sea-level survived for the whole year and at this point no net change in surface level was recorded. It was assumed from this evidence that the loss of ice due to these processes was slight. Further attempts to measure surface loss were therefore abandoned and attention was directed to the problem of the mass lost by calving, which proved to be very large.

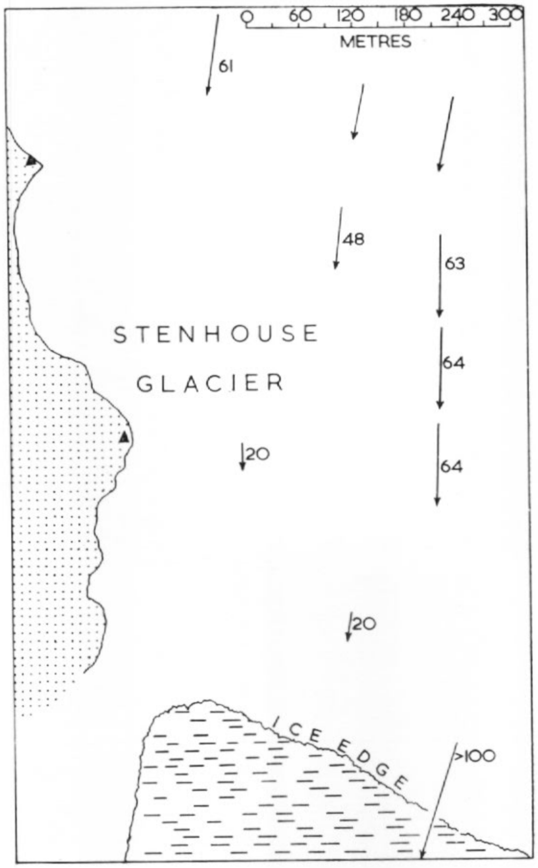

Fig. 4. Sketch map of part of Stenhouse Glacier (see Fig. 1), showing the velocity vectors in cm./day for 1957–58. The stippled area is exposed rock and scree.

Movement of ice at the glacier's surface. From mid-August until December 1957 movement observations were made at roughly 14-day intervals using a pattern of flagged stakes (Figs. 1 and 4). Another observation was made on 26 March 1958 in order to calculate the average movement over the summer months. The rate of flow showed no significant change with temperature or season.

The observations suggest that there is a slight acceleration towards the snout of the glacier, and measurements made using stake No. 2 (Fig. 4) before it was lost over the ice cliff in May 1957 indicate that this acceleration is more marked in the summer months when the glacier is calving actively.

Changes in the position of the terminal ice cliff. During February and March 1957 the glacier calved violently, but this activity decreased after 22 March when the sea temperature dropped below 0° C. By the middle of May calving had almost ceased, and the temperature of the water in Visca Anchorage continued to fall until it reached the freezing point of sea-water on 6 June.

As soon as calving activity declined the ice cliff began to advance. Fig. 5 shows its positions at different times according to plane-table surveys. On 23 August the net advance was approximately 80 m. and by 14 December this had increased to 150 m. By this time, however, the glacier's edge had become fractured and in several places large parts appeared to be only just attached to the main body of ice.

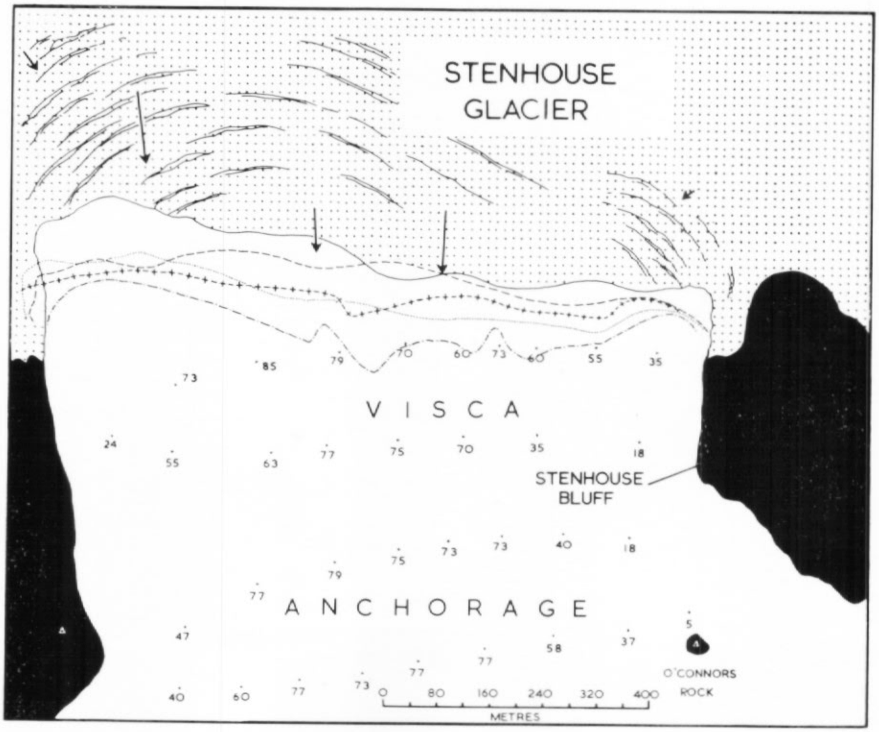

Fig. 5. Sketch map of the snout of Stenhouse Glacier, showing the positions of the frontal ice cliff at different dates: solid line, 1 April 1957; dashed line, 17 May 1957; dotted line, 23 August 1957; dot-dash line, 14 December 1957; cross-dash line, 27 February 1958. Velocity vectors in this area of Stenhouse Glacier are also shown. The black areas are ice-free. The soundings in Visca Anchorage are given in metres.

Calving began again in the middle of December and by the end of the budget year the glacier had broken back somewhat, leaving the net advance for the year at about 80 m.

The measurement of ice lost by calving. For the purpose of calculation the advance of the glacier front between 17 May and 23 August 1957 is assumed to represent the total flux of ice down the glacier, i.e. that no calving took place during that period. The ice which did in fact break off was trapped in the sea ice and it could be seen that it was negligible. This assumption does not, therefore, introduce a large error.

During the same period a tide mark developed on the face of the ice cliff, indicating that the front of the glacier was not floating. The hydrographic survey carried out by R.R.S. *Shackleton* in 1957 recorded the depth of water along the cliff front before it advanced.

From this survey and from the plane-table maps (Fig. 5), the total flux of ice into the ablation zone for the appropriate time interval was calculated. This was then extrapolated to cover

TABLE I. BUDGET OF STENHOUSE GLACIER, 1957–58

Areas	
Total area of glacier	$7 \cdot 7 \times 10^6$ m.^{2}
Outlet valley	$3 \cdot 7 \times 10^6$ m.^{2}
Ice field	$4 \cdot 0 \pm 0 \cdot 8 \times 10^6$ m.^{2}
Accumulation region	$7 \cdot 2 \times 10^6$ m.^{2}
Ablation region	$0 \cdot 5 \times 10^6$ m.^{2}
Ratio—ablation region/total area of glacier	0·06
Accumulation and ablation	
Accumulation	$6 \cdot 9 \pm 0 \cdot 8 \times 10^6$ m.^{3} water
Ablation	$7 \cdot 3 \times 10^6$ m.^{3} water
Discharge (from accumulation region to ablation region)	$9 \cdot 1 \times 10^6$ m.^{3} water
Budget	$-0 \cdot 4 \pm 0 \cdot 8 \times 10^6$ m.^{3} water
Specific budget (budget/area)	$-0 \cdot 064 \pm 0 \cdot 11$ m. water
Specific accumulation budget	$-0 \cdot 322 \pm 0 \cdot 147$ m. water
Specific ablation budget	$+3 \cdot 6$ m. water

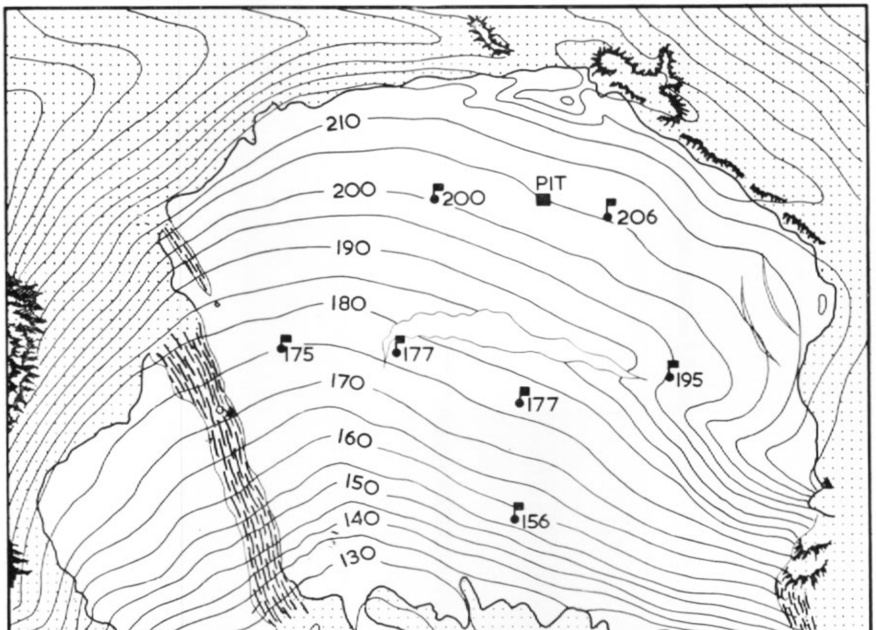

Fig. 6. Sketch map of Flagstaff Glacier (see Fig. 1), showing the positions of marker stakes with their respective heights above sea-level. Contours are in metres at 5 m. intervals. The stippled areas are exposed rock and scree.

the budget year by assuming a constant rate of flow. In view of the results of the movement study this is a fairly reasonable assumption.

Table I gives the budget and related data for Stenhouse Glacier.

The possible error of ± 20 per cent in the estimation of the ice-field region has been taken into account but it is considered that other errors are unlikely to have a cumulative effect and have therefore been ignored.

The quotients (budget/area) for the regions specified in Table I, the so-called "specific budgets" of the I.G.Y. data form have also been included. These represent a theoretical rise or, in this case, a fall of the glacier's surface level. The difference between the specific budget for the glacier as a whole and the specific budget for the accumulation zone is due to the fact that much of the ice discharged from the accumulation zone did not calve at the snout but instead resulted in a net advance of the glacier front. Since a single season giving warm water in Visca Anchorage might easily wipe out this advance and increase the negative value of the specific budget to equal the specific accumulation budget, the latter is considered to present a more reliable estimate of the glacier's condition.

Flagstaff Glacier

Flagstaff Glacier is a small glacier filling a cirque on the east side of Flagstaff Hill (278 m.) (Figs. 1, 6 and 7), which is at the southern end of Keller Peninsula. Although it is barely 3 km. from Stenhouse Glacier, Flagstaff Glacier is an undernourished patch of ice lying between the 120 and 225 m. contours. The firn area occupies only its north-western corner and, apart from minor cracks, its only crevasse is permanently choked with old snow.

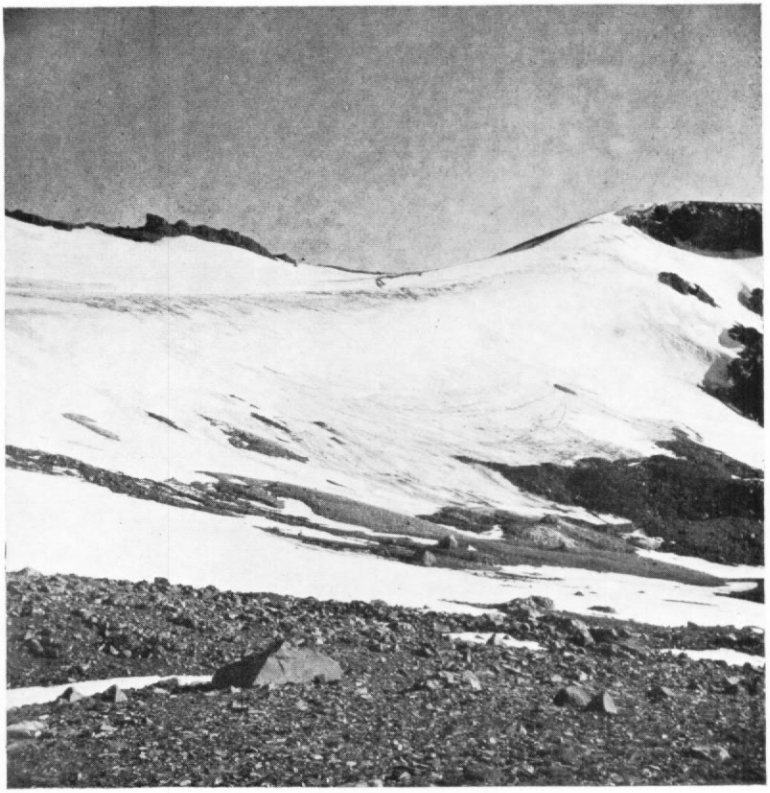

Fig. 7. General view of Flagstaff Glacier. March 1958.

1. *Accumulation*

Accumulation observations were made in three ways: by measurements made against a set of seven poles, by noting the profile in the wall of a small firn pit at a height of 205 m. and lastly, since a distinct dirt layer formed on the glacier in summer, it was possible to make approximate measurements over a wide area by using a coring drill.

A comparison between the net accumulation for the budget year 1957–58 (Table II) and the accumulation for the previous year has been made, and two points appear to be relevant:

i. The position of the "firn line" was similar in the two years mentioned.
ii. Net accumulation near the centre of the firn region was:

1956–57 . . .	155 cm. of water.
1957–58 . . .	70 cm. of water.

2. *Ablation*

Ablation (Table II), measured by using the same pattern of poles, was found to be greatest on the steep snout. Little snow could collect on the glacier snout and as a result bare ice with an albedo lower than that of a snow surface was exposed to radiation early in the ablation season. The absorption of radiation was also increased by the expanse of exposed rock in the vicinity and by the thin cover of dirt, which was spread on the glacier's surface during the summer months. Dirt mounds formed and surface drainage was common. Englacial drainage was not observed but might well have taken place.

TABLE II. BUDGET OF FLAGSTAFF GLACIER, 1957–58

Areas	
Total area of glacier	$94 \cdot 8 \times 10^3$ m.^{2}
Accumulation region	$20 \cdot 8 \times 10^3$ m.^{2}
Ablation region	$74 \cdot 0 \times 10^3$ m.^{2}
Ratio—ablation region/total area of glacier	0·78
Accumulation and ablation	
Accumulation	$4 \cdot 8 \times 10^3$ m.^{3} water
Ablation	$55 \cdot 7 \times 10^3$ m.^{3} water
Budget	$-50 \cdot 9 \times 10^3$ m.^{3} water
Specific budget (budget/area)	−0·53 m. water

The stakes were inserted on 10 March 1957 but there was little change in surface level until early June when the first accumulation took place. In contrast with this the following ablation season appeared to be over by 31 March 1958. The 1958 season had therefore only half the duration of the 1957 season. Since little extra ablation took place during the extension to the 1957 season, the main effect was to alter the length of the accumulation period.

3. *Movement*

The movement of Flagstaff Glacier is too slow for short-term measurement by plane-tabling methods. Observations were made on the annual movement, but these results are not considered to be reliable.

THE THERMAL REGIME OF STENHOUSE AND FLAGSTAFF GLACIERS

Temperature observations were confined to the ice cap above Stenhouse Glacier and to the firn area of Flagstaff Glacier.

Method. The portable drilling equipment used has been fully described by Ward (1952). A fresh hole was bored for each temperature profile and a suitably lagged thermometer of the "Rototherm" bimetallic element type was lowered down at intervals while the hole was gradually deepened.

Results. Fig. 8 shows the plot of the temperature of the ice-cap firn against depth for four separate occasions. These results indicate that the ice of King George Island is temperate below the layer of annual temperature fluctuation. This "cold wave" seems to penetrate

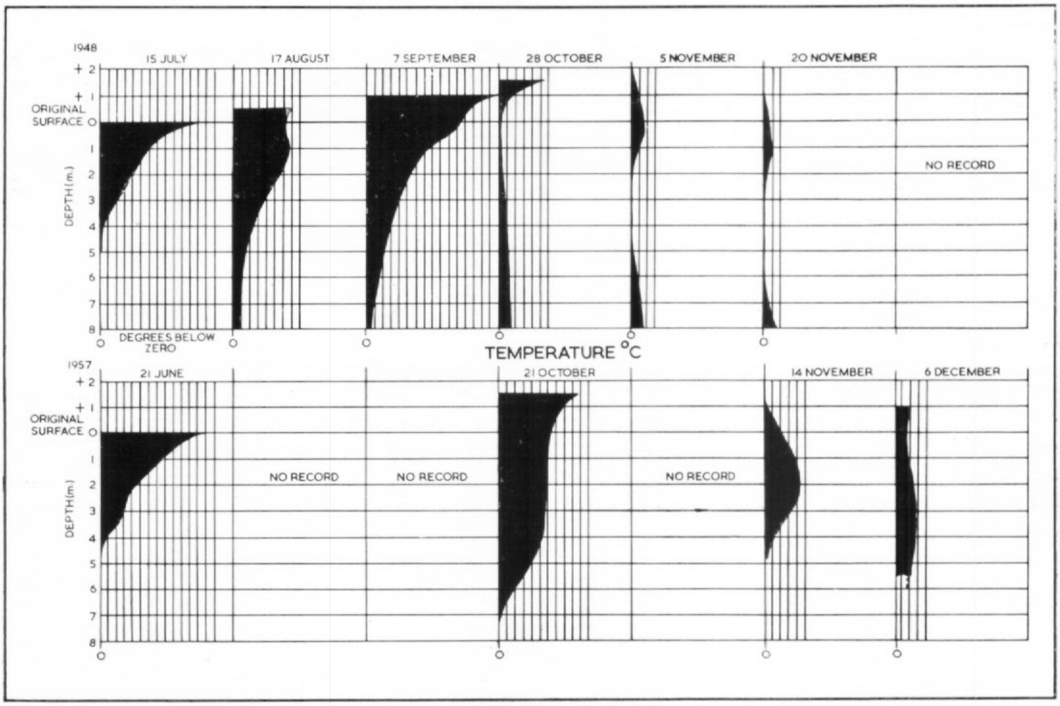

Fig. 8. The thermal regime of the firn area of Stenhouse Glacier (1957; lower part of figure) compared with the 1948 observations (upper part of figure) on the ice piedmont south-west of Lussich Cove.

to a depth of 8–12 m., and its condition is similar to that found by Ahlmann and Sverdrup on Isachsen's Plateau (Sverdrup, 1935). The final obliteration of the cold wave results from the re-freezing of about 5 cm. of melt water and is typically irregular (Sharp, 1951).

Fewer observations are available for Flagstaff Glacier but roughly the same conditions prevail. Here, the presence of fewer ice layers in the firn facilitates the rapid penetration of melt water.

These results are in agreement with those obtained by Hattersley-Smith (1949), who worked on the ice piedmont south-west of Lussich Cove* (Fig. 8), on the east side of Admiralty Bay.

Summary

The numerical data recorded here are tentative but they are the best estimates available. Nevertheless, a number of points can be made with some degree of confidence.

i. In recent times there has been a general reduction in the amount of ice on King George Island.
ii. A condition of undernourishment prevailed for all glaciers on King George Island during the International Geophysical Year, 1957–58, and this was accentuated for those glaciers not fed by the ice cap which constitutes the main reservoir of ice.
iii. The position of the terminal ice cliffs of the tidal glaciers varied considerably during the budget year 1957–58, and this short-term fluctuation depended primarily on the temperature of the sea and not on the "budget".
iv. Along the south coast of King George Island the calving of ice from the snouts of glaciers terminating in the sea accounted for most of the ice lost from the island's supply.

* The precise site of this work has never been satisfactorily re-located in the field, but the position of the ice piedmont is lat. 62°06′S., long. 58°22′W.

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