GLACIER FLUCTUATIONS IN SOUTH GEORGIA, 1883–1974

By R. J. C. HAYWARD

ABSTRACT. South Georgia has been continuously occupied since 1904 by personnel associated with the whaling industry or by members of scientific expeditions. Although these pioneers made no formal glaciological studies, many photographs were taken and some surveying was carried out. Data from archives and from personal collections have been assembled and analysed for evidence of fluctuations in the positions of glacier snouts. Different glacier types show differing responses to climatic change. Of 38 glaciers, for which multiple observations have been made, 13 show no significant change. The remainder have undergone oscillations during the present century which are, however, small compared with changes that have occurred in glaciers in the Northern Hemisphere. A comprehensive list of the sources of all known material on South Georgia glaciers is given in the Appendices.

SOUTH GEORGIA (lat. 54°20′S, long. 37°00′W) is the largest of the islands in the Scotia arc, being about 170 km long and 30 km wide at the broadest part. The long axis of the island stretches in a north-west to south-east direction which lies across the path of the prevailing westerly winds. The island was probably discovered by La Roché in 1675 (Burney, 1803–17), but it was not until 1775 that the first landing was made by Cook (1777). Cook's discovery of the presence of fur seals aroused the interest of British and American sealers, who visited the island frequently until 1831, by which time the seals had been almost exterminated. Between 1831 and 1902 the only visitor to the island, apart from an occasional sealer, was the German International Polar Year Expedition, which occupied a station in Royal Bay from August 1882 to September 1883 (Neumayer, 1891). In 1902 the Swedish South Polar Expedition under the leadership of Nordenskjöld (1904) spent 2 months mainly in the Cumberland Bay area. Sightings of large numbers of whales induced C. A. Larsen to form the Compaña Argentina de Pesca and to set up the first permanent whaling station in Cumberland Bay. Since 1904 the island has been continuously occupied; by the whalers until 1965, then by Government officials and now by the British Antarctic Survey.

Table I lists expeditions and Table II lists visitors who have added to the knowledge of glacier fluctuations. Two important contributions were those of the Discovery Investigations (Hardy, 1928), which maintained biological laboratories at Grytviken from 1925 to 1932, and the South Georgia Survey Expeditions under the leadership of V. D. Carse (1958, 1959), who between 1951 and 1957 produced the first proper map of the island at a scale of 1:200 000 (Directorate of Overseas Surveys, 1958). Apart from some minor work by the German

TABLE I. EXPEDITIONS TO SOUTH GEORGIA (FROM ROBERTS, 1958*a*, *b*)
(Ship names are given in parentheses.)

Date	*Name*	*References*
1882–83	German Internation Polar Year Expedition (*Moltke*)	Neumayer, 1891
1901–03	Swedish South Polar Expedition (*Antarctic*)	Nordenskjöld, 1904
1910–12	German South Polar Expedition (*Deutschland*)	Brennecke, 1921; Filchner, 1923
1914–16	Imperial Trans-Antarctic Expedition (*Endurance*)	Shackleton, 1919
1915–16	United States expedition (*Carnegie*)	Ault, 1922
1921–22	Shackleton–Rowett Antarctic expedition (*Quest*)	Wild, 1923; Douglas, 1930
1925–32	Discovery Investigations	*Discovery Reports*
1925–27	German Atlantic Expedition (*Meteor*)	Spiess and others, 1926
1927–28	Norwegian (Christensen) Antarctic Expedition (*Norvegia*)	Holtedahl, 1929
1934–37	British Graham Land Expedition (*Penola*)	Rymill, 1938
1951–57	South Georgia Survey	Carse, 1958, 1959
1954–55	British South Georgia Expedition	Sutton, 1957
1964–65	Combined Services Expedition	Burley, 1966

TABLE II. VISITORS TO SOUTH GEORGIA

Date	*Name*	*Reference*
1905	E. Sörling	Lönnberg, 1906
1906	A. Szielasko	Szielasko, 1907
1909	C. J. F. Skottsberg	Skottsberg, 1911
1911–12	D. Ferguson	Ferguson, 1915
1912–13	R. C. Murphy	Murphy, 1914*a*
1914	J. G. Correia	Murphy, 1914*a*
1923, 1926, 1929	A. Carcelles	Carcelles, 1931
1928–29	L. Kohl-Larsen	Kohl-Larsen, 1930
1936	German expedition	Guseva, 1937
1946	C. A. Gibson-Hill	Gibson-Hill, 1949
1946–47	N. Rankin	Rankin, 1951

expedition of 1882–83 and the British South Georgia Expedition of 1954 (Brown, 1956; Sutton, 1957), no glaciological work was carried out until 1957 when Smith (1958) and Stansbury (1961) of the Falkland Islands Dependencies Survey spent 2 years studying mainly Hodges Glacier but also making glaciological observations elsewhere. From 1971 to 1977, the British Antarctic Survey maintained a continuous glaciological research programme, concentrating on the mass and energy balance of Hodges Glacier.

Although doing no specific glaciological work, the earlier visiting expeditions provided useful information in the form of photographs, and in many cases it has been possible to compare these with later photographs to see whether changes have taken place.

PHYSIOGRAPHY

South Georgia (Fig. 1) is very mountainous, having 20 peaks over 2 000 m high culminating in Mount Paget (2 934 m). Most of the island is dominated by the Allardyce and Salvesen Ranges, which extend over two-thirds of the length of the island but lie closer to the south-western shore. North-west of the Allardyce Range, the peaks are more scattered and lower, being in general 700–1 000 m high. Except for the low, extreme north-western peninsula, the land is heavily glacierized with 56 % ice coverage. This figure was measured from the 1 : 200 000 map (DOS 610, 1958) and is almost certainly an overestimate of the glacierization because much of the ice-free area is too steep for snow to accumulate and for glaciers to form. It is only the north-western peninsula and the low coastal area which can truly be considered ice-free.

The configuration of the mountain chains divides the island into three areas of glacierization:

Area north-east of the Allardyce and Salvesen Ranges

The accumulation areas are generally large cirques carved out of the mountains with high and very steep back walls. Glaciers are often nourished by ice avalanches from smaller glaciers and snow fields above the back walls in addition to their local snow accumulation. Ice usually flows out of gently sloping and crevasse-free areas, over a steep ice fall and into a gently sloping but heavily crevassed ablation area. Glaciers are normally separated by sharp high ridges and they descend into large fjord-type bays evidently formed during a period of heavier glacierization.

Area south-west of the Allardyce and Salvesen Ranges

Owing to the symmetry of the mountains, the land here is steeper, in places rising to 2 000 m in less than 10 km. Cirques and the fjord-type coastline are not so pronounced; glaciers flow from the crests of the main ranges in a series of ice falls and confused ice to the sea. Unlike the north-east area, many of the dividing ridges are themselves ice-covered, leading to large complex glacier systems with several outlets to the sea.

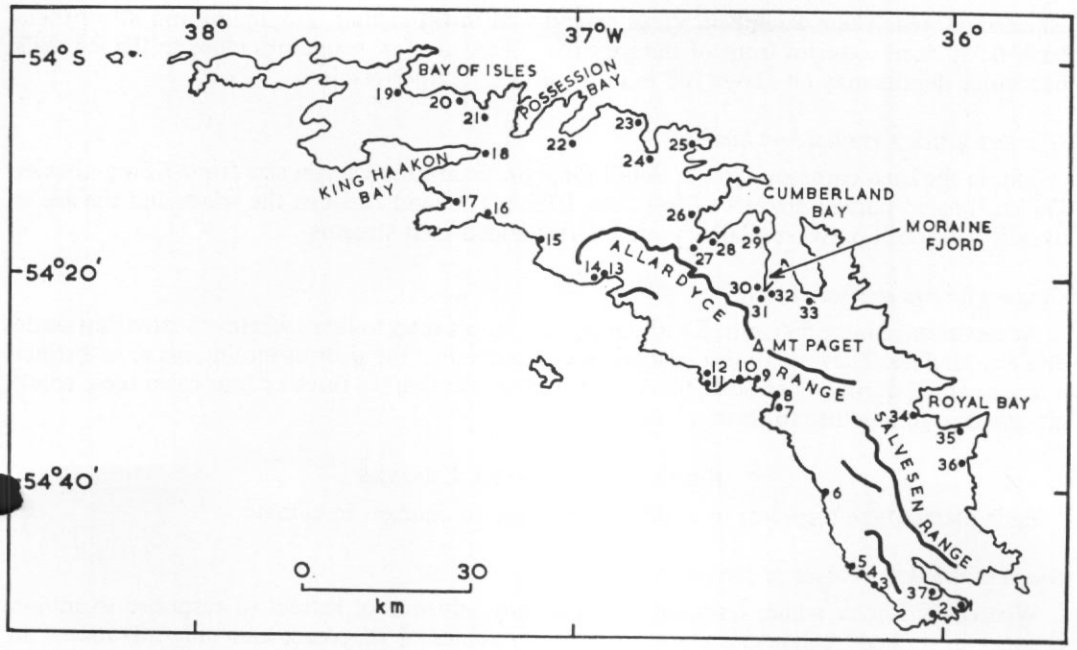

Fig. 1. Glaciers studied in South Georgia.
1. Un-named glacier; 2. Un-named glacier; 3. Graee Glacier; 4. Un-named glacier; 5. Harmer Glacier; 6. Novosilski Glacier; 7. Brøgger Glacier; 8. Un-named glacier; 9. Reusch Glacier; 10. Un-named (two) glaciers; 11. Helland Glacier; 12. Un-named glacier; 13. Lancing Glacier; 14. Un-named glacier; 15. Keilhau Glacier; 16. Esmark Glacier; 17. Un-named glacier; 18. Un-named glacier; 19. Brunonia Glacier; 20. Lucas Glacier; 21. Morris Glacier; 22. Crean Glacier; 23. Fortuna Glacier; 24. König Glacier; 25. Un-named glacier; 26. Neumayer Glacier; 27. Geikie Glacier; 28. Lyell Glacier; 29. Hodges Glacier; 30. Hamberg Glacier; 31. Harker Glacier; 32. De Geer Glacier; 33. Nordenskjöld Glacier; 34. Ross Glacier; 35. Weddell Glacier; 36. Bertrab Glacier; 37. Philippi Glacier.

Area north-west of the Allardyce Range

The land here consists of scattered low peaks linked by long, gently sloping ice-covered ridges. The glaciers are wide compared with those on the rest of the island and surfaces are relatively uncrevassed. There is little or no cirque development. Ice flows out of large snow fields with no break in slope between the accumulation and the ablation areas.

Glacier Types

Glaciers on South Georgia can be divided into four types depending mainly on the position of the snout. Each of the four types are found in all three areas described above.

Glaciers which terminate at the coast

This is the commonest type of glacier in South Georgia and it accounts for the greatest percentage of the total ice cover. Sizes vary from Fortuna Glacier (58 km^2) to glaciers of less than 1 km^2. In front of the terminus of all these glaciers there is a strip of land which may be a shingle beach or a series of rocks and small cliffs over which the glacier spills into the sea.

Glaciers which enter the sea

At least 11 glaciers have no beach in front of the snout. Six of these, Ross, Novosilski, Brøgger, Esmark, Neumayer and Nordenskjöld Glaciers together comprise 33% of the total

glacierized area. Their catchment areas extend well into the main mountains and all of them have fairly deep water in front of the ice cliffs. There are few soundings close to the ice cliffs but water depths may be about 100 m in front of the larger glaciers.

Glaciers which terminate on land

This is the least common type in South Georgia. Examples vary in size from König Glacier (36 km^2) to un-named glaciers of less than 1 km^2. The land between the snout and the sea is usually a smooth outwash plain covered with braided melt streams.

Cirque glaciers and ice caps

At elevations above 500 m in South Georgia, glaciers tend to form wherever snow can settle and accumulate. They are found in shallow concavities on the sides of mountains or in distinct cirques carved during a period of more intense glacierization. In three or four cases these small glaciers merge together to form a small ice cap.

Response to Climatic Changes

Each glacier type responds in a different manner to changes in climate.

Glaciers which terminate at the coast

Whereas a glacier which terminates inland may advance or retreat in response to minor changes in its mass balance, a glacier which terminates at the coast can only advance if it begins to discharge ice faster than can be eroded by the sea. Thus, in order to advance at all, it will require a major change in mass balance. Similarly, it will only retreat if ablation on land begins to exceed the amount formerly discharged across the coast. For this reason, glaciers which terminate at the coast tend to show no response to minor climatic fluctuations.

Glaciers which enter the sea

If the ablation due to the sea remained constant, these glaciers would react to a change in the climate by an advance or retreat of the snout, but short-lived conditions such as storms or periods of calm weather may cause sudden changes. In a long period of stable climate, the mean position of the snout should remain the same but oscillations around this position will be caused by short-lived instabilities.

Glaciers which terminate on land

Glaciers ending on land should be very good indicators of climatic trends as they are in other parts of the world. König Glacier, for example, which has an even and gentle slope along its entire length, should be sensitive to any change in the height of the equilibrium line. Unfortunately, this type of glacier is relatively uncommon on South Georgia and the few that there are have not attracted much attention from visiting expeditions.

Cirque glaciers and ice caps

Cirque glaciers and ice caps respond to climatic changes but, owing perhaps to the sluggish motion of such glaciers, changes generally appear small. Most examples of this type are at a sufficiently high altitude for snow to lie for much of the year; snow commonly hides the extent of the actual glacier ice.

Observed Glacier Variations

Glacier variations have been small in comparison with some Northern Hemisphere regions. Thirty-eight glaciers have been mapped or photographed on more than one occasion. Of these,

13 (Table III) have shown no change in their snout positions and it may be significant that in front of each glacier there is a small beach.

TABLE III. GLACIERS OF SOUTH GEORGIA WHICH HAVE NOT CHANGED

Name	*Position* (lat., long.)	*Years in which observed*
Geikie Glacier	54°17′S, 36°40′W	1954, 1956, 1972, 1973, 1974
Bertrab Glacier	54°37′S, 35°57′W	1914, 1928, 1934, 1956, 1960, 1974
Philippi Glacier	54°49′S, 36°03′W	1921, 1928, 1973, 1974
Un-named glacier on Nattris Head	54°50′S, 35°57′W	1956, 1974
Graee Glacier	54°49′S, 36°11′W	1956, 1974
Un-named glacier south-west of Ranvik	54°48′S, 36°14′W	1956, 1974
Harmer Glacier	54°47′S, 36°16′W	1956, 1974
Two un-named glaciers west of Reusch Glacier	54°30′S, 36°32′W	1956, 1965, 1974
Lancing Glacier	54°20′S, 36°55′W	1954, 1955, 1965, 1974
Un-named glacier in Newark Bay	54°21′S, 36°57′W	1954, 1965, 1974
Lucas Glacier	54°03′S, 37°18′W	1947, 1955, 1974
Fortuna Glacier	54°05′S, 36°50′W	1925, 1955, 1956, 1973, 1974

Glaciers which terminate at the coast

Crean Glacier (32.9 km²; lat. 54°08′S, long. 37°01′W) observed in 1925, 1953 and 1974.

Only the 1974 photograph is clear but part of the snout descends over a 100–150 m high cliff. From the amount of rock exposed, it appears that the glacier advanced between 1925 and 1953 but has since retreated to a position farther back than the 1925 position.

Helland Glacier (25.4 km²; lat. 54°29′S, long. 36°39′W) observed in 1954, 1956, 1972 and 1974.

In 1954 part of the snout was at the coast while another part protruded into the sea. There has been no change in that part of the glacier in the sea but between 1956 and 1972 the part ending on land retreated about 100 m. There was no noticeable change between 1954 and 1956 nor in the period 1972–74.

Keilhau Glacier (90.2 km²; lat. 54°17′S, long. 36°05′W) observed in 1928, 1951, 1954, 1956 and 1974.

A wide snout ends partly on land and partly in the sea with low spurs of rock projecting from under the ice. Only part of the snout was visible in 1928 but its position then was close to that in 1974. Between 1928 and 1951, the glacier advanced and parts of the snout which earlier had been on land reached the sea and formed ice cliffs. The glacier was stable between 1951 and 1954 but by 1956 it had retreated 5–10 m. This retreat continued and by 1974 some of the ice cliffs had disappeared and again 200 m of ice-free ground appeared.

Weddell Glacier (23.0 km²; lat. 54°34′S, long. 36°00′W) observed in 1883, 1960 and 1965.

A map and sketched panorama of 1883 show Weddell Glacier extending to the mouth of a smaller bay off Royal Bay. In 1960 and 1965 the glacier occupied a position about 600 m farther into the fjord and appeared to have rocks or a small beach in front of the ice.

Lyell Glacier (25.6 km²; lat. 54°17′S, long. 36°37′W) observed in 1956, 1957, 1972 and 1974.

Lyell Glacier is unusual because a large part of the ice is covered by a thick layer of moraine. This material is thickest on the eastern side where it completely obscures the underlying ice. Along the snout, there are small rocks and a partial beach. Although the actual shape of the snout changes constantly, the average position has changed very little since 1955. Along the eastern side, however, where the ice is unconfined by a valley wall, the glacier has deposited a series of moraines while retreating 30–40 m.

Morris Glacier (14.4 km²; lat. 54°05′S, long. 37°14′W) observed in 1953 and 1974.

In 1974 there was a beach along the greater part of the ice cliffs at the snout. In 1953 a beach was only visible at high tide, whereas in 1974 it was 15–20 m wide.

Glaciers which enter the sea

Novosilski Glacier (98.4 km²; lat. 54°40′S, long. 36°20′W) observed in 1956 and 1974.

Jonassen Rocks lie off the snout and make good reference points for the position of the ice cliffs. Between 1956 and 1974 the front of the glacier advanced about 250 m and in 1974 it was only about 100 m from Jonassen Rocks. On the other hand, the ice which overlaps the land at the edge of the snout has changed very little.

Esmark Glacier (100.2 km²; lat. 54°15′S, long. 37°14′W) observed in 1925, 1930, 1954 and 1956.

Photographs only show part of the snout but it appears that between 1925 and 1930 there was an advance of the order of 20–30 m. However, by 1954 the glacier had retreated to its earlier position. Between 1954 and 1957 there was a further retreat of about 30 m which uncovered some large rocks.

Neumayer Glacier (108.8 km²; lat. 54°15′S, long. 36°40′W) observed in 1938, 1951, 1956, 1957, 1972, 1973 and 1974.

Between 1938 and 1972 the ice on the northern shore retreated about 80 m, although 70 m of this retreat had occurred by 1957. A lack of identifiable terminal moraines suggests that this retreat was fairly steady. No change in position was discernible between 1972 and 1974.

Nordenskjöld Glacier (104.5 km²; lat. 54°22′S, long. 36°22′W) observed in 1929, 1938, 1947, 1954, 1957, 1972 and 1973.

The glacier is in its most advanced position of recent times. The lack of any indentation where the western margin crosses from land to sea, and the steepness of the snout where it is on land, suggest that the glacier is still advancing. In 1938 the glacier occupied a position about 150 m behind the present one. Between 1938 and 1947 the ice retreated about 250 m. There was an advance in the early 1950's not reaching the present position but probably within 100 m of it. This was followed by a retreat leaving a long patch of dead ice on the land in 1957. Since 1957 the glacier has advanced to its present position. In 1929, a photograph of the eastern extemity showed a very steep terminus on land and, although it is impossible to fix the position of the snout, it is probable that the glacier was advancing at that time.

Brøgger Glacier (147.7 km²; lat. 54°32′S, long. 36°28′W) observed in 1956 and 1974.

With Spencely Glacier this is the largest glacier on the island. Between 1956 and 1974 the glacier advanced about 100 m and on the southern side it appeared to be overriding tussock grass, indicating that it had reached its most advanced position in recent times.

Ross Glacier (100.3 km²; lat. 54°32′S, long. 36°03′W) observed in 1882, 1883, 1902, 1912, 1921, 1926, 1928, 1955, 1960, 1965 and 1972.

The snout of Ross Glacier was plotted four times in 1882 and 1883 by the German International Polar Year Expedition (Neumayer, 1891) and the same base map was used to plot the snout both in 1902 (Nordenskjöld, 1904) and 1921 (Wild, 1923). A comparison of this early map with the very good map produced by the Combined Services Expedition (1970) shows that there were large errors in the German map. However, some idea of the trends can be gained from the general shape of the snout and from reports at the time.

Between August 1882 and August 1883 there was considerable retreat in the central part, probably due to rough sea conditions. By 1902 the glacier had advanced once more to the outermost position plotted by the German expedition, but by 1912 the ice had again retreated.

There followed a period of equilibrium until at least 1921 but by 1926 the glacier had advanced again by about 300 m at its southern edge. This advance continued until 1928. There are no further records until 1955 when the glacier was found to have retreated slightly, and vertical photographs taken in 1960 show the front still retreating. In 1965 the glacier was once more advancing and this advance has continued to the present time with the glacier in a more forward position than at any time since 1928.

Un-named glacier at the head of Shallop Cove (2.1 km²; lat. 54°13′S, long. 37°19′W) observed in 1951 and 1956.

Two small glaciers merge to form a common snout which terminates in ice cliffs in the sea. Between 1951 and 1956 there was an advance of the order of 30–50 m.

Un-named glacier at the head of King Haakon Bay (27.5 km²; lat. 54°09′S, long. 37°16′W) observed in 1965 and 1974.

This is the large glacier beside which E. H. Shackleton started his journey across the island in 1916. In 1974 there was a partial beach from the northern side to a large rock protruding from the ice in the centre of the glacier. The southern part of the snout has what appears to be deep water in front of the ice cliffs. Between 1965 and 1974 there was a retreat of 400–600 m on the southern side and in the middle of the snout. A photograph of the northern side is indistinct but the retreat was probably much smaller there.

Un-named glacier in Doubtful Bay (1.0 km²; lat. 54°51′S, long. 36°01′W) observed in 1956 and 1974.

Although it is difficult to scale the photographs, it is clear that between 1956 and 1974 the glacier retreated 100–150 m. Kelp growing in front of the ice cliff in 1974 indicated that the retreat must have taken place a few years ago.

Un-named glacier in Undine South Harbour (6.6 km²; lat. 54°31′S, long. 36°28′W) observed in 1956 and 1974.

The snout of the glacier enters the sea and appears to have quite deep water in front except at its sides where there is a narrow beach and some rocks. Between 1956 and 1974 the glacier advanced about 20 m, covering some of the rocks.

Reusch Glacier (18.2 km²; lat. 54°30′S, long. 36°31′W) observed in 1956, 1965 and 1974.

Part of the glacier ends in a beach or spills over a small cliff and part ends in the sea. Between 1956 and 1974 there was retreat of about 5 m in the part that ends on land and a retreat of about 250 m in the part that reaches the sea. The position in 1965 was about half-way between the other two positions, suggesting that the retreat was fairly steady.

Brunonia Glacier (19.5 km²; lat. 54°03′S, long. 37°28′W) observed in 1947 and 1974.

In 1947 the snout was remarkably straight, stretching across the fjord with a beach in front of its southern half. On the 1:200 000 map surveyed in 1955 the snout is also shown as a straight line but in 1974 there was a large bay in the northern part of the snout where about 1 km² of ice had disappeared. Along the straight section that still remains there is a small beach but the ice along the rest of the glacier ends in what appears to be deep water.

Hamberg Glacier (8.2 km²; lat. 54°21′S, long. 36°30′W) observed in 1914, 1930, 1954, 1957, 1958, 1972 and 1974.

Fig. 2 shows the various positions of the snout since 1914. There was no significant change between 1914 and 1958, the snout oscillating about a line across the mouth of the fjord. Some

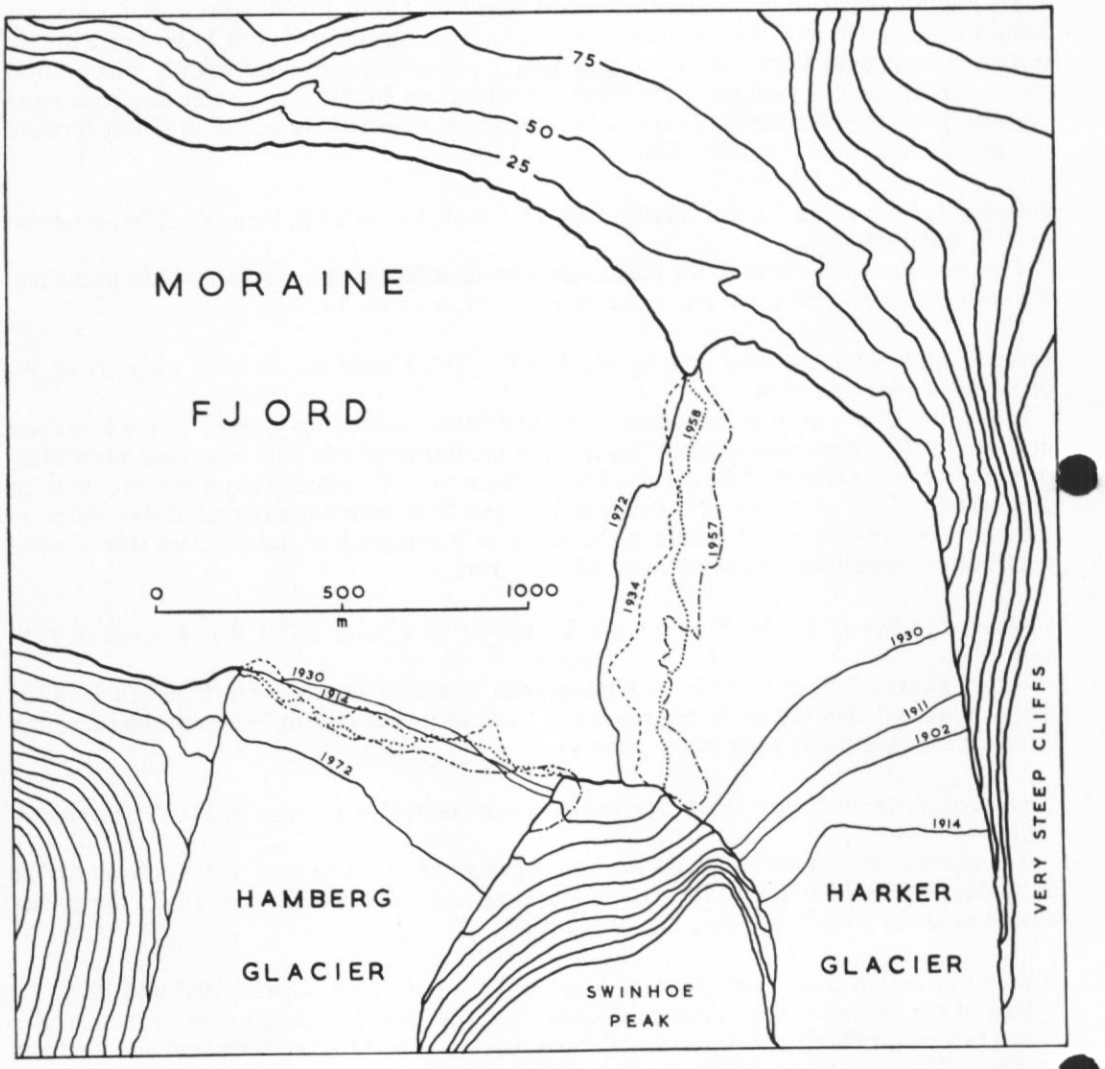

Fig. 2. Fluctuations of Harker and Hamberg Glaciers.

time between 1958 and 1972 there was a large retreat mainly on the southern side. Since 1972 the position has appeared quite stable.

Harker Glacier (11.5 km²; lat. 54°22′S, long. 36°30′W) observed in 1902, 1911, 1914, 1930, 1954, 1957, 1958, 1972 and 1974.

Fig. 2 shows the positions of the snout since 1902. Unlike the adjacent Hamberg Glacier, Harker Glacier has shown large changes in the position of its snout. Between 1902 and 1911 the glacier advanced about 30 m but in the next 3 years it retreated about 300 m on the eastern shore. From 1914 to 1954 there was an advance of more than 1 km in places with no evidence of any retreat during that period. Between 1954 and 1957 the glacier retreated up to 100 m in places but since then there has been a new advance of about 200 m and the glacier is now at its most advanced position in recent times.

Glaciers which terminate on land

Un-named glacier behind Leith Harbour (5.0 km²; lat. 54°08′S, long. 36°44′W) observed in 1911, 1914 and 1954.

This is a steep glacier descending from a series of ice-filled shallow cirques; there are several nunataks and rock outcrops. The snout lies well inland but at an elevation of about 100 m a.s.l. Between 1911 and 1954 the glacier retreated about 200 m. The whaling station at Leith Harbour obtained its water from the melt stream of this glacier and the whalers consistently reported that the glacier was retreating. At least one moraine now present on the ice-free ground indicates that the retreat was not steady.

Un-named glacier (1.1 km²; lat. 54°29′S, long. 36°39′W) observed in 1928, 1954, 1956 and 1974.

This glacier descends quite steeply down a narrow valley and ends on a sloping plain at the edge of a low foreland. Between 1928 and 1954 the glacier advanced about 50 m but thereafter it retreated about 5 m between 1954 and 1956. Since 1956 the snout has retreated further and now lies in a position 15–20 m behind the 1928 position.

König Glacier (36.0 km²; lat. 54°09′S, long. 36°48′W) observed in 1917, 1927, 1956, 1965, 1973 and 1974.

König Glacier is the largest on the island to terminate on land. It flows gently down a broad valley before ending on a flat plain about 800 m from the sea. E. H. Shackleton passed in front of König Glacier while crossing the island in 1916 and he described a wide plain in front of the snout. Matthews (1931) also described a wide plain but he gave no estimate of the distance between the glacier and the sea. A series of photographs taken since 1956 shows that the glacier retreated about 150 m between 1956 and 1965 but since then it has advanced to its 1956 position.

Cirque glaciers

De Geer Glacier (3.2 km²; lat. 54°22′S, long. 36°29′W) observed in 1901, 1914, 1938, 1955, 1956 and 1974.

This is a small glacier with a tongue extending to about 100 m a.s.l. There was an advance after 1901, probably reaching a maximum in the late 1920's but in 1938 it was still about 50 m in front of the 1901 position. By 1955 the ice had retreated to a position about 200 m behind that of 1901; this retreat has continued so that in 1974 the glacier was 30 m farther inland.

Hodges Glacier (0.3 km²; lat. 54°16′S, long. 36°32′W) observed in 1955, 1957 and 1972–74 (Fig. 3).

This small cirque glacier was studied by the British Antarctic Survey from 1971 to 1977. Between 1955 and 1974 the glacier retreated about 5 m without any discernible thinning. Most of the retreat appeared to have taken place in the very warm summer of 1973–74.

Conclusions

Glacier fluctuations have been deduced from photographs and maps made since 1882. Observations, however, have been sporadic and cover differing periods for different glaciers. A photograph represents but a single observation and it is often impossible to tell whether the glacier was advancing or retreating at the time. Where the interval between observations is considerable, some fluctuations may have passed unobserved. It is difficult to assign specific dates for regional maxima and minima but from the evidence available it appears that there was an advance in the first decade of this century with a maximum in about 1910. This was followed by a short period of retreat. The glaciers then advanced quite rapidly for a longer period,

reaching a maximum in the late 1920's. Some glaciers continued their advance until the early 1930's. There followed a period of slow retreat until the late 1940's with a short rapid advance in the early 1950's, most glaciers having reached a maximum by 1956. Since that time the glaciers have generally retreated slowly and most appear to be still retreating. However, some of the very large glaciers have advanced again recently. Whether this is a rapid response to a contemporary change in climate or a slow response to an undetected change which may have occurred in the 1960's is not clear.

Some anomalous behaviour is evident in certain glaciers. The very large and consistent advance of Harker Glacier appears to be due to increased accumulation in the southern cirque, although no explanation can be offered for the increase. Harker and Hamberg Glaciers are of similar size and their snouts enter Moraine Fjord very close to each other (Fig. 2). Since 1957, Harker Glacier has advanced markedly after a small retreat but Hamberg Glacier has retreated after a long period of stability.

There is no evidence that any of the South Georgia glaciers have surged, nor do they have the characteristics which are common to surging glaciers. Many other glaciers have been photographed in addition to those discussed here. A large number of photographs are not yet usable in glacier-fluctuation studies, either because a glacier has been photographed once only or because the angle at which the photograph was taken differed so greatly that comparison with other photographs was impracticable.

Certain glaciers, especially those in the Cumberland Bay area, have been photographed annually by helicopters from HMS *Endurance* since 1972 and it is hoped that these observations will continue. From annual data it should be possible to distinguish between variations due to sea action alone and variations due to climatic trends.

Appendix I lists all known glaciers on South Georgia together with references to observations. Appendix II lists photograph collections and published maps and photographs.

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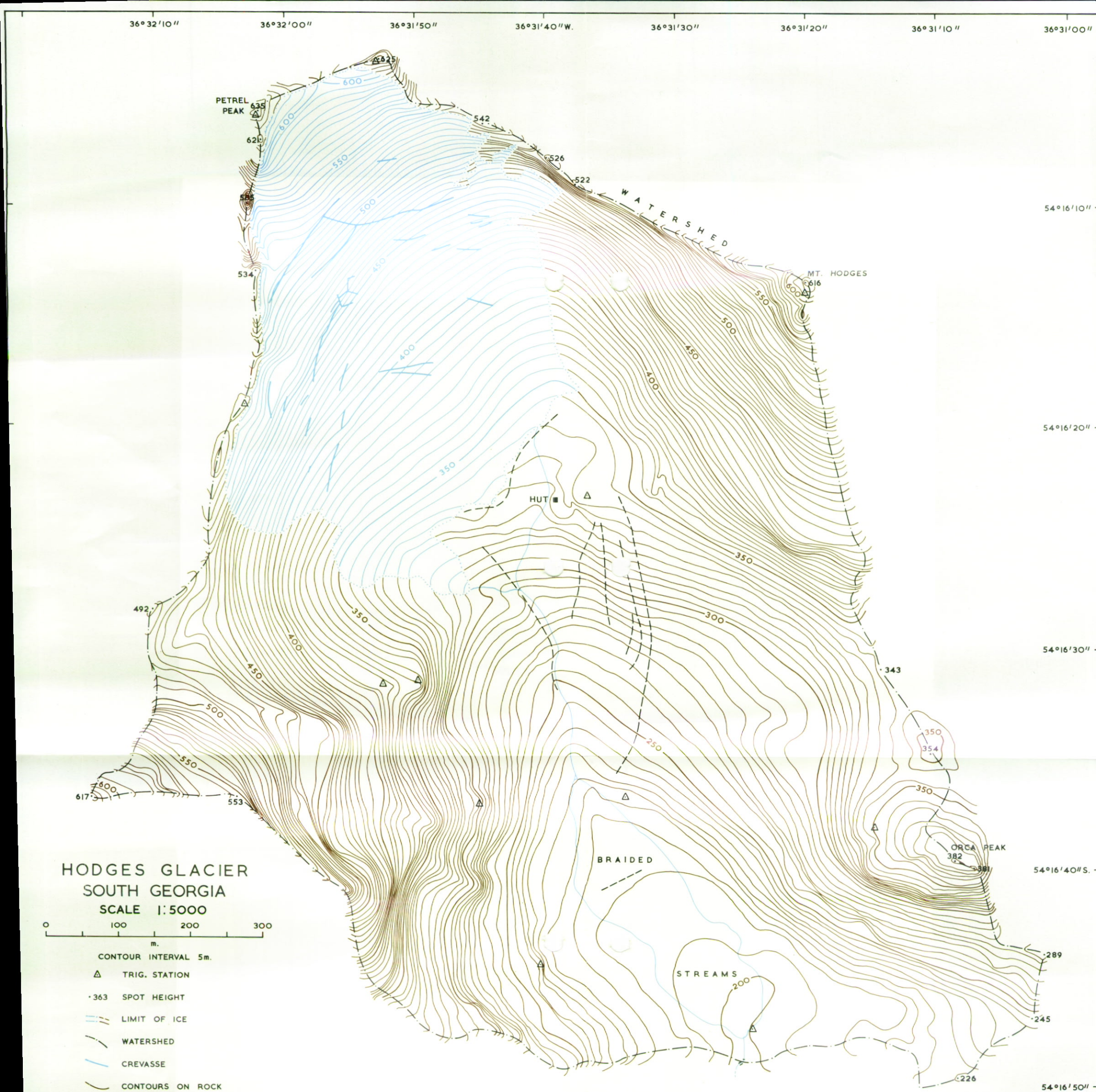

HODGES GLACIER
SOUTH GEORGIA
SCALE 1:5000

0 100 200 300
m.

CONTOUR INTERVAL 5m.

- △ TRIG. STATION
- ·363 SPOT HEIGHT
- LIMIT OF ICE
- WATERSHED
- CREVASSE
- CONTOURS ON ROCK
- CONTOURS ON ICE
- MORAINE
- STREAM

Fig. 3. Ho s Glacier.

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APPENDIX I

LIST OF GLACIERS OF SOUTH GEORGIA

	Area (km²)	*Position of snout* Lat. S	Long. W	*References* (*see Appendix II*)
Un-named glacier (Nattris Head)	1.0	54°50′	35°57′	3, 11
Un-named glacier	0.8	54°51′	35°56′	11
Un-named glacier (Esbenson Bay)	0.6	54°51′	35°59′	11
Un-named glacier (east Doubtful Bay)	0.5	54°51′	36°01′	3
Un-named glacier (west Doubtful Bay)	1.0	54°51′	36°01′	3, 11
Un-named glacier (east Smaaland Bay)	1.8	54°52′	36°03′	11
Un-named glacier (west Smaaland Bay)	1.8	54°52′	36°05′	10, 11
Un-named glacier	0.3	54°53′	36°05′	10
Un-named glacier	1.7	54°53′	36°03′	3, 11
Un-named glacier	0.5	54°53′	36°06′	11
Un-named glacier (Rogged Bay)	3.8	54°51′	36°06′	3, 8, 10, 11
Un-named glacier	0.6	54°50′	36°08′	
Un-named glacier	2.5	54°50′	36°07′	11
Graae Glacier	11.7	54°49′	36°11′	3, 11
Un-named glacier (two snouts)	7.0	54°48′	36°14′	3, 11
Harmer Glacier	18.4	54°47′	36°16′	3, 11
Un-named glacier	1.6	54°46′	36°16′	11
Un-named glacier	1.4	54°45′	36°17′	11

APPENDIX I—*continued*

	Area (km²)	*Position of snout* Lat. S	Long. W	*References* (*see Appendix II*)
Un-named glacier	11.0	54°43′	36°19′	3, 11
Un-named glacier	0.8	54°41′	36°19′	11
Novosilski Glacier	98.4	54°40′	36°20′	3, 11
Un-named glacier	2.7	54°38′	36°25′	11
Un-named glacier	0.9	54°37′	36°24′	11
Un-named glacier	1.1	54°36′	36°24′	3, 11
Wheeler Glacier	15.1	54°36′	36°25′	3, 11
Un-named glacier	0.6	54°35′	36°25′	11
Un-named glacier	1.1	54°35′	36°26′	11
Un-named glacier	1.8	54°34′	36°28′	11
Un-named glacier	1.1	54°32′	36°28′	
Brøgger Glacier	147.7	54°32′	36°28′	3, 8, 11
Un-named glacier	6.6	54°31′	36°28′	3, 8, 11, 17
Un-named glacier	0.4	54°31′	36°30′	
Reusch Glacier	18.2	54°30′	36°31′	3, 11, 14
Un-named glacier	3.5	54°30′	36°32′	3, 11, 14
Un-named glacier	4.4	54°30′	36°33′	3, 8, 11, 14
Un-named glacier	1.2	54°30′	36°35′	11
Un-named glacier	0.6	54°30′	36°37′	8, 11
Helland Glacier	25.4	54°29′	36°39′	3, 8, 10, 11, 17
Un-named glacier	1.1	54°29′	36°41′	3, 8, 10, 11, 17
Un-named glacier	1.7	54°28′	36°43′	
Henningsen Glacier	17.4	54°28′	36°45′	
Un-named glacier	3.7	54°28′	36°46′	
Un-named glacier	0.9	54°26′	36°49′	
Un-named glacier	6.7	54°26′	36°48′	
Christopherson Glacier	95.5	54°25′	36°48′	
Un-named glacier	0.9	54°24′	36°49′	
Un-named glacier	1.7	54°23′	36°50′	
Un-named glacier	4.2	54°23′	36°51′	8
Un-named glacier	1.0	54°22′	36°52′	
Kjerulf Glacier	51.6	54°21′	36°52′	14
Christensen Glacier	18.0	54°21′	36°52′	10
Lancing Glacier	32.5	54°20′	36°55′	8, 10, 14, 18
Un-named glacier (Newark Bay)	7.5	54°21′	36°57′	8, 14, 18
Un-named glacier	1.4	54°21′	37°00′	10
Un-named glacier	0.5	54°20′	37°02′	10
Un-named glacier	0.2	54°20′	37°03′	10
Keilhau Glacier	90.2	54°17′	37°05′	8, 9, 10, 11, 17
Un-named glacier	4.0	54°16′	37°08′	8, 9, 10, 11, 17
Esmark Glacier	100.2	54°15′	37°14′	10, 11, 16, 21
Un-named glacier	1.1	54°15′	37°18′	
Un-named glacier	0.1	54°15′	37°19′	
Un-named glacier	0.3	54°16′	37°20′	
Un-named glacier	0.3	54°15′	37°20′	
Un-named glacier (Shallop Cove)	2.1	54°13′	37°19′	9, 11
Un-named glacier	3.2	54°13′	37°21′	11
Un-named glacier	1.2	54°13′	37°22′	11
Un-named glacier	1.2	54°12′	37°22′	11
Un-named glacier	1.0	54°11′	37°23′	
Un-named glacier	5.1	54°10′	37°21′	
Un-named glacier	2.5	54°10′	37°19′	
Un-named glacier	7.1	54°10′	37°18′	14
Un-named glacier	2.5	54°10′	37°16′	14
Murray Snowfield	28.7	54°09′	37°09′	3, 8, 10, 11, 14
Un-named glacier (two snouts)	17.9	54°08′	37°18′	

APPENDIX I—*continued*

	Area (km²)	*Position of snout* Lat. S	Long. W	*References* (*see Appendix II*)
Un-named glacier	19.3	54°09′	37°23′	
Price Glacier	34.0	54°08′	37°28′	
Un-named glacier	16.0	54°08′	37°33′	
Un-named glacier	2.5	54°08′	37°34′	
Un-named glacier	4.8	54°09′	37°34′	
Un-named glacier	0.3	54°10′	37°33′	
Un-named glacier (Nilse Hullet)	1.0	54°10′	37°35′	
Un-named glacier	1.4	54°10′	37°36′	11
Un-named glacier	3.6	54°10′	37°38′	11
Un-named glacier	0.1	54°10′	37°39′	11
Un-named glacier	0.1	54°10′	37°40′	
Un-named glacier (Elephant Cove)	2.5	54°09′	37°40′	11, 16
Schrader Glacier	12.0	54°07′	37°39′	16
Un-named glacier	0.6	54°06′	37°42′	29
Un-named glacier	0.8	54°05′	37°40′	
Un-named glacier	0.5	54°05′	37°37′	
Un-named glacier (Miles Bay)	6.5	54°04′	37°38′	
Ryan Glacier	25.5	54°03′	37°36′	11
Un-named glacier (Ernesto Pass)	10.9	54°02′	37°44′	11
Un-named glacier (Snow Peak)	8.7	54°01′	37°52′	
Un-named glacier (Cape North)	4.0	53°59′	37°43′	
Un-named glacier	3.5	54°01′	37°32′	
Un-named glacier	0.6	54°02′	37°30′	
Un-named glacier (Camp Bay)	0.7	54°02′	37°28′	
Brunonia Glacier	19.5	54°03′	37°28′	3, 19
Un-named glacier	4.4	54°04′	37°26′	
Grace Glacier	13.6	54°03′	37°22′	3, 19, 20
Lucas Glacier	22.5	54°03′	37°18′	3, 10, 19
Morris Glacier	14.4	54°05′	37°14′	3, 10
Austin Glacier (Beckman Fjord)	3.8	54°04′	37°11′	
Purvis Glacier	7.3	54°06′	37°09′	3, 11
Un-named glacier	3.2	54°07′	37°04′	
Un-named glacier	1.0	54°05′	37°03′	
Crean Glacier	32.9	54°08′	37°01′	3, 10, 21
Un-named glacier	0.7	54°06′	36°56′	3, 11
Fortuna Glacier	58.2	54°05′	36°50′	2, 3, 10, 11, 21
König Glacier	36.0	54°09′	36°48′	3, 10, 11, 14
Un-named glacier	0.1	54°07′	36°45′	
Un-named glacier	1.0	54°07′	36°44′	
Un-named glacier (Leith Harbour)	5.0	54°08′	36°44′	10, 24, 27
Un-named glacier (Stromness)	0.1	54°09′	36°45′	11
Un-named glacier (Husvik)	1.4	54°11′	36°44′	
Un-named glacier	0.3	54°12′	36°43′	
Un-named glacier	0.3	54°12′	36°42′	
Un-named glacier	0.2	54°11′	36°37′	
Neumayer Glacier	108.8	54°15′	36°40′	1, 2, 3, 5, 7, 8, 9, 11, 29
Geikie Glacier	9.1	54°17′	36°40′	1, 2, 3, 8, 11
Lyell Glacier	25.6	54°17′	36°37′	1, 2, 3, 5, 8, 11, 17
Hodges Glacier	0.3	54°16′	36°32′	4, 8, 9
Un-named glacier (Glacier Col)	0.6	54°18′	36°33′	8, 24
Un-named glacier	0.1	54°16′	36°32′	
Un-named glacier	0.1	54°17′	36°33′	
Un-named glacier	0.1	54°18′	36°34′	
Hamberg Glacier	8.2	54°21′	36°30′	2, 3, 5, 8, 9, 11, 13, 16, 25, 26, 28, 29, 30, 31

APPENDIX I—*continued*

	Area (km²)	*Position of snout* Lat. S	Long. W	*References* (*see Appendix II*)
Harker Glacier	11.5	54°22′	36°30′	2, 3, 5, 8, 9, 11, 13, 15, 16, 24, 25, 26, 27
De Geer Glacier	3.2	54°22′	36°29′	7, 8, 10, 11, 23, 24, 27
Un-named glacier	0.1	54°21′	36°26′	
Un-named glacier	0.1	54°21′	36°26′	
Un-named glacier	0.1	54°22′	36°26′	
Un-named glacier	0.3	54°23′	36°27′	
Un-named glacier	0.4	54°22′	36°25′	
Nordenskjöld Glacier	104.5	54°22′	36°22′	1, 2, 4, 5, 7, 8, 11, 13, 15, 16, 19, 20, 21, 28, 30
Szielasko Ice Cap	7.1	54°19′	36°18′	
Un-named glacier	1.2	54°25′	36°17′	
Heaney Glacier	33.6	54°25′	36°11′	8, 16, 30
Cook Glacier	16.4	54°20′	36°10′	8, 16
Un-named glacier (Doris Bay)	8.0	54°28′	36°09′	
Ross/Hindle/Webb Glaciers	100.3	54°32′	36°05′	6, 8, 14, 17, 21, 22, 27, 31
Un-named glacier	0.7	54°34′	36°03′	
Weddell Glacier	23.0	54°34′	36°00′	6, 17
Bertrab Glacier	22.9	54°37′	35°57′	6, 8, 11, 12, 13, 16
Un-named glacier	3.2	54°38′	35°57′	6
Un-named glacier	0.6	54°40′	35°56′	
Un-named glacier	4.7	54°41′	35°57′	
Herz Glacier	14.0	54°42′	35°57′	6, 8, 11, 17
Twitcher Glacier	57.5	54°43′	35°55′	6, 10, 11, 17
Un-named glacier	6.2	54°45′	35°52′	6, 11
Un-named glacier	2.1	54°47′	35°50′	6, 11
Salamon Glacier	20.2	54°47′	35°54′	8, 11
Un-named glacier	3.0	54°48′	35°56′	11, 16, 17
Un-named glacier	5.5	54°47′	36°01′	3
Un-named glacier	2.0	54°47′	36°03′	2, 19
Un-named glacier	3.8	54°46′	36°05′	2, 19
Risting Glacier	19.1	54°46′	36°05′	2, 3, 8
Jenkins Glacier	6.4	54°46′	36°05′	2, 3, 8
Un-named glacier	0.9	54°47′	36°05′	2, 3
Philippi Glacier	19.0	54°49′	36°03′	2, 3, 17, 22, 29
TOTAL	1 955.1 km²			

APPENDIX II

PHOTOGRAPH COLLECTIONS AND PUBLISHED MAPS AND PHOTOGRAPHS OF GLACIERS OF SOUTH GEORGIA

1. Oblique photographs by helicopters of HMS *Endurance*, 1972 (British Antarctic Survey files).
2. Oblique photographs by helicopters of HMS *Endurance*, 1973 (British Antarctic Survey files).
3. Oblique photographs by helicopters of HMS *Endurance*, 1974 (British Antarctic Survey files).
4. Vertical photographs by helicopters of HMS *Endurance*, 1973 (British Antarctic Survey files).
5. Vertical photographs by helicopters of HMS *Protector*, 1957 (British Antarctic Survey files).
6. Vertical photographs by helicopters of HMS *Protector*, 1960 (British Antarctic Survey files).
7. Collection of photographs by G. Fowler, 1938 (British Antarctic Survey files).
8. Photographs by members of British Antarctic Survey, 1972–74 (British Antarctic Survey files).
9. Collection of negatives and prints by South Georgia Survey, 1951–52 (Scott Polar Research Institute files, P54/19).
10. Collection of negatives and prints by South Georgia Survey, 1953–54 (Scott Polar Research Institute files, P56/40).

APPENDIX I—*continued*

11. Collection of negatives by South Georgia Survey, 1956–57 (Scott Polar Research Institute files, P58/6).
12. Collection of photographs by British Graham Land Expedition (Scott Polar Research Institute files, P51/8).
13. Album of photographs by F. Hurley, 1914–17 (Scott Polar Research Institute files, P66/18).
14. Collection of photographs by Combined Services Expedition, 1964 (Scott Polar Research Institute files, P65/17/1–53).
15. Collection of photographs by Imperial Trans-Antarctic Expedition, 1914–17 (*Endurance*) (Royal Geographical Society files).
16. Collection of photographs by members of the Discovery Investigations (Institute of Oceanographic Sciences files, Wormley, Surrey).
17. Holtedahl (1929).
18. Sutton (1957).
19. Rankin (1951).
20. Murphy (1914*a*, *b*).
21. Matthews (1931).
22. Wild (1923).
23. Brown (1971).
24. Wordie (1921).
25. Hurley (1925, 1948).
26. Chaplin (1932).
27. Ferguson (1915).
28. Saunders (1950).
29. Gunther (1928).
30. Kohl-Larsen (1930).
31. Spiess and others (1926).