THE GEOLOGY OF NORTH-WESTERN SOUTH GEORGIA: I. PHYSIOGRAPHY

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ABSTRACT. Geomorphological mapping was carried out in the area bounded by the Bay of Isles, King Haakon Bay and Wilson Harbour during the austral summer seasons of 1972–73 and 1973–74.

The terminal moraines of the valley glaciers are subdivided into three groups according to their morphology, vegetation cover and relative position. The youngest group of moraines may represent a slight annual winter advance of the ice margin, pushing glacial debris into ridges. The presence of up to 25 terminal ridges at the snouts of the south-facing cirque glaciers east of Elephant Cove therefore suggests that the final retreat stage commenced about 25 years ago in this area. Clapperton (1971) believed that glacier retreat commenced 43 years ago on the central north coast of South Georgia, and the 18 year difference is now attributed to the harsher climate prevailing on exposed south-facing slopes.

Raised beaches and fluvio-glacial outwash fans, distinguished by their grading characteristics, range in height up to 25 m. a.m.s.l. The 2 m. raised beach may have been formed in response to the stage of glacial recession during which the youngest moraines were deposited.

Sorted stone circles, polygons and nets are thought to be genetically related to each other, because different forms develop within each other. Sorted stripes tend to be restricted to areas with a substantial moraine cover.

THE sub-Antarctic island of South Georgia is the largest on the Scotia Ridge and it lies approximately 2,000 km. east of Cape Horn between lat. 54–55°S. and long. 36–38°W.

The first geomorphological mapping of South Georgia was undertaken by Clapperton (1971) in the area between Cumberland Bay and Stromness Bay; from his field work in other parts of the north-east coast, Stone (1974) has given a further account of the physiography. The coastline of South Georgia is characterized by extensive wave-cut platforms surrounding headlands, whereas at the heads of sheltered bays beaches of sand or shingle pass landwards into raised marine features and outwash fans. On the outer coast, vertical cliffs terminate a tussock-covered coastal feature which rises gently inland from about 30 m. a.s.l. to the base of a steep rock wall or scree slope at a height of approximately 150 m. a.s.l. Holtedahl (1929) called this feature the "foreland" and attributed its development to a piedmont glaciation of the coastal areas which presumably took place during a glacial event of ice-cap proportions. This *ice-cap stage* is thought to have reached its maximum at least 10,000 yr. ago (Clapperton, 1971), when the author believes that islands up to 5 km. from the mainland were denuded to the 30 m. level. Following a period of retreat, the ice re-advanced as valley glaciers, the *valley-glacier stage* reaching its maximum approximately 5,500–6,500 yr. ago (Clapperton, 1971). After a prolonged period of milder climate, the glaciers advanced once again to reach a maximum position about 100 yr. ago. Since the final glacial maximum in the late 1920's (Smith, 1960), the glaciers have retreated slowly to their present positions.

Field data used in this paper were collected during the course of geological mapping of the Bay of Isles and Wilson Harbour areas of north-western South Georgia (Fig. 4, inset) in the summer seasons of 1972–73 and 1973–74. The pre-existing 1 : 100,000 map (sheet 1) of this area proved unsatisfactory, even when enlarged to 1 : 50,000, as a base for geomorphological work and so the area was re-mapped at 1 : 10,000 by plane-table survey.

TOPOGRAPHY

There is no apparent geometrical relationship between structural features such as fold limbs, hinges, etc. and the directions of glacier flow. However, the similarity between glacier orientation and joint pattern, as measured throughout this area (Fig. 1), suggests that glacier development may be controlled largely by the extensive north- and east-trending joint systems, either directly, or through their control of a pre-glacial drainage system. Two topographical regimes are recognized in the area studied (Fig. 2): broad glaciers with gentle gradients and

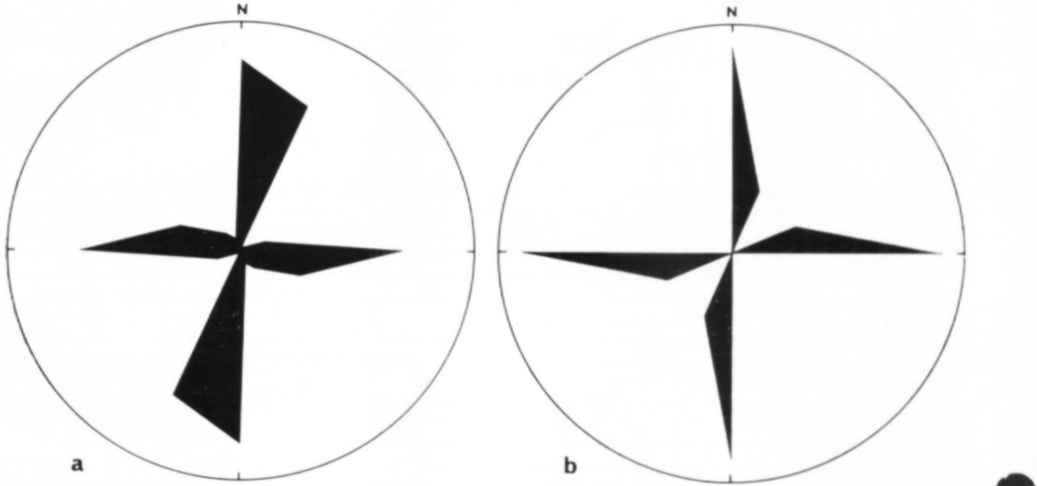

Fig. 1. The similarity between joint-plane orientation (a) and glacier orientation (b) in north-western South Georgia.

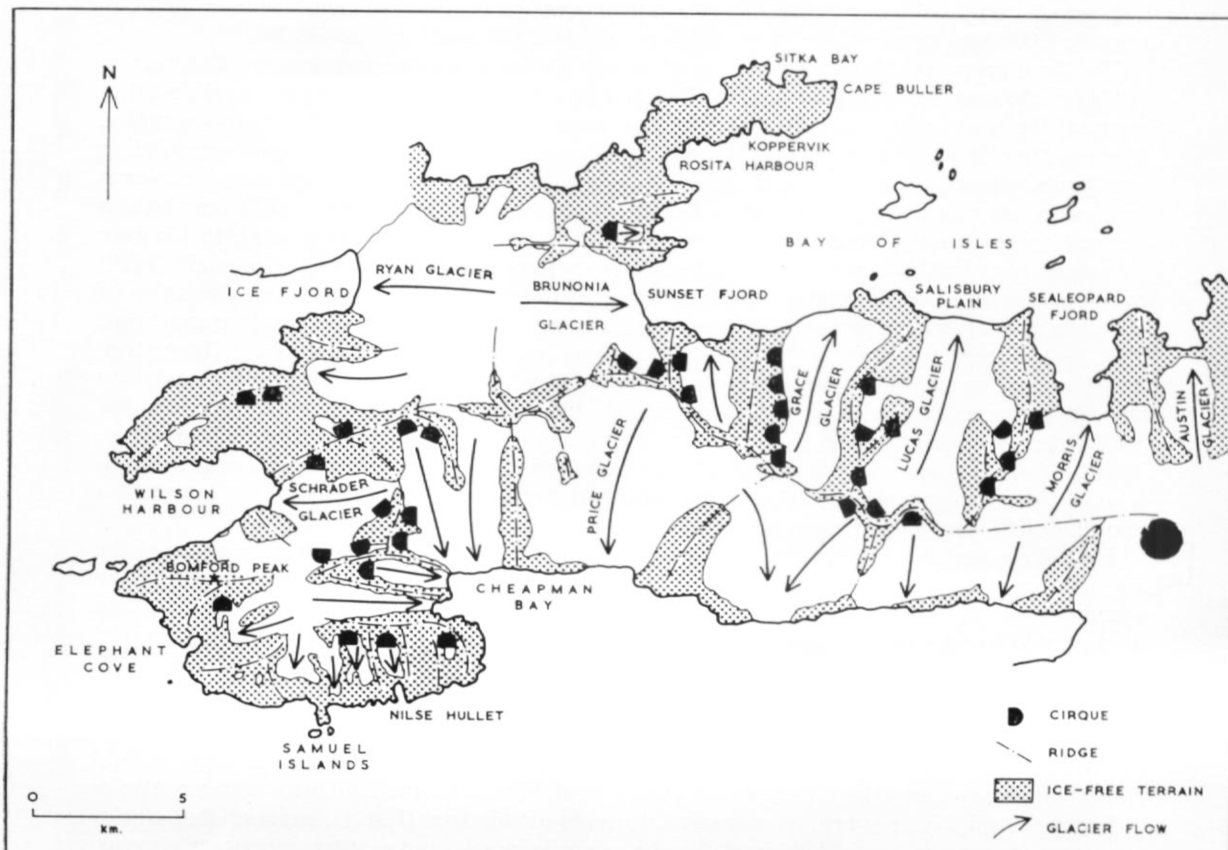

Fig. 2. Sketch map of north-western South Georgia showing the distribution and flow directions of cirque and valley glaciers.

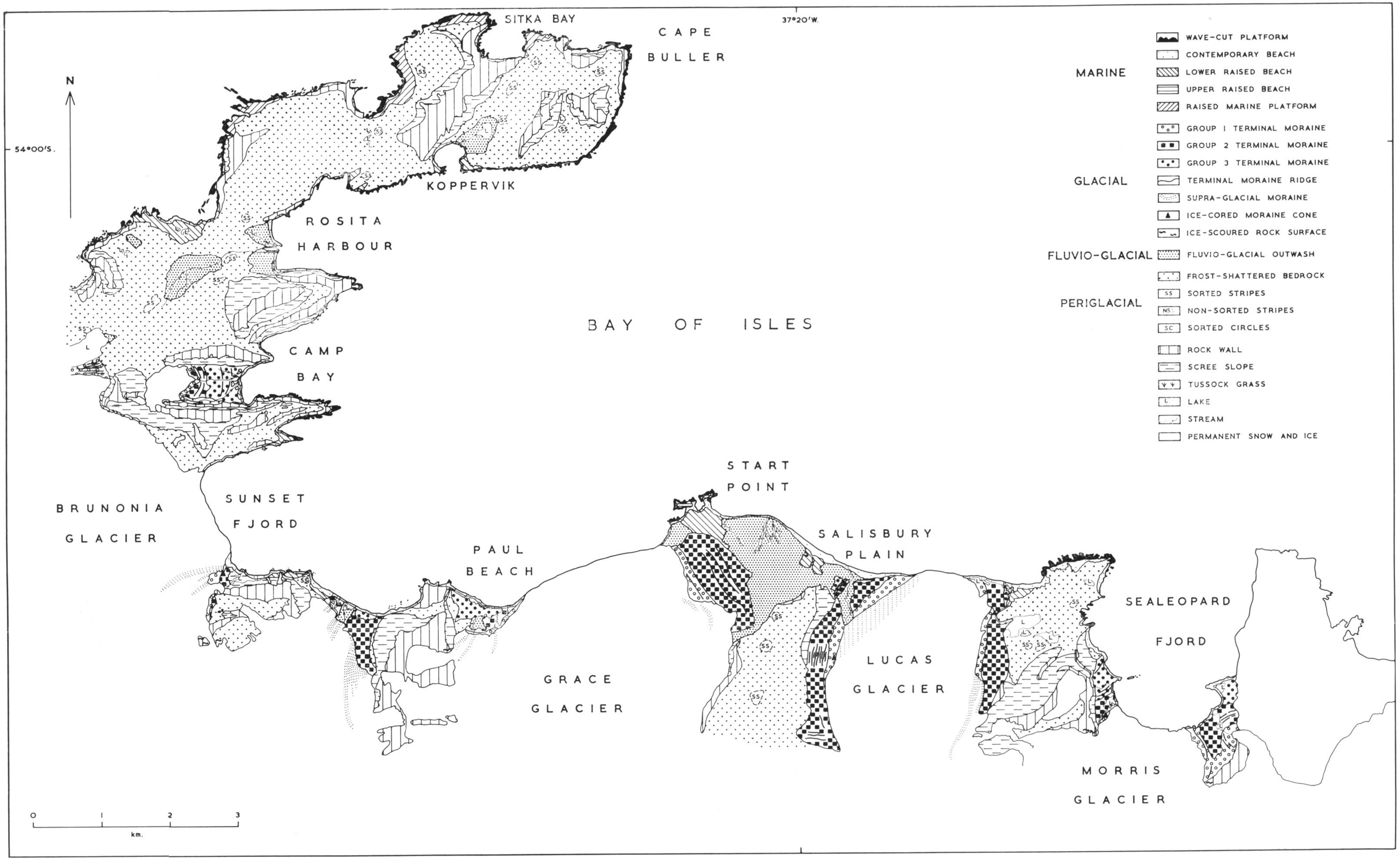

Fig. 3. Geomorphological map of the area to the south and west of the Bay of Isles, north coast of South Georgia. The legend also applies to Fig. 4.

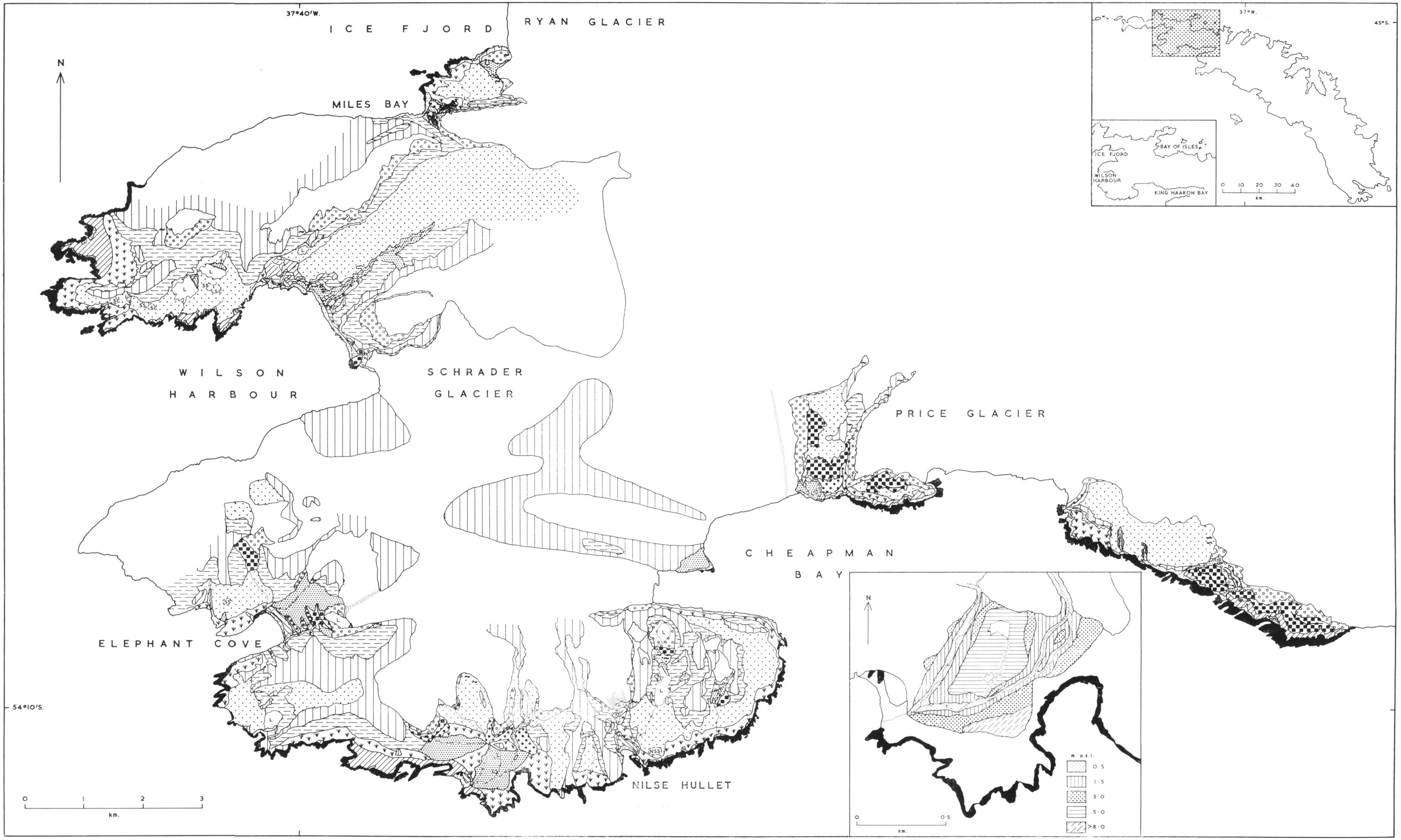

Fig. 4. Geomorphological map of the area bounded by Cheapman Bay, Wilson Harbour and Ice Fjord, western South Georgia. The inset in the top right-hand corner shows the location of the area studied (stippled); the other inset is an enlargement of the area 2 km. west of Nilse Hullet. The legend is the same as that for Fig. 3.

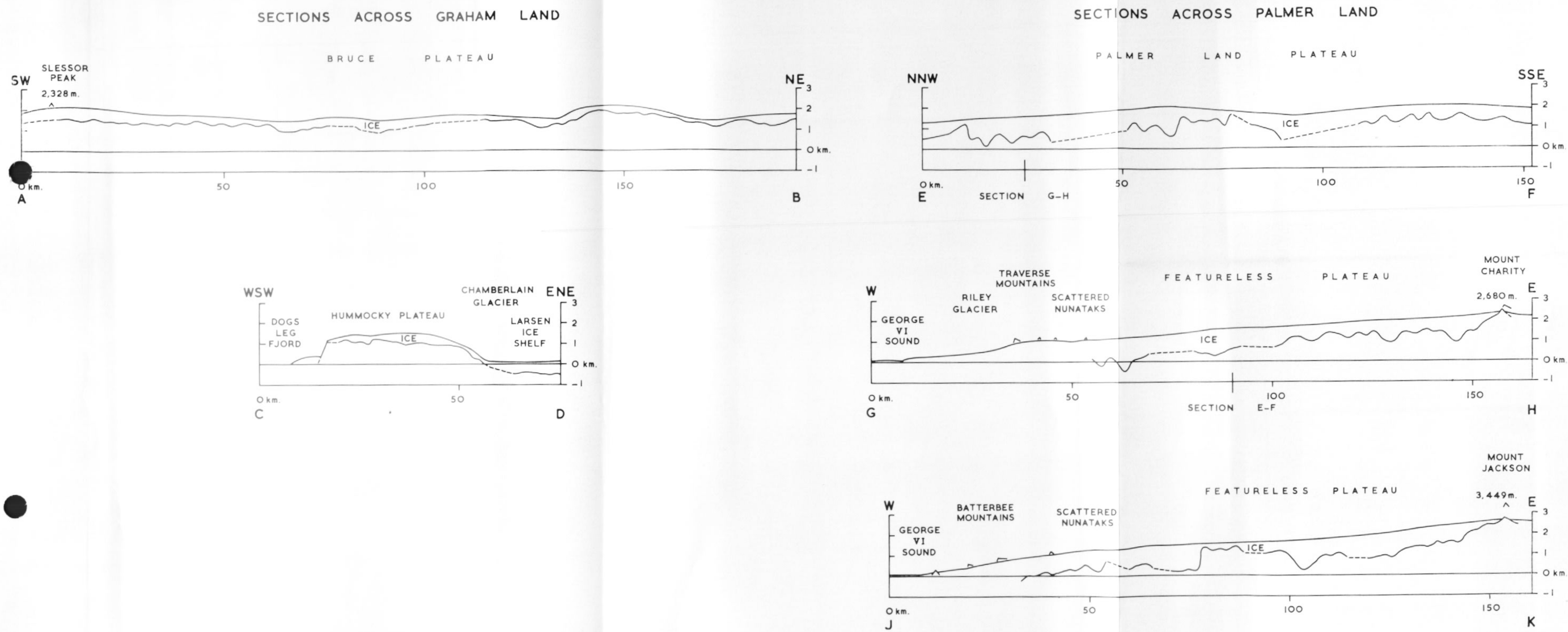

Fig. 3. Longitudinal (A–B and E–F) and transverse (C–D, G–H and J–K) sections across Graham Land and Palmer Land showing ice depths and the relief of the rock surfaces beneath the snow plateaux. The positions of the lines are shown in Fig. 1. Note that section C–D is across a narrow part of southern Graham Land, whereas sections G–H and J–K are across the western and central parts of northern Palmer Land (because of the limited data distribution). Vertical exaggeration ×5.

TABLE I. RIDGE CHARACTERISTICS OF MORAINE GROUPS 1–3

Glacier	Group 1				Group 2				Group 3			
	Number of ridges	*Average height* (m.)	*Average width* (m.)	*Distance from snout* (m.)	*Number of ridges*	*Average height* (m.)	*Average width* (m.)	*Distance from snout* (m.)	*Number of ridges*	*Average height* (m.)	*Average width* (m.)	*Distance from snout* (m.)
Morris, west	5	2	3	0–100	3	5	12	100–300	4	5	15	300–600
Lucas, west	14	1	2	0–100	3	20	50	100–500	3	5	30	500–600
Grace, east	3	2	4	0–100	3	40	100	100–700				
Murphy	10	1	2	0–80	1	20	50	80–150	3	5	20	200–300
Brunonia, south	4	2	5	0–40	2	30	100	40–200				
Camp Bay*	14	2	3	0–80	3	5	8	80–250	2	2	3	250–600
Price	20	1	2	0–100	1	10	40	100–300	1	10	40	300–400
Cheapman, north	8	1	2	0–150	2	15	40	200–400				
Nilse Hullet	10	1	2	0–80	3	3	6	80–200	1	10	40	200–300
Nilse Hullet, east*	16	1	3	0–150	No distinct ridges			150–250				
Samuel Islands, east*	25	1	1·5	0–100								
Samuel Islands, centre*	23	1	1·5	0–100	No distinct ridges			200–250	3	5	10	250–300
Samuel Islands, west*	22	1	2	0–80	No distinct ridges			80–200	2	3	7	200–275
Elephant Cove	24	1	2	0–200	1	10	50	200–500	3	5	60	500–800
Schrader, north	4	2	5	0–20	4	3	8	20–150				
Miles Bay	3	3	8	0–50	3	3	5	50–300	4	5	30	300–400

* Cirque glaciers.
For glacier location see Figs. 3 and 4.

sea snouts flow north into the Bay of Isles and south to King Haakon Bay, whilst to the west, in the area bounded by Wilson Harbour, Cheapman Bay and Sunset Fjord, valley glaciers with steeper gradients have an easterly or westerly flow direction. The inter-valley ridges in this western area rise inland to describe a dome centred on Bomford Peak (1,141 m.), the highest in north-western South Georgia.

Glacial Deposits

Three depositional stages have been recognized in South Georgia (Clapperton, 1971) and they are based largely on morphology, relative position and vegetation cover of the terminal moraine ridges. Each stage is separated by a substantial time interval and in certain areas glacial re-advance has occurred over previously deposited moraines. Details of the moraine ridges are summarized in Table I and their distribution is shown in Figs. 3 and 4.

Group 1 moraines

Terminal ridges. These moraines are currently forming at the glacier margins and are found up to 150 m. from the snouts of cirque glaciers and 100 m. from the snouts of valley glaciers. The number of ridges varies considerably from four to 25 depending on the size of the parent glacier. Moraines of group 1 are much more numerous in front of cirque than valley glaciers (Table I), indicating the greater sensitivity of the former to climatic changes. The sharply defined ridges in this group are generally 2–5 m. wide, 1 m. high and 2–5 m. apart. They are totally devoid of vegetation cover and surface stones are not discoloured. Those derived from within the glacier retain a dark grey hue, whilst material from the supraglacial moraine is usually rusty brown in colour. The extreme regularity and absence of distortion in these moraines suggest a fairly even retreat, punctuated by brief pauses or even slight re-advance which allowed small ridges to develop.

Contrasting with the majority of cirque-glacier moraines of this age, which are characterized by a fairly constant ridge height and crestal spacing (Table I), a small cirque glacier east of Nilse Hullet has deposited a complex series of moraines. The oldest moraines of group 1, located within 50–150 m. of the glacier, range in height from 0·5 to 1 m. with an average width of 3 m. The 12 ridges in this sub-group are separated from the glacier margin by a 5 m. high, 4 m. wide complex ridge with four crests (Fig. 5).

In Miles Bay, dark grey ridges of fluvio-glacial material have been deposited by subglacial or englacial streams at the glacier snout (Fig. 6). The high clay content of these short ridges has enabled them to dam back a pro-glacial lake. Terraces at 20 and 50 cm. above present water-level have been formed by wave action followed by abrupt drainage. A much larger pro-glacial lake has been dammed by recent moraines at the snout of the Elephant Cove glacier. Ancient shorelines have been cut at heights of 40, 60, 100 and 200 cm. above present water-level.

Group 2 moraines

These moraines are present within 20–700 m. of the glacier front (Table I). The group rarely consists of more than three ridges which range in height from 2 to 40 m. and in width from 5 to 100 m. with a crestal spacing of 10–50 m. Crests are broad, moraines are light grey to brown in colour with a sparse cover of mosses and lichens, particularly in damp and sheltered places. Patterned ground occasionally develops in the loosely consolidated moraine and surface debris is generally frost shattered.

In Sealeopard Fjord, these moraines never exceed 5 m. in height but all low-lying areas up to 500 m. in advance of the present glacier snout have a thick covering of glacial till which averages 5 m. in thickness and is absent only in areas where erosion by rejuvenated melt streams has occurred.

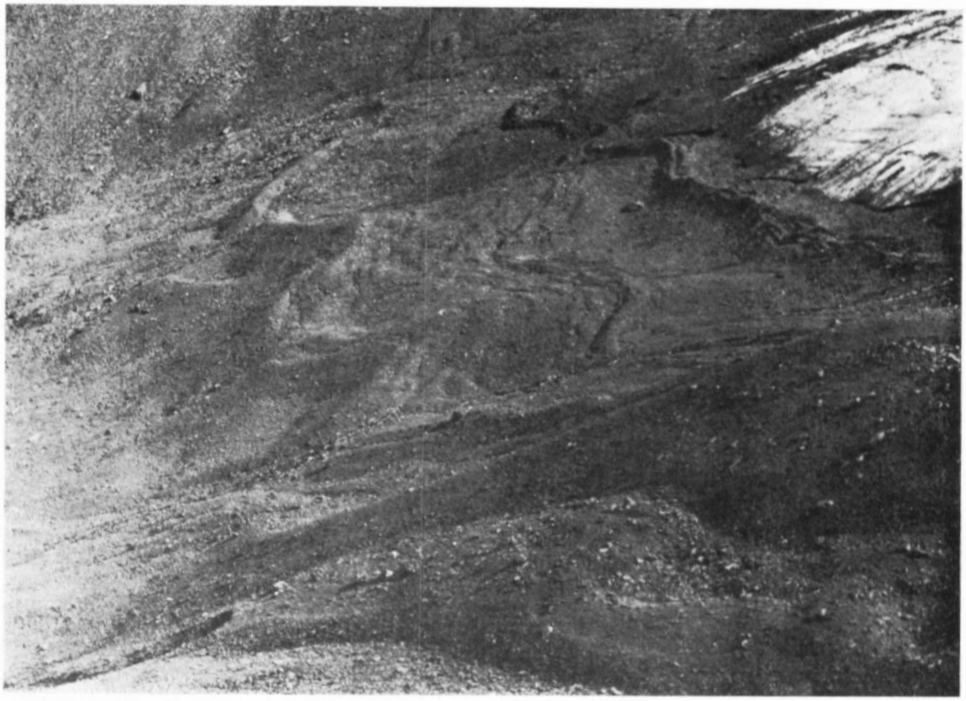

Fig. 5. Group 1 moraine ridges deposited by a small cirque glacier east of Nilse Hullet.

Fig. 6. Moraines of groups 1, 2 and 3 in Miles Bay.

Group 3 moraines

The moraine ridges of this group are located within 200–800 m. of the glacier margin. They range from one to four in number with rounded crests, a height of 5–10 m. and a width of 5–60 m., depending on size and load of the parent glacier (Table I). These clearly spaced tussock-covered ridges are often heavily dissected by melt streams, leaving them as discontinuous remnants of once much more extensive moraines. A characteristic feature of group 3 moraines is the size and variety of frost-heaved phenomena which develop in places with no vegetation cover.

Age relations of the moraine groups

In the Cumberland Bay area, Clapperton (1971) has identified a moraine group outside the limits of the group 3 moraines. These deposits of stony till do not form conspicuous ridges and occur mainly as ground moraine. Although they have not been recognized in north-western South Georgia, this older group of moraines has been identified up to 360 m. a.s.l. on two coastal peninsulas in the Cumberland Bay area (Clapperton, 1971).

Moraines of group 3 were deposited during a subsequent re-advance at least 5,500 yr. ago (Clapperton, 1971). A prolonged period of climatic amelioration and corresponding glacial retreat then followed until the glaciers started to re-advance, reaching a maximum about 100 yr. ago. In Miles Bay, group 2 moraines abut against moraines of group 3, suggesting that the stage 2 advance of 1875 (Smith, 1960) was in some areas almost as extensive as the previous glacial event.

The most recent glacial maximum was reached about 40 yr. ago (Smith, 1960), since when both cirque and valley glaciers have been in retreat with consequent deposition of group 1 moraines. Clapperton (1971) suggested that the presence of 38 terminal ridges in front of a glacier near Husvik on the north coast of South Georgia implied retreat since 1930. The recent retreat of cirque glaciers in the coastal area east of Elephant Cove is marked by the deposition of 22–25 parallel terminal ridges, which, if regarded as annual features, indicate a continuous glacial retreat since 1948. The delayed start of glacial retreat on the south coast may be attributed to the cooler climatic conditions which prevail on exposed south-facing slopes. A temporary halt or re-advance since retreat began on the north coast over 40 yr. ago seems unlikely as these group 1 moraines show no signs of distortion or irregularity in ridge spacing.

Although several mechanisms have been suggested for terminal ridge formation, only two could be applicable in the Elephant Cove area. Boulton (1967) has suggested that debris bands originate as subglacial material which is brought to the surface either along flow lines or shear planes. As the glacier margin is thinned by ablation, the supraglacial ridges are lowered at the snout to form superficial ridges on the ground moraine. Alternatively, these ridges could have been formed as moraine is pushed up frontally by periodic re-advance of the glacier (Gwynne, 1942). Worsley (1974) has described annual moraine ridges at Austre Okstindbreen, north Norway, which have been formed by ice push each winter since 1957. If the debris-band mechanism controlled ridge formation, the number of terminal ridges would be controlled not only by the rate of ablation but also by the number of flow lines or shear planes in the snout area. As each glacier has unique flow characteristics, variation in ridge size and spacing would be expected from one cirque to another but this is not the case. The uniformity of ridge height and crestal spacing, together with the absence of debris along shear planes in the snout regions of cirque glaciers in this area, tends to preclude a debris-band mechanism for ridge formation. The continuity of group 1 ridge characteristics from one cirque glacier to another is therefore perhaps best explained by a slight annual winter advance of the ice margin, pushing the moraine into ridges.

Fluvio-glacial Deposits

A large proportion of glacially transported material is removed from the vicinity of the glacier snout and re-deposited over large areas of outwash plain by melt-water streams. So effective is this process that, in some areas, large boulders strung out in concentric lines across the valley floor appear as remnants of once substantial terminal moraines.

Outwash fans and plains

Beyond the terminal moraines of most glaciers there are areas of fluvio-glacial material which range in extent from several hundred square metres to several square kilometres. In stream section, the outwash plains show banding from sand grade through fine and coarse pebbles to cobbles. At the seaward margin of the plain in Miles Bay, these bands are 2–10 cm. thick and probably represent changes in the course of the melt stream. 17 bands were counted in a thickness of 83 cm., indicating an almost constantly changing flow regime. The mouth of the stream responsible for the deposition of this material migrated laterally over 100 m. during a 7 day period.

Stones in the outwash fans show a preferred orientation, lying flat with their long axes parallel to the flow direction. An unusually small number of stones (20 per cent) dip up-stream in normal imbricate fashion with 50 per cent dipping down-stream at 5–20°.

Many apparent raised beach deposits are the seaward margins of outwash fans. In a section through a 13 m. level at Wilson Harbour no beach material was found; this feature is underlain by fluvio-glacial sand with a single pebble horizon 2 m. from the top. At the same locality, the lower levels at 2 and 3 m. a.m.s.l. exhibit the graded banding characteristic of fluvio-glacial material. The outwash plain at Wilson Harbour surrounds islands of similar material graded to higher sea-levels and extends inland for 3 km. as a narrow valley train floored by coarse pebbles, cobbles and boulders.

Salisbury Plain is the largest area of outwash deposits in north-western South Georgia and is one of the most extensive on the island. It lies between Grace and Lucas Glaciers in the Bay of Isles (Fig. 3), is triangular in shape with a coastal base exceeding 3 km. in length, and the apex is situated approximately 2 km. inland. More than 90 per cent of the plain is graded to present sea-level by braided melt streams emanating from the north-east corner of the Grace Glacier snout, the remainder having been levelled to 2·5 m. a.m.s.l. The contemporary outwash plain is devoid of vegetation cover and pavements of water-worn gravel with stones rarely exceeding 10 cm. in diameter cover large areas. The plain slopes at about 2° seawards so sorting at its distal margin is good.

To the north of the Samuel Islands, confluent melt streams from three cirque glaciers have deposited a 3 m. wide outwash plain with river terraces. The terraces, at 0·5, 1·5, 3 and 5 m. above stream-level, grade towards the sea at 1 m./km. They indicate a successive lowering of sea-level and are covered by a layer of peat from 40 to 150 cm. thick overlying the outwash gravel.

Upland outwash fans are not common because material suitable for fluvial re-working is generally confined to glacier-snout areas near sea-level. A 200 m. wide fan has formed on the north face of peak 2,538 (Fig. 4) extending outwards from the base of the mountain front across the valley train. These upland fans occur on flattish coastal forelands at the base of steep mountain flanks. They are concave in form and consist of coarser, more angular material than is found in the outwash plains.

Raised Marine Features

Raised beach deposits

Raised beach deposits generally occur at the heads of sheltered bays as tussock-covered flat-topped terraces underlain by smooth beach cobbles and shingle. Whale bones and wood fragments are abundant in the lower beaches, thus distinguishing them from outwash fans which exhibit fluvial banding of stones with a preferred orientation. An Abney level was used to height the raised beaches and the results are shown in Table II.

TABLE II. RAISED BEACH DATA FOR NORTH-WESTERN SOUTH GEORGIA

Locality	*Height above sea-level* (m.) S.L.	1	2	3	4	5	6	7	8	9	10
Cheapman Bay, west				3·0							
Cheapman Bay, east				3·5							
Cheapman Bay, south				3·0							
Wilson Harbour, south			2·0	3·0			6·0		8·0		10·0
Wilson Harbour, north				3·0		5·0		7·5			
Kade Point				3·0			6·0	7·0			
Ice Fjord, south-west				3·0			6·0				
Miles Bay			2·0 2·5			5·0			8·0		
Nilse Hullet				3·5			6·5				
Samuel Islands						5·5					
Elephant Cove				3·0							
Salisbury Plain				3·0							
Sealeopard Fjord				3·0					8·0		
Paul Beach			2·5								
Rosita Harbour			2·0	3·0		5·5					
Camp Bay				3·0		5·5					
Koppervik				3·0							

The most recent raised beach at 2 m. a.s.l. is rarely vegetated and it is suggested that this feature was formed in response to the final glacial retreat which began in 1926 and during which the moraines of group 1 were deposited. The continuity from contemporary beach through storm beach to 2 m. raised beach suggests that the series represents a continuous pro-grading shingle deposit which has been forming continuously over the last 40–50 yr. (Clapperton, 1971).

The most extensively developed raised beach at 3 m. a.s.l. (Fig. 7) has a dense tussock covering. In Wilson Harbour, the flat-shaped stones in this feature average 5 cm. in length and are set in a sandy matrix. The 3 m. raised beach in Cheapman Bay is typically composed of cobbles from 10 to 30 cm. in length and in which whale bones and wood fragments have been found. A maximum age of 200 yr. for the 3 m. level is indicated by the presence of whale carcasses on this lower platform (Clapperton, 1971). Clapperton (1971) tentatively correlated the 3 m. level with the slight isostatic recovery of South Georgia following the glacier recession responsible for the deposition of the group 2 moraines.

The higher raised beaches are of limited extent and are often difficult to distinguish from graded outwash fans. The 7·5 m. level in Sealeopard Fjord probably represents an abrasion surface, since tussock-covered till exposed on the western side of the fjord is nowhere overlain by beach material. The narrow contemporary beach consists of large rounded to sub-angular beach cobbles derived directly from the till cliff. This is a typical beach development in coastal areas backed by large terminal moraines such as at Cheapman Bay (Fig. 4), whereas the material found on both raised beaches and currently forming beaches along the seaward margins of outwash fans is much finer, consisting largely of rounded and sorted pebbles.

The upper raised levels at 10, 13 and 17 m. a.s.l. consist mainly of degraded remnants except in Wilson Harbour (Fig. 8), where distinct levels of fluvio-glacial fines are overlain by up to 1 m. of peat.

A quantitative summary of raised beach data for six areas on the north coast of the island (Fig. 7) shows two main groupings: a lower level at 2–3·5 m. a.s.l. and an upper level at 5–6·5 m. These figures agree well with Clapperton's (1971) results from Cumberland Bay,

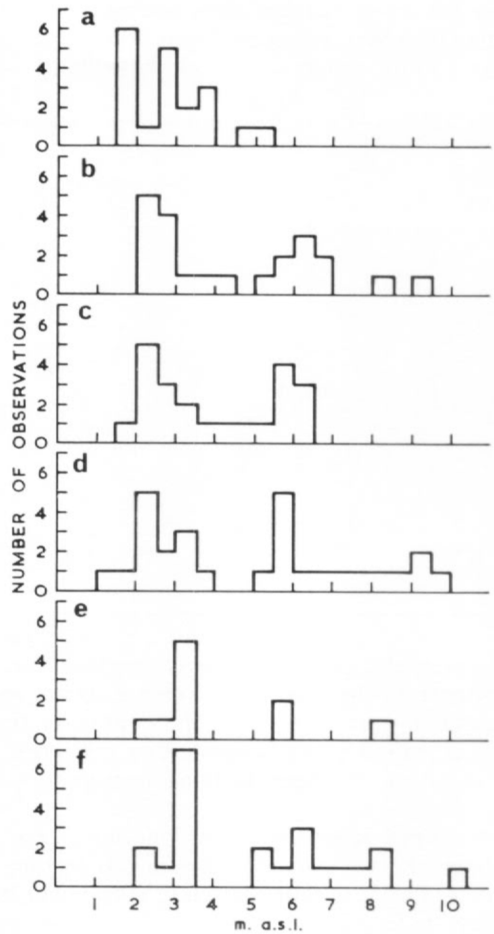

Fig. 7. Summary of raised beach data for South Georgia.
a. Cooper Bay area (Stone, 1976); b. Royal Bay area (Stone, 1974); c. Barff Peninsula (Stone, 1974); d. Stromness Bay (Skidmore, 1972); e. Bay of Isles area (present author); f. Wilson Harbour area (present author).

where he recognized a low raised beach at 2·5 m. a.s.l. and a broad upper level at 3·5–7·4 m. a.s.l. Higher raised beaches are not as widespread but there are well-defined levels at heights of 8–8·5 and 9–9·5 m. a.s.l. in several areas (Fig. 7).

Raised beaches in the Cooper Bay area at the extreme eastern end of the island are slightly lower, forming two groups at 1·5–2 and 2·5–4 m. a.m.s.l. A slight increase in raised beach height can be discerned towards the west (Fig. 7), the lower group forming a mean at 2–2·5 m. on Barff Peninsula (Fig. 7c), increasing to 3–3·5 m. a.s.l. in the Wilson Harbour area at the western end of the island. This variation could perhaps be attributed to a slower rate of glacial unloading at the eastern end of the island.

Direct correlation of raised marine levels on South Georgia with raised beaches in the Falkland Islands (Adie, 1953), the South Orkney and South Shetland Islands (Adie, 1964; John and Sugden, 1971), and elsewhere in Antarctica is of doubtful value since they almost certainly relate to local glacio-isostasy.

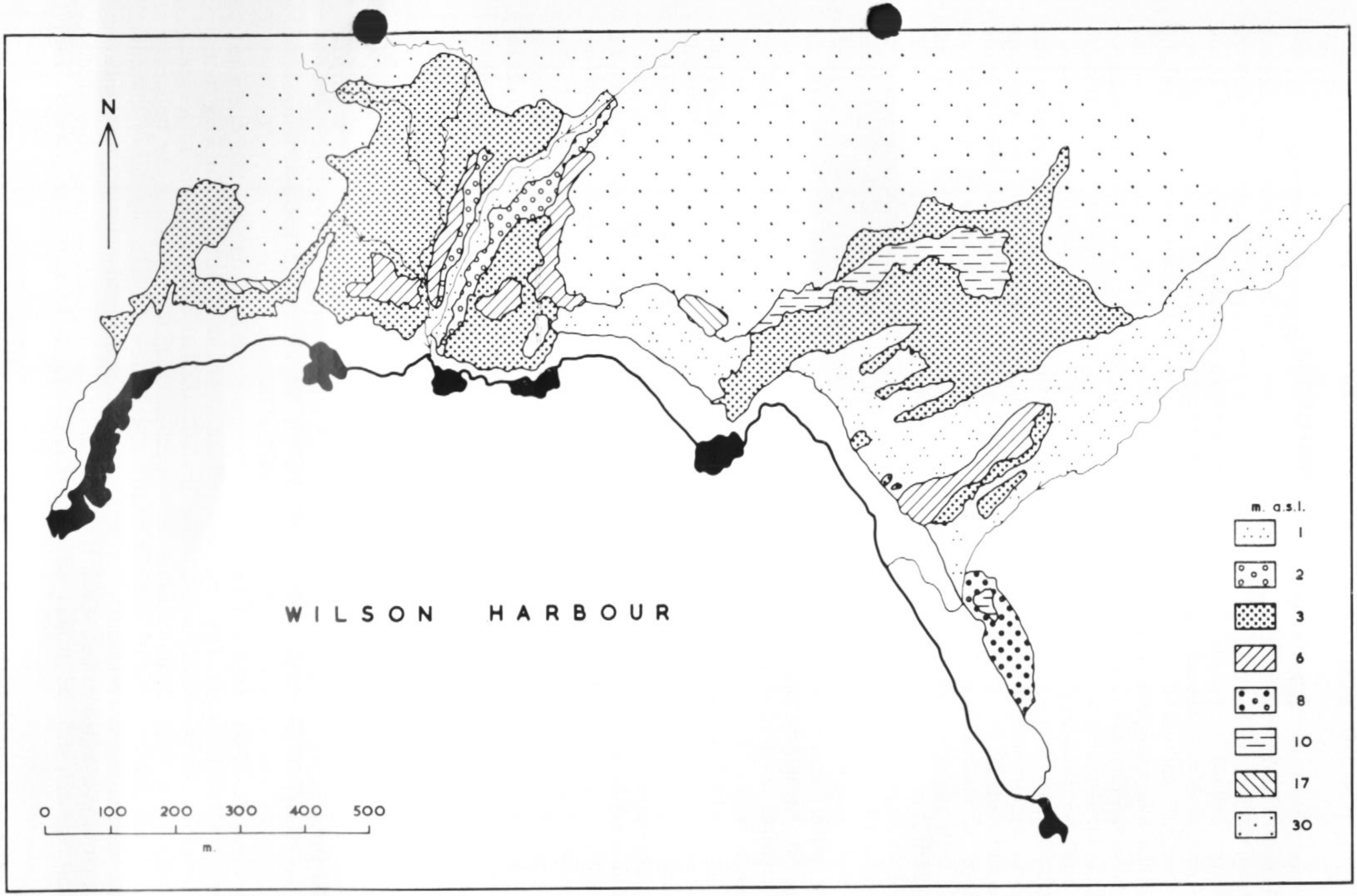

Fig. 8. Sketch map of Wilson Harbour showing the distribution of raised beaches and their heights above sea-level.

Periglacial Weathering

There are several areas of well-developed patterned ground on the extensive coastal foreland north of Wilson Harbour. Large stone circles show a high degree of sorting and they are generally confined to glacially sculptured basins or broad channels between bedrock knolls. The circles, 1–3 m. in diameter, consist of a coarse border surrounding an inner zone of fines, granules and small pebbles (Fig. 9). Tabular stones in the outer border are arranged on edge with their long axes parallel to the circle margin. Although a slight gradation in stone size can be seen within the inner zone, the fines, comprising about half the total circle diameter (Fig. 9), generally abut sharply against the coarse border. A third intermediate zone is occasionally developed between the border and the centre, and the end product of circle grading is a coarse rim, fine intermediate zone and hollow centre. On the basis of mesh diameter, three distinct stages in circle growth are recognized: small (mean diameter 25 cm.) with an average stone maximum length in the outer border of 2 cm. (Fig. 10), grading through medium (mean diameter 80 cm.) with an average stone length in the outer zone of 6 cm. (Fig. 11) to large (mean diameter 200 cm.) with an average stone length in the outer border of 10 cm. (Fig. 9). It is not uncommon to find small circles within the medium ones and medium circles within the large ones (Fig. 9) but the association of circles of all three sizes is rare. True stone circles with a diameter less than 150 cm. are seldom found in isolation and the largest circles exceed 300 cm. across, with pits 40 cm. below the enclosing rims.

The smaller-scale types of patterned ground, with a mesh diameter of 20–150 cm., are rarely circular and the majority fall into the sorted net category (Fig. 10). Only one small area of patterned ground with a predominantly polygonal mesh was found on the foreland surface at Wilson Harbour (Fig. 11). The polygons have an average mesh diameter of 80 cm. and are subdivided internally by poorly developed nets. Sorted nets (Washburn, 1956), intermediate in geometry between polygons and circles, are typically developed in well-drained areas, whilst mature circles occur along the margins of small lakes and ponds. These nets, ranging in mesh diameter from 20 to 100 cm., occur at approximately 150 m. a.s.l. and, since no marked increase in size was noticed with increasing altitude, it is suggested that form size may be largely controlled by the availability of water which is necessary for cryoturbation.

The origin of stone circles and related forms is generally considered to be polygenetic because no single hypothesis can adequately explain the variety of patterns that exist. Washburn (1973) has suggested that, while different forms are produced by specific genetic processes, the same form types can be formed by a variety of processes. As both circles and polygons appear to develop in similar environments on South Georgia and in some areas a gradational sequence from polygons through nets to circles can be found, it seems possible that no single form can be directly attributed to a particular group of processes. The occurrence of small nets within polygons (Fig. 11) and polygons within circles indicates interaction of several processes at some stage in their development.

Where slope gradient exceeds approximately 5°, stone circles flow down-slope as stripes. Unlike stone circles, polygons and nets which are almost totally restricted to the north foreland of Wilson Harbour, stone stripes are present throughout north-western South Georgia on coastal foreland areas between 50 and 200 m. a.s.l.

On slopes of 15–30°, angular fragments are generally arranged on edge and orientated down-slope to form stripes. These mobile zones are separated by bands of flat-lying stones with their long axes orientated roughly perpendicular to the flow direction. There is a tendency for stones to be dragged parallel to the flow direction along the margins of the stationary zones. Consequently, stones are partially rotated so that their flat sides dip steeply towards the flow channels of vertical stones. This arrangement of mobile and stationary zones differs from that of non-sorted stripes, which have been described by Washburn (1956) as parallel lines of vegetation-covered ground with intervening strips of relatively bare ground. The

Fig. 9. Large stone circles divided internally by transitional forms.

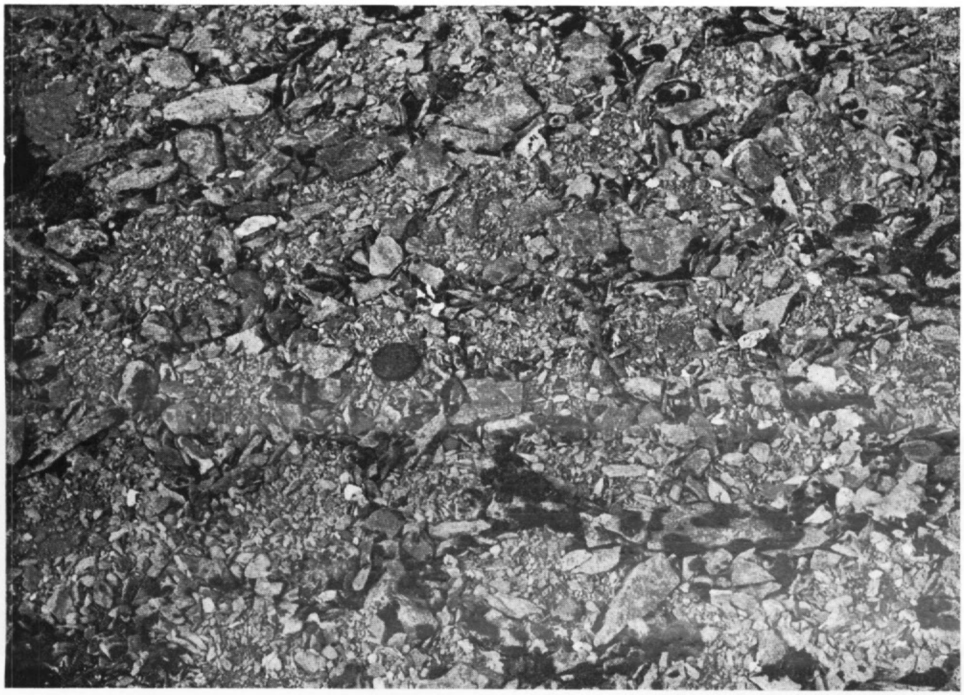

Fig. 10. Stone nets showing well-developed sorting and alignment of tabular stones parallel to their margins.

Fig. 11. Sorted stone polygons with indistinct internal stone-net development. Note the lichen growth in the surrounding inactive area.

mobile zones develop in foreland areas, where bedrock knolls undergoing intense frost shattering contribute large quantities of angular and platy rock fragments to the transported mantle. All mobile zones examined were active and totally devoid of a vegetation cover. Both mobile and stationary zones average 30 cm. in width and, where the angle of slope exceeds 30°, all stones become mobile.

Sorted stripes generally develop on glacial till which contains a high percentage of fines. Large pebbles and cobbles are arranged on edge in zones, with an average width of 10 cm., separated by bands of fines, granules and small pebbles in random orientation (Fig. 12). The fine bands show no grading and vary in width from 8 to 12 cm. They are characterized by a maximum pebble diameter of 1 cm., whereas the average diameter of stones in the coarse zone is approximately 2 cm. Sorted stripes usually develop on a slope of 10–30°, extending for up to 20 m. down-slope and maintaining a constant width throughout.

The runs and flows, which develop on moderate to steep slopes, generally terminate on relatively flat ground in cone-shaped fans that vary in size but average approximately 5 m. in width. Stone orientation within the flows is governed by position with respect to the flow axis and therefore relative flow speed. In the centre of the fan, the angular fragments are arranged on edge and aligned perpendicular to the flow axis, dipping at 40–50° up-slope. Towards the margins of the flow, the long axes of the stones retain their perpendicular orientation with respect to the flow direction but the stones are no longer imbricated. There is also vertical zoning with the stones in the centre of the flow lying horizontally, whereas stones at the base dip gently down-slope.

To the north of Koppervik, on a steep west-facing slope, rapid movement of the substantial talus cover has taken place along curved shear planes, following the spring melt of frozen ground water. This water-induced slumping has given rise to 50 cm. high ridges up to

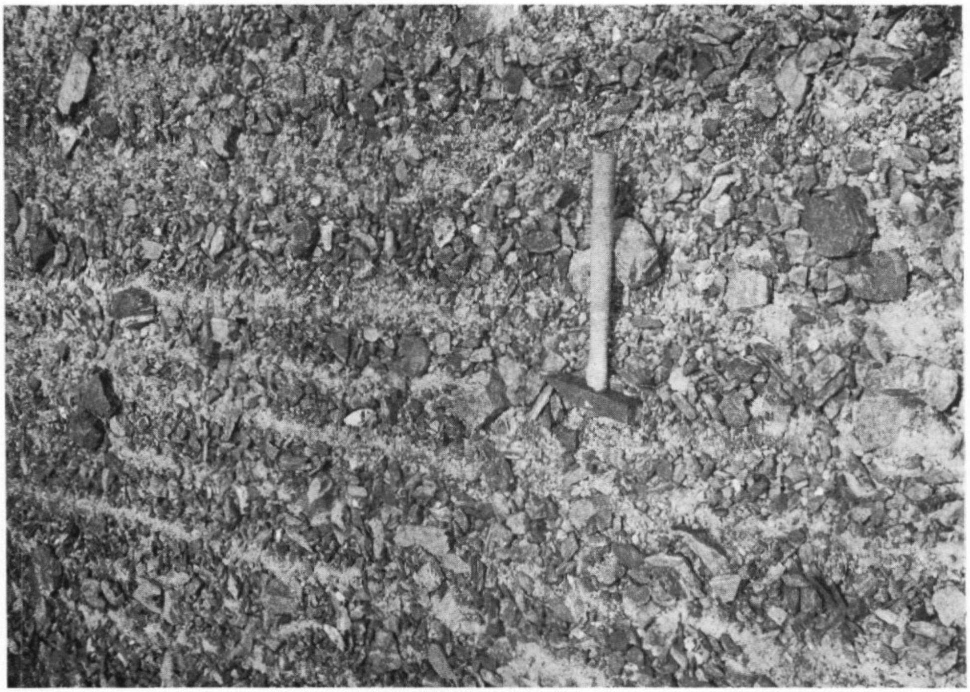

Fig. 12. Sorted stone stripes; coastal foreland south of Sunset Fjord.

20 m. in length on a slope of approximately 40°. These ridges, composed predominantly of fines and small scree fragments, contour the mountain side as a 10 m. wide band of roughly parallel lines. Each ridge is fronted on the up-slope side by a small furrow which rarely exceeds 30 cm. in depth.

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