

XXIII.—**Geological Observations in South Georgia.** By **D. Ferguson**, Mem. Inst. M.E.,
F.R.G.S. *Communicated by* Professor **J. W. GREGORY**, D.Sc., F.R.S.

(MS. received March 2, 1914. Read July 6, 1914. Issued separately May 20, 1915.)

[Plates LXXXI–XCI.]

CONTENTS.

	PAGE		PAGE
Introductory	797	The Geological Age of the Rocks of South Georgia	812
South Georgia : Position of the Island	797	Concluding Observations	813
Physical Character of South Georgia	798	Explanation of the Plates	813
Previous Geological Literature	800	Appendix on the Physiography. By Professor	
The Rocks of South Georgia	802	GREGORY	814
Local Distribution of Rocks	805		

INTRODUCTORY.

In the investigation of a remote and isolated island for mineral and metalliferous deposits its geological structure and the character of the rock masses of which it is formed are of primary importance. Where the evidences of metalliferous deposits are more or less openly and widely exposed the geological structure, while still of interest, is not so important. Ore deposits, as a rule, occur in rock-bodies which have definite relations to each other, a characteristic geological structure.

In the island of South Georgia, where the exposed evidences of metalliferous ores are very slight, the investigation of its rock-bodies, their character and geological structure, is a necessity. By making an examination of that kind, we endeavour to ascertain if there may be concealed ore-bodies which further exploratory prospecting may with a reasonable probability expose to view. Where the peculiar types of geological structure generally identified with metalliferous ore-bodies are not sufficiently developed, only small and scattered ore deposits can be reasonably anticipated. The presence of metalliferous ores in an indefinite form over any area under investigation necessitates a more detailed examination of it, in order that no evidence bearing on their possible occurrence may be omitted. The island of South Georgia is an area of that kind, and the prospecting work undertaken there was conducted in conformity with that opinion.

SOUTH GEORGIA : POSITION OF THE ISLAND.

The island of South Georgia occupies one of the corners of an irregular four-sided figure, while the Falkland Islands, the South Orkney Islands, and the South

Sandwich Islands are severally at the other three corners. The position in relation to these other islands may be defined as follows :—

From South Georgia (Leith Harbour) to Port Stanley, Falkland Islands is about 890 miles in a direction N. 80° W.

From South Georgia (Leith Harbour) to the South Sandwich Islands is under 400 miles in a direction S. 67° E.

From South Georgia (Leith Harbour) to the South Orkney Islands is under 600 miles in a direction S. 30° W.

The position is more definitely fixed by the latitude and longitude of Cape Saunders at the north-west entrance to Stromness Bay and Leith Harbour, and that of King Edward's Point, Cumberland Bay, on which is situated the meteorological station of the Argentine Government.

Their positions are as follows :—

Cape Saunders—Lat. $54^{\circ} 9' \text{ S.}$, long. $36^{\circ} 32' \text{ W.}$

King Edward's Point—Lat. $54^{\circ} 18' 15'' \text{ S.}$, long. $36^{\circ} 26' 15'' \text{ W.}$

The position of the observation point at the head of Moltke Harbour, Royal Bay, used by the German Meteorological Expedition of 1882, has also been carefully determined and found to be :—

Lat. $54^{\circ} 30' 53'' \text{ S.}$, long. $36^{\circ} 5' 44'' \text{ W.}$

The central position of the island, and its most prominent and elevated feature, is the crest of Mount Paget, rising 8383 feet above sea-level, and overlooking Cumberland Bay, about 10 miles south of King Edward's Point.

PHYSICAL CHARACTER OF SOUTH GEORGIA.

From whatever direction the island is approached its coasts are rock bound, and more or less precipitous. No open beach or detrital flat exists anywhere on its outer margin. There is a valley about a mile wide in Moraine Flat, which runs up from the enclosed south-west rim of Cumberland Bay, near King Edward's Cove, for about 4 miles to an ice-field and glacier. There are also several patches of detrital flats and moraines, which probably occupy hollows scooped out by glacial action. Leith Harbour is one of these; Husvik Harbour, where the Bucentaur Whaling Company is located, is another; Elsie Harbour and Adventure Harbour, on the north-west corner of the island, originally scooped out by ice into one channel, have been separated into two safe refuge anchorages by morainic detritus blocking up several miles of its centre.

The coast, always rock bound, has generally a stern and rugged appearance, not unlike parts of the north-west Highlands of Scotland. Along the north-east coast, running from north-west to south-east, the outer escarpments are succeeded inland by

rocky heights, having ice-fields in every hollow, and eventually culminate in the central or Allardyce range of mountains. The central range, except in steep rock escarpments and splintery crests, is covered with a permanent cap of ice-fields and snow.

Mount Paget, the highest point of the central range, 8383 feet above sea-level, has almost vertical escarpments of gnarled rusty-brown rocks which reach to its summit; the escarpments are surrounded by ice-fields and glaciers, which slowly flow down to the edge of the Nordenskjöld, Moraine Fiord, and Moraine Flat Glaciers in Cumberland Bay.

Looking up Cumberland Bay on a fine clear day, rather an event in South Georgia, we have a magnificent view of the steep walls of uniformly bedded and stratified rocks, which run into narrow chasms and gorges, like Moraine Fiord, and rise into frowning reddish-brown ramparts and walls to the crest of Mount Paget, the Sugar Loaf, and the Nordenskjöld Peak. The red-brown colour of the rocks is contrasted perfectly with the sparkling white of the ice-fields and glaciers, and presents to the eye a view of lake and mountain scenery at once grand and picturesque.

There can be little doubt that the north-east coast of South Georgia has that definite arrangement of naked rocky heights and exposures, ice-fields and glaciers, which give it the premier place for picturesque and grand scenery over all the other Antarctic and semi-Antarctic islands with which it is indirectly grouped: the South Orkney, the South Sandwich, and the South Shetland Islands.

The south-west coast of South Georgia, extending from Cape Nunes past Annenkov Island to the Novosilski Bay, is one vast sheet of ice, through which Mount Paget can only be distinguished by its great height. This coast is probably much indented, as rock escarpments form the coast-line, and inlets open into the interior at various points; but they are filled up with ice, which terminates in glacier edges at sea-level.

The mass of South Georgia owes its existence to-day to the character of its rocks, and to crustal movements which date back to a remote geological period. The ice-fields and glaciers may be attributed to the influence of the great land mass of the now well-defined continental area of Antarctica. The existence of that huge continent, wreathed in one vast ice-cap, is sufficient to account for the rigorous climate of South Georgia. The fact that the south-west coast of the island is much more under the influence and presence of the ice-cap and glaciers than the north-east coast, is evidence in support of that view.

The northern coast of Newfoundland, of which the writer has had experience along Notre Dame Bay, up to the Straits of Belleisle, nearly corresponds in northern latitude to South Georgia in southern latitude. However, it is warmer in summer, and consequently permanent ice-fields and glaciers do not exist. There is no polar continent sending its cold winds over Newfoundland, although to some extent Greenland is a refrigerating influence. Again, South Georgia has no such beneficial

influence as the Gulf Stream. The more open character of the scenery and the less rigorous character of the climate on the north-west and south-east coasts of South Georgia, in contrast to the coasts exposed to the polar influences, must be attributed to the winds from the north-west, north, or north-east.

The line of permanent snow on the coast facing the north-east is at not less than 2000 feet above sea-level. Even here, however, ice-fields and glaciers extend down to sea-level; but these are due to ice formed above the line of perpetual snow, pushing its way down to sea-level.

Coronda Peak, overlooking Leith Harbour to the north-west, is 1400 feet above sea-level; Spencer Peak, in Cumberland Bay, 1700 feet above sea-level; and the peak above Moltke Harbour, Royal Bay, 2297 feet above sea-level, are clear of snow in summer. The hollows in each of the ranges from which these peaks rise have permanent ice in them, and streams of water run from the melting edge. The existence of the streams is due to small cirque-like hollows, into which the sun's rays penetrate sufficiently to keep them active.

South Georgia is a mere rock fragment rising out of the South Atlantic. It has a rigorous climate, which is not, however, detrimental to men of ordinary sound physique. The ice-fields and glaciers cannot fail to keep down the average temperature, but they furnish the island with copious supplies of the purest water.

The island as a whole is a lenticular rocky mass, with Mount Paget as its central altitude, from which it slopes down into the sea to the north-west and to the south-east. Its greatest width, across Mount Paget, is a distance of about 30 miles. The axis of the island and also the general strike of its rock-bodies is also the axis of the central range of the Allardyce Mountains.

PREVIOUS GEOLOGICAL LITERATURE.

Captain Cook called the island Georgia in honour of King George III. He sailed down the north-eastern coast from Willis Island to Cooper Island, at the south-east extremity. We owe to this explorer the names of many of the promontories and bays, first discovered by him, and now familiar to navigators in the South Atlantic. Possession Bay was named by Captain Cook on account of his landing there and taking possession of the island in the name of King George III. He refers to rocky islets and rocky hillocks but does not give any details of geological structure.

He makes the interesting statement that he did not find a stream of fresh water on the whole coast, and that only along the escarpments of the north-eastern coast is there warmth enough to melt the snow. In recent years the whaling industry has obtained ample supplies of the purest fresh water, flowing from the base of the glaciers, on the north-eastern coast.

Captain JAMES WEDDELL* also visited the island, and described it as so deeply

* JAMES WEDDELL, *A Voyage towards the South Pole*, pp. 50-54.

indented that boats are frequently transported overland from one coast to the other.

Dr OTTO NORDENSKJÖLD* states that the general features of the South Georgian landscape are similar to those of Spitsbergen. Mountains and fiords follow each other in the same way, but the fells of South Georgia rise from the coast in most places precipitously to almost inaccessible ridges. He describes this island, situated in lat. 54° S., as having glaciers as large as those of Spitsbergen, in lat. 80° N. He found traces everywhere in Mai Viken, Cumberland Bay, of a former ice-covering with morainic gravel, and beautifully striated stones, which proved that an immense mass of ice had once filled the entire valley. During a visit he paid in 1902 to Moraine Fiord in Cumberland Bay, he discovered the first fossil found in South Georgia, imbedded in an enormous block of stone.

K. FRICKER† in his account of South Georgia adopts the view that it is connected with the Cordilleras of South America and with the South Sandwich Islands. He considers the outline, the narrow extended form, and the deep fiords prove the fact that in South Georgia we have a portion of a broken and submerged mountain chain. He quotes the geological features described by HANS THÜRACH, the geologist of the German Meteorological Expedition of 1882. Near Royal Bay the rocks are clay slates, alternating with phyllite gneiss, upon which follows clay slate, alternating with quartz slate, and he says that huge banks of shale or diabase-tuff and sandstone occur near the Weddell Glacier.

Dr FRITZ HEIM,‡ geologist to the German Antarctic Expedition (1911), led by Lieut. FILCHNER, states that the rocks at Royal Bay are chiefly phyllites, schists, and tuffs(?) of unknown age, and that the rocks have a north-west and south-east strike and a southerly dip. According to his observations, the entire north coast, with the exception of Royal Bay and part of Cumberland Bay, appears to be built up of interstratified dark-grey to bluish-grey schists and greenish tuffs. The rocks of Royal Bay are of different appearance from all seen on the north coast, and also from those in the inlets east of Royal Bay. He considers, despite the scanty observations yet made, that South Georgia is a folded mountain chain, the general strike of the folds probably coinciding with the strike of the island. Volcanic rocks were discovered from Novosilski Bay round to Drygalski Fiord on the south-east end of the island. In Larsen Harbour pebbles of crystalline rock of dioritic habit were found; and at Slosarczyk Fiord, everywhere in the moraines, numerous blocks of acid rock of granitic type occurred. He gives a qualified support to the view that South Georgia is allied to the Patagonian Cordilleras.

* OTTO NORDENSKJÖLD, *Antarctica*, p. 340; and "Die schwedische Südpolar Exped. und ihre geographische Tätigkeit," *Wissensch. Ergeb. schwedisch. südpolar-Exp.*, 1901-03, I, i, 1911, p. 211.

† K. FRICKER, *The Antarctic Regions*, 1900.

‡ FRITZ HEIM, "Geologische Beobachtungen über Süd-Georgien," *Geologie der deutschen Antarktischen Expedition*, *Zeit. Ges. Erd.*, Berlin, 1912, No. 6, pp. 451-6.

THE ROCKS OF SOUTH GEORGIA.

In a small island rising out of the Atlantic, and remote from any other land area, a volcanic origin may reasonably be expected. The Canary Islands, Madeira, the Azores, Cape Verd, Ascension, St Helena, Tristan da Cunha, and other Atlantic islands are of volcanic origin. South Georgia is a striking exception. It is a mass of sedimentary rocks. Its coasts are formed of stratified rocks, indurated generally in places occasionally somewhat altered by pressure-metamorphism.

With the exception of two comparatively small exposures of sedimentary rocks in Cumberland Bay and Cape George Harbour, the stratified rocks belong to one main series, which may be conveniently called the Cumberland Bay Series, and divided into upper, middle, and lower divisions. The older rocks exposed in Cumberland Bay and Cape George Harbour, and separated from the Cumberland Bay Series by a well-defined unconformity, we have named the Cape George Series.

Cumberland Bay Series, Upper Division (Creamy-White Rocks).

These sedimentary deposits overlying, as they do, the rusty-brown rocks, occupy the highest horizon in the island. Though not all creamy white, that colour predominates. There is no apparent break in continuity between this and the middle division or between the middle division and the lower division. The rocks of the upper division show a grey colour on a fresh fracture, but differ little in texture from the underlying brown rocks. The junction is not very clearly defined. Elsie Harbour, on the north-west corner of the island, is situated right on the apparent junction. The rocks on the south-east side are of the rusty-brown division, and on the other side are the bluish or purple-blue shales of Bird Island. The shales which form a considerable part of Bird Island pass up into the creamy-white rocks of the central part of the island.

The purple-blue shales descend below sea-level at Cape Pariadin, and only the overlying creamy-white rocks are exposed in that promontory. The thickness of the shales cannot be accurately estimated owing to folding, but it may be from 300 to 500 feet. The thickness of the creamy-white rocks above may be provisionally put at 1000 feet. The finest exposure of the rocks of this upper division is at Cape Pariadin, where they contain volcanic tuffs. Other good exposures are provided by the escarpments of Cooper Island and the adjacent mainland. Owing to the difficulties of landing, no specimen was obtained from Cooper Island.

The Cumberland Bay Series, Middle Division (Rusty-Brown Rocks).

The north-west and south-east coast is occupied for a great part of its length by rocks of rusty-brown colour. They form a distinct group which is easily distinguished and is useful as an horizon in locating the positions of the rocks overlying and under-

lying them. The colour is due to the oxidation of ferrous iron in the rocks to the ferric state. The colour is superficial, as the rocks are greyish on a fresh fracture. They are generally crumpled and indurated. They are highly siliceous, and while some of them are fine-grained others are more or less gritty. Interbedded with them, in places, are still coarser rocks which may be regarded as fine conglomerates. There are also interbedded black shales which are not of great thickness in any one body. There are also beds of volcanic tuff.

The black shales are finely fissile, and slides cut from them show a cherty structure with usually a carbonaceous and fine-grained matrix. The shales, although black when freshly fractured, take the rusty-brown colour of the great mass of the rocks with which they are interbedded, so that their presence is generally obscured in the numerous exposures on the north-east coast and in the adjacent glens and fiords or gorges.

The rusty-brown rocks are not only the best horizon for determining the stratigraphical succession of the various rock-forming bodies in the island, but their pronounced colour differentiates them sharply from the rocks above and below them. They are also useful in giving us an idea of the total rock thickness. There are compact masses of these rocks at Leith Harbour and Port Gladstone, the latter rising to an exposed thickness of about 1500 feet, and resting on an exposure of 133 feet down to sea-level of the rocks underlying them. The exposure is in the steep sloped hill at the head of Port Gladstone Harbour (Pl. XC, fig. 2).

A much greater thickness is exposed in Moraine Fiord, Cumberland Bay, and in the rocky escarpments on the shoulders of Mount Paget. There is an apparently continuous body of these rocks, rising to the top of the wall-like escarpment shown in Pl. LXXXVII, fig. 2. As there is no break in continuity with the rocks underlying them, only a change of colour, we have from the sea-level in Moraine Fiord to the top of the big escarpment a thickness of 4200 feet.

Unless there is some concealed line of faulting, that thickness is entirely composed of stratified rocks in regular and unbroken succession. As the rocks underlying the rusty-brown rocks rise to a considerable height in Moraine Flat and the north-west side of Moraine Fiord, a part of the total thickness must be attributed to them. A rough approximation is about 3000 feet of rusty-brown rocks and 1200 feet of the lower rocks.

*Cumberland Bay Series, Lower Division (Dark Shales, Greywackés,
Tuffs, Gritty Shales, etc.).*

These rocks are the downward continuation of the rusty-brown rocks, without an apparent unconformity. They are much the same in texture as those above them, but dark fissile shales reach considerable thicknesses in this division, and collectively are the predominant rock. They alternate with gritty and fine-grained arenaceous shales, with coarser arenaceous rocks which may be regarded as greywacké, and with

volcanic tuffs. There are rounded and angular felspathic grains in the greywacké, and their prevailing grey colour, contrasted with the black of the shales, gives a distinguishing shade to the rocks of this division.

The total thickness of the rocks of the lower division is not disclosed in any of the exposures seen, as they invariably descend below sea-level; and when we do find rocks unquestionably underlying them, they are covered unconformably by the rusty-brown rocks. The lower division may also end downward in an unconformity.

The unconformity between the oldest rocks and the rusty-brown rocks, which are apparently conformable with the dark shales and greywacké division, shows also that the dark shales and greywackés filled up the hollows in the old land surface on which they were laid down. The higher ground of the old land surface was sufficiently elevated to be only completely covered when the lower portion of the rusty-brown division was being deposited.

The greatest thickness of the dark shales and greywackés will be above the deepest hollows of the old land surface on which it was deposited. So far as present observation has been made these are not exposed, and we cannot therefore state definitely the full thickness. It is not likely, however, to exceed greatly the thickness exposed in Cumberland Bay, about 1200 feet.

Diabase.—In the black shales of this division in Moraine Fiord, Cumberland Bay, there is a sill of diabase. It was probably intruded during the deposition of the rocks of the middle division, and was contemporaneous with volcanic eruptions which took place when the lower beds of that division were laid down. There are much volcanic debris and some tuffs in the beds of the middle division, and their red rusty-brown colour is very probably due to the decomposition of the trachytic lavas.

Cape George Series (Greenish-Grey Rocks).

These rocks occupy the lowest geological horizon on the island. They are separated, as already noted, from the rocks overlying them by an unconformity. The irregularities of their upper surface form the heights and hollows of an old land surface. They were tilted and probably folded before the beginning of the denudation which shaped the old land surface.

They are of a glistening greenish-grey colour, thinly banded, and intensely hard. The banding is a secondary cleavage which shows "Augen" structure, and both this and the indurated character of the rocks are due to crustal or folding movements, producing pressure-metamorphism.

They were only seen in two detached small masses, one on the south-east shore of Cumberland Bay, adjacent to Moraine Fiord, and the other in the harbour of Cape George and the glacier glen leading into it from the north-west. They descend below sea-level in both cases, and do not rise 500 feet above it. We never find them on the higher slopes of the central range.

Their total thickness cannot be estimated. There is evidence to show, however, that they are at least 500 to 1000 feet thick in the glacier glen at Cape George, but that may be only a small part of them.

THE SUCCESSION AND THICKNESS.

We can now state the order in which the various rocks succeed each other in South Georgia and the estimated thickness of each of them.

Cumberland Bay Series :—

Upper division.	The creamy-white rocks and all rocks exposed above the rusty-brown rocks	1500 feet
Middle division.	The rusty-brown rocks	3000 „
Lower division.	The dark shales, greywackés, etc.	1200 „
Total thickness exposed		5700 feet

Unconformity.

Cape George Series :—

Greenish-grey rocks with “Augen” structure. Exposed, about	500 feet
--	----------

The lowest greenish-grey rocks are separated from the Cumberland Bay Series both on account of the unconformity between them and the more severe pressure-metamorphism they have been subjected to in early crustal movements. The three divisions of the Cumberland Bay Series overlying them are apparently in continuous succession. They have been broken, folded, and contorted in various parts of the island, but their original continuity is notwithstanding easily distinguished. Their subdivision into three sections by colour is useful, as it enables us to note the various horizons exposed in different parts of the island, as shown on the geological map and section through Mount Paget (Plates LXXXI and LXXXII).

LOCAL DISTRIBUTION OF ROCKS.

Leith Harbour and Stromness Bay.

The rocks are in every case stratified and of sedimentary origin. They are all more or less indurated, but their original bedding and character is still distinct. Lateral pressure has tilted and folded the strata so that there is no general dip.

A line of weakness is plainly evident from the centre of Mutton Island (Pl. LXXXV, fig. 1) to the crumpled rock exposure in the centre of the glacier (Pl. LXXXIII, fig. 2). This line strikes south-east of Mutton Island and reaches the south shore of Stromness Bay in crumpled strata. The line of weakness was originally a fold in the rocks, with its axis running north-west from Mutton Island to the upper end of Leith

Harbour. When the centre of the fold was depressed to its full extent the rocks snapped along its axis, and the sinking of the north side of the fold produced the crumpling which can be noted in Pl. LXXXV, fig. 2. The rocks which divide the glacier of Leith Harbour into two parts are on the line of weakness and fracture. Leith Harbour is simply a drowned land valley due to a general sinking of the island.

The rocks surrounding Leith Harbour belong to the middle division of the Cumberland Bay Series. At the south-east corner, turning into Nansen Harbour, the lower division comes in directly under the middle division and is represented by fairly thick bodies of black cherty shales, grey arenaceous rocks, greywackés, and tuffs. These rocks are faulted in places and tilted at slight angles. Further up Nansen Harbour they dip more steeply under sea-level, and on the south side of the harbour only the rocks of the middle division are seen.

Husvik Harbour and the greater part of the southern shore of Stromness Bay are formed of rocks of the middle division of the Cumberland Bay Series. Tonsberg Point and the western half of Mutton Island belong entirely to the lower division. The eastern half of Mutton Island has some blue-purple shales along the line of rupture. These may be a fragment of the upper division and similar to the shales of Bird Island.

Fossil Impressions in the Lower Division at Leith Harbour.—The dark shales and the fine arenaceous shales forming a rocky promontory where Leith Harbour and Nansen Harbour join has been the most productive exposure for fossils in the island. The fossils are described by Professor GREGORY.

Cumberland Bay.

The rocks of the middle division, the rusty-brown type, are well developed. They occupy both sides of the bay on the outer coast, and running up King Edward's Cove form the lofty escarpment at the head of it. A fringe of the lower division is seen coming in under the middle division at Sappho Point, and runs round to the neighbourhood of the meteorological station.

Mount Paget itself is formed of rocks of the middle division, an escarpment of which, at its crest, can on a clear day be distinguished by its colour. The apparently continuous section of middle and lower division rocks, rising out of Moraine Fiord to the big wall-like escarpment on the shoulders of Mount Paget, we have already noted, and it represents a thickness of 4215 feet. Of this thickness we have given 3000 feet as the part occupied by rocks of the middle division, the lower division making up the remaining thickness.

As Mount Paget is 8383 feet above sea-level, the rocks of the Middle Series, if they were continuous, from Moraine Fiord to the top of it would be as follows:— $8383 - 4215 = 4168$ feet thicker than we have estimated them, thus giving a total thickness of 7168 feet. And as we know that rocks of the upper division occur

along the shore escarpment below Mount Paget on the south-west coast, powerful faults must run along the shoulders of Mount Paget.

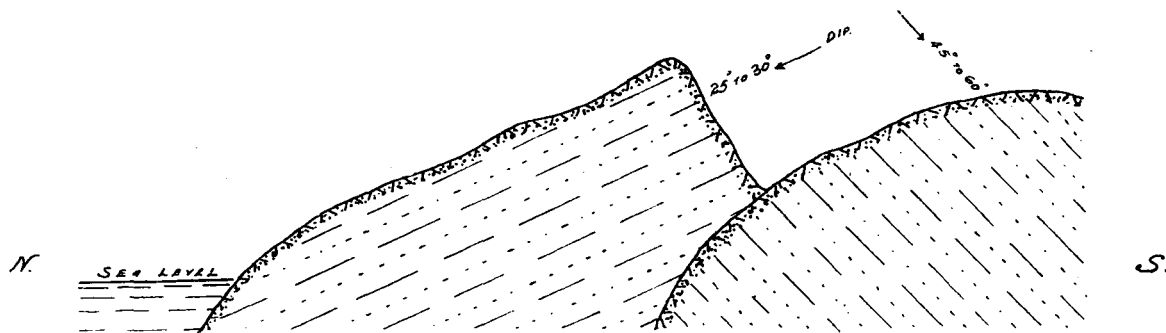
These faults have let down the strata on either side of the axis of the central range. The escarpment at the crest of Mount Paget is in all reasonable probability the same as occurs in Moraine Fiord. Hence a powerful fault must run parallel to the axis of the central range, and effect a downward displacement towards Cumberland Bay of not less than 4000 feet. The throw is more than likely to be over that amount, and may readily be 6000 feet.

On the south-east side of Moraine Fiord occurs one of the patches of the old rocks of the Cape George Harbour Series. They are tilted up at a steep angle and dip into Cumberland Bay. With the above exception the rocks surrounding Cumberland Bay are very similar to those of Leith Harbour. The rocks of the middle division occupy all the high grounds, and those of the lower division fringe the rim of the bay in places near sea-level. There is no evidence of any rocks of the upper division. Pl. LXXXVII, fig. 2, shows the uniform banding of the middle and lower divisions, rising out of Moraine Fiord, and the middle division rocks are also seen at the crest of Mount Paget.

The most intense folding and crumpling of the rocks here, as at Leith Harbour, is nearest the north-east coast (Pl. LXXXV, fig. 2).

Cape George and Vicinity.

The rocks on the coast here belong to the middle division. At the head of Cape George Harbour, while the dips are steep in places, the crumpling has to a considerable extent disappeared, and the middle division rests unconformably on the oldest rocks in the island, the greenish-grey banded rocks of the Cape George Series.



Rocks of the middle division resting unconformably on the Cape George Series.

The middle division dips 25 to 30 degrees to the north, while the Cape George Series dips 45 to 60 degrees in a direction south 20 degrees west. The sketch shows the relative position of the two series of rocks and the line of unconformity.

The rocks of the middle division, the rusty-brown type, are without doubt unconformable to the Cape George Series underlying them. The latter dip at

steeper angles in an opposite direction to the rocks of the middle division, and are more indurated and show evidence of greater alteration than any of the series overlying them.

New Fortune Bay.

The harbour of New Fortune Bay is mainly cut out of the rocks of the middle division, but on the high ground above it to the south-west the lower division appears on the surface, and is well developed in the glen leading down to Cumberland Bay, opposite the Nordenskjöld Glacier.

In this glen are some black shales seamed with secondary quartz along their cleavage planes, similar to the larger exposures at Royal Bay. The black shales belong to the lower division. The quartz is of a granular sugary character or texture, not unlike some of the gold-bearing varieties in Rhodesia and Southern India.

On the outer coast there are some small exposures of the creamy-white rocks, which may be a fringe of the upper division, coming on above the rusty-brown rocks of the middle division.

Royal Bay.

The rocks of the coast and around the inner rim of Royal Bay are confined to the middle and lower divisions. The middle division occupies all the high ground from Cape Charlotte round to the Great Glacier, and the highest points above Moltke Harbour. The lower division fringes the sea-level, and forms the low escarpments from Cape Charlotte to the Great Glacier. It rises up into hills at least 1200 feet above sea-level, on the north-west and south-east side of Moltke Harbour, and the north-west side of Royal Bay. It also runs some miles north-west along the Atlantic coast.

The streams from the ice-fields running down the old glacier courses to the north-west of the upper end of Moltke Harbour have cut through the rocks of the lower division, while the middle division occupies the higher ground. South-west of the Great Glacier there is a huge ice-field, through which only the higher grounds of the central or Allardyce range are seen, and these are all of the middle division rocks.

There is some folding in the rocks on the south-east side of Royal Bay near the coast. Round Moltke Harbour, up the glacier glens to the north-west of it, and along the north-west side of Royal Bay, occupied largely by rocks of the lower division, there is very little folding. The rocks are lying at slight angles of dip along the north-west side of Moltke Harbour and Royal Bay; frequently they are horizontal.

The lower divisions are formed of dark shales, dark and grey-banded arenaceous shales, gritty arenaceous shales and greywackés. There are thick bodies of dark shales, and these, with the dark and grey-banded arenaceous shales, are probably the largest portion of the lower division. The Cape George Series is not seen around

Royal Bay, and the presence of a great thickness of the rocks of the lower division is evidence that one of the hollows in the Cape George Series existed here, and has been filled up by the younger rocks.

There are several horizons of dark shales in the lower division, which are seamed with secondary quartz, which is extensively but not anywhere continuously developed. They occasionally carry some iron pyrites and tiny specks of copper pyrites. In other places the black graphitic shales display iron pyrites and incrustations of gypsum. We will refer to all these occurrences at a later stage of the report.

Cape Charlotte to Cooper Island and the S.E.

A short distance below Cape Charlotte the low foothills disappear, and the coast recedes into the slopes coming down from the main range. The slopes of the range are practically one continuous ice-field, and every recess or little fiord is occupied by a glacier right down to sea-level. Between Cape Charlotte and Cooper Island three large and three small glaciers come down to sea-level.

It is a snow- and ice-covered country, merely a collecting ground for glaciers, while here and there rock escarpments and splintery crests rise above the cover of ice and snow. From Cooper Island to the south-east point of the island, Cape Disappointment, the coast is bordered by steep hills with deep rugged glens, each containing a glacier, coming down to sea-level. The glaciers were formerly connected with broad ice-fields, which covered most of the hills and left only the steeper ridges and crests exposed.

Leaving Cape Charlotte and going towards the south-east, the island recedes several miles to the south-west and the rocks of the middle division appear to have sunk under the sea. The exposed rock standing out to sea, between Cape Charlotte and Cooper Island, apparently belongs to the middle division. At Cooper Island a complete change takes place. It is formed of a hard resistant rock, dipping at very steep angles in a north-west to north direction, but the dip does not appear to be uniform.

The rock weathers to a creamy-white colour along the shore and for 50 to 100 feet above it; but nearer the highest point, where a cirque has been cut into it, the colour is more of a greyish blue.

On the mainland opposite Cooper Island the same rock appeared to strike inland in a direction west-north-west or thereby, in a broad ridge rising into steep slopes and splintery ridges, from which it was impossible to obtain specimens.

From Cooper Island to the south-east point of the mainland the rocks appear to be different from anything seen on the north-east coast. About a mile or two from the south-east point another ridge of steeply inclined rocks, with steep slopes and splintery crests, runs west-north-west. It is composed of creamy-white rocks apparently of the same character as those on Cooper Island.

These rocks, from their appearance and position, are much like those of Cape Pariadin, but if they are identical, specimens recently obtained show they are penetrated by igneous rocks.

Port Gladstone and Possession Bay.

The rocks of the Middle or Lower Series are well exposed in Port Gladstone Harbour. The steep conical hill at the upper end of Port Gladstone (Pl. XC, fig. 2) presents a fine section of the rocks of the middle division, which are some 1500 feet thick and rest on the lower division, which descends below sea-level.

In Possession Bay the middle division extends from a little above sea-level to the hill crest seen above the ice-fields of the Great Glacier. The lower division forms a fringe near sea-level and descends below it.

Locally the dip is in all directions due to folding and crumpling. A good instance of this is seen in Pl. XC, fig. 2, where the rocks in the conical hill are almost flat, while those to the right of it, extending to the little ice-field and corrie, are nearly vertical. This steep dip is due to a fracture plane, along which a former glacier scooped out the harbour of Port Gladstone. It has been formed in exactly the same way as Leith Harbour, but there the glacier has only receded and still exists.

Another fine example of folding and erratic dips is seen in Pl. XCI, fig. 1, in the escarpment on the south side of Port Gladstone Harbour. The folding occurs along a fracture parallel to that in which the harbour has been cut out. At one place the rocks are vertical, and to the south side of the fracture plane they are horizontal.

The rocks of this locality all belong to the middle division. Allowing for all the eccentricities of dip, due to folding and fractures, there is a general dip to the south-west. It is not very evident at any one point, but viewed as a whole the rocks appear to be gently sinking in that direction.

Port Gladstone to Adventure Harbour.

The rocks along the coast from Port Gladstone to Elsie Harbour belong for the greater part to the middle division. The lower division sinks under the sea as we proceed to the north-west. At Cape Buller, Welcome Island, Right Whale Bay, and Cape North the rocks belong to the middle division. Between Cape North and Elsie Harbour the middle division forms all the coast-lands up to the ice-fields behind it; but the heights beyond are probably of rocks belonging to the upper division.

At Elsie Harbour the middle division disappears, and the upper division is exposed on its western side. There may be a fault running through the line of Elsie Harbour and St John's Harbour. They form a low depression right across the island (Pl. XCI, fig. 2), which has been cut through by a glacier, and is now blocked in the middle by several miles of glacial detritus. This morainic material has produced two of the most useful refuge anchorages in the island.

At Cape Pariadin the *purple-blue* shales have disappeared below sea-level, and the creamy-white rocks and tuffs are alone evident. In Adventure Harbour these rocks are well developed from the entrance at Cape Pariadin for some distance inwards. Pl. XCI, fig. 2, shows exposures and escarpments of the rocks of the Cumberland Bay Series.

The dips are not as a rule very steep in Adventure Harbour or round Cape Pariadin, nor is there the same amount of folding to be witnessed as on the north-east coast of the island.

Wilson Harbour, Cape Demidov and Cape Nunes.

The rocks surrounding Wilson Harbour and the island at its south-west point are of the creamy-white variety of the upper division. The general dip is more or less flat, with a very gentle inclination to south-south-west, but some sharp folds also occur.

Cape Nunes is composed of the same rocks as Cape Demidov. They probably belong to the upper division, close to the junction with the middle division.

Cape Nunes to Annenkov Island.

The coast from Cape Nunes to a point opposite Annenkov Island is one continuous sheet of snow or ice-cap. There are splintery crests of hills and fringes and patches of rock between the glaciers at sea-level, or within 100 feet or so above it. The rocks exposed appear to be similar to those of Cape Nunes and the coast north-west of it.

The rocks of Annenkov Island are similar to those of Cape Demidov and Cape Nunes. A line of fracture evidently runs through the island from north-west to south-east. Just at the centre of the island the dip becomes vertical, and there is some folding.

The south or south-east side of the island is low, and formed of rocky escarpments, which appear to run into the island, as there was a channel on which the sea was breaking at the entrance. The rocks are the same as Cape Pariadin, and in the centre of the island rise to a height of over 1000 feet above sea-level.

The rocks dip apparently at very gentle angles to the south-west, and the rocks of the upper division appear generally to occupy the south-west coast of South Georgia and the various rock channels which are cut into it from the sea.

South Georgia is a ridge mainly of stratified rocks, the axis of which, the central or Allardyce range, is parallel with the general strike of the rocks. It has parallel faults on either slope of the ridge, letting down the rocks to the north-east and the south-west. The faulting is proved by the fact that the middle division of the Cumberland Bay Series occupies the crest of Mount Paget, and has a slight south-westerly dip, while the upper division forms the coast at sea-level on the southern side of the island, and is seen in a few straggling beds on the northern

coast near New Fortune Bay. The rocks, moreover, have been greatly crumpled and contorted along the north-eastern coast, especially at King Edward's Cove, Cumberland Bay; Leith Harbour; Stromness Bay; and Possession Bay. The direction of thrust is from the north-east.

Professor J. W. GREGORY has kindly examined the fossils brought home by the writer from South Georgia. The fossils recognisable by the naked eye were found with one exception in the beach rocks, where Leith Harbour turns round into Nansen Harbour. The one exception was found in the beach rocks, King Edward's Point, Cumberland Bay, and was apparently a fucoid, similar to those found at Leith Harbour. The whole of the fossils were obtained from the lower division of the Cumberland Bay Series. That specimens may be obtained in the same division in other parts of the island is highly probable. Leith Harbour was well searched, because it was near the writer's headquarters and easily accessible.

The finding of an ammonite in the middle division of the Cumberland Bay Series in Port Gladstone, Possession Bay, by the German Antarctic Expedition is very important. Owing to the kindness of Dr HEIM, the writer was privileged to see the specimen, which was sent over to Glasgow from Heidelberg.

THE GEOLOGICAL AGE OF THE ROCKS OF SOUTH GEORGIA.

The precise age in geological time of the rocks of South Georgia is still indefinite. The Falkland Islands are for the larger part of Devonian rocks, which appear to be younger than those of South Georgia. The rocks of the South Orkneys, from the few fossils found in them by Dr BRUCE's Expedition, are either Ordovician or Silurian, and they are strikingly similar to those of the Cumberland Bay Series, which form the main mass of South Georgia.

The writer obtained in South Georgia, through the courtesy of the manager of the Falkland Whaling Company, ten samples of the rocks of Washington Strait, Coronation Island, South Orkneys. They are very similar to those of South Georgia, which was also noted by Dr HARVEY PIRIE,* geologist to the *Scotia* Antarctic Expedition, who saw them in the Geological Department, Glasgow University.

The lithological resemblance between the rocks of the South Orkneys and South Georgia is no certain proof that they are of the same geological age, but, taking all the facts into consideration, the lower rocks of South Georgia would appear to be not later than Silurian, and may be even earlier. The palæontological evidence examined by Professor GREGORY suggests that the middle and upper divisions of the Cumberland Bay Series are Mesozoic, while the lower division is Ordovician or Silurian. The marked lithological resemblance of the rocks of the lower division to the graptolite-bearing rocks of the South Orkneys suggests that both of them may be of Palæozoic age.

* J. H. HARVEY PIRIE, *Rep. Sci. Res. "Scotia,"* vol. viii, part 3, and *Proc. Roy. Soc. Edin.*, vol. xxv, pp 463-470.

CONCLUDING OBSERVATIONS.

In conclusion, the writer would like to put on record the generosity of the Messrs CHR. SALVESEN & Co., the well-known shipowners of Leith, and of Mr THEO. E. SALVESEN, the member of the firm who directs their extensive whaling industry in South Georgia, the South Shetlands, and the Falkland Islands. They are the lessees of the minerals and mining rights on all the islands owned by His Majesty King George V. in the South Atlantic, outside the Falkland Islands. They have not, however, confined themselves to their own special interests, but have assisted and encouraged the elucidation of the interesting geological problems presented in that outlying portion of the empire. They have also presented the rock and fossil specimens brought home from South Georgia to the Geological Department, Glasgow University, and the Scottish Oceanographical Laboratory, Edinburgh.

The writer is much indebted for help in the examination and description of the material collected to Professor J. W. GREGORY, D.Sc., F.R.S., and his assistants in the Geological Department, Glasgow University; Miss M. MACPHEE; G. W. TYRRELL, Assoc. Roy. Col. Sc., F.G.S.; and W. R. SMELLIE, M.A., B.Sc.

Professor GREGORY's discussion of the physiography of South Georgia forms an Appendix to the present paper. His discussion of the geological relations and of the fossils, and Mr TYRRELL's description of the petrology, form separate papers following immediately on this.

EXPLANATION OF PLATES.

PLATE LXXXI.

Geological Map of South Georgia.

PLATE LXXXII.

Geological Section across South Georgia on line A, B on Map.

PLATE LXXXIII.

Fig. 1. Leith Harbour, Stromness Bay, Whale Oil and Guano Works, South Georgia Co., Ltd.

Fig. 2. Leith Harbour, looking from S.E. to Moraine and N.W. Glacier.

PLATE LXXXIV.

Fig. 1. Tonsberg Point, looking out of rock cavern to Stromness Bay.

Fig. 2. Tonsberg Point, looking S. to central hill range.

PLATE LXXXV.

Fig. 1. Stromness Bay, Mutton Island and central range viewed from 1100 feet above sea-level.

Fig. 2. Crumpled rock strata, 1100 feet above sea-level, at Leith Harbour.

PLATE LXXXVI.

Fig. 1. Mai Viken Glen and glacier loch, near Gryt Viken, King Edward's Cove.

Fig. 2. Moraine Flat, glacier, loch, and stream, Cumberland Bay.

PLATE LXXXVII.

Fig. 1. Moraine Flat, glacier, rock strata, and loch, Cumberland Bay.

Fig. 2. Moraine Fiord, Mount Paget, rock strata and glaciers, Cumberland Bay.

PLATE LXXXVIII.

Fig. 1. Cape George and folded rock strata.

Fig. 2. Cape George Harbour, folded rock strata and cirque.

PLATE LXXXIX.

Fig. 1. Coast-line, Cape George to Royal Bay.

Fig. 2. Moltke Harbour, Royal Bay, cirque, glacier, and penguin rookery.

PLATE XC.

Fig. 1. Royal Bay, Weddell Glacier and cirque.

Fig. 2. Port Gladstone, rock strata, 1633 feet to crest, and whaling factory steamer.

PLATE XCI.

Fig. 1. Port Gladstone, folded rock strata and cirque.

Fig. 2. Adventure Harbour, looking across neck to Elsie Harbour.

APPENDIX.

The Physiography of South Georgia as shown by Mr Ferguson's Photographs.

By Professor J. W. GREGORY, D.Sc., F.R.S.

MR FERGUSON'S photographs of the northern coast of South Georgia illustrate clearly the chief features in the physiography of the island. They show that it is a mountainous country with a very rugged and young topography. The mountains often come close to the shore, and project in bold headlands, between which the main valleys have been cut down to base level. The country consists of stratified rocks, which have a moderate dip, and in the photographs is usually less than 45° (Pl. LXXXIII, fig. 1; Pl. LXXXVII, figs. 1 and 2). The beds are often crumpled and contorted (Pl. LXXXV, fig. 2), and are sometimes vertical (Pl. XCI, fig. 1). The photograph of Leith Harbour (Pl. LXXXIII, fig. 1) suggests that the rocks occur in a regular conformable series; but the photograph of Port Gladstone (Pl. XCI, fig. 1) shows the lower beds of the Lower Cumberland Bay Series with an almost vertical dip, covered unconformably by the less inclined beds belonging to the Middle Cumberland Bay Series.

The photographs also show that the country has been intensely dissected, and the mountains often occur as isolated pyramidal peaks, as at Port Gladstone (Pl. XC, fig. 2) or Cape George (Pl. LXXXVIII, fig. 1); but in places, as in the view of the central range from Stromness Bay (Pl. LXXXV, fig. 1), the peaks rise to one

general level as if the present rugged topography had been carved out of an ancient pene-plane. In this denudation glaciers have no doubt played their part. The photographs of King Edward's Cove (Pl. LXXXVII, fig. 2) and other places show that the country still contains numerous glaciers and extensive snowfields. The photographs, it should be remembered, were taken in the South Georgian summer. The glaciers include great valley glaciers, and some of them flow down from high snowfields and reach the sea, as shown in the view of Royal Bay (Pl. XC, fig. 1). Beside Cumberland Bay is a high-level glacier, from which one lobe flows down to the lowland, but most of its discharge appears to be by avalanches which form a series of recemented glaciers at the foot of the cliffs (Pl. LXXXVII, fig. 1). The effect of the glaciers is well shown on many of the photographs. The sweeping away of the decayed rock material has left many tarns, as near Tonsberg Point (Pl. LXXXIV, fig. 2), and the lateral erosion of the valley glaciers is shown by the spurless rock walls in Royal Bay (Pl. XC, fig. 1).

The former greater extension of the ice is also shown by the old moraines, as in Pl. LXXXIII, fig. 2.

Frost shattering has obviously played a very active part in developing the present topography. Some of the mountains rise into rock pinnacles, such as that seen above Mai Viken Glen (Pl. LXXXVI, fig. 1, and in Pl. XC, fig. 2); these rough crags must either be post-glacial or have stood in glacial times above the limit of the ice. The recent but extensive talus screes (Pl. XC, fig. 2) are probably also the result of frost. Corries, which may be explained here as elsewhere by the shattering of rock walls by frost on the borders of sheets of snow and ice, can be recognised in Pl. LXXXVIII, fig. 2, and Pl. LXXXIX, fig. 2, as well as at Cape George.

The photographs also show that in addition to the movements which have folded the older rocks, South Georgia has been subject to many modern bradysismic movements. The most important was a subsidence which has given the whole coast a drowned topography, as shown in the photographs of Leith Harbour in Pl. LXXXIII, fig. 1, and Pl. LXXXV, fig. 1.

Some of the inlets of South Georgia have been described as fiords, and some of those illustrated by Mr FERGUSON's photographs belong to the category of fiords (Pl. LXXXIII, fig. 1).

The main subsidence has been succeeded by successive elevations, which have led to the formation of raised rock platforms and beach lines. The highest of these is a wide plain of marine denudation which is shown, for example, beside Leith Harbour in Pl. LXXXIII, figs. 1 and 2; Pl. LXXXV, fig. 1. This rocky coast platform increases the general resemblance of this South Georgian coast to that of parts of Norway. At a lower level occurs another rocky shore platform, as around Leith Harbour. The lowest and last elevation is indicated by the toe-like projections from the promontories which are a characteristic feature of coasts that have undergone a small recent uplift. These projections are well shown in a view of Stromness Bay (Pl. LXXXV,

fig. 1), in the instructive view of the coast from Cape George to Royal Bay (Pl. LXXXIX, fig. 1), and in greater detail in the view of Adventure Harbour (Pl. XCI, fig. 2). Marine abrasion during one of the stages between the uplifts no doubt excavated the caves at Tonsberg Point (Pl. LXXXIV, fig. 1). That the country has been stationary for some time past is indicated by the widespread alluvial plains near sea-level (Pl. LXXXVI, fig. 2).

Mr FERGUSON's photographs, therefore, represent South Georgia as a glaciated mountain land composed of ancient folded rocks, in which the folds have no direct relation to the existing topography, as the country had been planed down to a pene-plane. It is obviously part of a much larger land. In modern times subsidence has drowned the northern coast, and the effects of recent uplifts show that the area is probably still in a state of oscillation, in which the vertical movements are separated by intervals of comparative rest.

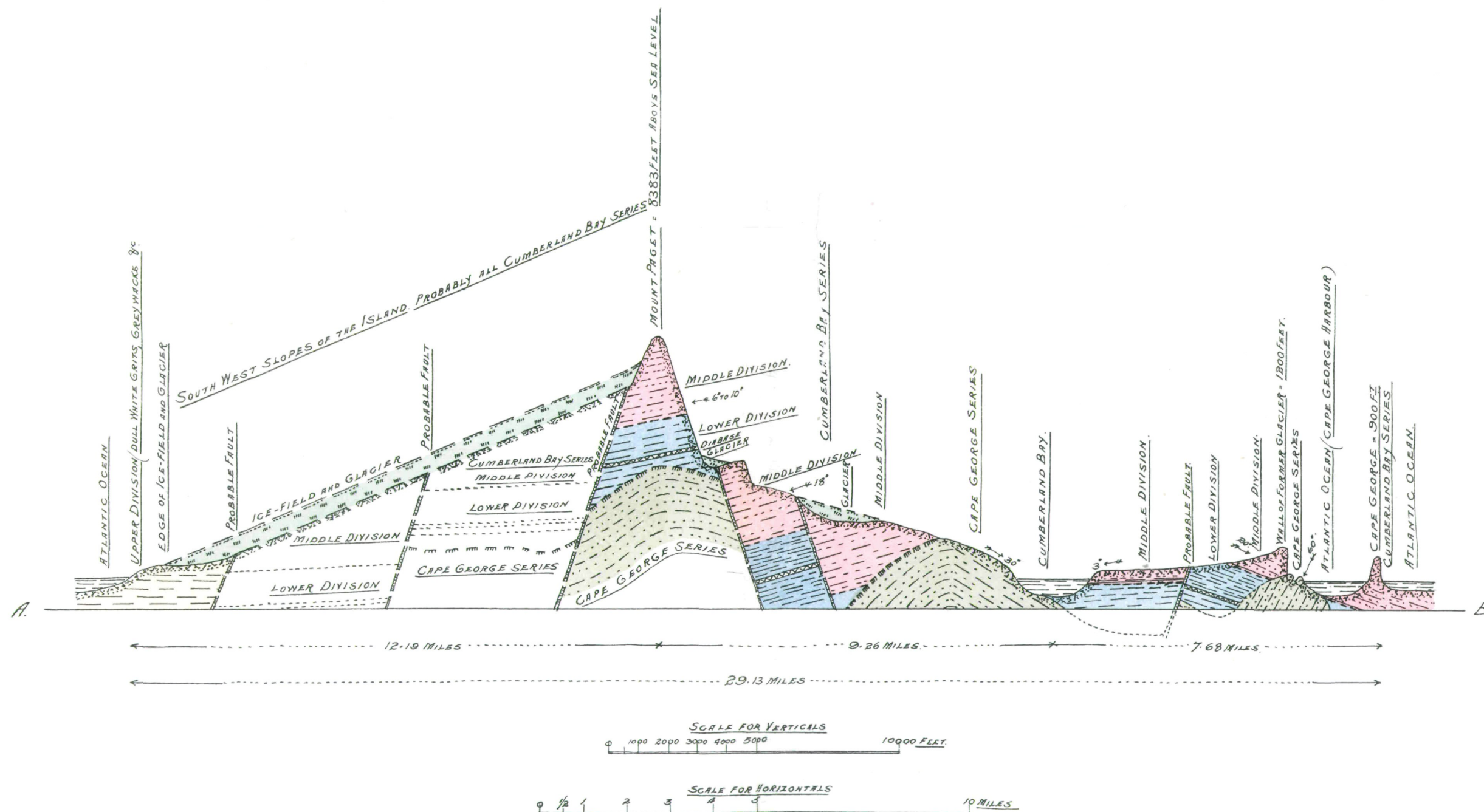
Further reference may also be made to the plates accompanying Mr THEODORE E. SALVESEN's paper "The Whale Fisheries of the Falkland Islands and Dependencies," appearing in *The Scientific Results of the Voyage of the "Scotia,"* vol. iv, part xix, in which several features of South Georgian landscape appear.

[illegible][illegible]

NOTE. - AN UNCONFORMITY BETWEEN THE MIDDLE AND LOWER DIVISIONS OF THE CUMBERLAND BAY SERIES MAY EXIST, AND
IS SUGGESTED AT ROYAL BAY AND BY PROFESSOR GREGORY'S EXAMINATION OF THE FOSSIL EVIDENCE.

Glasgow July 5th 1912. David Ferguson

Geological Section across South Georgia on line A.B. on Map.



Glasgow July 5th 1912. Davis Ferguson.

MR D. FERGUSON ON "Geological Observations in South Georgia."—PLATE LXXXIII.



FIG. 1.—Leith Harbour, Stromness Bay, Whale Oil and Guano Works, South Georgia Co., Ltd.



FIG. 2.—Leith Harbour, looking from S. E. to Moraine and N. W. Glacier.

Mr D. FERGUSON on "Geological Observations in South Georgia."—PLATE LXXXIV.

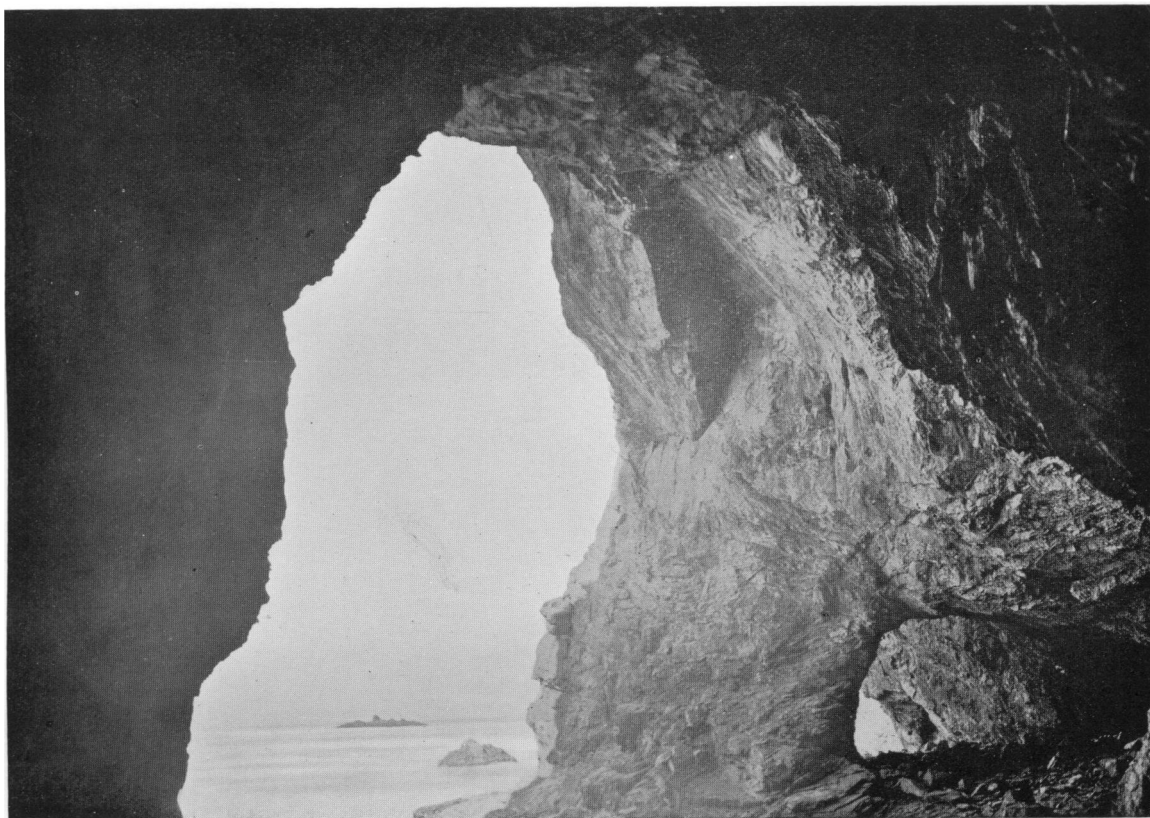


FIG. 1.—Tonsberg Point, looking out of rock cavern to Stromness Bay.



FIG. 2.—Tonsberg Point, looking S. to central hill range.

MR D. FERGUSON ON "Geological Observations in South Georgia."—PLATE LXXXV.



FIG. 1.—Stromness Bay, Mutton Island and central range viewed 1100 feet above sea-level.



FIG. 2.—Crumpled rock strata, 1100 feet above sea-level, at Leith Harbour.

Mr D. FERGUSON on "Geological Observations in South Georgia."—PLATE LXXXVI.



FIG. 1.—Mai Viken Glen and glacier loch, near Gryt Viken, Cumberland Bay.



FIG. 2.—Moraine Flat, glacier, small loch and stream, Cumberland Bay.

Mr D. FERGUSON on "Geological Observations in South Georgia."—PLATE LXXXVII.

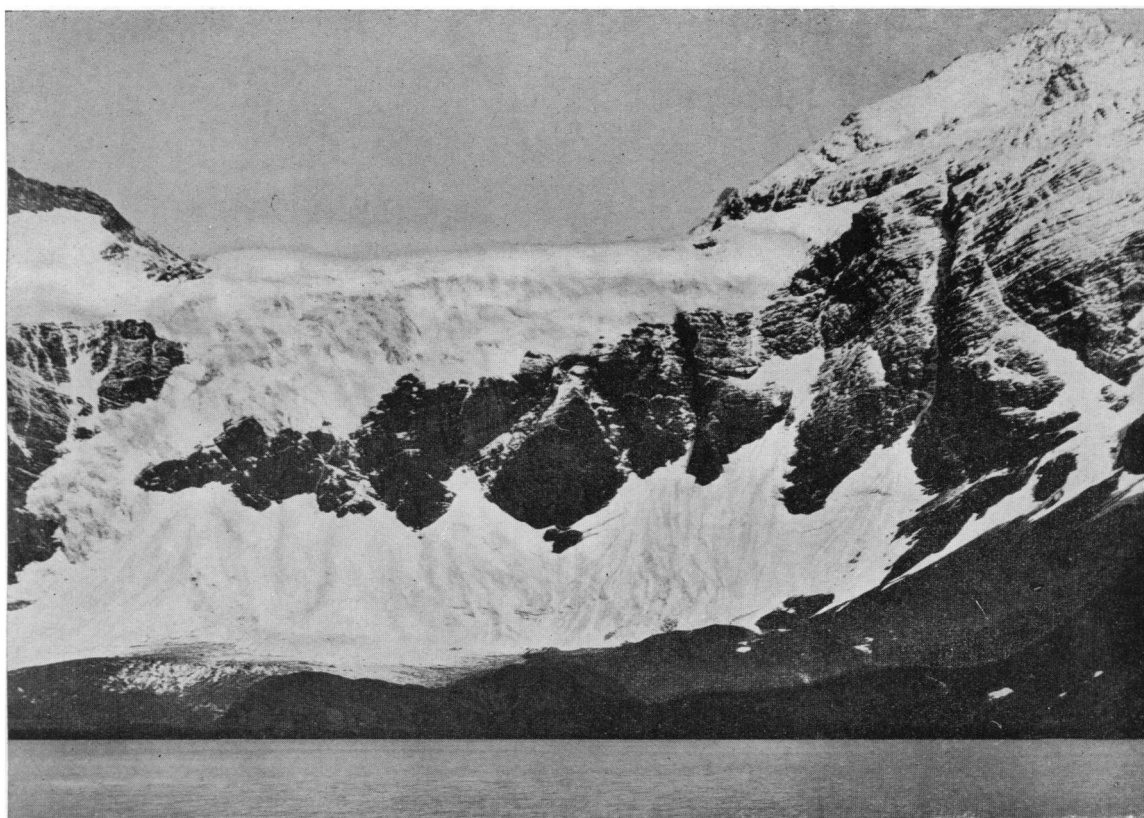


FIG. 1.—Moraine Flat, glacier, and rock strata, Cumberland Bay.



FIG. 2.—Moraine Fiord, rock strata, Mount Paget and glaciers.

MR D. FERGUSON ON "Geological Observations in South Georgia."—PLATE LXXXVIII.



FIG. 1.—Cape George and folded rock strata.



FIG. 2.—Cape George Harbour, rock strata and cirque.

MR D. FERGUSON on "Geological Observations in South Georgia."—PLATE LXXXIX.



FIG. 1.—Coast line, Cape George to Royal Bay.

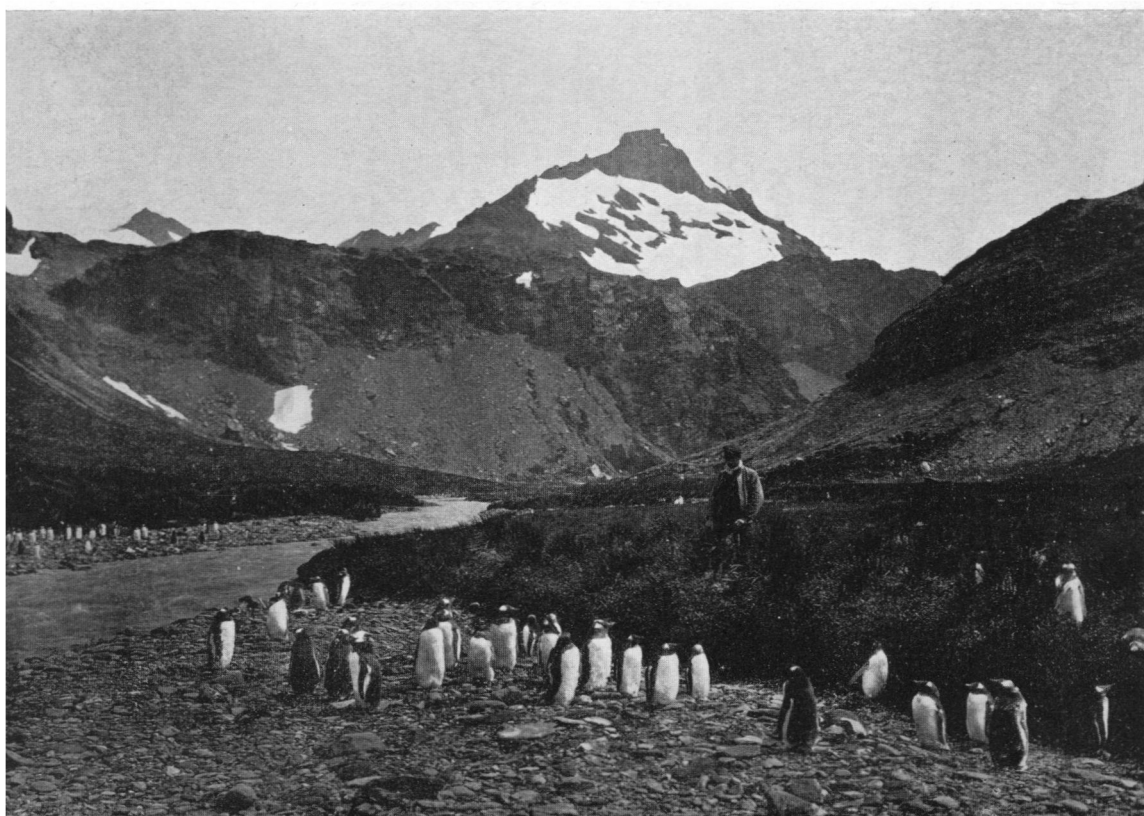


FIG. 2.—Moltke Harbour, beach and penguin rookery, cirque and glacier.

Mr D. FERGUSON on "Geological Observations in South Georgia."—PLATE XC.



FIG. 1.—Royal Bay, Weddell Glacier and cirques.



FIG. 2.—Port Gladstone, rock strata, 1633 feet to crest ; floating factory s.s. *Restitution*.

MR D. FERGUSON ON "Geological Observations in South Georgia."—PLATE XCI.

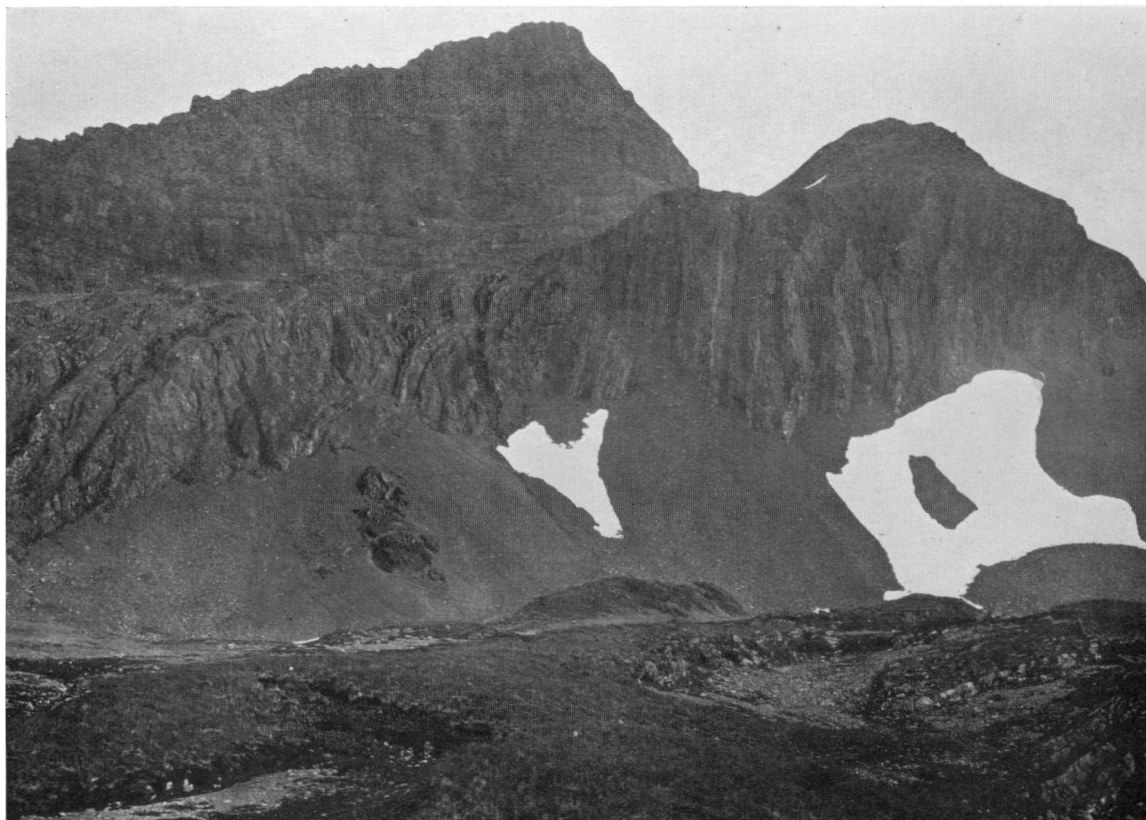


FIG. 1.—Port Gladstone, folded rock strata and cirque.



FIG. 2.—Adventure Harbour, looking across neck to Elsie Harbour.