III.—Geological Observations in the South Shetlands, the Palmer Archipelago, and Graham Land, Antarctica.

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CONTENTS.

Introductory.

The following observations were made during a prospecting expedition which left the Falkland Islands in the late spring of 1913 for the South Shetlands, the Palmer Archipelago, and Graham Land. The cost of the expedition was provided by Messrs Salvesen of Leith, the well-known shipping and whaling firm, who are lessees from the Colonial Office of the minerals in these remote areas. Arrangements were made to prospect as large an area as possible during the whaling season 1913–14. The steamer *Hanka*, a modern whaler, proved very suitable for prospecting work, owing to its light draught, small size, and fairly high speed. It could, however, owing to its small capacity, operate only within a limited radius of a supply base, and Messrs Salvesen's big whaling factory ships in King George Island; Leith Harbour, Belgica Strait, Graham Land; and Fournier Bay, Schollaert Channel, Anvers Island, formed effective bases of supply.

Thanks to the wide range of work thus rendered possible, the expedition traversed 3000 miles of the difficult Antarctic seas, and was able to collect 131 bags of rock specimens

from an area extending from the N.E. point of King George Island to the S.W. end of Belgica Strait, a distance of about 270 miles (text-fig. 1). I am greatly indebted to Mr G. W. TYRRELL for the microscopic examination of these rocks, and most of the rock names in this paper are due to his determinations. The writer would like to record the generosity of Messrs SALVESEN, and his thanks to Mr THEODORE SALVESEN, the member of the firm who supervises their whaling interests, for, amongst other courtesies, the opportunity to use documents and photographs belonging to them. The extensive collection of mineral and rock specimens made during the expedition has been presented by them to the Geological Department of Glasgow University; and from it collections have been sent to the Natural History Museum, South Kensington, the Royal Scottish Museum, Edinburgh, and the Sedgwick Museum, Cambridge.

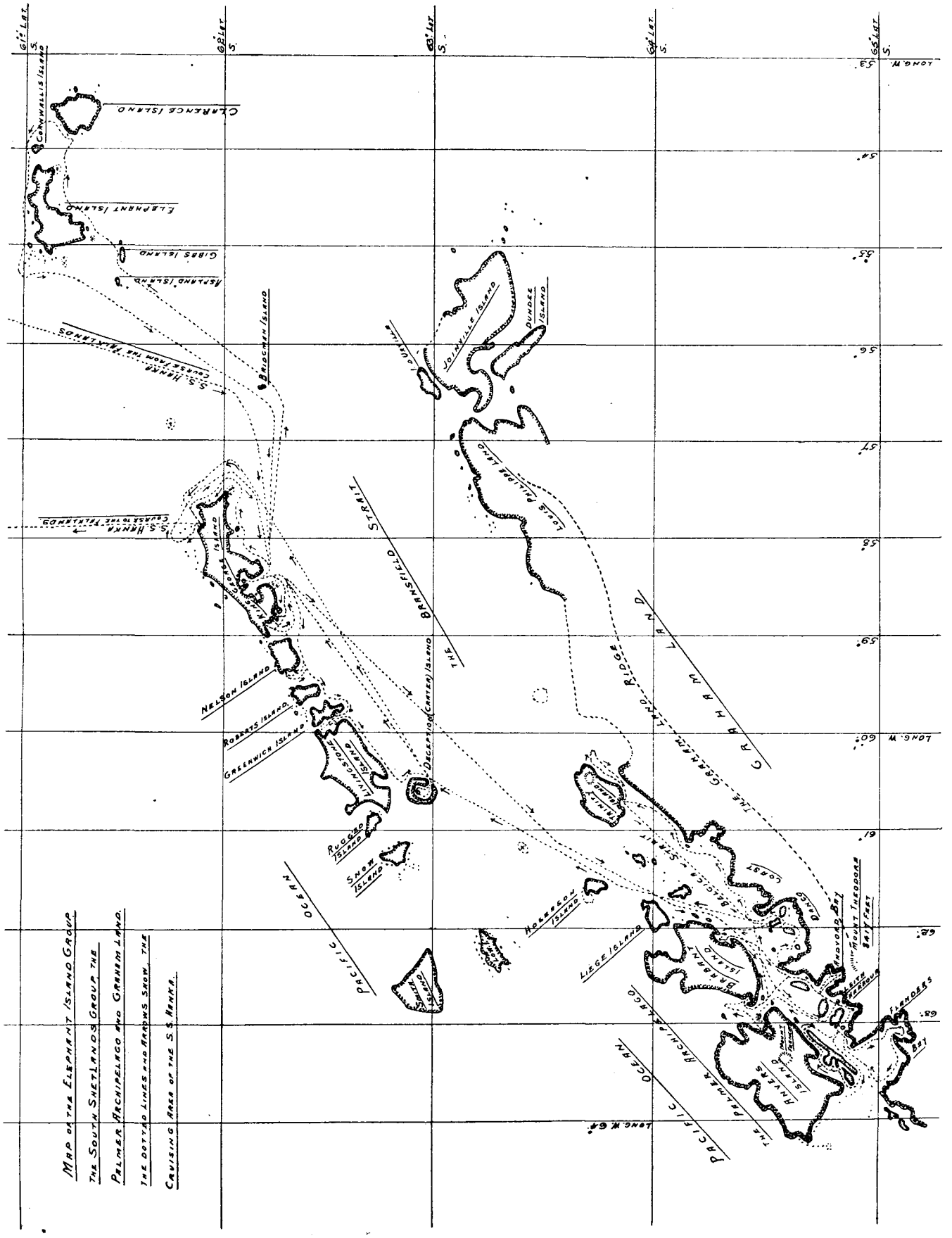
ANTARCTIC ISLAND GROUPS AND GRAHAM LAND IN RELATION TO THE FALKLAND ISLANDS.

The Falkland Islands, the outlying British Antarctic Islands, and Graham Land together form a Crown Colony, with headquarters at Port Stanley, the capital of the Falkland Islands.

THE PROBLEM OF THE SOUTH SHETLAND ISLANDS AND ADJACENT LANDS.

The South Shetland Archipelago stands on the southern side of Drake Strait, the channel between America and Antarctica. As the Andes approach the southern end of South America they give off easterly branches (*cf.*, *e.g.*, GREGORY, *Structural Geography*, 1908, pl. xxvi); in South Patagonia the main chain itself bends suddenly eastward and disappears into the Southern Ocean at the E. end of Tierra del Fuego; in the opposite part of the Antarctic Continent the lofty mountain chain that forms the axis of Graham Land trends from S.W. to N.E., and the South Orkneys continue this mountain line, but on a course nearly due eastward, and nearly parallel to the southernmost ranges of the Andes. The mountains of Graham Land have striking agreements in age, composition, and structure with the Southern Andes, and it was natural therefore to regard both of them as having originally belonged to one mountain system which has been broken up by the formation of Drake's Strait. This view is well known from its adoption by SUESS, who considered that the line of the Andes, recovering from its deflection eastward in Patagonia, continued on a fish-hook-shaped band into Graham Land. He explained South Georgia and the South Orkneys as fragments of this great South Andean loop. An alternative explanation is that the Andes of South Patagonia and the mountains of Graham Land were once continuous across Drake Strait, that the trend of South Georgia and of the South Orkneys was due to their being both parts of a dismembered South Atlantic land, instead of parts of an Andean-Antarctic loop; the view was suggested by Professor GREGORY in a paper on my collections from South Georgia (1), and has been supported by Mr TYRRELL'S petrographic investigation (9).

The decision between these rival views is of primary importance in regard to the relations of South America and Antarctica, to the history of the South Atlantic, and to the structure of the Antarctic continent. The most direct evidence available is that from the South Shetland Archipelago, as they are the only land between the Andes and Graham Land. The general structure of the southern end of South America and of Graham Land has been determined; but the geology of the South Shetlands remained practically unknown, and Messrs SALVESEN'S enterprise has thus rendered possible a first contribution to the description of an area of special geological significance.


61° LAT. S.
62° LAT. S.
63° LAT. S.
64° LAT. S.
65° LAT. S.
LONG. W.
CLARENCE ISLAND
CORNWALLIS ISLAND
ELEPHANT ISLAND
GIBBS ISLAND
ASPLAND ISLAND
S.S. HANNA COURSE FROM THE FALKLANDS
BRUCE ISLAND
JOINVILLE ISLAND
DUNDEE ISLAND
LOUIS PHILIPPE LAND
BRANSFIELD STRAIT
THE
DECEPTION (CARTER) ISLAND
NELSON ISLAND
ROBERTS ISLAND
GREENWICH ISLAND
LIVINGSTONE ISLAND
RUGGED ISLAND
SNOW ISLAND
PACIFIC OCEAN
HOSEASON ISLAND
LIEGE ISLAND
GRAHAM LAND
THE GRAHAM LAND RIDGE
ANVERS ISLAND
PALMER ARCHIPELAGO
PACIFIC OCEAN
MAP OF THE ELEPHANT ISLAND GROUP THE SOUTH SHETLANDS GROUP, THE PALMER ARCHIPELAGO AND GRAHAM LAND. THE DOTTED LINES AND ARROWS SHOW THE CRUISING AREA OF THE S.S. HANNA.

TEXT-FIG. 1.

Physical Character of the South Shetlands and Graham Land.

The South Shetlands and Graham Land are more grimly icebound, especially in the higher latitudes, than South Georgia, which was examined in 1911–12 by Messrs Salvesen's first prospecting expedition (cf. *Trans. Roy. Soc., Edin.*, vol. l, part iv, no. 23, no. 24, and no. 25 (20/5/15)).

The rugged rock-bound coasts, the wall-like escarpments, and steep hill masses are not, however, unlike those of South Georgia, but on a much larger scale. The main mass of the latter is formed of sediments more or less indurated, sheared, or altered, while the South Shetlands are largely made up of volcanic rocks, and Graham Land is almost wholly plutonic. Most of the South Shetlands and Graham Land are covered by ice-fields and glaciers. The rocks exposed occur in steep wall-like escarpments on the coasts, in hill ridges, and nunataks. Every channel, roadstead, or anchorage examined had a glacier discharging into its inner end from ice-fields on the adjacent heights; and wherever the land sloped down to sea-level a glacier discharged direct into the sea. The base of the glacier is sometimes at about sea-level, but frequently below it, and deep water extends close to the ice front. Thus at Leith Harbour, behind Lemaire Island, near Belgica Strait, the depth was 45 fathoms a short distance from a glacier edge.

Detrital flats were not seen anywhere on the outer coasts, and the short patches of beach shingle are situated in protected coves or natural harbours. Patches of morainic material along sheltered anchorages are not uncommon in parts of the South Shetland Islands, but scarce along Belgica Strait and in Graham Land. All the arms of Admiralty Bay in King George Island end in glacier-walls, but fringes of morainic or glacial debris occur along its sides in several places. The inner shore of the crater of Deception Island has much the largest display of morainic flats and slopes of any part of the South Shetland area examined. Port Foster, the harbour of Deception Island, is fringed by glacial debris formed largely of volcanic scoria and pumice. Hospital Cove, on the S.E. side of Greenwich Island, is another little harbour fringed by glacial detritus.

Such patches of glacial material and occasional beaches formed by the resorting of moraines were the only drift deposits seen.

The coasts of the South Shetland Islands are generally steep rock walls, which render their aspect usually stern, though it is occasionally picturesque. The character of the rock walls varies considerably. Some of them, as in parts of Nelson, Roberts, and Greenwich Islands, are low and capped by ice, which rises inland to dome-shaped ice-caps. At the entrance to Admiralty Bay, the North Foreland, Cape Melville, and other parts of King George Island, the walls are higher and consist of dark rusty-brown volcanic rocks.

The axial trend of the South Shetland Islands is N. 60° E., and S. 60° W., and the line produced on this bearing to the N.E. cuts through Elephant Island. The line produced from Elephant Island to cut the South Orkney Island group turns round to the more easterly course of N. 83° 45′ E.

The axial line of the Belgica Strait, of its associated islands, and of the adjacent heights of Graham Land is N. 46° E. and S. 46° W. between Cape Renard, Flanders Bay, and Trinity Island. The same trend continues to the S.W. as far as the Biscoe Islands and Loubet Land, but in the N.E. direction along the Bransfield Strait it gradually bends round to a more easterly bearing. On the N.W. coast-line of Louis Philippe coast and Joinville Island, the N.E. termination of Graham Land, the axial line is N. 73° 30′ W., and S. 73° 30′ W. The axial line or longitudinal direction of all the island groups (including the South Shetlands,

the Elephant Island group, the South Orkneys, the Belgica and Bransfield Straits, as well as the Graham Land ridge), conforms to the gently curving rim of the continental land mass of Antarctica.

The coasts of Graham Land and the islands of Belgica Strait are even more grimly rock-bound than those of the South Shetland group. The rock walls are more rugged and higher; the rocks rise in splintery crests along Belgica Strait, and the edges of level plateaus form the sky-line of the heights of Graham Land. The scenery is in parts picturesque and even grand, although glaciers fill every hollow and cover all the gently inclined slopes from sea-level to mountain summit.

Previous Expeditions and Geological Records.

In 1819 William Smith, the discoverer of the South Shetlands, landed on King George Island, and recorded the existence of bluish-gray slate pebbles which he found on the beach. This is the first record of sedimentary rocks in these islands. In 1820 Capt. Bransfield, R.N., surveyed St George's Bay and the little Penguin Island lying between Cape Melville and Admiralty Bay, King George Island; his work is commemorated by the name of Bransfield Strait.

A series of expeditions followed in rapid succession. In the same year Bellingshausen, the Russian explorer, passed the South Shetlands south-west to Alexander Land and Peter Island in lat. 70° 15′ S., long. 91° 30′ W. In 1821 Capt. Powell, in the sloop *Dove*, discovered the South Orkney Islands, and cruised along the N.W. coast of the South Shetlands as far as Smith Island. In 1823 Weddell discovered the great sea which bears his name, and reached lat. 74° 15′ S., long. 34° 17′ W., in open sea, with only a few floating ice-masses in sight. At noon on 18th February his position was 72° 38′ S., with no ice in sight, but many whales, and the sea was literally covered with blue petrels. He also visited the South Shetlands and passed close to Bridgman Island in 1821, and observed "smoke" issuing from fissures in it with great force.

Near King George Island in lat. 62° 30′ S., long. 60° W., he found fine black sand bottom at 40 fathoms. He reported the rocks of the South Shetlands to include quartz with disseminated iron pyrites and concretions of prismatic stained quartz with some copper green and copper pyrites.

In 1829 Commander Foster, R.N., of H.M.S. *Chanticleer*, surveyed the extremely interesting Deception (crater) Island; and Webster, his ship's surgeon, discovered granite or syenite on an island N.W. of Belgica Strait.

In 1832 Biscoe cruised from the South Shetlands to the S.W. of the islands named after him, and reached Adelaide Island in lat. 67° 14′ S., long. 68° 11′ W.

In 1838 Dumont D'Urville explored the N.W. of Louis Philippe Land, Graham Land, and Joinville Island. He examined Weddell Island in the South Orkney group and found "quartz-schists."

In 1843 Sir James Ross examined Cockburn Island near the large James Ross Island on the N.E. coast of Graham Land, and found it capped by volcanic rocks.

A long interval intervened before the expedition in 1873–74 of Capt. Dallman in a German steam whaling-ship, which reached lat. 65° S. or thereby in the Bellingshausen Sea.

During the expedition sent out in 1892, with the *Balæna* and three other steamers of the Dundee whaling fleet, some loose rocks were collected on Dundee Island by

Capt. ROBERTSON. They were described by Sir A. GEIKIE (petrographical examination by Sir J. J. H. TEALL), and included red jasper with traces of Radiolaria (2).

In the same year, 1892, Capt. C. A. LARSEN, the pioneer of whaling in South Georgia, took a sealing expedition into the Weddell Sea. In 1893, in the *Jason*, he made his way as far S. as lat. 68° 10′ S., long. 60° W., and during his return northwards discovered the small active volcanoes, the Lindenberg and Christensen Islands, and Kainozoic fossils on Seymour Island.

In 1897–99 the Belgian Expedition under DE GERLACHE discovered the Belgica Strait, and made the collection of rocks examined by A. PELIKAN. Granite was found at three landing-places—Flanders Bay, Bank Island, and Wilhelmina Bay; serpentine at Cape Anna; and porphyrite at two landings in Errera Channel (3).

In 1901–03 the Swedish Antarctic Expedition examined the geology of Snow Hill Island, Seymour Island, Cockburn Island, part of James Ross Island and others adjacent, Hope Bay on Graham Land, and the S.W. coast of Antarctic Sound. The geological evidence then collected by Dr OTTO NORDENSKJÖLD, leader of the expedition, and Dr J. GUNNAR ANDERSSON, is the most informing so far obtained in this part of Antarctica (4).

The "Geology of Graham Land," by GUNNAR ANDERSSON, describes the structure of Graham Land and its relationship to the Kainozoic and Mesozoic sedimentary rocks, and the Kainozoic lavas on the N.W. edge of the Weddell Sea. A marked consanguinity of American and Antarctic eruptives was advanced as evidence of the tectonic connection of Graham Land and South America.

In 1902–04 the Scottish National Antarctic Expedition under Dr W. S. BRUCE discovered Coats Land on Weddell Sea, in lat. 72° 18′ S., long. 17° 59′ W. On Graptolite Island, near the S.E. corner of Laurie Island of the Orkney group, Dr J. H. HARVEY PIRIE, the geologist of the expedition, discovered graptolite-bearing rocks of Ordovician age (5).

In 1904–05 the French Antarctic Expedition under Dr CHARCOT went to the South Shetlands and examined the geological structure of the Palmer Archipelago and Belgica Straits (6). The rocks collected have been described by Dr E. GOURDON. They include quartz-diorites, hornblende granites, uralitic gabbros, trachy-andesites, hornblende- and mica-dacites, andesites with associated tuffs, labradorite rocks, diabase basalts, micro-granites with pyroxene and soda-hornblende. GOURDON also described crystalline schists, quartzite, and quartz veins. He considers that the igneous rocks belong to the eruptive series of the Andes.

The expedition of 1911–12, sent out by Messrs SALVESEN of Leith, was concerned only with South Georgia. Its geological structure is, however, related to that of the South Orkneys, the Elephant Island group, and the South Shetlands (7). The collection of fossils and rock specimens secured by the expedition is preserved in the geological museum of Glasgow University. Professor GREGORY described the palæontological material, and showed that there is a reasonable probability of the Ordovician or Silurian age of the lower division of the Cumberland Bay Series, and the Cretaceous age of the middle division, and that the general evidence does not support SUESS's theory that the island is part of an Andean loop (8). Mr TYRRELL, of the Geological Department of Glasgow University, has described the petrology, and his conclusion is also adverse to SUESS's view (9). The field evidence was described by the writer, and shows the large extent of sedimentary rocks in the island.

The Imperial Trans-Antarctic Expedition, 1914–16, in its valuable explorations in the Weddell Sea, and the paper by Lieut. WORDIE, on "The Drift of the *Endurance*" (10), extended the work of WEDDELL, BRUCE, and FILCHNER, in defining the ice-barrier and coasts of the Weddell Sea.

Geological Structure of the South Shetland Group of Islands.

The rocks from Clarence Island and from the same longitudinal axis further E., from the South Orkney Islands to Livingstone Island and probably also to Smith Island, the S.W. extremity of the South Shetland Island group, are predominantly sedimentary. These islands are the remains of a long band of stratified rocks, including shales, sandstones, banded grits, and graywackes. The most conspicuous of these rocks is a dark-bluish or black mudstone, occasionally cherty in character.

The Elephant Island Group.

Elephant Island, although separated from the N.E. extremity of King George Island by 100 miles of open sea, is doubtless part of a former N.E. extension of the South Shetland group.

The prospecting steamer was caught in a terrific gale from the N.E. near Elephant Island, and had to shelter under the lee of a rocky islet, called Gibbs Island, about 10 or 12 miles S. of it. It was not possible to land there, but the steamer was sufficiently near to show that the rocks are mainly stratified sediments. The rocks on the W. side of Gibbs Island are dark gray and banded, and dip about 40° W. A higher horizon is represented by some uniformly and well-bedded grayish-white rocks which dip about 18° W. They extend for about $\frac{1}{4}$ mile, and look soft and friable in places.

Aspland Island, 5 or 6 miles W. of Gibbs Island, is evidently formed of the same regularly bedded rocks, but they dip E.

It was found impossible, owing to the high seas raised by the storm, to land on Elephant Island. The rocks at the S.E. corner of the island are light gray to dark, and more or less banded. The gray rocks appear to be stratified, as the bedding is uniform, but some of the darker rocks may be bedded lavas.

Ice-fields and glaciers cover a large part of the surface, but rock exposures are frequent. Much of the island appears to be formed of stratified sediments. Along the extreme W. coast, and some 8 to 10 miles out W. to sea, is a series of sea-worn hummocks roughly banded with smooth slopes, which resemble dark-coloured, table-topped lavas. Their appearance is an exact copy of Cape Melville or Admiralty Bay, King George Island, where the rocks are lavas. The same mound structure is seen on King George Island from Penguin Island to Admiralty Bay. The geological structure of Elephant Island is evidently to a considerable extent similar to that of King George Island.

The E. coast of the island is like Gibbs Island in the character of its rocks; the same light-gray and well-bedded rocks alternate with some of the darkish colour.

Cornwallis Island.

This little island is a mere patch of rock about 5 or 6 miles E. of the N.E. corner of Elephant Island, in lat. 61° 3′ S., long. 54° W. It was not possible to land, but the steamer got very close in. It rises sheer out of deep water in splintery crests, and is partly covered with snow. The highest point of the island may be 1000 feet or more above sea-level. The slopes are very steep, often quite vertical, and there is consequently much bare rock. It is different in structure from the other islands of the Elephant Island group or any other part of the South Shetlands, the Palmer Archipelago, or Graham Land that came under the

observation of the expedition. It is formed of light-gray schistose rocks, the foliation planes having a direction about N. 70° to 80° E., with a nearly vertical dip. They are probably the oldest rocks in this group of islands.

Clarence Island.

The island lies about 10 miles S.E. of Cornwallis Island, and about 15 or 16 miles E.S.E. of Elephant Island. The N.E. coast is a wall-like rampart, 500 feet or more in height, of very regular and well-bedded rocks, light gray, dark gray, and drab coloured. The W. coast shows light-gray finely banded rocks with a nearly vertical dip in places, and a broad band of brownish rock, evidently an intrusion, was seen at one place cutting through them.

The island appears to contain less volcanic rock than Elephant Island, and to be mainly a mass of stratified sediments. The highest ground on the S. or S.W. side of the island rises about 5000 feet or more above sea-level. It has the mound-like form of Elephant Island, which suggests that the island has some lavas resting on a sedimentary platform.

The most interesting feature of the island is the high escarpment of finely bedded rocks on the N.E. coast. They do not resemble those of any other part of South Georgia, the South Shetlands, the Palmer Archipelago, or Graham Land, seen by the writer; but they are not unlike the bedded light-gray to white volcanic tuffs described by GUNNAR ANDERSSON on Mount Flora, Hope Bay, on the N.E. coast of Graham Land. The Hope Bay tuffs rest conformably on Jurassic rocks, which have yielded many fossil plants.

Bridgman Island.

This little island, the vent of a very recent volcano, lies 84 miles S.S.W. of Elephant Island, and 33 miles W.S.W. of Cape Melville, the N.E. corner of King George Island. It has a remarkable similarity to Ailsa Craig in the Firth of Clyde. The height of the island, estimated from a rough triangulation from a base measured by the run of the steamer, is about 1100 feet. A sounding of 328 fathoms has been got quite close to the island.

The island has remnants of a lava-like rock lying at steep angles on its E. side. It gives the S.E. and N.E. slope a dome-shaped appearance. The W. half of the original neck has either been denuded or blown away, as that face shows the internal structure of the volcano. It is formed of red and greenish lava or tufaceous material. An analysis of a basalt from Bridgman Island has been given by GOURDON.*

Several early explorers—WEDDELL (1821–23), POWELL (1821), and DUMONT D'URVILLE (1839)—stated that they saw volcanic vapours issuing from the crater, and we must accept their statements, as they could not all be mistaken. The statement of two sealers who landed on it in 1880, and saw "smoke" issuing from it, and a seal with its fur partly burnt by contact with lava, need not be taken seriously. There is now snow on some parts of the island, and no appearance of any existing volcanic activity. There is no record of any landing on the island by any reliable explorer.

This island and Deception Island are the most recent seats of volcanic action in the South Shetlands; but Bridgman Island was discharging only volcanic vapours a hundred years ago, and probably no lavas or tuffs had been erupted for a long time previously.

* H. S. WASHINGTON, "Chemical Analyses of Igneous Rocks," Prof. Paper 99, *U.S. Geol. Surv.*, 1917, p. 549.

King George Island.

This is the largest and most north-easterly island of the South Shetland group. Its length from Cape Melville, the N.E. extremity of the island, to Three Brothers Hill at the S.W. corner on Fildes Strait is about 40 miles. The greatest width, between Admiralty Bay and St George's Bay, is about 16 or 17 miles (text-fig. 2).

Admiralty Bay is one of the best roadsteads in the South Shetlands, with deep water well into the land. This island is geologically the most interesting and instructive of the South Shetland group. The oldest rocks seen on it are stratified sediments with interbedded lavas; these have been eroded, and on the denuded surface basic lavas and tuffs have been laid down. Large intrusions of quartz-mica-diorite, orthoclase-felsite, and andesite have intersected the stratified rocks and andesitic lavas, and in the vicinity of some of them metosomatic replacement has produced large bodies of pyritic ores accompanied by veins of quartz. There are two volcanic series; the older series consists of andesites which rise to the level of over 2000 feet; the younger series consists of Kainozoic basalts and olivine-andesites which rise little, if at all, above the level of 1000 feet (text-fig. 2).

Admiralty Bay, King George Island.

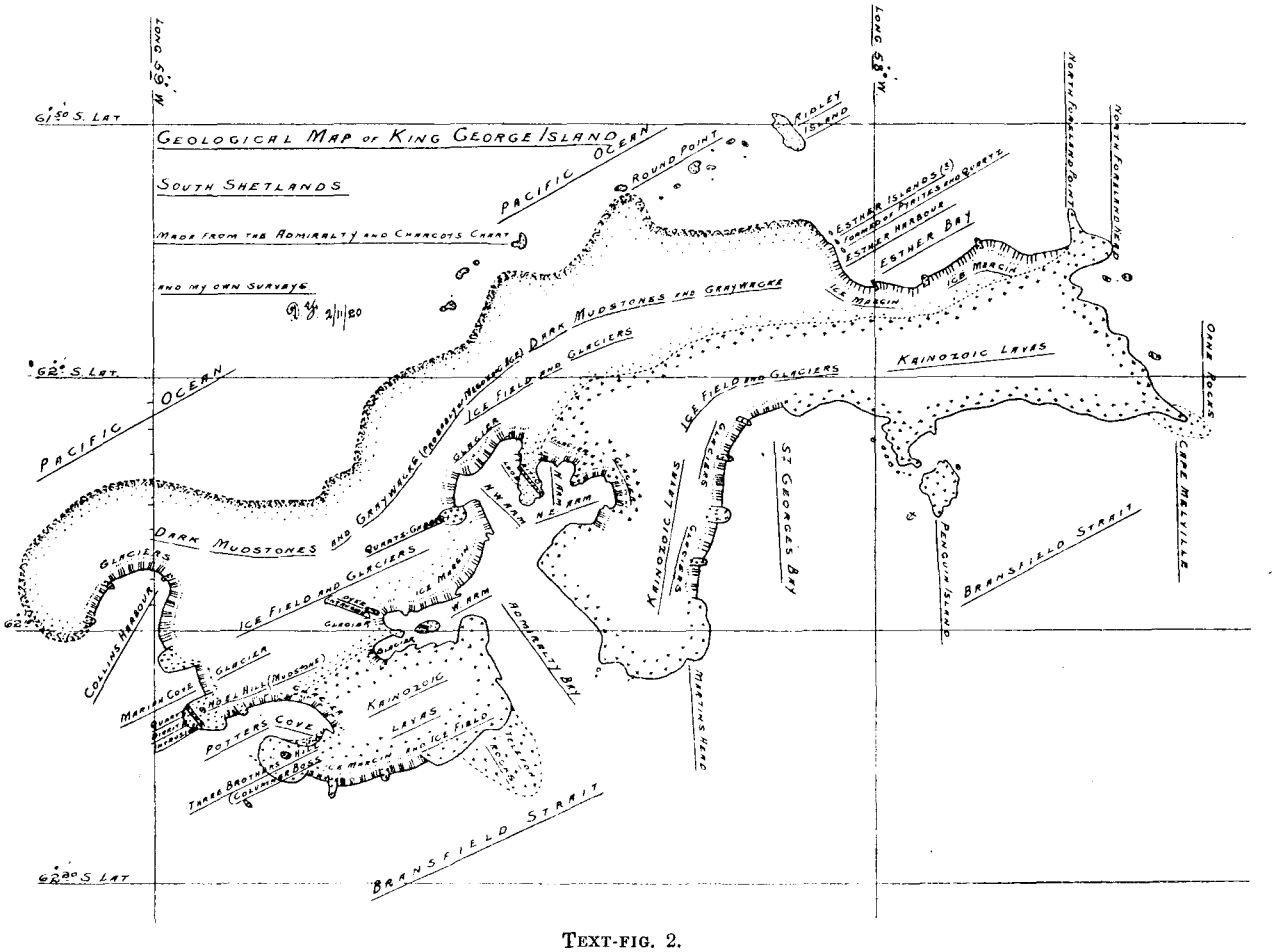
The largest development of stratified rocks with their interbedded lavas is in Admiralty Bay (Pl. III, fig. 1). The bay runs N.N.W. from Bransfield Strait, as a channel about 4 miles wide, for about 8 miles; it then opens out into a number of branches along lines of structural weakness. Between the N. and the N.W. arms of the bay a broad hilly buttress of the stratified sediments and interbedded lavas runs S. for several miles from the ice-fields and glaciers (text-fig. 3). It is hardly possible to get a continuous geological section, and the following section has been pieced together from different exposures:—

		Thickness.
Bluish-black hard mudstone (perhaps cherty)	about	100 feet.
Tuff and agglomerate (greenish-gray)	„	20 „
Blue-black mudstone (hard and looks cherty)	„	80 „
Tuff (greenish-gray)	„	20 „
Blue-black mudstone (hard and looks cherty)	„	80 „
Tuff (rusty-red)	„	20 „
Sediments (siliceous, fine-grained and fine-bedded)	„	100 „
Tuff and agglomerate	„	20 „
Sediments (siliceous, fine-bedded and fine-grained)	„	50 „
Tuff and agglomerate (rusty-reddish, generally fine-grained)	„	20 „
Dark-gray andesite, with white phenocrysts	„	100 „
Darker andesite (fine-grained, with white phenocrysts)	„	50 „
Conglomerate (light-gray, with small quartz pebbles)	„	100 „
Dark-gray andesite (with white phenocrysts)	„	50 „
Tuff and agglomerate (rusty-red)	„	30 „
Sediments (siliceous, fine-grained and light-gray)	„	50 „
Tuff and agglomerates (with bands of siliceous rock)	„	20 „
Tuff and agglomerate (greenish-gray, with bands of siliceous rock)	„	50 „
Sediments (siliceous and fine-grained)	„	10 „
Tuff and agglomerate (reddish, with green incrustations)	„	20 „
Sediments (gray, siliceous, and fine-grained)	„	20 „
Tuff and agglomerate (reddish)	„	10 „
Sediments (siliceous with angular cleavage to lowest layer seen)	„	40 „
Total thickness of section	„	1060 „

This series occurs to the height of 1222 feet above sea-level, and extends N.W. probably to the Pacific side of the island, the highest point of which (1895 feet) is occupied by ice. The highest volcanic bed is 100 feet from the top of the series, and from that horizon down to sea-level amygdaloidal and porphyritic andesites, tuffs, agglomerate, and sedimentary rocks are interbedded, showing successive periods of sedimentation and volcanic activity.

A study of the various arms of Admiralty Bay shows that the sediments and interbedded andesites had undergone erosion for a long period before a renewal of volcanic activity discharged the later basic lavas and tuffs.

The geological map (text-fig. 2) shows the relations of the later or Kainozoic lavas to the

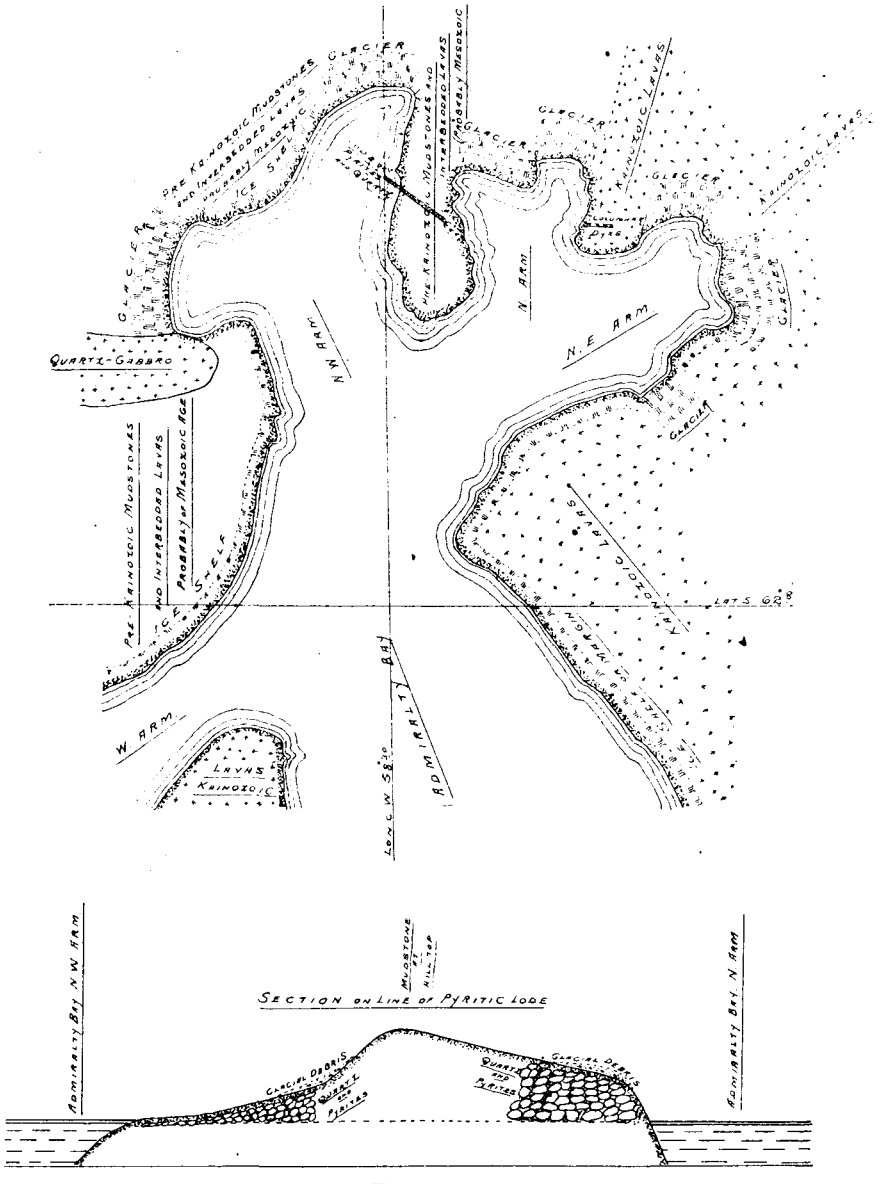


TEXT-FIG. 2.

eroded form of the island at their discharge. The S.E. coast began near the North Foreland and stretched S.W. to the buttress already described in Admiralty Bay. Thence it curved round to the N. wall of the W. arm of the bay and continued to the S.E. side of Noel Hill, the present N. boundary of Potter's Cove. The little island shown in the map near the head of the west arm of Admiralty Bay is formed of the older sediments and andesite lavas; while on the opposite shore the Kainozoic lavas stand up in an escarpment several hundred feet high.

The little island and the buttress in Admiralty Bay evidently existed before the outpouring of the Kainozoic basalts (olivine-andesites) and were ultimately buried beneath them. The broad band of these lavas, which stretch the whole length of the island on its S.E. coast from Cape Melville to Three Brothers Hill and Potter's Cove, has well-nigh

doubled the size of King George Island. In the area examined the Kainozoic lavas reach their greatest development on the S.E. coast along Bransfield Strait, and the N.W. part of the island consists of the older sediments and the interbedded andesitic series.



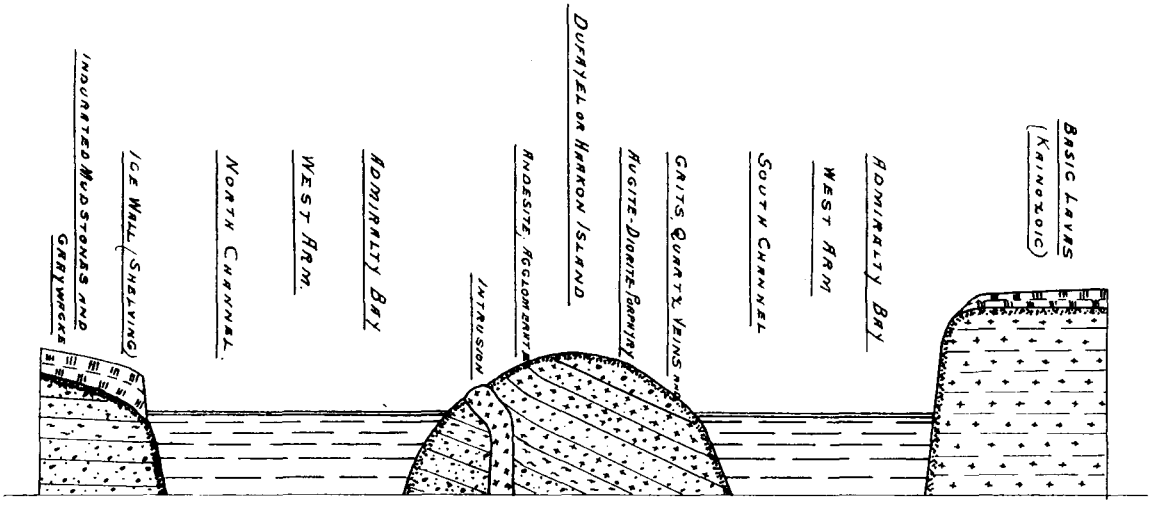
TEXT-FIG. 3.

Haakon (Dufayel) Island, Admiralty Bay, King George Island.

This little island is formed of the older sediments and andesites. It is very similar in structure to the hilly buttress between the N. and the N.W. arms of the bay. Blue-black mudstone is interbedded with lavas, which Mr TYRRELL identifies as pyroxene-augite-andesite, and with tuffs and agglomerate; the porphyritic andesite of the hilly buttress also occurs. The mudstone is not here the highest horizon, but is overlaid by considerable bodies of andesite.

A well-defined dyke of andesite-porphyry is seen on the N.W. side of the island and about a couple of miles further out to the N.N.W. In both places it has penetrated the

mudstone, of which it contains numerous inclusions. There is much quartz on both sides of the island. About half a mile from the W. end and on its S. side is a quartz vein in places 15 feet wide; it strikes about N. 60° E. and dips about 70° towards the S.E.; it is lenticular and in places thins to the thickness of a thread; it contains some pyrites. It has evidently been formed by solutions working along a fault plane or fissure. Quartz is also exposed close to the dyke of andesite-porphyry on the N.W. side of the island.



TEXT-FIG. 4.

Text-fig. 4, a section from N.N.E. to S.S.W. across Haakon Island, shows the contrast between the horizontal Kainozoic lavas and the tilted older series.

Metalliferous Deposits and Diorite Intrusions of Admiralty Bay, King George Island.

The andesite-porphyry intrusion of the W. arm of the bay is very small in comparison with the huge mass (Le Poing) of quartz-gabbro, rising to about 1100 feet above sea-level, in the extreme W. recess of the N.W. arm. This mass has horizontal jointing almost like bedding planes, as well as inclined jointing. A long way down the E. slope it abuts on mudstones and grits and bedded porphyritic andesite.

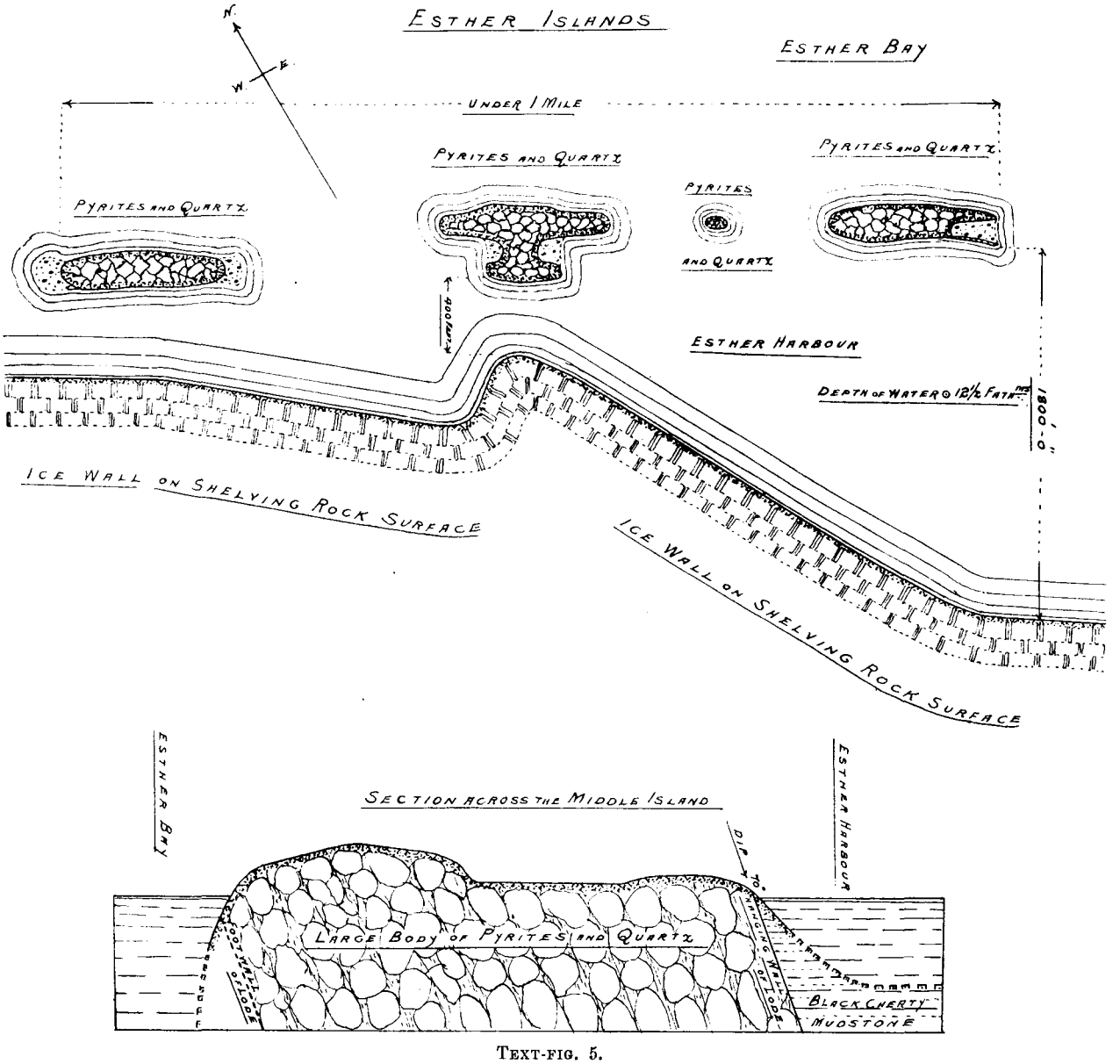
Morainic debris covers much of the buttress on the W. side of the N. arm; only a small patch of diorite was seen, but to its influence is doubtless due the abundance of quartz there.

As far as could be determined, the quartz-gabbro intrusions are confined to the older series and were not anywhere seen in the Kainozoic lavas.

On the W. side of the N. arm is a broad band of yellowish-white glacial detritus. Further up the hill slope to the W. is grayish-white angular quartz, of somewhat cellular structure in places. The patches of yellowish colour are evidently due to the oxidation of pyrites. Further N. along the hill slope is a parallel quartz body full of pyrites and very cellular in structure. The strike is about N. 80° W. The large amount of secondary quartz and pyrites is evidence of a large lode or vein, most of which is concealed by morainic debris and scree.

An exposure of quartz and pyrites practically at sea-level, and disappearing under it on the E. side of the N.W. arm of the bay, has the same line of strike and is the direct continuation of the vein on the W. side of the N. arm. Its total length must be fully 8000 feet. Much iron-stained quartz occurs at various points between the lower fringe of the hill and the

small glacier. Some of the quartz is a replacement of the andesites, pieces of which can be picked up in all stages of replacement. Extending out to sea, and partially submerged for about a hundred feet, is an outcrop of pyrites about 30 feet wide; it encloses fragments of the country rock, which look like chert. There is also quartz and pyrites in varying proportions,



TEXT-FIG. 5.

from pure quartz to nearly pure pyrites. Its length of fully 8000 feet and the thickness at each end indicate the persistence of the lode (text-fig. 3).

Metalliferous Deposits of the Pyritic Islands, Esther Harbour, King George Island.

The Pyritic Islands lie close to the N.W. corner of King George Island near the edge of the Pacific, and about 4 miles S.S.E. of Ridley Island. They are three in number, and each of them is formed of pyrites and vein quartz. They are the remains of a pyritic lode with quartz; the associated veins of spar are parallel to it. The islands represent metalliferous

bodies along the lode, and the sea between them covers the narrow or barren portions, which are more easily denuded,

The longitudinal axis of the islands, which is also the strike of the lode, trends about N. 80° W., which is the same as the pyritic lode of Admiralty Bay. The dip is obscure, but on its apparent continuation S.E. on the mainland it appears to be about 70° in a direction S. 10° W (text-fig. 5).

The islands are each about 750 feet long; average breadth, about 100 feet; average height at centre, about 30 feet. They appeared to be about 1000 feet apart, and the centre island only about 400 feet from the ice-wall to the S.W., the narrowest part of the little harbour.

The hanging wall of the lode is black cherty mudstone; the footwall was not seen. A dioritic intrusion occurs not far away, as pieces were seen on the beach of the S.E. island. The nature of the replacement of the cherty country rock is shown where the masses of pyrites seamed with quartz gradually pass into white mudstone so penetrated by quartz and pyrites that its original character is almost obliterated. At other places interlacing veinlets of quartz and pyrites traverse the black mudstone, and a little distance from the hanging wall the black mudstone is but little affected. This lode is an illustration of metasomatic replacement on a fairly large scale.

The pyrites exposed in the islands above sea-level amounts to many thousands of tons, and probably large deposits of similar character are concealed under the ice-fields of the mainland.

The S.W. Coast of King George Island, Potter's Cove, Marian Cove, and Collins Harbour. (Text-fig. 2.)

Potter's Cove is an excellent harbour at the S.W. corner of King George Island; the s.s. *Hanka* was evidently the first ship to run into it for a long time. A small boat and ropes were found on the beach, and had evidently been left behind by sealers of long-bygone days. Rocky islets at the entrance screen the real harbour, and no doubt led the present whalers to avoid it.

The Three Brothers Hill, a magnificent columnar boss which rises over 500 feet above sea-level on the S. side of the harbour, is a prominent feature. The rock is identified by Mr TYRRELL as a hypersthene-augite-andesite. It belongs to the Kainozoic volcanic period. The S. side of the harbour exposes only the hypersthene-andesite, but sedimentary rocks are seen at its N.W. corner. They extend along the N. side of the harbour and curve round the coast of Fildes Strait to Marian Cove, a little harbour parallel to Potter's Cove. Marian Cove has been excavated in the black mudstones and their associated grits and andesites.

Noel Hill, a prominent knob rising on the S. side of the Cove, is crowned by black or blue-black mudstone, which has been baked and indurated by large intrusions of a rock that Mr TYRRELL determines as quartz-diorite. A felsite or devitrified rhyolite also occurs. The intrusion trends from N. of W. to S. of E., and appears to dip 70° towards N. 30° W. The mudstone is altered as it approaches the intrusive rock, and becomes much impregnated with secondary quartz. Similar alterations of the country rock and formation of quartz are evident beside all the diorite intrusions seen on King George Island, with the exception of that at the western extremity of N.W. arm, Admiralty Bay.

Collins Harbour is a wide curving inlet a few miles to the N. of Marian Cove. It appears to be in the same rock as Marian Cove.

King George Island is enveloped in ice-fields which discharge glaciers into the sea. The

morainic material on the lower parts of the island shows that glacial action was once more widespread than it is at present. The climate is milder now than formerly, a fact of which South Georgia furnishes more convincing evidence.

Nelson Island.

This island is probably, to a considerable extent, similar in geological structure to King George Island, from which it is separated by Fildes Strait. It is largely covered by an ice-cap, but rock exposures on the coast are frequent. Its outline is nearly rectangular; its size is about 10 miles long by 8 or 9 miles wide. Its trend is S.W., similar to King George Island and all the South Shetland group.

The little harbour of Harmony Cove, near its S.W. corner opening into Nelson Strait, exposes hard, dark-gray quartz-diorite-porphyry, felsite-breccia, and agglomerate close to the beach. There is no definite separation between these rocks, as if there were a gradual passage from one to the other. Their structural lines are nearly vertical.

Roberts Island.

This island, on the opposite side of Nelson Strait from Nelson Island, is dome-shaped and ice-capped. The only harbour recorded in it is Copper Mine Cove on English Strait. The rocks in its neighbourhood appear to be Kainozoic basalts (see paper by Dr H. H. THOMAS), as they are rusty red in colour. They rise in escarpments along Bransfield Strait. The presence on the island of the older andesites and mudstones was not determined.

Greenwich Island.

This island lies between Roberts Island on the N.E. and Livingstone Island on the S.W. It is separated from the former by English Strait, and from the latter by Macfarlane Strait. Its length trends N.W. to S.E., and therefore across the normal trend of the South Shetland group. The greater portion of the island is covered with snow or ice.

The harbour of Hospital Cove on the S.E. corner of the island is formed by volcanic debris. It is protected on the S.E. by a lofty escarpment of volcanic rocks.

Along Bransfield Strait and Macfarlane Strait are large masses of the later basalts, of which those on the S.E. side of Hospital Cove are porphyritic and amygdaloidal lavas (olivine-andesites). They are associated with tuffs. Some of the lavas are fine grained. No evidence of the older sediments and interbedded lavas *in situ* was observed, but Mr TYRRELL has determined one rock as a quartz-diorite-porphyry, and among the specimens collected is a red chert that Mr TYRRELL thinks is possibly radiolarian.

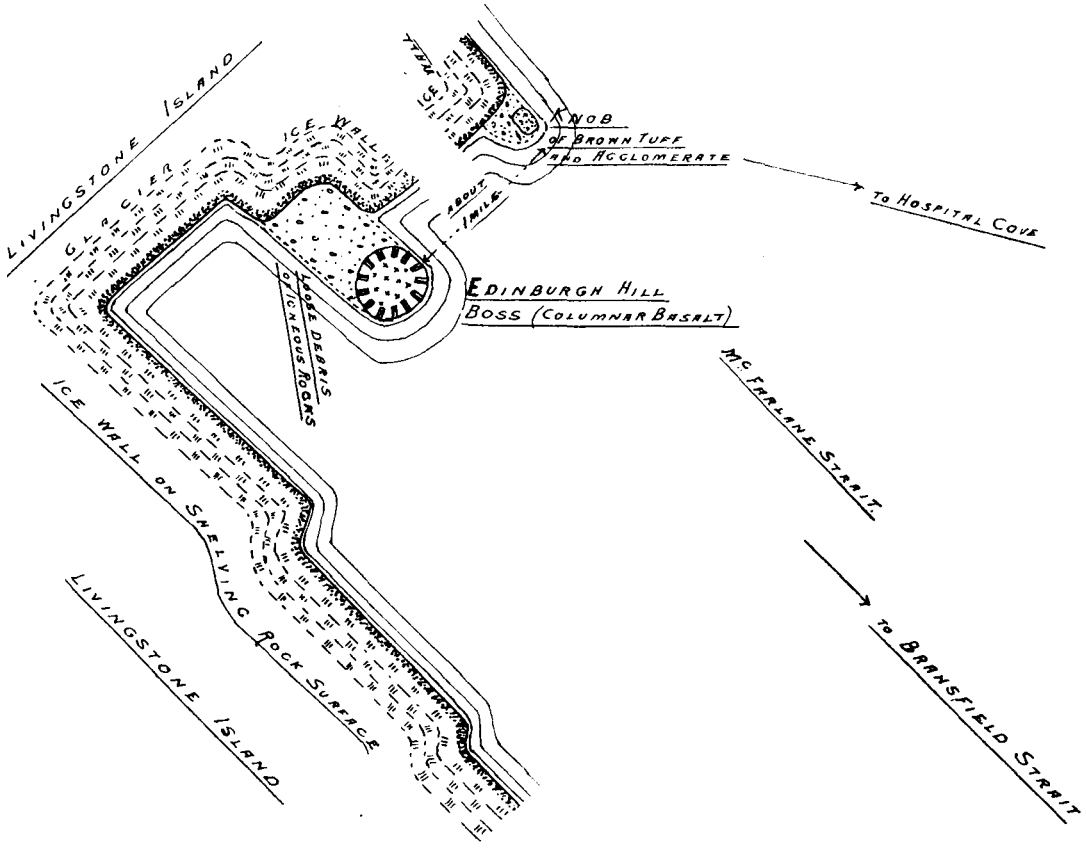
Livingstone Island.

Livingstone Island is the second largest of the South Shetland group. Its greatest length is about 37 miles in a N.E. and S.W. direction; its greatest width is about 18 miles. It rises into two lofty peaks—one near the N.E. corner of the island, and Barnard Peak on the S.E. coast. The heights on the Admiralty chart, 3104 feet and 3339 feet, appear much too low; they are probably both over 5000 feet.

The island for at least 12 miles along Bransfield Strait is formed of volcanic rocks belonging mainly to the later series. It must have been a centre of intense volcanic

activity; the two peaks are probably volcanic necks on a volcanic axis trending about N.E. and S.W.

Along the Macfarlane Strait close to the Pacific end the rocks seen all belong to the Kainozoic volcanic series. There may, however, be some evidence of the older sedimentary series on the N.W. coast-line. Keith Island, which is close to the mainland in Macfarlane Strait, is small, and consists of volcanic rocks. About 8 or 9 miles along Macfarlane Strait from Bransfield Strait is Edinburgh Hill, an isolated knob of columnar olivine-basalt rising out of the sea to the height of several hundred feet. It is capped by about 50 feet of tuff. The columns are generally vertical, but some of them curve a little near sea-level.



TEXT-FIG. 6.

They are irregularly hexagonal in cross section. Some of the columns are 2 to 3 feet in breadth (Pl. I, fig. 1) (text-fig. 6).

About a mile N.E. of Edinburgh Hill is a rather square-sectioned pillar of soft brown tuff at sea-level, containing basaltic agglomerate, gray quartz-diorite, and blue-black mudstone. It is over a hundred feet in height, and near the top is formed of fine-grained gray tuff, with few or no inclusions. It and Edinburgh Hill both belong to the most recent phase of volcanic activity in the South Shetlands. The presence of the blue-black mudstone and diorite in the agglomerate shows that they exist in Livingstone Island.

Deception Island.

Deception Island, the best-known and most accurately surveyed of the South Shetland Islands, is somewhat circular in outline, with the central part occupied by the sea. Its

greatest length is from north to south, and is fully 11 miles; its greatest breadth is from east to west, and is fully 9 miles. The lagoon is $6\frac{1}{2}$ miles long by $3\frac{1}{2}$ miles broad. The volcanic ring enclosing the crater varies from $3\frac{1}{2}$ miles at Mount Pound to $1\frac{1}{2}$ miles near the entrance channel.

The island clearly belongs to the latest phase of volcanic activity in the South Shetlands, which also includes Bridgman Island and the knob near Edinburgh Hill, Livingstone Island, and represents the end of the series which comprises the main volcanic activity of Livingstone Island.

The lowest rocks seen on it at the entrance channel and in Pendulum Cove are the brown tuff and agglomerate upon which rest red and iron-blue tuffs (Pl. III, fig. 2). The lavas are mostly very vesicular and slaggy: Mr TYRRELL has identified those from Pendulum Cove as hyalo-dacite, hyalo-basalt, and olivine-basalt; and some of the fragmentary beds as palagonite-tuff. Dr H. H. THOMAS has identified, in addition, pyroxene-andesite with tridymite, oligoclase-trachyte, and ophitic olivine-dolerite; and GOURDON has given analyses of trachyte, andesite, and "labradorite" (=felspar-basalt or basic andesite).* There is a well-marked dip of the tuffs inwards towards the lagoon on the lower slopes of Mount Pound. Glacial action in Deception Island is less extensive at the present day than formerly. At the N. side of the inner rim of the island is a fine glaciated corrie with the hollow occupied by a tarn (Pl. III, fig. 3). The water in this tarn is moderately warm, and is evidently fed from hot springs bringing the water up from heated rocks below. This is the only existing volcanic action on Deception Island.

GEOLOGICAL STRUCTURE OF BELGICA STRAIT, PALMER ARCHIPELAGO, AND GRAHAM LAND. (Text-fig. 7.)

Hoseason Island and Intercurrence Island near the junction of Belgica and Bransfield Straits, on examination through the field-glass, show several layers of rock with apparent columnar structure. If these are lavas, they may belong to the later volcanic series; otherwise the Kainozoic basalts of the South Shetlands do not appear to have extended to Belgica Strait, Palmer Archipelago, or Graham Land.

The sedimentary rocks of King George Island, including their most persistent representative, the blue-black mudstone, and the intrusions of diorite-porphyry and diorite, are extensively developed.

GUNNAR ANDERSSON, referring to the work effected by the Swedish and Belgian Expeditions on the W. coast of Graham Land, remarks the meagre exposures of sedimentary rocks. That statement is applicable only to the coast from Mount Bransfield to Cape Murray at the S.W. corner of Brialmont Bay; for sedimentary rocks, especially the mudstone, are ubiquitous along Belgica Strait, and are probably present in all the islands surrounding it.

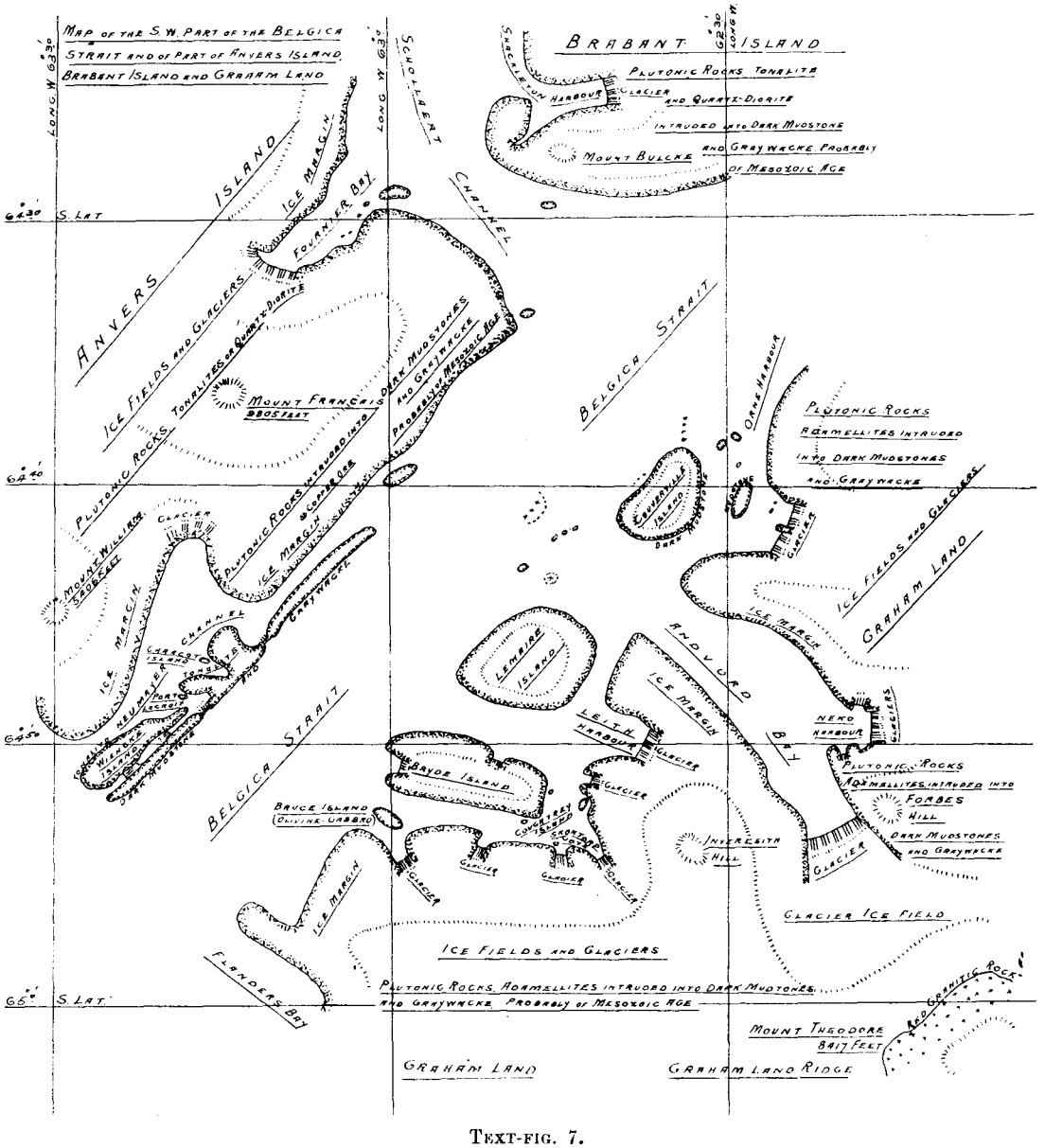
The Graham Land mountain range is a huge plutonic mass of diorite, granodiorite, and granite, with some basic or ultra-basic rocks on the margin. Plutonic action in the South Shetland group was much less important than along Belgica Strait.

Trinity Island, Graham Land.

Trinity Island is separated from Graham Land by a narrow channel near the junction of Bransfield and Belgica Straits. It is E. of Hoseason and Intercurrence Islands, and N.E. of Brialmont Bay. It is about 18 miles long in a N.E. and S.W. direction, and about 9 miles broad.

* H. S. WASHINGTON, "Chemical Analyses of Igneous Rocks," *Prof. Paper* 99, *U.S. Geol. Surv.*, 1917, pp. 160, 243, 467, 549.

Mikkelsen Harbour, on its S.E. corner, is a fairly good anchorage. Tower Hill, on the N.E. side of the island, is the most prominent natural feature, and rises over 3000 feet above sea-level. There are numerous rock exposures on the coast. Round Mikkelsen Harbour and the rocky islands adjacent to it are sediments altered to hornfels, beside intrusions of gray



TEXT-FIG. 7.

gabbro and quartz-gabbro, which are intersected by dykes of ophitic dolerite. A slate altered by contact with the gabbro occurs on the E. side of the harbour. The plutonic rocks evidently form the largest part of the island. Dr H. H. THOMAS mentions altered olivine-basalt and granophyre from Trinity Island.

Nansen Island, Wilhelmina Bay, Danco Coast, Graham Land.

Nansen Island is one of a series scattered over Wilhelmina Bay between Cape Anna and Cape Reclus, bordering Belgica Strait opposite Brabant Island.

S.E. of Cape Anna, where Wilhelmina Bay curves into the Danco Coast of Graham Land, is a large intrusion of light-gray diorite; and beyond it, forming the containing walls of a glacier, is the mudstone. The Danco coast is mostly enveloped in snow and ice, but the structure is no doubt of similar character until the Graham Land slope is reached.

Nansen Island is mainly wreathed in snow and ice, but round the coast-line there are many rock exposures in escarpments. Graham Harbour, the whaling centre, has a number of small rocky islands giving good exposures. The most persistent rock is an igneous breccia with greenish-gray base. The fragments range to about 12 inches in diameter. In one of the islands in Graham Harbour is a dyke of roughly columnar dolerite, about 5 feet wide, and trending E. and W.

Orne Harbour and Islands, South of Cape Anna, Belgica Strait.

Orne Harbour, a deserted whaling anchorage, occupies an island-studded channel between Belgica Strait to the N. and Andvord Bay to the S.W. (Pl. III, fig. 4). The small islands are mere rocks, rising not more than 20 feet above sea-level (text-fig. 7).

The large island consists of mudstones on the W. side, and of greenish tuffs and igneous breccia with large black angular fragments on the N.W. side.

The tuff and breccia form the base of a small island, and underlie a dark mudstone; they are remnants of the older series of sediments with interbedded andesites of the South Shetlands.

On the beaches of the large island, and of the two smaller islands N.E. of it, are boulders of granites, varying from macro-crystalline rock with light-pink to nearly white felspars, to micro-crystalline varieties. There are also boulders of mica-schist, some of which is beautifully crumpled. They may have been brought by icebergs from the Antarctic ice-barrier to the S.W., or by glaciers from Graham Land.

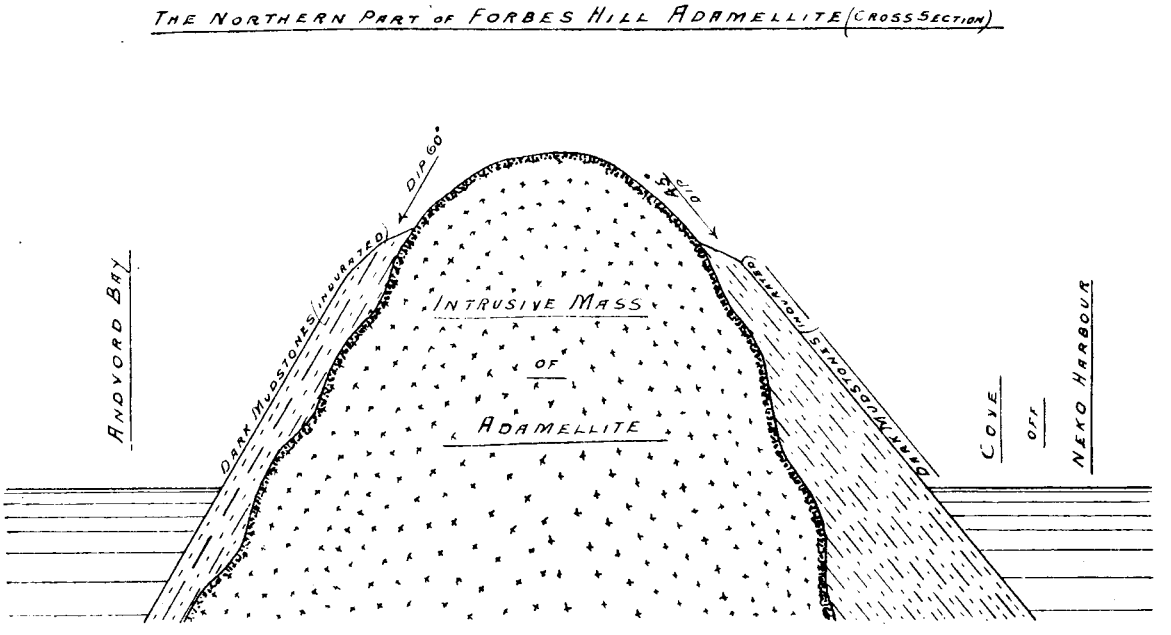
Andvord Bay.

This bay joins Belgica Strait between Couverville Island on its N.E. side, and Lemaire Island on the S.W. (text-fig. 7).

The bay runs about 11 miles S.E. from the Orne and Lemaire Channel, and terminates against a huge glacier, which comes from the N.E. shoulder of Mount Theodore, one of the heights of Graham Land (Pl. IV, fig. 1). The bay is about 3 miles in average width. About 7 or 8 miles S.E. of the Orne and Lemaire Channel, Neko Harbour branches off and runs about 3 miles N.E. About a mile from its inner end on the south-east side is a fine exposure of compressed and puckered mudstone and interbedded altered sandstone. The puckering of the sedimentary rocks is no doubt caused by intrusions of a granitic rock (which Mr TYRRELL identifies as adamellite), of which a huge intrusion forms Forbes Hill at the S.E. corner of Neko Harbour.

On the edge of the plutonic intrusion in Andvord Bay the mudstone is seen lying on it with a dip of 60° to 70° towards the bay. The mudstone is indurated for a few feet from the intrusion, but retains its blue-black colour until close to the contact it becomes a purple brown. A little cove to the S.E., off Neko Harbour, exposes the N.E. wall of the granodiorite, and with the mudstones dipping about 45° into the sea. The dip is here in the exactly opposite direction to that in Andvord Bay. The intrusion has clearly ruptured and uptilted the mudstones, as shown in text-fig. 8.

Mount Theodore, which towers above the S.W. side of the glacier that enters the head of Andvord Bay, is apparently, judging by its colour, composed of red granite. No rock seen on the west coast of Graham Land from Trinity Island to the S. of Flanders Bay resembles it, but the boulders of coarse red biotite-granite on the island in Orne Harbour resemble it and may come from the same massif. A boulder of gneiss on the same island must have



TEXT-FIG. 8.

come from the same place as the specimen of granite. The height of Mount Theodore, as estimated by the only method available to the writer, is just over 8400 feet.

Mount Theodore is the most imposing natural feature in the South Shetlands, Palmer Archipelago, or Graham Land.

Leith Harbour, Lemaire, Bryde, and Hanka Islands. (Text-fig. 7.)

Leith Harbour is a small bay, about three miles long, running parallel to Andvord Bay, from which it is separated by about four miles, mainly of plutonic rocks. There is a little patch of mudstone on the S. side of Leith Harbour, but otherwise the rocks seen were all plutonic (Pl. I, fig. 2; Pl. II, fig. 1). Hanka Island, a small island named after the s.s. *Hanka*, in the N.E. corner of the harbour, consists entirely of diorites, determined by Mr TYRRELL as quartz-augite-diorite and tonalite. Similar diorites form Penguin Island, a narrow island between Lemaire Island and the mainland. Lemaire and Bryde Islands are largely formed of the dioritic rocks with some disrupted sediments. Near the contact with the mudstone, the diorite has weathered brown. This colour is a useful guide to the distribution of the sedimentary rocks, as this staining was not observed within the plutonic rocks, and appears to be a marginal alteration.

Bruce Island, Skontorp Cove, and Coughtrey Island. (Text-fig. 7.)

Coughtrey Island, which is a short distance S.S.W. of Leith Harbour and opposite the east end of Bryde Island, is largely composed of sedimentary rocks, including thin-bedded mudstones, quartzites, and igneous breccia; these rocks are exposed in a fine escarpment on

the W. side (Pl. IV, fig. 2). They have been puckered and indurated by intrusions of augite-andesite, some of which have been rendered green by development of epidote. These greenish dykes were seen in Neko Harbour, Andvord Bay, and in Coughtrey Island. Near them in Coughtrey Island a few streaks of chalcopyrite were found. Bruce Island lies at the mouth of the channel running from Skontorp Cove to Belgica Strait (Pl. II, fig. 2). It is composed wholly of olivine-gabbro, which rises from steep walls on each side to a narrow median ridge. The dioritic rocks were not found *in situ*, but were seen in the screes on the E. side of the island. East of Bruce Island, on the S. or Graham Land side of the channel, exposures of the deep-brownish altered margin of the dioritic rocks were seen a short distance from the dark basic rocks.

Flanders Bay. (Text-fig. 7.)

Flanders Bay at Cape Renard is the S.W. limit of Belgica Strait, which at its upper end branches into a number of narrow channels between walls of gray-whitish plutonic rocks. From Cape Renard a series of small islands, mainly if not wholly plutonic, extends to the S.W. corner of Wiencke Island and the Neumayer Channel, at the S. corner of Anvers Island. No sedimentary rock was seen in any part of Flanders Bay. The numerous cliffs seen were all of gray diorite. The variety in a little rock island near the centre of the bay contains biotite.

Anvers Island, Wiencke Island, and the Neumayer Channel. (Text-fig. 7.)

Neumayer Channel extends about 20 miles north-easterly between Anvers Island to the N.W. and the Wiencke Island and Doumer Island to the S.E. Port Lockroy is an anchorage in Wiencke Island immediately opposite Doumer Island. Wiencke Island is bounded on the side facing Neumayer Channel by almost vertical walls of sedimentary rocks, including the bluish-black mudstone; it is, however, largely formed of gray diorite, which is the only rock present in the Doumer Island and Cairn Islands. The diorite of Isle Casabianca is vertically jointed, with some thin films of chalcopyrite along the joints.

Mount William, near the edge of the Neumayer Channel (alt. 5406 feet) at the S.W. corner of Anvers Island, and Mount Francis, near the centre of the island (alt. 9413 feet, *fide* the Charcot expedition), are apparently both of plutonic rock (Pl. IV, fig. 3); and Fournier Bay, an inlet off the Schollaert Channel on the N.E. side of Anvers Island, lies wholly in the same. The Neumayer Channel has been excavated along the junction between the sedimentary and plutonic rocks. On Anvers Island, about two miles from the outlet of Neumayer Channel to Belgica Strait, the diorite shows the brownish alteration which often indicates its contact with sedimentary rocks. Some distance inland from this point an exposure of rock is coloured bright green, apparently due to copper carbonate. Sedimentary rocks doubtless exist here and there over the greater part of Anvers Island, but plutonic eruptives preponderate and have in their uprise shattered and folded the pre-existing sediments.

Brabant Island, Shackleton Harbour, and Buls Bay. (Text-fig. 7.)

Brabant Island and Anvers Island are large islands on the N.W. side of Belgica Strait, and form part of the Palmer Archipelago. Brabant Island is similar in geological structure to Anvers Island, but it perhaps includes a higher proportion of sedimentary rocks. Plutonic exposures, however, are numerous. The sedimentary rocks are indurated, tilted, and broken up by large intrusions of dioritic rocks.

Shackleton Harbour, at the S.E. corner of Brabant Island, is bounded by a long line of steep and lofty rock exposures. The cliffs beside the harbour are formed of indurated mudstones and other interbedded sediments broken through by intrusions of gray dioritic rocks and associated porphyries. The dip of the mudstones and other sediments is almost or quite vertical, and is no doubt responsible for the pinnacles and splintery crests or edges of the rocky heights overlooking the harbour (Pl. IV, fig. 4). A dyke of gray tonalite-porphyry from 6 to 10 feet wide traverses the mudstones, about half a mile from the ice-wall of the glacier. Another similar intrusion, from 50 to 100 feet wide, occurs opposite the outlet to Schollaert Channel. Mr TYRRELL has also recognised in the rocks collected from this harbour quartz-diorite-porphyry, andesitic tuff, and igneous breccia. Above the large intrusion and further to the N.E., on the steep slope of a corrie, a band of altered diorite is of a deep rusty-brown colour, with a light-green staining on either side; this stain may be due to epidote, as Mr TYRRELL finds that one of the andesites of this locality is epidotic.

Buls Bay, on Belgica Strait, is about midway between the N.E. and S.E. corners of Brabant Island, and beside the Solway Mountains. The highest peak above Buls Bay is a prominent natural feature, and appears to be over 5000 feet above sea-level. The rocks at sea-level and in a cliff overlooking the bay are mudstones and grits, penetrated by basalt dykes from 4 or 5 feet down to a foot or less in width. The mudstones are dark gray, and show the effects of strong pressure. The Solway peaks are doubtless plutonic, and their intrusion has caused the induration and alteration of the sedimentary rocks.

TECTONIC BASINS ADJACENT TO THE SOUTH SHETLANDS AND GRAHAM LAND.

The extensive area of Bransfield Strait is clearly a tectonic basin. The sedimentary rocks on either side of it are on the same horizon and probably underlie it. Deception Island, 10 or 12 miles S.E. of Livingstone Island, rises from deep water for about 3 miles S. of the entrance to the crater; a sounding of 200 fathoms gave no bottom, and about 10 miles E. of its N.E. shore the depth is 563 fathoms. A sounding of 765 fathoms has been recorded at a point about midway between Cape Melville on King George Island and the N.E. corner of Graham Land, and about 28 or 29 miles S.W. of Bridgman Island. The available soundings indicate that the channel is flat-floored and is probably due to down faulting, for Bransfield Strait, except near the shore, has no steep slopes, and is a more or less flat depression. Its floor is probably formed of sedimentary rocks over long distances.

Belgica Strait is small and narrow compared with Bransfield Strait. Sedimentary rocks exist on both sides of it, and are greatly disturbed. A sounding of 722 fathoms is recorded between Hoseason Island and Trinity Island, and one of 388 fathoms at the confluence of the Belgica Strait with the Schollaert Channel, near Brabant and Anvers Islands.

This strait is also probably due to down faulting between the plutonic masses of Graham Land and of the Brabant and Anvers Islands.

THE PLATFORM OF THE SOUTH SHETLANDS, THE ELEPHANT ISLAND GROUP, AND THE SOUTH ORKNEYS.

A long, gently curving ridge, submerged at intervals, evidently underlies the South Shetland Islands, the Elephant Island group, and the South Orkney Islands. King George Island and Elephant Island are probably fragments of a formerly continuous land.

The sea between them conceals a submerged portion of the ridge, and not unlikely some of the sediments which were laid down upon it. The edge of the Pacific slope passes not far

W. of the South Shetlands, but does not curve into the area between King George Island and Elephant Island. The depression of Bransfield Strait is continuous past Bridgman Island and curves round to the S. of Clarence Island.

The relation of King George Island to Elephant Island and the continuity of the depression parallel to them suggest that the latter is tectonic, and that it is continued eastward by the submerged ridge extending from Clarence Island, past the South Orkneys, to the South Sandwich Islands. At the other end of the South Shetland group, S.W. of Smith Island, the ridge is submerged and is not indicated by any islands parallel to the Biscoe Islands, Adelaide Island, Alexander Land, and Charcot Land. Further to the S.W., however, Peter Island in the Bellingshausen Sea may represent an upward bulge of the ridge. The existence of sedimentary rocks in Belgica Strait, Anvers Island, and Brabant Island shows the S.W. continuation of the sunken band. Further light would be thrown on this question by knowledge of the Biscoe Islands and Charcot Land. The soundings, however, leave no doubt that a platform lies between the coast of Graham Land and the main Pacific slope. The best evidence of a subsidence along the inner fringe of this platform is the existence of sedimentary rocks in the islands.

The Geological Age of the Sedimentary Rocks and Interbedded Lavas, of the Eruptive Rocks and the Latest Lavas.

The volcanic eruptions of the South Shetland region belong to three distinct series—the oldest is that of the andesites and andesitic tuffs interbedded with the mudstones; they are certainly pre-Kainozoic and probably date from the middle Jurassic for reasons stated on p. 52.

The next series includes the basalts, basaltic agglomerates, and olivine-andesites of the coastal belts of the islands, and probably also the dykes of diorite-porphyry and diorite-aplite; this series probably belongs to the middle part of the Kainozoic. The third series includes the basalts and palagonite tuffs of Deception and Bridgman Islands, of which the last eruptions were geologically recent.

The determination of the ages of these volcanic series rests on indirect evidence, as no fossils have yet been found in the stratified rocks associated with them on the South Shetlands, Elephant Island, or N.W. coast of Graham Land. The Swedish Antarctic Expedition was, however, fortunate in the discovery of a highly fossiliferous area on the N.E. coast of Graham Land and N.W. shore of the Weddell Sea. They found Jurassic beds in Hope Bay on the W. side of Antarctic Sound, the channel connecting the Weddell Sea with Bransfield Strait; and Cretaceous rocks on Snow Hill Island and Seymour Island, about 80 miles south of Hope Bay. On Seymour Island they also discovered Kainozoic rocks directly overlying the Cretaceous.

The extensive lavas and tuffs of Cockburn Island and James Ross Island overlie Cretaceous rocks, but in the first-named island they immediately underlie a Pecten conglomerate, the age of which is considered to be Pliocene. The Kainozoic rocks overlapping the Cretaceous sediments on the N.E. part of Seymour Island are considered to be of upper Oligocene or lower Miocene age. They contain numerous pebbles derived from granitic rocks, but no fragments of basalt, and must therefore have been deposited before the beginning of the Kainozoic volcanic eruptions.

The volcanic tuffs and basalts of Cockburn Island are resting, not on the younger Seymour Island Cretaceous rocks, but on the older Snow Hill Island beds, which belong to the same

period as the Cockburn Island rocks and are clearly Kainozoic. The basaltic lavas and tuffs of the South Shetlands rest on or overlap the eroded surface of pre-existing sedimentary rocks and their interbedded andesites; these sedimentary rocks are not apparently similar to the Snow Hill Island or Seymour Island Cretaceous sediments. There can be little doubt, however, that the later lavas are contemporaneous with the Kainozoic lavas and tuffs of Cockburn Island and James Ross Island.

The Kainozoic volcanic outbreak has simmered until geologically recent time in both areas. The extensive lava flows which have built up the lofty mass of Livingstone Island must date back to the earliest Kainozoic outbreak. The brown palagonite tuff and agglomerate near its base, at sea-level in Macfarlane Strait, are clearly due to a later and waning volcanic effort, contemporary with similar products on Deception and Bridgman Islands.

There need be little doubt of the consanguinity of the later basaltic lavas and brown palagonite tuff of the South Shetlands with those of Cockburn Island, James Ross Island, and the N.E. shore of Graham Land. The products of this period of volcanic activity have not been recorded in the South Orkneys, but appear to occur on Elephant Island and steadily increase in amount westward from King George Island to Livingstone Island.

Far to the N. in Patagonia, extending up the valley of the Santa Cruz River and close to the Cordillera, are vast deposits of Kainozoic basaltic lavas; they are frequently columnar, as in the later lavas of the South Shetlands. These basalts were poured out in South America and Antarctica at intervals along at least 1000 miles.

The line of the Kainozoic volcanic activity in the South Shetlands, and that on the N.E. shore-line of Graham Land are practically parallel and coincident with the boundary faults of two great basins, Bransfield Strait and the Weddell Sea. There is not, so far, any clear evidence of Kainozoic lava on the Louis Philippe Coast or the N.W. shore-line of Graham Land, and the writer did not see any evidence of it from Trinity Island, along the Danco Coast, and as far as the S.W. corner of Flanders Bay. The volcanic forces due to subsidence in the two great basins evidently found relief along their N.W. boundary faults, and little or no volcanic action was manifested on the S.E. boundary fault of Bransfield Strait.

The mudstones and grits, and their interbedded lavas of the South Shetlands, Palmer Archipelago, and the N.W. coast-line of Graham Land are clearly pre-Kainozoic. They were deposited and subjected to partial erosion before the last volcanic period began. They could not have been laid down later than the Mesozoic. Inferential evidence, however, is all that can be put forward at the present time to fix their geological horizon. The work of the Swedish Antarctic Expedition in Hope Bay is very useful in this connection. A series of sediments were located of graywacke at the base, dark slate with Jurassic plant fossils in the centre, and over 300 feet of volcanic tuffs at the top. NORDENSKJÖLD has found that some of them are derived from acid volcanic rocks. Not far from them, but on the other side of a glacier further up the bay, there is an exposure of quartz-diorite. No fragments, nor any intrusions of it, have been noticed in the graywacke or Jurassic slates.

The dioritic intrusions of the South Shetlands, Palmer Archipelago, and N.W. coast of Graham Land are injected into the sediments and interbedded lavas, and preceded the Kainozoic volcanic activity, and are probably contemporaneous with the quartz-diorite of Hope Bay. That no intrusions were observed in the Hope Bay slates is very probably due to the small area left of them.

The superposition of the volcanic tuffs to the mudstone-andesite series points to volcanic

activity in the Jurassic or early Cretaceous period, as the latter is perhaps on a rather lower horizon of the same period as that of the Hope Bay tuffs. The mudstone-andesite series may be provisionally, but with considerable confidence, relegated to a late Jurassic or early Cretaceous date.

The middle division of the Cumberland Bay Series, South Georgia, has also much volcanic debris and contemporary volcanic tuffs amongst its sedimentary rocks. They are determined as Mesozoic on the evidence of a Cephalopod which is probably Cretaceous, and of radiolaria which are probably Jurassic (11).

At the southern extremity of South America, in Tierra del Fuego, a great clay-slate formation of Cretaceous age rests on lavas (12). During the Cretaceous or Jurassic periods lava streams were discharged during the deposition of the lower 3000 feet of strata at the Puenta del Inca, in Chili (13). The Uspallata tuffs and great streams of submarine lavas were probably intermediate in age between the Cretaceo-Jurassic and older Kainozoic formations (14).

Volcanic activity doubtless occurred over a wide area in South America and the adjacent parts of Antarctica in the Mesozoic Era.

Antarctica, Past and Present.

Antarctica has at present no direct connection with any other continental area. The continuation of the Patagonian Andes into an Antarctic Andes in Graham Land, by an eastward loop curving round by the South Sandwich Islands, was suggested by Suess. More recently Nordenskjöld and Gunnar Andersson have suggested a tectonic connection of Graham Land with Patagonia, on account of the similarity of the eruptive rocks and geological succession in both areas. The Graham Land ridge does not cross the abysmal depths of Drake Strait to Tierra del Fuego. Suess was right as to the curving round to the east of the land areas. The outer ridge of the South Shetlands curves eastwards towards Elephant Island, the South Orkneys, and the South Sandwich Islands. Tierra del Fuego also curves eastwards towards the Falklands, South Georgia, and the South Sandwich Islands. Had there been a line of Andean eruptions, they would have been expected on that curving line.

There is little doubt that Antarctica and South America were connected at one time. The submerged ridge surrounded by abysmal ocean depths which exists between Tierra del Fuego, the Falklands, South Georgia, the South Sandwich Islands, the South Orkneys, and the South Shetlands, is not composed of Kainozoic materials, but of the much older framework that united two continental areas.

The igneous rocks of South Georgia are pre-Kainozoic, and, so far as we know at present, the eruptives have not penetrated rocks of later age than Silurian. The Devonian rocks of the West Falklands rest on granites and on mica-schists which must be of Palæozoic age, if not older. The consanguinity of the Graham Land eruptives with those of the Patagonian Andes may be a good indication of contemporaneous origin; but the eruptives of South Georgia and the West Falklands give no evidence of a tectonic connection between the two areas.

The continuation southward of the so-called Antarctic Andes of Graham Land has not been clearly determined. They are different in structure and composition from the mountains of South Victoria Land to the west of the Ross Sea, on the opposite side of Antarctica. It has, however, been suggested that Graham Land is connected with the mountains east of the Ross Sea, and this suggestion seems possible.

The foundation of Graham Land is no doubt part of the original framework of Antarctica and dates back to a remote geological period. Its later eruptives are mainly exposed, and the original core may perhaps be indicated by the imposing mass of red granite of Mount Theodore, overlooking the head of Andvord Bay near Belgica Strait. This rock may be related to the red granite described by SHACKLETON in lat. 83° 28′ S., long. 171° 30′ E., near the Beardmore Glacier in South Victoria Land.

The Weddell Sea and Ross Sea have much in common; they are both huge basins. The coal and shales found by SHACKLETON on the western rim of the Ross Sea are of the age of the Gondwana beds; and the presence of Gondwana rocks in the Falkland Islands suggests their possible existence in the basin of the Weddell Sea.

That, in the time of Gondwana Land, Antarctica was united to South America, South Africa, and Australia, is not a visionary idea. Remains of this ancient land still exists in South Georgia, the South Sandwich Islands, Bouvet, Marian, Crozet, Kerguelen, MacDonald, and Macquarie Islands—the long chain of islands that lies along the Southern Ocean concentric with the coast of Antarctica. This land probably connected Antarctica with Gondwana Land in South America, South Africa, and Australia. Great subsidences have sunk most of the original area to great depths below the sea, and long-continued erosion has reduced the rest to a chain of islands.

In conclusion, the generosity of the Carnegie Trustees for the Universities of Scotland, in providing a grant defraying the cost of the illustrations of this paper, must be acknowledged.

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EXPLANATION OF PLATES.

PLATE I.

Fig. 1. Edinburgh Hill, Macfarlane Strait, Livingstone Island, South Shetland group. A plug of columnar olivine-basalt surmounted by agglomerate, indicating the site of a recent volcanic vent (p. 44, text).

Fig. 2. Leith Harbour, Danco Coast, Graham Land; showing exposures of the plutonic massif of Graham Land (p. 48, text).

PLATE II.

Fig. 1. Leith Harbour, Danco Coast, Graham Land. General view, showing exposures of the plutonic massif of Graham Land (p. 48, text), and s.s. *Neko*.

Fig. 2. Skontorp Cove, Danco Coast, Graham Land; showing exposures of the plutonic massif of Graham Land, and s.s. *Hanka*.

PLATE III.

Fig. 1. North arm of Admiralty Bay, King George Island, South Shetlands; showing exposure of later (Tertiary) andesite lavas, traversed by dyke (p. 37, text).

Fig. 2. Deception Island, South Shetlands. Entrance to harbour, seen from within. The entrance is a breach in the crater walls, consisting of tuffs and agglomerates, with a few slaggy lavas. The harbour is a sea-flooded crater (p. 45, text).

Fig. 3. Deception Island. Interior crater wall on north-western side, showing glaciated slopes of tuff, and a small tarn fed by hot springs (p. 45, text).

Fig. 4. Orne Harbour, Danco Coast, Graham Land. North entrance, showing pinnacles of the Graham Land plutonic rocks.

PLATE IV.

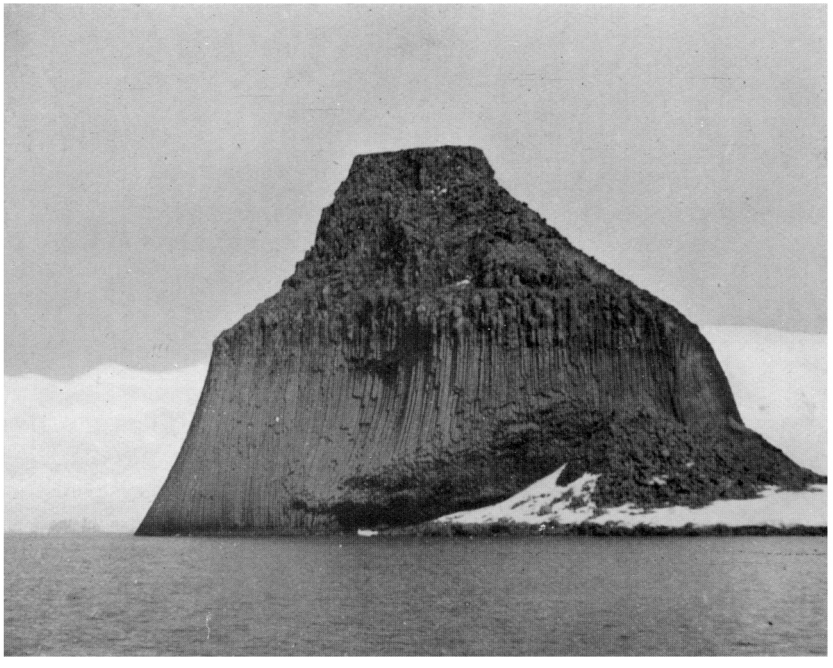
Fig. 1. Mount Theodore, Andvord Bay, Danco Coast, Graham Land. This is probably a great intrusive mass of red granite belonging to the plutonic massif of Graham Land (p. 47, text).

Fig. 2. Coughtrey Island, near Leith Harbour, Danco Coast, Graham Land; showing folded grits and mudstones with intrusive igneous rocks (p. 49, text).

Fig. 3. Mount William, Anvers Island, Palmer Archipelago. Believed to consist of plutonic rocks (p. 49, text).

Fig. 4. Shackleton Harbour, Schollaert Channel, Brabant Island, Palmer Archipelago. Folded and steeply inclined sediments intruded by massive diorite and associated porphyries (p. 50, text).

Mr DAVID FERGUSON: "Geological Observations in the South Shetlands, the Palmer Archipelago, and Graham Land, Antarctica."—PLATE I.



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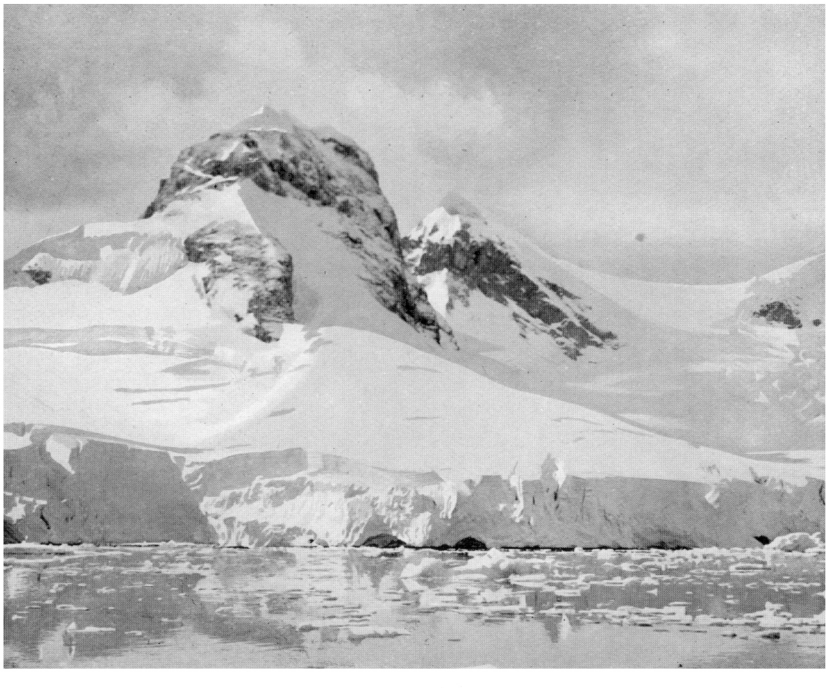


FIG. 2.

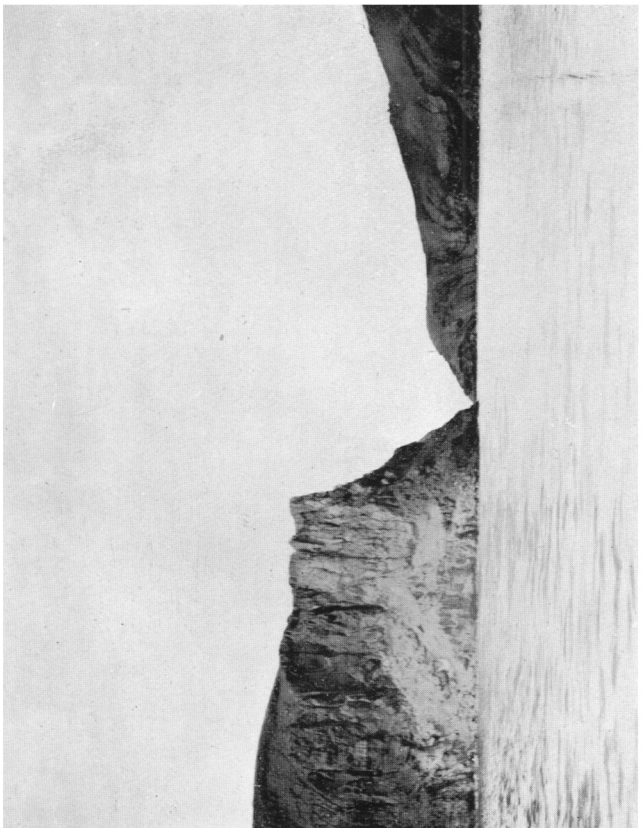
Mr DAVID FERGUSON: "Geological Observations in the South Shetlands, the Palmer Archipelago, and Graham Land, Antarctica."—PLATE II.

FIG. 1.

FIG. 2.

Mr DAVID FERGUSON: "Geological Observations in the South Shetlands, the Palmer Archipelago, and Graham Land, Antarctica."

PLATE III.



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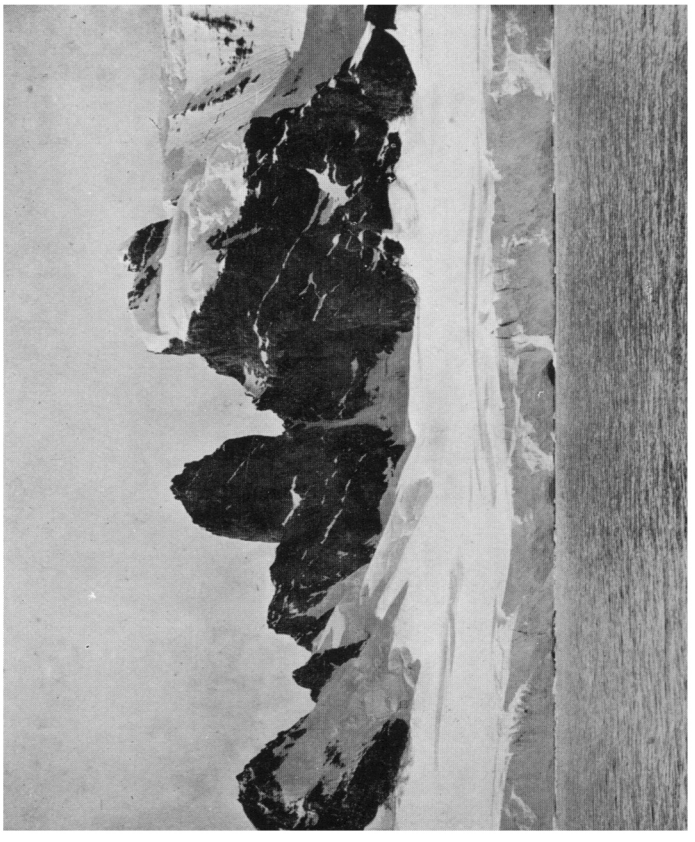

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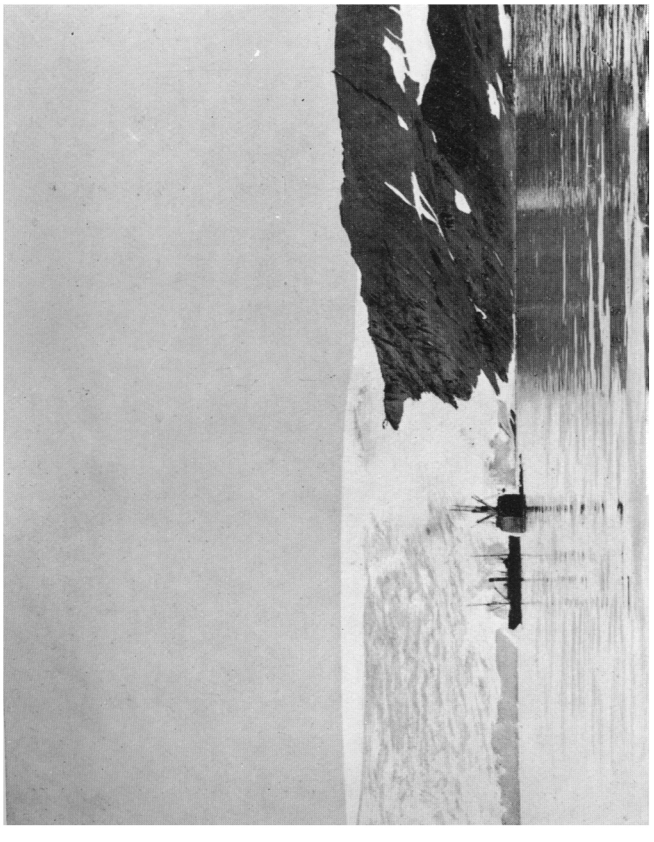

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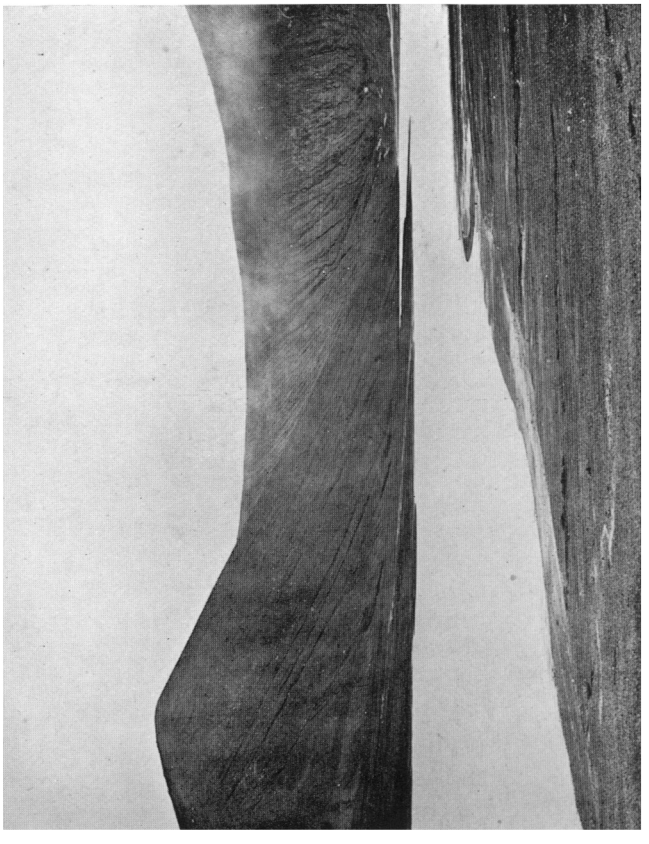
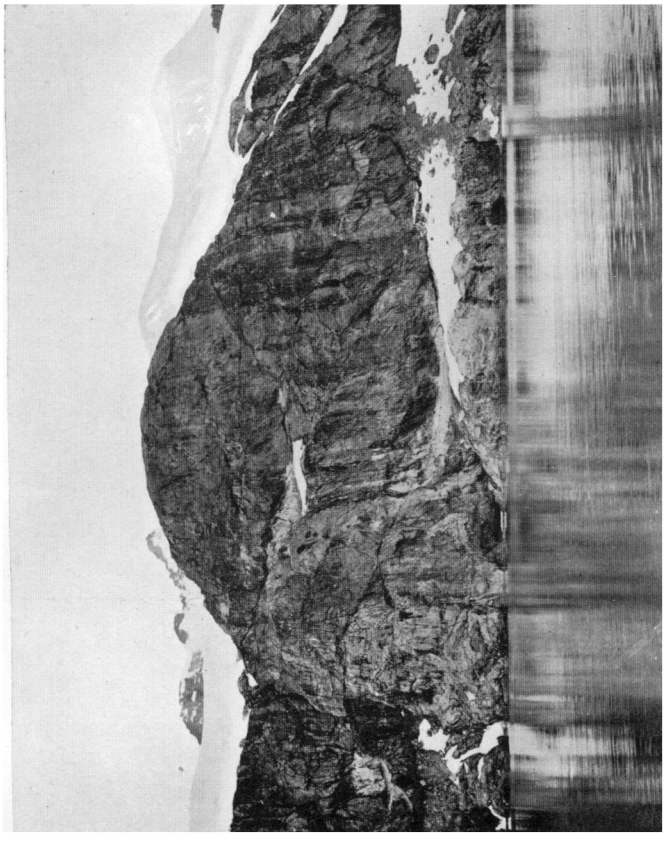


FIG. 3.

MR DAVID FERGUSON: "Geological Observations in the South Shetlands, the Palmer Archipelago, and Graham Land, Antarctica."

PLATE IV.



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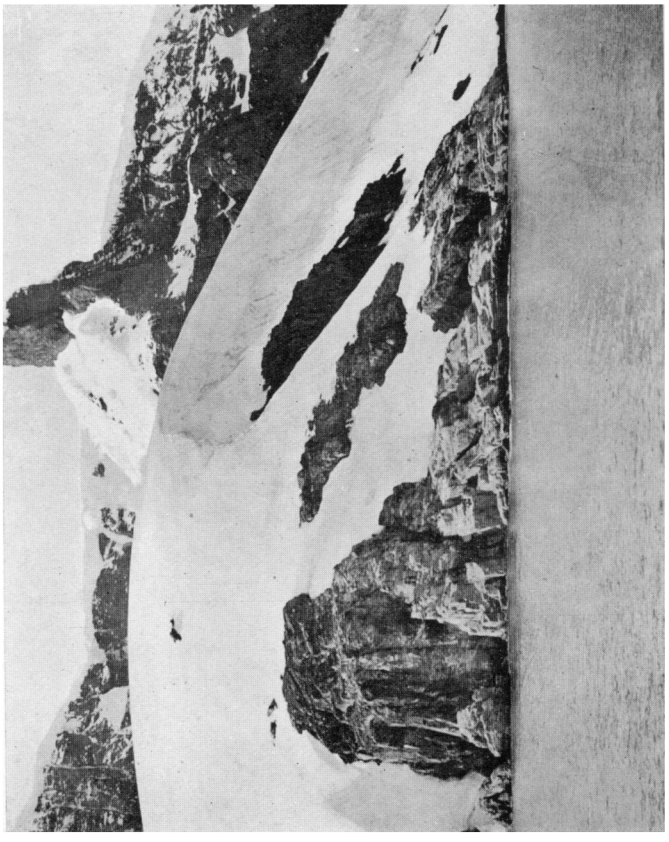

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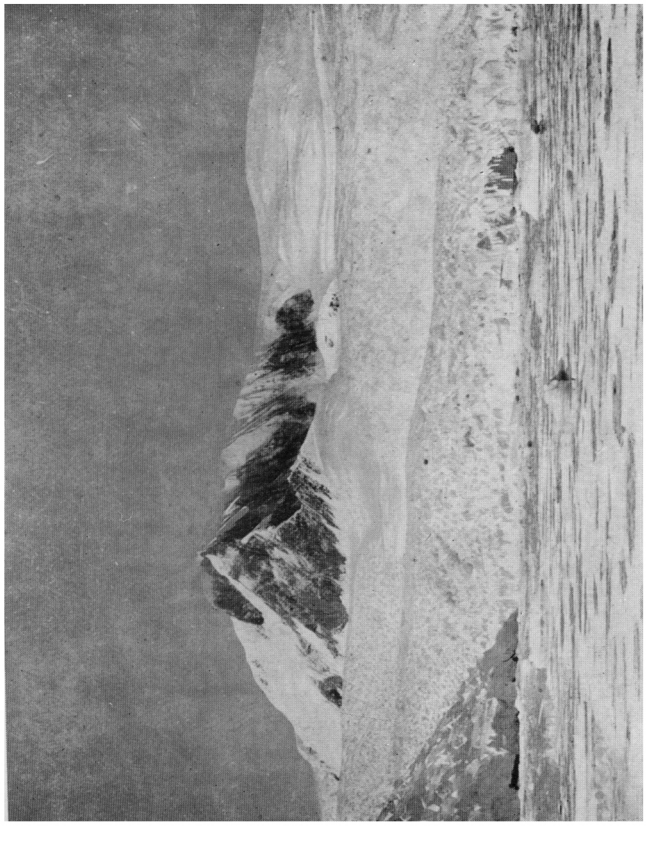

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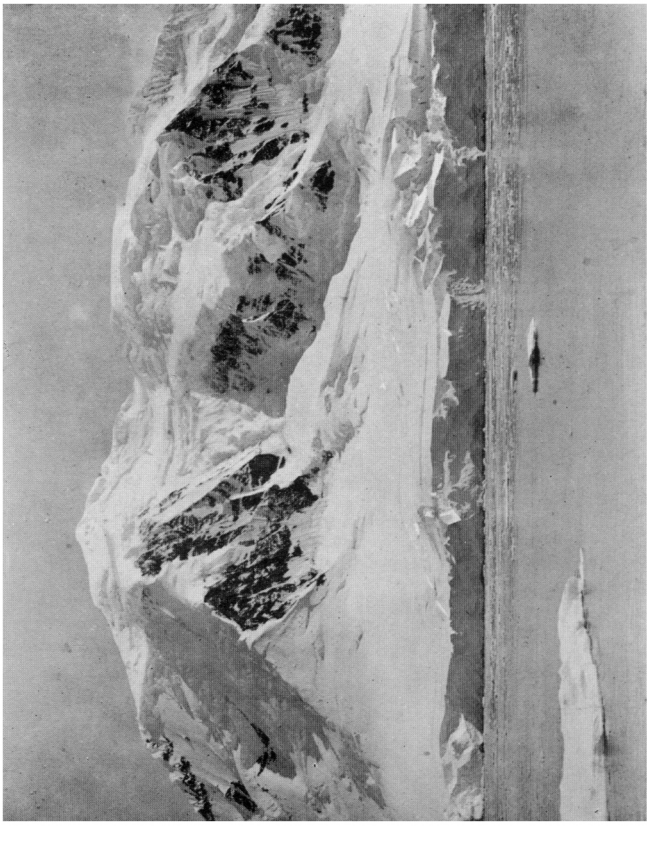

FIG. 3.