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THE GEOLOGY OF THE SOUTH SHETLAND ISLANDS

IV. THE GEOLOGY OF LIVINGSTON ISLAND

By

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and
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ABSTRACT

REPRESENTATIVE rocks, ranging in age from ? Precambrian to mid-Tertiary, are described from the second largest island of the South Shetland Islands. Separated from the Antarctic Peninsula by Bransfield Strait, these islands form part of the Scotia arc, which is a continuous submarine ridge joining South America to western Antarctica; this is an unstable tectonic zone of geological importance.

The False Bay schists, which are the oldest rocks, occur as small isolated exposures, while the Oligocene-Miocene lavas and associated sediments (Younger Volcanic Group) form the greater part of the island. The Miers Bluff Series is a 10,000 ft. (3,050 m.) thick eugeosynclinal sequence of predominantly arkosic greywackes and siltstones which form the limb of a major anticline plunging gently south-westward. The Older Volcanic Group forms much of the mountainous area, post-dates the Miers Bluff Series and has petrological affinities to the Upper Jurassic volcanic rocks of the Antarctic Peninsula. A tonalite apophysis, which is similar to the intrusive stock at Barnard Point, has characteristics of the Andean Intrusive Suite and it intrudes the Miers Bluff Series. The age of the Younger Volcanic Group has not yet been determined but similar volcanic rocks at King George Island with which they are correlated contain a rich fossil flora. On this basis several authors have considered them to have a time range in the Oligocene and Miocene. The conglomerates at Williams Point may well be of Pliocene age.

Several volcanic plugs have been recorded and these are probably centres of eruptions; some of these plugs can be related to lines of tectonic weakness. Three major parallel axial fault lines seem to accord reasonably well with a magnetic profile interpretation. The faulting is certainly later than the Oligocene-Miocene lavas and there is some evidence for post-Pliocene uplift. Numerous raised beaches indicate recent uplift, while glacial recession is a conspicuous phenomenon.

CONTENTS

I. INTRODUCTION

LIVINGSTON ISLAND, the second largest of the South Shetland Islands, is located between lat. 62°27′ and 62°48′S. and long. 59°45′ and 61°15′W. It is centrally placed in the South Shetland Islands; Snow Island lies to the west and Greenwich Island to the east.

Considerable conjecture and controversy has arisen over the discovery of the South Shetland Islands. According to Captain J. Horsburgh (Mill, 1905, p. 92), "American sealers had been at work in the South Shetlands since 1812, and had kept their operations a profound secret". The first clearly chronicled episode in the discovery of this region was the voyage of Captain William Smith in the brig *Williams*. He sighted the South Shetland Islands in February 1819 and confirmed his discovery by landing on King George Island in October 1819. Livingston Island, as distinct from the South Shetland Islands, was specifically referred to when sealers discovered the anchor stock and spars of the *San Telmo*, a Spanish vessel, on Half Moon Beach in about 1821. The name "Livingston's island" was published on Powell's chart of 1822, and has been retained on all published maps since that date, although American sealers during the season 1820–21 frequently referred to the island as "Freesland", "Frezeland" or "Frezeland island".

The first geological investigator to visit Livingston Island was J. G. Andersson in 1902. He collected a greenish porphyrite and dark-coloured eruptives from the easternmost point of Livingston Island, but unfortunately all these specimens were lost when the *Antarctic* sank in the Weddell Sea in February 1903.

During the whaling season of 1913–14 D. Ferguson, acting on behalf of Messrs. Chr. Salvesen and Co., contributed a great deal to the geological knowledge of the South Shetland Islands. Discussing the physiography of Livingston Island, Ferguson (1921, p. 43) stated that "the island for at least 12 miles [19·2 km.] along the Bransfield Strait is formed of volcanic rocks belonging mainly to the later series". He also described the olivine-basalt plug of Edinburgh Hill and the volcanic vent of Inott Point. Blue-black mudstone and diorite ejecta were recorded from the vent agglomerates of Inott Point and he inferred the presence of these rocks elsewhere on the island. In 1921 G. W. Tyrrell published a detailed petrological account of Ferguson's specimens.

In 1927 O. Holtedahl saw the South Shetland Islands at a distance but he did not land. Describing the topography as being typically glacial with features similar to the district of "Seven Glaciers" in Spitsbergen, Holtedahl (1929, p. 94) stated:

> "The marked ridges separated by very wide trough valleys are features which only glacial erosion can produce. Parts of this coast reminds one of the district of the 'Seven Glaciers' in Spitsbergen, occurring on the west coast between Magdalena Bay and Cross Bay, only the ice-streams are relatively much broader and more dominating in Livingstone [*sic*] Island. There can be no doubt that the sounds separating the South Shetland islands are formed in a similar way, by glacial transverse erosion and we must therefore assume that these depressions have once been ice filled."

Commenting on the relief of the island, Holtedahl (1929, p. 97) mentioned:

> "A quite peculiar feature concerning the relief of Livingstone [*sic*] Island is the extremely low and flat character of the land in the most western part, a relief most strikingly contrasted to the wild, mountainous topography of the district at the South and False Bay further east."

The writer was a member of a Falkland Islands Dependencies Survey party which spent the summer of 1957–58 (from 19 December 1957 to 15 March 1958) on Livingston Island. Much detailed geological work was carried out by means of day excursions from camps at Hannah Point, Barnard Point and Johnsons Dock. Also, between 2 and 15 January 1958 a manhauling journey to the western part of the island was made from the base camp at Hannah Point during which the Start Point peninsula on the west coast and Cape Shirreff were visited. In addition, the rate of movement of Charity Glacier was calculated between 28 January and 9 February 1958. The heights of the raised beaches at Barnard Point were also measured. A further week was spent on Livingston Island from 3 to 9 January 1959. This enabled the writer to examine the intrusive plug at Edinburgh Hill and visit the Williams Point area.

The routes followed in the course of geological work on Livingston Island are shown in Fig. 1.

The petrographic descriptions in this report are based on a laboratory examination of 104 specimens collected during the field work. A specimen from the olivine-basalt plug of Mount Plymouth, Greenwich Island, is also described. All the specimens and the thin sections are housed in the Department of Geology, University of Birmingham. The station and serial numbers given in this report refer to this collection, unless otherwise stated.

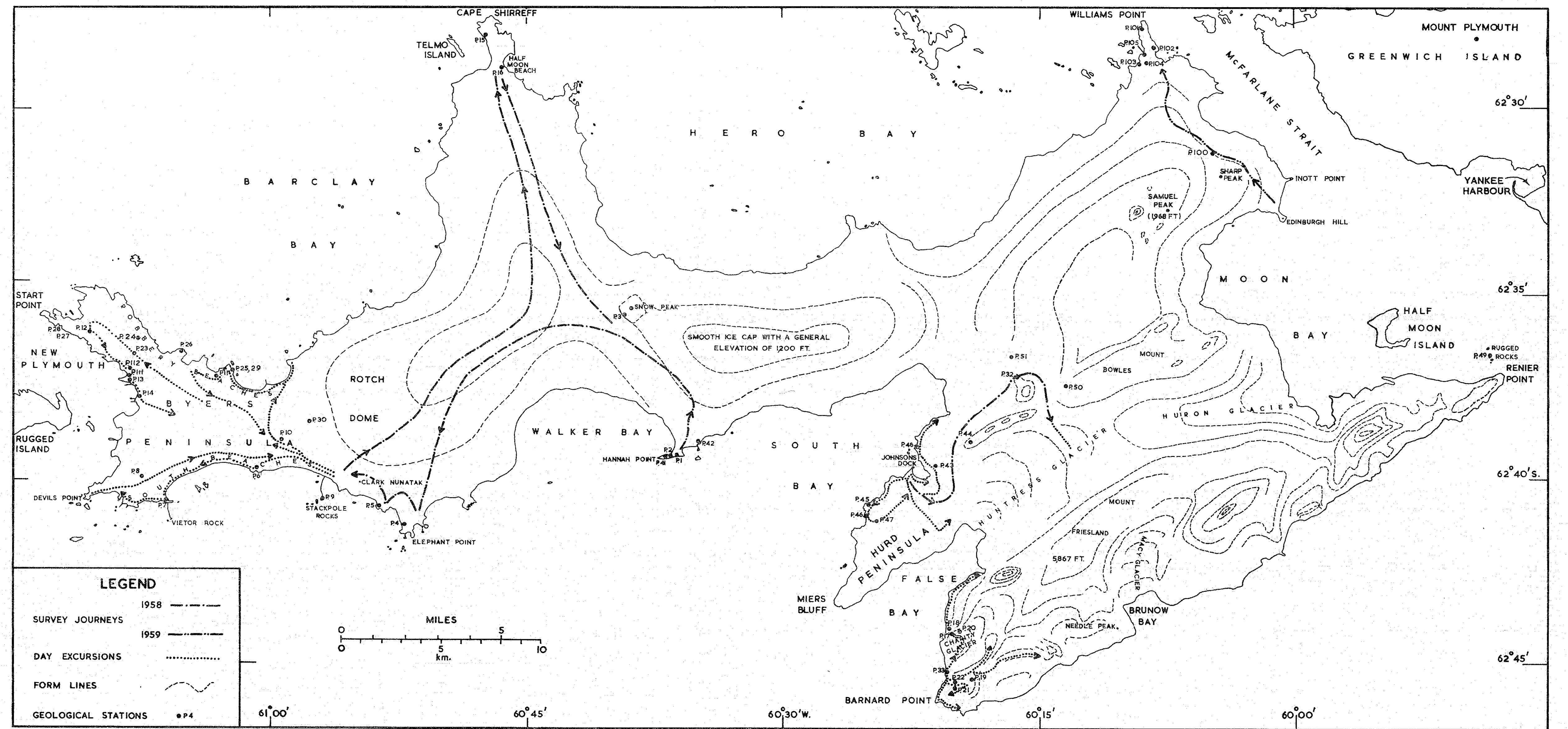

FIGURE 1

Map showing the physiography, geological station numbers and the survey routes on Livingston Island, South Shetland Islands.

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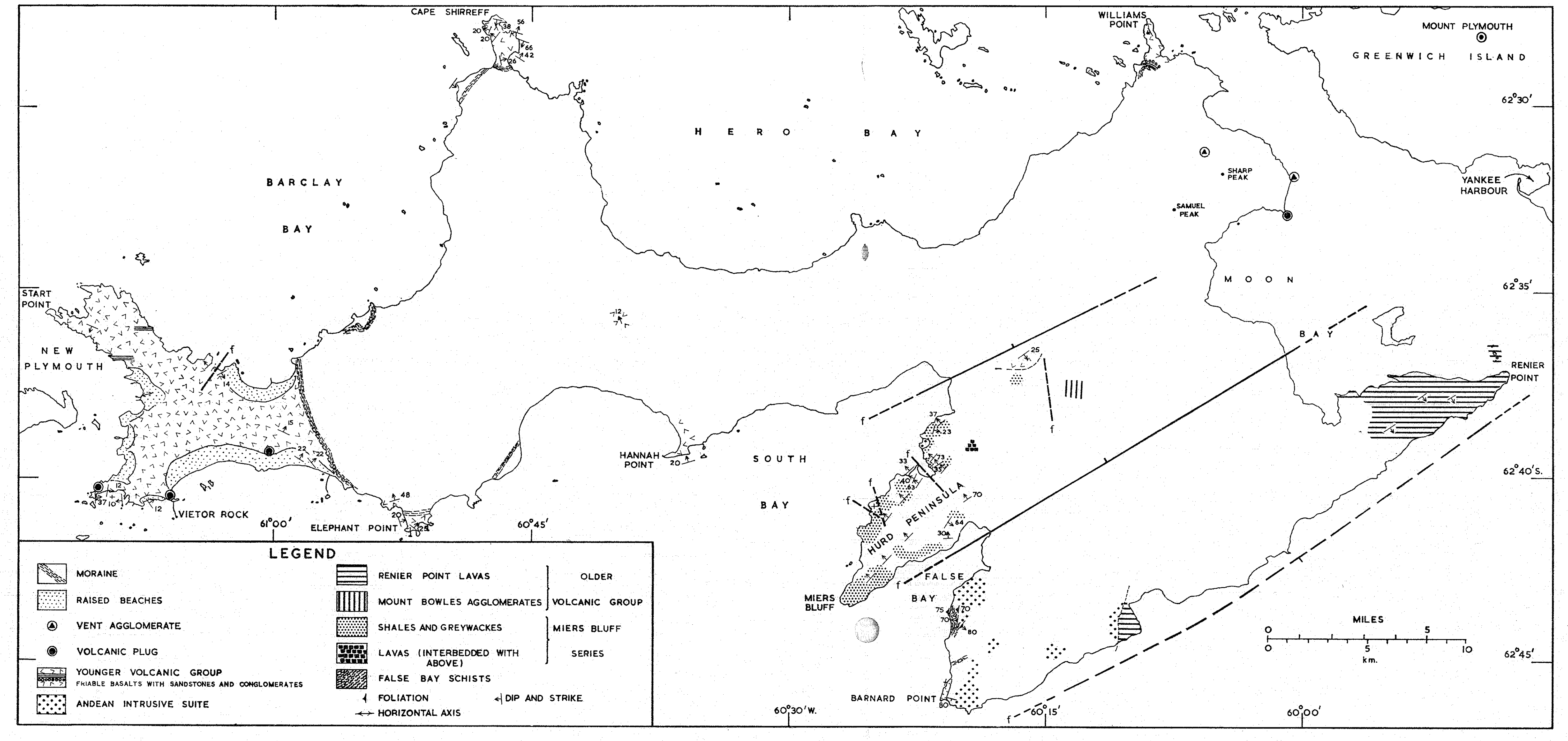

FIGURE 2

Geological map of Livingston Island, South Shetland Islands.

II. PHYSIOGRAPHY

THE physiography of Livingston Island has been described briefly by Holtedahl (1929, p. 94–97) and the relationship of the geology to the relief has also been commented on by Ferguson (1921, p. 43–44). Irregularly elongated in an east to west direction, Livingston Island is 47 miles (76 km.) in length (Fig. 1). On its eastern side, the island has a maximum width of 19 miles (31 km.), the central area averages 5 miles (8 km.) in width, and in the west it narrows to 2 miles (3·2 km.). The island consists approximately of 31 sq. miles (80 km.^{2}) of exposed rock and 294 sq. miles (765 km.^{2}) of snow- and ice-covered terrain.

Topographically, the island can be subdivided into three distinct areas, two of which are determined by the underlying geological structure (Fig. 2).

1. *Byers Peninsula*

Byers Peninsula, which is approximately 20 sq. miles (50 km.^{2}) in area, forms the western promontory of the island and is the largest area of exposed rock. This peninsula has a predominant west to east trend and an average altitude of 200 ft. (60 m.) above sea-level; it reaches its highest elevation of approximately 878 ft. (268 m.) on the Start Point peninsula. The remarkable low-lying but uniform elevation of the peninsula and its high proportion of exposed rock distinguish it from the other two areas. This peninsula consists mainly of Tertiary volcanic rocks, basaltic agglomerates and augite-andesites, with which are associated plugs and interbedded sediments.

Although snow and ice adhere to the highest points throughout the year and snow occupies gullies and erosional channels during the summer, this western rock peninsula is devoid of a true ice cap.

An explanation accounting for the absence of an ice cap on Fildes Peninsula, King George Island, has been advanced by M. J. Stansbury (personal communication). Fildes Peninsula, which is also the largest area of exposed rock on that island, is similar to Byers Peninsula in general elevation and occurs on the western side of the island. Stansbury attributes this phenomenon to the lack of snowfall associated with north-westerly winds, and this explanation might also apply to Byers Peninsula.

2. *The ice cap*

The greater part of Livingston Island is covered by an irregular west to east trending ice cap which extends from Byers Peninsula in the west to McFarlane Strait in the east. The ice cap averages 5 miles (8 km.) in width and is 29 miles (47 km.) in length. The western end, known as Rotch Dome, is smooth and gentle, and has an average elevation of 820 ft. (250 m.). The central area has similar topography, but in addition it has a prominent ice-capped rock bluff, Snow Peak, rising to 1,403 ft. (428 m.). Completing the ice cap is the eastern area which also has an average elevation of 984 ft. (300 m.) but it is broken up by numerous nunataks and is therefore more heavily crevassed. The highest nunatak is Samuel Peak, 1,968 ft. (600 m.) in height.

The ice cover appears to be comparatively thin and conforms to the sub-surface topography. The outward movement of ice gives rise to crevassed ice piedmonts, which terminate at the coast in cliffs 70 ft. (21 m.) high. These ice walls front all the larger bays and generally extend a short distance into the sea.

3. *The south-east mountainous area*

This is by far the most inaccessible and complex area of the island. It can be further subdivided into three parts.

a. *The Mount Bowles ridge* reaches an elevation of 2,624 ft. (800 m.) and consists of indurated andesitic agglomerates and lavas. The ridge trends in an east-north-east to west-south-west direction and continues towards the south-west, terminating in a peninsula of lower elevation (656 ft.; 200 m.). This peninsula is composed of greywacke-shale sediments, called the Miers Bluff Series, which strike in a south-west to north-east direction.

b. *The ice-filled trench.* The central part of the trench separating the two mountain ridges reaches an elevation of 1,804 ft. (550 m.), and forms a divide between the two major valley glaciers. Huntress Glacier flows to the south-west into the head of False Bay, while Huron Glacier flows eastwards into Moon Bay. Both glaciers are approximately the same length, 5 miles (8 km.), and have an average width of 2 miles (3·2 km.). In the south-west this trench follows a fault line which is the contact between the Miers Bluff

Series and the tonalite of the Andean Intrusive Suite and the False Bay schists. Towards the north-east a continuation of the same fault separates the Renier Point lavas from the Mount Bowles agglomerates of the Older Volcanic Group.

c. *The Mount Friesland ridge* trends in a west-south-west to east-north-east direction from Barnard Point in the south-west to Renier Point in the north-east, a distance of 21 miles (34 km.). This ridge averages between 2,000 ft. (610 m.) and 3,000 ft. (915 m.) in height but it rises to 5,248 ft. (1,600 m.) at Mount Friesland which is situated midway along the ridge. The Barnard Point area consists of tonalite with marginal hornblende-schist, while the Renier Point peninsula is formed of trachyte and basalt lavas.

Apart from Brunow Bay, the south-eastern side of the Mount Friesland ridge is remarkably straight and well defined for a coastline in a glaciated area. This feature probably represents a major fault line with the upthrown South Shetland Islands on its north-west side.

III. MARINE FEATURES

1. *Raised beaches*

Series of raised beaches occur on all the rock headlands of Livingston Island. Because of the differences in exposure, it is difficult to correlate raised beaches on the northern coast of the island with those on the southern coast and with those in sheltered bays. Usually three and sometimes four prominent raised beaches occur on the larger peninsulas, but on the smaller promontories, from which the ice has retreated more recently, only one or two raised beaches may be present. In general, the raised beaches are best developed on the south side of Byers Peninsula.

a. *Byers Peninsula.* The beaches on the south side of the peninsula extend without major interruption in a wide sweep from Clark Nunatak in the east to north of Vietor Rock in the west, a distance of 6 miles (9·7 km.), and they have a maximum width of 0·75 miles (1·2 km.). This stretch of raised beaches also presents difficulties of correlation, for even here a pronounced raised beach bifurcates without any apparent reason into two smaller beaches and then peters out against a small rocky outcrop (Plate Ia). The heights of the raised beaches have been estimated at 8–10, 20, 25 and 40 ft. (2·4–3·0, 6·1, 7·6 and 12·2 m.) above sea-level.

Most of the material forming the beaches has been derived from the Younger Volcanic Group, but occasional tonalite cobbles are present. These were probably derived from the Barnard Point area and reached their present position by longshore drift from the east. The beaches usually consist of a ridge of cobbles marking the former storm beach, and behind this is a smooth shingle, sand or ash slope which becomes progressively finer inland on the older beaches.

The beaches on the north side of Byers Peninsula occur at heights of 8–10, 20, 25 and 35–40 ft. (2·4–3·0, 6·1, 7·6 and 10·6–12·2 m.).

b. *Elephant Point.* Three raised beaches occur at Elephant Point (Plate Ib). These are particularly prominent, because they consist of well-defined ridges of cobbles (3–6 in.; 7·6–15·2 cm. diameter) which impede glacial run-off and result in the formation of melt-water pools.

c. *Barnard Point.* At Barnard Point (Plate Ic) there are four important raised beaches. Levelling of these beaches by theodolite and staff gave the profiles which are shown diagrammatically in Fig. 3. These profiles were measured above high-water mark on 12 and 18 February 1958, and later reduced to mean sea-level.

d. *Discussion.* Well-rounded water-worn pebbles, which are present in the numerous moraines fringing the ice cap of Livingston Island at an average height of 175 ft. (53 m.), suggest greater uplift than indicated by the raised beaches themselves. However, later field work established the occurrence of pebble conglomerates and tuffaceous conglomerates elsewhere on the island. At Williams Point, one rounded pebble was found at a height of 350 ft. (107 m.) in a lateral moraine extending from a buttress of tuffaceous conglomerate. Therefore, the presence of rounded pebbles in the moraines cannot be assumed to indicate recent uplift unless it is supported by the additional evidence of marine features at the same elevation.

Hattersley-Smith (1949, p. 33) recorded raised beaches at 10 and 15–20 ft. (0·9 and 4·5–6·1 m.) above sea-level at King George Island, and he correlated the lower beach with a series of caves at the same elevation on the eastern and north-eastern sides of Penguin Island. This beach apparently corresponds to the present storm beach at Livingston Island.

In eastern Antarctica, Nichols (1961, p. 401) has described an extensive raised beach at a height of 44–55 ft. (13·4–16·7 m.) on the west coast of McMurdo Sound between Granite Harbour and New Harbour. The highest beach he observed was 67 ft. (20·4 m.) above sea-level at Dunlop Island. A radiocarbon dating of a sample from an elephant seal buried in the 44 ft. (13·4 m.) beach at Marble Point gave an age of 4,600±200 yr. "The highest and oldest beaches are therefore some 6,000 years old." (Nichols, 1961, p. 401.) Although no fossil shells were found in the raised beaches of Livingston Island, a fossil whale was found in the 25 ft. (7·6 m.) raised beach approximately 500 yd. (460 m.) east of Clark Nunatak. This was the greatest height at which remains of a fossil mammal were found at Livingston Island.

The heights above sea-level of most of the raised beaches at Livingston Island were measured by aneroid barometer. Each measurement given was checked against high-water mark, with a limit of error of ±2 ft. (0·6 m.). In Table I they are tabulated and compared with the heights of the raised beaches at Barnard Point, which were measured by theodolite and staff.

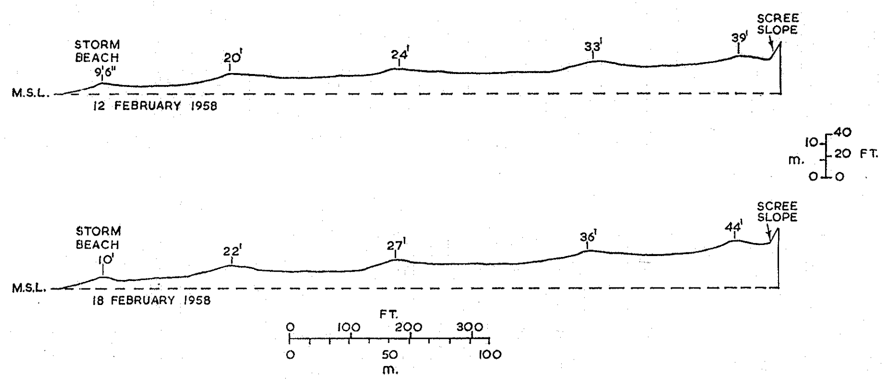

FIGURE 3

Profiles showing the heights above mean sea-level of the storm beach and the four raised beaches at Barnard Point, Livingston Island. The measurements were made to the top of the cusp of each beach deposit.

2. *Raised marine platforms*

The rock peninsulas of Byers Peninsula and Cape Shirreff, formed of the Younger Volcanic Group, are characterized by a marked horizontal surface at an elevation of approximately 150–175 ft. (46·2–53·3 m.) above sea-level. Platforms at lower elevations also occur at Elephant Point (125 ft.; 38·1 m.) and at Williams Point (75 ft.; 22·8 m., above sea-level). These platforms are not considered to be structural in origin, and subaerial or glacial erosion is unlikely to have produced such uniform features. The absence of morainic deposits on the platforms strongly suggests a marine mode of occurrence. The platforms are noticeably absent from peninsulas formed of older rocks. On the east side of False Bay, a 12 ft. (3·6 m.) high marine platform occurs south of Charity Glacier (Plate Id), and to the north another platform is at a height of 10 ft. (3·0 m.) above sea-level. Both of these platforms have been cut in tonalite. The wave-cut features described below at the various headlands are all rock platforms.

a. *Byers Peninsula.* The platform 150–175 ft. (46·2–53·3 m.) above sea-level attains its maximum development in Byers Peninsula, where it is 7 miles (11·3 km.) long and just over 1 mile (1·6 km.) wide. Apart from several rock buttresses standing up above the general elevation (one at least is a volcanic plug (Plate Ia)), the platform is characterized by a relatively smooth horizontal surface over the greater part of the peninsula. Due to frost-shattering of the rock and the resultant talus cover, the bedrock and their structures are usually obscured but the few well-exposed volcanic sequences tend to discount a structural origin.

On all sides this platform is abruptly terminated either by steep seaward-facing talus slopes or by precipitous cliffs approximately 100 ft. (30·5 m.) in height. Between the talus slopes of the platform and the present-day shoreline there is the Recent series of raised beaches.

Table I

ELEVATION OF RAISED MARINE FEATURES AT LIVINGSTON ISLAND, SOUTH SHETLAND ISLANDS

Locality	*Raised beaches* (ft.)					*Caves* (ft.)				*Platforms* (ft.)	*Remarks*
Barnard Point	(1) 12 9·5–11·5	(2) 17 13·5–15·5	(3) 26 22·5–24·5	(4) 34 28·5–30·5						12	Four well-developed raised pebble beaches (see Fig. 3)
False Bay (north of Charity Glacier)	10	—	—	—	—					10	Series of raised beaches in parallel, with well-developed platform
South Bay (south-east side)	—	—	25	30	40	10					Glacial recession since the formation of the 25 ft. (7·6 m.) raised beach
Hannah Point (east side)	—	ca. 20	—	—	—						
Elephant Point	8–10	—	25	—	40	—	25	80	ca. 100		Three well-defined beaches
South Beaches	8–10	ca. 20	25	—	35–40					150–175	Four extensive raised pebble beaches with a fossil whale in the 25 ft. (7·6 m.) raised beach
Robbery Beaches (eastern side)	8–10	ca. 20	25	—	35–40	8	—	—	—	80, 150–175	Four extensive raised pebble beaches with clearly defined platforms
Cape Shirreff	8–10	—	—	—	—					25–30, 40–50, 150–175	The two lower well-defined platforms are covered with well-rounded pebbles and boulders
Williams Point	8–10	—	25	—	—					75	

Measurements of the raised pebble beaches at Barnard Point have been corrected to mean sea-level and then recalculated to former sea-level stances from the profiles in Fig. 3.

b. *Cape Shirreff.* A platform with the same elevation as the one at Byers Peninsula cuts across the inclined lava flows forming Cape Shirreff. Two lower well-defined platforms at the same locality occur at elevations of 25–30 and 40–50 ft. (7·6–9·1 and 12·2–15·2 m.) above sea-level; they are strewn with rounded water-worn cobbles.

c. *Williams Point.* The platform at Williams Point is 75 ft. (22·5 m.) above sea-level, 1 mile (1·6 km.) in length and 500 yd. (457 m.) in width. The height of this platform has been largely determined by a lava flow, which forms conspicuous precipitous cliffs on the western side of the promontory. However, in the south-western part of the promontory the bench cuts across south-westerly dipping conglomerates and grits.

Diorite and mica-schist cobbles on the platform were at first considered to establish and confirm its marine origin. Large boulders of the same composition also occur in the moraine at the edge of the ice cap. Consequently, the cobbles on the bench are more probably outwash deposits derived from the moraine rather than former beach deposits.

A marine platform, of similar extent to the one at Byers Peninsula, but at an elevation of 80–100 ft. (24·4–30·5 m.) above sea-level has been described by Hattersley-Smith (1949, p. 31) from the west side of Fildes Peninsula, King George Island. He considered this platform to be marine in origin and to be of pre-glacial age, but no evidence for such an age has been recorded on Livingston Island.

3. *Caves*

The largest and most recent marine-eroded cave occurs at Robbery Beaches on the north side of the rock peninsula immediately west of Rotch Dome. The cave entrance is 22 ft. (6·7 m.) high, 28 ft. (8·5 m.) wide and it is approximately 45 ft. (13·7 m.) in depth, over which distance there is little or no narrowing of the cave. This cave is only 8 ft. (2·4 m.) above sea-level but it is apparently no longer subjected to periodic flooding by exceptionally high tides or stormy seas. Both angular debris and scree, which have accumulated at the cave entrance, show no sign of either having been removed or affected by wave action. Signs of occupation of the cave by fur sealers during summer months of the period 1820–25 suggest that it was also free from flooding at that time. This cave has been eroded into lavas of the Younger Volcanic Group along two major horizontal joints.

There is another cave at about the same elevation, 10 ft. (3·0 m.) above sea-level, midway along the north-west side of Hurd Peninsula. This cave is 8 ft. (2·4 m.) high, 7 ft. (2·1 m.) wide and 30 ft. (9·1 m.) deep. It has been cut in the sedimentary Miers Bluff Series.

On the eastern side of the Elephant Point promontories there is a former sea cave at a height of 25 ft. (7·6 m.) (Plate IIa). Frost action, although evident in the vicinity of the cave, has had no effect on the volcanic rock in which this cave has been eroded. Consequently, the marine origin of the cave is clearly revealed by its water-worn smoothed sides and by the cylindrically shaped vertical potholes gouged in the solid rock floor at the cave entrance.

On the same promontory, but on its western side, a smoothed wall crevice occurs along a joint plane in a rock buttress at an elevation of 100 ft. (30·5 m.). Drift snow, ice and 1 year's accumulation of snow on the floor of the crevice unfortunately prevented a search being made for any possible pebbles. Precise evidence concerning the origin of this cave is therefore lacking but the smoothed walls strongly suggest water erosion.

Smaller inaccessible caves in a former sea stack at Elephant Point occur about 80 ft. (24·4 m.) above sea-level. Together with the crevice mentioned above, they might possibly have resulted from subaerial weathering.

The heights of the caves above sea-level are tabulated in Table I where they are compared with the raised marine platforms and raised beaches of the larger headlands and peninsulas.

4. *Strands*

Stackpole Rocks, situated 0·7 miles (1·1 km.) offshore at the eastern limit of South Beaches, are connected to the island by a tombolo at right-angles to the general trend of the coastline. This is exposed only at low tide, is remarkably straight for its entire length and it has a constant width of 20 yd. (18·3 m.). Although it is composed almost entirely of well-rounded porphyritic volcanic rocks of local origin and averaging up to 1 ft. (0·3 m.) in diameter, a few hypabyssal rocks also comprise part of the strand. One or two larger boulders, up to 3 ft. (0·9 m.) in diameter and of hypabyssal composition, either resting on or standing up above the general surface, are comparatively recent additions to the tombolo.

Vietor Rock is also connected to Livingston Island by a tombolo just under 0·5 miles (0·8 km.) in length at South Beaches (station P.7). There are numerous smaller tombolos at right-angles to the general trend of the bays on the coast fronting New Plymouth.

IV. GLACIAL FEATURES

1. *Glaciers*

The glaciers of Livingston Island can be subdivided into four types: valley, mountain-valley, cirque glaciers and ice piedmonts.

a. *Valley glaciers*. A slight elevation midway along the trench separating the Mount Bowles ridge from the Mount Friesland ridge effectively divides the trench into two valley glaciers. These glaciers are approximately equal in length, 5 miles (8 km.), and they have a gentle gradient. Huntress Glacier flows south-westward into False Bay, whereas Huron Glacier flows north-eastward into Moon Bay.

b. *Mountain-valley glaciers*. These glaciers vary from 1 to 4 miles (1·6 to 4·8 km.) in length and they are characterized by heavily crevassed areas and steep profiles which are frequently interrupted by ice falls. They have well-defined valley sides and their source is in the Mount Friesland ridge. The Mount Bowles ridge is of insufficient elevation and extent to form mountain-valley glaciers. Fed by snow precipitation and by avalanches from the mountain peaks, these glaciers coalesce on the south-east side of the Mount Friesland ridge to form an ice piedmont, which terminates in a coastline of ice cliffs 80–100 ft. (24·4–30·5 m.) high trending parallel to the main mountain chain.

c. *Cirque glaciers*. Two cirque glaciers with a north-westerly aspect occur on the Barnard Point peninsula. Both of them are about 400 yd. (365 m.) in length and they have convex surface profiles. Movement in the northern glacier is still quite active, as indicated by convolute structures in the dirt bands at the snout of the glacier (Plate IIb). The southern glacier has a smooth ice slope, in which many recessional moraines are arranged concentrically with the pronounced crescent-shaped terminal moraine. The rate of ice movement in this glacier is evidently quite slow and it is gradually diminishing into an ice slab.

d. *Ice piedmonts*. The ice piedmonts have resulted either from the outward movement of the ice cap which covers the larger part of Livingston Island or by the coalescence of mountain-valley glaciers. Observations on the fronts of the ice piedmonts reveal the presence of two or frequently three dirt bands, which appear to have originated from the upward movement of rock flour and subglacial material along glide planes from the bedrock floor.

Few observations were made on the ice piedmont fronting Hero and Barclay Bays, but the many rocks, rocky islets and grounded icebergs are indicative of relatively shallow water extending a considerable distance from the north coast. Therefore, it is probable that little or no part of this ice piedmont is in fact floating. Of the ice piedmonts fringing Livingston Island, the one in the south-eastern area probably extends farthest into deep water. Here again, the indentation of Brunow Bay on an otherwise continuous straight ice-cliff coastline, 21 miles (34 km.) in length, suggests that most if not all of this ice piedmont rests directly on bedrock.

It is therefore suggested that continued recession of the ice piedmonts is unlikely to produce any marked change in the coastline of Livingston Island, and any changes will occur mainly at the snouts of Hero and Huntress Glaciers.

2. *Glacial deposits*

a. *Lateral moraines*. On the south side of Charity Glacier several successive morainic deposits are parallel to each other. These deposits together form the larger lateral moraine which is clearly visible on air photographs. The oldest of these deposits, which occurs next to the valley side, is to a limited extent covered by grass and lichen but as the more recent deposits are approached (nearer to the glacier), vegetation colonization decreases. There is no vegetation on the most recent morainic deposit. This latest moraine rests on glacier ice, which has been protected from ablation by the detritus itself, thus causing the moraine to have an elevation of 15–20 ft. (4·5–6·1 m.) above the general surface of the glacier.

b. *Medial moraines*. The development of a medial moraine from a lateral one occurs on Huntress

Glacier which flows into False Bay (Plate IIc). Here, loose stones and boulders, resulting from frost and ice action on a truncated rock spur forming the south-eastern side of the valley, form a lateral moraine at the foot of the buttress. At the confluence between Huntress Glacier and a mountain-valley glacier from the Mount Friesland ridge the lateral moraine is deflected from the valley side and thus forms a medial moraine.

c. *Terminal moraines*. There are several examples of terminal moraines on Livingston Island. The best example is the crescent-shaped moraine, 15–20 ft. (4·5–6·1 m.) above the snout of an exhausted cirque glacier just north of Barnard Point (Plate IId). On Hurd Peninsula several retreating outlets from the ice cap have also left terminal moraines. The largest on the island is the terminal moraine fringing the western margin of the ice cap at Rotch Dome. It can be traced from Clark Nunatak on the south side of the island to the eastern limit of Byers Peninsula on the north, a distance of 5 miles (8 km.).

d. *Glacial erratics*. Micaceous schist and tonalite glacial erratics are particularly abundant at Williams Point. The nearest known rocks of comparable mineralogy occur *in situ* on the east coast of False Bay. Apart from a small outcrop of tonalite near Johnsons Dock, the exposures north of Huntress and Huron Glaciers consist either of sedimentary or basic volcanic rocks.

The most probable explanation of the presence of these erratics is that they were part of the ejecta from the various volcanic outlets in this part of the island which were probably active before, during and after the last major glaciation.

e. *Block terraces*. Only one block terrace was observed on Livingston Island; this occurs just south of Charity Glacier and north of Barnard Point (Plate IIIa). At the break of slope between the terrace surface and the terminal seaward slope, the block terrace is 75 ft. (22·8 m.) high but, where the terrace slope merges into the talus slope at the foot of the cliff exposures it is 100 ft. (30·5 m.) above sea-level. The block terrace is about 100 yd. (91·4 m.) long, 40 yd. (36·6 m.) wide and has an angle of slope seaward between 7° and 20°, while the terminal slope has an angle of repose of 39°.

Similar block terraces have been described from the Marguerite Bay area by Nichols (1953) and Hoskins (1963). Nichols has explained the formation of these block terraces by the accumulation of boulders and talus on former fringing glaciers. By tracing a gradation from moraine-free fringing glaciers through moraine-veneered fringing glaciers to block terraces, he has deduced that the remarkable shape of the block terrace is governed by a residual core of ice. This cements the individual boulders and blocks together, thus preserving the profile of the former glacier. Without this ice core, the block terrace is assumed by Nichols to degenerate into a block field or ground moraine, unless, as he has pointed out, the morainic material is of sufficient thickness and the underlying and surrounding terrain is favourable to the formation of a block terrace. This appears to be the case at False Bay. Livingston Island is 500 miles (805 km.) north of Marguerite Bay and consequently deglaciation has proceeded further. It therefore seems doubtful that the False Bay block terrace has retained its shape because of a residual core of ice.

Hoskins (1963, p. 45) has also studied the block terraces in the Marguerite Bay area. From his observations on south-west Millerand Island he has concluded that no valley or fringing glacier was ever present in the area. His studies on Mount Nemesis and its relationship to Northeast Glacier also suggest that no fringing glacier existed on the north-west face of Roman Four Promontory. He therefore concluded that the block terraces in Marguerite Bay resulted from snow avalanches bringing down with them rock fragments from above.

However, the presence of small, well-rounded, marine-smoothed pebbles up to 1 in. (2·5 cm.) in diameter in the giant petrels' nests and the occurrence of larger rounded pebbles (Plate IIIb) in the block terrace at False Bay casts some doubt on both of these suggested origins.

It is possible to account for the presence of the smaller rounded pebbles in the giant petrels' nests by the fact that penguins could have occupied the block terrace as a rookery at one time. However, the larger 3 in. (7·6 cm.) pebbles are too heavy to have been carried by penguins (one weighs as much as 294 g.) and as yet there is no record of giant petrels carrying nesting material in flight (personal communication from W. L. S. Tickell).

Wentworth (1936) has shown that the rounded edges of cobbles and the absence of glacial striae is no indication that the cobbles are of other than glacial origin. One of the cobbles found has a parallel tabular shape with trapezoidal margins and is a tonalite (P.30.1; see bottom left of Plate IIIb). Another has a pentagonal or "flat-iron shape" and is a hypabyssal rock. It was probably derived from one of the many sheets and dykes which intrude the local tonalite. The stoss end of the latter cobble has a pronounced glacial notch or cut, while the snub end has the broken edge of a typical "flat-iron-shaped" cobble (P.30.2; immediately above field notebook in Plate IIIb).

Thus, while the smooth faces and rounded edges of these larger pebbles tend to indicate the possibility of a marine origin for the block terrace, their general shape corresponds to typical glacial forms and lends support to Nichols's suggested mode of formation.

The rounded edges of these pebbles therefore indicate either a marine or a glacial origin for this block terrace but they preclude an avalanche origin as suggested by Hoskins for the block terraces of the Neny Fjord area.

3. *Glacial recession*

a. *Hurd Peninsula*. Along the greater part of Hurd Peninsula, between Johnsons Dock and Miers Bluff, several minor valley glaciers, which are outlets from the ice cap, have receded considerable distances from the shoreline. Only one glacier, midway between Johnsons Dock and Miers Bluff, still reaches the sea and even the foot of this glacier occurs above mean sea-level, since a beach deposit occurs beneath its snout.

The glacier outlet immediately south-west of Johnsons Dock shows four well-defined stages of recession in the form of its terminal moraines. The last-formed of the moraines dams a pool of glacial melt water. There is a noticeable uniformity in the height of the material deposited behind each earlier moraine, suggesting that they also impounded pools of water. The height of the morainic material occurring at the present limit of the ice indicates that recession is still continuing. Recession of the glacier snout clearly took place after the formation of the raised beach which is 25 ft. (7·6 m.) above sea-level.

The presence of a prominent lateral moraine, which is 100 ft. (30·5 m.) above one of the outlet glaciers, indicates a minimum thinning of 100 ft. (30·5 m.) in the thickness of the ice cover in relatively recent times.

b. *Rotch Dome*. Skirting the western side of the Livingston Island ice cap is a well-defined moraine that extends from Clark Nunatak in the south to the eastern limit of Robbery Beaches in the north. This morainic material has the form of two prominent ridges and a less-pronounced third ridge. Recessional moraines also occur behind these larger moraines and dirt bands in many of the seaward-facing ice cliffs indicate that ablation is in excess of accumulation.

c. *Barnard Point*. Two small residual cirque glaciers are present on the north-western side of the Barnard Point peninsula. There is a poorly developed terminal moraine at the snout of one glacier and a well-developed crescent-shaped terminal moraine at the other. The latter moraine stands approximately 15 ft. (4·5 m.) above the present level of the glacier but an erosional gully, formed by glacial run-off cutting through the middle of the moraine, reveals the moraine has an ice core. It therefore appears that considerable recession has taken place comparatively recently. Since recessional moraines also occur along slip planes at the surface of the glacier, it seems that recession is continuing.

d. *Huntress Glacier*. It is interesting to record that a photograph of Huntress Glacier shows the existence of a rock exposure at the present limit of the glacier snout (Plate IIc). This photograph was taken from above the north-west corner of False Bay, and should another photograph be taken from the same position in the future, it could no doubt reveal interesting changes in the position of the glacier snout. Changes in the balance between ablation and accumulation take a considerable time to reflect themselves in valley glaciers, but such changes in the position of the glacier limit may not necessarily be in accord with the general situation of ice recession or advance in the area.

V. STRATIGRAPHY

A PROPOSED stratigraphical succession for Livingston Island is given in Table II (see also the geological map; Fig. 2), but the absolute ages of the stratigraphical units of Livingston Island have not yet been determined. Detailed correlation depends primarily on evidence of superposition or intrusion and lithological similarities, but the isolated nature of the exposures on Livingston Island often precludes certain lateral correlation.

TABLE II

STRATIGRAPHICAL SUCCESSION OF LIVINGSTON ISLAND

Recent	Glacial deposits Raised beaches	
Miocene	(Dykes) Younger Volcanic Group (with interbedded conglomerates and sandstones)	
Late Cretaceous to early Tertiary	Andean Intrusive Suite	
Upper Jurassic	Renier Point lavas Mount Bowles agglomerates	Older Volcanic Group
Triassic	Plant-bearing boulders in interbedded conglomerates in Younger Volcanic Group	
? Carboniferous	Miers Bluff Series	
? Precambrian	False Bay schists	

A. FALSE BAY SCHISTS

A series of metamorphic rocks, comprising mainly hornblende-schists with subordinate hornblende-biotite-schists, occurs on the east coast of False Bay in the cliff exposures immediately north of Charity Glacier. Since these schists are adjacent to the Andean tonalite pluton of Barnard Point, there is the immediate problem of distinguishing between the regional and contact metamorphisms that have affected the schists. The schists occur both as schlieren and xenoliths within hornblende-gneisses or primary foliated tonalites. They also form screens within the dioritic lenses. The hornblende-gneisses merge gradually into the massive homogeneous tonalite and they essentially represent a marginal foliated phase of the tonalite. A diagrammatic cross-section showing the relationship of the False Bay schists to the foliated tonalites is given in Fig. 4.

The foliated and planar structures of the hornblende-schists trend north–south parallel both to the intrusive contact and the foliated structures of the tonalite. The foliation is steeply inclined and it usually

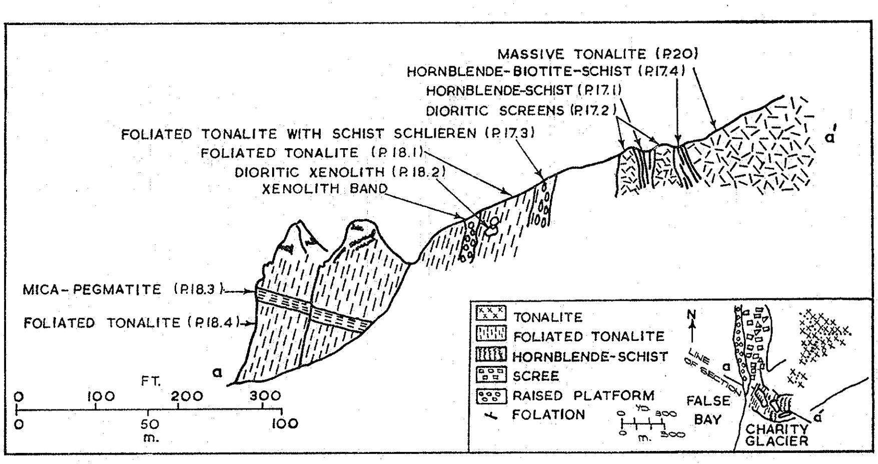

FIGURE 4

Diagrammatic cross-section along a–a′ on the inset sketch map of the foliated tonalites immediately north of Charity Glacier, Livingston Island (Fig. 1).

dips at 70–80° to the west but dips of 70–80° to the east also occur. The lineation of the schists also plunges at the same angles. The schists have an approximate thickness of 50 ft. (15·2 m.) and they extend only a short distance north of Charity Glacier, giving rise to limited exposures.

1. *Petrography*

The schists are dark grey or greenish black rocks. Felsic segregation banding is common in the planes of schistosity. Secondary slip planes, also showing segregation banding, are commonly present (e.g. P.17.1). Representative samples of the schists have been studied and the following detailed descriptions are typical of them.

Specimen P.17.4 (Plate Va), one of the lighter-coloured schists, is a dark grey rock in which felsic banding, 1–2 mm. in thickness, is developed in the plane of schistosity. Large flakes of biotite are occasionally present on the schistosity planes. In thin section, the essential constituents are hornblende, plagioclase, quartz and iron ore, but some biotite is also present.

Much of the hornblende is xenoblastic and it occurs as crystal aggregates. It constitutes 40 per cent of the rock and it is frequently twinned, occurring both as simple and repeated twins but the latter is commoner. Single crystals seldom exceed 0·6 mm. in length. Larger idioblastic hornblendes, up to 1·2 mm. in length, occur in the more felsic folia. The hornblende has a pleochroism scheme α = colourless to pale yellow-green, β = pale green, γ = olive-green, and an extinction angle, $\gamma{:}c = 20°$. Biotite flakes average 0·13 mm. in length and they are occasionally poikiloblastically enclosed by hornblende, having the same cleavage orientation. The biotite has a pleochroism scheme $\alpha = \beta$ = pale straw and γ = deep brown.

The plagioclase shows both albite and pericline twinning. It is usually unzoned but ranges in composition from $Ab_{62}An_{38}$ to $Ab_{55}An_{45}$. The feldspar in the narrower foliation planes is usually fresh and unaltered, whereas that in the coarser quartzo-feldspathic bands has a cloudy appearance and shows considerable alteration to sericite. Some orthoclase is present in the thicker felsic segregation bands.

The dominant mineral in the felsic bands is quartz; the crystals are as large as 3·7 mm. in length and they usually contain dusty plagioclase inclusions. Frequently the quartz forms granophyric intergrowths with the plagioclase.

Iron ore, which forms about 10–15 per cent of the rock in the mafic bands, is present as crystals up to 0·8 mm. in length and parallel to the schistosity. Apatite is a common accessory, while epidote rarely replaces hornblende. The iron ore also shows some alteration to haematite and there are occasional flakes of chlorite. The foliation is traversed by veins composed of similar minerals to those forming the rock but with the addition of clinozoisite.

A more highly schistose variety is represented by specimen P.17.1 (Plate Vb) in which the hornblendes show a marked foliation and a prominent lineation. However, the felsic banding in this specimen is not so pronounced and the thickest band is only 1 mm. thick.

In thin section this schist is composed essentially of hornblende, plagioclase and quartz. Hornblende forms about 60–70 per cent of the rock and, although it is similar to that in specimen P.17.4, it is idioblastic to a greater degree. Biotite is not present and iron ore only occurs as an accessory mineral. Plagioclase is considerably more basic, ranging in composition from $Ab_{36}An_{64}$ to $Ab_{31}An_{69}$.

A grey schistose xenolithic lens or schlieren of hornblende-schist included within the foliated tonalite (P.17.3) exhibits no important differences when compared with the normal schists. Although it possesses no pronounced foliation in the hand specimen, the schist xenolith has a fissility which under the microscope is revealed by alternate quartzo-feldspathic and ferromagnesian folia. This lens is composed largely of hornblende, biotite, feldspar and quartz with accessory iron ore, sphene and apatite, and secondary chlorite.

Hornblende forms xenoblastic crystals which have a preferred orientation and, although zoning is rare, the larger crystals (up to 0·6 mm. in length) possess an undulatory extinction and are frequently twinned. The hornblende has a pleochroism scheme α = pale yellow-green, β = olive-green, γ = dark green, and an extinction angle $\gamma{:}c = 25°$. Sporadic and unorientated flakes of biotite (0·6 mm. in length) are associated with magnetite. Well-defined biotite-rich lenticles trend parallel to the schistosity.

Quartz and plagioclase are present in equal quantities and they are frequently intergrown. The quartz usually shows undulose extinction. Both minerals have a definite foliation, their long axes lying in the plane of schistosity. The plagioclase is not zoned but it shows both albite and pericline twinning. The range of composition is from $Ab_{72}An_{28}$ to $Ab_{62}An_{38}$. Secondary chlorite replaces biotite, and accessory ilmenite is present both as drawn-out irregular blebs and laths (0·07 mm. in length) parallel to the schistosity and as somewhat larger grains (0·4 mm. in length) which are frequently surrounded by rims of sphene. Sphene also occurs as irregular grains and elongated laths parallel to the schistosity, while minor amounts of epidote and apatite are also present.

2. *Age of the schists*

The age of these metamorphic rocks has not been determined. They may well be part of a Precambrian basement which has been involved in the intrusion of the Andean plutons, or there is the possibility that they are metamorphic equivalents of the Miers Bluff Series.

If the False Bay schists are considered to be the metamorphic equivalents of the Miers Bluff Series, then an increase in the metamorphic grade of the sediments on a regional scale towards the tonalite intrusion should be expected. Apart from an isolated occurrence of low-grade metamorphic rocks north-west of Huntress Glacier, no such increase in metamorphic grade has been detected in the field. While it is possible to account for the scarcity of exposed regionally metamorphosed sediments by large-scale faulting or by glacial erosion of the schists along a shear zone associated with the Andean intrusions, the absence of high-grade metamorphism within the sediments tends to preclude a correlation of the Miers Bluff Series with the False Bay schists.

Since no conclusive evidence concerning the age of these metamorphic rocks is available from Livingston Island, it is necessary to draw a comparison with similar rocks that occur in Graham Land and other islands of the Scotia arc.

Rocks which are remarkably similar to the hornblende-schists of False Bay have been described from the Fallières Coast of Graham Land (Adie, 1954) as belonging to the Basement Complex and they have been assigned to the Precambrian, though they could well be early Palaeozoic in age.

From the Basement Complex of Signy Island, Matthews (1959) has described quartz-mica-schists with subordinate *para*-amphibolites and marbles, and the ages of eight of these rocks have been determined by Miller (1960) using the K-Ar method on micas. He found a close similarity in his results, indicating a Lower Jurassic–Upper Triassic age either for the original metamorphism *or for a subsequent metamorphism* of the schists. Since these schists are overlain by intensely folded greywackes, generally considered to be Carboniferous in age, and by slightly folded Mesozoic rocks, he concluded that radiogenic argon was released during the metamorphism induced by the orogeny which folded the greywackes. This conclusion lends some support to the suggestion that the Basement Complex of the South Orkney Islands could be Precambrian in age (Adie, 1962). This is the first positive evidence of a Triassic orogeny in the islands of the Scotia arc, but it is probably the same orogeny as that responsible for the dynamic metamorphism of the Trinity Peninsula Series of Graham Land described by Adie (1957).

Trendall (1959) has described acid gneisses and hornblende-quartz-plagioclase-gneisses from the south-eastern end of South Georgia, where they are associated with a paratectonic intrusion of post-Aptian age. The False Bay schists and gneisses may be of a similar age to the regionally metamorphosed rocks of South Georgia and are thus genetically related to the Andean intrusion of Barnard Point. If this is the case, the regional metamorphism would be post-Aptian or Cretaceous–Tertiary in age. However, regional metamorphism of the Trinity Peninsula Series definitely associated with the Andean intrusions has not yet been recorded from Graham Land (Adie, 1957).

Observations of regionally metamorphosed sedimentary rocks, which are considered to be equivalent to the Trinity Peninsula Series, in Andvord Bay on the Danco Coast, tend to confirm this (Hobbs, 1958). Immediately adjacent to the adamellite intrusion of "Forbes Hill" are shales and siltstones of comparatively low-grade metamorphism compared with the schists and gneisses of False Bay. If this is a valid correlation, the False Bay schists must be older than the Miers Bluff Series, and this conclusion would also account for the number of metamorphic rock fragments in the sediments of the Miers Bluff Series.

From the above comparisons with areas geologically related to Livingston Island, the False Bay schists could be Precambrian, Triassic or even Cretaceous–Tertiary in age. But the weight of the evidence presented thus far indicates that these schists are either pre-Carboniferous or even Precambrian in age. Until such time as a more precise age can be given to them it is preferable to regard the False Bay schists as being Precambrian.

B. Miers Bluff Series

1. *General lithology*

Hurd Peninsula, separating False Bay from South Bay, is formed entirely of sedimentary rocks, which consist mainly of shales, siltstones, arkosic greywackes and sandstones. The succession also contains interbedded conglomerates, intraformational conglomerates and tilloids (Pettijohn, 1957, p. 277). However, in the hinterland north-west of the peninsula poorly bedded volcanic rocks are interbedded with the sandstones.

The conglomerates (Plates Vc), which are thinly bedded, are not usually more than 1 ft. (0·3 m.) in thickness and they are composed largely of shale, sandstone and quartzite pebbles. The numerous volcanic pebbles are of plagioclase-porphyry, quartz-plagioclase-porphyry and silicified rhyolite. Granitic pebbles also occur but they are infrequent. These pebbles average 0·5–1·0 cm. in diameter and they range up to 2·5 cm. in diameter.

The intraformational conglomerates, consisting of thin or tabular fragments of shale enclosed in a sandstone bed, are quite common in the succession. The shale fragments generally measure 2–3 in. (5·0–7·6 cm.) in length and they are usually angular, although some of the fragments show signs of being rounded and worn by erosion. They usually occur at the top of a sandstone bed and differ in this respect from the normal occurrence of this type of deposit, in which the shale fragments are generally present at the base or in the lower part of a sandstone bed (Pettijohn, 1957, p. 277).

Conglomeratic mudstones, formed of rounded pebbles or sandstone fragments in non-laminated shale, are known as tilloids when they are of a non-glacial origin (Pettijohn, 1957, p. 265). The tilloids in the Miers Bluff Series are less frequent in occurrence and less persistent in extent than the intraformational conglomerates. The pebbles are usually 1–2 in. (2·5–5·0 cm.) in diameter, they lack a preferred orientation and are sparsely distributed in the shale matrix. As in the intraformational conglomerates, the pebbles tend to occur near the top of the shale matrix which is devoid of sedimentary structures.

In the ridge north-west of Huntress Glacier is a sequence of interbedded sandstones and basic andesites. These rocks have probably been contact metamorphosed by the tonalite intrusion now exposed to the south-east of Huntress Glacier, so it is possible that the andesites could be either sills or sheets. If this is not the case, the Miers Bluff Series could be analogous to the Cumberland Bay Series sediments of South Georgia which also contain interbedded spilites and basalts.

Current-bedding and flow-cast structures (Crowell, 1955) are prominent sedimentary features of the alternating siltstone and shale succession. The flute-casts trend 145–155° with their steeper ends to the north-west. Graded bedding is not particularly marked either in the arkosic greywackes or in the grey-green sandstones, but in the interbedded conglomerates the grading is frequently inverted.

2. *Petrography of the sandstones*

The sandstones have a uniform composition, falling within the arkosic greywacke division of Gilbert's classification (Williams and others, 1954).

a. *Texture*. Poorly sorted assemblages of quartz, feldspar and rock fragments are interspersed by a few fairly well-sorted and inconsistent lenses of finer material. The quartz grains average 0·13 mm. and they rarely exceed 0·4 mm. in diameter. The feldspars are equal in size to or somewhat larger than the quartz grains. The roundness of the quartz grains varies from angular to well rounded but they are predominantly sub-angular to sub-rounded with the latter shape predominating.

b. *Composition*. The rock fragments in the arkosic greywackes consist of shale, phyllite, schist, sandstone, quartzite, andesite, granite, granite-gneiss and vein quartz. The micro-rock fragments, consisting entirely of chlorite, probably represent altered volcanic rocks (Plate Vd).

Feldspar is the predominant mineral in the arkosic greywackes. The plagioclase feldspars are usually highly altered, so much so that twinning in many of them is completely obscured, but some of the plagioclases are quite fresh. Grains of orthoclase, microcline, orthoclase-microperthite and microcline-microperthite are common. Apart from a little kaolinization, all the potash feldspars mentioned above are fresh and unaltered. Zoning in the feldspars is rare.

Single grains of quartz are more abundant than composite ones and all show undulose extinction. A variety of composite grain, composed of individual grains having straight edges, is abundant. Small plates of biotite and feldspar form inclusions within the quartz. Bubble-train inclusions within the quartz are very frequent; one grain that was examined showed a zone of bubbles outlining a phantom crystal of quartz.

Biotite is common in the matrix of the arkosic greywackes and it is more abundant than muscovite. Chlorite and sericite are common and both have formed from original clay material.

Apatite is the commonest of the heavy minerals and the largest diameter measured was 0·27 mm. There are two sizes of zircon, the smaller ones having an average length of 0·05 mm. while the larger ones average 0·13 mm. in length. Both the small- and large-sized zircons vary in their degree of roundness from angular to well rounded. Angular grains of epidote are present, while iron ore occurs as irregular-shaped detrital grains and as anhedral authigenic iron pyrites crystals. Both types exhibit alteration to haematite.

3. *Petrography of the volcanic rocks*

The volcanic rocks and feldspathic sandstones at a nunatak north-west of Huntress Glacier show signs of intense deformation. The disturbed structures in these rocks, their indurated character and the abundant epidote impregnations suggest they have either been contact metamorphosed by the tonalite intrusion south of Huntress Glacier or they have been disrupted by the fault trending through Huntress Glacier.

A specimen of an altered medium- to fine-grained andesite (P.44.1) consists of a limited and variable proportion of plagioclase and hornblende phenocrysts set in a grey matrix. The ragged plagioclase ($Ab_{70}An_{30}$) phenocrysts, up to 1 mm. in length, show signs of intense cataclasis and alteration. Epidote occurs as finely disseminated granular masses, as distinct anhedral grains replacing plagioclase, and occasionally as larger prismatic crystals pseudomorphing plagioclase. Prismatic needles of tremolite are usually randomly orientated in the plagioclases but they sometimes develop along cleavage planes and twin lamellae. The plagioclase is often cloudy in appearance due to the development of magnetite and alteration products, and it is occasionally brown in colour.

The hornblende shows both simple and repeated twinning, and it is frequently zoned. It has a pleochroism scheme $\alpha =$ yellow-green, $\beta =$ olive-green, $\gamma =$ dark green and an extinction angle $\gamma{:}c = 23°$. It occurs both as irregular grains throughout the rock and as crystals up to 1·1 mm. in length forming glomeroporphyritic aggregates with plagioclase. Alteration to chlorite is common and acicular actinolite is frequently found in association with the hornblende. The hornblende is often fractured and bent. Sphene associated with quartz, plagioclase and iron ore occurs in veins. Epidote veinlets are also numerous.

4. *Discussion*

The Miers Bluff Series extends from Miers Bluff in the south-west, where it is well exposed, for a distance of 8 miles (12·9 km.) along the strike to the vicinity of Mount Bowles, where only a few isolated outcrops of sandstone occur. The sediments in the central area of Hurd Peninsula, between South Bay and False Bay, have a general dip of 45° to the north-west (Plate IIIc). There was no evidence of inversion in the succession of siltstones and shales exposed in the cliff section on the south-west side of Johnsons Dock. The whole sedimentary succession dips at between 33° and 63° to the north-west and current-bedding indicates a normal upward younging succession. The thickness of the Miers Bluff Series is estimated to be 10,000 ft. (3,050 m.). One or two measurements made on flow-casts (Crowell, 1955, p. 1359) reveal that the currents flowed from north-west to south-east. Sedimentary structures normally associated with geosynclinal sediments are surprisingly rare but reversals in the graded bedding are occasionally present in the interbedded conglomerates and coarser sandstones.

From the overall dip of this succession in one direction and that they are all the right way up, it is evident that there must be a major anticlinal structure to the south-east, the axis trending south-west to north-east. Incongruous drag folds pitch steeply approximately at right-angles to this major fold structure (Plate IIId). Small congruous drag folds also occur north of the entrance to Johnsons Dock with their axes plunging at approximately 10° to the west-south-west (Plate IVa).

The rocks of the Miers Bluff Series are typical eugeosynclinal sediments. The development of conglomerates, intraformational conglomerates and tilloids can be attributed to subaqueous sliding or turbidity currents promoted by earth movements. Thus, it is inferred that this geosyncline was unstable and it is likely that diastrophism and sedimentation took place simultaneously (Williams and others, 1954, p. 266).

The occurrence of bedded volcanic rocks in the sedimentary succession is characteristic of eugeosynclinal conditions, a feature of eugeosynclines being the rapid rate of subsidence accompanied by volcanism. Plagioclase, which forms a high proportion of the feldspars in the arkosic greywackes, could well have resulted directly from contemporaneous eruptions or the re-working of volcanic fragments.

The arkosic nature of the sandstones within the greywacke succession and the rock fragments contained within them both indicate that the source area was of high relief and was formed by a mixed series of rocks of granitic and metamorphic character. Plagioclase feldspar grains often show different degrees of alteration in the same specimen, suggesting that the climate of the source area was such as to promote rapid chemical decay (Williams and others, 1954, p. 314; Folk, 1959, p. 82). Feldspar grains are of similar size to the quartz grains, an indication that the sediments did not suffer prolonged erosion and that the source of supply was not too far distant. This nearness to the source area is also supported by the presence of conglomerates. The high degree of roundness of some of the quartz grains could be attributed to the presence of sedimentary rocks in the source area.

A feature of the Miers Bluff Series is the apparent absence of fossils. Invertebrate casts or tracks, similar to those recorded by Trendall (1953, p. 2–4) in the Sandebugten Series of South Georgia and by Adie (1957) in the Trinity Peninsula Series of Graham Land, were observed in the field; plant stems but no other identifiable fossil remains were found. Lithologically, the Miers Bluff Series resembles both the Sandebugten Series and the Trinity Peninsula Series. On the evidence of plant material from the Hope Bay area, W. N. Croft (Adie, 1957, p. 21) considered the Trinity Peninsula Series could not be older than the Carboniferous and not younger than the Jurassic. It is therefore considered justifiable to correlate the Miers Bluff Series tentatively with the Trinity Peninsula Series of Graham Land and the Sandebugten Series of South Georgia.

C. Older Volcanic Group

Isolated exposures of indurated rhyodacites, andesites and agglomerates occur at several localities in the Mount Bowles area. The indurated character and absence of well-developed bedding in these rocks renders them distinct from the younger friable lavas and agglomerates which occur at lower altitudes in the northern and western areas of the island. Their composition and proximity of the lavas to the greywacke-shale sediments of the Miers Bluff Series are features corresponding to the Upper Jurassic volcanic rocks of the Hope Bay area, Graham Land, where they usually rest unconformably on the Trinity Peninsula Series. Derived sedimentary rock fragments included within the lavas indicate that these volcanic rocks are younger than the Miers Bluff Series.

1. *Mount Bowles agglomerates*

Specimen P.50.1, from the south-west side of the Mount Bowles ridge, is representative of the volcanic rocks in this area. This rock is an indurated volcanic agglomerate composed of angular rock fragments up to 3 cm. in length set in a dark fine-grained matrix. Although the rock has an indurated character, it appears to have suffered considerable deformation. The slickensided surfaces of the rock, the green-coloured altered feldspars, the injected veinlets of feldspar and the closely spaced jointing are all indicative of deformation.

The rock fragments are mainly of oligoclase-andesine-trachyte. Closely packed or matted microlites with straight extinction usually exhibit pronounced flow structure. Less well-developed flow structures frequently occur in rock fragments of a similar composition. Many of the euhedral plagioclase micro-phenocrysts (not larger than 1·4 mm.) are replaced by albite, epidote, clinozoisite and chlorite. The epidote occurs preferentially in the crystal cores, but occasionally the whole of the plagioclase crystal is replaced.

A distinguishing feature of these rock fragments is the occurrence of penninite, calcite, quartz, epidote, iron ore and leucoxene as alteration products of former mafic minerals and as infillings of vesicles. The pseudomorphs of the coloured silicate minerals are occasionally well defined by chlorite rimmed by finely disseminated iron ore, which in turn has a very thin selvage of sphene. Frequently, no trace of the original form of the coloured silicate minerals remains.

Both magnetite and ilmenite are present in the trachytes. The former is usually confined to the ground-mass or is a replacement mineral with chlorite, but the latter is primary, since the plagioclase microlites show flow structure around the larger euhedral crystals. Ilmenite shows some alteration to both leucoxene and sphene. Occasionally it has a skeletal form but is more usually euhedral. In one case the magnetite grains occur as a narrow band trending parallel to the trachytic matrix.

A few poorly sorted feldspathic sandstone fragments are also present in the agglomerate. These sandstones consist of equal proportions of aggregate and veined quartz and plagioclase feldspar set in a matrix of chlorite and magnetite. The twin lamellae of the feldspars are bent and cataclastically distorted, indicating that the sandstones were subjected to deformation or folding before being included in the agglomerates.

Other rock fragments have either been completely replaced by epidote, or altered to epidote and chlorite, or to magnetite and chlorite.

Both quartz and plagioclase occur in the matrix as embayed and corroded xenocrysts. In one part of the thin section there is parallel alignment of crystals and rock fragments but generally this structure is obscured by the size of the larger rock fragments. The matrix of the agglomerate consists of plagioclase laths with an average composition of andesine ($Ab_{60}An_{40}$), finely divided iron ore, chlorite and epidote. It is difficult to distinguish between the matrix and the smaller rock fragments, since the margins between the fragments and the matrix are often indistinct.

This rock is injected by oligoclase veinlets and also by epidote and chlorite veins.

2. *Renier Point lavas*

Specimens representative of the Renier Point lavas were collected by N. A. Leppard from Rugged Rocks, north of Renier Point. Although no other geological information was obtained, an examination of the rock exposures above Renier Point with binoculars indicated that the lavas forming the peninsula dip at a moderate angle to the south-east.

Specimen P.49.1 is an altered porphyritic basalt. Large plagioclase laths up to 8 mm. in length are set in a fine-grained bluish matrix. In thin section the plagioclases are usually well formed but due to magmatic corrosion and replacement they are frequently anhedral. Alteration of the plagioclase has resulted in the formation of albite, chlorite, calcite and to a lesser extent epidote and sericite. The feldspars are not generally zoned but some of them show normal zoning. Although they are severely altered, the labradorite phenocrysts can be identified as ranging in composition from $Ab_{26}An_{74}$ to $Ab_{45}An_{55}$.

Rare phenocrysts of augite are up to 0·6 mm. in length and they have an extinction angle $\gamma{:}c = 42°$. The augite forms monomineralic clusters and glomeroporphyritic aggregates with feldspar.

The groundmass consists of basic labradorite ($Ab_{48}An_{52}$), magnetite, chlorite, sphene and less commonly epidote. The labradorite microlites occasionally exhibit a good fluxional structure. Patches of quartz are present.

A feature of specimen P.49.1 is the development of pseudomorphs after a ferromagnesian mineral and amygdales, the sections of which are outlined by finely disseminated vermicular iron ore. The pseudomorphs have the typical crystal form of the amphibole group. The alteration products, which are penninite, quartz, epidote, calcite, iron ore and sphene, mostly form as irregular aggregates but in some cases there is a definite zonal arrangement.

The iron ore marginal to the pseudomorphs usually has a narrow selvage of sphene on its outer side and occasionally on both sides. Adjacent to the magnetite border an irregular mosaic quartz zone is frequently developed and the greater part of the pseudomorph consists of penninite. Occasionally feldspar is present in the core of the pseudomorph in a spherulitic form. Calcite often occurs as irregular patches within the pseudomorphs together with granular crystals of sphene. The amygdales have rounded outlines and it is often difficult to distinguish them from pseudomorphs after minerals which have been rounded as a result of resorption.

Specimens P.49.2 and 3, also from Rugged Rocks, are fine-grained green-coloured trachytic rocks containing porphyritic feldspar laths and abundant mafic amygdales. In the hand specimen the feldspars are usually a pale green colour, frequently bright yellow-green and only occasionally vitreous and devoid of alteration. The mafic amygdales usually have a very irregular outline, and they are sometimes elongated as in specimen P.49.2 and give a crude flow structure to the rock.

In thin section the amygdales are composed of penninite spherulites bordered by an irregular selvage of calcite and lemon-yellow epidote.

The plagioclase phenocrysts, which occur both as glomeroporphyritic aggregates and as idiomorphic laths, are up to 6 mm. in length. Their composition varies between $Ab_{76}An_{24}$ and $Ab_{68}An_{32}$, while the twin lamellae show pronounced cataclastic structures. The plagioclase laths show intense alteration to epidote, chlorite, calcite and less intense alteration to sericite. The chlorite replacing the plagioclase occurs preferentially along cleavage and twin planes, and in certain concentric zones.

Epidote is present as anhedral crystals, occasionally idiomorphic after the plagioclase laths, and as aggregates in vesicles surrounded by calcite.

The groundmass exhibits a good trachytic texture of oligoclase laths ($Ab_{76}An_{24}$) around the phenocrysts. There is considerable alteration to epidote, chlorite and calcite. Epidote, again replacing plagioclase, is also idiomorphic. Ilmenite, in an irregular form, is abundant and it is partly altered to leucoxene.

D. Andean Intrusive Suite

Rocks of the Andean Intrusive Suite, which is probably late Cretaceous to early Tertiary in age, have been recorded from South Georgia (Trendall, 1959), King George Island (Hawkes, 1961) and Graham Land (Adie, 1955). These rocks range in composition from gabbros to biotite-granites.

At Livingston Island the Andean Intrusive Suite is represented by a tonalite pluton, which forms the Barnard Point peninsula and by a small tonalite apophysis just north of Johnsons Dock. Probably, further field mapping will reveal that much of the Mount Friesland ridge, which gives the west-south-west to east-north-east physiographic trend to the south-eastern part of the island, also consists of tonalite.

Quartz-diorite ejecta, similar to the tonalite of Barnard Point, have been described by Tyrrell (1921, p. 60) from the tuffs in the vicinity of Edinburgh Hill. The presence at Williams Point of abundant quartz-diorite blocks derived from the volcanic vents indicates that the Andean Intrusive Suite underlies a much greater area of Livingston Island than suggested by the exposed tonalite.

No direct evidence regarding the exact age of these Andean intrusions could be obtained from Livingston Island. The tonalite apophysis north of Johnsons Dock, however, clearly intrudes the Miers Bluff Series. Since the main tonalite mass at Barnard Point shows no intense cataclasis, it must therefore be younger than the earth movements to which the Miers Bluff Series was subjected.

At Needle Peak tonalite is in contact with and apparently intruded into red-coloured rocks which are presumed to be part of the Older Volcanic Group.

Although Livingston Island can provide no exact age for the tonalite intrusions, the field evidence obtained is consistent with the late Cretaceous to early Tertiary age established for the Andean Intrusive Suite of Graham Land, and the post-Aptian intrusions of South Georgia (Trendall, 1959).

1. *Tonalites*

The plutonic rock forming the Barnard Point peninsula is white, medium-grained and leucocratic, consisting of quartz, feldspar, hornblende and biotite. Apart from small variations in the proportions of the minerals present, this plutonic mass is unvaried and homogeneous in composition and texture over the greater part of the area examined. However, near the margin of the pluton, north of Charity Glacier, there is a greater variation with evidence of platy and linear flow structures. At station P.20.1, also on the north side of Charity Glacier, the country rock takes on a decidedly pink coloration due to an increase in the proportion of orthoclase present.

A typical specimen of the tonalite (P.22.3; Plate Ve), collected from the summit peak of Barnard Point, is medium-grained with a characteristic hypidiomorphic granular texture. A modal analysis is given in Table III. Hornblende usually occurs either as individual stout prisms showing sieve structure and enclosing plagioclase laths or as glomeroporphyritic clusters in association with biotite and magnetite. It frequently exhibits simple twinning but there is occasional repeated twinning. The pleochroism scheme is α = colourless to pale yellow, β = pale olive-green, γ = olive-green and the extinction angle $\gamma{:}c = 21°$.

The plagioclase is commonly andesine, ranging in composition from $Ab_{65}An_{35}$ to $Ab_{53}An_{47}$ and showing marked zoning. In the more heavily zoned plagioclases the outermost zones have a composition of $Ab_{70}An_{30}$. The basic cores are markedly altered to sericite, chlorite, epidote and calcite. The andesine has both combined Carlsbad-albite and pericline twinning. Calcite occurs along certain twin planes, replacing the andesine, but more frequently in veins together with plagioclase and orthoclase. The quartz usually

TABLE III
MODAL ANALYSES OF TONALITES

	P.20.1	P.22.3	G.23.7	G.25.1	D.754.1
Quartz	25·2	18·2	4·3	13·2	17·9
Plagioclase	47·7	56·0	66·7	61·0	60·2
Orthoclase	7·7	4·7	6·2	11·2	2·1
Sericite	5·5	2·5*	—	—	—
Biotite	1·8	4·1	—	0·2	14·2
Chlorite	9·9	2·6†	—	—	—
Hornblende	—	8·6	16·7	12·2	3·0
Augite	—	—	2·5	—	—
Magnetite	0·8	1·7	2·9	2·0	0·1
Rutile	0·2	0·2	—	—	—
Sphene	0·1	0·4	—	—	1·0
Apatite	0·3	0·3	—	—	0·4
Calcite	0·8	0·2	—	—	—

* Secondary after plagioclase.
† Secondary after biotite.

P.20.1 Tonalite, north side of Charity Glacier, Livingston Island.
P.22.2 Tonalite, summit peak of Barnard Point, Livingston Island.
G.23.7 Quartz-diorite, Crépin Point, King George Island (Hawkes, 1961).
G.25.1 Granodiorite, Rose Peak, King George Island (Hawkes, 1961).
D.754.1 Quartz-diorite, Gulliver Nunatak, Graham Land (Adie, 1955).

has an undulose extinction. Biotite is present in monomineralic clusters and as mantles on hornblende. It poikilitically encloses small plagioclase laths, magnetite and apatite, and to a large extent it is replaced by chlorite.

The accessory minerals apatite and zircon are in association with magnetite and sphene. Occasionally tourmaline, with a pleochroism of pale brown to blue-black, is associated with magnetite, hornblende and with lemon-yellow epidote replacing chlorite.

The most significant feature of this rock is the apparent replacement of plagioclase by orthoclase. The margins of plagioclase are quite frequently corroded by orthoclase. In one case the plagioclase crystal is almost bisected by orthoclase whereas in another the separation is complete (Plate Ve).

The tonalite (P.20.1) on the north side of Charity Glacier is medium-grained and pink in colour. The mode of this rock is given in Table III. The andesine ($Ab_{68}An_{32}$—$Ab_{64}An_{36}$) shows marked normal discontinuous zoning; it is heavily altered and the main product is sericite often accompanied by chlorite. The replacement of plagioclase by calcite and epidote is also common. There is some twinning of the plagioclase on the albite and Carlsbad laws but it is usually masked to varying degrees by the alteration products and often completely obliterated. The albite twin lamellae in the plagioclase are sometimes bent but more usually they are displaced and occasionally the entire crystal is sheared.

Orthoclase occurs in the interstitial areas as turbid allotriomorphic crystals associated with quartz, which shows intense deformation. It has an undulose extinction and is fractured. Lenticles of fine-grained mosaic quartz are present along shear planes and it also occurs sometimes as relatively elongated crystals.

There are two varieties of chlorite: subhedral crystals with parallel cleavage and straight extinction (containing numerous (?) rutile needles) which have largely replaced biotite, and a fibrous radiating form which occurs in irregular patches associated with calcite, sphene and magnetite, apparently replacing hornblende. Zircon and apatite are the accessory minerals.

The tonalite apophysis (P.48.1) north of Johnsons Dock is a medium- to fine-grained light grey rock in which alteration has imparted a green coloration to the feldspars. The less-altered plagioclase is andesine ($Ab_{64}An_{36}$), which shows both albite and Carlsbad twinning. The andesine is severely altered, and it has largely been replaced by epidote, prehnite, sericite and chlorite. The andesine often has a relatively unaltered narrow margin which is in marked contrast to the preferential replacement of the basic cores.

Biotite is now represented by chlorite, and irregular patches of chlorite, epidote, sphene and calcite replace hornblende. Quartz is common and the anhedral interstitial grains are partially recrystallized. It also occurs in veins together with calcite, epidote and chlorite.

The cataclastic and shear features that are typical of the tonalite north of Charity Glacier (P.20.1) can be attributed to its proximity to the contact. The intense alteration suffered by the tonalite north of Johnsons Dock (P.48.1) is probably the combined effect of localized tectonic activity and stress developed in the cooling mass by continued movement of the magma.

Although these rocks are called tonalites, they are similar to the quartz-diorites and granodiorites described by previous authors from the Scotia arc and Graham Land. Comparable features are zoning of the plagioclase, the absence of strain effects in the main rock mass and the slight alteration of the mafic constituents.

The modes of two of the tonalites from Livingston Island are given in Table III together with three others, which also fall in this category in Nockolds's (1954, p. 1008) classification.

2. *Foliated tonalites*

The tonalite is well foliated close to the margin of the pluton. Foliation is particularly marked to the north of Charity Glacier but it can be traced farther south to Barnard Point where it trends west–east. These plutonic structures of felsic and mafic banding illustrate part of the concentric arrangement marginal to many plutons. A typical example (P.17.3), a leucocratic medium-grained gneissose hornblende-biotite-tonalite, is in *lit-par-lit* relationship to screens of diorite. Alternating bands, consisting of felsic and mafic minerals, range from 0·25 to 10 mm. in thickness. In thin section the gneissose structure is not strongly marked but crystals of biotite and hornblende have a preferred orientation such that they lie in the plane of foliation (Fig. 4).

Quartz and plagioclase are in granophyric intergrowth. The feldspar is heavily altered, the main product being sericite. Prehnite also replaces plagioclase, and much of the biotite is altered to chlorite. There is a little epidote.

A thin section of specimen P.17.3 (Plate Vf) from near the contact with a lenticular xenolith of hornblende-schist is less intensely altered. The plagioclase ($Ab_{60}An_{40}$) occurs as subhedral phenocrysts (up to 0·7 mm. long) elongated with the foliation and enclosing small laths and flakes of hornblende and biotite. Zoning is marked, usually being normal from $Ab_{50}An_{50}$ to $Ab_{62}An_{38}$, but occasionally there is reversed zoning. Twinning of the plagioclase is on the albite, Carlsbad and pericline laws but there are occasional Baveno twins.

Quartz is very subsidiary to plagioclase and it usually has a marked undulose extinction. It is free from fracturing but it contains numerous inclusions in the form of hornblende flakes and biotite granules. There are ragged elongated crystals of hornblende with a pleochroism scheme $\alpha =$ pale yellow to pale green, $\beta =$ olive-green, $\gamma =$ deep grass-green and an extinction angle $\gamma{:}c = 22°$. Both simple and polysynthetic twinning are present. Hornblende occasionally includes biotite flakes. The biotite usually forms tabular crystals orientated in the plane of the banding. It is strongly pleochroic with $\alpha = \beta =$ pale straw and $\gamma =$ deep brown. Alteration to chlorite is slight. The groundmass has a nematoblastic texture and it is composed of plagioclase (0·3 mm. long), quartz, hornblende and biotite. Orthite, with a slight pleochroism from pale brown to darker brown, is occasionally euhedral. It is sometimes associated with iron ore which has been oxidized to haematite. Other accessories are apatite, zircon and magnetite.

At station P.18 there are foliated tonalites or injection biotite-gneisses containing layers rich in dioritic autoliths having platy flow structures with a similar strike and dip to the foliation in the gneisses (Fig. 4). A diorite autolith up to 6 ft. (1·8 m.) in diameter occurs in these layers. Specimen P.18.1 (Plate VIa) is light-coloured and medium-grained. Irregular dark biotite-rich schlieren and lenses up to 8 mm. thick and 15 cm. in length give the rock its gneissose structure. The coarser gneissic areas are characterized by a granoblastic texture of plagioclase and quartz together with biotite. The biotite lenses have a pronounced lepidoblastic texture. The plagioclase also occurs as porphyroblasts (up to 2·5 mm. in length) forming a poikiloblastic texture enclosing flakes and equidimensional crystals (1 mm. in length) of biotite. The average plagioclase composition is andesine ($Ab_{62}An_{38}$). Normal zoning is marked and the composition ranges from $Ab_{58}An_{42}$ in the cores to $Ab_{68}An_{32}$ at the rims. There is also oscillatory and reversed zoning. Twinning on the albite, Carlsbad and pericline laws is common. The plagioclase crystals are sometimes bent, but more usually only the twin lamellae are bent and frequently displaced.

The proportion of potash feldspar is variable but it has not been estimated. Quartz, showing both intense undulating extinction and fracturing, encloses biotite, which is present both as monomineralic aggregates and in association with magnetite. It has a pleochroism scheme $\alpha = \beta =$ pale straw and $\gamma =$ dark brown. Apatite and orthite associated with biotite are common accessory minerals, while zircon, magnetite and sphene are less common.

3. *Diorites*

These rocks form only a limited part of the plutonic intrusion. They are represented by autolith-rich bands and screens in *lit-par-lit* relationship with foliated tonalite and hornblende-schist near the margin of the intrusion (Fig. 4). The diorites appear to be part of an initial basic phase of intrusion injected along the foliation of the hornblende-schists and they were subsequently intruded, disrupted and to a certain extent metamorphosed by the more acid tonalite. No preferred orientation, schistose or flaser structure is discernible in the field or under the microscope in specimens from the dioritic screens.

A typical specimen from one of the screens (P.17.2; Plate VIb), from the east side of False Bay north of Charity Glacier, is a medium-grained dark green rock. Dark ferromagnesian minerals form phenocrysts in the lighter, grey-green, lustrous groundmass of the hand specimen.

Under the microscope the thin section of this rock reveals intense alteration. Its main constituent is hornblende, and there is also spinel and minor amounts of muscovite. The accessory minerals are biotite, magnetite, zoisite and apatite. The hornblende occurs as a plexus of large ragged plates poikilitically enclosing spinel, aggregates of muscovite, sericite, zoisite and magnetite, and fibrous masses of acicular tremolite. The hornblende has a pleochroism scheme $\alpha =$ pale yellow-green, $\beta =$ pale olive-green, $\gamma =$ light green and an extinction angle $\gamma{:}c = 20°$. It is partially altered to acicular tremolite ($\gamma{:}c = 20°$), replacement usually taking place around the margins of the hornblende crystals and also as irregular patches within them.

Plagioclase is absent from this rock and, while the term "hornblendite" might well be justifiable, the presence of irregular saussuritic aggregates indicates its former presence. Muscovite (up to 0·27 mm. in length) has formed from the sericite and zoisite in these aggregates.

Spinel, idioblastic with rectangular or rhomb-shaped outlines, occasionally forms independent crystals up to 0·3 mm. in length but it is more abundant as rounded grains in composite aggregates. The spinel is probably the green variety pleonaste and it frequently forms irregular crystals either mantling iron ore or enclosed within it. Iron ore often occurs in association with the tremolite replacing hornblende and it also develops in the hornblende as finely disseminated dusty patches. This rock appears to be a metamorphosed diorite but it has random orientation of the minerals and no banding.

A specimen of a solitary dark dioritic autolith (P.18.2), 6 ft. (1·8 m.) in diameter and included within the foliated tonalite (P.18.1), was collected at the head of the gully leading down to the beach north of Charity Glacier. The adjacent autoliths in the autolith-rich band are essentially of the same composition as the one described below but they are somewhat smaller in size, ranging from 6 in. to 1 ft. (15·2 to 30·5 cm.) in length.

This autolith has a medium-grained granular texture, in which the main constituent minerals, hornblende and plagioclase, occasionally form phenocrysts. Magnetite, sphene, biotite, apatite and angite are present in subsidiary amounts. The plagioclase occurs as closely packed anhedral laths (up to 0·4 mm. in length) forming the groundmass with hornblende and as smaller anhedral prisms poikilitically enclosed by hornblende. The average plagioclase composition is basic andesine ($Ab_{54}An_{46}$), two generations of which are present, an early one (An_{63-66}) seldom zoned but showing both albite and pericline twinning, and a later heavily zoned one in which twinning is absent. There are signs of intense recrystallization and some sericitization of both the matrix plagioclase and the prisms included within the hornblende. Preferential sericitization and calcite replacement of the plagioclase cores has occasionally taken place.

Hornblende forms glomeroporphyritic aggregates (individual anhedral crystals averaging 0·55 mm. in length) and rare large ragged phenocrysts (up to 6 mm. in length) poikilitically enclosing blebs and subhedral prisms of plagioclase together with biotite, magnetite, sphene, apatite and augite. It is frequently twinned and has a pleochroism scheme α = yellow, β = olive-green, γ = dark green and an extinction angle $\gamma:c = 21°$. A particular feature of the hornblende phenocrysts is the presence of finely disseminated iron ore as irregular patches and in a network of parallel lines filling fractures within the crystal. The finely disseminated iron ore is noticeably absent from the smaller hornblendes.

Relict augite rarely forms a crystal core surrounded by a mantle of hornblende but more usually it occurs as tabular crystals poikilitically enclosed by hornblende. Biotite flakes, 0·1 mm. in length, associated with magnetite develop in the hornblende phenocrysts. Anhedral magnetite crystals which have partially altered to haematite are common throughout the rock and they are usually associated with and mantled by sphene, forming anhedral crystals 0·5 mm. in length. Other accessory minerals are apatite and zircon.

E. Younger Volcanic Group

A succession of stratified volcanic rocks forms outcrops over large parts of western and northern Livingston Island. They include andesite and basalt lavas, tuffs and agglomerates. Sediments are interbedded with the volcanic rocks, and they have been examined at two localities, Williams Point and near Start Point. Since pebbles of similar sedimentary rocks containing carbonized woods and fossil plant remains are frequently found in the moraines fringing the ice cap, it is apparent that these sediments have a very wide distribution.

Because of the paucity of good exposures and because of faulting in the Younger Volcanic Group, a complete stratigraphic sequence has not yet been established. Therefore the individual successions at the various localities are described separately.

1. *Hannah Point*

The basal 140 ft. (42·7 m.) of the succession at the eastern end of the Hannah Point promontory consists of massive andesites in which zeolites are prominently developed near the tops of the lava flows. Green agglomerates, fissile amygdaloidal lavas and tuffs are interbedded with the flows. The succeeding 360 ft. (110 m.) are composed of friable green and blue agglomerates, green and red fissile ashes and brown amygdaloidal lavas (Fig. 5). Another 640 ft. (195 m.) sequence of massive andesites interbedded with amygdaloidal lavas, in which the individual flows are much thicker than the previous outpourings of andesites, completes the succession.

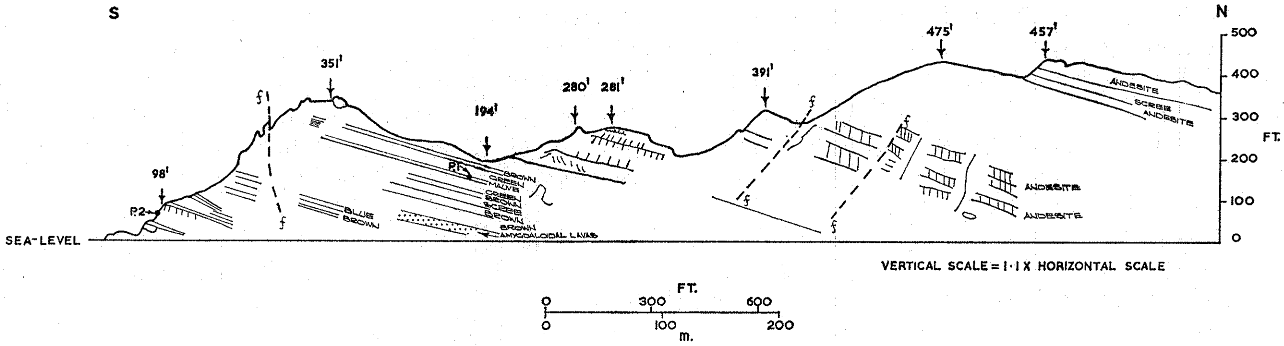

FIGURE 5

Cross-section showing the succession in the Younger Volcanic Group at Hannah Point.

An andesitic lava flow of unknown thickness is at the base of the Hannah Point exposure. The succeeding dark blue-grey andesite flow (P.2.1; Plate VIc), which is 6 ft. (1·8 m.) thick, is characterized by a greater abundance of amygdales throughout and these impart to the rock a rough fissility. The elongation of the amygdales is parallel both to the bedding and to the pronounced trachytic texture of the groundmass. The labradorite microlites of the groundmass have a composition of $Ab_{42}An_{58}$ and they average 0·07 mm. in length. The larger basic labradorite laths are up to 1·1 mm. in length and they have a composition of $Ab_{30}An_{70}$. Both euhedral and anhedral magnetite crystals are present. Granular augite which is altered to chlorite is also present. Chalcedony occurs as spherulitic sheaves filling vesicles, as banded aggregates and, in a spherulitic form, in veinlets. Calcite also occurs in vesicles, usually concentrically banded with the chalcedony or as complete infillings of the vesicles.

A green-coloured agglomerate (P.2.2), containing pyroclastic blocks up to 5 ft. (1·5 m.) in diameter, lies above the andesite flows. In the hand specimen the larger fragments are rounded and are up to 2 cm. in length but most of them are angular and do not exceed 7 mm. in diameter. This agglomerate is 1 ft. 6 in. to 2 ft. (0·45 to 0·6 m.) thick.

The groundmass of the agglomerate is kaolinized, cryptocrystalline and quartzo-feldspathic, containing a wide variety of rock fragments. They are usually andesitic in composition and are either heavily chloritized or haematitized. The numerous plagioclase phenocrysts are commonly andesine but they range in composition from $Ab_{35}An_{65}$ to $Ab_{70}An_{30}$. Some phenocrysts show partial replacement by calcite. There are also phenocrysts of subhedral quartz. The sparse olivines are serpentinized. Calcite frequently infills vesicles lined by chlorite.

The agglomerate is succeeded by a fine-grained blue-grey lava flow (P.2.3) which is a fissile andesite with the microlites displaying a trachytic texture. Plagioclase laths (up to 0·27 mm. in length) form glomeroporphyritic clusters with augite and a few flakes of biotite. Augite also occurs as microphenocrysts. Occasional plagioclase microphenocrysts have a compositional variation ranging from labradorite to bytownite ($Ab_{35}An_{65}$ to $Ab_{20}An_{80}$); some crystals show partial and complete replacement by calcite. The matrix consists of andesine microlites, granular augite and both euhedral and anhedral magnetite. The microlites average 0·06 mm. in length and they have a composition of $Ab_{53}An_{47}$. The amygdales are infrequent and do not exceed 4·2 cm. in length. Chloritic material and brown serpentinous areas usually rim the chalcedony-filled vesicles, which are elongated parallel to the trachytic texture.

This flow (P.2.3) differs from the preceding andesite flow (P.2.1) in that the magnetite grains, microlites and plagioclase laths (which are also more numerous in specimen P.2.1) are generally smaller in size. The finer grain-size, together with the less-marked trachytic texture of the andesite flow (P.2.3), could account for the relative decrease in the degree of fissility.

The succeeding flow (P.2.4) is 10 ft. (3 m.) thick, has a blue-grey colour and a rough fissility. It is an augite-andesite and has essentially the same composition as specimen P.2.3. Bytownite phenocrysts with a composition of $Ab_{23}An_{77}$ and length up to 0·8 mm. occur both singly and as monomineralic clusters. Augite, with an extinction angle $\gamma{:}c = 54°$, also forms single microphenocrysts but not glomeroporphyritic clusters with plagioclase laths as in specimen P.2.3. The microlites of the groundmass show a trachytic texture particularly around the bytownite phenocrysts and monomineralic clusters. The andesine microlites have a composition of $Ab_{53}An_{47}$ and the rock is identical in this respect to specimen P.2.3. However, the microlites and the grains of magnetite are larger and calcite is more abundant in the matrix.

A banded agglomeratic or lithic tuff (P.1.1), collected higher up the succession at 140 ft. (42·7 m.) above sea-level, consists of reddish and green-coloured rock fragments averaging 1·5 mm. in length but they are up to 5 mm. in length. They are mainly angular and are haematitized andesites, devitrified glass and chloritized rocks. Palagonite inclusions and zeolites (stilbite) with a lamellar or fibrous structure are also present. The groundmass is largely cryptocrystalline quartzo-feldspathic material packed with augite and oligoclase microlites 0·03 mm. in length.

Euhedral oligoclase crystals as well as occasional subhedral quartz crystals form the phenocrysts. The oligoclase phenocrysts show varying degrees of alteration to (?) stilbite. The zeolites normally occur as sheaf-like aggregates and they often have a localized brown coloration at the margin surrounded by a clear rim. Therefore, the zeolites generally have a pronounced zoned structure.

The banded character of this rock suggests that the tuff was deposited in an aqueous environment, while the numerous zeolites and volcanic ejecta indicate a not too distant source.

Specimen P.1.2, also from the eastern side of the ridge at Hannah Point, is a dark mauve-coloured agglomeratic tuff overlying the lithic tuff (P.1.1). It consists of euhedral tabular laths and embayed and corroded plagioclase phenocrysts together with broken euhedral crystals of augite in a dominantly cryptocrystalline matrix. The plagioclase, which shows repeated zoning, ranges in composition from $Ab_{70}An_{30}$ to $Ab_{62}An_{38}$. The rock fragments are mainly of a rhyolitic composition. A pronounced flow structure, consisting of saussuritized bands and composed mainly of quartzo-feldspathic material, together with chlorite, sericite and magnetite alternating with bands of chloritized microspherulites, is a marked feature of the matrix.

The remaining flows which complete the exposed succession in the ridge at Hannah Point are also andesitic and they are similar to andesitic lavas described previously.

2. *Williams Point*

The northern promontory of Williams Point is composed entirely of a massive lava flow 75 ft. (22·8 m.) in thickness and dipping slightly westwards. This lava is amygdaloidal and is veined by minerals similar to those filling the vesicles. South-west of Williams Point fine-bedded conglomerates 5–10 ft. (1·5–3·0 m.) thick occur at the base of a massive unbedded pebble conglomerate, approximately 50 ft. (15·2 m.) thick.

The well-rounded pebbles of the massive conglomerate average 1 ft. (0·3 m.) in diameter. No fossils were observed in the conglomerates but a 6 ft. (1·8 m.) thick coarse green conglomeratic sandstone overlying the massive conglomerate contained poorly preserved fossil plant stems. The conglomerates are overlain by massive lava flows 200 ft. (61 m.) thick in which vertical jointing is well developed.

Where the buff-coloured tuffaceous boulders from the conglomerates have weathered out and have been exposed to constant freeze-thaw conditions, they have split along bedding planes revealing well-preserved plant fossils. Orlando (1968) has identified *Asterotheca crassa* n. sp., *Thinnfeldia* sp., *Coniopteris distans* n. sp., *Xilopteris* cf. *elongata* Carr. and fragments of Dipteridaceae and Osmundaceae in this plant material, and he has assigned it a Lower to Middle Triassic age.

The nunatak forming the highest point on the promontory is also composed of conglomerate containing water-worn pebbles set in a dominantly tuffaceous matrix. There is no sign of bedding in these rocks and the relationship of this exposure to the lava flows is obscured by ice and moraine.

Specimen P.105.1, collected from the 6 ft. (1·8 m.) conglomerate, contains a considerable amount of volcanic material and it would appear that there was volcanic activity during the deposition of the conglomerate. Grey-green in colour and medium-grained, the conglomerate constituents average 1–3 mm. in diameter and well-rounded pebbles occasionally up to 3 cm. in length. Sub-angular grains of quartz with numerous well-rounded rock fragments (up to 2 mm. in length), consisting of a mosaic of welded quartz aggregates of metamorphic origin, together with augite crystals and plagioclase laths, form the principal constituents of the conglomerate. The matrix is largely calcareous with some palagonite in the banded rhyolitic areas.

Specimen P.102.1, a pale pink-coloured flaggy sandstone containing carbonized woody stems and plant material, was collected from the stream flowing into Dragon Cove. Angular quartz and augite are the dominant minerals; volcanic rock fragments are numerous, while fragments of the other rock types are completely chloritized.

3. *Byers Peninsula*

The predominant rock types forming Byers Peninsula are basaltic agglomerates and augite-andesites. At the highest feature inland from Start Point, the basaltic agglomerates contain pyroclasts as large as 4–5 ft. (1·2–1·5 m.) in length. These volcanic beds have a west–east strike with a shallow dip to the south. In this succession an angular agglomerate is followed by a lava flow into which pyroclasts of the succeeding agglomerate have sunk several feet.

In the hand specimen the basaltic agglomerate (P.12.1) is characterized by abundant plagioclase phenocrysts up to 4 mm. in length, haematitized rock fragments and by numerous zeolites in a dark mauve matrix. The anhedral bytownite ($Ab_{25}An_{75}$) phenocrysts show intense replacement by analcite and chlorite. The chloritization of the bytownite frequently takes place by means of chloritic veinlets along twin planes and fractures. Augite is infrequent as phenocrysts but it is more abundant in the groundmass, forming a fine intergranular texture with labradorite ($Ab_{40}An_{60}$) microlites and iron ore. Both the augite and labradorite of the groundmass are heavily chloritized. Analcite occurs as infillings of veinlets and vesicles.

This agglomerate is succeeded by a red- and green-coloured lava flow (P.12.2), which consists of euhedral plagioclase phenocrysts (up to 3·8 mm. in length) set in a haematitized groundmass. There are occasional euhedral augites with a pronounced hour-glass structure. The rock is mainly distinguished by vesicles which are filled by analcite and rimmed by chlorite. They are occasionally irregular or well rounded in shape but more frequently they are elongated giving a flow structure to the rock. The plagioclase phenocrysts are replaced by analcite and fibrous or sheaf-like stilbite.

The dominant lavas forming the northern part of the shore fronting New Plymouth are augite-andesites. A typical specimen of these andesites (P.13.1) possesses chlorite pseudomorphing hypersthene. Therefore, they have petrographic affinities to the hypersthene-augite-andesites and augite-andesites of the Point Hennequin Group of King George Island described by Hawkes (1961, p. 16).

In the hand specimen this rock possesses a porphyritic texture, consisting of euhedral and anhedral plagioclase phenocrysts (up to 7 mm. in length) set in a medium-grained grey matrix. The phenocrysts of labradorite ($Ab_{34}An_{66}$) are slightly zoned and exhibit varied but intense alteration. Sericite and saussurite are the normal alteration products, while there is some replacement by chlorite along fractures within the labradorite, and occasionally there is preferential replacement of the basic cores. The augite is pale green in colour and it has an extinction angle $\gamma:c = 45°$. It occurs both as subhedral microphenocrysts and as granules in the intergranular groundmass with abundant ilmenite. Only occasionally does it form glomeroporphyritic clusters.

F. Volcanic Plugs

There are several examples of volcanic plugs on Livingston Island. The most spectacular one is Edinburgh Hill, which was first described by Ferguson (1921). Two similar plugs form conspicuous features on South Beaches, Byers Peninsula. Another plug probably occurs near Devils Point, the south-westernmost point of Byers Peninsula. Although the author did not visit the volcanic plug midway between Clark Nunatak and north of Vietor Rock (P.7), South Beaches (Plate Ia), or the plug at Devils Point, stereoscopic pairs of aerial photographs indicate that both localities have a much higher relief than the adjacent rock exposures. Vertical columnar jointing is also clearly visible on the aerial photographs of both features.

1. *Edinburgh Hill*

Edinburgh Hill (Plate IVb) is a conspicuous cylindrically shaped volcanic plug, about 360 ft. (110 m.) high, which is situated on the north side of Moon Bay and connected to Livingston Island by a raised tombolo 50–60 ft. (15·2–18·3 m.) above sea-level.

This plug is composed of a fine-grained, grey olivine-basalt in which beautifully formed columnar jointing has developed. The lower half of the plug consists of sharp well-defined vertical columns 2–3 ft. (0·6–0·9 m.) across, which curve outwards at the base of the plug. In its upper half, the columnar jointing is less well-defined and the columns increase to 5–6 ft. (1·5–1·8 m.) across. A major horizontal cross-joint traverses the plug at the transition from the smaller and better-defined columns to the larger and less-defined ones.

Flow structures are a common feature of the plug. They are formed by a partial orientation of the feldspar crystals and of dark or light grey streaks or lenses in which the proportion of mafic minerals is either greater or less than the average composition of the plug. Flow layers, accentuated by weathering and also due to slight compositional variations in the basalt, can be clearly seen below the junction between the small- and large-diameter columns. There are occasional thin reddish flow lenses interbedded with the grey flows, and near the top of the intrusion where they reach their maximum thickness they are estimated to be 10–15 ft. (3·0–4·5 m.) thick.

This rock is composed of abundant phenocrysts of labradorite, augite and olivine in a holocrystalline matrix of augite granules, labradorite microlites and minute cubes of magnetite. A detailed petrographic description of specimens 57 and 58a and b, collected by Ferguson from the columnar rock, has been given by Tyrrell (1921, p. 66):

> "Idiomorphism is only pronounced in the felspar; the augite and olivine are usually quite anhedral. The felspar is zonal and has an average composition of An_{60}. The crystals are seriate in size, ranging from phenocrysts averaging 2 mm. in length down to microlites of the groundmass. The augite forms yellowish-green anhedrons of a size rather smaller than the large felspar phenocrysts. The felspars often partially

enclose the augites along their margins. The olivine is perfectly fresh, occasionally euhedral, but more often very irregular in shape. On the margins of the crystals the mineral is often intergrown with the augite granules of the groundmass."

The mode of the rock is given in Table IV.

TABLE IV
MODAL ANALYSES OF OLIVINE-BASALTS FROM THE VOLCANIC PLUGS AND VENTS OF THE SOUTH SHETLAND ISLANDS

	P.7.1	P.54.1	P.100.1	57	G.33.2
Plagioclase	63·4	42·9	69·9	37·8	54·1
Olivine	—	16·4	2·0	14·7	12·5
Serpentine	13·2	—	—	—	—
Augite	19·7	33·3	18·9	42·5	28·1
Iron ore	3·7	7·4	5·2	2·5	5·2
Glass	—	—	1·8	2·5	—
Analcite	—	—	2·2	—	—
Plagioclase composition					
Phenocrysts	An_{75-84}			An_{60}	An_{48-58}
Matrix	An_{67-70}	An_{59-65}	An_{53}		An_{48-54}

P.7.1 Altered olivine-basalt, Byers Peninsula, Livingston Island.
P.54.1 Olivine-basalt, Mount Plymouth, Greenwich Island.
P.100.1 Vesicular basalt (xenolith), nunatak 3 miles (4·8 km.) north-west of Edinburgh Hill, Livingston Island.
57 Olivine-basalt, Edinburgh Hill, Livingston Island (Tyrrell, 1921).
G.33.2 Olivine-basalt, Penguin Island (Hawkes, 1961).

2. *Inott Point*

Inott Point, which is situated 1·25 miles (2 km.) north of Edinburgh Hill, is a massive tower-shaped feature rising from sea-level to about 200 ft. (61 m.). Although it was not examined by the writer, the morphology and composition of the rock as described by Ferguson (1921) indicates that Inott Point is an agglomeratic vent intrusion. Tyrrell (1921, p. 73) has described a basalt-tuff (specimen 59) associated with the tuff as showing "small and extremely fresh chips of the basic olivine basalts of the vent, embedded in a paste of comminuted basaltic material containing fresh isolated crystals of olivine and augite".

From the presence of abundant blocks of quartz-diorite and numerous pieces of blue-black mudstone in the agglomerate, Ferguson (1921) inferred the existence of these same rocks elsewhere on Livingston Island. This has been confirmed by the present work.

3. *Plug 3 miles (4·8 km.) north-west of Edinburgh Hill*

On the east side of Livingston Island, 1 mile (1·6 km.) north of Sharp Peak, is an isolated nunatak (P.100) situated at the break of slope between the ice cap and the ice piedmont. This nunatak is composed almost entirely of fragmental, grey vesicular xenoliths of basalt in a fresh, buff-coloured, vesicular and cindery type matrix (P.100.1; Table IV; Plate VId). Apart from obscure horizontal stratification at one locality, the agglomerate is devoid of bedding. The character of the rock and the absence of any sign of bedding indicate that the nunatak is an eroded extrusive vent agglomerate.

Viewed in strong sunlight, its golden-bay colour matches that characteristic of Rosamel Island, which is at the southern entrance to Antarctic Sound off Trinity Peninsula, Graham Land. Rosamel Island is also regarded as an extrusive vent (Adie, 1953). The pronounced gully erosion evident on Rosamel Island which results in rock pillars standing out from the main cliff face is also present at this nunatak. It is conceivable that this vent agglomerate (P.100.1) could be contemporaneous with the Rosamel Island vent, which is related to the mid-Miocene James Ross Island Volcanic Group.

In thin section the medium-grained vesicular basalt xenoliths (P.100.1) consist of both anhedral and euhedral slightly zoned olivine phenocrysts (0·5–1·5 mm. in length) set in a trachytic matrix of plagioclase ($Ab_{42}An_{58}$) laths (average length 0·05–0·3 mm.) with subordinate anhedral granules of pale green augite, olivine and iron ore. Smaller olivine crystals are present in glomeroporphyritic aggregates with augite. Augite occurs as microphenocrysts (up to 0·6 mm. in length) exhibiting good hour-glass structure, concentric zoning and frequent twinning. There are two varieties of augite, a pale green one with an extinction angle $\gamma{:}c = 49°$, and a pale brown titaniferous augite with an extinction angle $\gamma{:}c = 54°$ (2V approx. 45°).

Numerous specks of iron ore associated with an indeterminate dust and possibly some devitrified glass fill the interstices of the rock, whilst the widespread vesicles (generally elongated parallel to the flow orientation of the plagioclase laths) are occasionally filled by analcite, or glass and analcite. The analcite forms colourless, slightly radiating aggregates of crystals at the centres of the vesicles, whereas the glass which is devitrified occurs as a brown, turbid discontinuous deposit at the edges of the vesicles. In addition, both minerals sometimes occur as irregular interstitial patches in the rock. The vesicles are filled by some glass and analcite, which is occasionally rimmed by calcite.

4. *Promontory north of Vietor Rock, South Beaches*

Another spectacular columnar-jointed volcanic plug (P.7) occurs 2 miles (3·2 km.) due east of Devils Point (Plate IVc). It is crescent-shaped in plan and rises to 250–300 ft. (76·2–91·4 m.) above sea-level. The vertical columns average 1·0–1·5 ft. (0·3–0·45 m.) across at the base, narrowing to 9 in. (0·23 m.) across at the top of the plug. Although the vertical columns of this plug, like those of Edinburgh Hill, thicken towards the base and show a slight tendency to curve or diverge outwards at the base, they are considerably narrower and the jointing is not so well developed. A further difference between these two plugs is that the columns at station P.7 gradually decrease in diameter towards the top of the plug, whilst those at Edinburgh Hill show a considerable increase.

A specimen from this plug (P.7.1; Table IV; Plate VIe) obtained at sea-level is a dark, medium-grained basalt with numerous dark, lustrous, porphyritic plagioclase phenocrysts. In thin section the plagioclase phenocrysts have a pronounced zoning; their cores usually have a composition of bytownite ($Ab_{16}An_{84}$) and the mantles are acid bytownite ($Ab_{25}An_{75}$) in turn rimmed by andesine ($Ab_{62}An_{38}$). These idiomorphic bytownite phenocrysts are up to 3·6 mm. (average 2 mm.) in length and they contain numerous inclusions from the groundmass (mainly augite, magnetite and serpentine) invariably arranged parallel to the twin planes of the bytownite phenocrysts, although in one crystal they are parallel both to the twin planes and to the cleavage. Some embayments of the larger phenocrysts show that resorption has taken place.

Augite is mainly confined to the groundmass but there are occasional clusters of microphenocrysts in which the crystals attain a length of 0·55 mm. (average 0·07 mm.). They are zoned and exhibit a good hour-glass structure. The serpentine pseudomorphs occasionally have the typical outlines of olivine crystals and in one case some original olivine is still present. The shape of a few bowlingite pseudomorphs is also suggestive of olivine.

The groundmass has an intergranular texture, consisting of platy feldspars (0·09–4·0 mm. in length), augite granules, anhedral magnetite, and serpentine with occasional patches of calcite. The labradorite laths of the groundmass usually have a composition of $Ab_{33}An_{67}$ and they do not exceed 0·44 mm. in length. The pale green serpentine of the groundmass occurs either with a fibrous habit with no pleochroism (antigorite), or as lamellar aggregates pleochroic in yellow-green and brown (bowlingite).

5. *Mount Plymouth, Greenwich Island*

During the summer of 1958–59 an opportunity arose to assist with the topographical survey on

Greenwich Island (Fig. 2). While the main objective of the field party was to complete the triangulation scheme linking with King George Island, it was also possible to make some geological observations.

Mount Plymouth is a volcanic plug situated in the northern half of the island (Plate IVd). Viewed from the south, it is a snow dome with a helmet-shaped appearance rising above the general level of the 1,500 ft. (460 m.) high ice cap to 2,080 ft. (635 m.), the highest feature of the island. The northern side of the mountain, due to its aspect, is formed by a rock face of fine-grained basalt intruded into thinly bedded flow agglomerates (Plate IVd). This intrusive olivine-basalt has a composition similar to that of the other basaltic plugs of Livingston Island and the South Shetland Islands (Table IV), and like Edinburgh Hill the vertical flow structures are parallel to the contact. However, the jointing systems are different. Whereas the polygonal jointing in the plugs of Livingston Island is essentially vertical or fan-shaped, that of the Mount Plymouth intrusion has a marked horizontal disposition, except near the top of the exposure where the horizontal columns are replaced by poorly developed vertical jointing. Volcanic plugs, such as Ternyck Needle and Esther Nunatak on King George Island, which also possess a pronounced horizontal polygonal jointing, have been previously described by Jardine (1950, p. 27).

A specimen of the olivine-basalt (P.54.1) from Mount Plymouth consists of olive and dark green mafic crystals in a fine pale blue-grey matrix. In thin section there are phenocrysts of euhedral augite, and subhedral and euhedral olivine. Augite occurs as monomineralic clusters and glomeroporphyritic aggregates in a subtrachytic matrix of labradorite microlites, granules of augite, olivine and magnetite. The augite ($\gamma{:}c = 56°$) shows both good hour-glass structure and concentric zoning (Plate VIf), and it frequently has a well-defined zone of inclusions parallel to the crystal faces. The olivine phenocrysts, varying in size up to 2·5 mm., contain inclusions of magnetite and they are commonly orientated parallel to microlites which often display a good trachytic texture. The labradorite microlites ($Ab_{41}An_{59}$) average 0·07 mm. in length and 0·01 mm. in width. The larger feldspar laths are slightly more basic ($Ab_{35}An_{65}$) and are up to 0·3 mm. in length and 0·05 mm. in width, but they are infrequent in the groundmass and are usually associated with the glomeroporphyritic clusters.

6. *Columnar jointing*

The four recorded columnar-jointed plugs of Livingston Island exhibit pronounced vertical jointing. Two of them show a gradual change from vertical columns near the top of the plug to ones which curve outwards near their exposed bases. In each case, the contact between the plug and the adjacent rocks has been obscured as a result of erosion or covered by scree and snow. Nearness to the contact is suggested only by the practically horizontal attitude of some of the columns, developed as a margin to the outermost vertical columns in the plug north of Vietor Rock.

In marked contrast to this example, the columns at Mount Plymouth are essentially horizontal for 400 ft. (122 m.) from one side of the plug to the other. The horizontal attitude of these columns can be compared with similar horizontal columns displayed by some dykes where the eruption is of the fissure type. This explanation appears to be most unlikely in view of the topographical form of Mount Plymouth which rises to a solitary peak, and the fact that one can hardly expect all other traces of a linear or fissure eruption to have been completely removed by erosion except for this isolated feature.

A possible explanation for outwardly curving columns and their relationship to horizontal columns has been suggested by Hunt (1938). From studies in the Mount Taylor area of New Mexico, he noted that in the upper parts of volcanic necks the columnar jointing is essentially vertical to platy joints which form a peripheral shell around the outermost set of vertical columns and that with increasing depth the outer columns curve and meet the plates at low angles. At greater depth the inner columns curve sharply and meet the plates at high angles. Although these curved columns were not actually traced into horizontal ones, Hunt estimated that for a volcanic neck 1,000 ft. (305 m.) in diameter horizontal columns would arise at 2,000 ft. (610 m.) in the volcanic necks of the Mount Taylor area. Horizontal columns must result, because the rate of lateral cooling is always greater than the rate of vertical cooling.

However, such an explanation does not seem applicable to the development of horizontal columns in the volcanic plug of Mount Plymouth. The transition from poorly defined vertical columns 2 ft. (0·6 m. across through curved columns into well-defined horizontal columns 6 in. (0·15 m.) across is usually quite abrupt but not clearly traceable. Nevertheless, the transition from vertical columns into horizontal ones can be seen in Plate IVd. The sudden change in the attitude and size of the columns suggests that there must have been a great difference between the vertical and horizontal cooling rates in the Mount Plymouth plug compared to what must have been a gradual change in the cooling rates in the Mount Taylor area described by Hunt.

VI. STRUCTURE

THE major west-south-west to east-north-east axial trend of the South Shetland Islands is reflected in the physiographic trend of the mountainous area of Livingston Island where the older rocks occur. Both the Mount Friesland and Mount Bowles ridges, together with the latter's prolongations into peninsulas, have a west-south-west to east-north-east trend, whereas Hurd Peninsula has a south-west to north-east trend. The Mount Friesland ridge and the Renier Point peninsula consist of the Older Volcanic Group but the Barnard Point area consists of tonalite. The Mount Bowles ridge also consists of the Older Volcanic Group, while Hurd Peninsula consists of the Miers Bluff Series. The western area of the island, however, has a dominant west to east trend and it is formed of the Younger Volcanic Group.

1. *Folding*

The False Bay schists have a north–south trend which varies to south-west–north-east. The foliation of the schists usually dips at 70–80° to the west but several similar dips to the east have also been recorded. A north–south trend has previously been noted in the metamorphic rocks of the Basement Complex of Signy Island (Matthews, 1959).

The sediments forming the Miers Bluff Series have a dominant south-west to north-east trend, varying to west-south-west to east-north-east. The north–south trend noted at several localities, particularly along the coast fronting South Bay, is attributed to minor dip faulting to the south-west of Johnsons Dock and to cross folding to the north-west.

In the well-exposed cliff section forming the south side of Johnsons Dock there is no isoclinal folding or overfolding in the sediments, and the rock exposures in the central part of the peninsula all dip uniformly at about 45° to the north-west and also young in the same direction. Apart from occasional reversals of dip, these greywacke-shale facies sediments therefore appear to form the north-western limb of a major anticline.

An incongruous drag fold above the north-west corner of False Bay (Plate IIId) indicates the presence of a minor syncline plunging to the north-east. But a congruous drag fold north of Johnsons Dock indicates that there has been some overfolding and that the projected major anticlinal structure of the Miers Bluff Series plunges to the south-west (Plate IVa). The age of this folding is probably Triassic, because the folded Trinity Peninsula Series of Graham Land, which is believed to be Carboniferous and of the same age as the Miers Bluff Series, is overlain by Middle Jurassic plant-bearing beds at Hope Bay and elsewhere (Adie, 1957, p. 21). K-Ar dating has also confirmed an orogeny during Triassic times in the South Orkney Islands (Miller, 1960).

2. *Faulting*

Major faults are inferred to occur parallel to the strike of the Miers Bluff Series. The fault trending in a west-south-west to east-north-east direction along False Bay and Huntress Glacier separates sedimentary rocks of (?) Carboniferous age from intrusive tonalites of late Cretaceous to early Tertiary age. This same fault can be traced through Huron Glacier to Greenwich Island. The difference in structure and composition of the volcanic rocks north and south of Yankee Harbour indicates that the same fault continues through Yankee Harbour as far as Discovery Bay. Horizontal basalts occur to the north-west of Yankee Harbour, while bedded porphyritic andesites and trachytes dip south-eastwards on the south-eastern side of the harbour. Its effect on the physiography is clearly reflected in the formation of both Yankee Harbour and Discovery Bay.

The coast of Livingston Island between Renier Point and Barnard Point, a distance of 21 miles (33·8 km.), is remarkably straight for a coastline in a glaciated area. This youthful feature trends in a west-south-west to east-north-east direction and it probably represents a major offshore fault, along which comparatively recent movement has occurred. There is clearly uplift of Livingston Island and the other members of the South Shetland Islands on the north-west side. Gravity and magnetic observations across

Bransfield Strait and the South Shetland Islands confirm the existence of such a fault trending along the south-east margin of the South Shetland Islands, and the uplift is of the order of 6,560 ft. (2 km.) (Griffiths and others, 1964, p. 39). The northern part of Deception Island lies only 0·6 miles (1·0 km.) from a projection of this proposed fault line, 12 miles (19·2 km.) south-west of Barnard Point. Penguin Island, a Recent volcano off King George Island, lies 67 miles (108 km.) to the east-north-east on a projection of the same fault line.

A similar west-south-west to east-north-east fault trends along South Bay and the northern shore of Moon Bay. It separates the Younger Volcanic Group on the north-west from the Miers Bluff Series and the Mount Bowles agglomerates on the south-east. The physiographic difference between the rugged Mount Bowles ridge and the smooth outlines and lower elevation of the ice cap to the north-west has been referred to on p. 4. Edinburgh Hill, a former centre of eruption, also lies on the eastward projection of this fault. An isolated outcrop of vesicular olivine-basalt occurring south-east of this fault suggests that the Younger Volcanic Group formerly may have covered much of the south-eastern area.

Two of the parallel set of three major axial or strike faults affect Tertiary rocks which have been generally regarded as Oligocene—Miocene in age. Considerable post-Miocene epeirogenic movements have therefore occurred, resulting in a minimum 500 ft. (152 m.) uplift of Livingston Island.

Hawkes (1961, p. 22–23) has demonstrated that three lines of crustal weakness, which apparently determined the pattern of Tertiary and Quaternary vulcanicity, are present at King George Island. He has further suggested "the existence of these same tectonic lines in other parts of the South Shetland Islands". Three well-defined faults are now known to occur at Livingston Island. It is doubtful, however, whether Edinburgh Hill lies close to the westward projection of Hawkes's line of olivine-basalts, connecting Cape Melville, Penguin Island and Low Head on King George Island. Edinburgh Hill, an olivine-basalt plug, appears to lie nearer to the westward projection of the "line of basaltic andesites" connecting Davey Point to Flat Top Peninsula on King George Island.

Hawkes has also referred to the problem of whether the Tertiary and Quaternary vulcanicity on King George Island is related to the Andean orogenesis or to the supposed subsidence of Bransfield Strait. Nordenskjöld (Hawkes, 1961, p. 22) suggested that the Recent volcanoes of Deception Island and Bridgeman Island bear a tectonic relationship to the subsidence of Bransfield Strait. Joplin (1959, p. 370–71) has drawn attention to the fact that igneous rocks in non-orogenic regions are characterized by olivine and pyroxene, whereas the femic minerals of the orogenic belts are hornblende and biotite. It should be borne in mind that the Tertiary and Quaternary lavas of King George Island described by Hawkes, as well as those of Livingston Island, contain olivine and pyroxene but no hornblende or biotite. Thus, it could be concluded that these volcanic rocks are probably related to the subsidence of Bransfield Strait rather than to the Andean orogenesis.

VII. GEOLOGICAL HISTORY

THE stratigraphical succession of Livingston Island is broadly comparable with those of King George Island, South Georgia and the Antarctic Peninsula (Table V).

The oldest rocks of Livingston Island, the False Bay schists, crop out on the eastern side of False Bay, north of Charity Glacier. This metamorphic assemblage, consisting mainly of hornblende-biotite-schists and hornblende-schists, occurs as schlieren and screens within the marginal foliated tonalite intrusion forming the Barnard Point peninsula. They are medium-grade regionally metamorphosed rocks, which are considered to be either Precambrian or early Palaeozoic in age (p. 14).

The nearest known occurrence of metamorphic rocks in the Scotia arc is 200 miles (320 km.) to the north-east at Elephant Island, where two more extensive metamorphic sequences have been recognized. Phyllitic schists form the northern part of the island (Cape Valentine) and mica-schists, *para*-amphibolites and marbles form the southern part (Lookout Harbour). Both sequences have been regarded as being metamorphosed sedimentary rocks (Tilley, 1930). Tyrrell (1945) considered them to be the low-grade metamorphic products of a greenstone-greywacke-mudstone succession similar to the Yaghan Formation of Tierra del Fuego (Matthews, 1959, p. 436).

However, their limited extent and the small variety in the metamorphic rocks of Livingston Island preclude any definite conclusion as to their origin. It is suggested that they are either regionally meta-

TABLE V

COMPARISON OF THE STRATIGRAPHY OF LIVINGSTON ISLAND WITH THE MAIN ISLANDS IN THE SCOTIA ARC AND THE ANTARCTIC PENINSULA

	Livingston Island	*King George Island* (modified after Hawkes (1961) and Barton (1965))	*Elephant and Clarence Islands* (after Matthews, 1959)	*South Orkney Islands* (after Matthews, 1959)	*South Georgia* (after Trendall, 1953, 1959)	*Antarctic Peninsula* (after Adie, 1964)
Recent	Glacial deposits Raised beaches	Penguin Island Group				
Pliocene	Williams Point conglomerate	Lions Rump Group				Pecten Conglomerate
Miocene Oligocene	(Dykes) Younger Volcanic Group (andesitic tuffs and lavas with interbedded conglomerates and sandstones)	Point Hennequin Group Fildes Peninsula Group Ezcurra Inlet Group Dufayel Island Group				James Ross Island Volcanic Group ~~~~~~ Seymour Island Series
Late Cretaceous to early Tertiary	Andean Intrusive Suite	Andean Intrusive Suite				Andean Intrusive Suite
Upper Cretaceous (Lower-Middle Campanian)				Conglomerate Shale	Post-Aptian intrusion and folding ~~~~~~	Snow Hill Island Series Cape Longing Series
Lower Cretaceous (Aptian)					Cumberland Bay Series	
Upper Jurassic	Older Volcanic Group	Jurassic volcanic rocks		Dolerite dykes		Upper Jurassic Volcanic Group
Middle Jurassic				Derived Series	(greywacke facies)	Plant beds Basal conglomerate
Triassic	Plant-bearing boulders within Younger Volcanic Group					
(?) Carboniferous	Miers Bluff Series			Greywacke-Shale Series	Sandebugten Series	Trinity Peninsula Series
Early Palaeozoic						Intrusive rocks Volcanic rocks
(?) Precambrian	False Bay schists	Basement Complex	Carbonaceous phyllites ~~~~~~ ? Schists	Basement Complex (metasediments)		Basement Complex

morphosed volcanic rocks of basic to intermediate composition, or metamorphosed calcareous shales derived from basic igneous rocks (Harker, 1950) associated with similar Precambrian sediments, rather than being derived from basic plutonic rocks.

The sediments of Hurd Peninsula, consisting of shales, siltstones, arkosic greywackes and sandstones, are clearly of geosynclinal facies. The occurrence of current-bedding and conglomerates indicates that deposition took place in relatively shallow water, while the presence of shale fragments in the sandstones and sandstone particles in the shales points to unstable conditions during sedimentation. The inter-bedding of altered volcanic rocks with feldspathic sandstones, north of Huntress Glacier, indicates that there was active volcanism during the deposition of the Miers Bluff Series.

Although the volcanic rocks are separated from the main succession of the Miers Bluff Series by about 1 mile (1·6 km.) of ice-covered terrain, there appears to be only a slight but no major discontinuity between these rocks and the main succession. This seems to suggest that vulcanicity occurred during the deposition of the middle or upper geosynclinal sequence. Volcanic rocks have not been previously recorded from the Trinity Peninsula Series of Graham Land, but the abundance of volcanic phenoclasts throughout the succession of north-east Graham Land (Aitkenhead, 1965, p. 25) substantiates the fact that there must have been some volcanic activity during the deposition of this sequence.

The provenance of the Miers Bluff Series sediments appears to have been to the north-west. Plant material consisting mainly of woody stems reveals that the source area could not have been too far distant and that the climate was congenial to plant growth. A "reef" limestone interbedded with the sediments of the upper part of the Trinity Peninsula Series of Graham Land (Fleet, 1965, p. 75) could be indicative of shallow-water conditions. A similar environment would appear to have existed during the deposition of the Miers Bluff Series.

No identifiable fossil remains have been found in the Miers Bluff Series. However, the Trinity Peninsula Series, with which these sediments have been tentatively correlated, are now believed to be Carboniferous in age. Evidence from K-Ar dating of the Basement Complex rocks of the South Orkney Islands (Miller, 1960) indicates the occurrence of an orogeny during Upper Triassic to Lower Jurassic times. The Palaeozoic sediments of Livingston Island, therefore, presumably attained their present attitude as a result of the same earth movements which uplifted and folded them into a dominantly anticlinal structure with a south-west to north-east axial trend.

During the Lower to Middle Triassic considerable uplift of this area, connected with the Upper Triassic to Lower Jurassic orogeny, gave rise to a landmass where the prevailing climate allowed the development of an Upper Gondwana flora.

Well-preserved fossil plants recovered from fragmented boulders from a conglomerate in the Younger Volcanic Group at Williams Point have recently been described and assigned to the Lower to Middle Triassic (Orlando, 1968). He has suggested that the fossil plant material accumulated in a lacustrine basin of limited extent and comparable with similar Lower to Middle Triassic basins in Argentina. Frenguelli (1948) has described such a basin as being tectonically active, allowing the accumulation of thick deposits in lacustrine environments with flat bottoms and shallow waters.

A period of renewed vulcanicity led to vast eruptions of trachytic andesites, andesitic agglomerates and basaltic lavas belonging to the Older Volcanic Group. Although there is no direct evidence for the age of these volcanic rocks, the agglomerates contain fragments of feldspathic sandstone similar to that of the Miers Bluff Series, indicating they are at least younger than the Miers Bluff Series. These volcanic rocks possess general petrological affinities to the Upper Jurassic Volcanic Group of Graham Land. The Upper Jurassic volcanic rocks of Cape Disappointment on the east coast of Graham Land contain carbonized woods (Adie, 1958, p. 8), while tuffs of the same age containing fossil woods have also been recorded from King George Island (Hawkes, 1961, p. 5), thus indicating a terrestrial source for many of the eruptions. However, Curtis (1966, p. 49) has demonstrated that the thick series of andesitic lavas along Penola Strait off the Graham Coast must have been deposited in water close to a shoreline and that there was subsidence during accumulation. It therefore seems most probable that similar conditions to those described above existed at Livingston Island during the extrusion of the rocks of the Older Volcanic Group.

Sediments of a Cretaceous age are apparently absent from Livingston Island and it would appear that at this time the island was above sea-level. There is evidence of similar conditions prevailing in the South Orkney Islands, where Matthews (1959, p. 434) has recorded a coarse-bedded conglomerate 1,700 ft.

(520 m.) thick which is believed to have been deposited on land. He has tentatively considered the conglomerate to be Cretaceous in age.

Plutonic intrusions, mainly with a tonalite composition, form the Barnard Point peninsula but the contact with the Miers Bluff Series unfortunately trends through False Bay. North of Johnsons Dock a tonalite apophysis which intrudes the Miers Bluff Series has petrographical affinities to the larger tonalite intrusion at Barnard Point and there is no doubt they are related to one another. From the field relations a post-Carboniferous age is therefore suggested for this plutonic intrusive phase.

In Graham Land, where the Andean Intrusive Suite forms a major part of the peninsula, a similar lack of evidence is noticeable concerning the age of the plutonic intrusions. Adie (1955) has stated that "From an abundance of field data it is now clear that the Andean intrusives are younger than both the Trinity Peninsula Series and the Middle to Upper Jurassic sediments and volcanics but nowhere has the relationship been established between the Lower and Upper Cretaceous sediments and the intrusives." On the basis of a petrological and geochemical analogy with the Andean intrusive rocks of the west Patagonian Cordillera, a late Cretaceous to early Tertiary age has been inferred (Adie, 1955, p. 4). Since the plutonic intrusions of Livingston Island also have Andean characteristics, it is probable they are of the same age.

Towards the end of the Oligocene renewed volcanic activity occurred, resulting in the eruption of a sequence of lavas, tuffs and agglomerates of andesitic composition with subsidiary flow basalts (the Younger Volcanic Group). The very occurrence of conglomerates and sandstones in this volcanic sequence suggests that many of these volcanic eruptions occurred in a shallow submarine environment. A number of volcanic necks have been recorded and these were the vents for the lavas, agglomerates and tuffs; most probably a whole series of vents and fissures erupted lavas along a west to east submarine ridge. At different times the submarine ridge must have risen above sea-level, resulting in the growth of a considerable vegetation cover indicative of a temperate climate during Oligocene—Miocene times.

Three major faults, which are possibly post-Pliocene in age, are indicative that faulting occurred after the formation of the Younger Volcanic Group. Some of the volcanic centres can be related to these faults and volcanic activity probably continued through the Pleistocene into the Recent and up to the present day, as at Penguin and Deception Islands. There are no post-glacial volcanoes such as Penguin Island at Livingston Island, but the numerous small gas discharges that have been recorded are indicative of volcanic dormancy.

It is clear that there has been a considerable recession in the ice cover, at least 100 ft. (30·5 m.) of thinning of the ice cap, and it is still continuing. The flat even appearance of Byers Peninsula is considered to indicate uplift of at least 175 ft. (53·3 m.) in relatively recent times.

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IX. REFERENCES

ADIE R. J. 1953. *The rocks of Graham Land.* Ph.D. thesis, University of Cambridge, 259 pp. [Unpublished.]

———. 1954. The petrology of Graham Land: I. The Basement Complex; early Palaeozoic plutonic and volcanic rocks. *Falkland Islands Dependencies Survey Scientific Reports*, No. 11, 22 pp.

———. 1955. The petrology of Graham Land: II. The Andean Granite-Gabbro Intrusive Suite. *Falkland Islands Dependencies Survey Scientific Reports*, No. 12, 39 pp.

ADIE, R. J. 1957. The petrology of Graham Land: III. Metamorphic rocks of the Trinity Peninsula Series. *Falkland Islands Dependencies Survey Scientific Reports*, No. 20, 26 pp.

———. 1958. Geological investigations in the Falkland Islands Dependencies since 1940. *Polar Rec.*, **9**, No. 58, 3–17.

———. 1962. The geology of Antarctica. (*In* WEXLER, H., RUBIN, M. J. *and* J. E. CASKEY, *ed. Antarctic research: the Matthew Fontaine Maury Memorial Symposium.* Washington, D.C., American Geophysical Union, 26–39.) [Geophysical monograph No. 7.]

———. 1964. Geological history. (*In* PRIESTLEY, R. E., ADIE, R. J. *and* G. DE Q. ROBIN, *ed. Antarctic research.* London, Butterworth and Co. (Publishers) Ltd., 118–62.)

AITKENHEAD, N. 1965. The geology of the Duse Bay–Larsen Inlet area, north-east Graham Land (with particular reference to the Trinity Peninsula Series). *British Antarctic Survey Scientific Reports*, No. 51, 62 pp.

BARTON, C. M. 1965. The geology of the South Shetland Islands: III. The stratigraphy of King George Island. *British Antarctic Survey Scientific Reports*, No. 44, 33 pp.

CROWELL, J. C. 1955. Directional-current structures from the Prealpine Flysch, Switzerland. *Bull. geol. Soc. Am.*, **66**, No. 11, 1351–84.

CURTIS, R. 1966. The petrology of the Graham Coast, Graham Land. *British Antarctic Survey Scientific Reports*, No. 50, 51 pp.

FERGUSON, D. 1921. Geological observations in the South Shetlands, the Palmer Archipelago, and Graham Land, Antarctica. *Trans. R. Soc. Edinb.*, **53**, Pt. 1, No. 3, 29–55.

FLEET, M. 1965. Metamorphosed limestone in the Trinity Peninsula Series of Graham Land. *British Antarctic Survey Bulletin*, No. 7, 73–76.

FOLK, R. L. 1959. *Petrology of sedimentary rocks.* Austin, Texas, University of Texas.

FRENGUELLI, J. 1948. Estratigrafía y edad del llamado "Rético" en la Argentina. *Gaea, B. Aires*, **8**, 159–309.

GRIFFITHS, D. H., RIDDIHOUGH, R. P., CAMERON, H. A. D. *and* P. KENNETT. 1964. Geophysical investigation of the Scotia arc. *British Antarctic Survey Scientific Reports*, No. 46, 43 pp.

HARKER, A. 1950. *Metamorphism: a study of the transformations of rock-masses.* 3rd edition. London, Methuen and Co. Ltd.

HATTERSLEY-SMITH, G. 1949. King George Island glaciological report for 1948–49. [Unpublished.]

HAWKES, D. D. 1961. The geology of the South Shetland Islands: I. The petrology of King George Island. *Falkland Islands Dependencies Survey Scientific Reports*, No. 26, 28 pp.

HOBBS, G. J. 1958. Geological report—Base O, January 1957–December 1958. (F.I.D. Sc. Bureau No. 22/59), 12 pp. [Unpublished.]

HOLTEDAHL, O. 1929. On the geology and physiography of some Antarctic and sub-Antarctic islands. *Scient. Results Norw. Antarct. Exped.*, No. 3, 172 pp.

HOSKINS, A. K. 1963. Block terraces in the Neny Fjord area, Marguerite Bay, Graham Land. *British Antarctic Survey Bulletin*, No. 1, 45–49.

HUNT, C. B. 1938. A suggested explanation of the curvature of columnar joints in volcanic necks. *Am. J. Sci.*, Ser. 5, **36**, No. 212, 142–49.

JARDINE, D. J. 1950. Base G, Admiralty Bay report (1949). Geology report. (F.I.D. Sc. Bureau No. 83/50), 31 pp. [Unpublished.]

JOPLIN, G. A. 1959. On the origin and occurrence of basic bodies associated with discordant bathyliths. *Geol. Mag.*, **96**, No. 5, 361–73.

MATTHEWS, D. H. 1959. Aspects of the geology of the Scotia arc. *Geol. Mag.*, **96**, No. 6, 425–41.

MILL, H. R. 1905. *The siege of the South Pole. The story of Antarctic exploration.* London, Alston Rivers, Limited.

MILLER, J. A. 1960. Potassium-argon ages of some rocks from the South Atlantic. *Nature, Lond.*, **187**, No. 4742, 1019–20.

NICHOLS, R. L. 1953. *Geomophology of Marguerite Bay, Palmer Peninsula, Antarctica.* Washington, D.C., Department of the Navy, Office of Naval Research. [Ronne Antarctic Research Expedition, Technical Report No. 12.]

———. 1961. Tufts College—National Science Foundation Antarctic Expedition, 1959–60. *Polar Rec.*, **10**, No. 67, 401.

NOCKOLDS, S. R. 1954. Average chemical compositions of some igneous rocks. *Bull. geol. Soc. Am.*, **65**, No. 10, 1007–32.

ORLANDO, H. A. 1968. A new Triassic flora from Livingston Island, South Shetland Islands. *British Antarctic Survey Bulletin*, No. 16.

PETTIJOHN, F. J. 1957. *Sedimentary rocks.* 2nd edition. New York, Harper and Brothers.

TILLEY, C. E. 1930. Petrographical notes on rocks from Elephant Island, South Shetlands. (*In Report on the geological collections made during the voyage of the "Quest" on the Shackleton-Rowett Expedition to the South Atlantic and Weddell Sea in 1921–1922.* London, Trustees of the British Museum, 55–62.)

TRENDALL, A. F. 1953. The geology of South Georgia: I. *Falkland Islands Dependencies Survey Scientific Reports*, No. 7, 26 pp.

———. 1959. The geology of South Georgia: II. *Falkland Islands Dependencies Survey Scientific Reports*, No. 19, 48 pp.

TYRRELL, G. W. 1921. A contribution to the petrography of the South Shetland Islands, the Palmer Archipelago, and the Danco Land coast, Graham Land, Antarctica. *Trans. R. Soc. Edinb.*, **53**, Pt. 1, No. 4, 57–79.

———. 1945. Report on rocks from west Antarctica and the Scotia arc. *'Discovery' Rep.*, **23**, 37–102.

WENTWORTH, C. K. 1936. An analysis of the shapes of glacial cobbles. *J. sedim. Petrol.*, **6**, No. 2, 85–96.

WILLIAMS, H., TURNER, F. J. *and* C. M. GILBERT. 1954. *Petrography: an introduction to the study of rocks in thin sections.* San Francisco, Freeman.

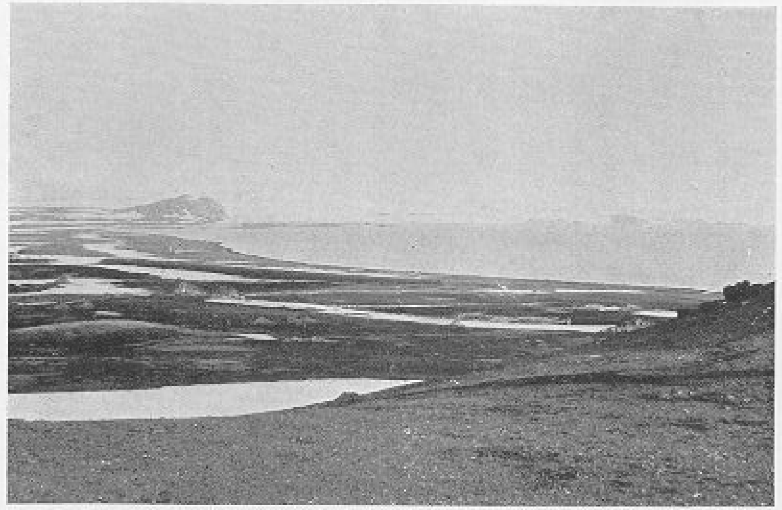
PLATE I

a. South Beaches viewed from the west, showing the raised beaches and a volcanic plug rising above the general level of Byers Peninsula. The distance between the volcanic plug and the beaches in the foreground is 3 miles (4·8 km.).

b. Three raised beaches which are respectively 8–10, 25 and 40 ft. (2·4–3·0, 7·6 and 12·2 m.) above sea-level at Elephant Point.

c. Four raised beaches and a storm beach at Barnard Point. The distance from the right-hand rock at sea-level to the camera is approximately 300 yd. (275 m.).

d. Large rounded tonalite boulders on a wave-cut platform, 12 ft. (3·6 m.) above sea-level, south of Charity Glacier.



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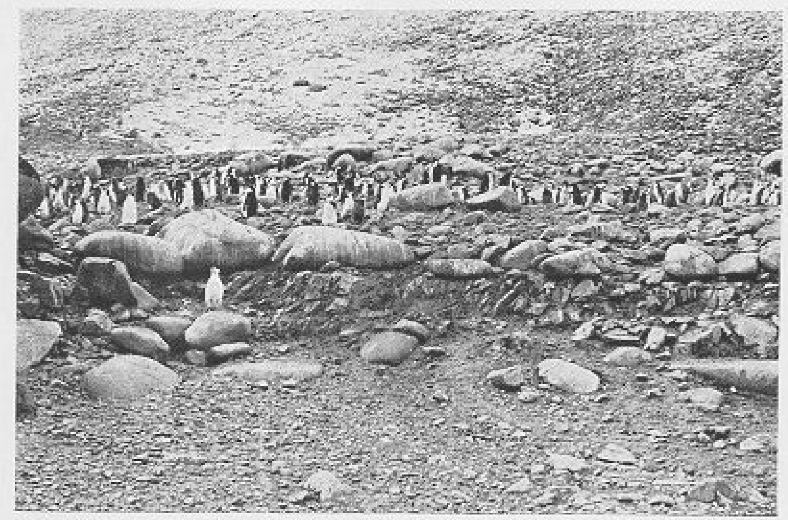

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PLATE I

PLATE II

a. Entrance to a raised sea cave 25 ft. (7·6 m.) above sea-level at Elephant Point.

b. Dirt bands showing convolutions in the snout of a retreating cirque glacier, with a poorly developed terminal moraine (right foreground), south of Charity Glacier. The exposed section of dirt bands in the glacier snout is approximately 20 ft. (6·1 m.) high.

c.. A view from Hurd Peninsula of the snout of Huntress Glacier, showing the marked medial moraine, a small rock exposure at the foot of the ice cliff (left foreground) and the Mount Friesland ridge in the background. The ice cliff is approximately 80 ft. (24·4 m.) high.

d. A crescent-shaped terminal moraine, 20 ft. (6·1 m.) high, at the snout of a retreating cirque glacier, Barnard Point.

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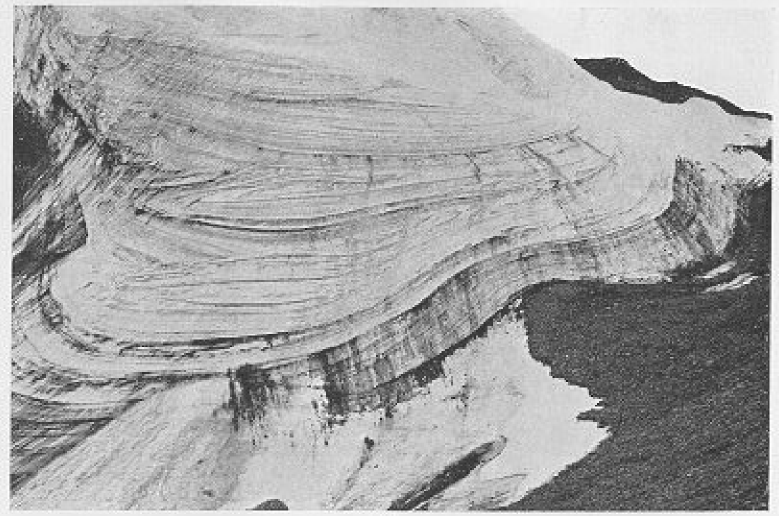

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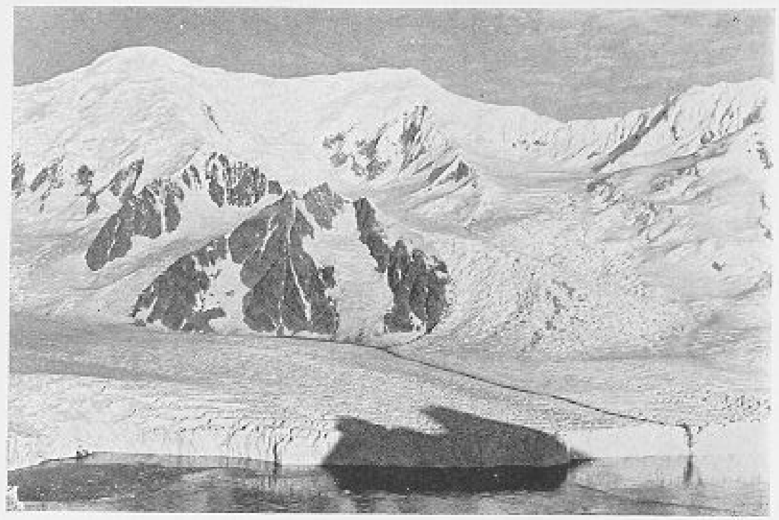

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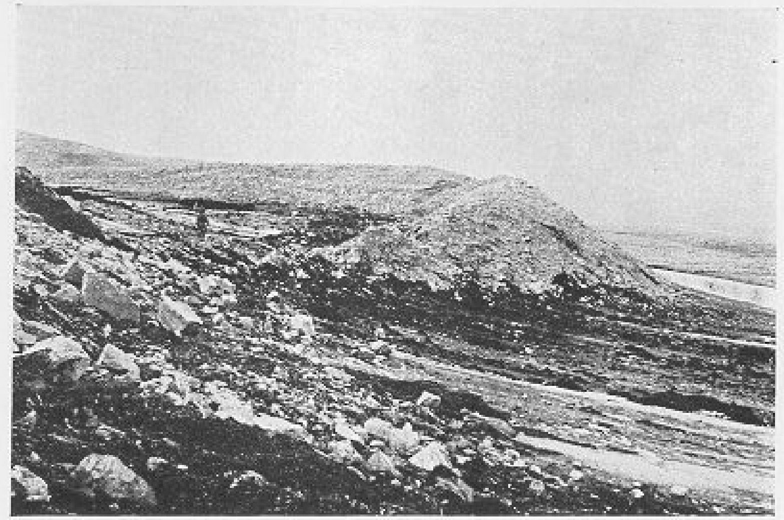

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PLATE II

PLATE III

a. A block terrace approximately 75 ft. (22·8 m.) above sea-level viewed from Charity Glacier. A wave-cut platform, 12 ft. (3·6 m.) above sea-level, can be seen in the foreground.

b. Rounded pebbles (P.33.1,2), the largest 3 in. (7·6 cm.) in length and weighing 294 g., found in a block terrace south of Charity Glacier.

c. General view of the Miers Bluff Series from above the north-west corner of False Bay towards the south-west. In the background the dip of the sediments to the north-west is just discernible.

d. Thinly bedded shales and greywackes of the Miers Bluff Series, above the north-west corner of False Bay, with incongruous drag folds pitching at right-angles to the south-west to north-east strike.

PLATE III

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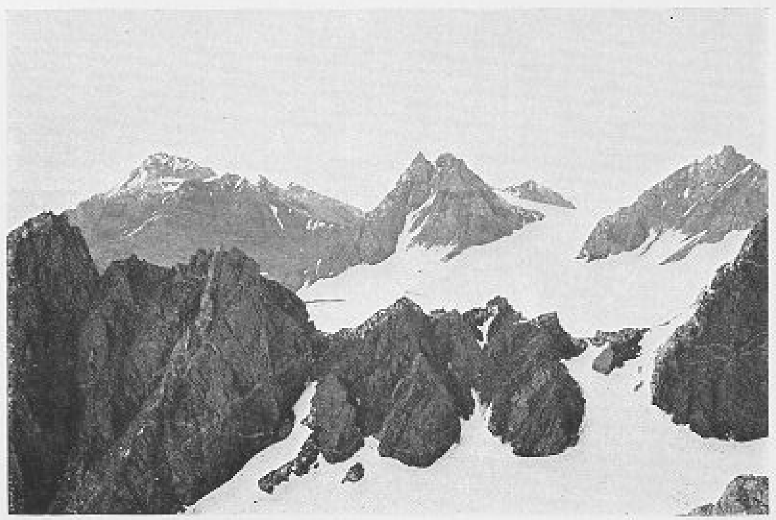

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PLATE IV

a. Small drag fold plunging at 10° to the west-south-west in the Miers Bluff Series; north of the entrance to Johnsons Dock.

b. Edinburgh Hill (360 ft.; 109·7 m.), a volcanic plug on the west side of McFarlane Strait, viewed from the north-east.

c. A volcanic plug with vertical columnar jointing on the promontory north of Vietor Rock, South Beaches (P.7). At the top left of the photograph the columnar jointing is almost horizontal, indicating proximity to the contact.

d. Mount Plymouth (2,080 ft.; 635 m.), a volcanic plug with horizontal columnar jointing. The contact with bedded basaltic agglomerates can be seen in the lower part of the photograph.

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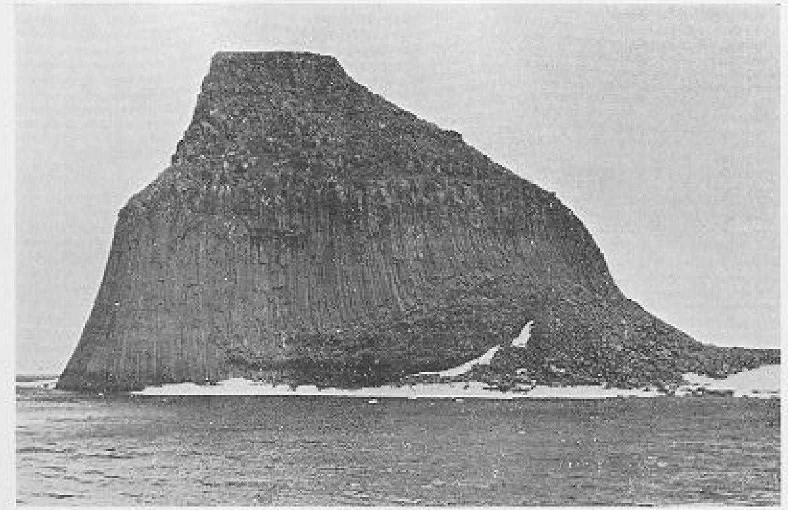

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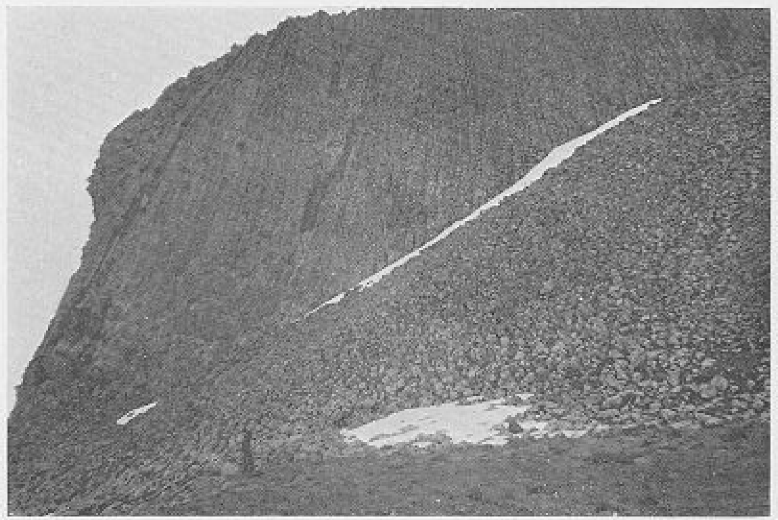

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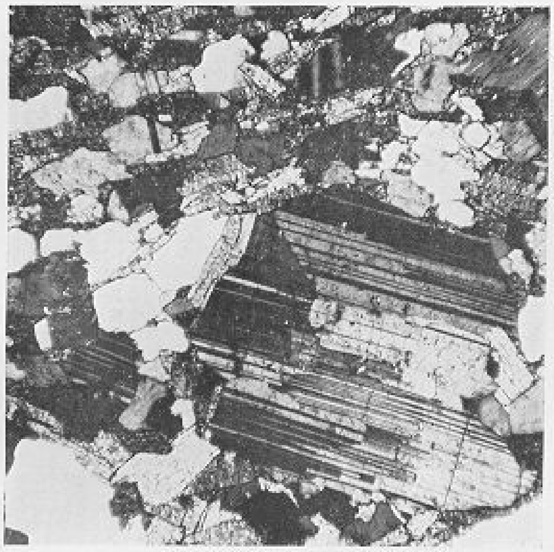
PLATE IV



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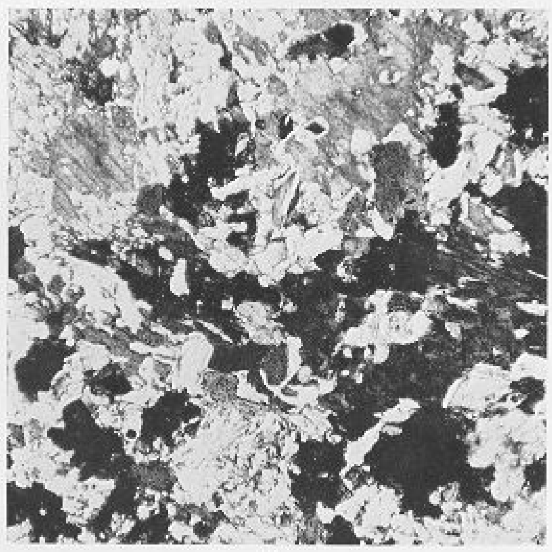

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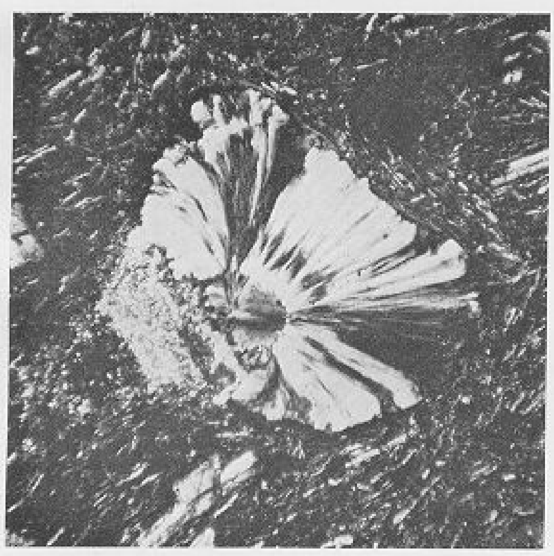

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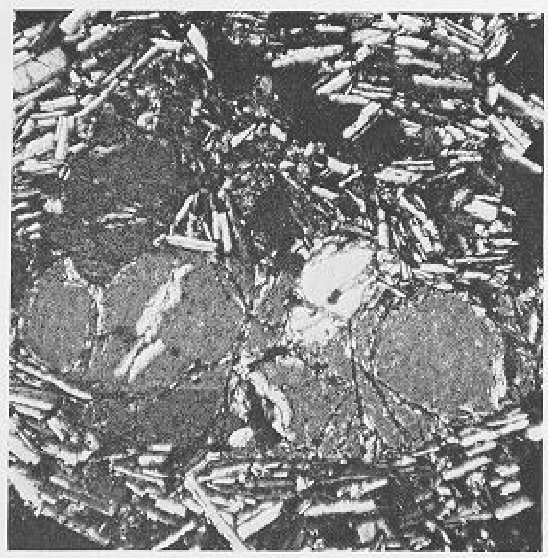

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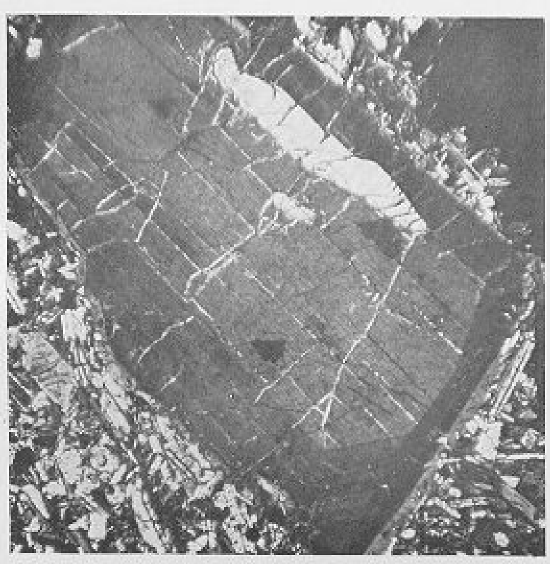

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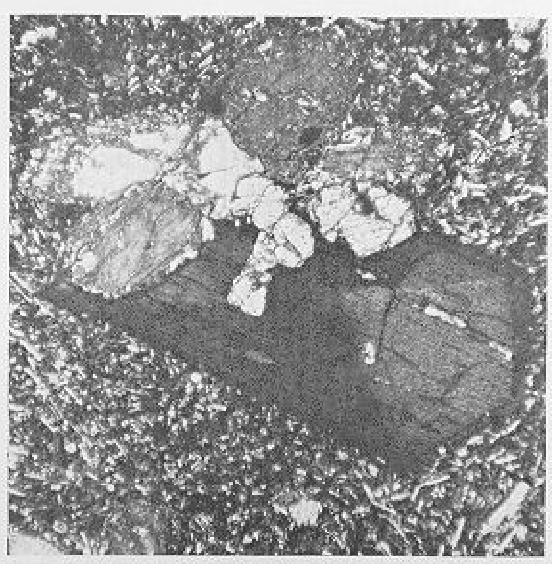

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PLATE V

a. Hornblende-biotite-schist from the north side of Charity Glacier (Fig. 1). Hornblende, andesine, quartz and iron ore are the principal constituents with minor amounts of biotite. The hornblende shows a slight foliation to the felsic folia (P.17.4; X-nicols; ×52).

b. Hornblende-schist showing pronounced lineation of the hornblendes to the mafic folia. Biotite is no longer present and iron ore occurs only as an accessory mineral (P.17.1; X-nicols; ×47).

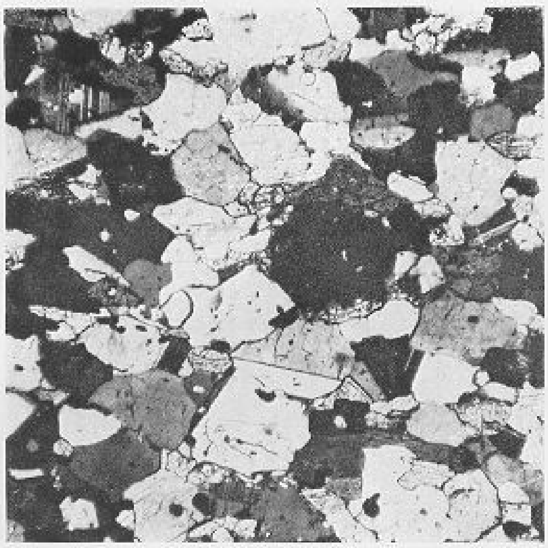
c. Interbedded conglomerate from the Miers Bluff Series to the east of Johnsons Dock. The photograph shows a rounded quartz-plagioclase-porphyry pebble together with parts of shale and sandstone fragments. Altered plagioclase, quartz and calcite are also present (P.43.1; X-nicols; ×40).

d. Arkosic greywacke from the Miers Bluff Series. The photograph shows that altered plagioclase forms the principal constituent of the rock together with sub-angular to sub-rounded quartz. Chlorite and biotite occur in the matrix (P.32.1; ordinary light; ×52).

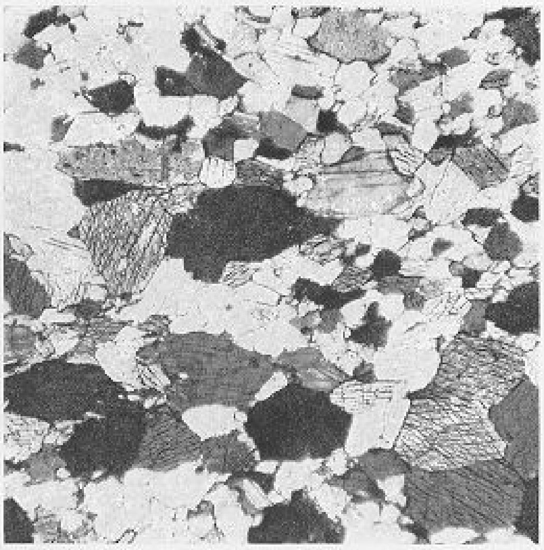
e. Tonalite from the summit peak of Barnard Point. A phenocryst of orthoclase poikilitically encloses tabular plagioclase laths, which show pronounced corrosion of their edges. Twinned hornblende crystals and some iron ore are also present. The mode of this rock is given in Table III (P.22.3; X-nicols; ×48).

f. Foliated tonalite. Laths of hornblende and flakes of biotite are foliated with the banding, together with quartz and plagioclase (P.17.3; ordinary light; ×44).

PLATE V



a



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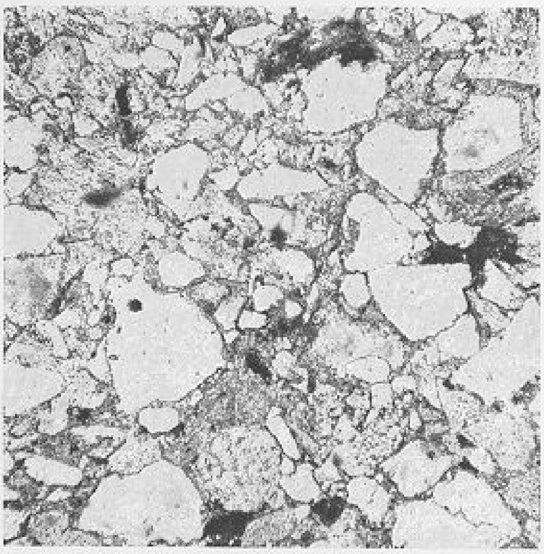

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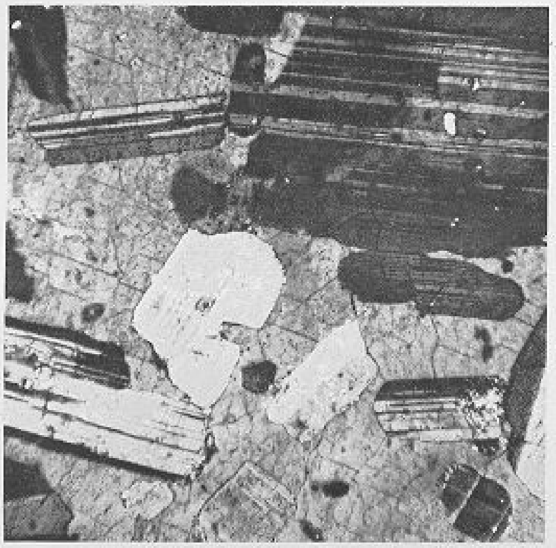

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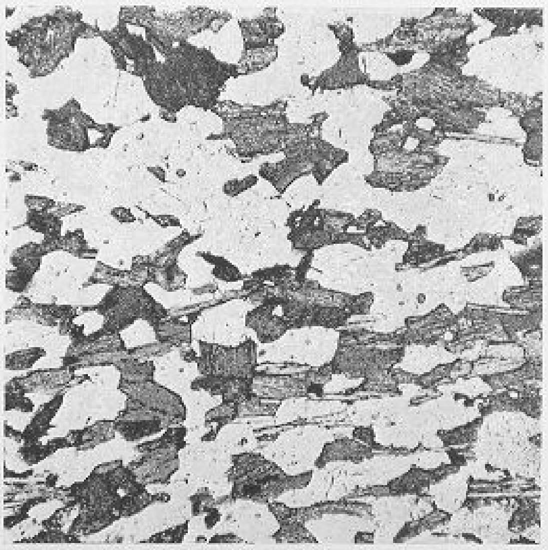

f

PLATE VI

a. Foliated tonalite contact showing the coarser gneissic areas consisting of plagioclase and quartz with a granoblastic texture, and biotite in lenses with a lepidoblastic texture (P.18.1; X-nicols; ×42).

b. Specimen from an altered diorite screen on the north side of Charity Glacier. Hornblende occurs as a plexus of large ragged plates poikilitically enclosing (?) spinel and a saussuritic aggregate of muscovite, sericite, zoisite and magnetite (P.17.2; ordinary light; ×46).

c. An andesitic lava from the base of the cliff exposure at the eastern end of Hannah Point. Spherulitic sheaves of chalcedony fill vesicles in a groundmass of trachytic texture (P.2.1; X-nicols; ×47).

d. Xenolith of vesicular basalt. Olivine phenocrysts are set in a trachytic matrix of plagioclase laths with subordinate granules of augite, olivine and iron ore. The vesicles are filled by analcite (P.100.1; X-nicols; ×42).

e. Altered olivine-basalt from a volcanic plug. Zoned phenocrysts of plagioclase occur in a groundmass of intergranular texture consisting of platy plagioclase, augite granules and anhedral magnetite, with serpentine and calcite (P.7.1; X-nicols; ×40).

f. Olivine-basalt from the Mount Plymouth plug. Olivine and augite form a glomeroporphyritic texture within a subtrachytic groundmass of augite, labradorite microlites, granules of augite, olivine and magnetite (P.54.1; X-nicols; ×40).