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THE PETROLOGY OF THE GRAHAM COAST, GRAHAM LAND

By

R. CURTIS, B.Sc., Ph.D.
Falkland Islands Dependencies Survey
and
Department of Geology, University of Birmingham

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ABSTRACT

THE petrology of the Graham Coast and the adjacent offshore islands is described in detail. The succession of siltstones, shales and feldspathic greywackes, which has been found in a few isolated areas, has been correlated with the late Palaeozoic Trinity Peninsula Series. These sediments have suffered pre-Jurassic, low-grade regional metamorphism, and thermal metamorphism where they are adjacent to Andean intrusions.

The Upper Jurassic Volcanic Group has a minimum thickness of 5,000 ft. (1,525 m.), comprising approximately 1,000 ft. (305 m.) of andesite lavas and interbedded tuffs overlain by 4,000 ft. (1,220 m.) of pyroclastic rocks. Extensive hydrothermal alteration is a characteristic feature of the volcanic rocks, but where they are intruded by members of the Andean Intrusive Suite the volcanic rocks have been thermally metamorphosed.

The initial gabbro intrusion phase of the Andean Intrusive Suite was followed by successive intrusions of granodiorite magma. The early granodiorite magma intrusions incorporated large quantities of gabbroic material, a process which resulted in their basification to a hybrid dioritic composition. Basification had been completed before the magma attained its present level. Successive intrusions of granodiorite magma were progressively less modified and the trend of intrusion, diorite—tonalite—granodiorite, is one of decreasing contamination. The late granites and granophyres are thought to represent crystallization-differentiation products of the granodiorite magma. Intrusive activity on the Graham Coast closed with the emplacement of post-Andean dyke swarms. However, these hypabyssal rocks have not yet been studied.

It is suggested that the present morphological configuration of the Antarctic Peninsula is due to large-scale faults which developed during the late Tertiary uplift.

CONTENTS

I. INTRODUCTION

THE Antarctic Peninsula is approximately 900 miles (1,450 km.) long and extends from the mainland of Antarctica towards the southern tip of South America. The peninsula varies in width from 25 miles (40 km.) to 150 miles (240 km.); it trends south to north for 400 miles (645 km.), then south-west to north-east towards its northern termination. The Graham Coast is situated on the west coast of the peninsula between lat. 66°15′ and 65°00′S., and is approximately 100 miles (160 km.) long (Fig. 1). In this region the flat-topped peninsula has an average height of 5,500 ft. (1,675 m.) and is bounded by steep cliffs, many of which are over 2,000 ft. (610 m.) high. The coastline is severely indented and there are numerous offshore islands.

The first recorded observations in the Graham Coast area were made by John Biscoe, who sailed along the west coast of the Biscoe Islands as far south as Adelaide Island in February 1832. In 1874 Dallman discovered and named Bismarck Strait and a group of islands at the northern end of the Graham Coast. In 1893 Evensen sailed for several days between the Biscoe Islands and the mainland. The Graham Coast was first investigated geologically by Gourdon during Charcot's 1903–05 and 1908–10 expeditions. Charcot named many of the islands in Grandidier Channel and prominent features on the mainland. Gourdon made a systematic collection of rock specimens, describing hornblende-granites, quartz-diorites, uralitized gabbros and fine-grained volcanic rocks from the area between Wiencke Island in the Palmer Archipelago and Cape Tuxen. He concluded that the intrusive rocks constituted a continuous petrographic series, and that continuity was most evident between the quartz-diorites and the granites. He considered the volcanic rocks were of recent origin (Gourdon, 1905, 1906, 1907, 1908, 1910, 1914*a*,*b*). Gourdon's (1908) geological map of the Penola Strait–Lemaire Channel area contains certain inconsistencies; at the height of summer when rock exposure is at a maximum, the writer examined much of the area covered by Gourdon and found no relation between the rock types at the exposures (Fig. 2) and those shown on Gourdon's map.

Although the Danco Coast and Anvers Island to the north were further investigated in 1913 by Ferguson (1921) and in 1927 by Holtedahl (1929), the Graham Coast was not visited again until 1934 when the British Graham Land Expedition set up a base station at the Argentine Islands. The geologist, W. L. S. Fleming, worked both locally and in the Beascochea Bay area, but some specimens were also collected during a sledge journey to Marie Island at the southern end of the Graham Coast. It is unfortunate that, apart from a short preliminary note (Fleming and others, 1938) in which are listed the rock types found, no further geological information was published.

The Graham Coast (see Sheet W 65 64, D.O.S. 610, Series D 501, 1959), in common with much of the west coast of Graham Land, consists of a series of broad bays which are rarely more than 10 miles (16 km.) deep. The head of each bay is formed by the snout of a glacier or glacier system which cuts back deeply into the mainland. There are numerous offshore islands and groups of islands, many of which are of the strandflat type. Bays, glaciers and deep channels trending parallel to the coast form a rectangular pattern, the significance of which is discussed below. South of Takaki Promontory, as far as Cape Evensen, the coastline is almost one continuous ice cliff 100–200 ft. (30·5–61 m.) in height. Inland snowfields rise up to heights of 1,500–2,000 ft. (455–610 m.) and end at the foot of the plateau wall. The snowfields, which correspond to Holtedahl's (1929) strandflat glaciers, vary from 3 to 9 miles (4·8 to 14·5 km.) in breadth, and they are occasionally broken by serrated ridges, distinct peaks and more massive remnants of the plateau. The coastline north of Beascochea Bay is not severely embayed, strandflat glaciers are greatly reduced in both width and number, and much of the coastline consists of high rock cliffs.

Most of the offshore islands are of strandflat type, the origin of which has been the subject of detailed study by Holtedahl (1929, p. 9–28, 146–67). Comparing the fjord coastline of western Norway with the broad bays of the west coast of Graham Land, he concluded that the former arose from the glaciation of an upland area with a predetermined erosion pattern, such as a system of river-cut valleys. Along these valleys ice erosion was concentrated. For Graham Land he suggested that glaciation started on a fairly undissected post-Andean peneplain, resulting in a system of relatively short broad bays, sometimes making a very composite pattern, yet with certain dominating lines. This hypothesis, however, is not consistent with the rectangular pattern shown by the trends of the bays, glaciers and offshore channels. It appears that there was some predetermined pattern along which ice erosion was concentrated. The present writer favours structural control of glacial erosion. Large-scale faulting can be demonstrated in Lemaire Channel, one of the most spectacular offshore channels on the west coast of Graham Land. Hydrographic data indicate that the deep water of Lemaire Channel continues southward parallel to the coast, forming a submarine

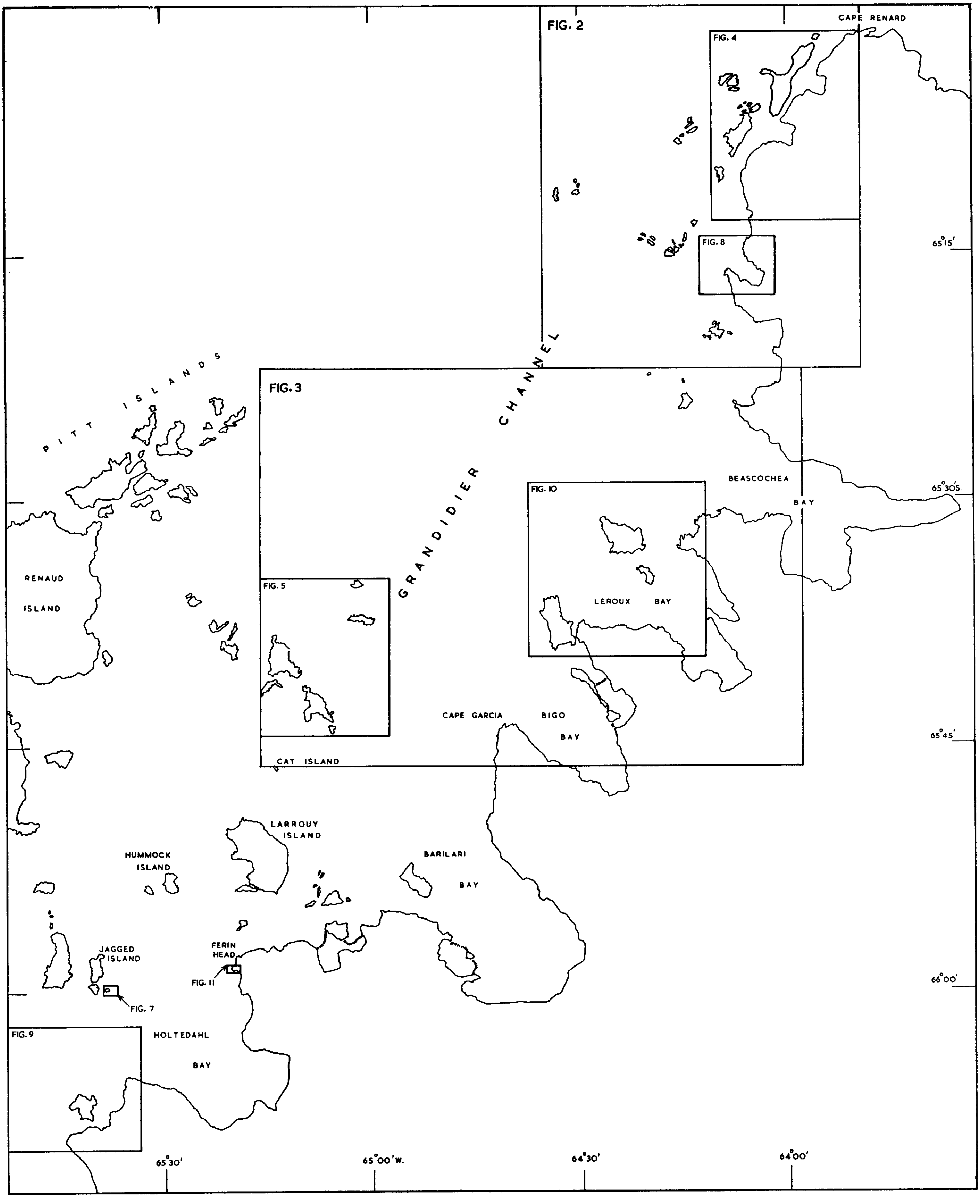

FIGURE 1
Sketch map of the Graham Coast showing the locations of detailed maps appearing elsewhere in this report.

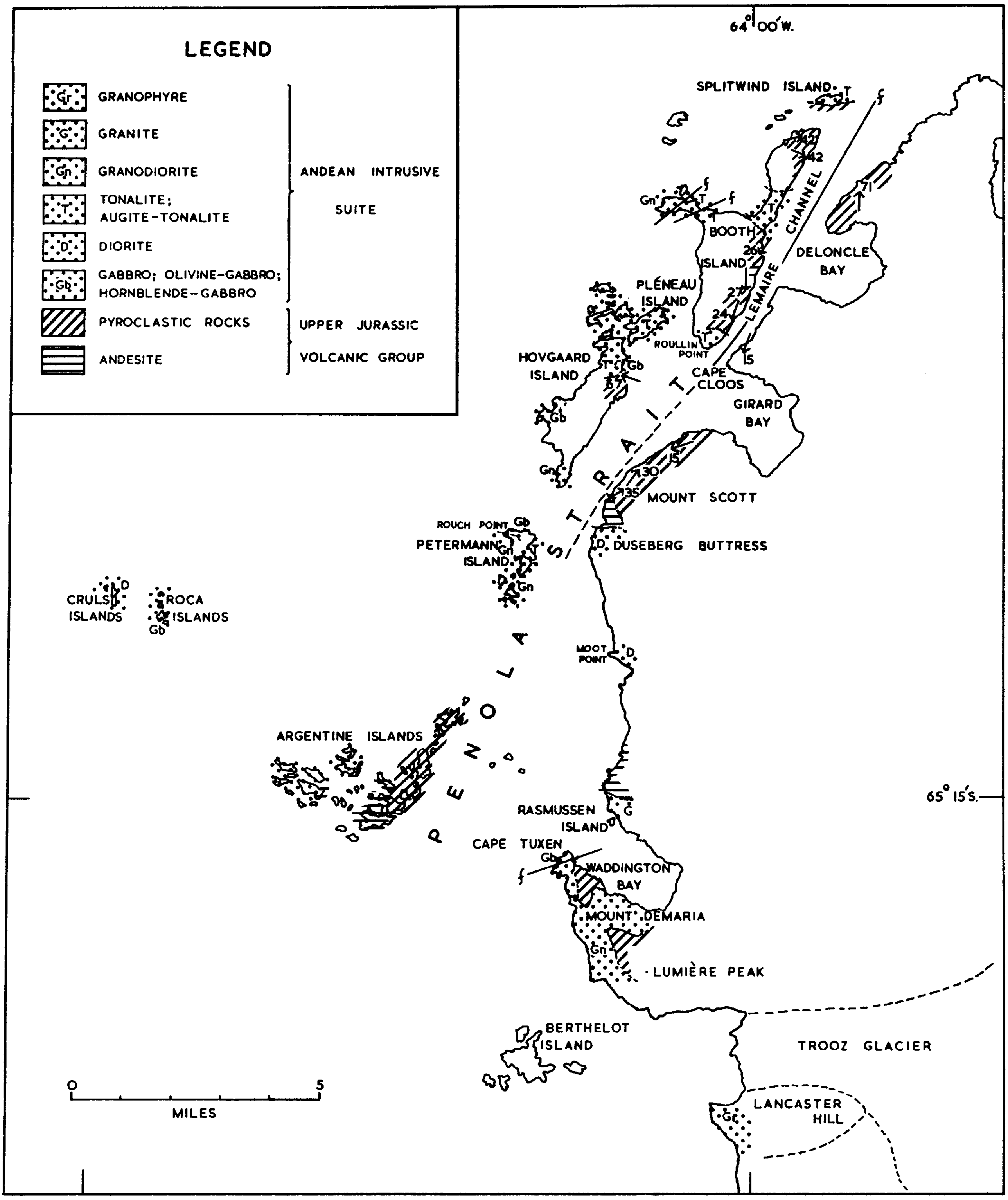

FIGURE 2

Geological map of the Penola Strait—Lemaire Channel area and offlying islands.

valley. Corresponding deeps at right-angles occur between the Argentine Islands and Petermann Island, and opposite Girard Bay. Hooper (1962) has described severe block-faulting on Wiencke Island and along Neumayer Channel, and has emphasized the role played by block-faulting in the uplift of Graham Land. Along much of the east coast, Adie (1955) has shown the existence of large-scale longitudinal faults. It is suggested, therefore, that the overall trend of the glacial valleys, bays and coastline are controlled by a system of rectangular faults marginal to the main area of uplift. This would facilitate the splitting up of the land into "peninsulas and islands" prior to the formation of the areas of strandflat, as envisaged by Holtedahl.

It must be emphasized that as yet there is no definite proof of the exact age of the stratigraphical units of the Graham Coast. The ages given in Table I result from comparison with similar types of rocks in the fossiliferous area of Hope Bay (Adie, 1953).

TABLE I

STRATIGRAPHY OF THE GRAHAM COAST

Tertiary	Dykes
Upper Cretaceous to early Tertiary	Andean Intrusive Suite
Upper Jurassic	Upper Jurassic Volcanic Group (pyroclastic rocks, andesite lavas)
Upper Palaeozoic	Trinity Peninsula Series (low-grade regionally metamorphosed sediments)

The oldest rocks recorded on the Graham Coast are a series of low-grade regionally metamorphosed siltstones, shales and feldspathic greywackes. They occur only in two areas: the eastern half of Lahille Island and the southern shore of Beascochea Bay (Fig. 3). In both these areas they have been cut by Andean intrusives. These sediments are identical with types recorded in the Trinity Peninsula Series and therefore they are provisionally correlated with this series. In areal extent, the Upper Jurassic Volcanic Group comprises the largest stratigraphic unit of the Graham Coast. These volcanic rocks crop out along many miles of coastline, particularly in the Lemaire Channel and Penola Strait areas. Extensive hydrothermal alteration and local thermal metamorphism are characteristic features of the volcanic rocks. The Andean Intrusive Suite ranges in composition from olivine-gabbro to calc-alkali granite and a basic to acid sequence of intrusion has been clearly demonstrated at a number of localities. The initial phase of gabbro intrusion was followed by successive intrusions of granodiorite magma. The diorites and tonalites are regarded as hybrid rocks formed by the contamination of the granodiorite magma by gabbroic material.

II. TRINITY PENINSULA SERIES

ALTHOUGH sediments of the Trinity Peninsula Series crop out extensively both in the type area of Trinity Peninsula and along much of the Antarctic Peninsula east coast as far as lat. 75°S., few exposures have been recorded on the west coast south of Trinity Peninsula. Trinity Peninsula and the east coast have been studied by Adie (1957), who has recorded greywackes, dark grey shales, conglomerates, grits, arkoses, quartzites, calcareous shales and rare argillaceous limestones. These rocks, which are regarded as being Carboniferous in age, have suffered pre-Jurassic cataclastic deformation and superimposed thermal metamorphism adjacent to Andean intrusions. Sedimentary rocks discovered by Ferguson (1921) at Andvord Bay and Paradise Harbour on the Danco Coast have been studied by Tyrrell (1921). Tyrrell has recorded fine-grained greywackes, quartzites and argillites, and this has been confirmed by Olsacher (1959) and Hobbs (1958). Altered sediments found by the British Graham Land Expedition, 1934–37, in Beascochea Bay on the Graham Coast have been tentatively assigned to the Trinity Peninsula Series by

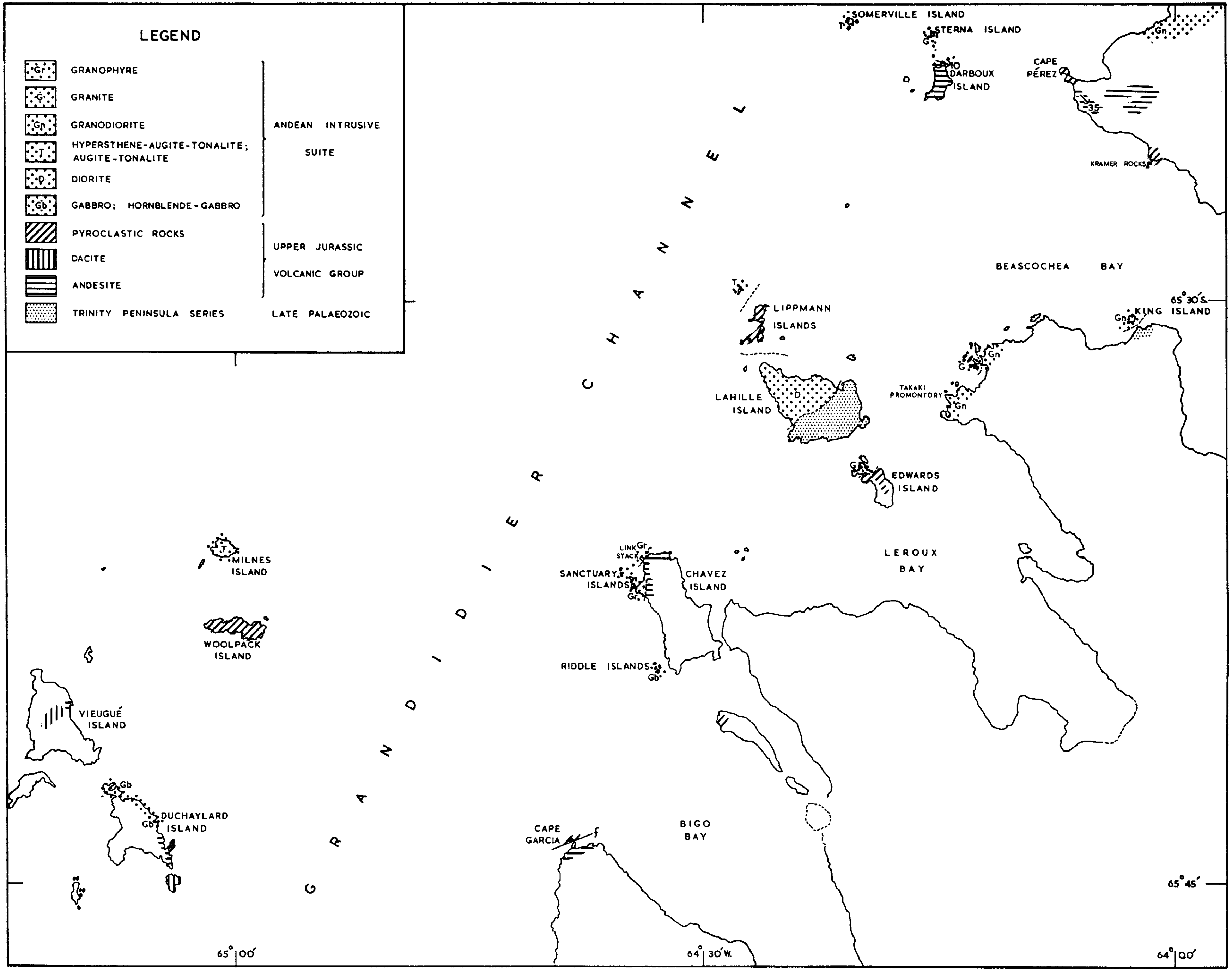

FIGURE 3

Geological map of the Beascochea Bay—Bigo Bay area and offlying islands.

Adie (1957, p. 18–19). The present investigation has yielded one further outcrop at Lahille Island. This is the southernmost outcrop of the Trinity Peninsula Series recorded on the west coast of Graham Land.

Sediments of Trinity Peninsula Series type compose the eastern half of Lahille Island (Figs. 3 and 10). Here they are intruded by diorite and at the contact the sediments have been shattered, slightly overturned and form high mountains trending north-east to south-west across the island. Alternating shales and siltstones crop out at a large exposure on the northern shore of the island. Individual beds vary in thickness from 0·06 to 3·0 in. (0·16 to 7·6 cm.) and show small-scale current-bedding and slump structures (J.735.8). Low-grade regional metamorphism has given these rocks a slaty appearance. In the hand specimen the siltstones (J.735.3) are fine-grained, brownish grey in colour and contain thin shaly partings. This rock type is composed essentially of quartz and biotite with subordinate plagioclase, sericite and iron ore. The quartz has recrystallized to form a mosaic in the groundmass. Small flakes and aggregates of biotite have grown interstitially to the quartz and in the more argillaceous partings they form a continuous framework in which the quartz is set. Small crystals of iron ore bordered by biotite are scattered throughout the rock. Accessory minerals include detrital zircon, tourmaline and apatite, which together with iron ore are concentrated along the bedding planes. These rocks are cut by veins of medium-grained quartz containing laths of muscovite and chlorite, a little potash feldspar and rare calcite.

The shales (J.735.8) are much darker in colour than the siltstones (Plate VIa), due to their higher percentage of biotite and iron ore which completely masks the other constituents. The iron ore occurs as small rounded crystals and as swarms of minute grains, which together with biotite are aligned parallel to the cleavage, making an angle of 15° with the bedding. Slight thermal metamorphism by the nearby diorite has resulted in spotting in some of the shales (J.735.5). The spots define areas from which the micas have been partially expelled and their rhombic or rectangular shape suggests that they may be incipient chiastolites.

Shales and siltstones also crop out at the eastern tip of Lahille Island (J.737). Here they are composed essentially of quartz, sericite and iron ore, but biotite is conspicuously absent. Associated with the shales and siltstones are medium-grained, dark greenish grey feldspathic greywackes (J.737.1). Microscopic examination shows they contain angular fragments of quartz and andesine, and fine-grained aggregates of quartz and feldspar, set in a fine-grained groundmass of quartz, feldspar, biotite, sericite, chlorite and iron ore. The margins of the quartz fragments are crenulate and frequently lined with flakes of biotite and sericite. In many cases, small irregular crystals of quartz have coalesced to form a single large crystal; it is probable that the original clastic quartz has been enlarged during partial recrystallization of the groundmass. The plagioclase fragments are severely altered and corroded. The early stage of alteration consists mainly of the formation of small flakes of sericite, chlorite, patches of quartz and new albitic feldspar. In the more advanced stages sericite and chlorite are expelled from the quartz-albite aggregates. The bedding in the greywacke is marked by alternations of arenaceous and argillaceous zones. Biotite is absent from the former, whereas the argillaceous zones have a high percentage of biotite and ilmenite (much of which is altered to sphene). Accessory minerals include zircon and epidote, and the rock is cut by thin quartz-clinozoisite veins.

Quartz-veined biotite-hornfelses (B.G.L.E. 130, 134, 138) and quartz-muscovite-biotite-schists (B.G.L.E. 87, 88) have been recorded from the south shore of Beascochea Bay (Adie, 1957, p. 18–19). Only one exposure in this area was re-visited in 1957, when quartz-veined biotite-hornfelses (J.696.3) were found in close proximity to the granodiorite of King Island.

Owing to the limited occurrence of the Trinity Peninsula Series on the Graham Coast, little can be added to what is already known from other parts of Graham Land (Adie, 1957). The sediments of the Graham and Danco Coasts appear to be closely comparable with one another and they do not show the marked variation of sedimentary types found in Trinity Peninsula. The predominance of shales and siltstones at Lahille Island and in Beascochea Bay suggests that deposition took place in relatively deep water or, if in shallow water, during periods of crustal stability. The greywackes of Lahille Island are noticeably different from those of Trinity Peninsula. The greywacke conglomerates of Hope Bay contain fragments of a great variety of rock types, some of which have been derived from bedded volcanic rocks, the Basement Complex and the geosynclinal sediments themselves. No such rock fragments have been observed in the greywackes of Lahille Island and therefore they may have been derived from the area of Basement Complex and Lower Palaeozoic granites of Marguerite Bay which Adie (1953) has suggested was being actively eroded until Upper Jurassic times.

III. UPPER JURASSIC VOLCANIC GROUP

A. Stratigraphy

The Upper Jurassic Volcanic Group crops out at numerous localities along the Graham Coast and on the offshore islands. The most important exposures are on the mainland coast of Penola Strait and on the shores bordering Lemaire Channel. It is only in these areas that comparatively thick successions of volcanic rocks can be established. Elsewhere the accessible exposures are usually small, but homogeneous and without signs of stratification.

Approximately 5,000 ft. (1,525 m.) of volcanic rocks crop out between Duseberg Buttress and Girard Bay in the Penola Strait area. The volcanic rocks have been folded into an asymmetrical syncline with its axis trending north-west to south-east, and 0·5 miles (0·8 km.) north of Duseberg Buttress they have been intruded by diorite. The volcanic succession can be divided into a lower group composed of andesite lavas with occasional tuff beds, and an upper group composed entirely of tuffs (Plate Ia). A summary of the successions at the stations visited is given in Table II.

Table II

VOLCANIC SUCCESSION BETWEEN DUSEBERG BUTTRESS AND GIRARD BAY

	Rock Type and Specimen Number	*Thickness* (ft.)	
Tuff Group	*		4,000
	Lithic tuff (J.652.3)	>30	
	†		
	(J.653.8)	10	
	Crystal tuffs (J.653.7)	50	
	(J.653.6)	25	
	Tuff (J.653.5)	3	
	(J.653.4)	3	
	Crystal tuffs (J.653.2)	5	
	(J.653.1)	>75	
	‡		
	(J.654.5)	>85	
	Crystal tuffs (J.654.4)	30	
	(J.654.3)	4	
	Tuff (J.654.2)	6	
	(J.654.1)	10	
	(J.655.1)	5	
	Crystal tuffs (J.655.2)	20	
	(J.655.4)	4	
	(J.655.5)	20	
	Lithic tuff (J.655.9)	18	
	Crystal tuffs (J.655.10)	12	
	(J.655.11)	>120	
Andesite Group	Andesite (J.638.7)	?	1,000
	(J.638.6)	?	
	Crystal tuff (J.638.1)	?	
	Andesite (J.625.1)	>150	

* A further 1,100 ft. (335 m.) of beds to the top of the succession.
† Approximately 2,100 ft. (640 m.) of beds uninvestigated.
‡ Approximately 320 ft. (98 m.) of beds uninvestigated.

A short succession of steeply dipping lavas is exposed at Cape Cloos at the southern end of Lemaire Channel. The lavas have been strongly faulted and brecciated. 0·25 miles (0·4 km.) to the north, gently dipping striped tuffs, current-bedded crystal tuffs and volcanic conglomerates crop out (Table III). The striped tuffs are highly distinctive and can be correlated with similar rocks farther north on the east coast of Booth Island. The horizontal displacement of these beds is 1 mile (1·6 km.), which together with their dip shows that Lemaire Channel is the site of a fault with a downthrow to the west of over 3,000 ft. (915 m.) (Fig. 4).

TABLE III

VOLCANIC SUCCESSION AT CAPE CLOOS

Rock Type and Specimen Number	*Thickness* (ft.)
Andesite (J.650.9)	>50
Basaltic andesite (J.650.6)	4
Andesite (J.650.5)	30
Andesite-breccia (J.630.13)	?
Oligoclase-andesite (J.630.10)	5
Andesite (J.630.8)	9
Hornblende-andesite (J.630.6)	4
Andesite (J.630.5)	6
Basaltic andesite (J.630.4, 3)	9
Hornblende-andesite (J.630.2)	3
*	
Volcanic conglomerates (J.641.7, 6, 5)	50
Current-bedded crystal tuffs (J.641.4)	
Volcanic conglomerates (J.641.3)	
Striped tuff (J.641.1)	

* Separated by approximately 0·25 miles (0·4 km.).

Little of stratigraphic significance can be gained by a study of the volcanic rocks of the Graham Coast south of Penola Strait. Localities and corresponding rock types are listed fully in Table IV.

B. PETROLOGY

1. *Andesites*

Andesites are by far the commonest lava type on the Graham Coast. They vary widely in petrography and mineralogy, and without exception they have undergone hydrothermal alteration, which has been severe in most cases. The more important andesite localities on the Graham Coast are north of Penola Strait, and for the purpose of description they will be reviewed geographically.

a. *Lemaire Channel and Penola Strait.* At Cape Cloos ten individual andesite flows comprising approximately 120 ft. (37 m.) of beds have been recorded (Table III). The most important flow at this locality is at the southern end of the exposure. In the hand specimen this andesite (J.650.9) is a black, fine-grained rock, speckled with pyrites and cut by thin dark veins. Microscopic examination shows rare highly altered phenocrysts of plagioclase set in a groundmass of plagioclase microlites (An_{35}) with abundant fine-grained iron ore, actinolite, patches of chlorite and subsidiary pyrites. The plagioclase phenocrysts contain large amounts of actinolite, chlorite and iron ore, which also form pseudomorphs, probably after pyroxene. Cutting the andesite are thin veins composed of actinolite, clinozoisite, chlorite and pyrites (Plate VIb). Andesites similar to specimen J.650.9 occur at a number of horizons farther north along the exposure (J.630.5, 8; 650.5). Northwards, specimen J.650.9 is succeeded by a thin flow of basaltic andesite (J.650.6) in which the plagioclase phenocrysts contain frameworks of chlorite arranged along the (010) and (001) cleavage traces. Chlorite containing aggregates of granular epidote and fine needles of actinolite almost

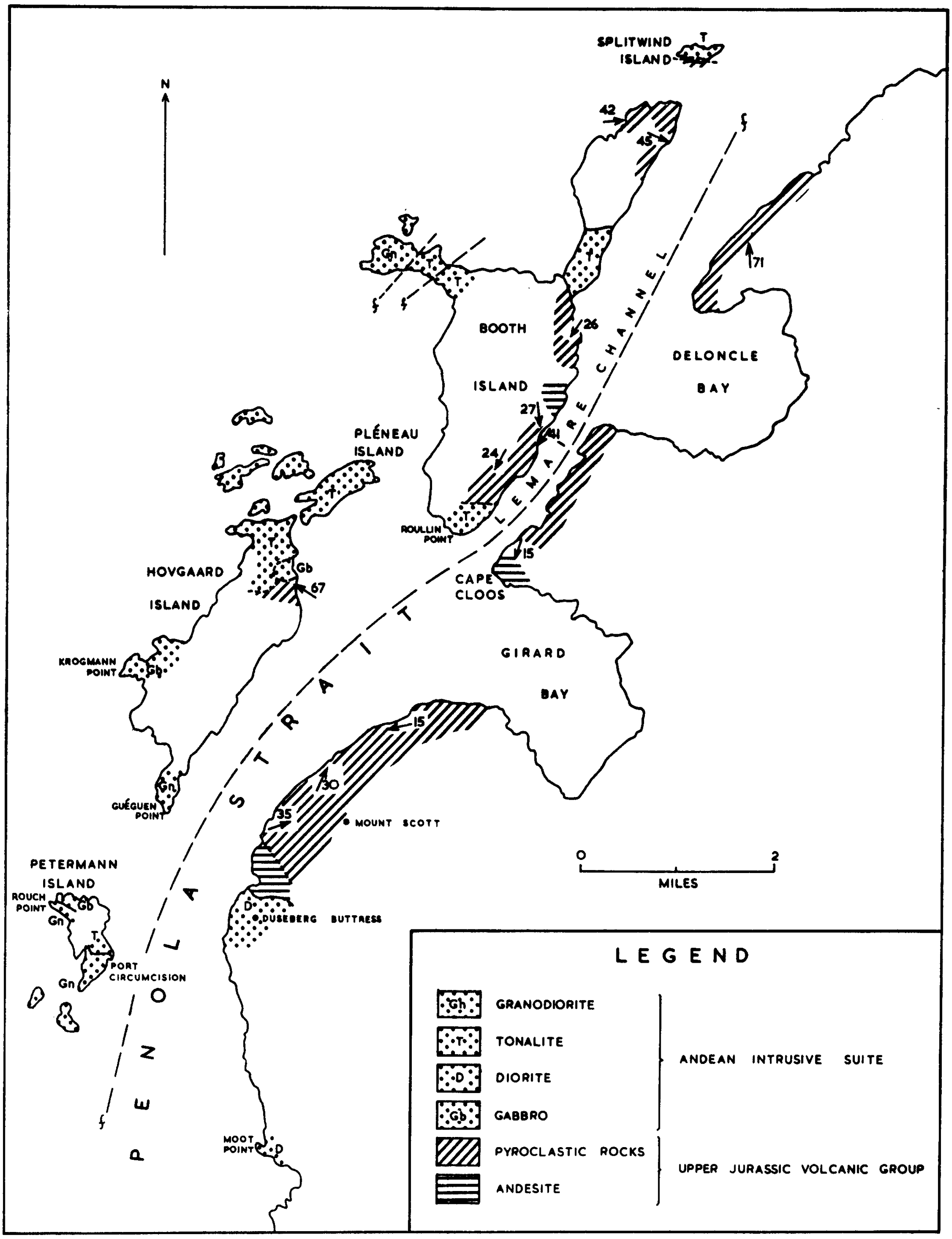

FIGURE 4

Geological map of the Penola Strait—Lemaire Channel area.

entirely replace the plagioclase phenocrysts. Actinolite, with minor amounts of iron ore, epidote and quartz, forms pseudomorphs after hornblende and pyroxene. In the groundmass, chlorite with subordinate sphene and epidote fill the interstices between the plagioclase microlites (An_{60}). Epidote also occurs as aggregates and large individual crystals. Chlorite amygdales, outlined by trains of sphene, are common. Basaltic andesites similar to specimen J.650.6 have been recorded farther north along the exposure (J.630.3, 4). Towards the northern end of the exposure there is an andesite-breccia. In the hand specimen the breccia (J.630.13) has black fine-grained andesite fragments set in a network of greyish green veins. Under

TABLE IV

UPPER JURASSIC VOLCANIC GROUP OF THE GRAHAM COAST SOUTH OF PENOLA STRAIT

Locality	*Rock Type* and Specimen Number*	*Thickness* (ft.)
Cape Tuxen	Andesite (J.703.1)	
	Lithic tuff (J.704.1)	
Lancaster Hill	Tuff (J.678.1)	
Cape Pérez	Crystal tuff (J.635.1)	
	Lithic tuff (J.635.4)	
	Andesite (J.674.6) }	?1,000
	Andesite (J.674.7) }	
Kramer Rocks	Lithic tuff (J.698.1)	
Darboux Island	Andesite (J.673.1)	
	Andesite (J.673.2)	
Lippmann Islands	Andesite (J.669.2)	3
	Lithic tuff (J.669.1)	20
	Andesite (J.669.7)	6
	Lithic tuff (J.669.8)	10
	Crystal tuff (J.736.1)	
Edwards Island	Tuff (J.712.6)	
Chavez Island	Basaltic andesite (J.730.1)	
Cape Garcia	Lithic tuff (J.720.2) }	150–200
	Welded tuff (J.720.3) }	
	Andesite (J.721.1)	
	Andesite-breccia (J.721.2)	
Duchaylard Island	Dacite (J.555.1)	
	Andesite (J.554.1)	
	Lithic tuff (J.558.1)	
	Andesite (J.560.4)	10
	Andesite (J.560.3)	5
	Mylonite (J.560.2)	4
	Andesite (J.560.1)	4
Vieugué Island	Andesite (J.572.1)	
	Dacite (J.573.1)	
	Dacite (J.573.3)	
Woolpack Island	Crystal tuff (J.566.1)	
Hummock Island	Lithic tuff (J.543.2)	
Black Head	Lithic tuff (J.520.1)	

* Where a rock type is part of a succession, the thickness of the bed is given.

the microscope the andesite fragments are conspicuous because of their high granular iron ore content (Plate VIc). Iron ore, chlorite, epidote and sphene fill the interstices between the plagioclase microlites. Both chlorite and epidote form large patches in the groundmass, the former surrounded by fine-grained quartz and replaced by fine-grained green biotite. The veins are composed of fine-grained plagioclase, now almost totally replaced by a mosaic of epidote. Throughout the epidote are networks and rare irregular patches of actinolite, chlorite, green biotite and quartz.

Oligoclase-andesite and hornblende-andesite are the remaining rock types in the succession to the north of the andesite-breccia. In the oligoclase-andesite (J.630.10) plagioclase phenocrysts (An_{20}) containing aggregates and individual crystals of epidote and finely divided sericite and set in a groundmass of fine-grained plagioclase (An_{15}), quartz, aggregates of actinolite, chlorite and epidote. Fine-grained biotite has developed from both the actinolite and chlorite. Oligoclase-andesites have also been recorded near the top of the andesite group in the Penola Strait succession (J.638.6, 7). Both porphyritic and non-porphyritic hornblende-andesites have been recorded. In the porphyritic variety (J.630.6) the plagioclase and hornblende phenocrysts are set in a groundmass composed essentially of fine-grained, greenish brown biotite and subsidiary microlitic plagioclase. The hornblende phenocrysts have been severely altered to actinolite and biotite, both of which contain numerous grains of sphene and epidote (Plate VId). The plagioclase phenocrysts are full of epidote and sericite with occasional flecks of calcite. The non-porphyritic hornblende-andesite (J.630.2) has a pilotaxitic texture and actinolitic hornblende, together with epidote and leucoxenized ilmenite, fills the interstices between the plagioclase microlites (An_{30}). Epidote, quartz and chlorite form prominent aggregates. Non-porphyritic hornblende-andesite, similar in many respects to that described above, has been recorded at the lowest horizon visited in the andesite group of the Penola Strait succession. However, the Penola Strait rock (J.625.1) contains abundant fine-grained greenish brown biotites and shows a marked alignment of the microlitic plagioclase.

Highly altered lavas have been recorded at two localities on the east coast of Booth Island (J.661.9, 662.1). The petrology of these rocks suggests that they were once hypersthene-augite-andesites. Euhedral pseudomorphs of biotite and actinolite after clinopyroxene, pseudomorphs of antigorite after hypersthene, and hornblende altered to actinolite, are set in a medium- to fine-grained groundmass of plagioclase laths (An_{35}) with interstitial actinolite, biotite and chlorite (J.662.1). The plagioclase laths have a well-defined flow texture. Specimen J.661.9 contains large aggregates of chlorite (penninite) and actinolite in a groundmass of fine-grained greenish brown biotite, microlitic plagioclase, chlorite, epidote and iron ore. The actinolite aggregates in some cases surround antigorite pseudomorphs and in turn they may be surrounded by fine-grained quartz or iron ore. Quartz also surrounds the chlorite aggregates. In both of these rocks biotite replaces chlorite and actinolite.

b. *Graham Coast south of Penola Strait.* The andesite localities south of Penola Strait are listed in Table IV. With the possible exception of Cape Pérez (Fig. 3) exposures of andesite lavas are limited to individual flows or to thin successions of andesites and tuffs. The south face of Cape Pérez is a vertical cliff approximately 1,500 ft. (460 m.) high. It is composed of south-easterly dipping lavas intruded by granite sheets and lenses aligned parallel to the bedding. Although only the base of the cliff is accessible, the homogeneous nature of the exposures suggests that the whole of the south face is composed of andesite lavas. If this is so, then over 1,000 ft. (305 m.) of lavas are represented at this locality. In the hand specimen these andesites vary in colour between light and dark grey, have a greenish tinge and contain small epidote amygdales. In thin section the light grey type (J.674.7) has plagioclase phenocrysts (An_{21}) set in a felt of irregularly shaped plagioclase laths (An_{15}) with interstitial quartz, epidote, sphene and minor chlorite. In the darker type (J.674.6) the plagioclase phenocrysts are rare and chlorite is abundant. Both rock types are characterized by numerous small quartz crystals, epidote amygdales with borders of chlorite and quartz, and quartz-epidote veins. These effects are probably the result of a nearby granite lens intruded into the volcanic rocks. Andesites, similar to those described above, have been recorded at Darboux Island (J.673.1, 2), the Lippmann Islands (J.572.1) and Vieugué Island (J.572.1).

A small succession of andesites has been recorded on the south-east coast of Duchaylard Island (Fig. 5; J.560). The lowest exposed flow is a porphyritic andesite (J.560.1) in which the plagioclase phenocrysts ($An_{56\text{-}30}$) contain fine-grained iron ore with occasional aggregates of skeletal sphene and chlorite, and large stellate epidotes. Between station J.560.1 and the uppermost andesite exposed (J.560.4) are lens-shaped beds of mylonite and epidotized andesite. Microscopic examination of the mylonite (J.560.2) shows that the plagioclase forms a fine-grained, almost cryptocrystalline mosaic which is partially sericitized and contains abundant fine-grained iron ore. The iron ore frequently occurs as small irregular crystals and aggregates of grains slightly altered to haematite. In thin zones the plagioclase has been almost wholly converted to sericite. In the epidotized lava (J.560.3) all that remains of the original rock are small patches of highly altered andesite. These are composed of mis-shapen plagioclase laths, small irregular crystals of quartz, and interstitial chlorite, iron ore, sphene and epidote. The remainder of the rock consists of medium- to coarse-grained epidote with subordinate quartz, some large aggregates of quartz showing undulose extinction and small crystals of leucoxenized ilmenite. In contrast to the underlying rocks, the porphyritic andesite at the top of the succession is virtually unaltered (J.560.4). The mylonitization suggests that this andesite has been thrust into its present position.

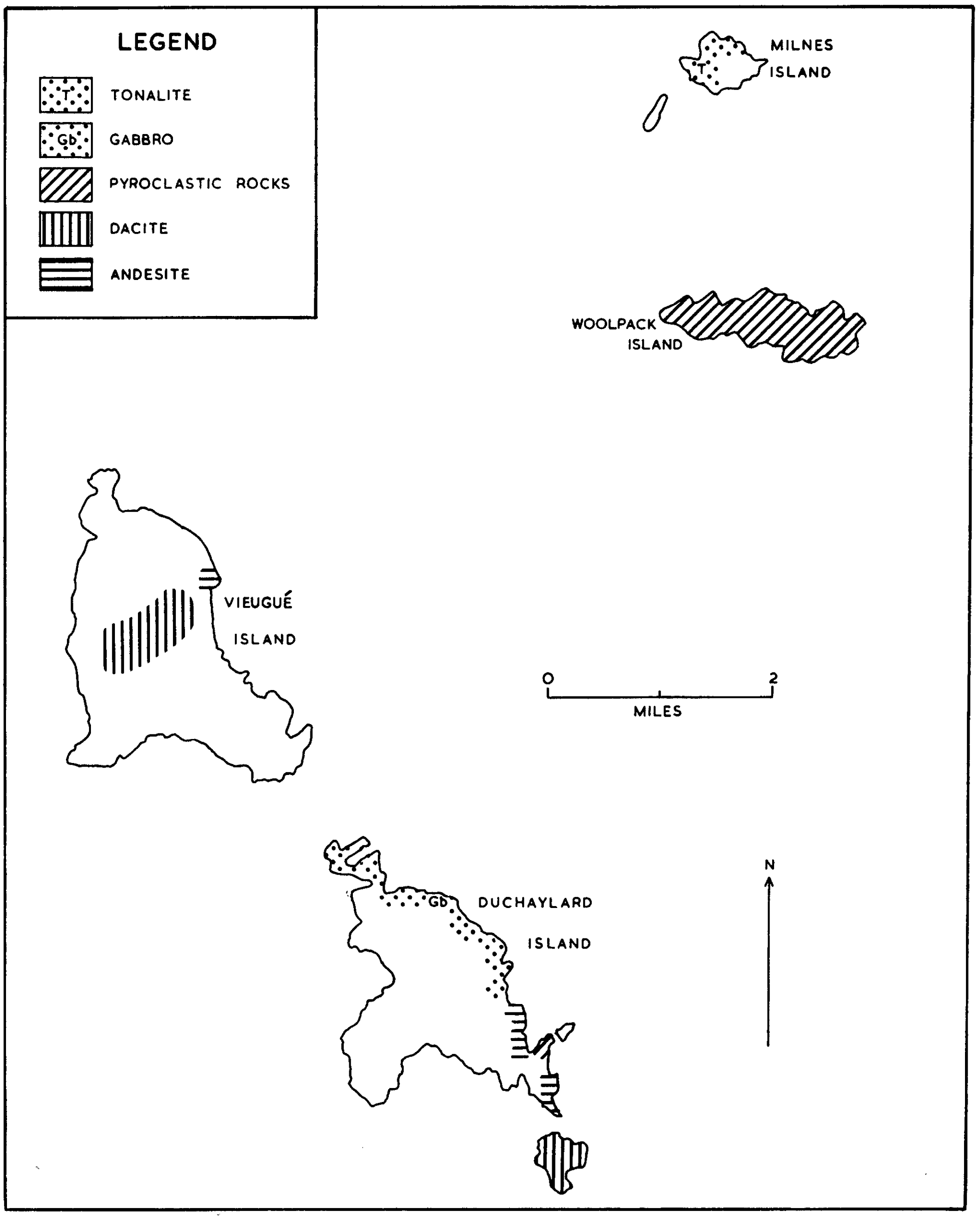

FIGURE 5

Geological map of Vieugué and Duchaylard Islands.

Shearing in andesite lavas has been recorded 0·5 miles (0·8 km.) south of station J.560 on Duchaylard Island (J.554). Fragments of andesite (J.554.1) in the shear zone have been lensed out and shear lines are marked out by sericite, iron ore and cryptocrystalline plagioclase. The major feature of this rock is the abundance of iron ore which almost completely fills the interstices between the plagioclase microlites (An_{46-38}).

2. *Dacites*

Dacite lavas are uncommon on the Graham Coast and have been recorded at only two localities: a small island off the southern tip of Duchaylard Island and on the south-east coast of Vieugué Island. At Duchaylard Island the dacite (J.555.1) is aphanitic, light grey in colour with a greenish tinge and contains milky white plagioclase phenocrysts. Microscopic examination shows subhedral to euhedral albite phenocrysts ($<$ 4 mm.; $\simeq$ An_7), dusty with minute inclusions, set in a groundmass of plagioclase microlites, small irregular quartz aggregates, irregular albite, leucoxenized ilmenite, chlorite and numerous flecks and patches of calcite. Calcite is the main alteration product of the plagioclase and in the phenocrysts it is associated with fibrous sericite and grains of epidote. Rare glomeroporphyritic aggregates of plagioclase contain abundant interstitial calcite and chlorite with subsidiary epidote, sericite, sphene and ilmenite. Contacts between the crystal faces of the plagioclase phenocrysts and the groundmass are sharp but where the phenocrysts do not possess crystal faces their growth into the groundmass can be clearly seen. In the groundmass the quartz and the albite have included and replaced the plagioclase microlites ($\simeq An_{20}$).

At Vieugué Island the plagioclase phenocrysts have been replaced almost entirely by aggregates of medium-grained epidote or rarely by fine-grained sericite (J.573.1). The groundmass is riddled with fine-grained epidote, ilmenite, sphene and small patches of calcite. Small quartz crystals, patches of chlorite and crystals of pyrites are common. The pyrites is frequently altered to haematite.

3. *Pyroclastic rocks*

The most complete succession of pyroclastic rocks on the Graham Coast occurs in Penola Strait where 435 ft. (135 m.) of beds have been examined in a succession about 4,000 ft. (1,220 m.) thick (Table II). At the base of the succession, overlying the andesite group, the crystal tuffs (J.655.11) are black and fine-grained with fragments of small milky white plagioclase and translucent quartz. Microscopic examination shows crystal fragments of quartz and plagioclase set in a fine-grained groundmass of quartz, plagioclase, green biotite, sericite and iron ore. The plagioclase crystals have been severely altered to quartz, sericite, chlorite and epidote, and several crystals have been partially albitized, but the quartz is porphyroblastic (Plate VIe). The main characteristic of the groundmass is the abundance of fine-grained green biotite which occurs as small aggregates, frequently associated with iron ore. In the aggregates of biotite, quartz and epidote which replace plagioclase, the biotite is medium-grained and partially replaced by chlorite. Above specimen J.655.11 is a thin bed of crystal tuff (J.655.10) which differs only in that it contains a lower percentage of biotite. As a result of this, the rock is of much lighter colour in the hand specimen. Crystal tuffs similar to specimens J.655.10 and 11, but with a biotite content intermediate between the two, occur at several horizons higher up in the succession (J.653.1, 2, 4, 654.3, 4, 655.3). A crystal tuff of this type but with no biotite at all forms the whole of Woolpack Island (J.566.1).

The crystal tuffs at the base of the tuff group are succeeded by a lithic tuff (J.655.9) in which fragments of andesite, quartz and plagioclase are set in a fine-grained groundmass of quartz, plagioclase, iron ore, biotite and chlorite. The quartz and plagioclase fragments show all the characteristics of the crystal tuffs described above. The andesite fragments are full of chlorite and biotite, and the plagioclase microlites have broken down to a mixture of fine-grained quartz and albite. In many cases the fragments can only be distinguished from the groundmass by their paucity of iron ore.

In the overlying crystal tuff (J.655.9) the groundmass is much reduced and the main part of the rock is composed of cracked quartz and plagioclase fragments (J.655.5). In many cases the fragments are outlined by trains of iron ore and fine-grained biotite, and crystals of leucoxenized ilmenite have been concentrated into bands parallel to the bedding. In the groundmass fine-grained aggregates of brown biotite have developed, which are sometimes surrounded by fine-grained quartz. Marginal to these aggregates are numerous tiny actinolite needles, and aggregates of actinolite are common. Similar but finer-grained crystal tuffs occur not only higher in the succession (J.653.7), where they show current-bedding perfectly marked out by iron ore/biotite concentrations along the bedding planes, but also on the east coast of Booth Island (J.660.1, 661.2).

Above specimen J.655.5 there are a number of beds of crystal tuff (J.654.1; 655.1, 4) in which, with the exception of specimen J.655.2, the crystal fragments are far subordinate to the groundmass. At this exposure the beds show conspicuous current-bedding (Plates Ib, c, d). They consist mainly of micro-fragments of quartz and altered plagioclase in an almost cryptocrystalline groundmass of quartz, plagioclase, sericite, chlorite, biotite and iron ore. Similar crystal tuffs were recorded higher in the succession (J.653.5, 6) and at the Lippmann Islands (J.736.1).

Overlying the current-bedded tuffs is a rock (J.654.5) in which micro-fragments of plagioclase and andesite are set in a groundmass composed essentially of biotite, plagioclase and iron ore, with subsidiary actinolite, quartz and pyrites. Actinolite also occurs with biotite in aggregates replacing the andesite lava fragments. Similar rocks occur on the east coast of Booth Island (J.663.1) and at Black Head (J.520.1). The uppermost bed examined in the Penola Strait succession is a lithic tuff (J.652.3). Microscopic examination shows altered andesite fragments and fragments composed of a quartz-plagioclase mosaic in a cryptocrystalline matrix containing fine-grained biotite and epidote.

A small succession of striped tuffs, current-bedded crystal tuffs and volcanic conglomerates crops out approximately 0·5 miles (0·8 km.) north of Cape Cloos in Lemaire Channel. In the hand specimen the striped tuffs (J.641.1; Plate IIa) are fine-grained with alternating grey and purple beds varying in thickness from 1 to 4 in. (2·5 to 10 cm.). Microscopic examination shows that the colour difference is due to the presence of fine-grained brown biotite in the purple beds and its absence in the grey beds, which, however, contain more chlorite. Apart from these differences, both types are composed of micro-fragments of quartz and altered plagioclase crystals in a fine-grained groundmass of quartz and feldspar with leucoxenized ilmenite, spher ulitic chlorite, sphene, zircon, pyrites and rare epidote. Tuffs identical to these were recorded on the east coast of Booth Island (J.661.8).

The current-bedded crystal tuffs (J.641.6), apart from a higher percentage of quartz and plagioclase fragments, are identical to the purple type of striped tuff. The plagioclase crystals have been severely altered to chlorite, actinolitic hornblende and epidote, and in some cases they are albitized. Trains of partially leucoxenized ilmenite mark out the bedding planes. Similar crystal tuffs were recorded on the east coast of Booth Island (J.661.6). The volcanic conglomerates (J.641.5; Plate IIb) occur as thin horizons in the crystal tuffs. In the hand specimen they consist of closely packed well-rounded pebbles, and small quartz and milky white plagioclase crystals set in a white and grey groundmass. Most of the pebbles are aphanitic in texture and vary in colour between light grey and light purple. Microscopic examination shows that all the pebbles are of volcanic origin and include andesite lavas with flow or felty textures and tuffs. The lavas with flow textures are composed essentially of sericitized plagioclase microphenocrysts (An_{35}) in a groundmass of irregular plagioclase microlites (An_{30}) with epidote, ilmenite, sphene and chlorite. The andesite pebbles with a felty texture have remnant microlitic plagioclases in irregular aggregates of newly formed, occasionally spherulitic plagioclase (? albite) and quartz. The tuff pebbles are fine-grained and almost cryptocrystalline, and some contain fragments of andesite lava. Similar volcanic conglomerates were recorded on the east coast of Booth Island (J.660.2).

Highly altered lithic tuffs were recorded at the northern end of Booth Island (J.665.1; 666.1, 2). Many of the andesite fragments consist entirely of microlitic plagioclase and iron ore with small aggregates of biotite. Similar rocks were found at Duchaylard Island (J.558.1) and at Cape Garcia (J.720.2).

C. Thermal Metamorphism

In comparison with the extensive hydrothermal alteration the Upper Jurassic Volcanic Group shows only local thermal metamorphism at contacts with members of the Andean Intrusive Suite. The thermally metamorphosed rocks of the Upper Jurassic Volcanic Group recorded on the Graham Coast are summarized in Table V.

1. *Splitwind Island*

At the southern tip of Splitwind Island (Fig. 4) intrusion by tonalite has resulted in brecciation of the volcanic rocks for a distance of 10 ft. (3 m.) from the contact. A network of tonalite veins cuts the brecciation zone. Two types of hornfelses have been recorded from the brecciation zone: a hypersthene-cordierite-biotite-hornfels and a sillimanite-andalusite-cordierite-hornfels. In the hand specimen the hypersthene-cordierite-biotite-hornfelses are fine-grained, light or dark grey in colour and are speckled with small biotites. Under the microscope the light grey variety (J.643.1) shows abundant biotite and quartz poikiloblasts, small irregular cordierites, subhedral plagioclase ($<$ 2·5 mm.; An_{62}) and scattered crystals of hypersthene (Plate VIf) in a medium- to fine-grained granoblastic groundmass of plagioclase, quartz and iron ore. The groundmass plagioclase shows reversed zoning (An_{50-57}) and every stage of replacement by the quartz poikiloblasts. The dark grey variety (J.643.2) differs in that it contains a higher percentage of hypersthene and iron ore. Hypersthene forms approximately 25–30 per cent of the rock and the quartz/biotite content is consequently reduced. The groundmass plagioclase forms a fine-grained mosaic.

A specimen taken at a contact with a tonalite vein (J.667.2) shows a highly spotted light-coloured zone, 0·5–1·0 cm. wide, against the contact. This grades into a dark fine-grained rock which in the hand specimen is similar to specimen J.643.2. Microscopic examination shows that the contact zone is composed of

TABLE V

SUMMARY OF THE THERMAL METAMORPHISM OF THE UPPER JURASSIC VOLCANIC GROUP

Locality	*Rock Type and Specimen Number*	*Intruding Rock*
Splitwind Island	Hypersthene-cordierite-biotite-hornfels (J.643.1, 2; 667.2) Sillimanite-andalusite-cordierite-hornfels (J.667.3, 8) Hypersthene-augite-biotite-hornfels (J.645.3)	Tonalite
Booth Island	Quartz-biotite-hornfels (J.646.2) Quartz-muscovite-hornfels (J.646.4)	Tonalite
Hovgaard Island	Quartz-hornblende-biotite-hornfels (J.658.1)	Tonalite
Duseberg Buttress	Quartz-muscovite-hornfels (J.624.3)	Diorite
Cape Tuxen	Hypersthene-augite-hornfels (J.617.1)	Gabbro

poikiloblastic cordierites ($<$ 3 mm.) set in a granoblastic groundmass of plagioclase (An_{40}), quartz and iron ore with rare patches of calcite. The cordierite porphyroblasts ($2V\alpha \simeq 65°$) are full of inclusions and are altered to a fine-grained chloritic substance (? pinite) marginally, along cleavage traces and in cracks. The transition from the contact zone into the main part of the rock is abrupt (Fig. 6). In the latter, irregular

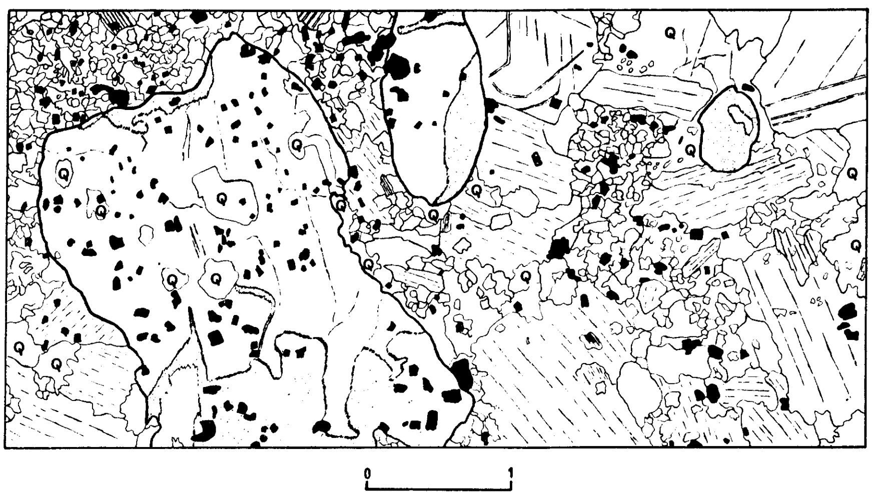

FIGURE 6

The cordierite-rich contact zone between hypersthene-cordierite-biotite-hornfels and tonalite at Splitwind Island. The cordierite (clear and prominently outlined) contains extensive areas of pinite alteration (stippled). Quartz (Q), magnetite (black), platy plagioclase (hachured) and granoblastic plagioclase (clear); (J.667.2).

plagioclase, numerous small crystals and laths of biotite, and rare hypersthene, all of poikiloblastic habit, are set in a fine-grained plagioclase-hypersthene-quartz mosaic.

Sillimanite-andalusite-cordierite-hornfelses have been recorded both in the brecciation zone and in the small exposure of hornfelses which lies outside the brecciation zone. Microscopic examination shows that the hornfels from the brecciation zone is composed of porphyroblasts of andalusite ($<$ 1·5 mm.) and altered cordierite, quartz and rare orthoclase poikiloblasts containing sillimanite needles and aggregates of fibrous muscovite in a groundmass of granoblastic plagioclase (An_{47}), quartz and magnetite. The most

TABLE VI

MODAL ANALYSIS AND CALCULATED CHEMICAL COMPOSITION OF A SILLIMANITE-ANDALUSITE-CORDIERITE-HORNFELS FROM SPLITWIND ISLAND (J.667.3)

Modal Analysis		*Calculated Chemical Composition*	
Plagioclase	33·2	SiO_2	40·90
Orthoclase	1·7	Al_2O_3	32·37
Quartz	9·6	K_2O	0·53
Andalusite	35·1	Na_2O	1·77
Cordierite	2·8	CaO	2·67
Sillimanite	1·3	MgO	0·21
Muscovite	1·4	FeO	6·85
Pyrophyllite (?)	1·4	Fe_2O_3	14·59
Iron ore	13·5	H_2O	0·11
	100·0		100·00

striking feature of the rock is the abundance of andalusite (Table VI). The andalusite ($\alpha = 1 \cdot 627, \beta = 1 \cdot 631, \gamma = 1 \cdot 637 \pm 0 \cdot 001$, 2V$\alpha$ = 74°) has a pleochroism scheme α = light pink, $\beta = \gamma$ = colourless, and is crowded with iron ore inclusions (Plate VIIa). Between crossed nicols many crystals are characterized by marginal shadows which have anomalous blue interference colours. Most of the cordierite (2Vα = 63°) has been altered to a light yellow-green chloritic substance (? pinite). Cutting the rock are thin stress zones marked out by veins of fine-grained micaceous material with which are associated aggregates of sillimanite needles. The only difference between this rock and that outside the brecciation zone (J.667.8) is that muscovite and cordierite are more abundant and sillimanite is rare.

2. *Booth Island*

Thermally metamorphosed volcanic rocks cap a tonalite intrusion at the east–west trending peninsula on the west coast of Booth Island (Plate IIc). Both hornfelses and tonalite have been caught up in fault zones which cut the peninsula (Plate Va). Two main types of hornfels have been recorded: a hypersthene-augite-biotite-hornfels and a quartz-mica-hornfels. In the hand specimen the hypersthene-augite-biotite-hornfels (J.645.3) is fine-grained, dark grey in colour and with numerous small but prominent biotites. Microscopic examination shows abundant small porphyroblasts of hypersthene and red-brown biotite, rare diopsidic augite and hornblende set in medium-grained granoblastic plagioclase ($An_{65\text{-}45}$) with scattered grains of iron ore and rare quartz. A hornfels similar to this but with no biotite and a higher augite content has been recorded in the volcanic rafts at Cape Tuxen (J.617.1; Plate IId).

Both biotite- and muscovite-bearing types have been recorded in the quartz-mica-hornfelses. In the former, biotite commonly occurs as laths and aggregates of laths surrounding crystals of iron ore (J.646.2; Plate VIIb). The groundmass is composed of granoblastic quartz and plagioclase (An_{25}) with rare larger plates of oligoclase-albite and orthoclase. A thin discontinuous prehnite vein cuts the rock. The accessories include pyrites, haematite, sphene, zircon and apatite. In the quartz-muscovite-hornfels (J.646.4) the groundmass plagioclases (An_{25}) have thin borders of albite ($\simeq An_8$). Albite forms rare porphyroblasts and orthoclase is an important constituent of the groundmass.

A quartz-muscovite-hornfels (J.624.3) has been recorded at the diorite/volcanic rocks contact near Duseberg Buttress (Plate IIIa). In this rock the groundmass is composed of porphyroblastic quartz, laths of muscovite, sericitized plagioclase and rare potash feldspar. Relict rock fragments have recrystallized to form aggregates of albite-oligoclase, quartz and muscovite.

3. *Hovgaard Island*

Steeply dipping thermally metamorphosed volcanic rocks have been found on the north-east coast of Hovgaard Island (J.658). Individual beds vary from 6 in. to 1 ft. (15 to 30 cm.) in thickness. Two types of hornfels were recorded: one with abundant hornblende and iron ore (J.658.1) and the other with a high quartz content (J.658.2). The former is composed essentially of equigranular hornblende and ilmenite in a groundmass of andesine (An_{49}) with subordinate quartz and rare poikiloblasts of partially chloritized biotite. Many of the ilmenite crystals have narrow borders of sphene. Skeletal augites occur in narrow quartz veins cutting the rock. In the second type of hornfels the groundmass is composed essentially of quartz with subsidiary iron ore, plagioclase, biotite and hornblende. Quartz also forms relatively large porphyroblasts containing marginal zones of minute inclusions.

D. Metasomatism

Complex contacts between acid intrusive rocks and the Upper Jurassic Volcanic Group have been recorded on the mainland (J.691) opposite Rasmussen Island, at the Sanctuary Islands (J.728) off the north-west corner of Chavez Island, and at the Straggle Islands (J.723) between Larrouy Island and the mainland.

At station J.691, on the mainland, the volcanic rocks have been intimately veined and metasomatized for distances up to 30 ft. (9·1 m.) from the contact with a small boss of medium-grained granite. Along the gradational contact the effect of metasomatism has been to produce rocks of granitic texture and composition from the volcanic rocks. A series of specimens taken from a single bed in the volcanic rocks shows the progressive changes in the rocks as the contact with the granite is approached.

The least altered rock, an andesite (J.691.9A), has original plagioclase phenocrysts partially replaced by quartz, albite and epidote (Plate VIIc) set in a black fine-grained groundmass in which the plagioclase microlites are obscured by fine biotite, hornblende and iron ore. There are rare pseudomorphs of green biotite after clinopyroxene. The more advanced stages of metasomatism (J.691.9B, 11, 12) are marked by the appearance of large whitish porphyroblasts and a diminution of groundmass. The original plagioclase phenocrysts are replaced by quartz-albite porphyroblasts (Plate VIId) and some of the albite is marginally replaced by potash feldspar. The groundmass consists of fine-grained quartz, plagioclase, epidote, biotite and chlorite in which small quartz and albite porphyroblasts have developed. The ilmenite has been partially leucoxenized and occasional actinolite laths are present.

Nearer the contact (J.691.13) the rock appears to be a contaminated granodiorite, in which the groundmass is minimal and interstitial to large quartz and plagioclase crystals. Quartz/potash feldspar intergrowths and the replacement of albite by potash feldspar are common (Plate VIIe). The remaining groundmass is composed of small patches and veins of biotite, chlorite, iron ore, epidote and actinolite with subsidiary quartz.

The most metasomatized rock (J.691.14) has the appearance of a granodiorite containing irregular patches and veins of dark minerals. Under the microscope it is composed of medium- to coarse-grained albite, quartz and microperthitic orthoclase, the latter replacing albite. The darker patches and veins are of fine-grained quartz, chloritized biotite and iron ore.

At the Sanctuary Islands and the Straggle Islands, the contacts are identical to one another. The least altered rocks are medium- to fine-grained, patchy light and dark grey in colour, and speckled with small ferromagnesian minerals. Their grain-size suggests that they were originally volcanic rocks. Here the intruding rock is a granophyre, which has intimately veined and included numerous fragments of the country volcanic rock. All gradations, from altered cores to granitized margins, are present in these xenoliths and it is frequently impossible to detect their margins. A series of specimens taken from the core to the margin of a large xenolith at the Sanctuary Islands (J.728) shows interesting petrographic changes which are discussed below.

Specimens from the centre of the xenolith (J.728.2, 3) are medium- to fine-grained, patchy, light and dark grey in colour, and speckled with numerous small ferromagnesian minerals. The plagioclase crystals ($\simeq An_8$) are dusty with minute inclusions and they have corroded outlines; they are included in and replaced by porphyroblasts of quartz and calcite (Plate VIIf), and occasionally replaced marginally by potash feldspar. In many of the plagioclase crystals there are aggregates of epidote, often associated with chlorite and sericite. Quartz, veined by calcite, is abundant in the interstices with ilmenite altered to sphene. Rare hornblende crystals are replaced mainly by chlorite with subsidiary quartz and calcite.

Nearer the xenolith margin (J.728.5, 6) the rock is medium- to coarse-grained with prominent potash feldspar and quartz crystals, subsidiary plagioclase and scattered dark minerals. The replacement of plagioclase by potash feldspar (Plate VIIIa) has developed to a greater degree than in the central parts of the xenolith, and the remaining plagioclase is severely altered to calcite, epidote and sericite. Chloritized hornblende appears as conspicuous laths, and calcite, ilmenite and sphene are subsidiary. Chlorite is common as spherulites in the interstices. The accessories include zircon and apatite.

At the margin of the xenolith the rock is a granophyre (J.728.1) composed of orthoclase and quartz (often in micrographic intergrowth), dusty albite with broad rims of orthoclase and full of fine-grained sericite, patches of chlorite and rare epidote. Ilmenite is the main ferromagnesian mineral, occurring as small crystals scattered throughout the rock. The rare remnant hornblende is mostly chloritized.

E. Summary

The stratigraphic successions established in the Upper Jurassic Volcanic Group in Penola Strait and elsewhere on the Graham Coast cannot as yet be confidently correlated with those recorded in other parts of Graham Land. In the Upper Jurassic Volcanic Group of Marguerite Bay, Adie (1953) has recognized an andesitic to rhyolitic trend of volcanic activity. "Quartz-plagioclase-porphyries" similar to those recorded on the east coast of Graham Land by Adie (1953) have also been described from material dredged off the west coast of Adelaide Island (Tyrrell, 1945). On the east coast the "quartz-plagioclase-porphyries" are the youngest representatives of a thick succession of the Upper Jurassic Volcanic Group and, by tentative correlation with the rocks dredged off Adelaide Island, Adie (1953) has suggested that the Upper Jurassic volcanic rocks of Marguerite Bay are younger than those on the east coast of Graham Land. "Quartz-plagioclase-porphyries" and rhyolites have not been recorded from the Graham Coast and, assuming Adie's correlation to be correct, the volcanic rocks of the Graham Coast would appear to occupy an intermediate position in the Upper Jurassic volcanic succession.

The pink acid tuffs recorded by Bayly (1957) from the Danco Coast do not occur on the Graham Coast. However, Bayly has recorded rhythmic layering in re-worked ash in the acid tuffs which may be compared with the layered striped tuff north of Cape Cloos.

The most consistent feature of the Upper Jurassic Volcanic Group is the widespread hydrothermal alteration. Alteration of this type has been recorded at King George Island (Hawkes, 1961), at Anvers Island (Hooper, 1962) and on the Danco Coast (Bayly, 1957). The variability, both in kind and amount, of the alteration products in adjacent beds, particularly in the lavas, suggests that the governing factor was the original composition of the rock. The most abundant minerals produced as a result of hydrothermal alteration are epidote, chlorite, fine-grained greenish brown biotite and actinolite. The particular abundance of epidote has been commented on by Hawkes (1961) and by Bayly (1957).

The thermal metamorphic rocks of Splitwind Island are silica-free members of the pyroxene-hornfels facies. Field evidence suggests a volcanic origin for these rocks but the types of hornfels recorded are characteristic of thermally metamorphosed pelitic sediments. Of particular interest is the sillimanite-andalusite-cordierite-hornfels (J.667.3). The modal analysis and calculated chemical composition of this rock are given in Table VI. They show that the rock has an abnormally high alumina content and the overall composition of a residual clay. That it should be a residual clay is incompatible with the field evidence. The concentration of andalusite (J.667.3) and cordierite (J.667.2) suggests enrichment in Al, Mg and Fe by some form of metamorphic differentiation. In the Orijärvi region of Finland, Tuominen and Mikkola (1950) have shown that enrichment in Mg, Fe and Al has been brought about by the removal of K, Ca, Na and Si. If the available alumina did not exceed the amount required for the formation of plagioclase with the existing lime and alkalis, then Mg/Fe enrichment produced rocks rich in cordierite and, in the case of Splitwind Island, hypersthene (J.667.2). If, however, alumina exceeded the amount necessary for the plagioclase, aluminium metasomatism took place and produced rocks which on recrystallization were very rich in andalusite (J.667.3).

IV. ANDEAN INTRUSIVE SUITE

A. Gabbros

Basic intrusive rocks, though not common, occur at widely scattered localities along the Graham Coast. In comparison with the extensive development of intermediate rocks, gabbros form only minor intrusions.

Wherever field relations indicate an age relationship with adjacent intrusive rocks of more acid character, the gabbros have invariably been found to be the older. As a result of this, in many cases they have been severely altered.

1. *Olivine-gabbros*

All the olivine-gabbros recorded, except those from the islands 1 mile (1·6 km.) north of Dodman Island, are closely comparable in texture and mineralogy. At the Roca Islands (Fig. 2) widespread late-stage activity has resulted in the formation of numerous pockets of crystals and veins of iron ore. However, the main mass of the olivine-gabbro is fresh and relatively unaltered and, since it possesses most of the characteristics of rocks of this type along the Graham Coast, the Roca Islands will be regarded as the type locality. In the hand specimen the olivine-gabbro (J.706.1) is dark and coarse-grained, the ferromagnesian minerals possessing a distinct layering. Over much of the island examined the layers have a general trend of 312° mag. and dip a few degrees either side of the vertical (Plate IIIb). In thin section the rock has a coarse-grained hypidiomorphic texture with plagioclase and occasional olivine crystals attaining lengths of over 3 mm. The olivines possess thin reaction rims of hypersthene and a well-developed cleavage. Although most of the olivines are unaltered, all stages of pseudomorphing by serpentine and talc are present, and pseudomorphs of these minerals are surrounded by rims of unaltered hypersthene. Within unaltered olivine small grains of iron ore are concentrated along cracks, while in the marginal hypersthene iron ore forms dactylitic intergrowths. Most of the hypersthene is associated with olivine but a number of individual crystals are present. These show exactly the same alteration products as the olivine, with the addition of a little biotite, and there is a tendency for alteration to be concentrated along the cleavage traces.

Augite (2V $= 60°$, $\gamma{:}c = 40°$) occurs as large ragged crystals with sieve texture, often twinned on (100) and occasionally replaced marginally by fibrous blue-green actinolite, which in association with chlorite occurs in the interstices of the rocks and as thin veinlets cutting the plagioclase. Hornblende ($\alpha =$ light yellow-brown, $\beta =$ light brown and $\gamma{:}c = 20°$) occurs mainly as a replacement of augite, forming numerous small patches within the host crystal and imparting to the augite its sieve texture. Magnetite is abundant and occurs as large irregular crystals which often possess a narrow margin of brown amphibole or occasionally biotite. The plagioclase is usually fresh and is only rarely altered to epidote and calcite.

At the Roca Islands the olivine-gabbro contains numerous miarolitic cavities, veinlets of iron ore and veins of granophyre. The cavities range from approximately 1 to 4 in. (2·5 to 10 cm.) in diameter and are entirely separate from one another. Three main types can be recognized: those with augite and subsidiary hornblende as the predominant ferromagnesian minerals lining the cavity; those in which the pyroxene occurs only as remnants in large hornblende crystals; and cavities with an abundant development of epidote. In all types iron ore is abundant. Modal analyses of the olivine-gabbros are given in Table VII.

In the olivine-gabbros of Cat Island (J.577.1) the alteration of the olivines (2V $= 86°$; $Fo_{77}Fa_{23}$) ranges from the poor development of chrysotile and magnetite along cracks to complete serpentine-talc-chlorite pseudomorphs in which the magnetite is often concentrated marginally as well as in the cracks.

In the olivine-gabbros of Girdler Island (J.522.1) and Upper Island (J.523.1), Mutton Cove, the olivine crystals are heavily cracked and have been replaced both marginally and along the cracks by hypersthene. The marginal hypersthene contains dactylitic intergrowths of iron ore similar to those seen at the Roca Islands. Although talc is the end product of the alteration of both olivine and hypersthene, olivine appears to have been more susceptible and rounded talcose pseudomorphs after olivine often retain their original hypersthene margins.

At a height of approximately 300 ft. (91·4 m.) on Cape Tuxen altered olivine-hypersthene-gabbros have been recorded. They have been subjected to considerable tear-faulting which has taken place along the site of a dyke. The main fault zone which corresponds to the entire thickness of the dyke is about 30 ft. (9·1 m.) wide, is vertical and trends 060° mag. Although most of the movement appears to have taken place within and along the margins of the dyke, highly polished shear planes occur for as much as 20 ft. (6·1 m.) into the adjacent gabbro. Numerous deep slickensides on these planes indicate that the movement was entirely horizontal.

A specimen from a shear plane in the gabbro, away from the main fault zone, is essentially an uralitized olivine-hypersthene-gabbro (J.701.2) in which the pyroxene has been partially converted to actinolite, and the olivine completely pseudomorphed by chlorite and serpentine. The olivine pseudomorphs are surrounded by continuous borders of uralitized pyroxene. Large ophitic crystals of augite contain numerous

TABLE VII

MODAL ANALYSES OF OLIVINE-GABBROS

	J.522.1	J.523.1	J.537.1	J.538.1	J.577.1	J.706.1
Plagioclase	45·3	55·2	54·3	54·1	77·6	55·3
Augite	40·1	27·2	28·6	15·5	12·6	20·2
Hypersthene	1·6	2·0	—	0·2	1·6	3·4
Olivine	2·8	0·3	2·0	1·5	2·1	2·8
Hornblende	5·8	1·8	2·1	18·4	0·4	5·3
Iron ore	1·3	5·1	11·4	8·6	1·0	8·5
Biotite	0·4	0·1	—	—	—	0·2
Epidote	0·1	2·2 [Epidote + Chlorite]	—	1·2	0·4	0·4
Chlorite	*		1·6 [Chlorite–Serpentine]	0·6 [Chlorite–Serpentine]	1·0	1·3
Talc	2·6 [Talc + Serpentine]	6·1 [Talc + Serpentine]			3·7 [Talc + Serpentine]	2·5
Serpentine						
Calcite	*	*	—	*	*	0·1
Sphene	—	—	—	*	—	—
Plagioclase composition	An_{82-56}	An_{88}	An_{67-76}	An_{70}	An_{80-66}	An_{85-72}

* Present but not estimated.

J.522.1 Olivine-gabbro, Girdler Island, Mutton Cove.
J.523.1 Olivine-gabbro, south shore of Upper Island, Mutton Cove.
J.537.1 Olivine-gabbro, north-east shore of island 1 mile (1·6 km.) north of Dodman Island.
J.538.1 Summit of island 1 mile (1·6 km.) north of Dodman Island.
J.577.1 Olivine-gabbro, Cat Island.
J.706.1 Olivine-gabbro, Roca Islands.

inclusions which are associated with actinolite and tend to be concentrated both marginally and along the cleavage traces. The plagioclase crystals (An_{88}) have a large variation in grain-size and there is a slight tendency towards crystal orientation; though only slightly altered they have been heavily cracked. The cracks are filled with actinolite. Pleonaste occurs as an accessory in this rock. The gabbro at the southern margin of the dyke (J.701.4) shows all the features described in the previous specimen to a more marked degree.

Gabbroic rocks are exposed at Krogmann Point (J.634.1) on the western shore of Hovgaard Island. Large areas of chlorite containing abundant iron ore are characteristic of the thin section of this rock. Part of the iron ore is in the form of dactylitic intergrowths typical of that in hypersthene marginal to olivine in the rocks described previously. It seems likely that the chlorite represents former olivine and that the rock was originally an olivine-gabbro.

The olivine-gabbro of the islands immediately north of Dodman Island (J.537.1, 538.1) differ from all the other olivine-gabbros recorded in that they have a medium-grained granular texture. A characteristic feature of these rocks is their high magnetite content which occurs as small irregular crystals often possessing a coating of brown hornblende; this is particularly obvious when the magnetite is adjacent to augite.

2. *Normal gabbros*

Exposures of gabbro have been recorded on the northern shore of Jagged Island (Fig. 1). Apart from the absence of olivine, this rock (J.526.1) is similar to the olivine-gabbro described from Mutton Cove. However, it shows several features not seen in the olivine-gabbros. Large crystals of augite (2V = 53°, γ:c = 45°) contain thin lamellae of hypersthene, and individual hypersthene crystals (2Vα = 62°) have been severely replaced by biotite and magnetite. Biotite pseudomorphs after hypersthene are sometimes surrounded by a symplectite of radiating vermicular amphibole in the adjacent plagioclase (Plate VIIIb).

The gabbro at Shag Rock, Mutton Cove, is characterized by its coarse grain-size and high plagioclase content. In this rock (J.722.1) augite occurs only as small remnants in the centres of hornblende crystals, the latter showing slight alteration to chlorite. Biotite has been almost completely altered to chlorite with subordinate epidote and leucoxene, the epidote forming thin columnar aggregates parallel to the cleavage traces. Quartz occurs interstitially and is often separated from the plagioclase by small, fibrous, sheaf-like aggregates of actinolite. Quartz also occurs in the gabbro at Curtis Island (J.531.1), 3 miles (4·8 km.) north of Jagged Island. It is mainly interstitial and shows minor replacement of the adjacent plagioclase. This rock contains rare, small crystals of orthoclase and has been cut by small granitic veins. Quartz, orthoclase and the granitic veins are probably related to a nearby granodiorite intrusion. At the Riddle Islands, near the south-west corner of Chavez Island, gabbroic rocks have also been intruded by granodiorite, resulting in severe alteration of the ferromagnesian minerals. Modal analyses of the gabbros are given in Table VIII.

Gabbro is exposed on the eastern coast of Hovgaard Island, approximately 0·75 miles (1·2 km.) from its northern end. The exposures are in close proximity to rocks of the Upper Jurassic Volcanic Group. The gabbro has a distinct flow layering of ferromagnesian minerals which dips at 50° in a direction 079° mag. Two phases of pegmatite veining cut the rock. In thin section the gabbro (J.657.1) has a hypidiomorphic-granular texture. The plagioclase is fresh and unaltered, and has a large variation in grain-size. The

TABLE VIII

MODAL ANALYSES OF GABBROS

	J.526.1	J.722.1	J.657.1	J.531.1
Plagioclase	70·6	85·0	47·7	57·5
Potash feldspar	—	—	—	0·4
Augite	18·0	0·8	32·7	10·8
Hypersthene	3·2	—	—	—
Hornblende	0·9	4·4	16·2	12·1
Iron ore	5·3	0·8	2·9	2·6
Biotite	1·8	1·0	*	—
Chlorite	0·2	1·9	0·5 (Chlorite + Epidote)	4·2
Epidote	—	0·4		0·8
Actinolite	—	3·6	—	5·7
Quartz	—	1·4	—	5·2
Calcite	—	—	—	0·6
Apatite	—	—	—	0·1
Prehnite	—	0·7	—	—
Plagioclase composition	An_{85-80}	An_{80-52}	An_{86-65}	An_{84-36}

* Present but not estimated.

J.526.1 Gabbro, northern end of Jagged Island.
J.722.1 Gabbro, Shag Rock, Mutton Cove.
J.657.1 Gabbro, eastern shore of Hovgaard Island.
J.531.1 Gabbro, Curtis Island.

pyroxene, which forms over 30 per cent of the rock, is a colourless augite (2V = 55°, $\gamma{:}c$ = 47°) and varies in grain-size from 0·5 to 0·1 mm. in diameter with occasional crystals up to 1·0 mm. Two large glomero-porphyritic aggregates of augite occur in the thin section examined, and in both the aggregates and individuals the augite has been replaced internally and marginally by hornblende. Hornblende (α = yellow-green, β = olive-green, γ = green and $\gamma{:}c$ = 22°) also occurs as small subhedral and rare euhedral crystals scattered throughout the rock and as interstitial frameworks and thin veinlets. Several large poikilitic hornblendes have developed by replacement in augite-rich areas and this has resulted in the production of myriads of minute iron ore grains. Small irregular crystals of iron ore are common.

Two phases of veining are present: an early phase of hornblende-pegmatites and a later phase composed entirely of quartz and orthoclase, often in micrographic intergrowth. Although the pegmatites usually occur as narrow veins, large patches have developed in both types. In one instance the hornblende-pegmatites expand from a vein 1 in. (2·5 cm.) wide to a large rounded area 4 ft. (1·2 m.) in diameter, in which hornblende crystals 3 in. (7·6 cm.) long have been recorded. Microscopic examination shows that the hornblende-pegmatites are composed essentially of hornblende, oligoclase and quartz. The large hornblende crystals (> 1 cm.; α = light greenish yellow, β = light olive-green, γ = green and $\gamma{:}c$ = 20°) are fresh and show only incipient alteration to chlorite and sphene. The oligoclase is untwinned and has a poikilitic relationship towards the crystals of andesine (An_{45}). The quartz occurs in coarse- to medium-grained crystals which sometimes have euhedral outlines.

3. *Norites*

Rocks of noritic composition have been recorded at the northern tip of Larrouy Island and on the north-eastern shore of Jagged Island. At Larrouy Island the norite is intruded by diorite and at Jagged Island the exposures of norite are in close proximity to those of the gabbro described on p. 22. In both localities the contacts are not exposed. Modal analyses of the norites are given in Table IX.

In the hand specimen the norite from Larrouy Island (J.546.1) is coarse-grained and has an overall light colour due to its high plagioclase percentage. The only recognizable ferromagnesian mineral is pyroxene. Microscopic examination shows that the plagioclase has a wide range in grain-size. Much of the plagioclase is coarse-grained but occasional crystals attain lengths of 5 mm. Smaller crystals, up to 1·5 mm. in diameter, fill the interstices between the large ones. The smallest plagioclase crystals range from 0·05 to 0·5 mm. in diameter and are confined to the ophitic pyroxene crystals. The plagioclase also has a wide variation in composition (Table IX) and there are several early crystals of anorthite with resorbed margins and over-growths of more acid plagioclase. Some crystals are characterized by large cores of anorthite surrounded by a sharp narrow zone of approximate composition $Ab_{25}An_{75}$, and followed by broad margins zoned down to $Ab_{46}An_{54}$. Olivine crystals vary from 1·25 to 0·20 mm. in diameter. Although some of the smaller crystals have been completely pseudomorphed by serpentine, the olivine is for the most part unaltered. Much of the olivine is cleaved and when it is enclosed by augite it invariably possesses a narrow rim of hypersthene. This is generally, though not always, the case when the olivine is enclosed by plagioclase. Augite occurs as subhedral to anhedral crystals with diameters less than 1 mm. Aggregates of augite crystals are completely enclosed in large crystals of hypersthene but some of the augite possesses narrow margins and internal flecks of brown hornblende, which is particularly noticeable when the augite is adjacent to iron ore. Hypersthene (α = β = light pink, γ = colourless) forms approximately 60 per cent of the total ferromagnesian minerals in the rock and occurs mainly as large ophitic crystals. Adjacent to included iron ore, small flakes of red-brown biotite and brown hornblende have developed. Iron ore (magnetite) occurs as large irregular poikilitic crystals many of which possess irregular borders of red-brown biotite.

At Jagged Island the norite (J.525.1) contains much more hornblende and the hypersthene is slightly replaced by actinolitic hornblende and iron ore. Iron ore grains are concentrated in the narrow marginal rims of the colourless amphibole, the whole being surrounded by broad margins of green hornblende.

4. *Hornblende-gabbros*

Although hornblende-gabbros were recorded at only three localities, rapid variation in their mineral content, even at a single locality, makes it preferable to describe each individual intrusion. Modal analyses of the hornblende-gabbros are given in Table X.

a. *Uralitized hornblende-gabbros of Cape Tuxen.* Gabbroic rocks form the last 0·5 miles (0·8 km.) of the Cape Tuxen peninsula. Two rock types are present: at the tip of the peninsula hornblende-gabbros

TABLE IX

MODAL ANALYSES OF NORITES

	J.546.1	J.525.1
Plagioclase	70·7	64·4
Augite	7·5	8·3
Hypersthene	17·7	11·5
Hornblende	0·2	10·2
Iron ore	2·3	5·6
Olivine	0·7	—
Biotite	0·7	—
Serpentine	0·2	—
Plagioclase composition	An_{75-54}	An_{88-70}

J.546.1 Norite, northern tip of Larrouy Island.
J.525.1 Norite, north-eastern shore of Jagged Island.

comprise the country rock but farther inland altered olivine-hypersthene-gabbros have been recorded. Both types have suffered extensive uralitization. The uralitized hornblende-gabbro is faintly banded and individual bands rarely exceed 1 ft. (30 cm.) in width. On the shore the bands are vertical but a short distance inland they dip at 85° in a direction 100° mag. Specimens were taken from adjacent bands (J.614.1, 615.1) and the modes of these rocks indicate the varying percentage of light and dark minerals, which is the main characteristic of the exposure (Table X). Microscopic examination shows that the clinopyroxene of both specimens has mostly been pseudomorphed by fibrous blue-green actinolite. Hornblende (α = light yellow-green, β = olive-green, γ = green and $\gamma{:}c$ = 26°) has also suffered marginal replacement by actinolite. The range in composition of the plagioclase varies in adjacent bands and in both types there has been only incipient alteration to sericite and epidote. The plagioclase crystals are slightly orientated parallel to the bands. Ilmenite is present as large ragged platy masses and small subhedral crystals often showing cleavage. Peripheral alteration to sphene is common and the individual sphene crystals in the rock have probably been derived in this way. The proximity of iron ore to the areas of uralitization appears to have intensified the alteration of ilmenite to sphene. Accessory minerals include apatite, biotite, quartz and zircon. Similar hornblende-gabbros have been recorded at a number of exposures along the north-east coast of Duchaylard Island but they have not been uralitized.

b. *Petermann Island.* Hornblende-gabbros have been recorded at Rouch Point at the north-west corner of Petermann Island. In this area the gabbros are cut by late-stage veins and have been intruded by granodiorite. At this exposure there are two main types of gabbro (J.705.1, 2) and, although the occurrence of each type is irregular and there is no recognizable contact between them, one (J.705.2) can easily be distinguished by its coarser grain-size and in particular by the presence of large platy crystals of plagioclase, the latter not occurring in the adjacent rock (J.705.1).

Microscopic examination shows that specimen J.705.2 carries over 8 per cent of augite and is rich in iron ore, whereas the augite in specimen J.705.1 occurs as tiny remnants within large hornblende crystals and only a minor amount of iron ore is present. The plagioclase in both rocks has a total compositional variation from An_{86} to An_{47} but most of the plagioclase has a range of An_{70}–An_{47}; this surrounds solution and replacement remnants of earlier more calcic crystals. In specimen J.705.2 the augite (2V $\simeq$ 55°; $\gamma{:}c$ = 48°) occurs as large ophitic crystals up to 6 mm. long and every stage of replacement by hornblende can be clearly seen (Plates VIIIc, d, e). In both rocks hornblende is abundant, occurring mainly as subhedral crystals up to 1·5 mm. long and as glomeroporphyritic aggregates. Both rocks are cut by fine-grained hornblende veinlets, which in specimen J.705.1 also contain andesine (An_{45}). The veinlets follow fine shear fractures in the gabbros along which there has been considerable displacement of albite lamellae in the plagioclase.

TABLE X

MODAL ANALYSES OF HORNBLENDE-GABBROS

	J.614.1	J.615.1	J.705.1	J.705.2	J.569.1	E.30.5	E.30.4
Plagioclase	62·3	51·7	79·5	67·3	66·3	56·2	39·1
Augite	4·6	0·1	—	8·6	7·7	8·7	3·5
Hornblende	12·8	14·5	18·8	16·8	12·8	11·7	33·7
Actinolite	11·8	19·9	—	—	2·8	13·8	15·9
Hypersthene	—	—	—	—	1·1	—	—
Iron ore	6·6	9·4	1·7	7·1	5·8	5·3	6·4
Biotite	—	—	—	—	1·3	—	—
Talc	—	—	—	—	—	—	—
Serpentine	—	—	—	—	2·2	—	—
Chlorite	0·4	0·4	—	—	—	—	—
Epidote	*	—	—	0·2	*	3·2	—
Quartz	0·6	—	—	*	*	—	—
Sphene	0·5	—	—	*	*	—	—
Apatite	0·4	3·8	—	—	*	1·0	0·7
Pyrites	—	—	*	—	—	—	0·3
Haematite	—	—	*	—	—	—	0·2
Plagioclase composition	An_{60-51}	An_{69-63}	An_{70-47}	An_{70-47}	An_{73-55}		

* Present but not estimated.

J.614.1 Uralitized hornblende-gabbro, Cape Tuxen.
J.615.1 Uralitized hornblende-gabbro, Cape Tuxen.
J.705.1 Hornblende-gabbro, Rouch Point, Petermann Island.
J.705.2 Hornblende-gabbro, Rouch Point, Petermann Island.
J.569.1 Hornblende-gabbro, north-east coast of Duchaylard Island.
E.30.5 Uralitized hornblende-gabbro, Cape Bryant (Adie, 1955).
E.30.4 Uralitized hornblende-gabbro, Cape Bryant (Adie, 1955).

Apart from the hornblende-andesine veinlets there are two major phases of late-stage veining cutting the hornblende-gabbros at Rouch Point. They are (in order of intrusion): coarse gabbroic pegmatites and a series of cross-cutting veins of microgabbro composition. The pegmatites vary from veinlets to 6 in. (15 cm.) in width and have gradational contacts with the gabbro. They are essentially the coarser-grained equivalents of specimen J.705.2 and they contain large ophitic crystals of augite up to 2 cm. long, glomeroporphyritic aggregates of smaller augite crystals, rare crystals of orthopyroxene severely altered to tremolite-actinolite, and abundant magnetite. The augite crystals possess thin margins of hornblende, while numerous flecks and occasional large aggregates of medium-grained subhedral hornblende have developed internally. The magnetite occurs as large irregular crystals with narrow margins of either hornblende or biotite. The marginal biotite is later than the hornblende, which is cut by short biotite veinlets. The plagioclase (An_{58-52}) is unaltered and is sometimes intergrown with hornblende.

The cross-cutting veins (J.705.18) which followed the pegmatites generally do not exceed 6 in. (15 cm.) in width. They are composed entirely of medium- to fine-grained plagioclase, hornblende and iron ore. The plagioclases have a marked crystal orientation and reversed zoning, the compositions varying from An_{56} (cores) to An_{61} (margins). There are, however, occasional phenocrysts and groups of phenocrysts with cores of anorthite composition. Hornblende occurs in almost equal quantity to the plagioclase. The hornblende crystals (α = light green, β = olive-green, γ = green and γ:c = 26°) are subhedral to anhedral and are often clouded with minute grains of iron ore. Small rounded grains of magnetite are abundant. The contacts between the veins and the gabbro are sharp and there has been no marginal chilling or alteration. Both pegmatites and veins are displaced by small shear planes which cut the gabbro (Plate IVa).

5. *Contact phenomena*

a. *Gabbros—Upper Jurassic Volcanic Group.* Contacts between the gabbro and the Upper Jurassic Volcanic Group have been found only at Cape Tuxen (Plate IIIc). Near the shore, at the end of the peninsula, lenticular rafts of the volcanic rocks (the largest of which is 300 ft. (91·4 m.) long by 50 ft. (15·2 m.) thick) have been preserved in the gabbro. Although the volcanic rafts have been thermally metamorphosed, it is clear that they belonged originally to a succession of tuffs and agglomerates. The host rock is an uralitized olivine-hypersthene-gabbro (J.617.1) which does not differ essentially from that described on p. 21 (J.701.2). The gabbro has not been chilled at the contact and the only difference between it and the gabbro at a distance from the contact is that the former contains small interstitial wedges of quartz and the augites tend to be glomeroporphyritic and dusty with magnetite inclusions.

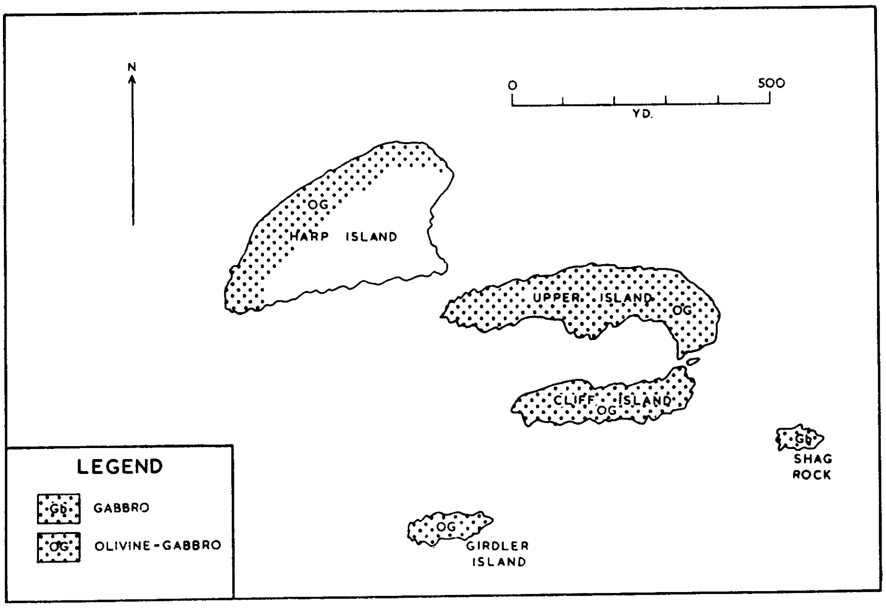

FIGURE 7

Geological map of the Mutton Cove area.

b. *Gabbros—later intrusive rocks.* At Cliff Island, Mutton Cove (Fig. 7), dioritic veins invade the olivine-gabbro in a complicated manner. There are no well-defined contacts between the two rock types and microscopic examination of a diorite vein (J.524.2) shows that it has been highly contaminated by the olivine-gabbro. Two types of plagioclase are present: a rare highly altered basic variety with a composition of An_{75} and the unaltered plagioclase of the matrix ($An_{47\text{-}14}$). The basic plagioclase has broad mantles of clear andesine-oligoclase and there is a marked difference in refractive index. Hornblende is the main ferromagnesian mineral and it occurs in small ragged crystals which have been altered to chlorite and sphene. Aggregates of fibrous blue-green actinolite, chlorite, iron ore and sphene probably represent former pyroxene. Most of the iron ore in the rock is confined to these aggregates.

At a small promontory 0·5 miles (0·8 km.) south of Cape Tuxen (Fig. 8), gabbro has been intruded by granodiorite (J.686). The main contact is inaccessible (Plate IIIc) but a small offshoot of the granodiorite is exposed at sea-level and allows examination of the contact phenomena. This offshoot is in the form of a sheet 12 ft. (3·6 m.) thick at the exposure and tapering slightly towards the sea (Plate IVb).

The type gabbro (J.686.1) in this area only differs from those found near the shore at the tip of Cape Tuxen in that it has not been uralitized. Microscopic examination shows that the composition of the

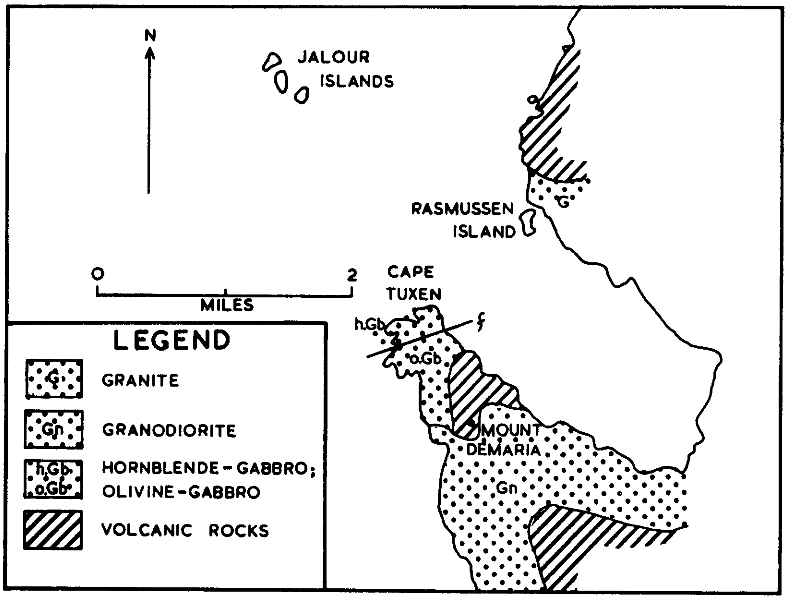

FIGURE 8

Geological map of the Cape Tuxen area.

plagioclase varies from large cores of An_{63} to narrow rims of An_{17}. Some of the plagioclase crystals have distinct outlines and individual zones are sharply separated right up to the margin. However, many lose their clarity at the margins and sodic plagioclase has been replaced by potash feldspar with which a perthitic relationship is assumed. Throughout the rock there are large areas of orthoclase and quartz in micrographic intergrowth. The main alteration product of augite is biotite which occurs as clusters of small unorientated laths. There has been a little replacement of pyroxene by hornblende and rarely by actinolite. Small anhedral crystals of magnetite are common and these are often surrounded by marginal clusters of fine-grained biotite. The gabbro xenoliths (J.686.5) within the granodiorite (Plate IVc) are medium- to fine-grained, most of the plagioclase having recrystallized and become intimately associated with quartz. Remnants of the original plagioclase are cloudy with sericite and epidote in comparison with the clear recrystallized oligoclase. Large poikiloblastic crystals of quartz have been formed and similar but smaller crystals of hornblende are common. The hornblende is slightly altered to calcite and sphene, and the biotite is severely altered to chlorite, sphene and epidote.

At Rouch Point, Petermann Island, hornblende-gabbros and associated pegmatites have been intruded by granodiorite (Plate IVd). Approaching the contact, the most noticeable feature of the gabbro is the increase in fine-grained biotite developing from hornblende and iron ore. However, biotite disappears entirely at the contact and for a distance of 0·5–1 in. (1·3–2·5 cm.) the gabbro has been hornfelsed (J.705.33). Most of the plagioclase has been recrystallized, forming a medium-grained matrix containing relicts of the original plagioclase. Intimately associated with the plagioclase and in almost equal quantities is fine-grained hornblende with occasional aggregates of slightly larger crystals up to 0·5 mm. in diameter. Irregular medium-grained crystals and crystal clusters of iron ore are abundant and they frequently possess narrow rims of sphene. In the pegmatites (J.705.34) thermal metamorphism has resulted in the conversion of augite to aggregates of medium- to fine-grained biotite. Biotite has also developed from hornblende and from large areas of tremolite. Large irregular plates of iron ore are abundant and the accessories include pleonaste and apatite.

At the Riddle Islands, near the south-west corner of Chavez Island, gabbros have been intruded by granodiorite veins. The gabbros (J.552.1) have been affected by severe hydrothermal activity, resulting in the alteration of augite to actinolite, the replacement of actinolite, hornblende and biotite by a mixture of chlorite, epidote and leucoxene, and the formation of sericite and epidote in the plagioclase. The rock is remarkably rich in apatite, which forms an irregular discontinuous vein of large euhedral crystals, broken and injected by later quartz.

6. *Summary*

Owing to the widespread scattering of the gabbro outcrops there is a paucity of evidence to indicate the contact relationships between the different varieties of gabbro. At Cape Tuxen, banded hornblende-gabbros grade into olivine-hypersthene-gabbros, both types of gabbro belonging to the same intrusion. It is difficult to reconcile the high angle of the banding with their formation by gravitational crystal settling, yet the differences in mineral and plagioclase composition in adjacent bands in the hornblende-gabbro and the gradation of this rock type into olivine-hypersthene-gabbro suggest such a process. Similar features in gabbroic rocks have been attributed to tilting after original formation in a roughly horizontal position (Stewart, 1947). Although tear faulting can be demonstrated in the gabbro at Cape Tuxen, there is little evidence to suggest tilting. No satisfactory conclusions can be reached concerning this phenomenon at Cape Tuxen but adjustment of the intrusion to stress before complete recrystallization, the shape of the intrusion and possibly sinking of large volcanic rafts may have been contributing factors.

At Mutton Cove there is no evidence that the olivine-gabbros of Cliff Island and Upper Island, and the gabbro of Shag Rock are separate intrusive phases but their close proximity suggests that both gabbro types belong to the same intrusion. The paucity of early ferromagnesian minerals at Shag Rock appears to be due to their early removal by gravitational sinking. The widespread hydrothermal alteration of the olivine-gabbro indicates that the main body of the diorite is near the surface around Mutton Cove. The uppermost level of the diorite is exposed on the north shore of Cliff Island where contamination by the gabbro has resulted in hybrid rocks.

At Petermann Island no regularity in the occurrence of the two types of gabbro has been observed, although the slightly coarser grain-size, large platy crystals of plagioclase and high content of iron ore aid easy distinction of one from the other. With the replacement of augite by hornblende there is a perfect gradation between the two. Similar phenomena have been recorded by Miller (1937) in the San Marcos gabbro of southern California, where he found complete gradations between the many types of gabbros intimately associated in the field. At Rouch Point the varying composition of the gabbro is probably the result of local concentrations of volatiles during the later stages of crystallization.

Little evidence was found to indicate the method of intrusion of the gabbro but the presence of volcanic rafts of considerable size at Cape Tuxen suggests large-scale stoping. The gabbros are free of inclusions but the variation in grain-size in some types, particularly in the norites, the irregular zoning in the plagioclase and the presence of remnant calcic cores suggest that their composition has been slightly modified by contamination. Although no inclusions were found, this may be due to their complete re-working by the gabbro magma.

It appears that in the early stages of the Andean Intrusive Suite the gabbros were emplaced into the Upper Jurassic Volcanic Group and the Trinity Peninsula Series as a number of small intrusions fed from a magma chamber at depth. It is probable that the gabbro magma was essentially homogeneous and that the variations noted have resulted mainly from the loss, retention or concentration of volatiles, crystal differentiation by gravitational settling and contamination.

B. Diorites

The preponderance of intrusive rocks of intermediate composition over all other members of the Andean Intrusive Suite in Graham Land has been noted by many previous workers in this area. The Graham Coast is no exception in this respect, since intermediate rocks form large sections of the coastline and many of the offshore islands. Diorites, though not as abundant as tonalites, form intrusions of considerable size in some areas, which are described in detail below. Modal analyses of the diorites are given in Table XI.

Hypersthene-augite-diorites have been recorded at a number of localities in the Saffery Islands (Fig. 9). Widespread hydrothermal activity has resulted in the alteration of the ferromagnesian minerals over most of the area and this has been accompanied by three phases of veining. In the hand specimen the unaltered type rock (J.515.1) is medium- to coarse-grained, grey and black in colour and contains large prominent biotites. In thin section, although the plagioclase has a medium- to coarse-grained hypidiomorphic texture, the dark minerals (in particular the augite) have considerable variation in grain-size, the crystals ranging from 0·25 to 2·5 mm. in diameter. The main bulk of the plagioclase varies in composition from An_{46} to An_{32} but there are several corroded cores with a noticeably higher relief and with a composition of

TABLE XI

MODAL ANALYSES OF DIORITES

	J.700.1	J.734.1	J.544.1	J.515.1	J.518.1	J.514.2	J.514.1
Plagioclase	64·5	64·5	66·5	63·0	65·6	65·1	67·7
Orthoclase	1·7	5·3	5·4	—	—	—	—
Quartz	5·2	7·4	3·4	2·3	6·3	*	*
Augite	3·5	0·2	4·0	10·8	4·5	0·7	—
Hypersthene	—	—	4·3	3·7	1·4	—	—
Hornblende	18·3	8·1	4·9	10·0	10·4	18·6	12·1
Actinolite or tremolite	—	5·6	3·0	—	—	—	—
Biotite	2·4	*	2·5	7·2	3·6	—	—
Iron ore	2·6	3·6	4·6	2·6	2·2	2·8	1·4
Chlorite	0·7	4·9	0·3	0·4	5·4	6·7	9·8
Epidote	—	0·3	—	*	*	5·4	6·9
Sphene	0·1	—	—	*	0·3	0·7	0·5
Apatite	1·0	0·1	1·1	*	0·2	*	0·8
Pyrites	—	—	—	*	*	*	*
Haematite	—	—	—	*	0·1	*	0·3
Zircon	—	*	*	—	—	—	—

* In insufficient quantities to be recorded.

J.700.1 Augite-diorite, Cruls Island, French Passage.
J.734.1 Diorite, western end of Lahille Island.
J.544.1 Hypersthene-augite-diorite, western end of Larrouy Island.
J.515.1, J.518.1, J.514.2, J.514.1 Hypersthene-augite-diorites, Saffery Islands.

An_{67}. Crystals which contain these basic cores have a patchy extinction. Where the plagioclase is adjacent to quartz it has been slightly corroded. Augite (2V $\simeq$ 55°; $\gamma{:}c = 45°$) is the most abundant ferromagnesian mineral, occurring as ragged crystals with sieve texture, which in some cases shows Schiller structure, and as small glomeroporphyritic aggregates of these crystals. The augite which is frequently twinned on (100) possesses broad margins and numerous internal flecks of hornblende but biotite has developed when it is in contact with iron ore. Augite together with hypersthene forms a large glomeroporphyritic aggregate 6 mm. in diameter, within which is an area 2 mm. in diameter composed entirely of hypersthene crystals. In the latter concentration, iron ore has formed a small dactylitic intergrowth from which biotite has developed. The glomeroporphyritic aggregates of augite, and augite and hypersthene, contain large apatites, interstitial frameworks of hornblende and irregular patches of quartz, the latter replacing both hornblende and biotite when present. Most of the hornblende in the rock has a pleochroism scheme α = light greenish yellow, β = olive-green, γ = dark green and $\gamma{:}c = 28°$, and where it replaces pyroxene it can have a brownish green colour, but immediately adjacent to hypersthene it is often colourless. Biotite has usually developed around iron ore crystals, particularly in the vicinity of pyroxenes, but there are several independent broad laths of biotite which show incipient alteration to chlorite and epidote. Ilmenite occurs as medium- to coarse-grained irregular crystals with rare marginal alteration to sphene and replacement by pyrites. The pyrites has been further altered to haematite.

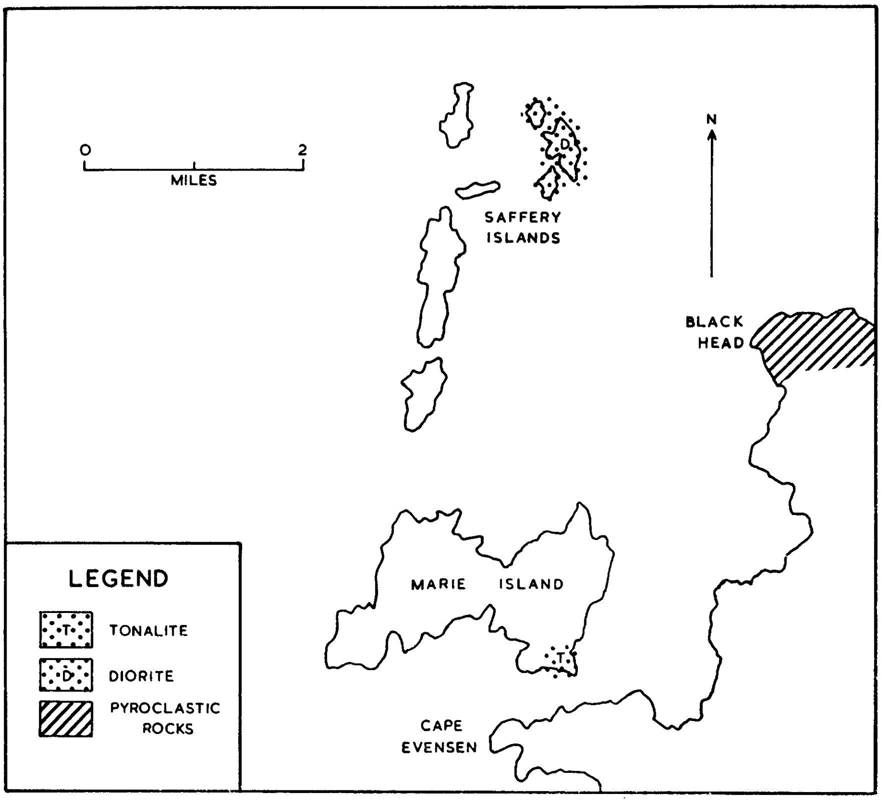

FIGURE 9

Geological map of the Black Head—Marie Island—Saffery Islands area.

In the early stages of hydrothermal alteration of the diorites of the Saffery Islands both biotite and hypersthene have been partially converted to chlorite and plagioclase has been slightly altered to sericite and epidote. However, the main bulk of the rock is unaffected (J.518.1). With increasing alteration the cores of the plagioclase have developed large crystal aggregates of epidote, which also occurs as large interstitial wedges and in association with chlorite and sphene in the complete replacement of biotite. Hypersthene has been pseudomorphed by chlorite and iron ore (J.514.2). Hornblende, which is the most abundant ferromagnesian mineral in this rock, shows incipient alteration to chlorite along the cleavage traces. Severe alteration has resulted in the development of large areas of chlorite containing radiating aggregates of epidote, an increase in the amount of interstitial epidote and in the amount of hornblende alteration to chlorite (J.514.1). Large crystals of apatite are scattered throughout the rock and the outlines of biotite crystals replaced by chlorite are marked by trains of sphene granules. The three phases of late-stage veining in this area are (in order of intrusion): thin epidote veins, veins consisting essentially of medium- to fine-grained oligoclase, orthoclase-microperthite and quartz, which vary in width from 1 in. (2·5 cm.) to 1·5 ft. (45 cm.), and veins of orthoclase and quartz in micrographic intergrowth with oligoclase and subordinate hornblende and biotite.

Hypersthene-augite-diorites (J.544.1) have also been recorded on the central west coast of Larrouy Island. In the hand specimen they differ markedly from those of the Saffery Islands, being medium-grained, dark in colour and closely resembling a rock of gabbroic composition. Microscopic examination shows that the plagioclase ($An_{46\text{-}32}$) has a large variation in grain-size (0·2–3·0 mm.) and, though it is for the most part hypidiomorphic, marginal myrmekitic intergrowth with quartz and slight replacement by potash feldspar have resulted in irregular outlines in many cases. Remnant corroded cores of basic plagioclase (Plate VIIIf) enclosed in the plagioclase of the matrix have also been recorded in this rock. The ferro-magnesian minerals are evenly distributed throughout the rock as small individuals and aggregates. Irregular crystals of colourless augite ($2V \simeq 60°$; $\gamma{:}c = 45°$) possess very narrow borders of hornblende and are riddled with fine-grained iron ore from which biotite has developed; together with the patchy replacement of hornblende and blebs of quartz and plagioclase it has given the augite crystals a sieve texture. Hypersthene has been partially pseudomorphed by fibrous tremolite with the separation of abundant iron ore granules; adjacent to iron ore crystals and around the granules the tremolite often shows a faint green coloration. Much of the tremolite in the smaller pseudomorphs has been converted to chlorite. Hornblende most commonly occurs as ragged poikilitic crystals enclosing pyroxene. The hornblende has corroded outlines against both quartz and feldspar, particularly potash feldspar, and blebs of quartz inside the hornblende suggest that it has in part been replaced by quartz. The rock is especially rich in iron ore. Apart from the swarms of granules described above, the rock contains abundant subhedral to anhedral medium-grained crystals of magnetite around many of which biotite has developed. Accessories include apatite, zircon, pyrites and haematite. Of these apatite is by far the most important, appearing as small basal sections and euhedral prisms which show a tendency to concentrate in the ferromagnesian aggregates.

0·5 miles (0·8 km.) north of Duseberg Buttress diorite has intruded the Upper Jurassic Volcanic Group. The contact with the volcanic rocks, though irregular, is distinct and clear cut. The adjacent volcanic rocks have been thermally metamorphosed and are cut by a maze of hydrothermal veins from the diorite (Plate IIIa). The type rock in this area is a medium- to coarse-grained hornblende-biotite-diorite in which the hornblende occurs as small ragged crystals showing incipient alteration to actinolite and chlorite, and containing aggregates of fine-grained biotite which probably represent former pyroxene. Much of the biotite in the rock has developed around ilmenite crystals and sphene is also a common marginal alteration product of ilmenite. Plagioclase (An_{50-35}) has only been slightly altered to sericite and epidote, quartz is confined to the interstices and the accessory minerals include apatite and zircon. Similar diorites have also been recorded at Lahille Island (J.734.1) and at Rassa Point (J.579.1).

C. Tonalites

Tonalites are the most abundant members of the Andean Intrusive Suite on the Graham Coast. Although their occurrence is limited on the mainland, many of the offshore islands particularly in the northern area are composed partially or entirely of tonalite. In view of the abundance and extensive distribution of the tonalites, it is preferable to describe separately the areas where they form intrusions of considerable size and importance and to compare these with similar rocks of more local occurrence. Using Nockolds's (1954) classification, the quartz-diorites described by Tyrrell (1921), Knowles (1945) and Adie (1955) would be included here. Modal analyses of the tonalites are given in Table XII.

1. *Booth Island*

Tonalites are exposed on the east–west trending peninsula on the west coast of Booth Island, where they intrude the Upper Jurassic Volcanic Group and are in turn intruded by granodiorite (Fig. 4; Plate IIc). At the junction of the peninsula and the main mass of Booth Island the tonalites have been cut by severe north-east to south-west trending faults and weathering along the fault zones has produced deep ravines (Plate Va). In the hand specimen the tonalites (J.644.1, 645.1) are coarse-grained grey rocks with subordinate but prominent ferromagnesian minerals. In thin section, the plagioclase of the matrix (An_{48-30}) often shows oscillatory zoning, complex twinning and zoning in the cores and rarely can be found surrounding small corroded aggregates of earlier more basic plagioclases that have composite zoning patterns (Plate IXa). Where it is adjacent to quartz and potash feldspar the plagioclase has been corroded and replaced. Hornblende and biotite are the most abundant ferromagnesian minerals. The hornblende ($\gamma{:}c = 24°$) occurs as ragged poikilitic crystals with a patchy coloration. It appears that the hornblende originally had a brownish green colour but this has been converted to light green in patches and along the cleavage traces of many crystals. The hornblende shows slight alteration to chlorite and sphene, and together with prehnite these two minerals have also replaced some of the biotite. Sphene is frequently marginal to the small subhedral ilmenite crystals in the rock. Most of the quartz shows undulose extinction which agrees with the field evidence of intense faulting. The accessory minerals include apatite, zircon and orthite.

Tonalites (J.664.1) exposed at the isthmus connecting the mountainous areas of the northern and southern ends of Booth Island show only minor differences from those of the western peninsula. The plagioclase (An_{54-15}) has patchy and irregular zoning and it often surrounds corroded cores of bytownite.

TABLE XII

MODAL ANALYSES OF TONALITES

	J.644.1	J.645.1	J.629.1	J.639.1	J.620.3	J.633.1	J.699.1	J.707.1	J.637.1	J.719.1	J.519.1	J.672.1
Plagioclase	56·6	63·8	54·8	53·3	63·0	57·1	62·5	62·4	57·8	57·7	63·2	54·3
Potash feldspar	7·5	0·9	2·6	6·7	4·0	—	0·2	1·4	0·3	5·9	—	2·6
Quartz	16·6	12·0	13·7	19·6	12·1	14·1	12·3	18·0	13·9	11·5	13·7	16·8
Augite	—	—	5·8	0·6	—	—	11·1	*	1·6	8·4	3·1	2·8
Hypersthene	—	—	—	—	—	—	—	—	*	1·5†	—	3·0
Hornblende	8·5	11·0	9·1	10·4	11·1	17·4	4·8	7·3	14·7	0·7	4·8	5·2
Actinolite	—	—	—	—	—	—	—	—	—	—	—	1·6
Biotite	8·3	4·5	10·2	7·9 (Biotite and Chlorite together)	7·0 (Biotite and Chlorite together)	6·1	10·2	7·0	9·9	9·9	14·0	8·0
Chlorite	0·9	3·2	0·1			2·5	4·9	2·0	0·4	1·1	*	3·3
Iron ore	1·3	2·4	2·7	1·0	1·7	1·6	2·8	1·0	1·4	2·9	1·2	2·3
Sphene	0·3	1·9	0·3	0·5	0·6	1·1	—	0·5	—	—	*	*
Epidote	*	—	—	*	0·5	*	1·0	*	*	—	—	*
Pyrites	—	0·3	—	—	—	*	*	—	—	—	*	—
Haematite	—	*	—	—	—	*	*	—	—	—	*	—
Apatite	*	—	0·7	*	*	0·1	0·2	0·2	*	0·4	*	0·1

* Present but in insufficient amounts to be recorded.
† Includes serpentine and talc.

J.644.1 Tonalite, western shore of Booth Island.
J.645.1 Tonalite, western shore of Booth Island.
J.629.1 Augite-tonalite, north-east coast of Hovgaard Island.
J.639.1 Tonalite, Pléneau Island.
J.620.3 Tonalite, Port Circumcision, Petermann Island.
J.633.1 Tonalite, Vedel Islands.
J.699.1 Augite-tonalite, south-easternmost of Dannebrog Islands.
J.707.1 Tonalite, small island at entrance to French Passage.
J.637.1 Augite-tonalite, Somerville Island.
J.719.1 Hypersthene-augite-tonalite, Milnes Island.
J.519.1 Augite-biotite-tonalite, Marie Island.
J.672.1 Hypersthene-augite-tonalite, Lippmann Islands.

Biotite is the main ferromagnesian mineral and it occurs as large laths. Ragged hornblende crystals contain small remnant pyroxenes and a minor amount of hypersthene is present.

Altered tonalites recorded at Roullin Point at the southern tip of Booth Island are characterized by a high content of fine-grained green biotite. The biotite is often concentrated into aggregates within which it is associated with actinolite and ilmenite. Much of the plagioclase has been replaced by an intergrowth of quartz and potash feldspar, and it has been severely sericitized.

The tonalite which forms Splitwind Island differs from that of the western peninsula of Booth Island only in that it contains occasional augite crystals.

2. *Hovgaard Island and Pléneau Island*

Tonalites have been recorded on the north-east shore of Hovgaard Island and they also form the whole of Pléneau Island. The only difference between the rocks of these two areas is that at Hovgaard Island the tonalite (J.629.1) contains approximately 6 per cent of augite, whereas at Pléneau Island (J.639.1) augite occurs only as small remnants in the cores of large hornblende crystals. In both rocks most of the ferromagnesian minerals, especially the hornblendes, occur in irregular crystal aggregates and have a wide variation in grain-size. Much of the hornblende has a pleochroism scheme of α = light yellow-green, β = olive-green, γ = green and $\gamma{:}c = 28°$, but where aggregates of small hornblende crystals have replaced augite the former are often much lighter in colour and are rarely colourless. The hornblende has been slightly replaced by sphene and biotite. The aggregates of ferromagnesian minerals rarely contain corroded basic plagioclase and large apatites. All degrees of alteration occur in the biotite, ranging from the unaltered mineral to complete chlorite-sphene-leucoxene pseudomorphs. Apart from that derived from the biotite, sphene has also developed marginally to the ilmenite and it occurs as relatively large individuals with irregular penetrating margins.

In some cases the plagioclase in the tonalite at Pléneau Island has a patchy extinction and many of the cores have been severely sericitized. Marginally, the plagioclase crystals (An_{42-30}) have been replaced by quartz and potash feldspar. At Hovgaard Island the plagioclase (An_{47-38}) is much less altered but it contains skeletal remnants of more basic plagioclase.

Occasional xenoliths have been recorded at Pléneau Island; they are small with diameters between 1 and 4 in. (2·5 and 10·0 cm.), and display a distinct tendency to aggregate into small clots. In the hand specimen the xenoliths are slightly darker than the host rock with which they have a gradational contact. Microscopically, the only differences between them and the tonalite are a slightly higher content of ferromagnesian minerals and a finer grain-size.

3. *Petermann Island*

Tonalites comprise the northern shore of Port Circumcision where they have been intruded by granodiorite. The tonalites are similar in most respects to those of the west coast of Booth Island but they differ mainly in that the potash feldspar is a microcline-microperthite. The potash feldspar has replaced the plagioclase (An_{27-18}) marginally. The ferromagnesian minerals are evenly distributed throughout the rock, although there is a slight tendency towards aggregation. Hornblende (α = light golden-yellow, β = light brownish green, γ = grass-green; $\gamma{:}c = 24°$) has altered in small patches to a deep blue-green coloured amphibole identified as ferrohastingsite (p. 38), which is the stable amphibole of the intruding granodiorite. Often the hornblende is crowded with small apatite crystals. Greenish brown biotite forms distinct laths and it is also scattered throughout the rock in fine-grained aggregates; hornblende within these aggregates has been partially converted to biotite. The contact with the granodiorite is sharply demarcated by a concentration of dark minerals (Plate Vb). Microscopic examination shows that this concentration is composed of chloritized biotite, small subhedral crystals of iron ore and occasional hornblendes (J.620.1). The ragged laths of hornblende have been more completely replaced by ferrohastingsite and sphene than in the rock away from the contact.

4. *Local occurrences of tonalite*

In most of the remaining localities where tonalites have been recorded their textural and mineralogical relationships compare closely with the tonalites of Booth Island and Hovgaard Island. Tonalites which are comparable with those from Hovgaard Island have been recorded at three localities: the south-easternmost island in the Dannebrog Islands group, an island at the seaward (western) entrance to French Passage and at Marie Island at the southern end of the Graham Coast. At Marie Island the plagioclase in the tonalite (J.519.1) contains small corroded cores of bytownite (An_{71}) surrounded by plagioclase varying in composition from An_{40} in the cores to An_{24} at the rims. The plagioclase also contains small rounded inclusions of augite, hornblende and biotite. Apatite is a common accessory mineral.

In the tonalite (J.707.1) from the island in French Passage, remnant cores of plagioclase have a composition of An_{55} and they are surrounded by plagioclase zoned from An_{46} to An_{24}. Some of the plagioclase shows oscillatory zoning. The hornblende and biotite tend to form aggregates; the hornblende is poikilitic, patchy in colour and often partially replaced by sphene.

The tonalite (J.699.1) from the Dannebrog Islands group is distinctive in that it contains the highest percentage of augite of any of the intermediate rocks examined. The augite has a sieve texture, a large variation in grain-size and often forms glomeroporphyritic aggregates welded together by interstitial hornblende. Corroded basic plagioclase cores are sericitized, whereas the plagioclase in the matrix is fresh.

Tonalites similar to those from the west coast of Booth Island have been recorded at the Vedel Islands. Here the tonalite (J.633.1) contains numerous small xenoliths (J.633.2) which have a hornfelsic texture and consist essentially of plagioclase (An_{52-32}), hornblende, augite, hypersthene and biotite. The contacts with the host rock are sharp and apart from slight sericitization of the plagioclase the host rock appears to be unaffected. The plagioclase in the tonalite (An_{37-30}) contains occasional highly corroded and altered basic cores which have complex zoning and twinning. Hornblende has been replaced by frameworks of sphene and in part by biotite. Quartz replaces both hornblende and plagioclase.

Hypersthene-augite-tonalites, similar to those described from Trinity Peninsula (Adie, 1955), have been recorded at a number of localities. In the hypersthene-augite-tonalite (J.672.1) from the Lippmann Islands the hypersthene has been partially replaced by actinolite, chlorite and biotite, and is commonly margined by hornblende, though it rarely possesses a rim of augite. Hypersthene also forms large glomeroporphyritic aggregates containing dactylitic intergrowths of iron ore (Plate IXb). The plagioclase (An_{54-27}) contains corroded remnant cores of approximate composition An_{70}.

At Milnes Island (J.719.1) much of the hypersthene is pseudomorphed by serpentine, chlorite, talc, iron ore and calcite. Augite occurs as large ragged ophitic crystals and internal replacement by hornblende and biotite has given the augite a sieve texture. In many places augite has been replaced by an aggregate of granular quartz with chlorite, calcite and actinolite (Plate IXc). The plagioclase contains remnant basic cores and marginally it has been replaced by potash feldspar; as a consequence of this the plagioclase has developed a myrmekitic border in some cases (Plate IXd).

At Somerville Island (J.637.1) hypersthene occurs only as small cores in large hornblende crystals. The ferromagnesian minerals form small aggregates and augite is replaced by aggregates of small hornblende crystals. Remnant calcic cores in the plagioclase are rare and plagioclase, hornblende and biotite have all been partially replaced by quartz.

In the small group of islands (J.535.1) 1 mile (1·6 km.) north of Curtis Island, hypersthene and augite form small glomeroporphyritic aggregates in which the hypersthene is altered to actinolite, chlorite, talc and iron ore.

D. Granodiorites

In the hand specimen there is very little difference between many of the granodiorites and the tonalites described above. The granodiorites, with the exception of those from Beascochea Bay (p. 38), vary from the mottled grey and black colour typical of the tonalites to light grey rocks with a pinkish tinge and speckled with small ferromagnesian minerals. Microscopic examination shows that the major differences between the granodiorites and the tonalites are a decrease in the percentage of dark minerals, and an increase in the amount of potash feldspar which together with the plagioclase and quartz totals between 85 and 95 per cent of the rock. Modal analyses of the granodiorites are given in Table XIII.

Granodiorite has been recorded at Rouch Point on the north-west shore of Petermann Island, where it intrudes hornblende-gabbros. The granodiorite (J.705.31) is a medium-grained grey rock with distinct milky white plagioclase crystals and small and scattered ferromagnesian minerals. Microscopic examination shows that plagioclase, potash feldspar and quartz comprise 93 per cent of the rock. In the cores of the plagioclase crystals (An_{27-12}) minor amounts of sericite, epidote and chlorite have developed but at their

TABLE XIII

MODAL ANALYSES OF GRANODIORITES

	J.705.31	J.685.1	J.686.4	J.649.1	J.619.1	J.656.1	J.542.1	J.533.1	J.530.1	J.699.6
Plagioclase	47·6	45·7	44·5	41·8	50·3	41·4	59·5	48·1	56·7	45·1
Potash feldspar	22·3	19·8	15·4	19·6	23·0	23·0	11·1	17·0	12·5	13·3
Quartz	23·2	22·3	18·4	28·1	20·1	28·2	20·2	19·4	16·0	24·6
Hornblende	1·8	3·5	5·8	2·4	1·1†	—	1·4	7·3	6·1	5·2
Biotite	2·9	5·5	10·2	6·7	1·7	4·1	3·2	0·1	*	9·6
Chlorite	0·7				2·3	2·2	2·7	5·5	4·2	
Augite	—	—	—	0·2	—	—	—	0·3	*	*
Hypersthene	—	—	—	—	—	—	0·1	—	—	—
Iron ore	1·2	1·5	2·2	0·9	0·8	0·9	1·7	1·6	3·8	1·6
Sphene	0·3	0·8	1·9	0·3	0·4	0·2	—	*	0·2	0·5
Epidote	*	0·4	0·3	*	0·3	*	*	0·6	0·3	0·1
Zircon	*	*	*	*	*	—	*	*	0·1	*
Apatite	*	*	—	*	*	*	*	*	0·1	*
Orthite	*	—	*	—	—	—	*	—	—	—
Calcite	—	0·2	0·8	—	—	—	*	—	*	*
Pyrites	—	—	0·5	—	—	—	—	0·1	—	*
Haematite	—	—		—	—	*	—	*	*	*

* Present but not recorded.
† Ferrohastingsite.

J.705.31 Granodiorite, Rouch Point, Petermann Island.
J.685.1 Granodiorite, small promontory, 0·75 miles (1·2 km.) south of Cape Tuxen.
J.686.4 Granodiorite, small promontory, 0·5 miles (0·8 km.) south of Cape Tuxen.
J.649.1 Granodiorite, end of peninsula on the west coast of Booth Island.
J.619.1 Granodiorite, Port Circumcision, Petermann Island.
J.656.1 Granodiorite, southern tip of Hovgaard Island.
J.542.1 Granodiorite, north-east shore of Hummock Island.
J.533.1 Granodiorite, Curtis Island.
J.530.1 Granodiorite, Curtis Island.
J.699.6 Granodiorite, south-easternmost island in the Dannebrog Islands group.

margins the outlines of the plagioclase crystals have been severely modified by quartz-potash feldspar replacement. Remnant basic cores and oscillatory zoning are rarely seen in the plagioclase. The potash feldspar is orthoclase-microperthite which occurs in the interstices and as occasional large crystals. The ferromagnesian minerals are present as small crystals scattered throughout the rock and in partially dispersed aggregates. Hornblende forms small ragged laths, aggregates and irregular patches associated with iron ore and biotite. Rare large crystals of hornblende have a sieve texture and they have been replaced by biotite, plagioclase, iron ore and sphene. Small aggregates of biotite laths, intimately associated with ilmenite, show a high degree of alteration to chlorite and sphene, and both hornblende and biotite are replaced in part by quartz. The accessory minerals include zircon, apatite, epidote and orthite. There is a distinct tendency for small zircon crystals to be attached to and associated with ilmenite.

The content of potash feldspar in the granodiorite decreases near the gabbro/granodiorite contact (Plate IVd), and at the contact itself the rock contains no potash feldspar and is essentially tonalitic in composition. At the contact, hornblende also disappears and biotite and iron ore become more abundant. In the contact rock (J.705.25), which has a hornfelsic texture, the plagioclase (An_{27-21}) contains small inclusions of fine-grained plagioclase, biotite and iron ore. Trains of fine-grained biotites are concentrated in some of the zones of the plagioclase. Similar but larger inclusions are a common feature of the rock. Occasionally, the biotite is altered to chlorite and leucoxene. Quartz is particularly abundant and occurs as small crystals in the interstices and as large irregular poikiloblasts including all other constituents. Biotite forms aggregates of fine-grained laths containing numerous small grains of iron ore. These probably represent altered inclusions.

At Port Circumcision on the south-east coast of Petermann Island, granodiorites which are petrologically distinct from those of Rouch Point have been recorded. Here the granodiorite intrudes tonalite (Plate Vb). In the hand specimen the granodiorite (J.619.1) is a medium- to coarse-grained white and pink rock. Small biotite crystals are prominent though widely scattered. In thin section the rock has a granitic texture with large crystals of plagioclase varying in composition from An_{20} in the cores to An_{10} at the rims. In some cases the cores are sericitized and contain rare epidote. Much of the plagioclase has been replaced marginally by perthitic potash feldspar which often shows distinct cross-hatch twinning. Potash feldspar also occurs as large individuals intergrown with quartz and in which exsolved albite is twinned. Quartz occurs as large poikiloblastic crystals and is abundant in the interstices.

The amphibole in the rock has the unusual pleochroism scheme of α = yellow-green, β = brownish green, γ = deep blue-green and $\gamma{:}c = 21°$. It has a small negative 2V with an almost uniaxial interference figure. These properties suggest that it is ferrohastingsite. A similar mineral has been recorded in the granodiorites of Beascochea Bay (p. 38). The ferrohastingsite has been partially pseudomorphed by sphene and chlorite, and it is sometimes replaced by quartz. Sphene has also formed marginally to the small grains of ilmenite scattered throughout the rock. Small laths of biotite have been altered to chlorite, sphene and epidote, and in one case biotite which has been partially altered to chlorite is surrounded by ferrohastingsite partially altered to sphene. The biotite here has probably been derived from pyroxene. The accessory minerals include apatite and zircon. At the contact with the tonalite the only noticeable effect in the granodiorite is the more severe alteration of biotite. Banding is a common feature at the contact between granodiorite and gabbro xenoliths (Plate Vc).

Approximately 0·5 miles (0·8 km.) south of Cape Tuxen, granodiorite has been recorded intruding gabbro (p. 27; Plate IIIc). Although the granodiorite (J.686.2) does not differ essentially from that described from Rouch Point, it has suffered slight hydrothermal alteration. The plagioclase (An_{32-20}) is characterized by ragged patchy zoning and alteration to sericite, epidote, chlorite and calcite is common but not severe. Biotite has been altered to chlorite and leucoxene, and hornblende to aggregates of chlorite, calcite, leucoxene and epidote. The rock has a remarkably high content of sphene, which occurs as mantles around some of the iron ore crystals, as large skeletal crystals inside feldspars, in the alteration products of hornblende and biotite, and as individual crystals not obviously derived from biotite, hornblende or iron ore.

Granodiorite crops out at the end of the peninsula on the west coast of Booth Island (Plate IIc). In this rock (J.649.1) the plagioclase (An_{37-21}) contains rare remnant calcic cores and hornblende crystals contain remnant pyroxenes. The hornblende has a patchy coloration and appears to have originally been brownish green in colour, though this has now been partially replaced by a green colour. The potash feldspar is orthoclase-microperthite which forms large irregular crystals and interstitial masses. The exsolved albite is often twinned and where the perthite is in contact with plagioclase the latter has often developed a narrow marginal zone of clear albite. Included in the perthite are small plagioclase crystals, blebs of quartz and altered laths of hornblende and biotite.

Contaminated rocks of granodioritic composition have been recorded at Guéguen Point at the southern tip of Hovgaard Island. In the hand specimen the rock is coarse-grained, dark grey in colour and with patchy areas of ferromagnesian minerals. At the exposure the granodiorite contains numerous xenoliths varying from 1 in. (2·5 cm.) to several feet in diameter. Some of the xenoliths, particularly the smaller ones, are altered to such an extent that they are virtually indistinguishable from the country rock. The plagioclase of the granodiorite (J.656.1) varies in composition from An_{41} to An_{20}, but rare crystals have albite margins of approximate composition An_9. The plagioclase is dusty with minute inclusions of iron ore and it has been replaced marginally by interstitial intergrowths of quartz and potash feldspar. Quartz also occurs as irregular crystals which have delicate lobing contacts with the plagioclase.

The main characteristic of the rock is an abundance of fine-grained greenish brown biotite in irregular-shaped aggregates and long narrow veinlets. The biotite (α = light greenish yellow, β = olive-green, γ = dark greenish brown) shows incipient alteration to chlorite. It is, at least in part, an alteration product of the ferromagnesian minerals in the xenoliths. Examination of the xenoliths shows that fine-grained biotite has replaced most of the hornblende and, at a stage when the xenoliths border on complete digestion, the biotite has dispersed throughout the main bulk of the rock. Hornblende appears to have been abundant in the original rock. The plagioclase of the xenoliths is heavily zoned (An_{55-26}) and the laths often have irregular margins of untwinned oligoclase. The outlines of the plagioclase crystals are severely indented and lobed, and veinlets and patches of hornblende and biotite occur within them.

Only two intrusions of granodiorite have been recorded on the Graham Coast south of Cape Tuxen: at Hummock Island and Curtis Island. In the granodiorites of these two areas the potash feldspar and biotite contents are slightly lower and the hornblende content is higher than in most of the rocks recorded in the northern area. Otherwise, they show only minor differences from the granodiorites of Rouch Point and Cape Tuxen.

Beascochea Bay granodiorite

This type of granodiorite differs from those described above both in the hand specimen and in petrography. The intrusion is comparatively large and can be traced from Takaki Promontory (Figs. 3 and 10) 5 miles (8 km.) northwards along the coast towards Beascochea Bay. Outcrops have also been recorded along the southern shore of the bay. Modal analyses of the granodiorite are given in Table XIV, where they are compared with similar rocks from Trinity Peninsula.

In the hand specimen the granodiorite (J.713.1) is coarse-grained with large crystals of milky white plagioclase, pale pink orthoclase and translucent quartz. The ferromagnesian minerals have a patchy distribution and are confined to the interstices. The plagioclase (An_{20}) is extremely dusty, shows patchy extinction and has rounded irregular outlines; potash feldspar has replaced some of the plagioclase crystals. Quartz is abundant, occurring both in the interstices and as large irregular crystals which show slight undulose extinction. Ferrohastingsite and biotite are the main ferromagnesian minerals. The ferrohastingsite (α = yellowish or brownish green, β = deep brownish green, γ = dark green; γ:c = 14°; $2V\alpha = 38°$; $\alpha = 1\cdot677$, $\beta = 1\cdot684$, $\gamma = 1\cdot692$) occurs as small ragged crystals and as crystal aggregates. Some of the larger crystals ($< 2\cdot5$ mm.) contain inclusions of plagioclase, zircon and iron ore, and blebs of quartz. The biotite is very darkly coloured (α = golden-yellow, γ = dark brown, almost black) and is probably the iron-rich variety, lepidomelane. It occurs as small ragged crystals in the interstices and has been slightly chloritized. In a rock from a nearby island (J.695.1) the lepidomelane has been strongly chloritized, potash feldspar is more abundant and the rock is veined by clinozoisite.

At Takaki Promontory the granodiorite contains remnants of large inclusions, which are medium-grained, grey-speckled with small ferromagnesian minerals and occur either as large patches or streaked out in vein form. A specimen (J.713.3) from a large inclusion shows on microscopic examination a fine- to medium-grained mosaic of quartz and plagioclase ($\simeq An_{20}$) with occasional larger crystals of both orthoclase and abundant small ferromagnesian minerals. Some of the larger crystals of plagioclase are slightly sericitized and contain more basic remnant cores. Quartz is the most abundant constituent and some of the larger crystals have an undulose extinction. Small crystals of ferrohastingsite and lepidomelane are abundant (Plate IXe). Rare larger crystals of ferrohastingsite contain remnants of hornblende at their cores. Accessories include zircon, orthite and iron ore.

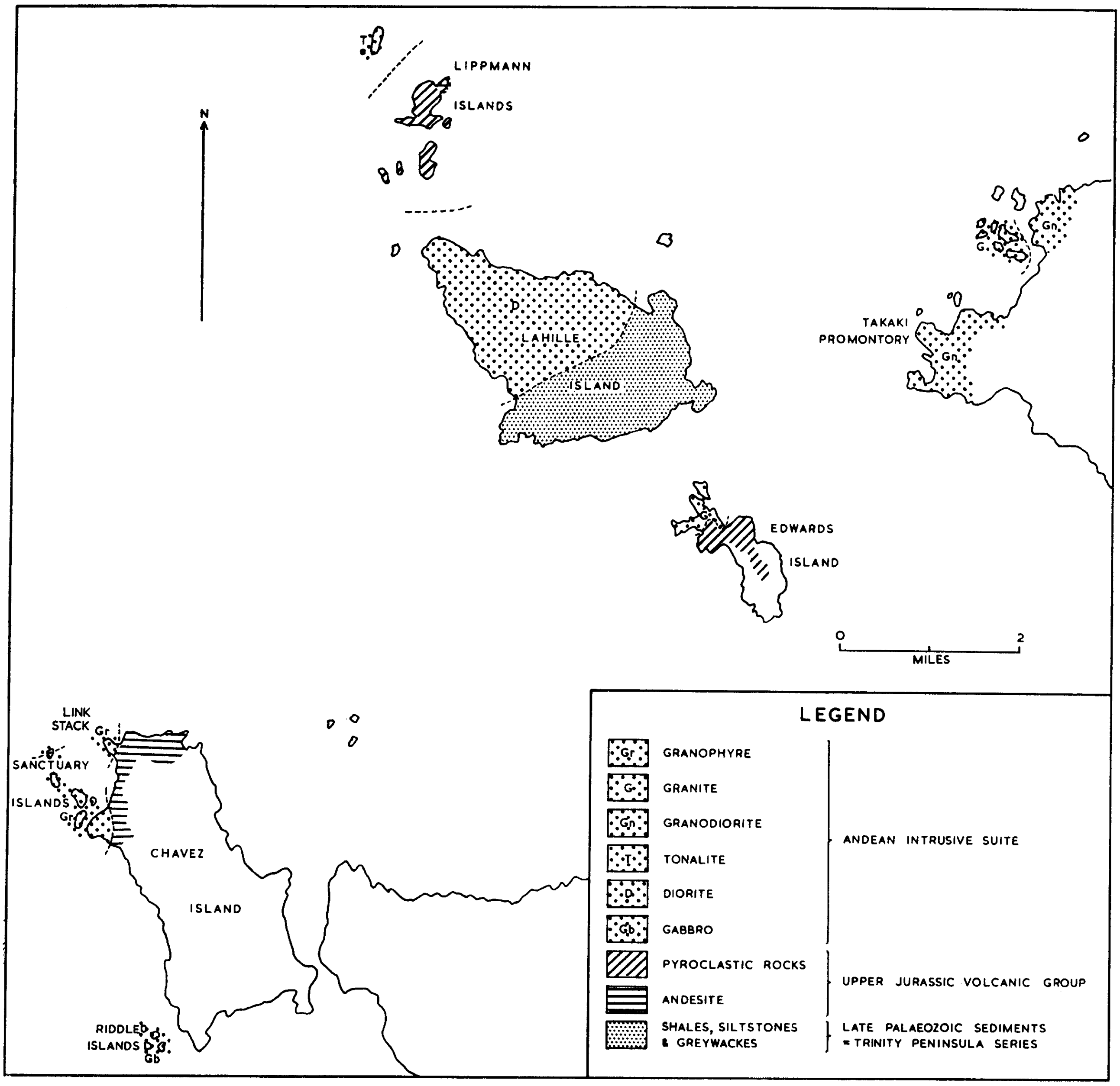

FIGURE 10

Geological map of the Lahille Island—Chavez Island area.

There are all degrees of potash feldspar replacement of plagioclase in the granodiorite from King Island, off the south coast of Beascochea Bay (J.697.1). The replacement begins marginally and continues until the affected crystal is an irregular patchwork of potash feldspar and plagioclase. At an advanced stage all that remains are small islands of lamellar-twinned plagioclase bounded by (001) and (010) cleavage traces. Some of the potash feldspar has distinct cross-hatch twinning and is undoubtedly microcline-microperthite.

E. GRANITES

Coarse-grained granites are the rarest rock type in the Andean Intrusive Suite of the Graham Coast. The granites are comparable in the hand specimen with the early Palaeozoic "Coarse Pink Granite" (Adie, 1954). However, at Takaki Promontory (Fig. 10) they intrude the granodiorite and near Rasmussen Island they intrude the Upper Jurassic Volcanic Group.

TABLE XIV

MODAL ANALYSES OF BEASCOCHEA BAY GRANODIORITES

<table>
<tr><th></th><th>J.713.1</th><th>J.697.1</th><th>J.677.1</th><th>D.337.1</th><th>D.375.2</th></tr>
<tr><td>Quartz</td><td>31·9</td><td>33·2</td><td>28·8</td><td>38·9</td><td>33·9</td></tr>
<tr><td>Orthoclase</td><td>23·4</td><td>—</td><td>25·0</td><td>23·6</td><td>22·3</td></tr>
<tr><td>Microcline</td><td>—</td><td>25·8</td><td>—</td><td>—</td><td>—</td></tr>
<tr><td>Plagioclase</td><td>36·8</td><td>36·9</td><td>41·2</td><td>33·4</td><td>36·2</td></tr>
<tr><td>Hornblende</td><td>—</td><td>—</td><td>—</td><td>0·1</td><td>0·1</td></tr>
<tr><td>Ferrohastingsite</td><td>4·0</td><td>—</td><td>—</td><td>—</td><td>—</td></tr>
<tr><td>Biotite</td><td>3·6</td><td rowspan="2">3·0</td><td rowspan="2">2·6</td><td>3·0</td><td rowspan="2">7·5</td></tr>
<tr><td>Chlorite</td><td>*</td><td>1·0</td></tr>
<tr><td>Iron ore</td><td>*</td><td>*</td><td>1·0</td><td>*</td><td>*</td></tr>
<tr><td>Sphene</td><td>0·3</td><td>0·6</td><td>*</td><td>—</td><td>—</td></tr>
<tr><td>Epidote</td><td>—</td><td>0·5</td><td>1·4</td><td>—</td><td>—</td></tr>
<tr><td>Zircon</td><td>—</td><td>*</td><td>*</td><td>*</td><td>*</td></tr>
<tr><td>Orthite</td><td>*</td><td>*</td><td>*</td><td>—</td><td>—</td></tr>
<tr><td>Apatite</td><td>—</td><td>—</td><td>*</td><td>*</td><td>*</td></tr>
</table>

* Present but not recorded.

J.713.1 Granodiorite, Takaki Promontory.
J.697.1 Granodiorite, King Island.
J.677.1 Granodiorite, southern edge of Trooz Glacier.
D.337.1 Biotite-granite, Cape Roquemaurel (Adie, 1955).
D.375.2 Biotite-granite, Mount Reece (Adie, 1955).

At Takaki Promontory granite occurs on a number of offshore islands which are separated from the granodiorite of the mainland by a narrow channel. The contact forms the channel but granitic veins in the granodiorite indicate that the latter is the earlier intrusive rock. Microscopic examination of the granite (J.715.1) from this area shows large irregular crystals of quartz and potash feldspar (< 6 mm.), smaller crystals of plagioclase ($< 1\cdot5$ mm.; An_{12}) and rare small aggregates of iron ore, chloritized biotite, orthite and zircon. The quartz, apart from the large individual crystals, also occurs in micrographic intergrowth with the potash feldspar and as large aggregates. Modal analyses of the granites are given in Table XV. The potash feldspar is microcline-microperthite in which the exsolved albite often has lamellar twinning. The replacement of plagioclase by potash feldspar is evident in most cases but it is not severe. Where the microcline-microperthite is adjacent to or encloses plagioclase crystals, the latter are usually corroded but in some cases the contacts merge and often the albite stringers extend into and replace adjacent plagioclase (Plate IXf).

Similar granites were recorded at Edwards Island (J.694, 712), near Rasmussen Island (J.691, 692) and at Sterna Island (J.636). At Edwards Island there is a faulted contact between the granite and the Upper Jurassic Volcanic Group, resulting in slight granulation of the granite.

Medium-grained phase of the granites

Near Rasmussen Island and at Sterna Island the granites have been intruded by a medium-grained phase of similar mineralogical composition. At Sterna Island the medium-grained granites occur only in small veins but near Rasmussen Island it forms the bulk of the granite outcrop and separates the coarser granite from the Upper Jurassic Volcanic Group. The contact (J.692.3) between the coarse- and medium-grained granite is sharp and the only effect has been slight chilling of the latter. Modal analyses of the medium-grained granites are given in Table XVI.

TABLE XV

MODAL ANALYSES OF GRANITES

	J.715.1	J.712.3	J.692.1
Quartz	39·4	34·7	39·8
Orthoclase	—	43·7	34·6
Microcline	50·3	—	—
Plagioclase	9·5	19·0	22·7
Biotite	0·5	—	*
Chlorite	0·2	1·5	1·6
Iron ore	0·1	1·0	1·0
Sphene	—	0·1	0·2
Epidote	—	*	*
Orthite	*	—	0·1
Apatite	—	—	*
Calcite	—	*	—

* Present but not recorded.

J.715.1 Granite, small spear-shaped island on north side of bay in Takaki Promontory.
J.712.3 Granite, western end of Edwards Island, 3 miles (4·8 km.) south of Takaki Promontory.
J.692.1 Granite, small island north of Rasmussen Island.

TABLE XVI

MODAL ANALYSES OF MEDIUM-GRAINED PHASE OF THE GRANITE

	J.691.1	J.691.2	J.691.3	J.692.4
Quartz	37·3	40·3	38·1	36·3
Orthoclase	40·3	35·1	35·8	44·5
Plagioclase	19·4	19·3	19·0	18·5
Chlorite	1·2	1·1	1·6	*
Iron ore	0·7	*	0·2	0·5
Sphene	0·6	1·5	0·3	0·2
Epidote	0·3	2·9	5·0	*

* Present but not recorded.

J.691.1, J.691.2, J.691.3 } Granite, mainland north of Rasmussen Island.
J.692.4 Granite, small island north of Rasmussen Island.

The type rock (J.691.1) is reddish pink in colour and apart from the difference in grain-size it is similar in most respects to the coarse granite. It differs in that it contains narrow veins of quartz, feldspar and epidote. In many cases the veins cut clearly through the rock but they often follow crystal boundaries.

F. GRANOPHYRES

Granophyres are well represented on the Graham Coast. Omitting the Prospect Point igneous complex which is described below, the most important exposures of granophyre are at the north-west corner of Chavez Island and at the nearby Sanctuary Islands (Fig. 10). The granophyres are similar in petrography and mineralogy to the Red Rock Ridge granite of Marguerite Bay (Adie, 1955) with which they may be provisionally correlated.

In the hand specimen the granophyres (J.717.1) are medium-grained, pink in colour and speckled with black ferromagnesian minerals. Rarely they contain small xenoliths. Microscopic examination shows that the plagioclase ($\simeq An_{10}$) is not zoned and is marginally irregular due to quartz-orthoclase replacement. Internally the plagioclase is dusty with alteration products, including aggregates of fine-grained epidote and occasional crystals have been completely pseudomorphed by medium- to fine-grained sericite and calcite, which are often surrounded by a narrow mantle of orthoclase. The greater part of the rock is composed of a granophyric intergrowth of quartz and orthoclase but there are a number of individual crystals of both these minerals. The main ferromagnesian minerals are chlorite, epidote and ilmenite. The chlorite occurs in small irregular patches and laths, which in association with sphene, calcite and leucoxene often fringe the ilmenite. Marginal growths of sphene on ilmenite are common and sphene often forms relatively large euhedral crystals. The accessories include orthite and zircon.

The rock described above is from the centre of the largest of the Sanctuary Islands. This island is separated from Chavez Island by a straight narrow channel. Approaching the channel from the centre of the island there is a gradual change of colour in the granophyre from pink to grey. In this section the grey facies (J.717.3) differs from the red in that it contains much more plagioclase and, although the quartz-orthoclase intergrowths are still abundant, they have more of an interstitial aspect. This rock also contains remnants of blue-green hornblende and biotite with chlorite aggregates. At the Sanctuary Islands and at Link Stack on Chavez Island faulting has shattered the granophyres.

Similar granophyres were recorded at Lancaster Hill in the middle of Trooz Glacier (J.679.2), intruding the Upper Jurassic Volcanic Group at Darboux Island (J.673.19) and at Prospect Point (J.586.2).

G. PROSPECT POINT IGNEOUS COMPLEX

Prospect Point is a small promontory on the mainland, 1·5 miles (2·4 km.) south of Ferin Head (Fig. 1). Most of the promontory is snow-covered but during the summer season a length of approximately 1,500 ft. (460 m.) of foreshore is exposed. The foreshore forms a flat-lying shelf varying in width between 10 and 80 ft. (3 and 24 m.). Fig. 11 shows the geology of Prospect Point.

1. *Gabbro*

The gabbro is now seen mainly as large rounded xenoliths, one of which measures 60 by 30 ft. (18 by 9 m.). A relatively large area of gabbro near the survey pillar is connected to that on which the pillar stands. A similar area of gabbro 150 ft. (45 m.) south-east of the station hut reappears 40 ft. (12 m.) west of the station hut (Fig. 11). These two outcrops are probably connected across the centre of the point and it seems likely that inland the remainder of the peninsula is composed of gabbro.

In the hand specimen the gabbro is a medium-grained dark grey rock with a greenish tint. Throughout the rock there are small patches of epidote and narrow light grey veins of dioritic composition. Microscopic examination shows that the gabbro (J.604.1) has been seriously affected by the latter intrusive rocks. The plagioclase crystals which are dusty with finely divided sericite, epidote and, in some cases, calcite, are highly zoned (An_{75-35}) and possess an irregular mantle of sodic plagioclase of albite-oligoclase composition. Quartz is abundant both interstitially and as small irregular crystals. It replaces the plagioclase, which loses its albite twinning and becomes patchy in the process. The sodic mantles around the plagioclase are also replaced by quartz. Hornblende (α = yellow-green, β = light brown-green, γ = green; $\gamma{:}c = 23°$) occurs

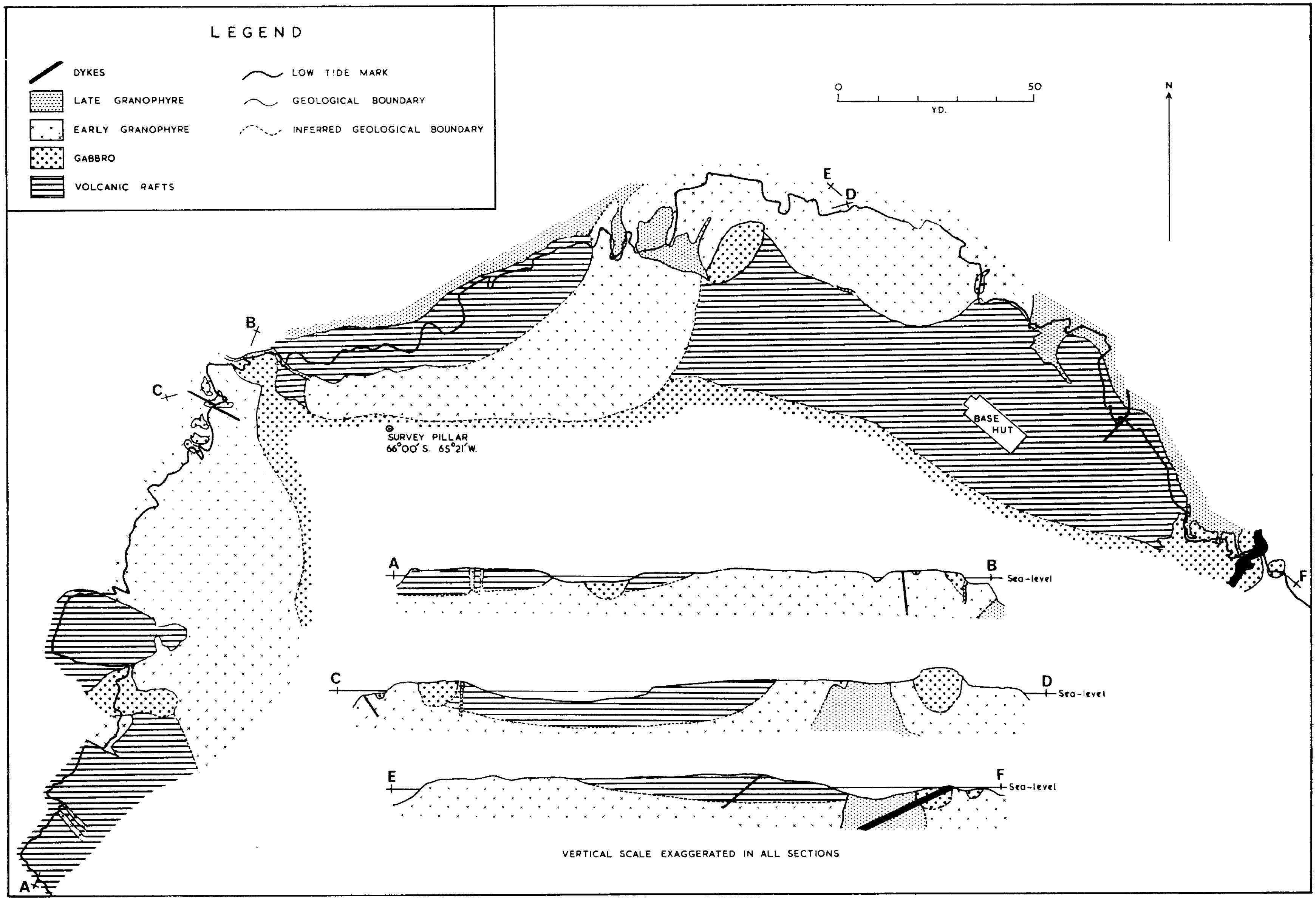

FIGURE 11

Detailed geological map of Prospect Point.

abundantly as small ragged crystals which rarely contain remnant pyroxene. Small irregular patches of chlorite are widespread throughout the rock and frequently associated with them are laths of actinolite and small amounts of calcite, sphene and iron ore. These aggregates probably represent former pyroxenes. Biotite has been almost completely converted to chlorite. Numerous small crystals of ilmenite (sometimes skeletal) are marginally altered to sphene. Apart from the epidote described above, it also forms large poikiloblastic crystals.

2. *Volcanic rafts*

A phase of veining followed the intrusion of the gabbro at Prospect Point. The gabbro contains only occasional veins but the volcanic rafts have been completely brecciated and they are now represented by small closely packed xenoliths set in a network of medium-grained diorite veins. The preferential veining of the volcanic rafts suggests that intrusion of the gabbro severely shattered the volcanic rocks. This would render the volcanic rocks more susceptible to veining than the more massive gabbros.

The andesite xenoliths (J.584.1) have a fine-grained intergranular texture with occasional plagioclase phenocrysts ($An_{63\text{-}34}$) and ragged crystals of hornblende set in a fine-grained groundmass of plagioclase, hornblende, ilmenite, sphene, leucoxene, epidote and chlorite. The plagioclase phenocrysts and laths are surrounded by narrow irregular mantles of oligoclase. The plagioclase has been partially recrystallized at the contacts with the dioritic veins. The main ferromagnesian minerals in the xenoliths are hornblende, iron ore and chlorite. Hornblende occurs abundantly as small irregular flakes and occasional larger ragged crystals peppered with iron ore. The larger hornblende crystals are altered to chlorite and sphene, and they rarely contain minute cores of pyroxene. The xenoliths contain numerous small grains of ilmenite which frequently possess marginal alteration to sphene. Chlorite and epidote are abundant and some of the chlorite in association with leucoxene has developed from biotite. The contacts with the xenoliths are sharply defined in most cases but gradational contacts are not uncommon.

In the veins the plagioclase varies in composition from large cores of An_{46} to narrow irregular margins of albite. As in the xenoliths, the main alteration product of the plagioclase is fine-grained epidote but here there is slight marginal alteration by quartz and potash feldspar. Quartz forms irregular patches and interstitial areas, and it is occasionally intergrown with potash feldspar. Hornblende (α = light yellow-green, β = light brownish green, γ = brown-green; $\gamma{:}c = 25°$) forms ragged laths and small anhedral to subhedral crystals which rarely contain remnant cores of pyroxene. All stages of alteration to chlorite and sphene are present. Ilmenite crystals are in some cases skeletal and they are frequently margined by sphene.

The contacts between the rafts and the gabbro consist of bands of veining material devoid of xenoliths and varying in width from 1 to 9 in. (2·5 to 23 cm.). Contacts are well exposed at the western end of Prospect Point (J.589) and 150 ft. (45 m.) south-east of the station hut (J.612). These bands (J.589.2) are slightly coarser than the material in the veins away from the contact and there is much less alteration in the plagioclase. Most of the plagioclase crystals are devoid of sodic rims but where they occur they are less distinct. Quartz, potash feldspar and intergrowths of the two minerals are more abundant and there is also greater replacement of plagioclase. Several large crystals of sphene are present and calcite is an important alteration product of the ferromagnesian minerals. The contacts between the bands and the gabbro are distinct and unchilled, and no visible reaction appears to have taken place.

In most cases the contacts between the volcanic rafts and the early granophyre are distinct and clear-cut with no alteration of the rafts. However, in some cases, the contact (J.586.1) is marked by a zone 2–3 mm. wide, in which there is a slight concentration of small crystals of granular iron ore, sphene, chloritized biotite and hornblende. This is followed by a narrow zone in which the plagioclase of the veins does not show the usual severe alteration to epidote. These effects are probably due to slight thermal metamorphism.

At the contacts between the rafts and the late granophyre the plagioclases in the xenoliths (J.603.1) show a greater degree of recrystallization and quartz porphyroblasts have been formed. Aggregates of chlorite and actinolite contain frameworks of iron ore arranged in pyroxene cleavage patterns. One of these aggregates possesses an euhedral pyroxene outline. In the veins, granophyric intergrowths of quartz and potash feldspar have almost entirely replaced the plagioclase.

3. *Early granophyre*

The early granophyre is the most puzzling rock type at Prospect Point, since its appearance in the hand specimen can vary considerably. The type rock (J.586.2) crops out on the western shore of Prospect Point, where it is medium-grained, pink and speckled with black in the hand specimen, and it contains some highly altered xenoliths. Under the microscope the rock consists essentially of altered plagioclase ($\simeq An_8$) in a matrix of granophyrically intergrown quartz and potash feldspar. The plagioclase crystals are cloudy with epidote, sericite and chlorite. Apart from that in the granophyric intergrowth, quartz also forms occasional porphyroblasts. Chlorite with subsidiary iron ore, sphene, epidote and calcite forms small irregular aggregates. Medium- to fine-grained crystals of ilmenite have been marginally altered to sphene. The early granophyre is identical to that found at Lancaster Hill in the middle of Trooz Glacier (J.679.2).

The contact between the early granophyre and the gabbro is quite sharp in the hand specimen (J.588.2) but this is not so when seen under the microscope. This is due to the introduction into the adjacent gabbro of quartz and potash feldspar, which have crystallized as a granophyric intergrowth. Thus both rocks have a similar matrix. There is, however, a noticeable difference in the alteration products of the plagioclase. Whereas in the early granophyre they are mainly epidote with subordinate sericite, in the gabbro they are small but quite pronounced flakes of sericite with epidote concentrated along cracks.

At the contact between the early granophyre and the volcanic raft on the west shore of Prospect Point (J.590.2) the volcanic rocks are slightly chilled and dark grey in colour for a width of 6 in. (15 cm.) (Plate Vd). The grey marginal-facies rock differs from the type rock in that it contains much less potash feldspar, and marginal alteration of plagioclase by quartz and potash feldspar is not so severe. Hornblende, which is not seen in the type rock, has survived complete alteration but it is rarely without some alteration to chlorite. Apart from these differences, the marginal rock is similar to the type rock.

A relatively large area of granophyre, extending from the jetty along the foreshore towards the station hut, differs in the hand specimen from the pink-coloured type rock. The rock (J.607.1) in this area is similar to the grey marginal facies but it is much coarser and contains numerous gabbro and andesite xenoliths. The plagioclase (An_{45-24}) is surrounded by irregularly shaped mantles of oligoclase (An_{15}). Fine oscillatory and slight reversed zoning ($An_{33-41-16}$) are present but rare. The marginal replacement of plagioclase by potash feldspar, a granophyric intergrowth of potash feldspar and quartz, and the content of dark minerals are all similar to the marginal facies of the type rock.

4. *Late granophyre*

This rock type (J.611.2) is medium- to fine-grained, reddish pink in colour and contains fewer dark minerals than the earlier granophyre. It is clearly exposed at the northern part of Prospect Point and on the foreshore below the station hut. Under the microscope it differs from the early granophyre in that it is finer-grained, contains more potash feldspar and quartz, no hornblende and less chlorite and epidote. Ilmenite and sphene are present in approximately the same amounts as in the early granophyre.

5. *Dykes*

Igneous activity at Prospect Point closed with the intrusion of microporphyritic andesite dykes (J.595.1), of which three are present. They are composed of a plexus of plagioclase laths of andesine-oligoclase composition with iron ore, sphene, chlorite and epidote filling the interstices. Occasional microphenocrysts of dusty plagioclase and hornblende, aggregates of calcite and fine-grained sphene, crystals and crystal aggregates of epidote are scattered throughout the rock.

H. Discussion

The diorites and tonalites possess a number of textural features which suggest that they are hybrid rocks formed by contamination of an acid magma. These features include:

i. Remnant corroded basic cores of plagioclase surrounded by the plagioclase of the matrix; these cores often show patchy extinction, complex zoning and twinning.
ii. Glomeroporphyritic aggregates of ferromagnesian minerals.
iii. Sieve texture in the pyroxenes.
iv. Patchy coloration of the amphiboles.
v. Replacement of the ferromagnesian minerals by quartz, and replacement of plagioclase by quartz and potash feldspar.
vi. Heterogeneity of grain-size.
vii. Relative abundance of apatite and sphene.

Hybrid rocks of intermediate composition have been described from many areas and these rocks contain many of the textural features listed above. With very few exceptions, basic corroded cores surrounded by the plagioclase of the matrix occur in the diorites and tonalites of the Graham Coast and occasionally in the granodiorites; this is a common feature in rocks considered to be of hybrid origin or to have been contaminated. This has been noted by Deer (1935) in pyroxene-biotite hybrid rocks in the Cairnsmore of Cairsphairn igneous complex, and in granite-diorite hybrid rocks at Glen Tilt (Deer, 1938). Similar textural relationships have been recorded by Nockolds (1934) in the contaminated tonalites of Loch Awe, by Joplin (1944) in hybrid rocks formed during the intrusion of gabbro by quartz-mica-diorite, and by Leighton (1954) in an intermediate rock formed at the contact between gabbro and granophyre. Patchy extinction, complex zoning and twinning are often associated with the basic corroded cores and this has been noted by Joplin (1944) and by Farquhar (1953) in dioritic rocks formed by the permeation of hornblende-schists by trondhjemitic material.

Glomeroporphyritic aggregates of ferromagnesian minerals are characteristic of most of the intermediate rocks of the Graham Coast. Pyroxenes most commonly form the aggregates in the diorites, whereas in the tonalites and granodiorites hornblende and biotite are more frequent. Similar aggregates have been described in contaminated and hybrid rocks from a number of localities. In the Ardara granite diapir of County Donegal, Akaad (1957) recorded in a quartz-diorite ferromagnesian clots formed by contamination of granodiorite by basic material. Read and others (1926) have described a clotted and patchy distribution of the feldspathic and mafic constituents and hornblende-biotite aggregates in intermediate rock formed by the mixing of granite and ultrabasic rock. Biotite clots derived from inclusions almost completely digested by the Dhoon (Isle of Man) granite have been described by Nockolds (1931), who has also recorded aggregates of plagioclase and clots of hornblende, biotite and magnetite in the contaminated granite of Bibette Head, Alderney (Nockolds, 1932), and xenocrysts and xenocrystal aggregates of pale amphibole in contaminated granodiorite in the Garabal Hill–Glen Fyne igneous complex (Nockolds, 1941). Joplin (1944) has recorded clusters of biotite flakes, which represent almost completely digested xenoliths of diorite in a granite-porphyry, and Taylor and Gamba (1933) have described spongy aggregates of hornblende in dioritic rocks formed at the contact between gabbro and granophyre in the Oatland (Isle of Man) igneous complex.

The pyroxene crystals in the aggregates and the individual pyroxenes that might be present in the rock often possess a sieve texture. Pyroxenes with a sieve texture are an important characteristic of the diorites, but they are less frequent in the tonalites and absent in the granodiorites. However, some of the granodiorites contain small remnants of augite at the centres of the hornblende crystals. A sieve texture is characteristic of the pyroxenes in the hybrid rocks of Anvers Island (Hooper, 1962). Similar features have been described by Leighton (1954), Read and others (1926), and Taylor and Gamba (1933).

In the diorites of the Saffery Islands the sieve texture of the pyroxenes is due to patchy replacement by brownish green hornblende, although most of the individual hornblendes in the rock are green. In addition, hornblende immediately adjacent to hypersthene is colourless. In the tonalites on the west coast of Booth Island brownish green hornblende has been converted to a light green variety in patches and along cleavage traces. Colour variations in the amphiboles of contaminated rocks have been recorded by Nockolds (1934), Deer (1935), Leighton (1954) and Hooper (1962).

The replacement of plagioclase by quartz or potash feldspar, or both, can be seen in all but a few of the diorites, tonalites or granodiorites of the Graham Coast. The quartz usually forms delicate lobing contacts with the plagioclase and blebs of quartz frequently occur within the margins of the plagioclase, a feature noted by Leighton (1954). The marginal replacement of plagioclase by potash feldspar has often been arrested by one of two processes: by the development in the plagioclase of a fringe of myrmekite and by the development of a rim of albite. Similar reactions have been described by Nockolds (1932). Quartz also replaces some of the ferromagnesian minerals, and hornblende, biotite and augite are the minerals mostly affected.

Heterogeneity of grain-size, a characteristic of many hybrid rocks (Akaad, 1957; Deer, 1935; Joplin, 1944; Nockolds, 1932, 1934), is common in the diorites and tonalites of the Graham Coast. It applies to both light and dark minerals, and variations between 0·2 and 3·0 mm. have been noted in a single specimen.

Large apatites frequently appear in the ferromagnesian aggregates of the diorites and tonalites of the Graham Coast. Nockolds (1933) first drew attention to the relative abundance of apatite in contaminated rocks, which he considered to be due to the preferential absorption of volatiles by xenoliths, and Deer

(1950), Joplin (1944), Leighton (1954), Read and others (1926), Taylor and Gamba (1933), and Thomas and Campbell Smith (1932) have all remarked on the abundance of apatite in hybrid rocks.

Sphene is also an abundant accessory in some of the intermediate rocks, particularly the tonalites. It occurs mainly as a replacement product of ilmenite, hornblende and biotite, and it has also been found replacing plagioclase. Abundant sphene in hybrid rocks has been described by Read (1931), Read and others (1926), and Deer (1950).

Most of the textural relationships discussed above grade from prominence in the diorites and tonalites to almost insignificance in the Beascochea Bay granodiorite. It is evident therefore that the diorites and tonalites are highly modified representatives of a magma which was once much more acid in composition. These rocks may be classed as hybrids formed by the contamination of an acid magma by basic material.

Prior to the intrusion of the magma from which the intermediate rocks were derived, there were three major rock units which could provide material for contamination. They are the Trinity Peninsula Series, the Upper Jurassic Volcanic Group and the gabbros of the Andean Intrusive Suite. The limited outcrop of the Trinity Peninsula Series suggests that its contaminating effect on the magma is restricted to the area around Lahille Island. Undoubted volcanic xenoliths are now typically fine-grained hornfelses and they have retained their fine-grained character and sharp contact with the magma almost until the final stages of digestion. Gabbroic xenoliths are easily recognizable as such, since they have retained their gabbroic characteristics. In the final stages of digestion they are represented by concentrations of ferromagnesian minerals. Because of this, and even though the end products converge towards a single rock type, it is possible to distinguish between the two types of xenolith in the field. The majority of xenoliths recorded are of gabbroic type and this is also true of the Loubet Coast to the south (Goldring, 1962). Microscopic evidence supports this, since most of the corroded remnant cores of plagioclase in the xenoliths and intermediate rocks have a bytownite composition. Plagioclase of this composition is not present in the rocks of the Upper Jurassic Volcanic Group or the Trinity Peninsula Series of the Graham Coast and therefore it could only have been derived from the gabbros. On similar evidence, Hurlburt (1935) concluded that the abundant inclusions in the Bonsall tonalite of southern California were derived from the San Marcos gabbro. It therefore appears that contamination resulted mainly from the incorporation of gabbroic material.

The reactions that take place when basic material is incorporated by an acid magma follow Bowen's (1922) well-known principles, and Nockolds (1933) has described the methods by which xenoliths are brought into phase equilibrium with the host magma. Many of the textural features listed on p. 45 are essentially remnant features which have been preserved as a result of the failure of the magma to bring all the constituents of the xenoliths into equilibrium with itself. Fig. 12 shows the trends of replacement reactions which have been recorded in the intermediate rocks of the Graham Coast.

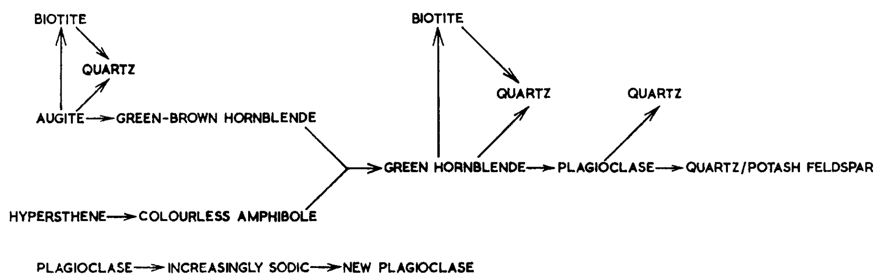

FIGURE 12
Trends of replacement reactions noted in hybrid rocks.

Field and microscopic evidence both indicate that contamination was not due to marginal assimilation at the contacts as they appear at present. The only contacts found involving the diorites are at Duseberg Buttress and Mutton Cove. At the former locality, where volcanic rocks have been intruded, the contact is sharp, the volcanic rocks have been hornfelsed and the adjacent diorite does not contain any xenoliths. If contamination was due to marginal assimilation of the volcanic rocks, then the absence of xenoliths would indicate their complete absorption by the magma. If this were so, then reaction between the acid magma and the volcanic rocks would be more severe than mere thermal metamorphism and no sharp contact and a certain amount of metasomatism might be expected. At Mutton Cove the diorite is present only as narrow veins and streaks invading the gabbro. In general, the diorites of the Graham Coast contain only occasional xenoliths, but the content of xenoliths in the tonalites and granodiorites varies considerably, and in areas where the xenoliths are abundant they are most frequently gabbroic and barely altered. In addition, gabbro has only a local effect on the granodiorite at gabbro/granodiorite contacts, which are sharp in the three cases examined.

The abundance in the diorites of the textural features listed on p. 45 indicates that they are the most basified representatives of a magma, once much more acid in composition. The even distribution of these textural features throughout the intrusion, plus the fact that contamination is not closely related to the present attitude of the intrusion or to the present distribution of xenoliths, suggests that contamination took place at depth prior to intrusion to the present level. The trend of intrusion, diorite → tonalite → granodiorite, is also one of decreasing contamination. The granodiorites represent the last basified rocks and therefore they are nearest in composition to the uncontaminated magma. In many of the granodiorites textural evidence of contamination, though present, is rare, which suggests that the uncontaminated magma was of granodioritic composition.

The formation of a granodiorite magma and its uprise by successive intrusions was therefore the second phase in the intrusive history of the Graham Coast. The early intrusions would necessarily incorporate large quantities of gabbroic material and it has been shown that basification to a magma of dioritic composition had been completed before the magma attained its present level. Following the basification of the early intrusions, the material available for contamination of the later ones would be mainly of dioritic composition. Successive intrusions would therefore be progressively less modified as the contaminating material increased in acidity. A sequence of events similar to that given above has been suggested by Joplin (1959) to account for the origin and distribution of hybrid rocks in discordant batholiths. At Mutton Cove, the field evidence indicates that the diorite was intruded before the gabbro had completely crystallized. However, the sharp contacts between the gabbros and the granodiorites suggest that at the time of intrusion of the granodiorites the gabbro had fully crystallized, although lack of chilling in the granodiorites at the contact indicates that the gabbro had not cooled appreciably.

The granites of the Graham Coast occur in small bosses and are comparatively rare. They differ from the Beascochea Bay granodiorite in the absence of amphiboles, a decrease in the amount of plagioclase and ferromagnesian minerals and a complementary increase in the amount of potash feldspar and quartz. These differences indicate increasing acidity and may be attributed to crystallization differentiation in the granodiorite.

The granophyres have mineralogical compositions which vary from granodioritic to granitic but their differences in grain-size and texture are probably due to differing physical conditions during crystallization.

Recent work on the Andean Intrusive Suite of Graham Land has been presented by Adie (1955) and Hooper (1962). By plotting geochemical data on triangular variation diagrams for intrusive rocks ranging in composition from gabbro to biotite-granite, Adie has shown that all but the most basic gabbros fall on smooth curves. The basic gabbros he has interpreted as basic accumulates and the continuous variation shown by the remainder as evidence that they lie on the same line of liquid descent from a parental magma, and have been derived from the parental magma by crystallization-differentiation. However, hybrid rocks of intermediate composition formed by inclusion of gabbroic material in granodiorite magma would behave as members of a differentiation series (Joplin, 1933, 1959; Deer, 1935), and the reactions involved are essentially those of "early formed crystals resorbed during the process of crystal fractionation" (Joplin, 1959). Such rocks plotted on triangular variation diagrams would, with the associated primary rocks, fall on smooth curves and consideration of the geochemical data available suggests crystallization-differentiation as the mechanism of origin for all the rock types involved. However, the textural evidence suggesting a hybrid origin for the intermediate members of the Andean Intrusive Suite is altogether too frequent and prominent to allow crystallization-differentiation as a satisfactory mechanism for their origin.

Hooper (1962) has established, with strong evidence, a widespread late Andean metasomatism in the Anvers Island area which as yet has not been paralleled anywhere in Graham Land. The metasomatism affected rocks of gabbro and tonalite composition, producing hybrids, which although essentially different from those of the Graham Coast, contain many of the textural features which are so prominent in the latter.

In his report on the Loubet Coast, Goldring (1962) made certain comparisons with the Graham Coast by reference to the present writer's unpublished Ph.D. thesis, and hence little further comment is necessary here. It is interesting to note, however, that Goldring agrees with the hypothesis of two primary magmas, one of gabbroic and one of granodioritic composition, and he was able to establish a group of hybrid intermediate rocks with textural characteristics similar to those of Anvers Island and the Graham Coast. It is clear that the history of the Andean Intrusive Suite of the Loubet Coast does not differ essentially from that of the Graham Coast.

V. GEOLOGICAL HISTORY OF THE GRAHAM COAST

THE oldest rocks present on the Graham Coast are a series of thinly bedded shales, siltstones and feldspathic greywackes, which form the eastern half of Lahille Island and a short strip of coastline in Beascochea Bay. These sediments were deposited in deep water under geosynclinal conditions. They are correlated with the Trinity Peninsula Series which has been tentatively assigned to the Carboniferous (Adie, 1957). The sediments have suffered low-grade regional metamorphism, probably as a result of late Palaeozoic earth movements, and slight thermal metamorphism where they are adjacent to Andean intrusions.

The absence of Permian, Triassic, and Lower and Middle Jurassic strata on the Graham Coast suggests that late Palaeozoic earth movements resulted in the uplift and formation of a landmass formed by the Trinity Peninsula Series and that erosion of this landmass continued uninterrupted until the Upper Jurassic. With the advent of the Upper Jurassic, the Graham Coast became the site of intense volcanic activity. The initial phase appears to have been the extrusion of a thick series of andesite lavas with interbedded tuffs. At Penola Strait approximately 1,000 ft. (305 m.) of andesites are preserved and they are overlain by a minimum thickness of 4,000 ft. (1,220 m.) of pyroclastic rocks. Small-scale current-bedding at a number of horizons in the pyroclastic rocks and the occurrence of volcanic conglomerates indicate that the pyroclastic rocks were deposited in water close to a shoreline and that there was subsidence during accumulation. The extensive development of volcanic rocks along the Graham Coast suggests that the entire area was inundated by volcanism. There is no field evidence to suggest an upper age limit for the volcanic activity.

At some time during the Cretaceous, or perhaps even later, the gabbros of the Andean Intrusive Suite were intruded into the Upper Jurassic Volcanic Group and what remained of the Trinity Peninsula Series. Before the gabbros had completely crystallized they were intruded by a granodiorite magma. In the early stages of intrusion the granodiorite magma incorporated large quantities of gabbroic material which resulted, before the completion of intrusion, in its basification to a hybrid magma of dioritic composition. The intrusion of a granodiorite magma continued at intervals, at least until the time when the crystallization of the gabbros had been completed and probably for some time afterwards. Successive intrusions of granodiorite magma were progressively less basified until during the final stages the granodiorite magma attained its present level without appreciable contamination. Crystallization-differentiation of the remaining granodiorite at depth in the magma chamber gave rise to a magma of granitic composition. Local physical conditions during the intrusion and crystallization of this magma resulted in the formation of either coarse-grained granite or granophyre.

It is not possible to determine an upper age limit of intrusive activity on the Graham Coast or in Graham Land as a whole, and therefore evidence must be sought in the comparable Andean batholith areas of South America. Adie (1955) has quoted evidence from the western Patagonian Cordillera which suggests that the Andean Intrusive Suite is late Cretaceous to early Tertiary in age. At Valparaiso in Chile, Brüggen (1934) has recorded boulders from the Andean batholith in basal Senonian conglomerate, and a similar field relationship has been found at Magellanes by Kranck (1932). In Peru, in the Cordillera Blanca and at Hualgayoc, Lower Senonian strata are intruded and metamorphosed by granites and granodiorites (Jenks, 1956). In all of these areas, however, rocks of the Andean batholith have not been recorded as intruding Tertiary formations. Therefore, correlation with South America suggests that the Andean Intrusive Suite of Graham Land could probably be Upper Cretaceous in age and that intrusive activity ceased before Tertiary times.

Epeirogenic movements during the Tertiary resulted in a considerable uplift of the Graham Coast and the whole of the Antarctic Peninsula region. Large-scale faults associated with this uplift developed parallel to the present axis of the Antarctic Peninsula. Major faults of this type are found on both east and west coasts of the Antarctic Peninsula, and they are particularly well developed in the northern part of the Graham Coast. Their position marginal to the Antarctic Peninsula suggests that the trend of the peninsula is controlled mainly by these faults. Dating of the Tertiary movements in South America indicates that the main uplift took place during the Pliocene. In Chile the elevation of the Coast Range commenced in the Oligocene and reached a maximum in the Pliocene. Large-scale coastal faulting and the formation of the submarine deep along the Chilean coast are regarded by Cristi (1956) as being Quaternary in age. It is interesting to note that linked with the epeirogenic movements during the Miocene and Pliocene in Chile there was a renewal of volcanic activity. The early lavas are augite- and hypersthene-andesites but basalts developed later and the most recent flows are olivine-basalts. A similar trend of volcanic activity has been recorded by Hawkes (1961) in the Miocene to Recent lavas of King George Island. In Bolivia, Upper Pliocene beds whose lithology and fauna indicate that they had originally formed low-lying land have been uplifted some 10,000–12,000 ft. (3,050–3,660 m.) during the late Pliocene and Pleistocene (Walker, 1949), and similar uplifts have been recorded in central Peru (Jenks, 1956). Harrington (1956) has stated that the present elevation of the Patagonian Cordillera and the Principal Cordillera of Argentina are due mostly to Miocene and Pliocene movements, and that the great displacement on the faults (5,000 m.) along the eastern foot of the Frontal Cordillera is due to late Pliocene movements. Comparison and correlation with South America therefore suggest that during the early Tertiary epeirogenic movements resulted in the uplift of the Antarctic Peninsula region and that these movements probably reached a climax in the Pliocene.

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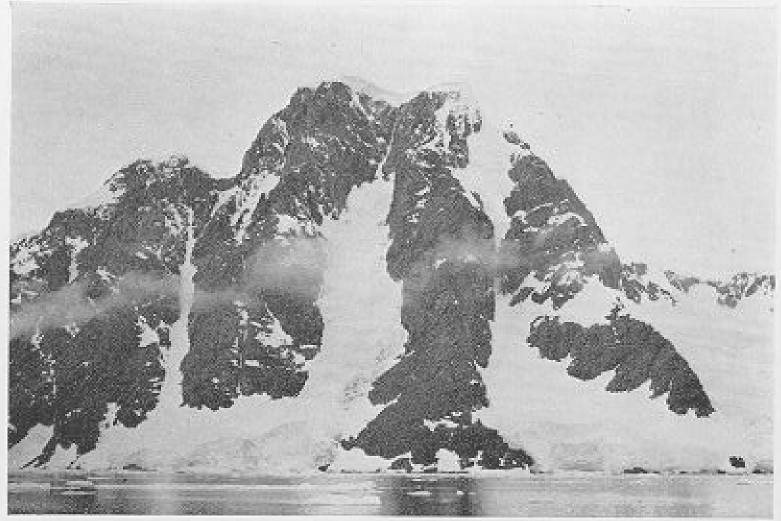
PLATE I

a. Mount Scott (2,500 ft.; 762 m.), Penola Strait, showing pyroclastic rocks overlying andesite lavas. The junction between these two rock types is in the lower right of the photograph.

b. Banded crystal tuffs of the tuff group; Mount Scott, Penola Strait.

c. Current-bedded crystal tuffs; tuff group, Mount Scott, Penola Strait.

d. Current-bedded crystal tuffs; tuff group, Mount Scott, Penola Strait.



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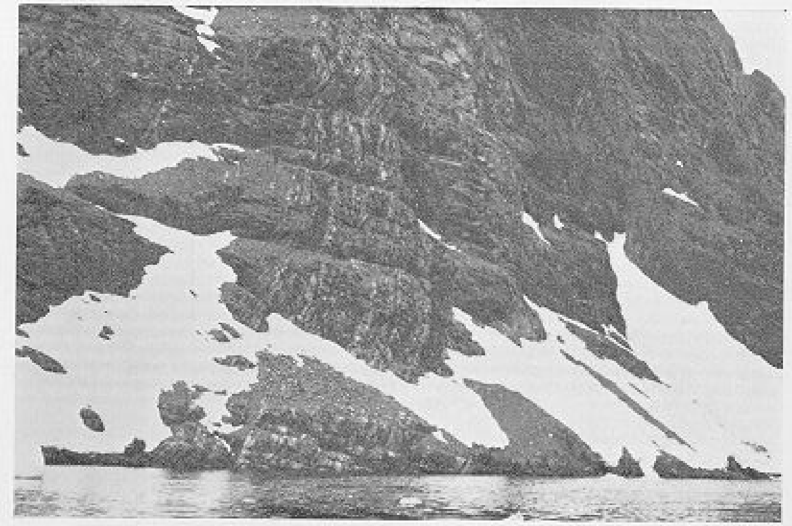

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PLATE II

a. Gently dipping grey and purple striped tuffs; 0·5 miles (0·8 km.) north of Cape Cloos.

b. Volcanic conglomerates interbedded with crystal tuffs; 0·5 miles (0·8 km.) north of Cape Cloos.

c. A view, looking west, of the peninsula on the west coast of Booth Island. In the foreground, Upper Jurassic volcanic rocks thermally metamorphosed to hypersthene-augite-biotite-hornfelses form a thin capping on tonalites, which also form the middle distance of the photograph. The hill in the background is composed of granodiorite separated from the tonalite by a fault.

d. The contact between gabbro and a volcanic raft at Cape Tuxen.

a

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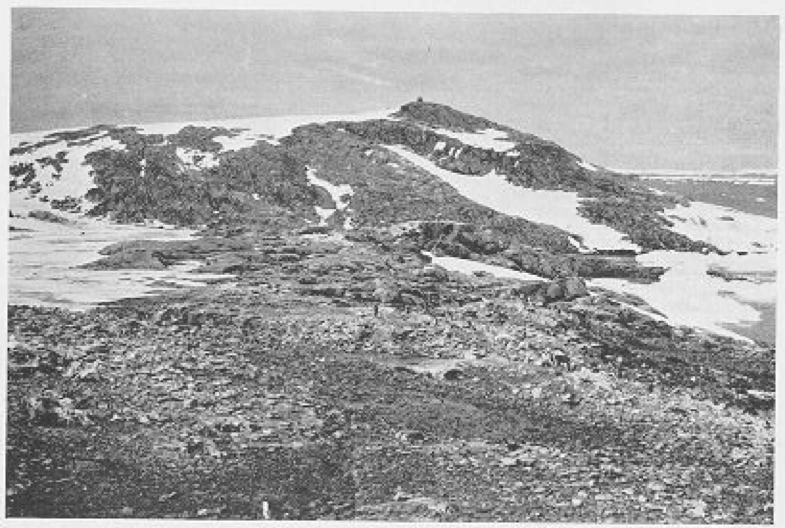

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PLATE II

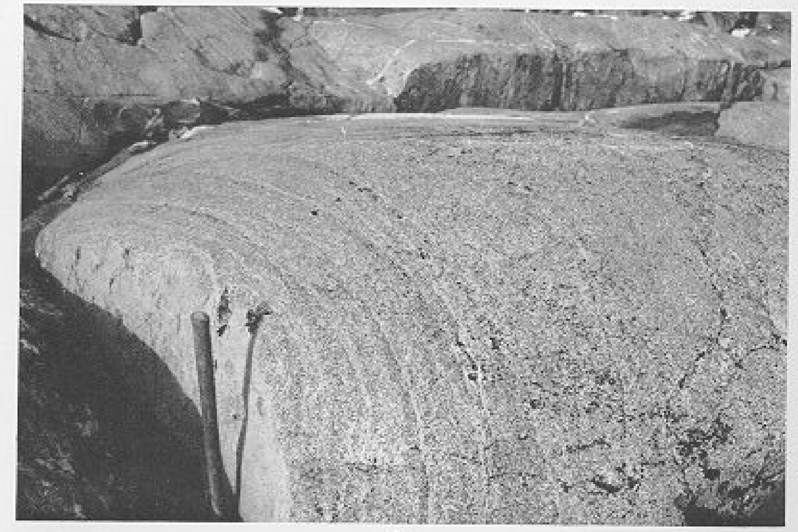
PLATE III

a. The contact between diorite and volcanic rocks of the andesite group; near Duseberg Buttress, Penola Strait.

b. Layering of ferromagnesian minerals in olivine-gabbro at the Roca Islands.

c. A view of Cape Tuxen and the western shore of Waddington Bay, showing the main contact between volcanic rocks and granodiorite (left), and the contact between volcanic rocks and gabbro at the end of the cape (right).

a



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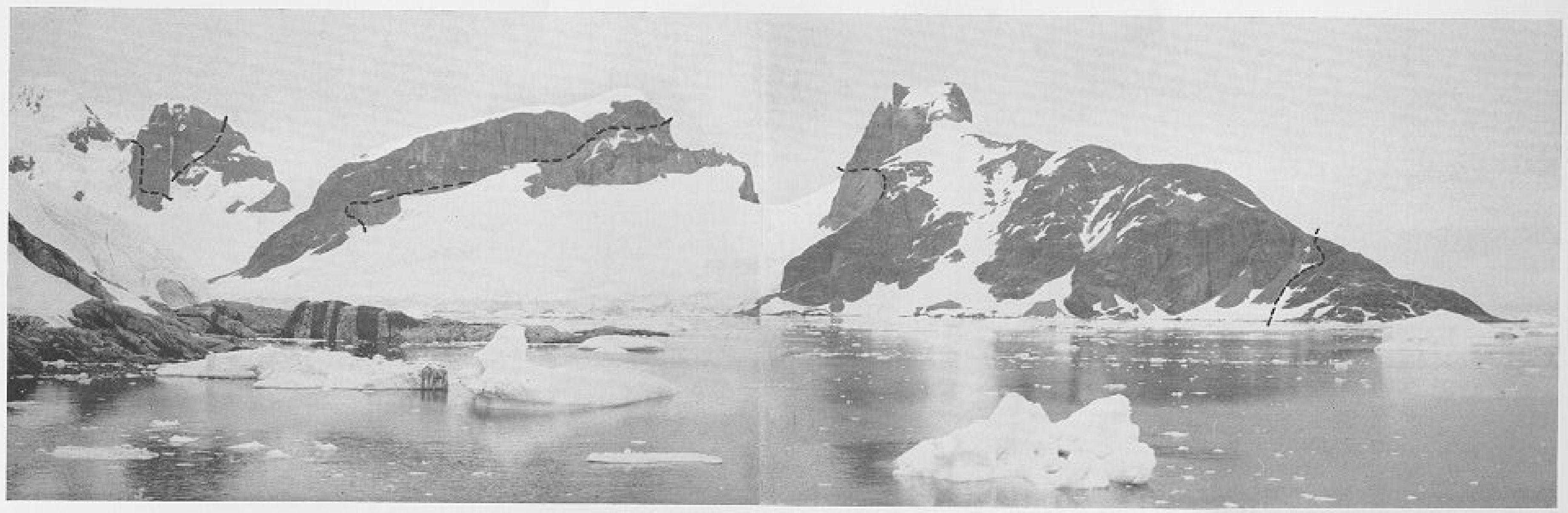

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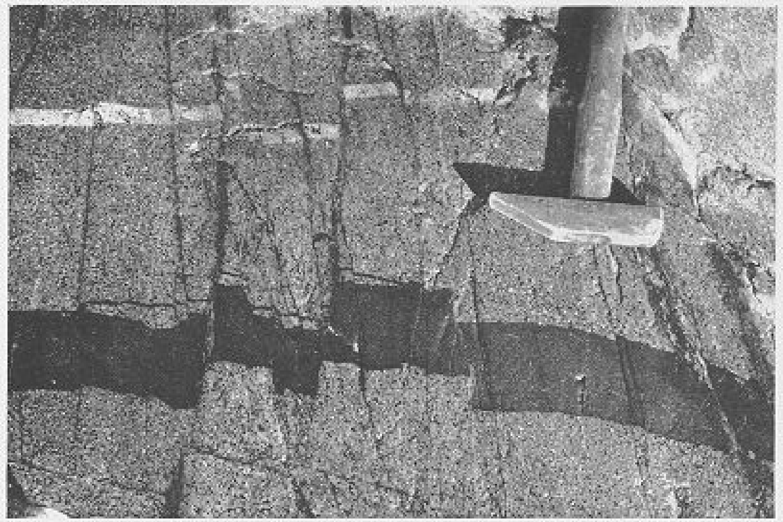
PLATE IV

a. Sheared hornblende-gabbro at Rouch Point, Petermann Island, showing displacement of late-stage hornblende-andesine and granophyre veins.

b. A granodiorite tongue intruding gabbro 0·5 miles (0·8 km.) south of Cape Tuxen. The granitic vein which defines the contact can be clearly seen.

c. A close-up view of the gabbro/granodiorite contact 0·5 miles (0·8 km.) south of Cape Tuxen.

d. The gabbro/granodiorite contact at Rouch Point, Petermann Island. The rock-filled gully in the foreground marks the contact.



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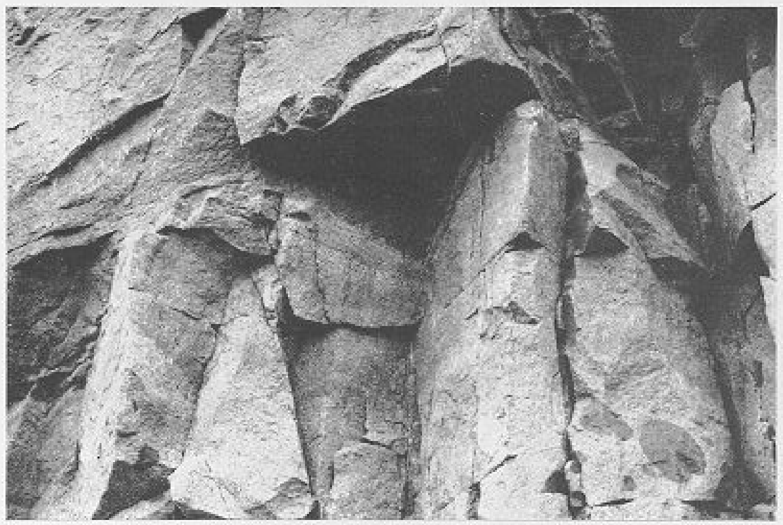

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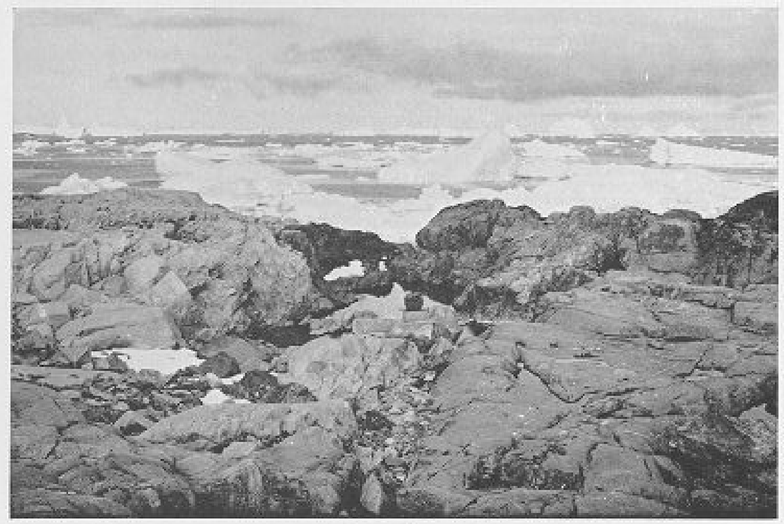

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PLATE IV

PLATE V

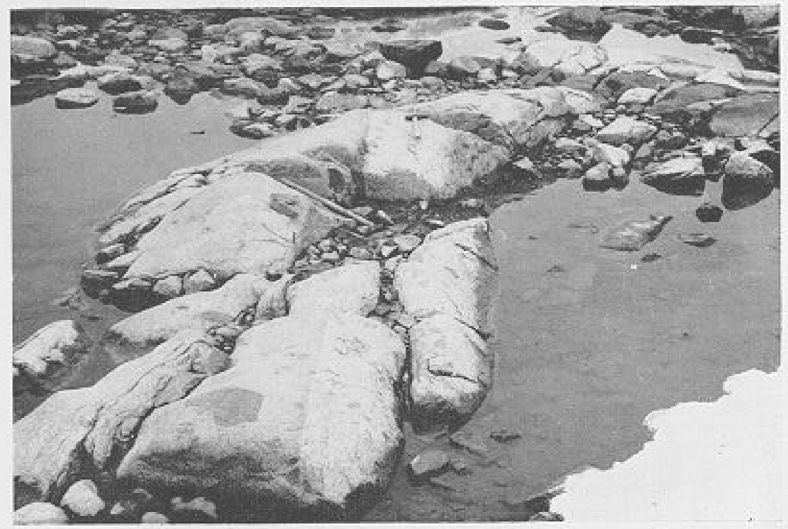
a. A fault zone in tonalite at the peninsula on the west coast of Booth Island. Mount Lacroix, which forms the northern part of Booth Island, can be seen in the background.

b. The tonalite/granodiorite contact at Port Circumcision, Petermann Island.

c. Banding at the contact between granodiorite (right) and a large gabbro xenolith (left) at Port Circumcision, Petermann Island.

d. A contact between an early granophyre and a raft of volcanic rocks at Prospect Point. The intense veining of the raft at the contact is marked.

a



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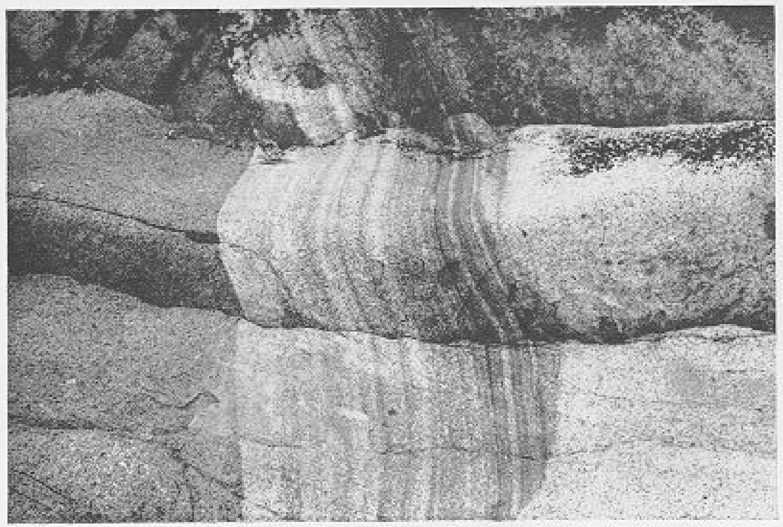

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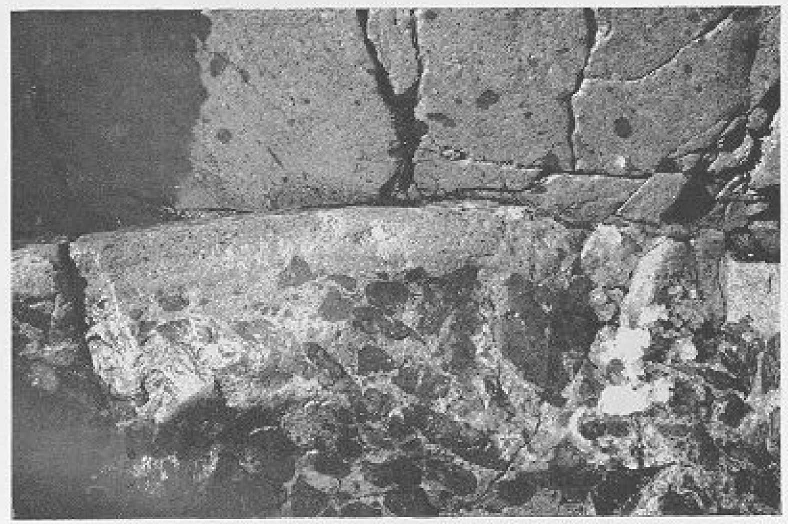

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PLATE V

PLATE VI

a. Shale/siltstone contact; north shore of Lahille Island. The shale (dark) is puckered and forms small offshoots into the siltstone along the trend of the fracture cleavage (J.735.8; ordinary light; ×69).

b. A thin vein composed of actinolite, clinozoisite and chlorite, and bordered by iron pyrites crystals, in an andesite at Cape Cloos (J.650.9; X-nicols; ×69).

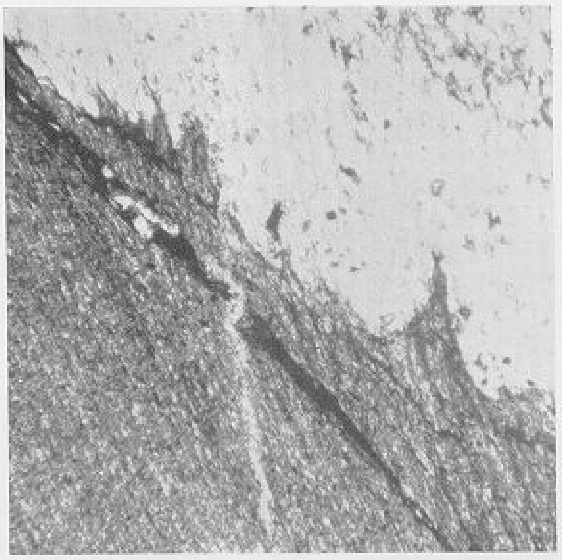
c. Fragments of andesite in a network of epidote veins in an andesite-breccia at Cape Cloos. The andesite fragments (upper part of the photograph) contain abundant iron ore (J.630.13; ordinary light; ×69).

d. A hornblende crystal severely altered to actinolite, biotite, sphene and epidote; hornblende-andesite, Cape Cloos (J.630.6; X-nicols; ×39).

e. A quartz porphyroblast in a crystal tuff; tuff group, Penola Strait (J.655.11; X-nicols; ×70).

f. A hypersthene crystal in an hypersthene-cordierite-biotite-hornfels; Splitwind Island (J.643.1; X-nicols; ×160).

PLATE VI



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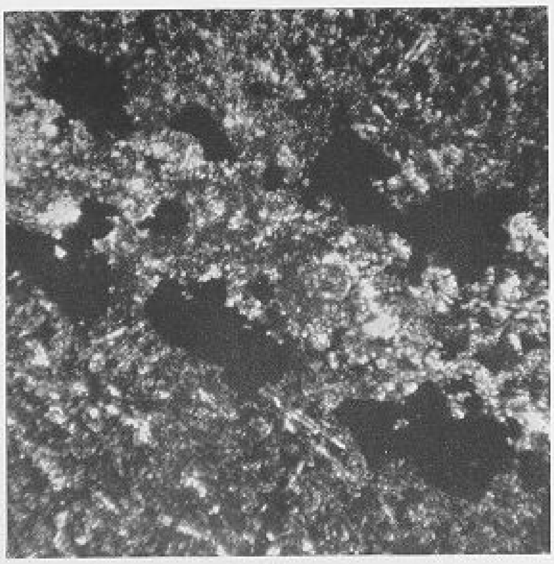

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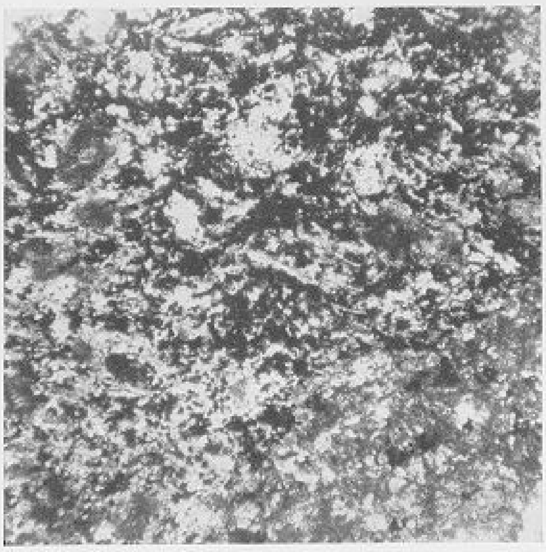

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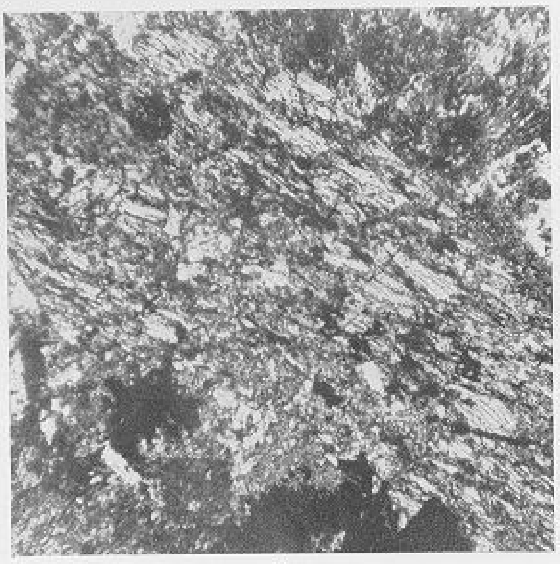

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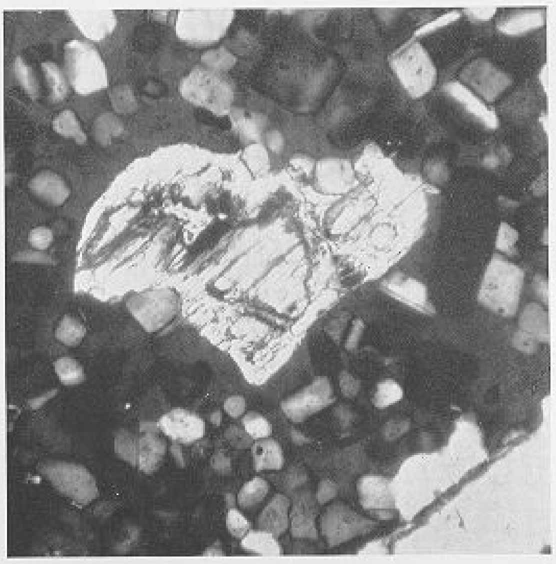

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PLATE VII

a. Sillimanite needles in narrow stress zones in a sillimanite-andalusite-cordierite-hornfels; Splitwind Island. The light grey crystals are of andalusite (J.667.3; ordinary light; ×160).

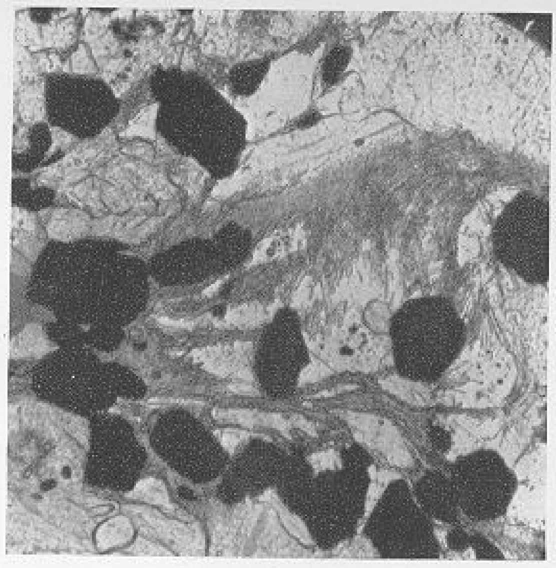
b. Biotite aggregates surrounding iron ore in a quartz-mica-hornfels; Booth Island (J.646.2; ordinary light; ×37).

c. Quartz-albite-epidote aggregates replacing plagioclase in a metasomatized andesite on the mainland near Rasmussen Island (J.691.9A; X-nicols; ×37).

d. Quartz and albite porphyroblasts in a metasomatized andesite on the mainland near Rasmussen Island (J.691.11; X-nicols; ×37).

e. Potash feldspar (dark grey) replacing plagioclase in a metasomatized andesite on the mainland near Rasmussen Island (J.691.13; X-nicols; ×37).

f. Quartz (in extinction) and calcite porphyroblasts replacing plagioclase in a metasomatized rock; Sanctuary Islands (J.728.6; X-nicols; ×67).



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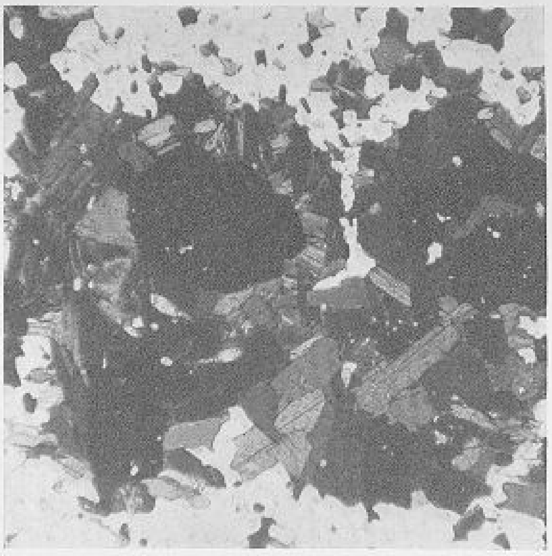

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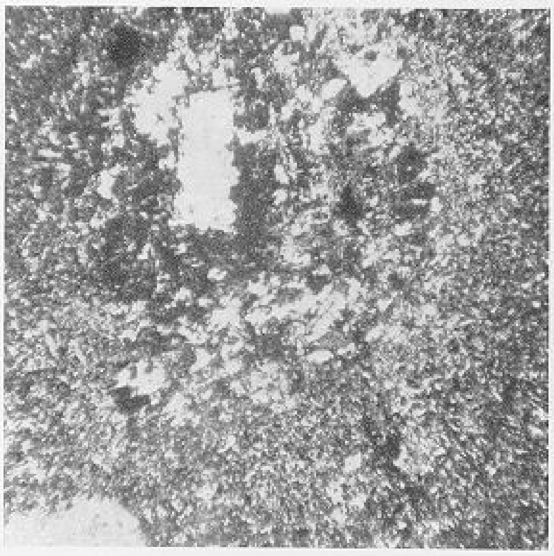

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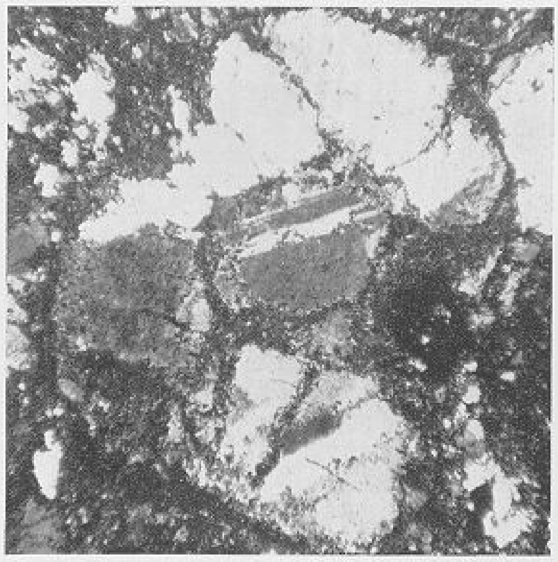

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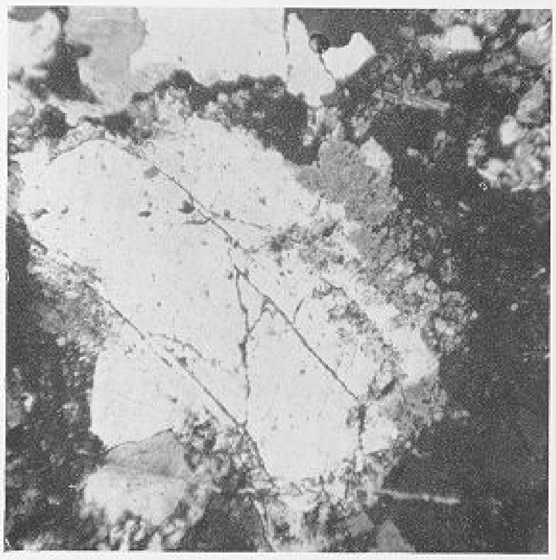

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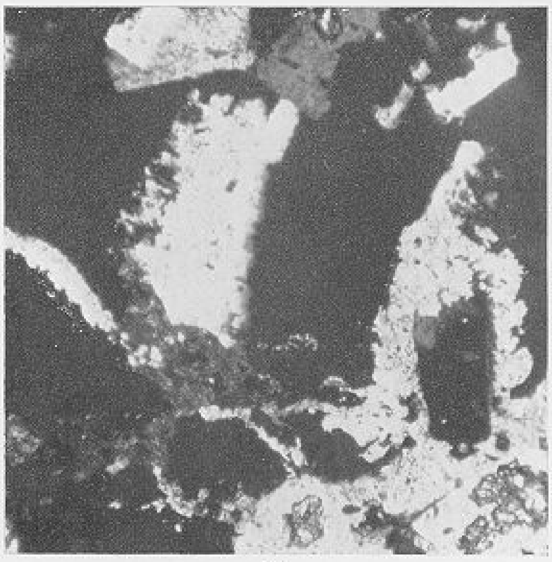

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PLATE VIII

a. A sericitized plagioclase crystal marginally replaced by potash feldspar (in extinction) in a metasomatized rock; Sanctuary Islands (J.728.6; X-nicols; ×67).

b. Biotite replacing hypersthene, surrounded by a symplectite of radiating vermicular amphibole in gabbro; Jagged Island (J.526.1; ordinary light; ×120).

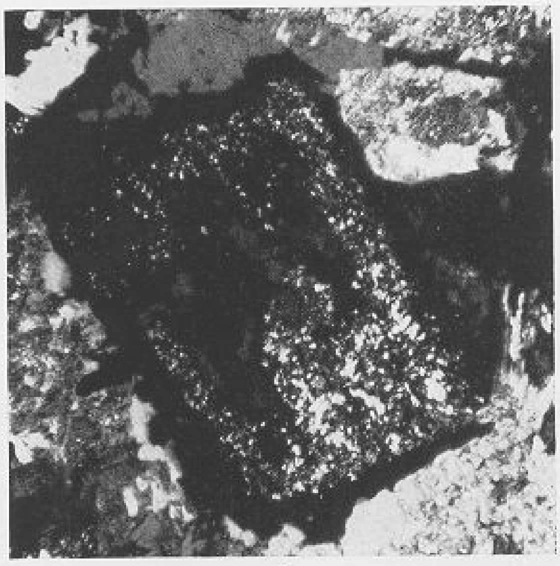
c. The initial stage in the replacement of augite by hornblende (in extinction) along cleavage traces in a hornblende-gabbro; Rouch Point, Petermann Island (J.705.2; X-nicols; ×37).

d. A later stage in the replacement of augite by hornblende (in extinction) in a hornblende-gabbro; Rouch Point, Petermann Island (J.705.2; X-nicols; ×37).

e. A very late stage in the replacement of augite by hornblende (in extinction) in a hornblende-gabbro; Rouch Point, Petermann Island (J.705.2; X-nicols; ×37).

f. A remnant corroded core of basic plagioclase surrounded by the main plagioclase of the matrix in a diorite; Larrouy Island (J.544.1; X-nicols; ×67).

PLATE VIII



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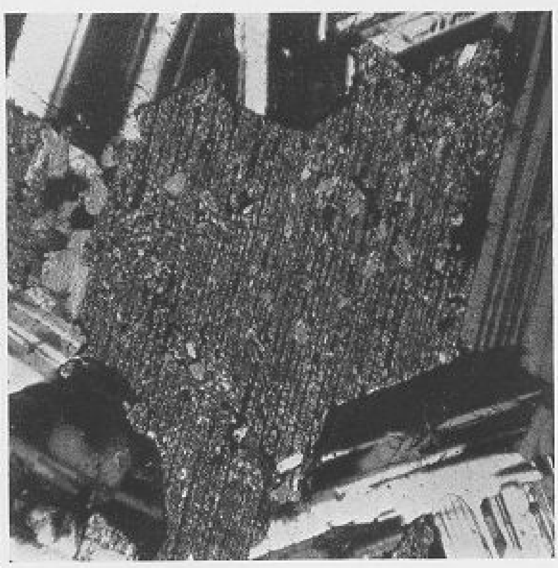

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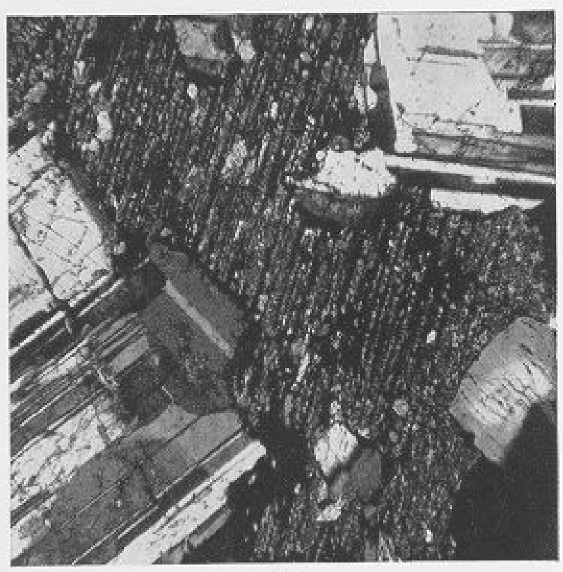

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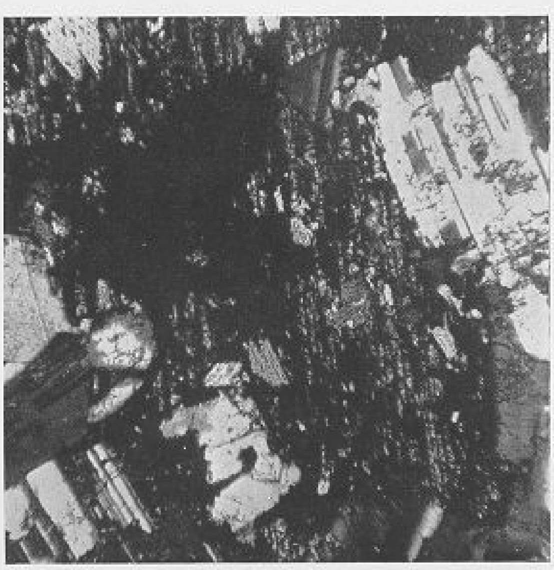

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PLATE IX

a. Composite zoning in aggregates of corroded basic plagioclase in a tonalite; Booth Island (J.644.1; X-nicols; ×67).

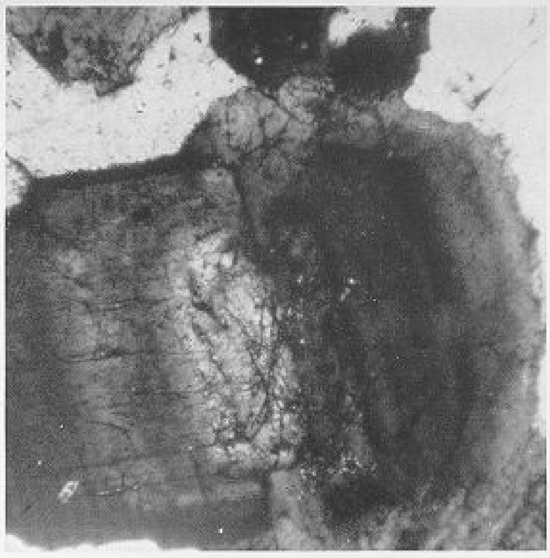
b. Glomeroporphyritic aggregates of small hypersthene crystals in a tonalite; Lippmann Islands (J.672.1; ordinary light; ×67).

c. Augite replaced by an aggregate of quartz, actinolite, calcite and chlorite in a tonalite; Milnes Island (J.719.1; X-nicols; ×67).

d. Myrmekite developed at the contact between plagioclase and potash feldspar in a tonalite; Milnes Island (J.719.1; X-nicols; ×67).

e. Recrystallized inclusion in granodiorite; Takaki Promontory (J.713.3; X-nicols; ×37).

f. Perthite replacing plagioclase in granite; Takaki Promontory (J.715.1; X-nicols; ×120).



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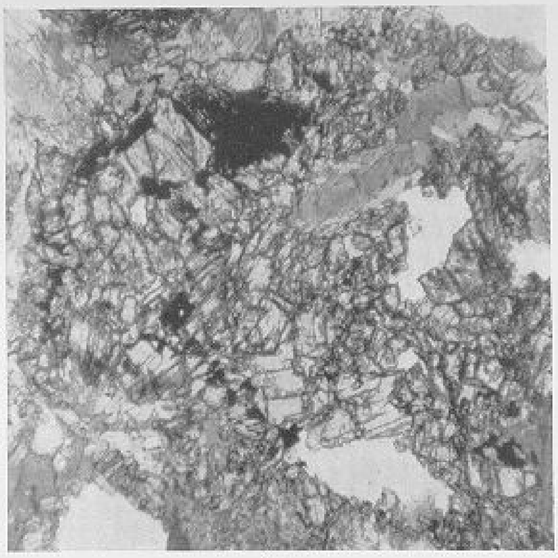

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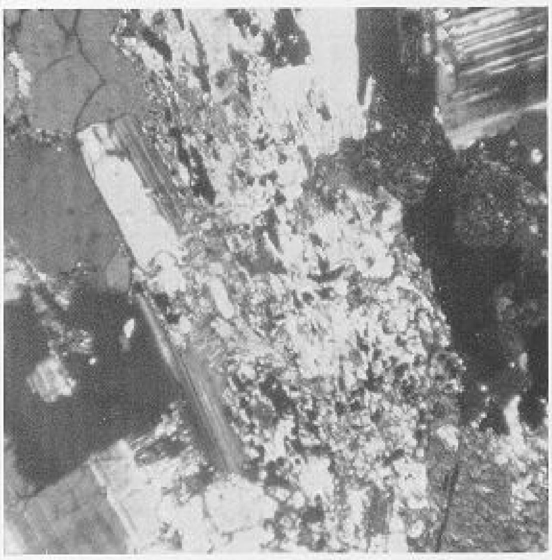

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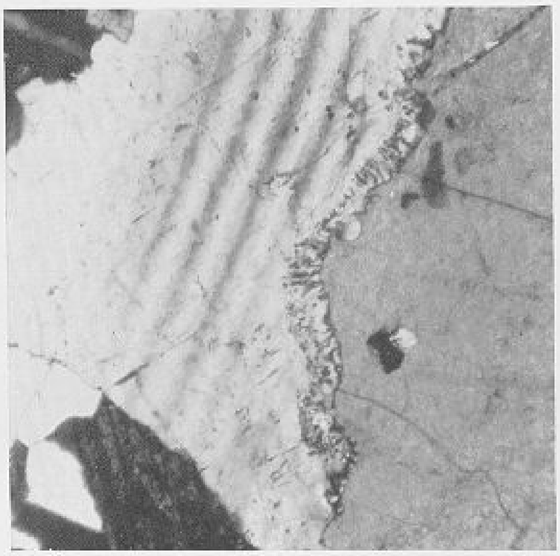

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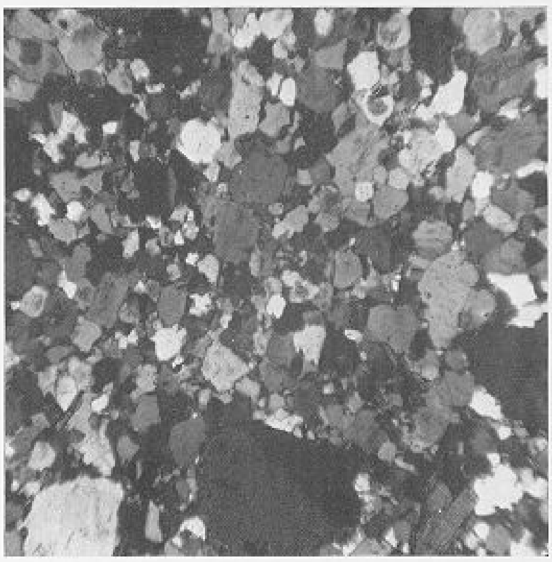

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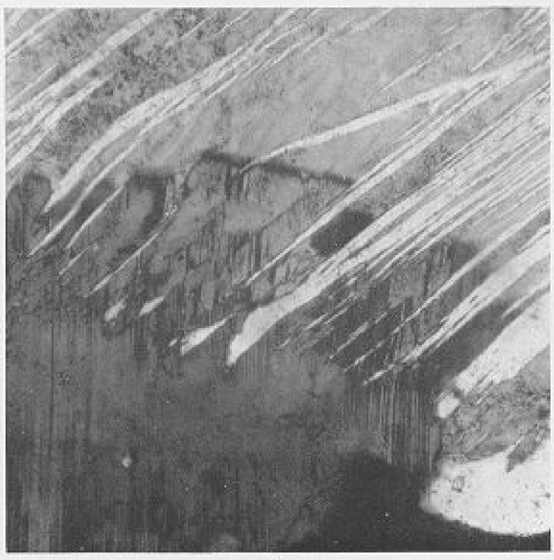

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