BRITISH ANTARCTIC SURVEY

(*formerly Falkland Islands Dependencies Survey*)

SCIENTIFIC REPORTS

No. 36

THE GEOLOGY OF THE LOUBET COAST, GRAHAM LAND

By

D. C. GOLDRING, B.Sc., Ph.D.

Falkland Islands Dependencies Survey,
Department of Geology, University of Birmingham

LONDON: PUBLISHED BY THE BRITISH ANTARCTIC SURVEY: 1962

THE GEOLOGY OF THE LOUBET COAST, GRAHAM LAND

By

D. C. GOLDRING, B.Sc., Ph.D.
Falkland Islands Dependencies Survey,
Department of Geology, University of Birmingham

(Manuscript received 30th September, 1960)

ABSTRACT

THE geology of the Loubet Coast of Graham Land is described. The rocks are nearly all igneous and comprise mainly volcanic rocks of an Upper Jurassic age and plutonics of the Andean Intrusive Suite. The Orford Cliff Suite, a distinctive suite of intrusive rocks occurring in the Lallemand Fjord area, is believed to be early Palaeozoic in age. Undoubted pre-Upper Jurassic intrusive rocks crop out near Detaille Island and occur as fragments in Upper Jurassic pyroclastic rocks. Rocks of the Orford Cliff Suite contain xenoliths of the Basement Complex and screens of early Palaeozoic volcanic and hypabyssal rocks. Two other phases of hypabyssal intrusion are recognized. The first forms an integral part of the Upper Jurassic vulcanicity but the second is later in age than the Andean Intrusive Suite. The sequence of intrusion in both of the plutonic suites is from femic to salic. There is some thermal metamorphism, assimilation and metasomatism of the volcanic and earlier plutonic rocks by later intrusions. Hydrothermal alteration is almost ubiquitous. Rocks of the Orford Cliff Suite have undergone intense deformation but the Upper Jurassic volcanic and the Andean intrusive rocks are little deformed. A comparison is made with the geology of adjacent regions which are very similar.

CONTENTS

I. INTRODUCTION

1. *Location*

The area described in this report comprises that part of the Loubet Coast of Graham Land between The Gullet (lat. 67°10'S., long. 67°38'W.) and Cape Bellue (lat. 66°20'S., long. 65°59'W.) together with a small part of the Graham Coast south of Cape Evensen (Fig. 1). It includes adjacent islands and the hinterland of Graham Land as far east as the central ice-capped spine of the peninsula.

2. *Previous investigations*

On his first expedition (1903–05) Charcot discovered and named the Loubet Coast, although Biscoe

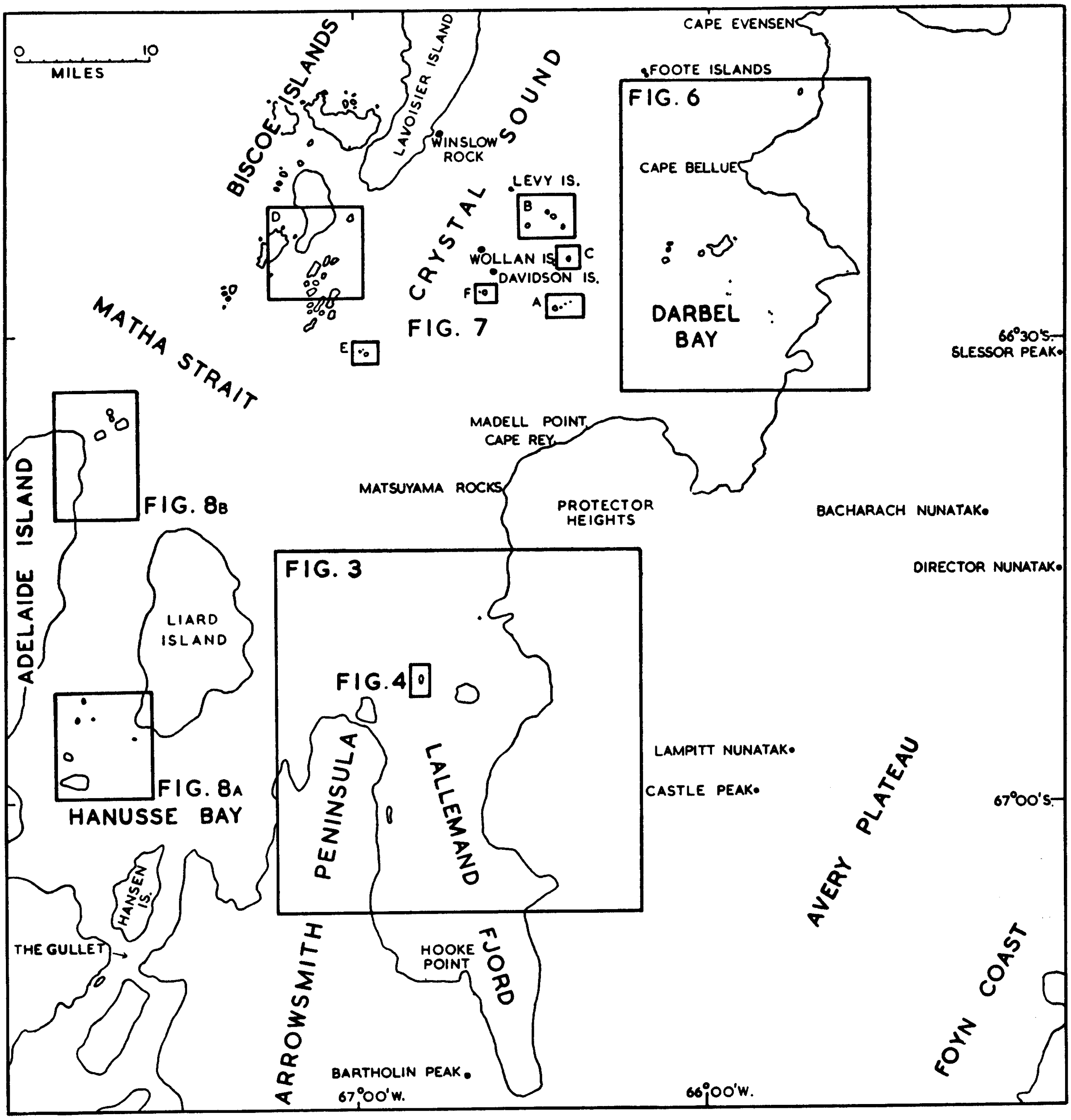


FIGURE 1

Sketch map of the Loubet Coast and adjacent islands. The respective positions and figure numbers of more detailed geological maps appearing elsewhere in this report are indicated. (Drawn from a map prepared by B. L. H. Foote.)

was the first to sight Adelaide Island and the Biscoe Islands in 1832. Charcot's expedition made at least one landing, on Detaille Island, but there is no record of geological work having been carried out. The only previous descriptions of rocks from this area are by Tyrrell (1945, p. 70), who has described specimens from islands said to be situated south-west of Cape Bellue. The locality is Rambler Harbour, where a sketch survey was made from R.R.S. *Discovery II* in January 1931. This anchorage is in a group of islands now named the Bragg Islands and not in the "Marin Darbel Islands"* as stated by Tyrrell.

The British Graham Land Expedition (1934–37) travelled through the area and a party from the United States Antarctic Service Expedition (1939–41) made a landing on Watkins Island. An Argentine party landed at Tutton Point on Liard Island in 1956 and also established a hut on a small island west of Watkins Island. The Falkland Islands Dependencies Survey activities along the coast from their station at Stonington Island in Marguerite Bay did not extend north of The Gullet, but in December 1946–January 1947 a party travelled along the central plateau of the Graham Land peninsula as far north as lat. 66°30′S.

3. *Present work*

The Falkland Islands Dependencies Survey station on Detaille Island (lat. 66°52′S., long. 66°48′W.) at the entrance to Lallemand Fjord was established during February 1956, and geological work was carried out during the following spring and summer by H. G. Wright. Stations at which he collected specimens are numbered W.21–93. The writer spent two seasons on the Loubet Coast, from February 1957 to March 1959. Stations visited between March 1957 and January 1958 are numbered W.300–363, while those visited between April 1958 and March 1959 are numbered W.364–558. Specimens were also collected from stations W.200–202 and W.250–262 by other members of the station.

Laboratory work was carried out from July 1959 to September 1960 in the Department of Geology, University of Birmingham, where all the specimens and thin sections referred to in this report are housed.

4. *Physiography*

The major physical features of the Loubet Coast† are shown in Fig. 1. Typical views are shown in Plate I. The much-embayed fjord coast faces west and trends from north-east to south-west. To the south-east, the land rises steeply to the central 5,000–7,000 ft. (1,524–2,134 m.) high ice-capped plateau of the Graham Land peninsula. Mountains and nunataks, especially frequent at the margins of the plateau, reach a height of 8,260 ft. (2,517 m.) (Castle Peak). A skeleton of narrow ridges, some of which have a uniform elevation of their high-altitude apices or truncated tops, finger from the plateau towards the west. They are divided by cirque glaciers, valley glaciers and occasionally by glaciers flowing directly from the plateau.

A belt of offshore islands extends for a distance of 30 miles (48·3 km.) to the north-west of the Loubet Coast. Some of the larger ones are mountainous and are physiographically comparable with the peninsulas connected to the mainland by glaciers and ice piedmonts not higher than about 1,500 ft. (457 m.). The mountains of these islands and peninsulas may reach the same height as the plateau; there are a few high ice-capped plateau areas of limited extent. Other large islands are mainly or completely covered by ice caps which are up to about 1,500 ft. (457 m.) in height. Ice piedmonts and ice shelves form a large proportion of the otherwise mountainous islands and the mainland coast. There are a few land areas of intermediate altitude which are only thinly covered by ice.

The smaller islands can be grouped as follows:

i. High rocky islands which are mainly fringed by ice shelves, e.g. Andresen and Weertman Islands.
ii. The almost completely ice-capped islands with few rock exposures, the summit of the island being ice-capped, e.g. the largest of the Darbel Islands and the larger of the islands in Crystal Sound.
iii. The small ice-capped islands with few rock exposures, in which the summit of the ice cap is at the south-facing ice cliff edge of the island, e.g. Sunday Island of the Bragg Islands, and Levy Island.
iv. The low-level rocky islets which are wave swept when surrounded by the open sea.

The piedmont and shelf ice are seldom seen to rest on bed rock or detrital deposits exposed beneath

* Now called Darbel Islands.
† The area described in this report is referred to as the Loubet Coast for convenience. The Loubet Coast, as defined geographically, extends from Cape Bellue to the head of Bourgeois Fjord and thus forms the northern coastline of Marguerite Bay.

the ice cliffs. For example, from Roux Island to The Gullet around the southern coast of Hanusse Bay there are only three rock exposures, all being seaward continuations of mountain ridges. This may be contrasted with descriptions of coasts to the north (Holtedahl, 1929).

Recent sea beaches are rare, the only good example being at Pfaff Island, where a beach grading on its landward side into a scree is fronted on its seaward side by an ice shelf. There is much evidence of present-day marine erosion (e.g. Plate IIa).

Erratics and glacial debris are often found on flat-lying rock exposures. They are especially abundant at Shanty Point, Phantom Point, Tutton Point and Orford Cliff. Glacial striae and grooving have been observed on rock platforms at Tutton Point, Phantom Point and Detaille Island. They certainly afford evidence of the past greater extent of the glaciers and their directions are in accord with present-day glacier trends.

II. AGE RELATIONSHIPS OF THE MAJOR ROCK GROUPS

EIGHT main rock groups have been recognized within the area described and they are shown in stratigraphical order in Table I.

TABLE I

THE STRATIGRAPHY OF THE LOUBET COAST

Tertiary	Hypabyssal rocks
Late Cretaceous or Early Tertiary	Andean Intrusive Suite
Upper Jurassic	Hypabyssal rocks Volcanic rocks
? Early Palaeozoic	Intrusive suite Hypabyssal rocks Volcanic rocks
? Precambrian	Basement Complex

Schists belonging to the Basement Complex are represented only as xenoliths in tonalites and granodiorites of the early Palaeozoic Intrusive Suite. Similarly, the early Palaeozoic volcanic and hypabyssal rocks are found as screens in the early Palaeozoic Intrusive Suite. Undoubted pre-Upper Jurassic intrusive rocks occur as fragments in the Upper Jurassic agglomerates. These plutonic fragments are especially numerous at a small islet (W.364) off Detaille Island where there is a contact between granodiorite and vent agglomerate. There is no direct evidence that the plutonic rocks which crop out in the area between Lallemand Fjord and Murphy Glacier and which have been named the Orford Cliff Suite are of early Palaeozoic age. This problem is discussed in greater detail on p. 8. The age determination of the early Palaeozoic volcanic and hypabyssal rocks also depends on this relationship, since it is only in the Orford Cliff Suite that they have been found.

The existence of pre-Andean hypabyssal rocks cutting the Upper Jurassic Volcanic Group can be demonstrated at several localities. They are clearly later in age than the local volcanic rocks which they intrude, but their relationship to the succession of the upper part of the Upper Jurassic Volcanic Group is not known. The intrusion of the Upper Jurassic Volcanic Group by gabbros, tonalites, granites, etc. is demonstrated at several localities. Post-Andean hypabyssal rocks intrude along the joint planes of both the Andean Intrusive Suite and the Upper Jurassic Volcanic Group.

The determination of the respective ages of these rocks as early Palaeozoic, Upper Jurassic and Andean (late Cretaceous or early Tertiary) is based on analogy with other parts of Graham Land (Adie, 1955, p. 4), since there is no direct evidence of age within the area.

III. THE BASEMENT COMPLEX

THE tonalites and granodiorites of the Orford Cliff Suite contain numerous xenoliths of hornblende-biotite-schist (Plate IId) and rarer xenoliths of quartz-biotite-schist and hornblende-gneiss. The more mafic varieties have been little assimilated but some inclusions have indistinct margins or are veined by a leucocratic facies of the plutonic rocks. The more felsic types carry lenses of bluish quartz which may be intricately puckered. Similar lenses are also present in the plutonic rocks and are relicts remaining after assimilation of the xenoliths.

A typical example of hornblende-biotite-schist (W.303.4) is medium-grained and strongly schistose. The foliation is planar and there are feldspathic lenses. Plagioclase ($Ab_{42}An_{58}$–$Ab_{52}An_{48}$) forms normally zoned xenoblastic crystals and hornblende (α = pale brown, $\beta = \gamma$ = brownish green; $\gamma{:}c = 21°$) forms idioblasts. Some cores of the hornblende crystals are colourless and the rims may have γ either green or bluish green. The hornblende often includes cores of diopsidic augite. The third main constituent is biotite ($\alpha = \beta$ = pale yellow, γ = reddish brown). Indented crystals of iron ore are fringed by sphene and there are patches of quartz which show undulose extinction. Strained crystals of biotite and hornblende also indicate post-crystalline deformation. There is accessory apatite. These schists are comparable with those described by Adie (1954, p. 7) from the east coast of Graham Land and from the Marguerite Bay area. The main differences are the more calcic nature of the plagioclase in the Loubet Coast schists and the occurrence of augite, which Adie found forming aggregates of idioblasts. A marginal phase of hornblendite has not been noticed in xenoliths of the Loubet Coast.

The xenoliths of hornblende-gneiss (W.363.1) consist of alternating mafic and felsic layers which are tightly folded. The plagioclase is remarkably calcic and is bytownite ($Ab_{13}An_{87}$). Hornblende has largely taken the place of augite. Biotite and quartz are abundant and have replaced both the bytownite and hornblende. The xenoliths of quartz-biotite-schist show an intensely contorted foliation and abundant lenses of quartz. In one example (W.363.2) the schist layers are formed principally of biotite, quartz, andesine and hornblende. The xenoliths of hornblende-gneiss and quartz-biotite-schist are in no way similar to any of the members of the Basement Complex described by Adie (1954). They may be regarded as felsic and mafic variants of the hornblende-biotite-schists.

IV. EARLY PALAEOZOIC VOLCANIC AND HYPABYSSAL ROCKS

METAMORPHOSED volcanic and hypabyssal rocks form screens within the acid plutonic rocks of the Orford Cliff Suite. Since this suite is tentatively assigned to the early Palaeozoic the screen rocks must be older.

The volcanic rocks were found at only one locality, station W.307. The screens have a fold-like form (Fig. 2a) within foliated gneissose granites. These rocks (W.307.3, 4) are dark fine-grained hornfelses and were originally porphyritic andesites. They are finely banded and the banding lenses around occasional plagioclase phenocrysts. In thin section the idiomorphic andesine ($Ab_{61}An_{39}$) phenocrysts are up to 3·0 mm. in length and they show slight oscillatory zoning with thin sodic rims. They are heavily replaced by sericite, greenish brown biotite, albite, calcite, epidote and bowlingite. The main constituents of the groundmass are reddish brown and greenish brown biotite, forming small anhedral flakes, and xenomorphic laths of plagioclase up to about 0·2 mm. in length. The plagioclase ($Ab_{56}An_{44}$–$Ab_{82}An_{18}$) shows normal zoning; the crystal cores are often twinned on the albite law but the rims are untwinned. Anhedral shreds of sericite are subsidiary in quantity to the biotite. The accessories are epidote, quartz, calcite, chlorite, leucoxene and bowlingite. Lenticular areas of quartz have been partly recrystallized to a fine-grained mosaic and the larger crystals show undulose extinction. The banding is defined by thin lamellae particularly rich in mafic constituents. Groups of pyrite idioblasts have been corroded and replaced by hematite. More coarsely crystalline patches of biotite and calcite have been formed adjacent to the quartz lenticles and the plagioclase phenocrysts, respectively.

The hypabyssal rocks form irregularly shaped screens at and near Orford Cliff and at McCall Point.

They are dyke-like bodies which are disrupted and intruded by the tonalites and granodiorites (Fig. 2b). Their orientations are variable but most screens lie in the plane of foliation of the country rocks. Microgranites were injected along the planes of weakness created by the presence of the screens. The microgranite dykes contain either numerous rounded inclusions of the screen rocks or occasional irregularly-shaped xenoliths.

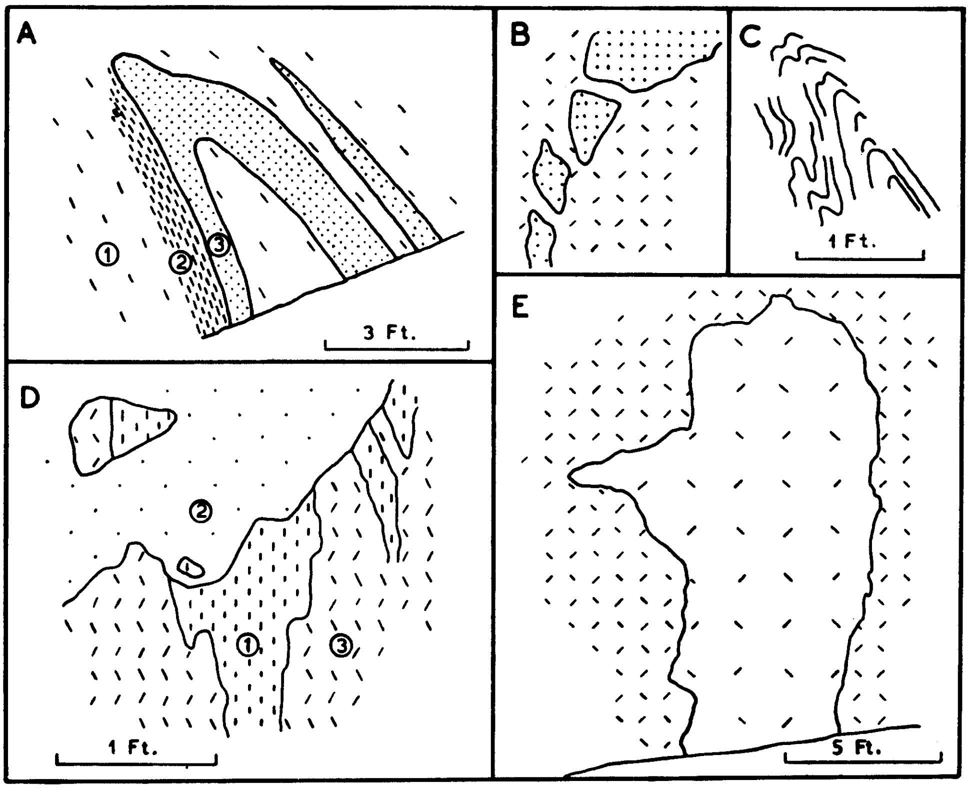


FIGURE 2

A. Screens of hornfelsed volcanic rocks in gneissose granites of the Orford Cliff Suite; nunatak 2·8 miles (4·5 km.) east-north-east of Neb Bluff (W.307; view from the north). 1. Foliated coarse augen-gneiss; 2. Strongly foliated mylonitized gneissose granite; 3. Finely banded hornfels.

B. Screen of hornfelsed dyke rock in the granodiorite of the Orford Cliff Suite; Orford Cliff (W.355; view from the north).

C. Flowage folds in gneissose rocks of the Orford Cliff Suite; cliff 1·5 miles (2·4 km.) east-south-east of Orford Cliff (near station W.313; view from the north-west).

D. Dykes of tonalite (1) and microgranite (2) in foliated granodiorite (3) of the Orford Cliff Suite; islets off Orford Cliff (plan view).

E. Granite boss intruding the granodiorite of the Orford Cliff Suite. Some parts of the contact are gradational and others are sheared; cliff 1·5 miles (2·4 km.) east-south-east of Orford Cliff (W.310; view from the north-east).

The screen rocks are typified by specimen W.362.3 from a screen of dark medium-grained hornfels associated with microgranite. Normally-zoned plagioclase ($Ab_{52}An_{48}$–$Ab_{64}An_{36}$) forms blastoporphyritic plates up to 3·0 mm. in length which is considerably larger than the mafic constituents which usually range from 0·1 to 1·0 mm. The plagioclase is partly sericitized and includes much hornblende and biotite. Hornblende (α = colourless, β = pale brown, γ = pale green or rarely brownish green; $\gamma{:}c = 22°$) forms small xenoblastic prisms. Biotite ($\alpha = \beta$ = very pale brown, γ = yellowish brown) laths are either enclosed in or are marginal to the hornblende. Iron ore, apatite, rutile, sphene, zircon and leucoxene are accessories. There are patches of quartz, some of which has replaced the plagioclase. The quartz is free of inclusions and shows undulose extinction. Thin veinlets are of orthoclase.

There is no evidence that these rocks have been metasomatized, although there has been some introduction of silica. They were probably of diorite composition and may now be described as andesine-biotite-hornblende-hornfelses.

V. THE EARLY PALAEOZOIC INTRUSIVE SUITE

A. The Granodiorite of Detaille Island and Included Fragments of this Suite in the Upper Jurassic Volcanic Group

Numerous plutonic fragments occur in agglomerates close to a steeply inclined contact with granodiorite at a small islet off Detaille Island. These fragments are similar to and show the same degree of alteration as the granodiorite, but there is no thermal metamorphism and the agglomerates fill a vent which cuts the plutonic rocks. The granodiorite (W.364.1) is coarse-grained, mottled and very altered. It is cut by dykes of pale pink microgranite and is sheared, epidote being present in proximity to the shear planes. Large subhedral crystals of plagioclase originally constituted about one-half of the rock, but these are now entirely replaced by chlorite, clinozoisite, albite and pistacite. There has also been slight replacement by orthoclase. Biotite, originally forming about 12 per cent of the mode, has been completely altered to chlorite and epidote. These minerals are associated with skeletal remnants of ilmenite bordered by leucoxene. Quartz occurs both as large anhedral crystals and as a coarse intergrowth with orthoclase surrounding former plagioclase. The quartz does not show undulose extinction. There is accessory apatite. The microgranite is composed of equigranular anhedral quartz and orthoclase, some of which is in micrographic intergrowth. Epidote, chlorite, iron ore and sphene are accessory. The plutonic fragments in the agglomerates (W.364.3, 4) are very similar. Some fragments are of the microgranite.

Undoubted pre-Upper Jurassic intrusive rocks occur as occasional fragments in agglomerates at Neb Bluff and on one of the Darbel Islands, and in siliceous tuffs 3 miles (4·8 km.) north-east of Cape Bellue. Three specimens were examined, but the small size of the samples precludes detailed description and modal analysis.

A fragment from Neb Bluff (W.304.4) is a leucocratic granodiorite. It has a sharp margin against the biotite-andesine-hornfels matrix of the volcanic agglomerate. Andesine, orthoclase and quartz have the same textural relationships as in the granodiorites of the Orford Cliff Suite but they show no strain effects. No mafic constituents were encountered in the small section examined.

A fragment from the north point of the largest of the Darbel Islands (W.348.3) is a dark tonalite, which has a sharp margin against a crystal lithic tuff matrix. About one-half of the rock consists of large subhedral crystals of plagioclase ($Ab_{62}An_{38}$–$Ab_{80}An_{20}$) showing oscillatory and normal zoning. The plagioclase is partly altered to albite, sericite and epidote. Large anhedral quartz crystals with a slight undulose extinction and a faint lamellar texture form about one-third of the mode. A little orthoclase is marginal to the plagioclase and interstitial to the quartz. Chlorite, epidote and leucoxene form aggregates after biotite and some of them surround indented iron ore crystals. The accessories are apatite and sphene.

Another fragment from the siliceous tuffs north-east of Cape Bellue (W.525.5) is a foliated mottled tonalite. About two-thirds of this rock consists of large subhedral crystals of plagioclase ($Ab_{66}An_{34}$). The feldspar is severely altered to albite, sericite and chlorite, and epidote, quartz and biotite form small veinlets within it. Quartz, showing no undulose extinction and forming about one-fifth of the mode, is interstitial to the plagioclase and occurs in larger areas of coarse mosaic. The grain boundaries within the mosaic are often marked by films of biotite. Biotite ($\alpha = \beta =$ very pale yellow, $\gamma =$ yellowish brown), which includes zircon and apatite, forms aggregates of flakes after large laths. Chlorite, iron ore and leucoxene are associated with the biotite. Granular pyrite is partly replaced by hematite. Aggregates of the mafic constituents spread as veinlets into the quartz and plagioclase and some of the feldspar has been replaced by them.

B. The Orford Cliff Suite

A suite of acid rocks is exposed in the area bounded by Lallemand Fjord, Salmon Cove and the Murphy Glacier. They are characteristically foliated and highly sheared, and have undergone intensive protoclastic and cataclastic deformation. Coastal and other exposures of these rocks were examined at Orford Cliff and on the mountain ridge and at the nunataks to the south and east (Fig. 3). At Neb Bluff Upper Jurassic volcanic rocks are intruded by plutons of the Andean Intrusive Suite, which are very different in character to the rocks of the Orford Cliff Suite. Rocks of the Orford Cliff Suite are exposed at McCall Point, south of Neb Bluff. Few of the inland exposures have been reached and the field relationships are not clear.

The establishment of the Orford Cliff Suite as being early Palaeozoic in age requires some comment. Adie (1954, p. 16) has described the occurrence of early Palaeozoic granites in the Marguerite Bay area.

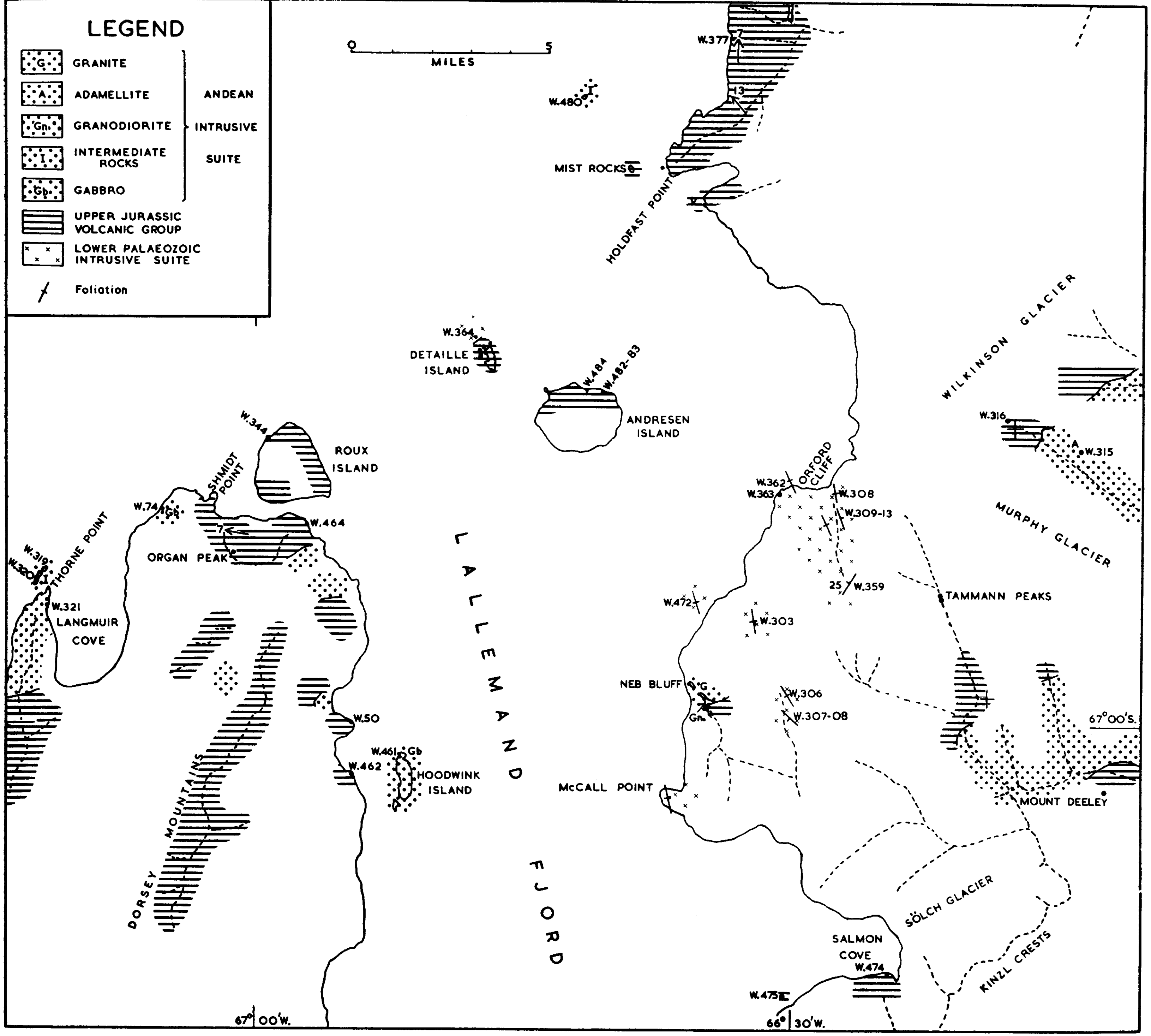


FIGURE 3
Geological sketch map of the Lallemand Fjord area.

He is now of the opinion (personal communication) that there is in fact a whole suite of plutonic rocks of this age. Evidence from palaeomagnetic studies (personal communication from Dr. D. J. Blundell) indicates that some of the plutonic rocks from Stonington Island and Horseshoe Island are pre-Upper Jurassic in age. The reasons for regarding the Orford Cliff Suite as early Palaeozoic are:

i. If the Orford Cliff Suite belongs to the Andean it is necessary to account for the presence of the undeformed plutonic rocks of Neb Bluff within the area of intensely deformed rocks. There is no evidence elsewhere for two cycles of Andean granitic intrusion.

ii. The Orford Cliff Suite rocks have a distinctive petrographic character which is different from that of the Andean Intrusive Suite.

iii. The rocks of the Orford Cliff Suite are most comparable with the early Palaeozoic granites described by Adie (1954).

1. *Tonalites, granodiorites and adamellites*

The extensive exposures in the immediate vicinity of Orford Cliff are of coarse-grained leucocratic rocks ranging in composition from tonalite to adamellite. They are foliated with schlieren and preferred orientation of biotite, which is the chief mafic constituent. Two major rock types can be distinguished: a coarse-grained darkish tonalite, in which the plagioclase is conspicuously idiomorphic in habit, and a coarse-grained leucocratic granodiorite, in which there are large prominent crystals of potash feldspar. The contact between the two rock types is sharp but very irregular in outline; it often lies in the same plane as the foliation (Fig. 2d). At some localities the granodiorite either injects the tonalite or includes it, but at other places (e.g. the small islets off Orford Cliff) dykes of tonalite intrude the granodiorite. There may be a gradation from one type into the other and porphyroblasts of potash feldspar are commonly developed in the tonalite close to contacts with the granodiorite. Dykes of coarse-grained leucocratic adamellite (Plate IIc) cut both the granodiorites and the tonalites. The margins of these dykes may be indistinct. The dykes are often along tonalite/granodiorite contacts and the adamellites are foliated.

The granodiorites and tonalites contain numerous inclusions which may be common to both types across a contact. The xenoliths are of dark coarse- to medium-grained gabbro, schist and gneiss. Lenses of bluish quartz are relicts remaining after the assimilation of schist xenoliths. Most of the inclusions have sharp margins, but a few have leucocratic borders; some have indistinct margins, whereas others have been fractured and veined by a leucocratic facies of the country rocks. The xenoliths of hornblende-biotite-schist tend to be orientated in the plane of foliation.

There are numerous dykes of pale microgranite and quartz-potash feldspar-pegmatite. These are especially associated with the screens and contain xenoliths of the early Palaeozoic hypabyssal rocks.

All the rocks are severely sheared. There are multitudes of dextral tear faults, having a maximum observed movement of 5 ft. (1·52 m.). In the vicinity of the hut at Orford Cliff the faults dip at steep angles and strike between 320° and 025° true. At McCall Point the faults are vertical and strike to 277° true. There has been considerable alteration adjacent to the shear planes where the main products are albite and epidote.

Typical examples of the tonalite, granodiorite and adamellite (W.363.7–9; Plate IVa) have a coarse granitic texture combined with great variation in grain size. Modal analyses of these rocks are given in Table II. Andesine ($Ab_{60}An_{40}$–$Ab_{69}An_{31}$) forms large subrectangular plates with rounded but indented outlines. It shows slight normal zoning but, in general, the composition is remarkably uniform throughout the range of rock composition. Crystals are often cracked and twin lamellae curved. In some places, particularly near shear zones, the plagioclase is altered to sericite and clinozoisite. There is marginal replacement and internal development of veinlets and patches of albite and oligoclase. This effect is most intense in the adamellite, in which some of the albite forms a symplectite with quartz adjacent to crystals of microcline. Biotite ($\alpha = \beta$ = pale brownish yellow, γ = reddish brown) forms large laths which are folded, strain-slipped and marginally frayed. It is partly replaced by chlorite, epidote, sphene and leucoxene. A mineral, probably prehnite, occurs in lenses between the cleavages. Magnetite, pyrrhotite, pyrite and chalcopyrite are present. Other accessories are graphite, apatite, orthite, sphene and zircon. The graphite occurs as small laths up to 0·1 mm. in length and in lenticles associated with the biotite. The graphite has a perfect basal cleavage and the reflection-pleochroism is O = yellowish grey and E = dark bluish grey. It is strongly anisotropic, the colour being brownish white. The Vickers micro-hardness is 10 to 12. The occurrence suggests late-stage formation in association with the alteration products. Large anhedral plates of quartz show an undulose extinction and partial recrystallization to a granoblastic mosaic, in which the undulose extinction is less pronounced. A multitude of minute granular inclusions in the quartz are either haphazardly arranged or lie in trails approximately parallel to (0001).

Microcline is only accessory in the tonalite (W.363.8) and it forms small plates (0·1–0·2 mm. in diameter) within the plagioclase. It is abundant in both the granodiorite (W.363.7) and the adamellite (W.363.9), forming large subhedral plates up to 3·0 mm. in length. Some of these contain lamellae of albite. In addition there are, as in the tonalite, small plates within the plagioclase, and microcline is interstitial to the quartz and the plagioclase. The crystal margins between microcline, plagioclase and quartz are irregular in detail and they are marked by finely granular quartz which also fills fractures and embayments within the feldspars. The texture is not indicative of extensive replacement.

TABLE II

MODAL ANALYSES OF THE ORFORD CLIFF SUITE

	W.363.8	W.363.7	W.363.9	W.310.1	W.359.1
Quartz	36·7	35·9	51·3	36·7	53·6
Microcline	0·4	19·4	22·2	45·8	26·4‡
Albite	4·1	1·5	6·9	†	†
Andesine	42·4	33·8	13·6	15·2	17·9
Biotite	11·6	5·3	2·1	0·2	0·8
Chlorite	1·7	2·7	2·4	1·3	0·7
Magnetite	*	*	*	—	*
Leucoxene	0·9	0·7	0·2	0·2	*
Pyrite	0·1	*	*	—	*
Pyrrhotite	*	*	*	—	—
Sphene	0·4	*	0·1	*	0·2
Epidote	0·2	0·3	0·5	0·4	0·3
Sericite	*	*	0·4	*	*
Apatite	0·1	*	*	*	0·1
Zircon	0·1	*	*	*	*
Rutile	0·5	*	*	*	*
Prehnite	0·8	0·1	0·2	0·2	—
Orthite	*	0·2	0·1	—	—
Graphite	*	*	*	—	—
Plagioclase composition	An_{40-34}	An_{38-31}	An_{39}	An_{33-31}	An_{31-29}

* Present in small quantity.
† Small proportion included with andesine.
‡ Some microperthite included.

W.363.8 Tonalite, Orford Cliff.
W.363.7 Granodiorite, Orford Cliff.
W.363.9 Adamellite, Orford Cliff.
W.310.1 Granite, 1·5 miles (2·4 km.) east-south-east of Orford Cliff.
W.359.1 Granite, 3·0 miles (4·8 km.) south-east of Orford Cliff.

Similar rocks crop out elsewhere in the area at stations W.303, 308, 361, 472 and 477. They show only minor variations from those described in detail above. Some of the adamellites (e.g. W.356.1) form large masses rather than dykes. At some localities hornblende (α = pale brown, β = greenish brown, γ = green; $\gamma{:}c = 24°$) is an important accessory, but it is always very subsidiary to biotite. The hornblende forms subhedral plates which may be fractured, the cracks being filled with a quartz mosaic. It is often margined by actinolite and partly or wholly replaced by small flakes of greenish brown biotite. This is also associated with chlorite marginal to the large laths of reddish brown biotite in some of the rocks. Important accessories are orthite and tourmaline. The orthite has pleochroic halos in marginal biotite or is fringed by pistacite. Some rocks show micro-faulting of the plagioclase crystals with displacements up to 1·0 mm.

2. *Granites*

For a distance of approximately 600 ft. (183 m.) to the south of station W.309 foliated biotite-granodiorites are intruded by irregularly shaped unorientated dykes and bosses of coarse-grained pink or grey granite. In one particular example (Fig. 2e) the northern margin is gradational over a distance of 2·0 to 3·0 mm., whereas the southern margin is strongly sheared. The granodiorites carry large porphyroblasts of microcline up to 1·0 cm. diameter and include masses of tonalite. All these rocks are cut by dykes of microgranite.

The granite (e.g. W.310.1) is intensely sheared on closely spaced planes which conform with the orientation of the foliation in the granodiorites and tonalites. It is a very leucocratic rock, the mafic constituents forming widely spaced aggregates. A modal analysis of this rock is given in Table II. Practically unzoned plagioclase ($Ab_{70}An_{30}$) rarely exceeds 1·0 mm. in length. It frequently has bent and micro-faulted twin lamellae and is replaced by sericite, quartz, epidote and microcline. The crystal margins are indented and the plagioclase is penetrated by a quartz mosaic. Small plates of plagioclase are completely enclosed by microcline by which it has been extensively replaced. Narrow borders of albite separate the andesine from the potash feldspar. The original biotite has been entirely replaced by chlorite, sphene, epidote, leucoxene and greenish brown biotite. Microcline forms large subhedral plates and close to andesine remnants it contains albite lamellae up to about 0·02 mm. in width. Large anhedral plates of quartz show a distinct undulose extinction and they are recrystallized to a fine-grained mosaic with sutural interlocking grain boundaries. This effect is particularly pronounced at the boundaries with feldspar crystals and in fractures within them. Shear zones up to 1·0 mm. in width contain angular and lenticular fragments of the granite, together with prehnite, epidote and albite.

Similar intensely sheared granites crop out at the southern end of the ridge (W.359). Massive areas (e.g. W.359.1) are, however, less altered. Large plates of plagioclase ($Ab_{70}An_{30}$) have clear borders but internally they are altered to sericite, chlorite and epidote. They also show evidence of strain. Substantial laths of biotite ($\alpha = \beta =$ yellow, $\gamma =$ dark brown or green) are bent, strain-slipped or marginally frayed, the edges forming a granoblastic aggregate with quartz. There is some alteration to chlorite, sphene and epidote, and the biotite includes iron ore, apatite and zircon. Large anhedral plates of quartz exhibit deformation lamellae and bands of finely recrystallized mozaic, and there is a great deal of undulose extinction. Planes rich in minute inclusions impart the pinkish grey colour seen in the hand specimen. The potash feldspar is microcline but much of it lacks good cross-hatched twinning, and some is microperthitic. It forms large plates which enclose remnants of andesine. The plagioclase crystals have very ragged margins and some are in optical continuity with larger crystals. Adjacent to the plagioclase, quartz is intergrown with microcline and veinlets of the symplectite penetrate the plagioclase. The potash feldspar itself contains narrow veinlets of quartz and epidote.

Rocks within the zones of intense shear are cataclasites (e.g. W.359.3). Angular fragments of quartz, microcline, andesine and orthite, all much strained, grade in size to a fine-grained matrix in which sericite, chlorite, epidote and quartz have been recrystallized.

At McCall Point (W.477) there are dykes and pod-like enclaves of granite in the foliated granodiorites and tonalites. The enclaves may be as small as 2 ft. (0·6 m.) in diameter. Contacts are gradational over a distance of 0·5 cm. but they are more often sheared. The granites are similar to specimen W.310.1 and there is clear evidence of strain.

3. *Gneissose rocks*

More intensely deformed rocks of similar composition to those already described have been examined at stations W.305–07, 309 and 312–14. At W.309 foliated biotite-granodiorites have a gneissose appearance with 4 or 5 bands per cm. Inclusions are drawn out into schlieren pierced by narrow planar and ptygmatic veinlets of a leucocratic facies of the country rock, which also borders the inclusions. At station W.313 and for a distance of about 300 ft. (91·4 m.) to the south strongly foliated gneissose rocks are injected by dykes of a coarse-grained pale granite. At one place disharmonic flowage folds have been formed (Fig. 2c). At W.314, on the ridge above these exposures, coarse pale granites cut up and inject foliated granodiorites. The granites are also foliated and contain large inclusions of gabbro and gneissose tonalite.

Banded tonalites with schlieren crop out at station W.305 2·8 miles (4·5 km.) east-north-east of Neb Bluff. Veins and lenses in and adjacent to the streaked inclusions are of leucotonalite. Locally there are masses of foliated granite. A thin section of the gneissose tonalite (W.305.1) shows similar characters to the tonalites of Orford Cliff but the effects of deformation are much more marked. There has been extensive alteration, the biotite having been replaced by chlorite, sphene, epidote and leucoxene, and the andesine by sericite, epidote and albite. Quartz, which shows an extreme degree of undulose extinction, has been granulated and recrystallized to a fine-grained mosaic. Euhedral pyrites is scattered throughout and there are veinlets of quartz and albite.

The nunatak to the south-east (W.306, 307) is composed of coarse-grained, intensely foliated granites. The biotite lenses around large crystals of quartz, plagioclase and microcline, the latter forming crystals as long as 2·0 cm. Thus, the rocks have the appearance of augen-gneisses. In thin section (W.306.1) the biotite forms thin shells around relicts of quartz, plagioclase and microcline. Anhedral plates of andesine ($Ab_{67}An_{33}$) are partially replaced by sericite and albite. Biotite ($\alpha = \beta =$ pale yellow, $\gamma =$ reddish brown), which is marginally replaced by greenish brown biotite, chlorite and sphene, forms large flakes which are folded and marginally frayed. Some of the quartz plates showing intense undulose extinction may be as much as 3·0 mm. across but most are recrystallized to a fine granular mosaic. Large subhedral crystals of microcline include the other constituents. It often contains coarse lamellae of albite and fractures, and replacement veinlets are filled with quartz and greenish brown biotite. Other veinlets are of quartz and epidote. The accessories are tourmaline, apatite and zircon. This rock is a granite in composition but there is probably more biotite present than in other granites of the Orford Cliff Suite.

The foliated granites contain screens of mesocratic foliated tonalite (e.g. W.306.2). The mafic constituents are arranged in folii which, with lenses of recrystallized quartz, give rise to flaser texture around relicts of quartz and feldspar. Biotite forms flakes not greater than 1·0 mm. in length. It is frayed marginally and this effect is associated with replacement by the greenish brown variety together with epidote, rutile and leucoxene. In this state the biotite typically forms small shreds in a quartz mosaic. Hornblende ($\alpha =$ pale brown, $\beta =$ bright green, $\gamma =$ green or bluish green), in small subhedral prisms, is very subsidiary in quantity to the biotite. It has been shattered and quartz has recrystallized between the fragments. The relicts of quartz and andesine ($Ab_{67}An_{33}$) have been intensely deformed.

At station W.307, about 150 ft. (45·7 m.) to the south-east, similar mylonitized granites include screens of the hornfels described on p. 6. Lenticular granoblastic areas of finely crystalline quartz, greenish brown biotite, sericite, chlorite, epidote and calcite are developed, particularly adjacent to relicts of reddish brown biotite. Other relicts include quartz, andesine ($Ab_{68}An_{32}$), microcline and orthite. A specimen from the most intensely foliated zone shown in Fig. 2a (W.307.2; Plate IVb) is finely banded, the bands lensing around relicts up to 1·0 cm. in diameter. In thin section there is a pronounced flaser texture with a very marked streaking out of fine-grained material derived from the original coarse-grained constituents. Pale green and yellowish green chlorite, which forms felted aggregates with cores of brownish biotite, are associated with lenticles of granular epidote and sericite, sphene, leucoxene, apatite and zircon. With the addition of quartz the texture is gradational from lepidoblastic to granoblastic. Thin lenticles of an opaque mineral are margined by greenish brown biotite. In one band acicular porphyroblasts of calcite are orientated in the plane of the foliation and have abundant twin lamellae on ($01\bar{1}2$). The other constituents of this band are albite, quartz, chlorite and pistacite. Relicts of microcline contain lamellae of albite and include patches of quartz and plagioclase. The cracks are filled with quartz. Rounded plates of andesine are heavily replaced by sericite, albite and clinozoisite. The quartz is almost entirely recrystallized to a fine mosaic but in the occasional coarse-grained lenses it shows an undulose extinction. There are a few relict grains of orthite and idioblasts of pyrite.

4. *Microgranites*

The microgranites typically have a saccharoidal texture and are locally pegmatitic. In specimen W.308.6 the main constituents are potash feldspar and quartz; most of the former is untwinned but some shows cross-hatched twinning and is microcline. The quartz shows undulose extinction and the sutural grain boundaries are suggestive of para-tectonic crystallization. Occasional normally zoned subhedral plates of plagioclase ($Ab_{69}An_{31}$–$Ab_{82}An_{18}$) are present and biotite ($\alpha = \beta =$ pale yellow, $\gamma =$ reddish brown) forms small laths which are frayed marginally and replaced by a greenish brown biotite and chlorite. The central parts of the microgranite dykes at station W.359 are either pegmatitic or are a coarse graphic granite.

5. *Inclusions*

The main types of inclusions in the tonalities and granodiorites of Orford Cliff have already been mentioned on p. 10. At Orford Cliff the cognate xenoliths are as frequent as those derived from the Basement Complex but at some other localities (e.g. W.303) the only inclusions are hornblende-biotite-schist.

The cognate xenoliths at Orford Cliff are unfoliated, mottled coarse- to medium-grained diorites, some of which have phenocrysts of plagioclase up to 5·0 mm. in length. In one case where such phenocrysts are absent (W.363.5), plagioclase ($Ab_{53}An_{47}$–$Ab_{57}An_{43}$) showing slight normal zoning forms anhedral crystals of very variable size. There are some more calcic cores of labradorite. Anhedral crystals of hornblende which poikiloblastically enclose the plagioclase show three well-defined colour zones:

i. Colourless hornblende sieved with quartz forms rounded cores in the crystals; it has replaced pyroxene.
ii. Broad margins to (i) and separate plates are of coloured hornblende (α = pale brown, β = brown, γ = greenish brown; γ:c = 23°).
iii. There are thin borders of actinolitic hornblende (α = colourless, β = green, γ = bluish green).

Biotite (α = β = pale yellow, γ = brownish red) forms laths within and marginal to the hornblende. Occasional porphyroblasts are intergrown with iron ore and include both hornblende and plagioclase. There is some quartz showing undulose extinction which has replaced hornblende, biotite, and plagioclase.

The marginal facies of this xenolith (W.363.3), a finer-grained mesocratic rock with a mottled appearance, is slightly foliated. It is intermediate in character between the inclusion and the tonalite forming the country rock. Biotite is by far the most important mafic constituent; hornblende is very subsidiary. The hornblende has γ = pale green and is much sieved by quartz which has also replaced andesine.

The plagioclase phenocrysts in other cognate xenoliths are calcic in composition (in specimen W.363.4 the plagioclase ranges up to $Ab_{54}An_{46}$) and they are almost completely replaced by sericite, clinozoisite and greenish brown biotite. The xenoliths have the composition of diorite. Since there has been replacement of pyroxene by amphibole, and of calcic plagioclase by a more sodic variety, as well as the introduction of free quartz, it is likely that the original rocks were more basic and were gabbros.

These xenoliths are similar to those which are abundant in the tonalities and granodiorites of Andean age. Accidental xenoliths of the Basement Complex have not yet been found in the Andean plutonic rocks of the Loubet Coast. Adie (1955, p. 9) has remarked on the abundance of xenoliths of basic composition in the Andean intermediate plutonic rocks of the south-east coast of Graham Land and the northern Marguerite Bay area. He has described foreign xenoliths of hornblende-schist, which are often the most common of the xenoliths in these intrusive rocks. Hence there is a curious contrast between these two southern areas and the Loubet Coast.

C. Other Early Palaeozoic Intrusive Rocks

Little is known of the geology of the areas adjacent to the southern part of Lallemand Fjord, but it is believed that the northern part of the Boyle Mountains massif is composed mainly of early Palaeozoic intrusive rocks.

At several localities beneath the ice cliffs to the south-east of Hooke Point (W.40, 41 = 476, 44) there are biotite-tonalities with a remarkably fresh appearance, and at some places they contain very numerous randomly orientated inclusions of hornblende-schist. These rocks have been little deformed. In one specimen (W.476.1) the plagioclase ($Ab_{58}An_{42}$–$Ab_{52}An_{48}$) forms subrectangular plates, which are mostly longest perpendicular to the albite law cleavage traces. There is little zoning. Some plagioclase is replaced by albite and sericite. The most important mafic constituent, a biotite with a brownish red colour, forms euhedral laths surrounding iron ore and pseudomorphs of quartz, chlorite and actinolite after hornblende. Marginally the biotite is coloured pale green and small traces of this colour are developed interstitially to the plagioclase. Quartz showing some undulose extinction forms anhedral plates and is interstitial to the andesine. This particular specimen contains more microcline-microperthite than usual and should be classified as a granodiorite. The alkali-feldspar has a very variable distribution over the thin section, in places forming substantial crystals. It includes plagioclase and biotite and curved plates of quartz so that there is a coarse symplectite. The accessories are magnetite, ilmenite, sphene, apatite, zircon, pistacite and orthite.

A single specimen collected from the north-west ridge of Bartholin Peak is a coarse-grained granodiorite (W.254.1). It is intensely sheared but not foliated. Large subrectangular plates of plagioclase ($Ab_{80}An_{20}$–$Ab_{96}An_{4}$) show normal zoning; the crystal rims are fresh but the cores are heavily altered to sericite, clinozoisite and albite. Some quartz is finely intergrown with the plagioclase. Microcline, containing lamellae of albite, forms large subhedral plates which include the other minerals. Their borders against plagioclase are serrated whereas adjacent to quartz they are often euhedral. Large anhedral plates of quartz show an undulose extinction. The major mafic constituents, chlorite and epidote after biotite, are associated with iron ore, sphene and apatite. Bluish green hornblende partly replaced by chlorite and sieved by quartz is very subordinate.

The adamellites exposed at the isolated Bacharach Nunatak (W.352) are most closely comparable with the Orford Cliff Suite. These rocks are extremely coarse-grained with crystals of purplish quartz up to 8·0 mm. in diameter and pink feldspar up to 2·0 cm. length set in a pale greenish white medium-grained matrix. In thin section (W.352.1, 2) euhedral crystals of plagioclase ($Ab_{67}An_{33}$–$Ab_{92}An_{8}$) up to 6·0 mm. in length show normal zoning and are internally replaced by sericite, clinozoisite, chlorite and biotite. It is marginally replaced by orthoclase-microperthite, which chiefly forms the huge crystals noted above. The boundaries between feldspar and quartz are indented and are marked by granular quartz which also penetrates as trails and replacement veinlets into the microperthite. Quartz also forms a coarse mosaic, the individual crystals being cracked and showing a slight undulose extinction. A granular mosaic is sometimes developed along the fractures. Dusty inclusions are responsible for the colour seen in the hand specimen. In a part of one section large laths of biotite ($\alpha = \beta =$ pale yellow, $\gamma =$ dark yellowish brown) are slightly bent and have frayed edges. Most of the biotite is either replaced by aggregates of greenish brown biotite or by chlorite together with epidote and sphene. In some cases the chlorite is partly converted to the greenish brown biotite. Accessories are iron ore, apatite and zircon.

D. Discussion

In addition to certain field evidence, Adie (1953, 1955) has been able to distinguish between the granites of early Palaeozoic and Andean age in Marguerite Bay on petrographic grounds. He found such characters as the colour of the quartz, the nature of the mafic constituents, the potash feldspar and the accessories to be reasonably diagnostic. Other workers (e.g. Curtis, 1960) have not been able to confirm this, since what they describe as variants of the Andean granites show all the characters supposed to define the older granites. The writer believes, however, that in most cases it is possible to distinguish between the younger and the older granites when the complete petrography is taken into account. However, this cannot take the place of the essential field evidence, which is unfortunately absent on the Loubet Coast.

Adie (1953) has described two early Palaeozoic granites from the Marguerite Bay area. They are very much alike and in fact may be contemporaneous. The more widespread "Coarse Pink Granite" is similar to some of the granites of the Orford Cliff area (e.g. those of station W.359) and Bacharach Nunatak (W.352), but it differs in not having undergone cataclastic deformation. Bodman (1916) has described "granitite" (biotite-granite) erratics from the islands off the north-east coast of Graham Land which Adie (1953, p. 17) has considered to be closely allied to the early Palaeozoic granites of Marguerite Bay.

It is clear from the descriptions given already that the Orford Cliff Suite underwent intensive deformation accompanied by re- and neo-crystallization. Three phases of deformation have been recognized in relation to the crystallization history:

i. Primary magmatic flow. The arrangement of the biotite flakes, the presence of schlieren and orientated inclusions all indicate flow at the time of intrusion, so that some of the rocks are protoclastic gneisses. The formation of the varieties of tonalite and granodiorite took place prior to this but most of the granites were later.

ii. Intensive secondary deformation involving structures with a similar orientation to those resulting from primary flow. The evidence of microscopic strain, granulation and the development of flaser texture indicates intensive deformation accompanied by the crystallization of quartz, albite, sericite, epidote, chlorite, actinolite, biotite and, probably, microcline. Rocks subjected to this are cataclasites. They include the granites.

iii. Late secondary deformation. The evidence of microscopic strain in the microgranites and the intense shearing and faulting accompanied by the crystallization of quartz, albite, epidote, prehnite and calcite belong to a late, mainly post-crystalline, phase of deformation. Such effects as the twinning of calcite must have been even later.

In some of the rocks there is considerable evidence of the replacement of plagioclase by potash feldspar, and the common occurrence of microcline porphyroblasts indicates that there has been a transfer of material in the solid medium. Other characters, notably the two varieties of tonalite and granodiorite and the presence of cognate xenoliths, can be attributed to earlier pre-intrusion differentiation. The form of many of the granite plutons suggests formation as a result of metasomatic transfer.

It is debatable whether the deformation is related to intrusion (of other plutons of the same suite) or is orogenic. Adie (1953) has detailed two periods of folding affecting rocks other than the Basement Complex. The first has affected the Trinity Peninsula Series of Upper Palaeozoic age and is pre-Jurassic (Adie, 1957, p. 5). The second is related to the Andean intrusions (Adie, 1955, p. 4), the time of intrusion being at a late stage of the folding. Adie (1953) has given no reasons for the assignment of the older plutonic rocks of the Marguerite Bay area to the early Palaeozoic, but it seems to the writer that these rocks, which are probably contemporaneous with those of the Loubet Coast, could have been intruded at a late stage of the folding and regional metamorphism of the Trinity Peninsula Series.

Hooper (1959, p. 183) has minimized the importance of orogenic folding but he has emphasized the rôle of block-faulting associated with the emplacement of the Andean plutons for the present structure and uplift of the Palmer Archipelago and adjacent parts of Graham Land. The author would concur with this view with respect to the Loubet Coast, but he would attach some importance to the emplacement of the pre-Upper Jurassic plutons in the building of the peninsula itself.

VI. THE UPPER JURASSIC VOLCANIC GROUP

A. Stratigraphy

The Upper Jurassic Volcanic Group comprises a thick succession of lavas and pyroclastic rocks which, although mainly of andesitic character, range in composition from rhyolite to basalt. They are exposed over very extensive areas and much of the mountainous terrain consists of them (Figs. 3 and 6). The volcanic rocks are either horizontally disposed or only slightly inclined. It has not been possible to establish a succession because the outcrops examined are separated from each other, and no definite estimate of the total thickness can be given. There is a minimum thickness of 5,000–6,000 ft. ($\sim$ 1,500–1,800 m.), that is, the heights of the mountain walls which are formed by the volcanic rocks.

The base of the succession has not been observed. However, the volcanic rocks of north Lallemand Fjord are probably close to the base, since early Palaeozoic rocks crop out in that area. Here, the volcanic rocks are mostly andesitic pyroclastics with subsidiary lavas and more siliceous rock types. There is seldom much indication of bedding.

In contrast, the upper part of the succession is characterized by lavas forming flows of uniform thickness which give a distinctive banded character to the cliffs of high altitude (e.g. Dorsey Mountains, Protector Heights). At Mount Lagally an Andean granite pluton intrudes these banded volcanics, clearly showing them to be pre-Andean in age. Unfortunately very few of these rocks have been examined since nearly all exposures are inaccessible.

B. Petrography

The pyroclastics form the bulk of the Upper Jurassic volcanic rocks that have been examined and these have come mainly from exposures near to sea-level. Lavas are subordinate but they have a widespread occurrence. At some localities lavas and pyroclastics are interbedded. At Detaille Island the lavas form large masses in coarse agglomerates and are clearly not in the original position of extrusion.

Specimens from the lavas can often be matched with fragments from the pyroclastics, but the pyroclastic rocks contain a greater variety of types. The majority of the ejecta are accessory and the rarer accidental ejecta have already been described (p. 8). The volcanic rocks are very altered as a result of hydrothermal and contact metamorphism. In general, the pyroclastics are more affected than the lavas. The volcanic rocks are often sheared, especially on closely spaced sub-vertical joint sets. Minor concentrations of pyrite have developed at a late stage of the hydrothermal activity; these are rarely cupriferous and give rise to malachite staining.

1. *Lavas*

a. *Basalts.* Small lava outcrops at Detaille Island are of basalt. Probably, like the dacites, these basalts are blocks within the agglomerates. One example (W.556.1) is dark grey in colour and has occasional plagioclase ($Ab_{30}An_{70}$–$Ab_{34}An_{66}$) and augite phenocrysts. The former are up to 3·0 mm. in length and show slight oscillatory zoning. They include granular augite and there are either shells or cores rich in minute orientated inclusions of chlorite and iron ore. These phenocrysts are altered along cracks to chlorite and in patches to calcite and albite. The other phenocrysts of titanaugite include granular and finely divided iron ore. Some of the augite is replaced by chlorite and calcite. Occasional microphenocrysts of iron ore are fringed by leucoxene. The groundmass consists of laths of labradorite ($Ab_{45}An_{55}$), subhedral granular augite and granular iron ore. There is a fine mesostasis of chlorite and, in part of the thin section, much of the augite has been replaced by chlorite and calcite. Chlorite, calcite and quartz patchily replace the entire groundmass and there are veinlets of calcite.

Other basalts crop out at Roux Island and at the Bennett Islands where they are difficult to distinguish from basaltic crystal tuffs. In specimen W.344.2 abundant phenocrysts of normally zoned plagioclase ($Ab_{44}An_{56}$–$Ab_{63}An_{37}$) are altered to sericite, clinozoisite, albite and actinolite. Frequent phenocrysts of titanaugite are replaced by yellowish green actinolitic hornblende grading marginally to a bluish green actinolite. Flakes of greenish brown biotite have been formed marginally. Other augite phenocrysts are altered either to aggregates of actinolite, chlorite and leucoxene or to actinolite and biotite. Indented microphenocrysts of iron ore are fringed by granular sphene or by decussate aggregates of biotite. The iron ore is included within the augite, as also are apatite and sphene. The groundmass consists mostly of aggregates of finely acicular actinolite with epidote, iron ore, leucoxene and greenish brown biotite. There is a background of recrystallized albite. An original flow texture is marked by trails of iron ore and leucoxene.

b. *Andesites.* Andesite lavas have been recorded at several localities in the north Lallemand Fjord area and in north-eastern Darbel Bay. Whereas some of these rocks with phenocrysts of labradorite and augite are related to the basalts, others with much free quartz and more sodic plagioclase are gradational into the dacites.

Practically unaltered porphyritic augite-andesites (W.447.1) crop out at the largest of the McConnel Islands. Abundant prismatic phenocrysts of plagioclase up to 5·0 mm. in length are contained in a fine-grained dark grey groundmass. These phenocrysts, which often form groups, show normal and oscillatory zoning and have a composition $Ab_{42}An_{58}$–$Ab_{52}An_{48}$. Many are twinned on both the Carlsbad and albite laws. There is slight alteration to sericite and chlorite. Scattered microphenocrysts of titanaugite include granular iron ore and are rimmed by chlorite. There are a few indented crystals of pyrite. The groundmass is composed of laths of plagioclase ($Ab_{50}An_{50}$–$Ab_{52}An_{48}$) in a fine matrix of yellowish green chlorite. There are abundant euhedral magnetite crystals and a little anhedral granular augite. Apatite is accessory and there are patches of equigranular quartz. These lavas contain rounded xenoliths (up to 15 cm. in diameter) of very fine-grained dark hornfels (W.523.1), which mostly consists of extremely fine-grained quartz and plagioclase with minute shreds of sericite.

Other augite-andesites are more altered in character. The major part of the north-easternmost of the Darbel Islands (station W.521) is formed of a greyish green porphyritic andesite. Abundant stumpy phenocrysts of andesine are almost entirely replaced by epidote, albite and sericite. Phenocrysts of augite are replaced by green and bluish green chlorite and by epidote. Microphenocrysts of ilmenite are rimmed and internally dissected by leucoxene. The groundmass is formed of laths of albite together with iron ore, leucoxene, chlorite and epidote. There are a few patches of quartz and apatite is accessory.

More severely altered andesites with former microphenocrysts of augite have been recorded at station W.316, at Mist Rocks and at the Fowler Islands.

Other andesites contain more quartz and lack original phenocrysts of augite. The quartz is always secondary and it is difficult to ascertain whether or not it was an original constituent of the lavas. It was undoubtedly original in the dacites of Detaille Island, since the matrix of the agglomerates which contains the dacite fragments often lacks free quartz, being andesitic in composition. Greyish green fine-grained lavas (W.431.1) which crop out at the most westerly of the Fowler Islands (Fig. 7c) are vitric andesites which have been secondarily silicified. Occasional microphenocrysts of plagioclase are replaced by quartz, chlorite and epidote. The groundmass is extremely fine-grained, consisting of andesine microlites, exhibiting flow texture, and granular leucoxene after ilmenite with chlorite after a former glassy matrix. There are patches of quartz and chlorite. Porphyroblasts of epidote are common and there is conspicuous euhedral pyrite. Ovoid vesicles are filled with quartz and chlorite and veinlets carry quartz, epidote, chlorite and pyrite.

c. *Dacites.* At Detaille Island flow-banded porphyritic dacites form large masses which are not in an original position of extrusion but which have collapsed into a vent. Thus the dips determined from the flow-banding are often steep, whereas lava/agglomerate contacts vary in attitude but are mostly near to the horizontal (Fig. 4). In places the lavas have been autobrecciated. It is difficult to distinguish between such rocks and lavas which have been brecciated as a result of the vulcanicity.

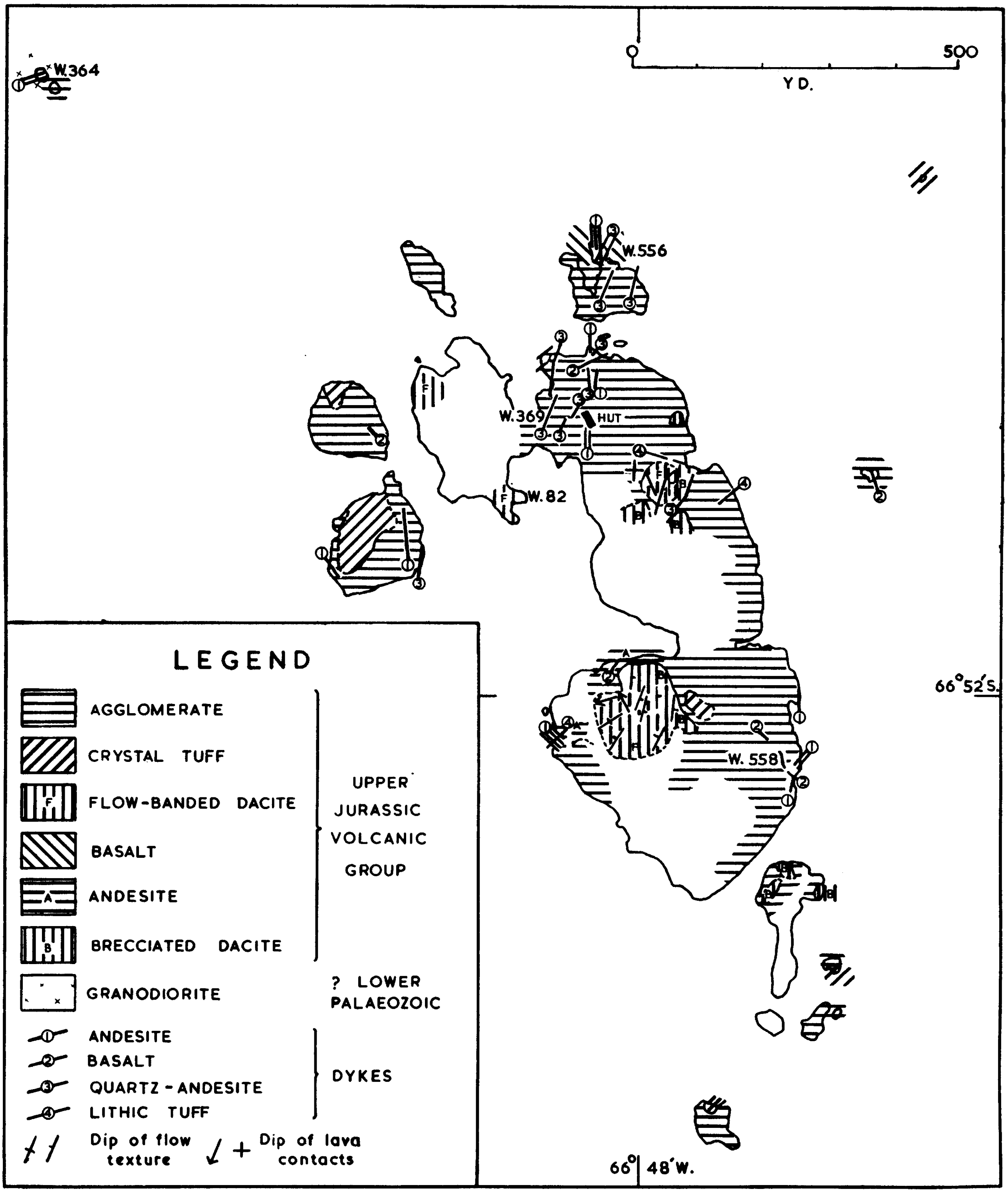


FIGURE 4
Geological map of Detaille Island. (Drawn from map prepared by B. L. H. Foote.)

The dacites are purplish or greenish fine-grained rocks with numerous phenocrysts of plagioclase. The flow-banding is defined by coarse colour banding (1 or 2 per cm.) or by thin lenticles rich either in quartz or the mafic constituents. In a typical example (W.82.1; Plate IVc) plagioclase phenocrysts up to 2·0 mm. in length are entirely replaced by epidote and albite. There are small euhedral magnetites margined by epidote, and patches of chlorite and epidote represent former mafic microphenocrysts. The groundmass consists of small laths of oligoclase ($Ab_{85}An_{15}$) with granular epidote, iron ore and chlorite set in larger crystals of quartz which have ill-defined sutural margins. The plagioclase exhibits good flow texture and banding is also shown by trails of iron ore and epidote. There are irregularly shaped patches of quartz mosaic relatively free of the other constituents. Quartz also occurs in small veinlets. Apatite is accessory and there is a little interstitial orthoclase.

Very similar lavas crop out on the small islets at the south-western point of Salmon Cove (W.34 = 475). The other dacites of Detaille Island lack flow textures as seen in the hand specimen.

d. *Rhyodacites and rhyolites.* Dark purplish flow-banded rhyodacites are exposed on the south-westerly of the Kidd Islands (W.453, 454). These lavas are strongly banded and contorted, and have a good flow texture. They consist of fine laths of albite set in larger crystals of orthoclase which have sutural outlines. There are elongate lenticles and irregularly shaped patches of quartz mosaic. Small, indented subhedral magnetites and tiny laths of ilmenite are abundant and are associated with a little epidote and chlorite.

At the western end of the buttress north of the Murphy Glacier (W.316) a bed of rhyolite about 1 ft. (0·3 m.) in thickness is interbedded with altered andesite lavas. This band is reddish brown in colour and shows coarse flow-banding. It is strongly spherulitic, the spherulites being in two sizes of 0·5 and 2·0 mm. in diameter. Occasional euhedral phenocrysts of quartz up to 2·0 mm. in diameter are embayed and include patches of the groundmass. The quartz contains finely disseminated inclusions of iron ore arranged in trails and shows slight undulose extinction. Some of the phenocrysts are fringed by quartz in optical continuity with them and they are dusty with finely divided iron ore. These overgrowths include laths of orthoclase and have formed at the expense of the groundmass. There are occasional phenocrysts of albite showing ragged and "chequer-board" twinning on the albite law. They are fringed by very finely granular epidote and iron ore, and orthoclase laths are arranged perpendicular to their margins. In the groundmass small aggregates of granular epidote and iron ore are surrounded by fine-grained quartz and sodic plagioclase. These groups form the nuclei of spherulites composed of fibrous orthoclase and quartz arranged perpendicular to the cores. Very finely intergrown quartz and orthoclase occurs interstitially to the spherulites.

2. *Pyroclastic rocks*

a. *North Lallemand Fjord.* At Detaille Island a former volcanic vent has been mapped (Fig. 4). It is filled with unbedded agglomerates which contain masses up to 9,500 sq. yd. ($\sim$ 7,950 m.^{2}) in area of flow-banded dacites and other lavas (basalts, porphyritic andesites and porphyritic dacites) which collapsed into the vent from an upper part of the volcano. The agglomerates contain an assortment of fragments of volcanic origin which vary in size up to the large masses. The majority of these are either andesites or dacites. Common varieties are porphyritic andesites, non-porphyritic andesites, vesicular andesites, devitrified andesites, flow-banded porphyritic dacites and porphyritic dacites. Other fragments are of basalt, rhyolite, previously consolidated agglomerates and crystal lithic tuffs of andesitic, dacitic and rhyolitic character and, at the vent margin only, early Palaeozoic granodiorite.

There are pockets of homogeneous fine-grained and crystal lithic tuffs and some of these have been squeezed into the agglomerates as veins or may even form dykes of uniform width. Some patches of the agglomerates have been heavily oxidized and consequently show enrichment in iron ore, especially hematite. Rounded, irregularly shaped nodules of hematite are common. Hematite replacement is partly restricted to a network of narrow veins. The whole rock is frequently affected, fragments as well as matrix being replaced.

The masses of flow-banded dacites are interbedded with the agglomerates but, in general, overlie them. At their margins these masses are brecciated, especially near the lower contacts where they grade into agglomerates whose larger blocks are of dacite but whose matrix and smaller fragments are andesitic in character.

In detail, the petrography of the fragments is similar to the lavas already described. Plagioclase phenocrysts are almost completely replaced by albite and clinozoisite, and augite phenocrysts are replaced by chlorite and epidote. The plagioclase of the groundmass has often been completely replaced by albite. Secondary quartz is often important. Fragments consisting mainly of albite and quartz are considered to have undergone extensive secondary replacement; originally they were andesitic rather than alkaline in composition. In some of the vitric andesites hematite-impregnated glass is still present but in other cases the glass has been replaced by chlorite and quartz.

All accessible exposures on Andresen Island up to a height of 295 ft. (90 m.) are lapilli tuffs interbedded with some crystal lithic tuffs. Fine-grained dark grey, greenish or purplish angular fragments are contained in a greyish green crystal lithic tuff matrix. There are occasional fragments larger than 3·2 cm., and rare dykes of lithic tuff inject the country rocks. In a typical lapilli tuff (W.484.1) most of the fragments are albitized andesite and dacite. Other fragments are rhyolite and these are abundant in a specimen (W.484.2) collected from rounded areas of about 3·3 ft. (1·0 m.) diameter which were only found at a single locality. Within and close to these patches the matrix has been replaced by quartz and epidote,

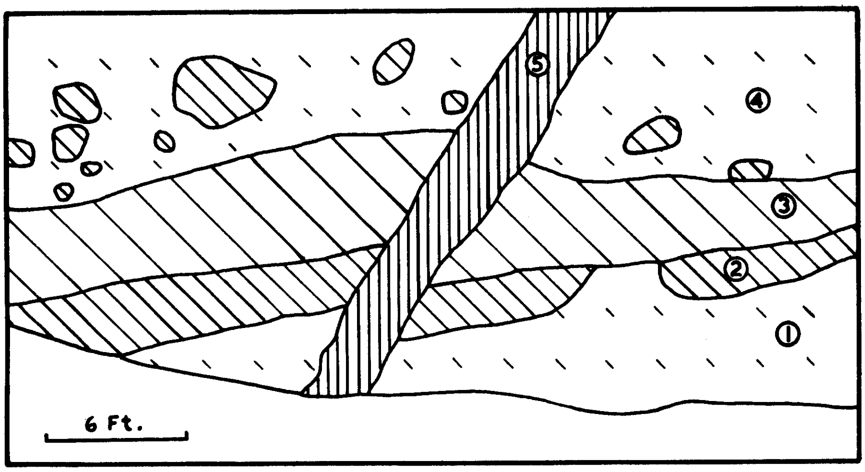


FIGURE 5

Bedded volcanic rocks at station W.377 (= W.481) near Holdfast Point (view from the south). 1. Altered andesite lava; 2. Siliceous tuff; 3. Finely banded siliceous tuff; 4. Altered andesite lava with irregularly distributed xenoliths of siliceous crystal tuff; 5. Dyke of altered andesite.

and albite xenocrysts by orthoclase. Quartz-orthoclase spherulites have formed adjacent to the rhyolite fragments. This form of replacement has resulted from hydrothermal alteration, the material being locally derived, since these patches were originally rich in alkaline rock fragments.

Many exposures were examined in the vicinity of Holdfast Point (W.345, 376, 377 = 481, 378–82). These rocks are principally pyroclastic with some interbedded andesite and dacite lavas. Most of the pyroclastics are lapilli tuffs. Most fragments are of andesite and dacite but locally (e.g. W.481) the siliceous tuffs contain a proportion of rhyolite fragments. The bedding is often quite well marked (Fig. 5). The petrography of the siliceous tuffs at station W.481 is of special interest. The lower tuff band (W.481.4) is a pale greyish green siliceous crystal lithic tuff containing numerous xenocrysts of quartz, some of which are euhedral whilst others are irregular in shape and well embayed. They have indistinct margins and contain pods and inclusions of the matrix. Some show undulose extinction or exhibit a faint lamellar texture. The plagioclase xenocrysts are represented by subrectangular aggregates of epidote associated in some cases with albite. The matrix consists of an even fine-grained aggregate of quartz, sodic plagioclase and epidote. There are patches of coarser quartz, and epidote with quartz. Larger irregularly shaped areas are composed of coarse-grained epidote, chlorite, sphene and albite.

The upper tuff band (W.481.3) is a dark grey fine-grained siliceous crystal tuff with occasional fragments of altered andesite. Angular but embayed xenocrysts of quartz have indistinct margins against the matrix and some show an undulose extinction. The xenocrysts of plagioclase are replaced by albite and epidote. The very fine-grained matrix has a good vitroclastic texture and is mostly quartz and plagioclase, but shreds of yellowish brown biotite and sericite are also abundant.

These tuff bands are overlain by a dark grey, altered porphyritic andesite lava containing xenolithic blocks of green or purplish banded siliceous tuff (W.481.1). The xenoliths contain abundant xenocrysts of quartz which show similar features to those described from the tuff bands. Xenocrysts of plagioclase are less frequent but some show patchy "chequer-board" twinning on the albite law and are replaced by clinozoisite, quartz and chlorite. Others contain abundant flakes of sericite. The matrix is mostly a fine-grained aggregate of quartz and sodic plagioclase together with some equigranular epidote and leucoxene. There are patches of more coarsely crystalline quartz and epidote, much of the former having a dusty appearance. Veinlets are filled by quartz and albite.

On the west side of Lallemand Fjord agglomerates and lapilli tuffs crop out in the vicinity of Organ Peak and at Cape Shmidt, where they grade into crystal lithic tuffs. Porphyritic andesite lavas are interbedded.

The agglomerates at Neb Bluff have been contact metamorphosed to high grade hornfelses by Andean plutons (p. 23). Andesite crystal tuffs, consisting chiefly of actinolite, chlorite and quartz, crop out at station W.33 (= W.474) in Salmon Cove. The granular leucoxene is partly arranged after the original vitroclastic texture. These tuffs are cut by quartzose veins up to 5·0 cm. in width and horizontally disposed. These veins consist of large quartz plates, showing undulose extinction, with granular quartz, epidote and acicular actinolite.

At station W.50 (= W.463), on the mainland west of Hoodwink Island, there are outcrops of purplish, reddish and yellowish grey rhyolite tuffs, often having a scoriaceous appearance. The grey variety (W.50.2) has occasional xenocrysts of quartz, some of which show an undulose extinction, and plagioclase, which have been replaced by albite, sericite, iron ore and calcite. The lithic fragments consist either of plagioclase microlites with chlorite and iron ore or are of even, very fine-grained quartz and plagioclase. The matrix, showing a good vitroclastic texture, consists principally of exceedingly fine-grained quartz and orthoclase. Small shreds of sericite are abundant and there are patches of quartz mosaic. In places the matrix has been replaced by calcite. In a specimen of the reddish variety (W.50.1) there is considerable patchy hematite staining and veinlets are filled with the iron ore. The shards themselves are of fibrous orthoclase, whereas the areas between them consist of quartz and chlorite. Pyritic hornfelses crop out about 1 mile (1·6 km.) to the south at station W.462.

At Cape Rey and Madell Point there are also exposures of lapilli and crystal lithic tuffs, all of which are andesitic in composition. Inland from Lallemand Fjord lapilli, crystal lithic and banded tuffs have been examined at Lampitt Nunatak. There are both andesitic and dacitic tuffs and they have been secondarily silicified. Pale-coloured reddish and greenish banded tuffs (W.317.2) are noteworthy. They contain small xenocrysts of quartz and the banding is related to the proportion of epidote present.

b. *Darbel Bay.* Numerous exposures of the pyroclastic rocks have been examined in Darbel Bay and the adjacent areas. They show a general similarity to those already described from Lallemand Fjord and most of them are lapilli and crystal lithic tuffs of andesitic composition. A small proportion of the fragments are of rhyolite, rhyodacite and dacite, and some of the tuffs are siliceous. The localities investigated are the Darbel Islands, Phantom Point, Workman Rocks, the McConnel Islands, the Kidd Islands, the Owston Islands and the rocky point south of the snout of the Erskine Glacier (W.350). To the west, in Crystal Sound, similar rocks crop out at the Fowler Islands, the Nakaya Islands and the small island (W.429) midway between the Bragg and Fowler Islands.

One of the siliceous tuffs (W.348.1) contains lithic fragments of andesite and rhyolite, and xenocrysts of quartz and plagioclase. The finely crystalline matrix is mainly quartz and plagioclase together with some epidote, chlorite, calcite and orthoclase. Shards replaced by chlorite are common. The siliceous tuffs are interbedded with lapilli tuffs of andesitic composition and at the north point of the largest of the Darbel Islands (W.348) approximately 30 ft. (9 m.) of bedded rocks are overlain by massive andesitic tuffs. Siliceous welded tuffs (e.g. W.347.1) also form the bulk of a small islet off the north point of the largest of the Darbel Islands. They carry fragments of andesite, dacite and rhyodacite and xenocrysts of andesine replaced by albite, quartz, sericite, epidote, chlorite and orthoclase. The matrix has a good vitroclastic flow texture in which the shards are composed of chlorite with some quartz and orthoclase, whilst the intervening areas are of quartz mosaic. There are aggregates of epidote and iron ore and occasional spherulites of quartz and orthoclase.

The siliceous crystal tuffs exposed at station W.350 are gradational in character to those of Auvert Bay described below.

In the more andesitic tuffs, quartz is confined to small patches of mosaic, and there is no orthoclase except close to the uncommon rhyolite and rhyodacite fragments. The main constituents are andesine, albite, chlorite, epidote, iron ore and leucoxene. Biotite and actinolite are also very commonly present. Some of the lapilli tuffs of the Fowler Islands (e.g. W.431.4) are basaltic in composition.

c. *Auvert Bay.* At station W.500, 1·6 miles (2·5 km.) south of Cape Bellue agglomerates are exposed and at W.503, a small islet 1·6 miles (2·5 km.) north-east of the cape, dark-coloured crystal tuffs crop out. At both localities the volcanic rocks are andesitic in character.

Cliffs situated 3–4 miles (4·8–6·4 km.) north-east of Cape Bellue are of siliceous crystal tuffs, having a thickness of about 1,000 ft. ($\sim$ 300 m.). These tuffs are intruded by a swarm of uniformly orientated dykes which give rise to marked banding dipping at 25° to 166° true (Plate IIb). The tuffs are pale and dark greyish green in colour and contain abundant xenocrysts of clear pinkish quartz up to 4·0 mm. in diameter and white plagioclase up to 3·0 mm. in diameter. Occasional fragments up to 15 cm. in diameter are angular in shape and have sharp margins against the tuffs. Most of them are porphyritic andesites but some fragments are of foliated tonalite. In two examples of the tuffs (W.525.1, 4; Plate IVd) the quartz of the xenocrysts is clear and unstrained but it contains dusty inclusions often arranged in trails. Individual crystals are either euhedral or anhedral. Deep embayments and inclusions of the matrix within the xenocrysts are common. Some crystals are fragmented along curved planes, and their boundaries against the matrix are often indistinct. In some cases the inclusion trails mark incipient penetration of the quartz by the matrix. Xenocrysts of plagioclase are less frequent than those of quartz; they are rounded or subhedral in shape and some show either multiple twinning or "chequer-board" twinning on the albite law. They are of albite, patchily replaced by orthoclase, with associated epidote, chlorite, quartz, iron ore and rare sericite.

The matrix is finely crystalline and consists principally of quartz and feldspar with some sericite. Irregularly shaped areas are of decussate aggregates of greenish brown biotite or brown biotite and iron ore. Marginally the biotite is green and is associated with chlorite, actinolite and epidote. The mafic minerals also occur in veinlets and within fractured quartz xenocrysts. There are patches of quartz mosaic with interlocking grain boundaries. Microspherulites up to 1·0 mm. in diameter are common especially adjacent to the quartz xenocrysts. They consist of radiating sheaves of orthoclase and have much green biotite at their outer margins. In one specimen (W.525.4) two stages of spherulite formation have been recognized: the earlier ones are clear and have quartz cores, whereas the later ones have angular margins and are brownish in colour.

d. *The southern Biscoe Islands.* Most of the localities visited in the southern Biscoe Islands (Fig. 7d) are composed of andesitic pyroclastic rocks, which are agglomerates, lapilli tuffs, crystal lithic tuffs and fine-grained homogeneous tuffs. They have been highly altered or contact metamorphosed with the crystallization of albite, epidote, green and brown biotite, actinolite, iron ore, leucoxene, pyrite, chlorite and, in some cases, the incipient formation of cordierite. Localities are the eastern Barcroft Islands, Watkins Island and adjacent islets near Kuno Point, Scholander Island, Winslow Rock and nearby outcrops on Lavoisier Island.

e. *Hanusse Bay.* The northernmost of the Bennett Islands are composed of uniform dark grey crystal lithic tuffs with occasional larger lithic fragments. They are mostly either basaltic or andesitic in character. Xenocrysts of plagioclase may be extremely abundant.

In a typical example (W.61.1) numerous xenocrysts of labradorite ($Ab_{40}An_{60}$–$Ab_{46}An_{54}$), often forming groups, show oscillatory zoning. They have thin rims of andesine ($Ab_{56}An_{44}$) and the crystals grade in size to microxenocrysts and small laths which are also andesine in composition.

Large subhedral crystals of iron ore have indented margins and are bordered by brown biotite. Mafic xenocrysts, represented by aggregates of skeletal ilmenite, brown biotite and hornblende (α = pale brown, $\beta = \gamma$ = brownish green), often occur in groups with the plagioclase xenocrysts. The matrix consists of finely acicular actinolite, minute flakes of biotite, subhedral granular iron ore and laths of andesine. There is a mesostasis of albite. A second example (W.327.1) carries lithic fragments of andesite, microporphyritic andesite and flow-textured andesite. The andesine xenocrysts are extremely altered to clinozoisite. The matrix is composed of yellowish brown biotite, bluish green actinolite, iron ore and plagioclase. There are some patches of mosaic quartz, and quartz has also partly replaced the plagioclase. Both euhedral magnetite and laths of ilmenite are present.

C. Thermal Metamorphism and Hydrothermal Alteration

Most of the Upper Jurassic volcanic rocks of the Loubet Coast have undergone hydrothermal alteration amounting to low grade thermal metamorphism. Three distinct mineral associations have been recognized:

1. A variable proportion of the original constituents are present with the following alteration products: albite, quartz, epidote (usually clinozoisite), chlorite, calcite, sericite and iron ore, which replace plagioclase; chlorite, epidote and calcite replace augite; epidote, leucoxene and sphene replace iron ore. These minerals are typical of low grade thermal reactions which are either deuteric in origin or related to later intrusions. In view of the widespread occurrence of the alteration phenomena and the definite thermal metamorphic character of the other mineral associations, the second mode of genesis is preferred. However, it is likely that some of the minerals (such as quartz, chlorite and iron ore) were formed as a result of deuteric reactions related to the vulcanicity.

2. Original constituents are subordinate to the alteration products which include all the minerals of the first association with the addition of orthoclase, which replaces albite, green or greenish brown biotite and actinolite. The mode of formation of biotite and amphibole is well seen in the amygdales. For example, in specimen W.412.1, an andesite lapilli tuff from Scholander Island, there are regularly arranged minerals filling cavities as follows:
    - i. Quartz, which forms bulbous growths against the margins of the cavities.
    - ii. Pale green chlorite, which encloses euhedral pistacite and actinolite.
    - iii. Fine-grained aggregates of green biotite.
    - iv. Bulbous areas of albite.
    - v. Quartz infilling the centres of the amygdales.

3. Some of the original constituents are still present together with the majority of the minerals of the second association. In addition, brown or reddish brown biotite, hornblende and cordierite may be formed.

In the Barcroft Islands rocks immediately adjacent to porphyritic microdiorite sills have been thermally metamorphosed to dark grey or purplish pyritic hornfelses. Some of these rocks are finely banded (5 bands per cm.) and may have been bedded homogeneous tuffs. There is, however, the possibility that they are of sedimentary origin. In one example, W.405.1, small angular xenocrysts of quartz are abundant and xenocrysts of plagioclase (altered to albite), sericite and iron ore, are rare. Small lithic fragments are of acid and andesitic lavas. The matrix consists of sericite, chlorite, pale brown biotite and iron ore. Pyrite is abundant and there are occasional porphyroblasts of epidote. A second specimen, W.407.1, is a uniformly fine-grained rock consisting mostly of sericite and red biotite with aggregates of subhedral and granular iron ore associated with the biotite. Poikiloblastic crystals of cordierite are full of biotite and sericite. Quartz forms small patches of mosaic.

Upper Jurassic volcanic rocks which have been thermally metamorphosed to a higher grade have only rarely been recorded. At Neb Bluff (W.304) rocks such as these occur adjacent to an Andean granodiorite intrusion. In the field angular fragments of the agglomerates and a network of intersecting dykes are easily discernible but under the microscope all these rocks are found to be fine- to medium-grained hornfelses. The agglomerate fragments (W.304.2) consist principally of zoned laths of andesine, granular augite and magnetite. There are some small flakes of yellowish brown biotite. Porphyroblasts of plagioclase have a similar appearance and composition to the phenocrysts of the granodiorite (p. 42). They are associated with larger crystals of magnetite, biotite, augite and hornblende. The intervening areas consist of andesine, augite, biotite and magnetite accompanied by pale green hornblende, quartz and orthoclase. The anhedral quartz crystals include the other constituents and granular quartz sieves biotite and augite. Anhedral plates of orthoclase poikiloblastically include the other minerals. A dyke rock (W.304.7), which is similar to the fragments described above, consists principally of plagioclase ($Ab_{60}An_{40}$–$Ab_{80}An_{20}$), augite, hornblende, biotite, magnetite, quartz and sphene.

D. Discussion

A general correlation between the volcanic rocks of the Graham, Loubet, Fallières, Oscar II and Foyn Coasts can be made. Adie (1953, p. 19) has been able to distinguish between the early Palaeozoic and Upper

Jurassic volcanic rocks of the Marguerite Bay area by means of their degree of alteration or metamorphism. Since most of the Upper Jurassic volcanic rocks of the Loubet Coast have been severely altered, this principle is not readily applicable. There is, therefore, the possibility that some of these volcanic rocks belong to the early Palaeozoic, although there is no doubt that most of them are of Upper Jurassic age. The order of extrusion is not known with any certainty, although the variety of rock types ranges from basic to acid. It is possible that there was more than one cycle of activity, as suggested by Adie (1953).

Adie (1953) has described the Upper Jurassic Volcanic Group of the Marguerite Bay area as a series of lavas, tuffs and agglomerates ranging in composition from porphyritic augite-andesites to rhyolites. The acid volcanics are confined to the southern part of Marguerite Bay. Adie (1953, p. 156, 170) has also shown, at the critical locality of Mushroom Island, that the more acid volcanic rocks were extruded later than the andesites. On the Oscar II and Foyn Coasts between lat. 66°S. and 67°S. he has recorded a succession of "quartz-plagioclase-porphyries" and associated agglomerates having a thickness of at least 7,800 ft. (2,377 m.). They are apparently younger than the rhyolites and interbedded tuffs of the Cape Disappointment area farther to the north on the Oscar II Coast.

The Upper Jurassic Volcanic Group of the Graham Coast (north of Cape Evensen) has been studied by Curtis (1960, p. 30–69). They comprise a succession of lavas and pyroclastic rocks, predominantly tuffs, most of which are andesites in composition but there are some basalts and dacites.

Tyrrell (1945, p. 74) has described the petrography of a collection of pebbles dredged from off the west coast of Adelaide Island. They include acid lavas, quartz-feldspar-porphyries and associated tuffs, and explosion breccias. These volcanic rocks range from the almost undeformed to some which have undergone intensive cataclastic deformation.

Hooper (1959, p. 181) has compared the porphyries from the Adelaide Island dredgings and the Oscar II and Foyn Coasts with the acid volcanic rocks of Anvers Island, which he believes have been partly metasomatized to granites. Volcanic rocks such as these have not been recorded either from the Graham Coast (north of Cape Evensen) or from the Marguerite Bay area. Their equivalents on the Loubet Coast and that part of the Graham Coast bordering Auvert Bay are the siliceous acid tuffs (cf. the acid tuffs described by Adie (1953) from Cape Disappointment) which are interbedded with the andesitic volcanic rocks. It is likely, from the evidence presented, that acid porphyries and andesites were extruded approximately contemporaneously from different centres. This hypothesis was suggested by Adie (1953, p. 29, 156) as an alternative to his more favoured argument that the porphyries are somewhat older than the andesitic volcanics of the Marguerite Bay area. Although the evidence presented here indicates great mobility of the salic and other constituents, as a whole the siliceous tuffs of the Loubet Coast have been little metasomatized.

VII. UPPER JURASSIC HYPABYSSAL ROCKS

NUMEROUS dykes cut the Upper Jurassic volcanic rocks. At some places, notably Neb Bluff, the dykes terminate against Andean pluton contacts or have been contact metamorphosed. The dykes often have variable thicknesses and irregular orientations and they are altered in the same manner as the volcanic rocks. It is likely that their intrusion was prior to the consolidation of the volcanic rocks and that this dyke phase formed an integral part of the vulcanicity.

The dykes of Detaille Island have been subdivided into three groups:

1. Andesites.
2. Porphyritic quartz-andesites.
3. Basalts.

In many cases their grain-size is such that the rocks fall into the medium-grained range (microdiorites and dolerites).

The andesites are dark greyish green in colour and sometimes have numerous plagioclase and mafic phenocrysts particularly towards the centres of the dykes. Some are highly vesicular. The dykes tend to be narrow and are irregular both in width and orientation. In one example (W.556.3) there are occasional small phenocrysts of plagioclase ($Ab_{37}An_{63}$) and pale brownish augite which tend to form glomero-porphyritic aggregates. Many of the augite phenocrysts are euhedral, but some have indented outlines to granular augite of the groundmass. There are a few microphenocrysts of ilmenite. The groundmass is composed of plagioclase laths ($Ab_{51}An_{49}$–$Ab_{60}An_{40}$), granular augite and iron ore. Chlorite replaces the plagioclase, especially the phenocrysts, and the augite. It also occurs in veinlets and in interstitial patches of the groundmass. The iron ore is bordered by sphene and there are some patches of secondary quartz. Other alteration products are calcite and sericite.

The porphyritic quartz-andesites are greyish in colour. Plagioclase phenocrysts up to about 1·0 cm. in diameter are abundant except at the thin darkish fine-grained margins of the dykes. These rocks form the most numerous and conspicuous dykes of Detaille Island. Some have a considerable width and are uniform in orientation. At one locality (W.556) an andesite dyke is cut by a quartz-andesite dyke. In one example (W.556.2) abundant phenocrysts of andesine ($Ab_{60}An_{40}$) have euhedral or subhedral outlines and show simple rather than multiple twinning. They are unzoned and are heavily altered to sericite, chlorite, calcite, epidote, albite and quartz. Occasional microphenocrysts of augite are replaced by epidote and chlorite, and iron ore is bordered by sphene and epidote. In the groundmass small laths of andesine ($Ab_{70}An_{30}$) are set in larger interlocking crystals of quartz. Small patches of quartz are free of plagioclase and parts of the groundmass have been replaced by chlorite, calcite and epidote. Epidote and calcite also form veinlets. There is a little orthoclase marginal to the plagioclase phenocrysts. Apatite is accessory. With a high proportion of free silica this rock is a dacite rather than quartz-andesite. In a second specimen (W.369.1) the groundmass is essentially similar, differing only in the presence of finely granular iron ore and acicular prisms of actinolite developed in calcite. The plagioclase phenocrysts are more calcic, having a composition range of $Ab_{29}An_{71}$–$Ab_{34}An_{66}$.

Both these groups of dykes are cut by all the joint sets, whereas the third group (basalts) have been intruded along pre-existing joint sets and have additional joint sets within themselves. Therefore, the first two groups are thought to be pre-Andean in age, whereas the basalts are post-Andean. Numerous dykes cut the early Palaeozoic granodiorite at station W.364. For example, specimen W.364.2 is an altered andesite.

At other localities in the volcanic rocks the distinction between post-Andean and pre-Andean dykes is difficult. It depends on a thorough study of the petrography of the hypabyssal rocks, which has not been attempted here. Most of the dykes that have been examined are either andesites or microdiorites and they are often severely altered. A dyke (W.431.2) cutting silicified basalt lavas on the islet west of the Fowler Islands is itself a silicified pyritic basalt.

North of Cape Bellue, at station W.525, siliceous tuffs are intruded by a swarm of dykes. These are wide and although their margins are fine-grained, their centres may be coarse-grained and almost gabbroic in texture. They are greyish green in colour and have patches of epidote up to 5·0 mm. in diameter. At one place the dyke swarm was cut by a dyke of Andean granodiorite but the exposure was inaccessible. It is likely that the swarm is earlier than Andean in age. In one example (W.525.6) there is a great deal of alteration, the dyke rock showing the same degree of metamorphism as the tuffs. The outlines of the plagioclase laths are indistinct. What was probably andesine formerly has been replaced by epidote, actinolite, sericite and albite. Small prisms of actinolite ($\alpha = \beta =$ pale yellowish green, $\gamma =$ bluish green) and flakes of greenish brown biotite constitute the bulk of the rock. There is some granular pistacite, which also forms the patches of coarse mosaic seen in the hand specimen. Skeletal and indented crystals of iron ore are bordered by leucoxene and pyrite is altered to hematite. Rounded patches of pale green chlorite are fringed by actinolite and epidote. The chlorite contains euhedral actinolite and pyrite.

Rather similar gently inclined dykes of altered microdiorite crop out at the Barcroft Islands (W.405, 407) where they are in juxtaposition to contact metamorphosed volcanic rocks. The central part of one dyke (W.405.5), originally a diorite, now consists of albite, clinozoisite, sericite, chlorite, actinolite, ilmenite and leucoxene. Marginally this dyke is porphyritic.

Some of the dykes which intrude the Orford Cliff Suite will now be described. The age of these depends upon the age given to the plutonic rocks, but some details of the petrography lend support to the view that these dykes are pre-Andean and that the plutonic rocks are also pre-Andean. Other dykes, which intrude the Orford Cliff Suite are post-Andean in age. Some dark greyish green dykes (e.g. W.312, 356) are banded and foliated in the plane of the dyke. They show much replacement by chlorite, epidote and quartz. An example (W.312.1) is an altered hornblende-microdiorite. The numerous dykes exposed at McCall Point (W.477) are all younger than the extensive shearing which the members of the Orford Cliff Suite have undergone. The most common dykes, which may be pre-Andean in age, are basalts and dolerites which are little altered but carry veinlets of actinolite and epidote. Other dykes of altered andesite and altered porphyritic quartz-andesite are more definitely pre-Andean.

VIII. THE ANDEAN INTRUSIVE SUITE

THE Andean plutonic rocks of the Loubet Coast form a large number of discrete intrusions. They vary in size from veins and dykes to plutons 12·5 miles (20 km.) in diameter. There is no evidence on the Loubet Coast for the existence of intrusions of batholithic dimensions. A great deal of petrographic variation is associated with the separate nature of the intrusions.

TABLE III

SUB-DIVISION OF THE ANDEAN INTRUSIVE SUITE

1. **Gabbros, etc.** The main types are troctolites, gabbros and norites.
2. **Intermediate rocks of hybrid origin.** The main types are quartz-diorites and tonalities.
3. **Acid rocks.** The main types are tonalites, granodiorites, adamellites, granites and alkali-granites.

The Andean plutonic rocks have been divided into three groups which are set out in Table III. The sub-divisions are relatively clear cut but some rocks of gradational type have been arbitrarily classified. The petrographic classification of Nockolds (1954) has been used generally, but the classification of the mafic igneous rocks has required additional definition. The main distinction between gabbros, etc., and diorites has been made on the composition of the plagioclase, the delineation being at $Ab_{50}An_{50}$. Rocks which are called norites have orthopyroxene in excess of clinopyroxene, but the rocks which are called troctolites have olivine in excess of the total pyroxene content. Rocks with essential bytownite and augite are common. They are referred to as gabbros and not as eucrites in this report. Similarly, some rocks with essential anorthite and olivine are called troctolites and not allivalites.

There is direct evidence, afforded by intrusion contacts and thermal metamorphism, that the order of intrusion was from basic to acid. The distribution of the Andean Intrusive Suite is shown in Figs. 3, 6, 7 and 8.

A. GABBROS AND RELATED ROCKS

The gabbros, troctolites and norites have been classified according to their mode of occurrence and mesoscopic structures (Table IV). Unaltered examples of all the groups have been found. The mineral constituents result from direct crystallization of a magma but, in some cases, there is heavy replacement and it can be shown from field evidence that earlier melts were only partly consolidated when later melts were intruded. There is considerable variation of the mafic constituents but the plagioclase often has a uniform composition. It shows practically no zoning and is typically unaltered. Plagioclase, olivine,

TABLE IV

SUB-DIVISION OF THE GABBROS AND RELATED ROCKS

1. Extremely coarse-grained types. They often have a graphic texture and seldom show magmatic flow structures.
2. Uniform coarse-grained types. They are massive and well-jointed but have few mesoscopic structures.
3. Coarse-grained types which have good magmatic flow structures.
4. Extremely coarse- to medium-grained dyke phases. The dykes are usually randomly orientated and intrude groups 1 and 3. They may be so extensively developed as to completely obscure earlier rocks.
5. Uniformly coarse- to medium-grained types which have been modified by later intrusions.

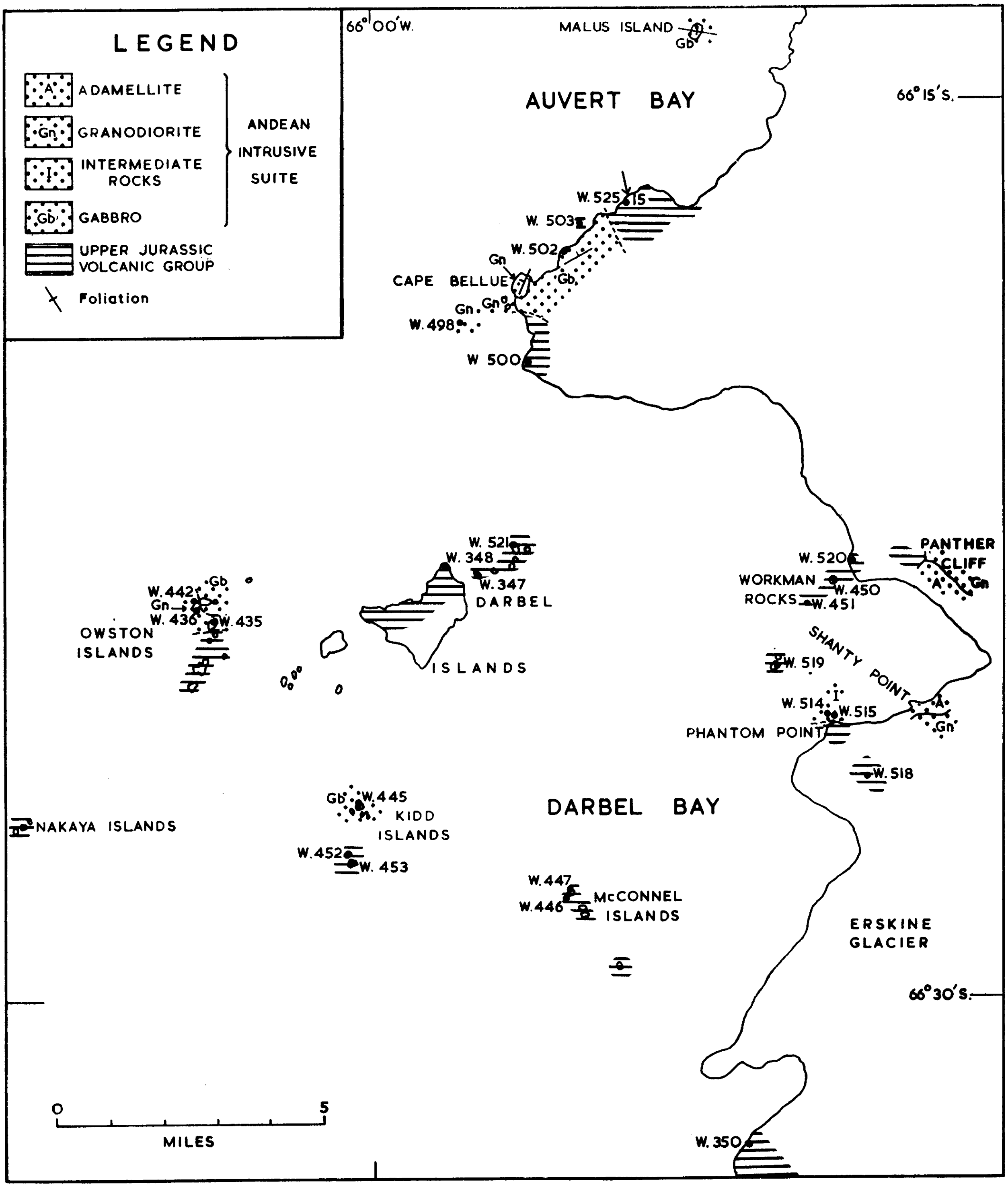


FIGURE 6
Geological sketch map of north-east Darbel Bay.

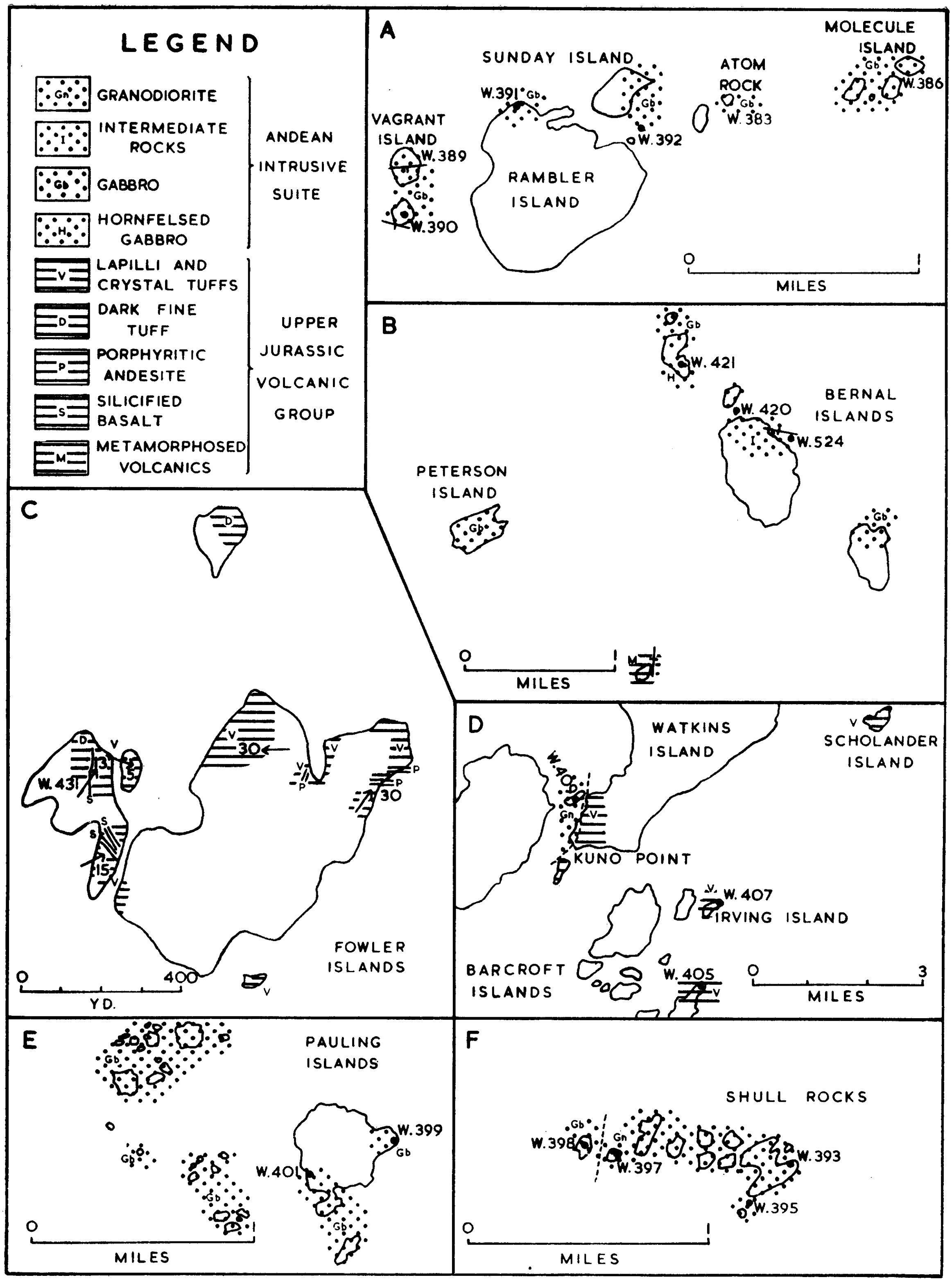


FIGURE 7

Geological sketch maps of island groups in Crystal Sound. (Drawn from maps prepared by B. L. H. Foote.)

A. Bragg Islands (lat. 66° 28′S., long. 66° 27′W.).
B. Bernal Islands (lat. 66° 22′S., long. 66° 28′W.).
C. Fowler Islands (lat. 66° 24′S., long. 66° 25′W.).
D. Part of the southern Biscoe Islands.
E. Pauling Islands (lat. 66° 32′S., long. 66° 57′W.).
F. Shull Rocks (lat. 66° 27′S., long. 66° 40′W.).

ilmenite and magnetite were the first minerals to crystallize and they were closely followed by augite and hypersthene. There was a certain amount of interaction at crystal margins following the initial crystallization. The mineral assemblages which occur at olivine/plagioclase boundaries are:

i. Augite.
ii. Hypersthene + magnetite.
iii. Hornblende.
iv. Hornblende + spinel.
v. Hornblende + magnetite.
vi. Biotite.
vii. Actinolite + chlorite.

Magnetite is usually fringed by pyroxene and biotite. Pyroxene, especially augite, is margined and internally replaced by hornblende. These minerals, although the result of replacement, formed during the closing stages of crystallization, whereas the formation of actinolite, chlorite, epidote, albite and sericite may be referred to later completely secondary reactions.

Some of the gabbros contain abundant amphibole which has replaced pyroxene, plagioclase and olivine, and has also been formed as a primary phase. These rocks are similar to the uralitized gabbros described by Adie (1955, p. 13).

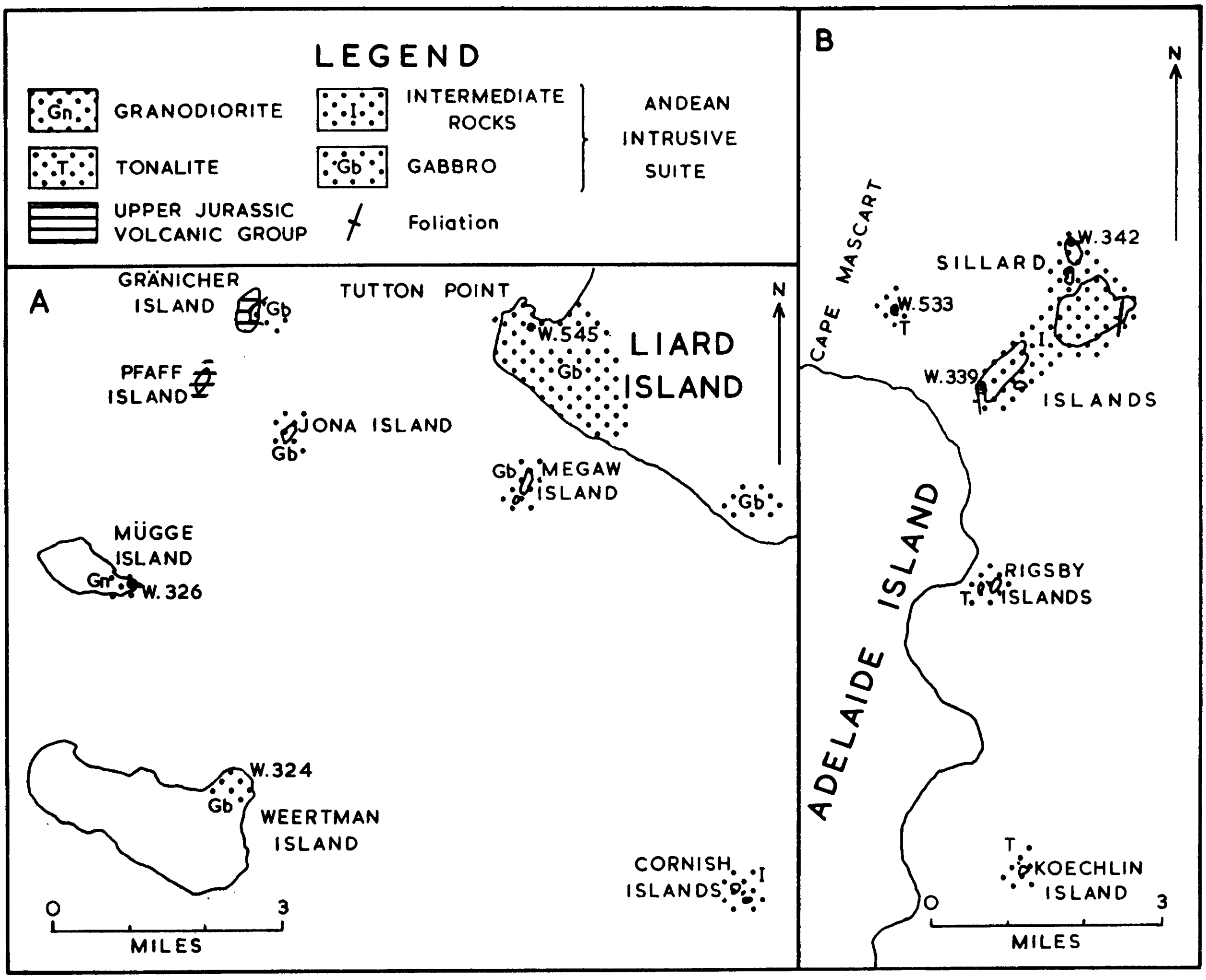


FIGURE 8

Geological sketch maps of island groups in Hanusse Bay. (Drawn from outline maps prepared by B. L. H. Foote.)
A. Bennett Islands.
B. Sillard Islands.

Dykes of diorite and of the more acid rocks, which are common within areas of the basic rocks, are mostly ramifications of later acid intrusions. Some gabbros which are quartz-bearing are gradational to the rocks of the intermediate group.

1. *Extremely coarse-grained rocks*

Gabbros and related rocks of this group are the commonest basic rocks of the Loubet Coast. They crop out at Tutton Point and at the Bennett Islands (Fig. 8a), at several of the islands in Crystal Sound (Figs. 7b, e, f), at the northernmost of the Kidd Islands and at Malus Island. It is convenient to describe one example in detail, although there are specific differences between rocks from various localities.

At Tutton Point there are substantial outcrops of extremely coarse-grained troctolites (W.335.3 (Plate IVe), 545.1). The mafic constituents are interstitial to rectangular areas of plagioclase up to 2·0 cm. in length, which results in a graphic appearance. A modal analysis of this rock and other representative examples of the gabbros are given in Table V. The plagioclase is bytownite ($Ab_{13}An_{87}$) which is unaltered

TABLE V

MODAL ANALYSES OF THE GABBROS AND RELATED ROCKS OF THE ANDEAN INTRUSIVE SUITE

	W.545.1	W.332.6	W.383.1	W.389.1	W.335.1	W.534.3	W.534.4
Quartz	—	—	—	5·7	—	—	—
Potash feldspar	—	—	—	*	—	—	—
Plagioclase	55·8	25·0	80·2	61·7	73·9	72·9	47·2
Augite	0·2	11·9	1·9	5·1	—	17·0	4·3
Hypersthene	0·3	1·3	9·8	1·3	0·1	4·3	—
Olivine	18·3	14·9	0·6	—	2·6	*	—
Hornblende	0·6	22·5	0·3	12·3	1·2	3·3	27·2
Actinolite	14·4	3·3	—	2·0	17·9	0·1	3·9
Chrysotile	2·1	2·4	0·2	—	*	—	—
Antigorite	0·9	2·7	2·3	—	1·5	—	—
Biotite	—	1·1	—	5·8	*	0·2	*
Chlorite	0·4	1·2	0·4	1·5	0·3	—	0·6
Iron ore	1·1	7·0	0·6	1·9	1·0	1·8	12·1
Spinel	1·8	*	—	—	1·2	—	—
Talc	—	0·6	1·3	—	—	—	—
Sphene	—	—	—	*	—	—	—
Clinozoisite	3·9	2·9	0·7	1·0	0·1	0·2	3·8
Pistacite	—	—	—	—	—	—	0·9
Sericite	0·2	3·2	0·8	1·5	0·1	0·2	—
Apatite	—	—	*	0·2	—	—	—
Bowlingite	*	—	—	—	—	—	—
Calcite	—	*	*	—	—	—	—
Plagioclase composition	An_{87}	An_{85}	An_{86-72}	An_{73-34}	An_{93}	An_{74-54}	An_{65-60}

* Present but not estimated.

W.545.1 Troctolite, Tutton Point.
W.332.6 Melatroctolite, Megaw Island.
W.383.1 Olivine-norite, Bragg Islands.
W.389.1 Quartz-bearing hornblende-gabbro, Bragg Islands.
W.335.1 Microtroctolite, Tutton Point.
W.534.3 Hypersthene-hornblende-gabbro, Megaw Island.
W.534.4 Hornblende-gabbro, Megaw Island.

and unzoned. Much of the multiple twinning is on the pericline law. The large rectangular areas are composed of several interlocking crystals individually up to 8·0 mm. in length. The crystals are heavily fractured, especially in the vicinity of olivine. Pale green and bluish green actinolite, tremolite, chlorite and sericite fill the cracks and replace the bordering plagioclase. Rounded but irregularly shaped crystals of olivine ($2V\gamma = 89° \pm 3°$; approximately $Fo_{89}Fa_{11}$) up to 3·0 mm. in diameter usually occur in groups between the areas of plagioclase. The olivine is fresh but fractured, cracks cutting the rock as a whole rather than spreading from the individual crystals. The cracks within the olivine are filled by chrysotile, antigorite and magnetite, but the fresh olivine has trails of iron ore. In a few places, particularly between the crystals of olivine, there is a dactylitic intergrowth of granular hypersthene and magnetite. However, the hypersthene has been mostly replaced by hornblende (α = colourless, $\beta = \gamma$ = pale green; $\gamma{:}c = 24°$). Aggregates of hornblende surround the olivine and individual crystals also penetrate and replace plagioclase. The amphibole is associated with anhedral crystals of green spinel which often border the magnetite. In some places clinozoisite has replaced plagioclase in the proximity of hornblende and olivine. Laths of colourless mica border and penetrate the hornblende. Augite is very subsidiary to olivine and there are rare prisms interstitial to the plagioclase. It includes both olivine and bytownite. Much of the augite is replaced by a hornblende (α = pale yellow, $\beta = \gamma$ = greenish brown) which is more strongly coloured than that adjacent to the olivine.

At Megaw Island, in the Bennett Islands, melanocratic gabbros have a coarse graphic texture and contain lenses of a leucocratic felsic rock. These lenses are orientated in a plane dipping at 70° to 260° true and the closely spaced joints within them trend in a direction 225° true. Some of the exposures show two varieties of gabbro (Fig. 9a). Most boundaries have the same orientation as the felsic lenses and there is sometimes a slight preferred orientation of the mafic constituents. Numerous dykes of gabbro are secondary to the early flow structures. The primary gabbros have a considerable range of composition but, in general, they resemble those of Tutton Point. The principal type found at the north end of the island (W.534.1) is a troctolite. The remnants of hypersthene marginal to olivine have broad rims of chlorite, colourless mica and bluish green actinolite. The mica marginal to olivine is either pale green or pale brown in colour. Much of the plagioclase (anorthite, Ab_9An_{91}) has been altered to sericite, chlorite, actinolite and calcite. Specimen W.535.1 illustrates well the petrography of the felsic lenses. The country rock, an olivine-gabbro, is particularly rich in mafic constituents for a distance of 1·0 cm. from the margin of the lens. It consists of bytownite, olivine and augite. The olivine is altered along fractures to chrysotile and magnetite, and in patches to antigorite and bowlingite. Augite, which is slightly in excess of olivine, invests and forms separate prisms to it. The pyroxene is replaced internally by small flecks of brown hornblende which are regularly orientated in relation to the crystallographic planes. The brown hornblende is replaced marginally by a pale green actinolitic hornblende, which also penetrates cracks within bytownite and replaces it.

A coarse-grained felsic band, 2·0–4·0 cm. in width, originally consisted of interlocking crystals of bytownite which have been severely replaced by sericite, albite, chlorite, calcite, actinolite and clinozoisite. Large subhedral prisms of pale brown hornblende are developed close to the margin of the lens; within the lens itself, adjacent to the hornblendes, large poikilitic crystals of augite have selectively replaced bytownite along specific crystallographic directions (Plate Va). In places the augite forms more complete xenomorphic prisms which have been replaced by colourless and bluish green actinolitic hornblende. A well-developed set of micro-fractures orientated perpendicular to the margins of the lens is filled by:

i. Sericite and chlorite with other alteration products of the bytownite.
ii. A pale brown weakly birefringent mineral (? chlorite) which replaces plagioclase adjacent to the fractures.
iii. Fibrous silica.

At the centre of Megaw Island there are small outcrops of extremely melanocratic heavy melatroctolites which represent a variation of the more usual rock types. One example (W.332.6) has a colour index of about 65.

An orbicular structure (Plate IIIa), as well as a good graphic texture, is developed in the gabbros at Jona Island. There are three common varieties among the orbs: those consisting of a few euhedral plagioclase crystals in radial arrangement; the same with a border of even-grained hornblende; the same with an outer shell of coarse-grained plagioclase. Rarer variations comprise three shells each of plagioclase and amphibole and an inner shell of amphibole enclosing a core of the graphic type of gabbro. The latter tend to be more variable in shape than the others and are up to 13·0 cm. in diameter.

These rocks are considerably more amphibolized than any of those described hitherto. In two cases (W.541.1 (Plate IVf), 2) the fresh unzoned bytownite ($Ab_{22}An_{78}$) forms large crystals up to 8·0 mm. across. Rounded pseudomorphs after olivine are enclosed by augite, or hornblende after augite, and consist of aggregates of tremolite and granular iron ore, which is concentrated marginally and in trails. Some relatively unaltered areas of augite carry bands of finely divided iron ore and small crystals of bytownite. The augite is almost completely replaced by hornblende. The internal flecks of hornblende are greenish brown whereas the marginal hornblende is pale green. Some of the olivine pseudomorphs have broad borders of acicular pale green or bluish green actinolite, in some cases associated with deep green spinel and pale green chlorite. Adjacent to the plagioclase the hornblende is bluish green and acicular prisms of actinolite are abundantly developed within it. The actinolite also penetrates and replaces the plagioclase. Lobes which penetrate the plagioclase at hornblende/plagioclase boundaries are especially rich in actinolite associated with anhedral plates of andesine and quartz. There is a little colourless mica. It is thus evident that the original minerals contributing to the graphic texture and the orbicular structure were bytownite, olivine and augite. The amphibole has resulted from secondary replacement which took place after consolidation. Similar amphibolized gabbros crop out at Weertman Island (W.324.2, 325.1).

Some of the Pauling Islands (e.g. W.401.1), the Bernal Islands (e.g. W.419.1), Wollan Island, Davidson Island and Shull Rocks (e.g. W.398.1) are mostly composed of olivine-gabbros and troctolites belonging to this group. At some localities they have been severely amphibolized.

At Malus Island there is a small enclave of extremely coarse-grained dark troctolite (W.528.3) in coarse-grained flow-banded troctolites (p. 34). This rock differs from those already described in showing the effects of thermal metamorphism. Large fresh crystals of bytownite ($Ab_{11}An_{89}$) have slightly more sodic rims. Olivine, forming groups of rounded crystals, is exceptionally well cleaved and includes a large amount of granular iron ore as well as the more usual trails of finely divided iron ore. It is slightly altered to chrysotile, magnetite and bowlingite. Discontinuous reaction rims are as follows:

i. Hypersthene + iron ore. These are particularly common close to crystals of primary magnetite.
ii. Greenish brown hornblende.
iii. Biotite ($\alpha = \beta =$ pale brown, $\gamma =$ reddish brown). Close to the bytownite the mica may be colourless, tinted pale green or bluish green.

Early-formed crystals of magnetite are bordered either by hypersthene or, more commonly, biotite. Only one crystal of augite was noted in the section examined, and this encloses rounded and embayed crystals of olivine and magnetite. Biotite and hornblende have developed as small plates within it. The presence of hornblende has been recorded, but it may be noted that it is often absent at olivine/bytownite boundaries where the reaction rims are of hypersthene and biotite or merely of biotite. The plagioclase is partly replaced by a network of actinolite and biotite.

The northernmost of the Kidd Islands (W.445, 513) consists largely of an extremely coarse-grained troctolite equally rich in biotite.

2. *Uniformly coarse-grained rocks*

The gabbros and norites of this group are massive, well-jointed and have few mesoscopic structures. They crop out at islands in Crystal Sound and at Cape Bellue.

The more north-easterly islets of the Bragg Islands (Fig. 7a) are composed of olivine-hypersthene-gabbros and olivine-norites. A typical specimen (W.383.1) is a dark coarse-grained rock with some leucocratic patches. Bytownite ($Ab_{14}An_{86}$–$Ab_{28}An_{72}$), forming subhedral crystals up to 3·0 mm. in diameter, shows some normal zoning. It is veined and replaced by chlorite and sericite. The olivine, forming rounded crystals up to 1·0 mm. in diameter, is partly altered to chrysotile with magnetite, chlorite, talc and bowlingite. Hypersthene occurs both as separate subhedral plates and as broad mantles to olivine, but some of it forms a dactylitic intergrowth with magnetite. Flakes of reddish brown biotite are developed within the hypersthene and marginally to it. Augite, which is subordinate to hypersthene, forms prismatic crystals interstitial to the plagioclase, and has narrow borders of a pale-coloured hornblende. A few indented crystals of ilmenite are fringed by sheaves of biotite. The accessories are apatite and calcite with chlorite, the latter resulting from the alteration of hypersthene. This rock is an olivine-norite. A second specimen (W.386.1 (Plate Vb), an olivine-hypersthene-gabbro) is similar to the rock described above but it has some differences of detail. The plagioclase is more sodic ($Ab_{30}An_{70}$–$Ab_{46}An_{54}$); some of the crystals have minute, crystallographically orientated inclusions of iron ore. The cores are sericitized and there is replacement along particular planes by actinolite, green biotite and chlorite. Indented crystals of iron ore are bordered by hypersthene, pale greenish brown hornblende and reddish brown biotite. Bulbous areas of a quartz/actinolite symplectite penetrate into the plagioclase. Olivine is often enclosed either by augite or hypersthene, but adjacent to plagioclase it is rimmed by hypersthene, pale green mica and a quartz/actinolite symplectite. The hypersthene is altered to actinolite, chlorite and leucoxene. In one part of the thin section biotite is abundant and is associated with quartz and apatite.

At other islands in Crystal Sound similar rocks grade into the extremely coarse-grained group. There is also a gradation to more acid quartz-bearing gabbros. The westernmost islet of Shull Rocks is formed of a dark coarse-grained amphibolized olivine-gabbro (W.398.1). The plagioclase ($Ab_{23}An_{77}$–$Ab_{45}An_{55}$) crystals have a very variable size and, together with olivine, augite and iron ore, they are enclosed by poikilitic crystals of brown, green or bluish green hornblende. Most of the amphibole, which commonly contains flakes of pale brown biotite, has formed at the expense of augite but some of it has replaced plagioclase. In a variation of this rock type (W.398.2) the addition of acid material is more marked. Hornblende (α = pale brown, $\beta = \gamma$ = yellowish green), forming large anhedral prisms whose interiors may be colourless, contains cores of augite, subrectangular areas of chlorite after hypersthene, rounded or embayed crystals of iron ore and rounded plates of plagioclase. Sheaves of actinolite are frequent at the margins of the hornblendes. The plagioclase has a very variable grain-size. The bytownite cores have been resorbed and they are surrounded by normally zoned labradorite. There is also some oscillatory zoning. The plagioclase is altered to sericite, chlorite and epidote. Quartz forms substantial interstitial plates. The texture, which is comparable to that of the intermediate rocks, is considered to have resulted from assimilation.

Gabbros of this group are exposed in the vicinity of Cape Bellue (W.501, 502) where they intrude the volcanic rocks and are associated with banded gabbros belonging to the third group.

3. *Coarse-grained rocks showing magmatic flow structures*

The more westerly islands of the Bragg Islands (Fig. 7a), including Rambler Island, are composed of gabbros, etc., which have good flow structures. Two norites described by Tyrrell (1945, p. 70) probably came from the north-west corner of Rambler Island, although they differ from the quartz-bearing gabbros collected by the author from the same locality. Tyrrell has described these rocks as follows:

> "The main rock of the island is a coarse plutonic type of a mottled, greenish grey tint, consisting of white feldspars and greenish black ferromagnesian minerals. In thin section the appearance of coarse grain is seen to be illusory, for the rock consists of large areas of fresh labradorite (An_{55}) in small crystals, alternating with larger and more isolated crystals of hypersthene, augite, and magnetite. The hypersthene is mainly fresh and distinctly pleochroic, but some crystals are in process of alteration to a pale green fibrous bastite mineral, and a few to brown biotite, both modes of alteration being accompanied by the disengagement of magnetite. There is also some primary iron ore. The hypersthene is apparently slightly preponderant over the pale diopsidic augite, and the periods of crystallization of the two minerals appear to overlap. Thus the rock is a norite or more exactly a hyperite, since the hypersthene is accompanied by a notable amount of monoclinic pyroxene. In another specimen the hypersthene has gone over completely to bastite."

The rocky islets to the south-west of the main island are of coarse-grained dark gabbros banded with more medium-grained flow-textured norites. There are enclaves of dark hornfels carrying porphyroblasts of plagioclase and biotite. The flow-textured rocks are especially well jointed. In one example (W.389.1) a preferred orientation of the mafic minerals gives rise to a horizontal lineation and a vertical foliation. The plagioclase forms subhedral crystals of very variable size up to 8·0 mm. in diameter and shows both normal and oscillatory zoning. Most of it has a composition within the range $Ab_{41}An_{59}$–$Ab_{53}An_{47}$ but the larger crystals have more calcic cores ($Ab_{27}An_{73}$) and sodic rims ($Ab_{66}An_{34}$). It is usually fresh but some cores are altered to sericite and clinozoisite. Augite, which is far in excess of hypersthene, is replaced by brown and green hornblende which, in turn, is replaced by actinolite. In addition there are some primary crystals of hornblende. There are some remnants of hypersthene which has been replaced by hornblende, actinolite, chlorite and magnetite. Large xenomorphic crystals of reddish brown biotite sometimes surround primary crystals of ilmenite and magnetite. The biotite is associated with interstitial quartz which has slightly replaced plagioclase, augite and hornblende. There is accessory apatite.

A similar rock from the north-west point of Rambler Island (W.391.1) has more quartz and a small amount of orthoclase. Practically all the pyroxene has been converted to amphibole. The accessories are apatite, sphene, zircon and pyrite.

One of the medium-grained types (W.389.3) has good relative elongation and alignment of both the plagioclase and the aggregates of the mafic constituents. The plagioclase ($Ab_{45}An_{55}$–$Ab_{50}An_{50}$) which shows only slight zoning forms subhedral crystals up to 4·0 mm. in length and markedly elongated parallel to (001). Abundant small prisms of slightly pleochroic hypersthene, up to 1·0 mm. long, altered marginally and along cracks to a pale green amphibole, are bordered by greenish brown hornblende and biotite. Subsidiary small crystals of augite are mostly replaced by hornblende. Indented crystals of iron ore are surrounded by a reddish brown biotite. Quartz is interstitial to the plagioclase and apatite is accessory. Similar rocks from the north-west point of Rambler Island (W.391.2) are more acid in character and are more properly described as diorites. The major mafic constituent, hornblende, is not obviously after pyroxene. Most of the plagioclase is a calcic andesine, and biotite, quartz and orthoclase are present.

The hornfels (W.389.5), consisting chiefly of plagioclase and augite, has been thoroughly recrystallized. The plagioclase forms fresh subhedral laths of 0·5 mm. average length and occasional larger crystals up to 2·0 mm. in length. The labradorite ($Ab_{33}An_{67}$) cores are mantled by more calcic bytownite ($Ab_{20}An_{80}$–$Ab_{25}An_{75}$) but the thin borders are more sodic ($Ab_{50}An_{50}$) in composition. The plagioclase includes both granular iron ore and augite, which are particularly frequent in the more calcic areas. Much of the augite present in the rock is granular and is enclosed by hornblende, biotite and quartz as well as plagioclase. Scarce aggregates of larger augite prisms are encompassed by hornblende and biotite. Individual crystals have serrated borders and carry finely divided iron ore. Pale reddish hypersthene, whilst being less abundant than augite, has the same granular mode of occurrence. Hornblende (α = pale yellow, β = yellowish green, γ = pale green) in small crystals borders and encloses plagioclase, augite, iron ore and hypersthene. Biotite ($\alpha = \beta$ = pale yellow, γ = dark reddish brown) forms large crystals which poikiloblastically enclose the other constituents. There are abundant euhedral iron ore crystals particularly in areas rich in granular augite. Quartz occurs in interstitial patches. In this rock the original mafic minerals of a coarse-grained intrusive rock have been reduced to give a granoblastic texture and much of the plagioclase has been reconstituted. This rock is an augite-hypersthene-biotite-hornblende-hornfels and belongs to the pyroxene-hornfels facies. Very similar rocks crop out at the small rocky islet in Rambler Harbour (W.392).

Gabbros and related rocks exposed at Malus Island have a good preferred orientation of the mafic constituents combined with schlieren and banding which results in a steeply inclined foliation trending in a direction 282° true. The dominant rock types are quartz-bearing olivine-gabbros and hypersthene-olivine-gabbros. Many bands are more basic and at the north-west point of the island strongly banded troctolites and olivine-norites lens around enclaves of extremely coarse-grained massive troctolite. In the dominant types (e.g. W.528.1, 529.1) olivine has a variable distribution, forming small rounded and embayed crystals often enclosed by augite. In specimen W.529.1 interstitial quartz is associated with a little orthoclase. It is not clear whether this is original or has resulted from replacement due to an adjacent micro-adamellite dyke. The more basic rocks are remarkable for their lack of alteration and reaction rims. One of the troctolites (W.527.1) is a dark, coarse-grained and reddish weathering rock. The main constituents are bytownite ($Ab_{22}An_{78}$), forming long prisms orientated in the plane of foliation, and olivine which forms aggregates of crystals lenticular in the plane of foliation. The olivine is well-cleaved, contains dense bands of iron ore and has thin cracks filled with bowlingite. It has the following types of narrow kelyphitic rim:

i. Hypersthene and magnetite, either in dactylitic or granular intergrowth.
ii. Green hornblende and hypersthene.
iii. Reddish brown biotite, hornblende and hypersthene.
iv. Reddish brown or pale green biotite.

Augite may occur adjacent to olivine but it usually forms plates interstitial to the bytownite; some is replaced by greenish brown hornblende. Abundant indented remnants of iron ore are bordered by golden brown biotite. There is accessory apatite and veinlets of actinolitic hornblende traverse the plagioclase.

4. *Extremely coarse- to medium-grained dyke phases*

Randomly orientated dykes of gabbro and related rocks, forming an integral part of the local intrusive sequence, are very common in exposures of the basic rocks, especially where the first phase of intrusion was of the extremely coarse-grained graphic-textured group. These dykes may be so abundant that they are only observed to intrude other earlier dykes.

At Jona Island (W.541) amphibolized gabbros are criss-crossed by dykes and veins of four types in the following order of intrusion:

i. A more even-grained variety of the country rock.

ii. Coarse-grained felsic bands. There may be a mass of large crystals of plagioclase with smaller crystals filling interstices or the whole rock is of even grain-size.
iii. Even-grained mafic bands of doleritic appearance.
iv. Veinlets of actinolite and epidote.

In some cases earlier dykes are displaced, indicating that the later dykes were intruded along shear fractures and that earlier phases had reached an advanced stage of consolidation. A band of type (i) (W.541.4) is essentially similar to the country rock except that there is wide variation of composition across small distances. The primary crystallization was of bytownite and augite. Later there was replacement by hornblende, actinolite, spinel, anthophyllite and chlorite. In an example of type (iii) (W.541.3; hypersthene-gabbro) fresh plagioclase ($Ab_{30}An_{70}$–$Ab_{37}An_{63}$) forms subhedral crystals of variable size up to 3·0 mm. and shows normal and oscillatory zoning. It is very full of finely divided iron ore. Some cores have recrystallized to a fine-grained aggregate of amphibole, magnetite and plagioclase. Augite is the dominant mafic constituent and small subhedral crystals include plagioclase and iron ore, and have trails of finely divided iron ore. The augite is marginally and internally replaced by hornblende. Prismatic crystals of weakly pleochroic hypersthene are heavily replaced by amphibole. Irregularly shaped crystals of iron ore wrap around the plagioclase and pyroxene. The iron ore is itself mantled by hornblende. Adjacent to a veinlet of actinolite there has been intense replacement, especially of the pyroxene, by actinolite.

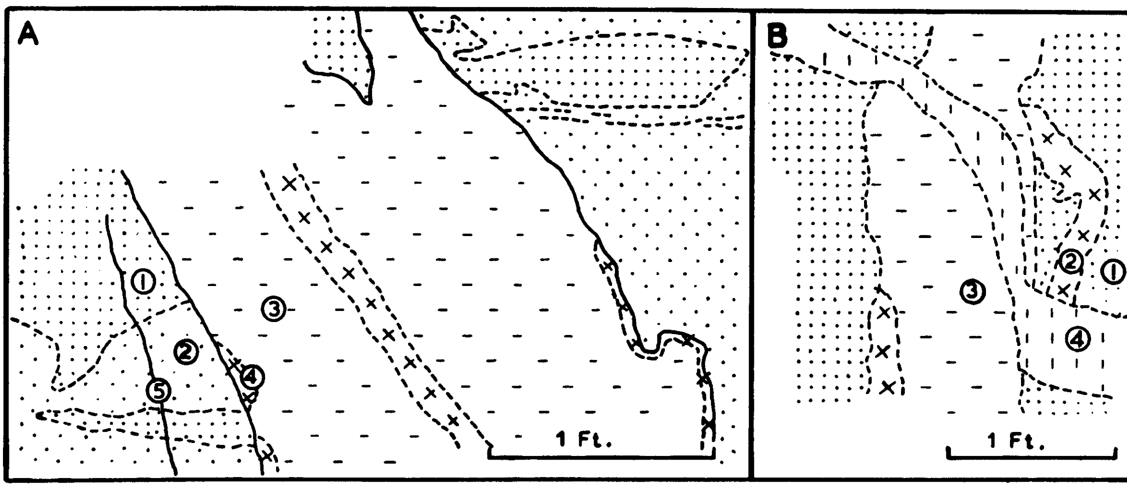


FIGURE 9

A. Varieties of gabbro at Megaw Island, Bennett Islands (W.536; plan view).
1. Coarse massive graphic gabbro; 2. Coarse massive gabbro, more felsic than (1); 3. Even-grained mafic gabbro; 4. Pegmatitic areas within and at the margins of (3); 5. Actinolite veins.

B. Banding in gabbros at Megaw Island, Bennett Islands (W.534; plan view).
1. Coarse olivine-gabbro (W.534.1); 2. Coarse or pegmatitic mafic gabbro with indistinct borders to (1); 3. Even-grained mottled gabbro (W.534.3); 4. Hornblende-gabbro with coarse graphic texture (W.534.4).

The country rocks of Megaw Island (troctolites and olivine-gabbros) are intruded by a complex series of gabbro dykes. Examples are illustrated in Plate IIIb and Figs. 9a and b. Specimens were collected from two of the three bands shown in Fig. 9b. Specimen W.534.3, from band (3), is a hypersthene-hornblende-gabbro. Zoned plagioclase ($Ab_{26}An_{74}$–$Ab_{46}An_{54}$) forms subrectangular plates up to 3·0 mm. in length. Xenomorphic prisms of augite up to 2·0 mm. across enclose small rounded crystals of plagioclase, ilmenite, magnetite and olivine. The augite is partly replaced by a greenish brown hornblende. Occasional prisms of hypersthene, also showing replacement by hornblende, sometimes border or enclose the clinopyroxene. Large irregularly shaped crystal aggregates of magnetite and ilmenite, margined by hornblende and biotite, surround the plagioclase. Ilmenite crystals are idiomorphic to magnetite, and ilmenite also forms lamellae within the magnetite. Veinlets are filled by actinolite and biotite which is partly altered to chlorite. Apatite is accessory. Adjacent to the veinlets there has been intense replacement with the generation of actinolitic hornblende, actinolite, chlorite and magnetite. Biotite is abundantly developed around relicts of earlier-formed iron ore. Specimen W.534.4, from band (4), is a hornblende-gabbro with abundant secondary iron ore. In the hand specimen the rock is dark and coarse-grained with large long prismatic crystals of plagioclase ($Ab_{35}An_{65}$–$Ab_{40}An_{60}$) up to 8·0 mm. in length, which is slightly zoned and altered to clinozoisite and actinolite. It is enclosed by and has lobed margins against augite which forms large poikilitic plates. The augite is heavily replaced by brown and green hornblende and by actinolite. Large, rounded and indented areas of magnetite and ilmenite up to 3·0 mm. across include and surround the plagioclase but are themselves enclosed by augite and hornblende. Cracks within the iron ore are filled by chlorite, actinolite and pistacite. This rock is cut by veinlets containing actinolite, tremolite and calcite. Adjacent to the veinlets both plagioclase and augite are replaced by actinolite.

At Tutton Point the extensive exposures of gabbro are cut by a mass of randomly orientated dykes. The main types are set out below but the time relationships between them are not clear, since they cut one another indiscriminately. However, at localities near sea-level dykes of type (iv) are known to be the youngest. Within the dykes there are often closely spaced joints on one or two sets which do not extend into the earlier rocks. Displacements of earlier dykes of up to about 1 ft. (0·3 m.) are common. In places rhythmical layering is developed in the plane of the dyke margins (Plate IIIc). In some bands there is a conspicuous slight enrichment of a deep green spinel. The main dyke types are:

i. Even-textured medium- to coarse-grained mesocratic bands.
ii. Pegmatitic and extremely coarse-grained bands. These form either the margins to or occur within the even-textured bands (i). Huge prisms of plagioclase and augite tend to be orientated perpendicular to the boundaries of the bands.
iii. Felsic bands, which occur either at the margins of type (i) or type (ii) bands.
iv. Brownish-weathering bands of doleritic appearance which have a more uniform width and orientation than that of the other groups.

A typical example of the type (i) bands is a microtroctolite (W.335.1). Unzoned equigranular anorthite (Ab_7An_{93}) forms the bulk of the rock. Small rounded olivines, almost completely altered to chrysotile, magnetite and antigorite, are bordered either by large crystals of pale green hornblende or by aggregates of hornblende and spinel which penetrate into the anorthite. Small, irregularly shaped crystals of iron ore have similar margins. An adjacent band is composed of rounded crystals of olivine bordered either by augite or by hypersthene with hornblende and spinel. There are a few interstitial areas of bytownite. A prominent fracture set is orientated in the same plane as the contact with the microtroctolite band. Cracks are filled with chrysotile and magnetite.

Many of the islands in Crystal Sound are of gabbro and related rocks whose main characteristic is the abundance of irregular dykes without any general preferred orientation. Examples are the south-eastern island of the Bernal Islands, Peterson Island, Wollan Island, Davidson Island and the Pauling Islands. Where older country rocks have been observed, they mostly belong to the extremely coarse-grained graphic-textured group of gabbros. The dykes are similar to those described from localities in the Bennett Islands. At some localities all rocks, including the dykes, have been amphibolized.

In contrast, no banding of this type occurs at the Bragg Islands and only one dyke, 2 ft. (0·6 m.) in width and orientated perpendicular to the plane of foliation, was recorded cutting the flow-banded gabbros of Malus Island. This rock is a medium-grained hypersthene-olivine-gabbro (W.528.2), which is intensely veined by biotite-adamellite. The main mineral constituents are bytownite and augite with subsidiary primary crystals of olivine, hypersthene and iron ore. Secondary reaction products are hypersthene, magnetite, hornblende and biotite. The olivine is altered along cracks to bowlingite.

5. *Modifications resulting from later intrusions*

Enclaves of basic intrusive rocks which have been thermally metamorphosed by flow-textured and banded gabbros have already been described (p. 32 and 34). At some localities the gabbros have undergone more widespread metamorphism as a result of the later intrusion of acid members of the Andean Intrusive Suite. The metamorphosed gabbros, which are allied to the gabbroic inclusions found in the tonalites and granodiorites (p. 45), occur as medium-grained dark-coloured hornfelses. At other localities the gabbros have undergone acidification, and the coarse-grained texture has been retained. This metasomatism is related to the extensive hydrothermal alteration of the gabbros. It is believed that accentuated magmas reacted with the gabbros in advance of the emplacement of the Andean acid plutons.

Olivine-hypersthene-gabbros are exposed at the islet off the north point of Davidson Island (W.426). Towards the southern end of this islet the gabbro becomes less coarse-grained and grades into an andesine-hornblende-biotite-hornfels veined by tonalite. The hornfels (W.426.3) has a crystalloblastic texture. The main constituents are andesine ($Ab_{53}An_{47}$), which forms small anhedral crystals, and hornblende (α = pale yellow, β = yellowish green, γ = pale green; $\gamma{:}c = 20°$) in small prisms. The cores of the hornblende crystals are sometimes colourless. There is subsidiary biotite ($\alpha = \beta$ = pale yellow, γ = yellowish brown) and iron ore.

A similar gradation can be traced in the north-western islets of the Bernal Islands (W.421). In contrast, at the islets off Thorne Point (W.319) hornfelsing of norites is confined to within a few centimetres of the contact with the quartz-diorite. Similarly, at one of the localities at Shull Rocks (W.395) a large inclusion covering several square yards has a hornfelsed margin. The major part of this large inclusion at Shull Rocks (W.395.2) is an acidified gabbro.

At Hoodwink Island basic gabbros are modified to a dioritic composition. For example, specimen W.461.3 (Plate Vc), which is an amphibolized quartz-gabbro, is coarse-grained with the mafic constituents occurring in aggregates. Bytownite forms subhedral crystals of very variable size and has been severely replaced by quartz. Poikilitic crystals of brownish green hornblende enclose corroded bytownite crystals and contain chlorite-leucoxene pseudomorphs after biotite. The hornblende is also replaced in part by quartz. In a second specimen from the same locality (W.461.1) there has been further acidification. The plagioclase ($Ab_{42}An_{58}$–$Ab_{52}An_{48}$) shows reversed zoning and is altered to albite, clinozoisite, sericite and prehnite. The hornblende has a xenomorphic habit and is replaced by quartz and actinolite. Chlorite, leucoxene and epidote form large laths after biotite and are associated with the amphibole. Quartz, forming large areas of mosaic, replaces both the plagioclase and the mafic constituents marginally and internally. A pegmatite associated with this rock consists of prisms of hornblende up to 3·0 cm. in length in a finer matrix of plagioclase and quartz.

Other quartz-bearing hornblende-gabbros, believed to have resulted from acidification, crop out at the northernmost of the Owston Islands adjacent to a granodiorite pluton and at the north-east point of the largest island of the Pauling Islands, where they are injected by dykes of tonalite. At Gränicher Island a quartz-hornblende-hypersthene-gabbro intrudes the Upper Jurassic volcanic rocks. A curious facies of this gabbro (W.60.3) contains relicts, represented by alteration products and some of the original constituents after olivine, augite, hypersthene and bytownite, set in a tonalitic matrix.

B. Intermediate Rocks of Hybrid Origin

In apparent contrast with other parts of Graham Land quartz-diorites and tonalites of the Andean Intrusive Suite are common but not abundant on the Loubet Coast. The rocks examined come from Hansen Island, the Cornish Islands, Thorne Point and the islets lying off it, the Sillard Islands, the Bernal Islands, Levy Island, the Foote Islands, Phantom Point, Director Nunatak, Matsuyama Rocks and an islet 2 miles (3·2 km.) north-west of Mist Rocks (W.480). This widespread distribution throughout isolated groups of islands suggests that the quartz-diorites and tonalites form large plutons beneath the present areas of sea.

These rocks are typically coarse-grained and mottled in appearance and they commonly contain abundant rounded inclusions of basic character. At some localities schlieren are developed and there is a preferred orientation both of the xenoliths and of the mafic minerals. In thin section these rocks compare closely with those of intermediate character described from other parts of Graham Land (e.g. Adie, 1955, p. 9). The plagioclase, which is mostly andesine, is heavily zoned; orthoclase is subordinate to quartz and the major mafic constituents are biotite and hornblende with subsidiary augite and hypersthene. Representative modal analyses are given in Table VI. Several textural features which are listed below indicate that these rocks have resulted from assimilation of basic material by a more acid magma.

i. The extreme variation in grain-size.
ii. The intense zoning of the plagioclase.
iii. The common occurrence of calcic cores within the plagioclase which often have a different crystallographic orientation to the surrounding plagioclase.
iv. The aggregated nature of the mafic constituents.
v. The presence of altered remnants of olivine and hypersthene.
vi. The replacement of augite by hornblende and biotite.

The accessories apatite, sphene, tourmaline and pyrite are exceptionally abundant.

TABLE VI

MODAL ANALYSES OF THE INTERMEDIATE ROCKS OF THE ANDEAN INTRUSIVE SUITE

	W.524.1	W.342.1
Quartz	14·2	4·1
Potash feldspar	1·4	—
Plagioclase	60·3	69·0
Augite	2·2	—
Hornblende	4·5	14·8
Biotite	12·1	8·3
Chlorite	1·6	0·8
Iron ore	0·6	2·5
Leucoxene	—	*
Pyrite	0·3	*
Sphene	0·3	—
Epidote	0·5	*
Sericite	1·0	0·2
Apatite	0·8	0·3
Zircon	—	*
Prehnite	0·2	—
Tourmaline	0·1	—
Plagioclase composition	An_{55-32}	An_{56-37}

* Present but not estimated.

W.524.1 Tonalite, Bernal Islands.
W.342.1 Quartz-diorite, north point of the Sillard Islands.

These rocks often contain a small proportion of potash feldspar which is either interstitial to the other constituents or forms small rectangular laths regularly orientated in the more sodic shells of the plagioclase. One specimen from Hansen Island (W.323.1) is unique in having orthoclase in excess of quartz. This specimen, which was not collected *in situ*, is foliated and is of medium grain-size. It has a similar appearance to some of the marginal facies of tonalites in contact with the volcanic rocks of the Joubin Islands (Hooper, 1962, p. 19). A metasomatic origin is suggested by the texture of the orthoclase which poikilitically encloses and has replaced andesine, biotite and hornblende.

Quartz-diorites comprise the several exposures at the foot of the ice cliffs round the Sillard Islands (Fig. 8b). These rocks are massive and mottled with fairly numerous inclusions, and some show flow structures. At the north point of the large easternmost island there is a sharp but irregular contact between a darker variety of quartz-diorite and a lighter-coloured, more quartz-rich variety. The darker variety (W.342.1) contains small dark medium-grained inclusions which have indistinct borders against the country rock; the lighter variety carries irregularly shaped medium-grained inclusions. In thin section the darker variety has an extremely variable grain-size, with plagioclase phenocrysts up to 4·0 mm. in length occurring in a relatively fine matrix. Large euhedral crystals or crystal groups of plagioclase ($Ab_{44}An_{56}$–$Ab_{63}An_{37}$) show normal and oscillatory zoning. There are a few more calcic cores. In the groundmass the plagioclase forms stumpy laths which mostly have a composition $Ab_{44}An_{56}$–$Ab_{52}An_{48}$. The larger crystals enclose granular hornblende and finely divided iron ore. The mafic constituents are in aggregates. Hornblende (α = pale brown, $\beta = \gamma$ = brownish green; $\gamma{:}c = 24°$) forms small anhedral prisms which include rounded crystals of plagioclase. The indented and subhedral magnetites are often bordered by large xenomorphic crystals of biotite ($\alpha = \beta$ = pale brown, γ = dark brown), which are marginally replaced by chlorite and sphene. Ilmenite occurs as separate grains and as lamellae within magnetite. In amount it is subsidiary to magnetite. The biotite with which apatite and zircon are associated also includes some plagioclase and hornblende. Quartz forms interstitial patches and the magnetite, hornblende and plagioclase crystals adjacent to it tend to be euhedral. It sometimes replaces biotite.

The more leucocratic quartz-diorites have essentially the same petrography as the example described above. In specimen W.339.1 there is in part of the thin section a definite demarcation between the plagioclase phenocrysts and the groundmass, whilst elsewhere there is every gradation in size. Its composition ranges from $Ab_{47}An_{53}$ to $Ab_{88}An_{12}$. The calcic cores may be severely sericitized. Biotite is more abundant than hornblende which is confined within the aggregates of mafic constituents. The biotite surrounds and replaces iron ore and hornblende. Apatite, zircon, orthite, sphene and chlorite are associated accessories. Most of the quartz is interstitial to the other constituents but some has replaced the sodic rims of the plagioclase. There is a little orthoclase.

In Hanusse Bay, the quartz-diorites of Hansen Island, the Cornish Islands and Thorne Point are all similar to those described above, although there are considerable differences in detail. For example, a quartz-diorite from Hansen Island (W.322.1) has numerous cores of bytownite within the plagioclase. The most abundant ferromagnesian mineral is augite which shows all stages of replacement by hornblende and biotite. Individual crystals have internal flecks and rims of hornblende, and aggregates of augite are margined by hornblende. Crystals of hornblende also contain remnants of augite. Some of the augite is bordered by plagioclase but some of it is rimmed solely by biotite. There are rare chlorite pseudomorphs after hypersthene. In contrast, a specimen from Thorne Point (W.321.1) commonly has remnants of hypersthene but it lacks augite. The hypersthene, which is partly altered to talc and is replaced by hornblende and biotite, is associated with granular iron ore, suggesting an original derivation from olivine. On the off-lying islets norites are traversed by veins of quartz-diorite. At the contact the norite is hornfelsed and is incorporated in the diorite as medium-grained inclusions. The veins of quartz-diorite thin out to stringers of plagioclase, quartz, epidote and pyrite. These are in turn cut by dykes of pink microgranite. The quartz-diorites are hydrothermally altered to albite, prehnite, tremolite, chlorite, sericite and epidote. The tonalites of the Cornish Islands have a higher quartz content than the rocks described so far but otherwise they are similar.

In Crystal Sound, the Bernal Islands (Fig. 7b), Levy Island and the Foote Islands are all formed of similar rocks. Two types of diorite, similar to those of the Sillard Islands, occur at the Foote Islands. The contacts are intricate and gabbroic inclusions may be common to both. In places the inclusions are abundant and may be lensoid in the plane of foliation (Plate IIId). The largest of the Bernal Islands and the smaller islands immediately to the north-west are formed of quartz-diorite varying to tonalite. The exposures are remarkably uniform in comparison with those of other localities and there are few inclusions. A distinct foliation is defined by preferred orientation of the mafic constituents. The quartz-diorite is cut by uniform dykes of microdiorite. Joint sets are well-developed and give rise to sea stacks and caves (Plate IIa). Examples (W.524.1 (Plate Vd), 418.1) are tonalite and quartz-diorite respectively. Although this pluton is uniform and homogeneous the textures are similar to those of the other intermediate rocks and it is necessary to infer a hybrid origin. Plagioclase ($Ab_{45}An_{55}$–$Ab_{68}An_{32}$) forms long subhedral plates and shows some alteration to sericite, chlorite and actinolite. The main mafic constituent, biotite, forms large plates enclosing iron ore and is altered to chlorite, sphene and epidote. Green hornblende forms anhedral prisms which enclose the plagioclase. It contains remnants of augite and rare chlorite pseudomorphs after hypersthene. Much of the quartz is interstitial but some augite and hornblende has been replaced by it. Pyrite, apatite and tourmaline are the accessories. There is a little orthoclase forming small rectangular plates, filling cracks within the plagioclase and occurring interstitially to the quartz.

The main constituents of a microdiorite dyke (W.420.1) with a hypidiomorphic texture are plagioclase ($Ab_{44}An_{56}$–$Ab_{60}An_{40}$), biotite, hornblende, augite, iron ore and quartz. Rounded remnants of augite are enclosed by strongly coloured green hornblende. Biotite tends to form large porphyritic plates at the expense of the other constituents and quartz is interstitial.

Two varieties of diorite occur again at Matsuyama Rocks in the Lallemand Fjord area. The rocks are quartz- and augite-bearing biotite-diorites and augite-bearing hornblende-tonalites. Some of the potash feldspar present in the tonalite is microcline.

The rocky islet 2 miles (3·2 km.) north-west of Mist Rocks (W.480) is composed of a quartz-diorite with augite, hypersthene and biotite in addition to hornblende. It shows the same hybrid textures.

C. Acid Rocks

Specimens from twelve separate intrusions of the acid group, in addition to numerous minor occurrences, have been examined. The existence of other plutons was noted in the field. Modal analyses of typical specimens are given in Table VII. The tonalites from islands off Adelaide Island, which are described below, possess a granitic texture and lack hybrid characters. The rocks of the acid group are, in general, similar to those of the Graham Coast (Curtis, 1960) and the Marguerite Bay area (Adie, 1955).

TABLE VII

MODAL ANALYSES OF THE ACID ROCKS OF THE ANDEAN INTRUSIVE SUITE

	W.543.1	W.526.1	W.393.1	W.326.1	W.300.2	W.315.1	W.449.1	W.300.1	W.318.1
Quartz	30·7	13·6	28·6	37·1	24·3	20·4	29·9	37·1	29·1
Potash feldspar	2·7	11·6	10·7†	13·8†	25·5†	40·0‡	33·2†	46·3‡	67·9‡
Plagioclase	48·1	51·7	51·4	44·3	44·6	37·9	30·4	15·3	—
Augite	—	—	—	—	—	—	*	—	—
Aegirine-augite	—	—	—	—	—	—	—	—	1·6
Hornblende	4·1	11·9	0·2	—	2·5	—	1·5	—	—
Riebeckite	—	—	—	—	—	—	—	—	0·9
Ferrohastingsite	—	—	—	—	—	0·6	—	—	—
Biotite	—	4·5	7·2	2·6	0·9	0·3	1·6	0·9	—
Chlorite	1·0	2·9	0·5	1·4	1·1	—	1·2	0·4	—
Iron ore	1·3	1·9	0·6	0·5	1·0	0·7	0·7	0·2	0·5
Leucoxene	0·3	0·6	*	0·1	*	—	0·1	—	—
Pyrite	—	—	—	—	*	—	—	—	—
Sphene	0·4	0·4	0·3	0·1	0·1	0·1	*	0·1	*
Clinozoisite	7·1	—	—	*	—	—	—	—	—
Pistacite	2·4	0·4	0·3	*	*	—	0·1	*	—
Sericite	1·1	*	*	*	*	—	*	*	—
Apatite	*	0·2	0·2	*	*	*	0·2	*	0·1
Zircon	*	—	—	—	*	*	*	*	*
Rutile	—	—	—	—	—	—	—	—	*
Prehnite	—	0·3	—	—	—	—	—	—	—
Orthite	—	—	—	—	—	*	—	*	—
Tourmaline	—	—	—	—	—	—	—	*	—
Plagioclase composition	An_{43-10}	An_{38-26}	An_{40-8}	An_{29-2}	An_{40-8}	An_{14-7}	An_{47-13}	An_{21-5}	—

* Present but not estimated.
† Includes some microperthite.
‡ Includes much microperthite.

W.543.1 Tonalite, Koechlin Island.
W.526.1 Granodiorite, Cape Bellue.
W.393.1 Granodiorite, Shull Rocks.
W.326.1 Granodiorite, Mügge Island.
W.300.2 Granodiorite, Neb Bluff.
W.315.1 Adamellite, 7·5 miles (12·1 km.) east-north-east of Orford Cliff.
W.449.1 Adamellite, Shanty Point.
W.300.1 Granite, Neb Bluff.
W.318.1 Alkali-granite, 2·0 miles (3·2 km.) north-west of Lampitt Nunatak.

1. *Tonalites*

The Rigsby Islands and Koechlin Island (Fig. 8b) are of coarse-grained tonalites with a granitic texture. These rocks contain occasional small dark medium-grained inclusions, and are sheared on closely spaced planes, with the generation of much epidote. Specimen W.543.1 from Koechlin Island consists mostly of plagioclase and quartz. The plagioclase ($Ab_{57}An_{43}$–$Ab_{90}An_{10}$), heavily zoned and altered to albite, epidote and sericite, forms subhedral plates and is marginally replaced by orthoclase. Large anhedral quartz crystals show some undulose extinction and their margins against the plagioclase are lobed. The mafic constituents tend to occur in aggregates. Xenomorphic prisms of hornblende (α = pale brown, β = yellowish green, γ = green) are associated with epidote, sphene, green and greenish brown biotite which have replaced former biotite. Sphene also surrounds indented crystals of ilmenite and magnetite with which apatite is associated.

Specimens from the Rigsby Islands (e.g. W.337.1) are similar to the rocks described above. Veinlets of albite, quartz, chlorite and sericite are cut by shear zones 1·0–2·0 mm. wide, in which lenticles of the tonalite (chiefly quartz) are surrounded by coarsely granular epidote. Near the shear zones the tonalite has been severely altered and only the quartz has been little changed. The alteration products are chlorite, epidote, sphene and actinolite. A similar tonalite from the isolated westernmost island of the Sillard Islands was also examined. At this locality (W.533) a quartz-rich tonalite intrudes thermally metamorphosed volcanic and hypabyssal rocks. The tonalite is very altered, A tonalite dyke similar to specimen W.543.1 cuts the gabbros at Tutton Point.

In some petrographic respects these rocks resemble the tonalites of the Orford Cliff Suite. It has not been possible to distinguish definitely between the older and younger plutonic rocks on mineralogical or textural grounds. Therefore, where other evidence is lacking, as in the cases described above, there is uncertainty as to the age of the plutons.

2. *Granodiorites*

At Cape Bellue and the offshore islets there is a uniform pluton of coarse-grained, mottled leucocratic granodiorite. The contact with underlying banded gabbros is sharp and dips at moderate angles to the west. The granodiorite is slightly foliated and has occasional dark medium-grained inclusions. In one specimen (W.526.1) zoned plagioclase ($Ab_{62}An_{38}$–$Ab_{74}An_{26}$), in subhedral plates of varying size up to 4·0 mm., is sericitized and there is slight marginal replacement by orthoclase. Hornblende (α = pale yellow, β = yellowish green, γ = olive-green; $\gamma{:}c = 25°$) is abundant as xenomorphic plates, which are marginally coloured bluish green. Biotite ($\alpha = \beta$ = pale yellow, γ = greenish brown), which is subsidiary to hornblende, occurs as large flakes partly replaced by chlorite, sphene and epidote. Indented crystals of ilmenite are bordered by sphene and enclosed by biotite. There is accessory magnetite and apatite. Most of the quartz is interstitial to the plagioclase but there are some large plates up to 1·0 mm. across. It has lobed margins against the feldspar. Some of the quartz is coarsely intergrown with orthoclase which is mainly interstitial to the plagioclase.

The granodiorite of Shull Rocks (Fig. 7f) is part of a similar uniform pluton intruding gabbros. It contains small, rather angular, dark medium- to fine-grained inclusions. A typical sample (W.393.1) is more acid in character than the granodiorite from Cape Bellue. Subhedral plates of plagioclase ($Ab_{60}An_{40}$–$Ab_{92}An_{8}$) show both normal and oscillatory zoning, and their cores are sericitized. The main mafic mineral, biotite ($\alpha = \beta$ = pale yellow, γ = reddish brown), forms large laths altered marginally and along cleavages to green biotite, chlorite, epidote and sphene. Xenomorphic crystals of iron ore are bounded by epidote and green biotite or are associated with sphene and occasional crystals of pale green hornblende, the latter replaced by aggregates of the green biotite. Large plates of quartz up to 2·0 mm. across show an undulose extinction. The orthoclase is mainly interstitial to the other constituents but some of it occurs as small plates within and as marginal indentations to plagioclase. A small proportion is microcline. There is some symplectitic intergrowth of the quartz and potash feldspar. Another specimen (W.395.1) has a coarser-grained appearance with euhedral plagioclases up to 5·0 mm. in length and anhedral quartz crystals as much as 3·0 mm. across. However, much of the intervening material is of a comparatively fine grain-size, consisting principally of either orthoclase or orthoclase-quartz symplectite.

The tendency to more extreme variation of grain-size is continued in the granodiorites of Watkins Island and Mügge Island. The exposures are meagre but there is no evidence that these rocks have an origin different from that of the other granodiorites. On the eastern point of Mügge Island there are exposures of a leucocratic granodiorite containing large crystals of plagioclase (up to 4·0 mm. in length) and blue-tinted quartz (up to 1·0 cm. across). There are occasional, small, pale grey medium-grained inclusions. The granodiorite (W.326.1) contains infrequent fine-grained aggregates of magnetite, ilmenite, sphene, chlorite, apatite and greenish brown biotite. These areas are undoubtedly relicts of former biotite but the material has spread outwards, especially into the surrounding plagioclase. The replacement mechanism was:

$$\text{biotite} \rightarrow \text{chlorite} + \text{sphene},$$
$$\text{iron oxide} + \text{chlorite} \rightarrow \text{biotite}.$$

The subrectangular plates of plagioclase ($Ab_{71}An_{29}$–$Ab_{98}An_{2}$) show considerable alteration to sericite and clinozoisite. The large plates of quartz are fractured and have an undulose extinction. Much of the remainder of the rock is medium-grained and consists of a symplectite of quartz and orthoclase or orthoclase-microperthite. Fingers of the microperthite penetrate into the quartz plates.

At the Biscoe Islands (Fig. 7d) granodiorites crop out near Kuno Point and at the rocky islet west of Watkins Island on which there is an Argentinian hut (W.409). In one specimen (W.409.1) large subhedral plates of plagioclase ($Ab_{55}An_{45}$–$Ab_{92}An_{8}$) show normal and oscillatory zoning. Locally there is alteration to sericite and epidote. Large well-formed laths of biotite ($\alpha = \beta$ = yellow, γ = dark brown) are altered marginally to chlorite, epidote and green biotite. Quartz has an irregular distribution and has formed as a result of replacement, particularly of plagioclase. It has a tendency to coalesce into large crystals up to 5·0 mm. in diameter and has a slight undulose extinction. Orthoclase is both marginal to the plagioclase, which it locally replaces, and forms separate interstitial crystals with quartz. Near Kuno Point the granodiorite is sheared and altered.

Granodiorites, similar to those of Cape Bellue and Shull Rocks, crop out on a small islet off Phantom Point (W.515), at the Foote Islands and at the Cornish Islands. At all three localities the granodiorites are associated with tonalites, which carry numerous inclusions and which are believed to be of hybrid origin. At the Cornish Islands (W.549) these granodiorites inject the tonalites as dykes, whose medium-grained margins are quartz- and potash feldspar-rich.

The granodiorite which forms the upper part of a composite intrusion at Neb Bluff (Fig. 10) differs in several respects from those already described. There is an irregular but sharp contact with the Upper Jurassic volcanic rocks, which have been thermally metamorphosed and assimilated by the intrusion. At the localities visited (W.300–02, 304) the granodiorite has only small dark inclusions up to 12·0 cm. in diameter but higher up the cliff there are broad layers 50–100 ft. (15·2–30·5 m.) in width which are extremely rich in dark inclusions.

In the hand specimen (W.300.2) the granodiorite is coarse-grained and is characterized by conspicuous black idiomorphic plagioclase crystals up to 4·0 mm. in length, bordered by pink potash feldspar. The plagioclase ($Ab_{60}An_{40}$–$Ab_{92}An_{8}$) shows both normal and oscillatory zoning, and shells of minute inclusions, arranged with respect to the zoning, are responsible for the dark colour. Some crystals have more calcic cores (up to $Ab_{50}An_{50}$) which may be sericitized. The euhedral plates of plagioclase are often completely enclosed by orthoclase; margins between the two minerals are indented. Sometimes the orthoclase contains patches of albite in optical continuity with the margins of the plagioclase plates, but elsewhere the orthoclase is microperthitic. Anhedral plates of quartz showing slightly undulose extinction and up to 2·0 mm. in diameter have extremely irregular margins against the potash feldspar, which lobes and fingers into the quartz and often occurs as included areas within it. Much of the orthoclase microperthite and quartz forms a coarse symplectite.

The mafic constituents occur in aggregates. The hornblende (α = pale yellow, β = pale yellowish green, γ = yellowish green; $\gamma{:}c = 22°$) often forms long prisms and is sieved by magnetite and quartz. Biotite ($\alpha = \beta$ = pale yellow, γ = yellowish brown), which is subsidiary to the hornblende, is replaced by chlorite and epidote. Indented iron ore crystals and accessory apatite, zircon and pyrite are associated with both the hornblende and biotite.

With an increased ratio of potash feldspar to plagioclase the granodiorites are gradational into the adamellites. This gradation has been observed in the more northerly of the Owston Islands within the limits of a single small intrusion. Specimen W.442.1, from the upper part of a steep rocky slope, is a pinkish coarse-grained adamellite with few mafic constituents. Plagioclase, orthoclase and quartz all form large plates. Some of the potash feldspar is perthitic and forms a symplectite with quartz. The plagioclase is often altered to sericite, clinozoisite and albite. Yellowish green hornblende forms euhedral prisms, while chlorite, epidote, sphene and leucoxene pseudomorph biotite. Idiomorphic crystals of iron ore are fringed by sphene. The other accessories are apatite, zircon, prehnite and actinolite. At the base of the slope a pale grey granodiorite carries very numerous inclusions of dark medium-grained hornfels. The plutonic rock (W.442.6) is similar to the adamellite described above but it has a smaller proportion of potash feldspar. It is heavily altered, the biotite being completely replaced and the hornblende partially replaced by actinolite. The hornblende rarely contains cores of augite, which have finely divided iron ore inclusions. A granodiorite collected from the middle part of the cliff (W.442.4) is intermediate between the two rocks described above. It is severely altered and contains small, angular fine-grained inclusions and aggregates of the mafic constituents.

Close to the margins of the intrusion (W.436.1) the rocks are free of inclusions but they still have the composition of a granodiorite. Quartz and orthoclase form a symplectite enclosing large plagioclase and quartz crystals. There has been some replacement of the plagioclase by quartz and orthoclase. The pale brown hornblende is partly replaced by pale green and bluish green actinolite and quartz. There are rare cores of augite.

Thermally metamorphosed volcanic rocks crop out on the small islets south of the localities described above. Close to these the granodiorite (W.435.1) is noteworthy in that it closely resembles that of Neb Bluff. Long slender plagioclase prisms reach up to 1·0 cm. in length and 0·5 mm. in width. They are enclosed in a medium-grained matrix which mainly consists of a quartz-orthoclase symplectite. The plagioclase ($Ab_{52}An_{48}$–$Ab_{83}An_{17}$), which is normally zoned, forms remarkably euhedral crystals but their borders are indented as a result of replacement by orthoclase and quartz. The cores are somewhat altered to albite and clinozoisite. A curious feature of the mafic constituents is the occurrence of hypersthene as small xenomorphic crystals bordered by hornblende and biotite. The hornblende also contains cores of augite. Anhedral prisms of hornblende (α = pale brown, $\beta = \gamma$ = yellowish green) are either sieved by plagioclase or dispersed into granular aggregates. Indented crystals of iron ore, flakes of yellowish brown biotite and apatite are associated. Occasional larger orthoclase (sometimes microperthitic) and quartz crystals occur with the finer symplectite.

3. *Adamellites*

The extensive exposures at Shanty Point are of uniform pale pink adamellite, composed of abundant euhedral plagioclase crystals up to 3·0 mm. in length, and containing rare, pale-coloured medium-grained inclusions. This adamellite forms the lower part of the composite pluton of Panther Cliff. There is a sharp gently inclined contact with a darker reddish-weathering intrusive. The pluton is very similar to that of Neb Bluff, the rocks examined being the equivalent of the lower granite part of the Neb Bluff intrusion.

In one specimen (W.449.1; Plate Ve) the plagioclase ($Ab_{53}An_{47}$–$Ab_{87}An_{13}$) shows good normal and oscillatory zoning. Most of it is fresh but in some places it is sericitized. Quartz and orthoclase form a micrographic intergrowth, in which the individual crystals are in optical continuity for distances of approximately 2·0 mm. There has been considerable replacement of the plagioclase by the quartz and potash feldspar. Some of the plagioclase crystals have concave terminations and fingers of microgranophyre penetrate them. Larger plates of quartz commonly have micrographic margins and include thin crystallographically orientated lamellae of orthoclase, but individual orthoclase crystals are rare. Biotite and hornblende are present in almost equal amounts. Rare grains of augite are enclosed in the cores of the plagioclase crystals. In places the hornblende (α = pale yellow, $\beta = \gamma$ = brownish green; $\gamma{:}c = 20°$) has been replaced by chlorite and sphene. The biotite ($\alpha = \beta$ = very pale yellow, γ = golden brown) is partly altered to chlorite, sphene and epidote. Idiomorphic crystals of iron ore have serrated margins and the accessories are apatite and zircon.

A large uniform pluton forms the mountains immediately to the north of the Murphy Glacier (Fig. 3). Outcrops of this pluton were examined at only one locality. This rock (W.315.1) is coarse-grained with crystals of pink potash feldspar up to 7·0 mm. in length and smoky grey translucent quartz up to 6·0 mm. in diameter. There are occasional dark medium-grained inclusions, and druses are occupied by terminated prisms of quartz and potash feldspar. The infrequent crystals of slightly zoned sodic plagioclase ($Ab_{86}An_{14}$–$Ab_{93}An_{7}$) are mostly replaced by potash feldspar. Orthoclase, in large subhedral plates, encloses plagioclase remnants which have a general optical continuity. The orthoclase also contains coarse irregular lamellae of albite and fine crystallographically orientated lamellae of albite, giving rise to microperthite. Large quartz plates exhibit a slight undulose extinction. There is little quartz-orthoclase symplectite but granular quartz occurs at the margins of the orthoclase crystals. The mafic constituents are present mainly as aggregates. The amphibole, in small irregularly shaped prismatic crystals, is strongly coloured and has α = greenish yellow, β = yellowish green, γ = green or bluish green and $2V\alpha = 30$–$40°$, indicating that it is ferrohastingsite. Biotite ($\alpha = \beta$ = very pale yellow, γ = dark brown) is less abundant than the amphibole. Indented crystals of magnetite are fringed by sphene. Orthite, apatite and zircon are conspicuous accessories.

4. *Granites*

The lower part of the Neb Bluff pluton (Fig. 10) is a uniform pale pink medium- to coarse-grained granite, which underlies a granodiorite with a sharp and dome-shaped contact. In one specimen (W.300.1) the plagioclase ($Ab_{79}An_{21}$–$Ab_{95}An_{5}$) is partly sericitized and occurs as subhedral plates up to 2·0 mm. in length. It is often replaced by orthoclase. The plagioclase crystals frequently have indented outlines and remnants in the orthoclase are in optical continuity. Some of the orthoclase shows "ghost zoning", resulting from the variation of fine inclusions of brownish iron oxide. Much of the orthoclase is microperthitic, containing fine albite lamellae about 0·01 mm. in width. Less regular but coarse albite lamellae are especially abundant where the plagioclase has been replaced. Quartz is present both as anhedral plates up to 2·0 mm. in diameter and as a coarse graphic intergrowth with the orthoclase microperthite. The larger crystals, which show no undulose extinction, are lobed into and include blebs of the microperthite. It contains trails of minute bubble inclusions.

The main mafic constituent is biotite ($\alpha = \beta =$ pale yellow, $\gamma =$ yellowish brown) which forms small laths partly altered to chlorite, epidote and sphene. The biotite is associated with subhedral indented crystals of magnetite. The accessories are apatite, zircon, ilmenite, tourmaline and orthite.

Dykes of granite intrude the gabbros at the Bragg Islands (W.389.4) and at Shull Rocks (W.398.4).

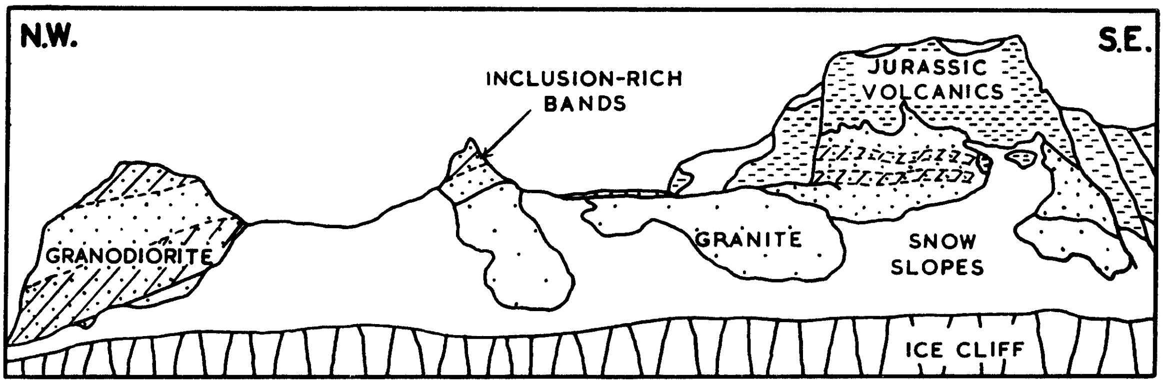


FIGURE 10

Contact relationships between the granite and granodiorite of the Andean Intrusive Suite and the Upper Jurassic Volcanic Group at Neb Bluff. View from the south-west.

5. *Alkali-granite*

The small outcrops 1·9 miles (3·0 km.) north-west of Lampitt Nunatak are of a reddish-weathering alkali-granite. This rock (W.318.1; Plate Vf) contains no individual crystals of plagioclase and the alkali-feldspar is microperthite, forming large plates and a micrographic intergrowth with quartz. The albite lamellae, which are about 0·02 mm. in width, are regular and have a single orientation within individual orthoclase crystals. These lamellae may be absent at the margins and cores of plates. About one-half of the total feldspar content is albite. Some of the quartz is in separate plates, dusty with inclusions, but most of it is intergrown with the microperthite. The quartz blebs maintain optical continuity over areas of about 1 sq. cm.

Corroded xenomorphic crystals of aegirine-augite are associated with anhedral riebeckite and subhedral and finely granular magnetite. The pyroxene, with $\alpha = \beta =$ grass-green, $\gamma =$ yellowish green and $\gamma{:}c =$ 68°, shows colour zoning in some crystals, the cores having $\alpha = \beta =$ light green, $\gamma =$ yellowish green and $\gamma{:}c = 62°$. Limonite is commonly developed along cracks. The riebeckite is strongly coloured with $\alpha =$ greenish blue, $\beta =$ pale brown, $\gamma =$ greyish blue. The amphibole has replaced pyroxene and finely granular magnetite is concentrated at its borders. The accessories are sphene, apatite, zircon and rutile.

6. *Microgranites*

Pale grey or pink microgranites occur as dykes with uniform orientations and thicknesses, which intrude gabbros, quartz-diorites, tonalites and granodiorites but are virtually absent in the adamellites and granites. Unlike the microgranites of the Orford Cliff Suite they are not associated with screens. Most of these dyke rocks have a granular saccharoidal texture and are aplites but others grade into pegmatites consisting principally of quartz and alkali-feldspar.

Specimens from Neb Bluff (W.300.2), Shull Rocks (W.397.2) and an islet near Watkins Island (W.409.2) are all similar to one another. In the microgranite (W.409.2) the major part consists of quartz and orthoclase-microperthite, developing an allotriomorphic granular texture. A small amount of albite forms separate anhedral crystals. The quartz shows a slight undulose extinction. The mafic constituents are sparse. A little chlorite and leucoxene pseudomorph biotite and there is some epidote and magnetite.

7. *Inclusions in the acid and intermediate rocks*

The inclusions fall into two groups according to whether they have been derived from either the Upper

Jurassic volcanic rocks or the Andean gabbros. No other types of inclusions have been found. In most of the intrusive rocks the majority of the xenoliths are hornfelsed gabbros. They are especially common in the intermediate rocks but they are also frequent in the tonalites and granodiorites. Xenoliths of Upper Jurassic volcanic rocks are uncommon but they can be found in bulk in a few plutons (Plate IIId). At Neb Bluff the volcanic rocks have been thermally metamorphosed to the pyroxene-hornfels facies and have been assimilated into a granodiorite pluton. The petrographic gradation from granodiorite to hornfels is set out in Table VIII. Solutions derived from the pluton have permeated into the volcanic rocks, giving rise to igneous textures and minerals. At the same time, the assimilation of the volcanic rocks has resulted in some basification of the magma.

TABLE VIII

CONTACT PHENOMENA AT NEB BLUFF

Specimen Number	*Rock Type and Field Occurrence*	*Petrography*
W.300.2	Granodiorite from pluton	Essential minerals are plagioclase, quartz and orthoclase microperthite. The plagioclase (An_{40-8}) forms euhedral crystals which are larger than anhedral crystals of quartz and potash feldspar. The texture is coarse-grained granitic. Pale green hornblende equals biotite (including chlorite after biotite) in quantity.
W.300.4	Granodiorite close to inclusion	Essential minerals are the same as in specimen W.300.2. The plagioclase (An_{37-13}) forms phenocrysts in an allotriomorphic granular matrix of quartz and orthoclase microperthite. Biotite is the major mafic constituent and pale green hornblende is only found in inclusion relicts. For a distance of 1 mm. from the inclusion margin the rock is free of inclusion relicts and plagioclase phenocrysts.
W.300.4	Hornfelsed volcanic inclusion in granodiorite	Essential minerals are plagioclase, hornblende, orthoclase and quartz. Plagioclase (An_{16}) forms xenomorphic laths and pale green hornblende builds anhedral prisms. Both are partly replaced by orthoclase and quartz. Numerous idioblasts of plagioclase have a similar detailed appearance to those in the granodiorite.
W.250.1	Hornfelsed volcanic inclusion cut by granite dyke	Essential minerals are plagioclase, hornblende and quartz. Plagioclase (An_{38-20}) forms indented laths and pale green hornblende builds anhedral prisms. Both have been replaced by quartz. The granite dyke consists of allotriomorphic quartz and orthoclase with some subhedral phenocrysts of plagioclase (An_{41-15}). Biotite exceeds hornblende in quantity. For a distance of 1–2 mm. into the inclusion from its border biotite displaces hornblende as the dominant ferromagnesian mineral and there is a smaller proportion of iron ore than in the inclusion.

The petrography of the gabbro xenoliths is consistent with that of basic rocks which have been metamorphosed by intermediate and acid intrusives. At a small islet off Phantom Point (W.514) a hypersthene-bearing tonalite crops out; this is a contaminated variant of the granodiorite exposed closer inshore. This tonalite is very full of dark medium-grained inclusions up to about 15·0 cm. in diameter and which have sharp margins against the country rock. In one example (W.514.1) indented laths of plagioclase (mostly labradorite) have marginal normal zoning. The chief mafic constituent is a green hornblende, which forms xenomorphic prisms poikilitically enclosing the plagioclase. It often contains remnants of augite and is marginally replaced by actinolite. Occasional large ragged crystals of biotite enclose the other minerals. Orthoclase and quartz, which are present in small amounts, have replaced the hornblende and plagioclase. The accessories are iron ore, pyrite, sphene, leucoxene and apatite. This rock was formerly a gabbro but it has been modified by introduction of material from the tonalite (notably silica and alkalis). At many localities a proportion of the gabbro-hornfels xenoliths carry large crystals of plagioclase up to about 1·0 cm. in diameter. These are relicts from the original gabbros and are often found to be bytownite in composition.

Small pale grey medium-grained inclusions, relatively few in number, are the only ones which occur in the granodiorite of Mügge Island. Specimen W.326.3 consists mostly of allotriomorphic crystals of oligoclase and quartz. The former includes concentrations of small greenish brown biotite flakes, sericite and clinozoisite and the quartz replaces the plagioclase, tending to form porphyroblasts. Occasional larger plagioclase crystals include granular quartz and show both normal and oscillatory zoning; they have formed at the expense of the matrix. The biotite is associated with iron ore, chlorite, sphene and leucoxene.

D. Discussion

1. *Comparison with adjacent areas*

The rocks of the acid group closely resemble those of the Marguerite Bay area (Adie, 1955) and the Graham Coast (Curtis, 1960). Intrusion sequences have been recorded from both these areas. Adie (1955, p. 9) has not reported any granodiorites from the Marguerite Bay area but he mentions occurrences on the east coast of Graham Land in the vicinity of Cape Robinson and in Trinity Peninsula. Curtis (1960, p. 132–47) has described several granodiorite plutons from the Graham Coast. The more basic granodiorites of the Loubet Coast are very similar to those with tonalitic affinities on the Graham Coast. Curtis (1960, p. 175, 180) has suggested that these rocks have resulted from contamination of a granodiorite magma by gabbroic material, although to a lesser degree than in the diorites and tonalites. The more acid granodiorites of Mügge Island and Watkins Island are rather like the potash feldspar-poor facies of the Cape Monaco Granite (Hooper, 1962, p. 44) and it is interesting that they have a similar geographical location.

Curtis (1960) has compared the Beascochea Bay granodiorite, an acid granodiorite, with the Cape Berteaux granite (Adie, 1955, p. 7), which is a biotite-adamellite according to the present classification. The adamellite of the Murphy Glacier area is very similar to the Beascochea Bay granodiorite. Curtis has suggested that this granodiorite is the closest approach to the original uncontaminated and undifferentiated acid magma.

Curtis (1960, p. 152) has correlated the granophyres of the Graham Coast with the typically granophyric Red Rock Ridge granite of the Marguerite Bay area. The coarse- and medium-grained granites of the Graham Coast (Curtis, 1960, p. 147–52) have no known equivalents in the Marguerite Bay area. Curtis (1960, p. 178) considers that the granites and granophyres, which form small intrusions on the Graham Coast, have resulted from crystallization-differentiation of the original granodiorite magma. Both of these rocks have a similar mineralogical composition and they differ only in grain-size and texture. Curtis suggests that, although they are of the same age, the differences are due to varying conditions of crystallization and, in particular, to the level of intrusion. The granite of Neb Bluff is similar to the medium-grained phase of granite of the Graham Coast but the granophyric adamellite of Shanty Point appears to be more basic than any of the granophyres of the Graham Coast.

The alkali-granite is the first to be recorded *in situ* from Graham Land. It is closely comparable with the alkaline microgranite found as a loose block on "Wandel Island" (now Booth Island) and described by Gourdon (1907, p. 1224). This rock carries phenocrysts of orthoclase, quartz, aegirine-augite and riebeckite, and the ferromagnesian minerals have almost identical properties to those of the alkali-granite described in this report.

Adie (1955, p. 9) has remarked that the quartz-diorites are the commonest of all the igneous rocks of Graham Land, but for the localities visited on the Loubet Coast this is not so. The quartz-diorites and tonalites are similar to those found elsewhere in Graham Land and correspond closely to those described by Curtis (1960) from the Graham Coast. However, he has not recorded any granitic-textured silicic tonalites such as those found at the islets off Adelaide Island.

In the abundance and range in composition of the gabbros and related rocks the Loubet Coast differs from adjacent areas. Adie (1955, p. 16) has recorded only a few gabbro intrusions from the Marguerite Bay area, the most interesting being that of the Terra Firma Islands, where a small gabbro intrusion shows rhythmic layering in its marginal part. The modal analyses of these rocks are distinctly different from those of the Loubet Coast gabbros. However, the uralitized hornblende-gabbros of Cape Bryant (Adie, 1955, p. 13) are similar to some of the amphibolized gabbros of the Loubet Coast. Small gabbro intrusions also have a widespread distribution on the Graham Coast (Curtis, 1960) and they generally form more uniform masses than those of the Loubet Coast. Some of the gabbros, norites and quartz-bearing gabbros are petrographically similar to those of the Loubet Coast but so far no troctolites have been recorded from the Graham Coast.

2. *Petrogenesis*

Many characters of intrusion have been observed and it is clear that the rocks of the Andean Intrusive Suite have a magmatic origin. The Andean plutonic rocks of the Graham Coast, the Loubet Coast and the Marguerite Bay area are all similar and it is probable that in all three areas they had the same genesis. However, the hypothesis of crystallization-differentiation presented by Adie (1955) does not seem to account adequately for *all* the characters noticed in the rocks of this area. First, the compositional range and the structures of the gabbros and related rocks indicate that these rocks are not direct crystal cumulates of an original quartz-diorite magma. Secondly, the textures of the quartz-diorites and tonalites show that they are probably hybrid in origin. Thirdly, the widespread occurrence of early Palaeozoic intrusive rocks on the Loubet Coast permits the possibility of re-mobilization of some of these rocks during the intrusion of the Andean rocks.

The acid Andean rocks of the Loubet Coast form a discontinuous series ranging from tonalite to alkali-granite in composition and individual members of this series occur in discrete plutons which, in themselves, have little variation. It is considered that the acid members of the Orford Cliff Suite resulted from segregation of an originally uniform magma at a relatively late stage of crystallization and that differentiation was completed at an advanced stage of consolidation by metasomatic processes. Except for the limited replacement of plagioclase by quartz and potash feldspar, evidence of metasomatism is absent in the acid rocks of the Andean Intrusive Suite. Therefore, it is likely that the acid members of the Andean Intrusive Suite have resulted from crystallization-differentiation of a magma originally of a granodiorite composition.

Thus, it seems there were two original magmas, one of granodiorite and the other of gabbro composition. Similarly, the rocks of the early Palaeozoic Intrusive Suite are thought to have been derived from two magmas of gabbro and granodiorite composition. Hooper (1962) has presented a very similar hypothesis for the genesis of the Andean plutonic rocks of Anvers Island older than the metasomatism. However, the hybrid rocks described by him are distinctly different from those of the Loubet Coast. The hybrid intermediate rocks of the Loubet Coast are in fact similar to the mobilized tonalites described by Hooper.

Groups 1 and 2 of the gabbros and related rocks (Table IV) represent the primary crystallization of a basic magma. The majority of these rocks are accumulates (Wager, Brown and Wadsworth, 1960), there having been continuous diffusion during crystallization between the magma chamber and the interprecipitate liquid. The variation in composition is not exceptional and it is not comparable with that shown by the layered gabbro intrusions, e.g. that of Skaergaard. Most of the mesoscopic structures result from magmatic flow, but the graphic texture and orbicular structure probably represent static crystallization conditions.

The gabbros of group 3 crystallized from a magma with greater fluidity and acidity. This magma also carried partly or wholly consolidated gabbros belonging to group 1. This magma either resulted from the crystallization-differentiation of the earlier one from which the gabbros of groups 1 and 2 crystallized or the acidification was from an exterior source, i.e. the Andean granodiorite magma.

The gabbro dykes (group 4) pose a special problem. Banded gabbros have also been recorded from Anvers Island by Hooper (1962, p. 27). From an examination of the rock exposures themselves and photographs, it is clear that the banding of these rocks is mostly comparable with that shown by the dyke phases of the Loubet Coast rather than with magmatic flow structures as claimed. Many of the Loubet Coast dykes have undoubtedly resulted from the primary crystallization of a magma which was often as basic as that from which the gabbros of group 1 crystallized. In some cases the intrusion was of a crystal mush rather than of a pure liquid. Such rocks completed their crystallization with little diffusion between the magma and the interprecipitate liquid.

The gabbros of group 5 are either normal thermally metamorphosed products of earlier gabbros or ones that have been acidified. In these cases it is more likely that the acid material was from an external source. Hydrothermal alteration and especially the amphibolization of many of the gabbros of all groups may be related to this final phase, immediately in advance of the acidic plutons of the Andean Intrusive Suite.

IX. POST-ANDEAN HYPABYSSAL ROCKS

BASALT and dolerite dykes which intrude the Andean plutonic rocks are later in age than all the effects related to the intrusion of the plutonic suite. These dykes invariably follow pre-existing joint sets. They are uncommon in comparison with the multitude of dykes which are of Upper Jurassic age. However, a few dykes have been found at most of the important localities. Dykes belonging to the same swarm intrude the Orford Cliff Suite and the Upper Jurassic Volcanic Group.

Tyrrell (1945, p. 70) has described four specimens from dykes cutting norites at the Bragg Islands. Three of these are olivine-basalts with microphenocrysts of bytownite (An_{90}) and olivine, and a groundmass consisting of plagioclase, augite and magnetite. The fourth specimen is described as a highly carbonated coarse basalt or dolerite.

A few representative samples of these dykes have been examined during the course of the present investigation but they do not include any from the Bragg Islands. A dyke from Megaw Island (W.537.1) which intrudes gabbros is an olivine-basalt. Rounded microphenocrysts of olivine have been completely replaced by chlorite, pyrite, tremolite and pistacite. The groundmass consists of laths of plagioclase ($Ab_{46}An_{54}$), euhedral crystals of pale brownish augite, granular iron ore bordered by leucoxene, and interstitial chlorite. The plagioclase is partly altered to chlorite and albite. Small prisms of yellowish brown hornblende, replacing augite, are developed adjacent to the pseudomorphs after olivine. A dyke from Detaille Island (W.558.1) which intrudes volcanic rocks is a quartz-dolerite. Laths, grading in size to microphenocrysts, of plagioclase ($Ab_{30}An_{70}$–$Ab_{49}An_{51}$) show both normal and oscillatory zoning. Narrow cracks are filled with chlorite. The other constituents are brownish augite, iron ore, leucoxene and chlorite. Prisms of brownish augite sometimes enclose small laths of plagioclase and euhedral iron ore. Elsewhere the iron ore is indented and fringed by leucoxene. Patches of quartz are associated with interstitial chlorite.

Other dykes contain a substantial proportion of hornblende. An example from Shull Rocks (W.393.4), which intrudes granodiorite, is a porphyritic hornblende-basalt. Phenocrysts of hornblende (α = pale brown, β = brown, γ = brown or yellowish brown; $\gamma{:}c = 24°$) up to 5·0 mm. in length contain orientated inclusions of iron ore and small crystals of plagioclase. Subhedral microphenocrysts of augite are partly replaced by chlorite and calcite, and the phenocrysts of plagioclase have been severely altered to sericite. The groundmass consists of plagioclase ($Ab_{44}An_{56}$–$Ab_{50}An_{50}$), iron ore, chlorite and calcite. A further example, from Malus Island (W.529.2), intrudes gabbros and is a hornblende-biotite-microdiorite. There are a few microphenocrysts of andesine, but the groundmass consists of plagioclase ($Ab_{60}An_{40}$–$Ab_{81}An_{19}$), yellowish green hornblende, brown biotite, magnetite and ilmenite.

There is a considerable range in the composition of the post-Andean dykes, from olivine-basalts to andesites. The basalts are probably the commonest and no acid dykes have been recorded.

X. STRUCTURE

THE dips of the rocks comprising the Upper Jurassic Volcanic Group are gentle and no low-angle faults have been recorded. Mesoscopic high-angle faults displace the volcanic rocks at Roux Island and near Holdfast Point. This faulting is earlier than the altered andesite dykes which intrude the volcanic rocks and may have taken place at the time of vulcanicity. There is very widespread jointing and shearing both of the Upper Jurassic Volcanic Group and the Andean Intrusive Suite which cannot be simply related to the observed form of the plutons. Hydrothermal alteration accompanies the shearing, the volcanic rocks and the gabbros being the rocks most affected. In some cases, e.g. at the islets off Thorne Point (W.320), microgranite dykes are younger than the hydrothermal veins. Some of the granite and adamellite plutons are unaffected. It is therefore likely that these shear phenomena are related to the late acid intrusions of the Andean Intrusive Suite, some of which are not exposed at the present level of erosion.

The major structures of this area are associated with the intrusion of the plutonic rocks and the Upper Jurassic Volcanic Group plays a comparatively passive rôle. The gabbros and related rocks form small plutons with irregular contacts in the volcanic rocks. Near-vertical foliation suggests upwards movement of the magma of the early gabbros at most localities. But this is not invariable and the gabbros of Cape Bellue have a foliation which is only gently inclined. Again, vertically disposed flow structures are commonest in plutons of the intermediate hybrid rocks, which also have intricate contacts with the earlier rocks. In contrast, the intrusions of the acid rocks are more uniform and have more regular walls. The composite plutons of Neb Bluff and Panther Cliff are of special interest since they have almost flat-lying structures. These represent a type of gravity layering resulting from assimilation. Other acid plutons lack primary internal structures. In all the intrusive rocks linear structures are only weakly developed.

The intensive deformation suffered by the Orford Cliff Suite is believed to have been prior to the Upper Jurassic vulcanicity. There is the possibility that the plutons were almost contemporaneous with an orogeny, and for this reason the intrusion of this suite forms an important part of the structural evolution of Graham Land.

To summarize, the stratigraphy of the area has been given in Table I. The phases of deformation are: first, the regional metamorphism and folding of the Basement Complex; secondly, that associated with the intrusion of the early Palaeozoic Intrusive Suite; thirdly, that allied with the Andean Intrusive Suite. In the last phase, deformation was very subsidiary to igneous intrusion, but in the second phase the effects of deformation were far more pronounced.

There is no clear geological evidence but it is likely that block-faulting took place after the intrusion of the Andean acid plutons but before the high-level planation. This would indeed account for much of the present coast and glacier trends. Major faults of this age have been suggested by Curtis (1960, p. 20) as being present in the Graham Coast area.

XI. SUMMARY

THE geology of the area extending from The Gullet to Auvert Bay and from the southern Biscoe Islands to the Avery Plateau has been described and compared with adjacent parts of Graham Land. The rocks are nearly all igneous and most of them are either volcanics of Upper Jurassic age or plutonics of the Andean Intrusive Suite.

The Orford Cliff Suite, a distinctive suite of plutonic rocks occurring in the vicinity of Lallemand Fjord, are believed to be early Palaeozoic in age. Undoubted pre-Upper Jurassic intrusive rocks crop out near Detaille Island and occur as rare fragments in the Upper Jurassic agglomerates and lapilli tuffs. Xenoliths of the Basement Complex and screens of early Palaeozoic volcanic and hypabyssal rocks occur in the Orford Cliff Suite. The early Palaeozoic intrusive rocks are mainly tonalites, granodiorites, adamellites and granites. The sequence of intrusion was from basic to acid and cognate xenoliths of gabbros are common. It is likely that much of the variation in composition has resulted from metasomatism at a late stage of intrusion. The rocks of the Orford Cliff Suite underwent intensive deformation at and after the time of their intrusion.

The Upper Jurassic Volcanic Group comprises a thick succession of lavas and pyroclastic rocks, having a minimum thickness of 5,000 ft. ($\sim$ 1,500 m.). Most of these rocks are of andesitic character but they range in composition from rhyolites to basalts. The sequence of extrusion is not certain. Siliceous crystal tuffs, sometimes having the appearance of quartz-plagioclase-porphyries, are interbedded with the other volcanic rocks. It is believed these are equivalent to the quartz-plagioclase-porphyry succession of the Oscar II Coast which was extruded contemporaneously with the andesitic volcanic rocks of the west coast of Graham Land. A phase of hypabyssal intrusion formed an integral part of the Upper Jurassic vulcanicity. Most of these dykes are andesites and dacites. The Upper Jurassic Volcanic Group has undergone extensive hydrothermal alteration and some local thermal metamorphism as a result of the Andean intrusions; there is little evidence of metasomatism.

The members of the Andean Intrusive Suite range in composition from femic troctolites to alkali-granites. They form a large number of discrete intrusions and the sequence is from basic to acid. Three major sub-divisions have been recognized. The first comprises the gabbros, norites and troctolites, which are believed to represent direct crystallization of a basic magma. The second group includes the quartz-diorites and tonalites, which are considered to have resulted from hybridization of salic and femic material.

The third group, the acid rocks, includes tonalites, granodiorites, adamellites, granites and alkali-granites, which are believed to be differentiates of a granodiorite magma.

The gabbros and related rocks have been further subdivided on the basis of their mesoscopic structures. They comprise rocks resulting from the crystallization of a basic magma in normal, static and fluid conditions. There was widespread injection of gabbro dykes. Some gabbros were metamorphosed by later acid Andean intrusions, whilst in other cases there has been some metasomatism. Many of the Andean plutonic rocks have been hydrothermally altered. The replacement process is believed to have resulted from the passage of solutions derived from the acid Andean magmas. Thermal metamorphism is confined to the immediate vicinity of contacts, but locally there has been assimilation of earlier plutonic rocks by later ones and of the Upper Jurassic volcanic rocks by the acid Andean intrusives.

A late phase of basalt dyke intrusion took place after all the Andean events.

Little is known of the large-scale structures of this area. The Upper Jurassic Volcanic Group is little disturbed and the major structures are the plutons of the Andean Intrusive Suite. Block-faulting accounts adequately for the major physiographic features of the area. It is likely that this was post-Andean and it was certainly earlier than the development of the high-altitude plateau. The present physiography has resulted mainly from glaciation with the base-level near to the present sea-level.

XII. ACKNOWLEDGEMENTS

THE field work was carried out from the Falkland Islands Dependencies Survey station at Detaille Island, Loubet Coast. I wish to thank Lt-Cmdr A. B. Erskine, Mr. B. L. H. Foote and the other members of the station for their counsel and assistance. The laboratory work was done in the Department of Geology, University of Birmingham, by kind permission of Professor F. W. Shotton. My thanks are due to Dr. R. J. Adie for supervising the work, for advice during the course of the study and for help in the preparation of the manuscript. I am also grateful to the members of the Falkland Islands Dependencies Survey research group for helpful discussion. I wish to thank Mr. L. W. Vaughan, who prepared the plates, Mr. D. J. Jones, who made the rock sections, and Mr. M. D. Rhodes, who drew the maps and diagrams.

XIII. REFERENCES

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

————. 1954. The Petrology of Graham Land: I. The Basement Complex; Early Palaeozoic Plutonic and Volcanic Rocks. *Falkland Islands Dependencies Survey Scientific Reports*, No. 11, 22 pp.

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

————. 1957. The Petrology of Graham Land: III. Metamorphic Rocks of the Trinity Peninsula Series. *Falkland Islands Dependencies Survey Scientific Reports*, No. 20, 26 pp.

BODMAN, G. 1916. Petrographische Studien über einige antarktische Gesteine. *Wiss. Ergebn. schwed. Südpolarexped.*, Bd. 3, Lief 15, 1–100.

CURTIS, R. 1960. *The Petrology of the Graham Coast and Offshore Islands, Graham Land, West Antarctica.* Ph.D. thesis. University of Birmingham, 199 pp. [Unpublished.]

GOURDON, E. 1907. Sur un microgranite alcalin recueilli sur la Terre de Graham par l'expédition antarctique du Dr. Charcot, *C.R. Acad. Sci., Paris*, **144**, No. 22, 1224–26.

HOLTEDAHL, O. 1929. On the Geology and Physiography of Some Antarctic and Sub-antarctic Islands. *Sci. Res. Norweg. antarct. Exped.*, No. 3, 172 pp.

HOOPER, P. R. 1959. *The Petrology of Anvers Island and Adjacent Islands, West Antarctica.* Ph.D. thesis, University of Birmingham, 193 pp. [Unpublished.]

————. 1962. The Petrology of Anvers Island and Adjacent Islands. *Falkland Islands Dependencies Survey Scientific Reports*, No. 34, 69 pp.

NOCKOLDS, S. R. 1954. Average Chemical Compositions of Some Igneous Rocks. *Bull. geol. Soc. Amer.*, **65**, No. 10, 1007–32.

TYRRELL, G. W. 1945. Report on Rocks from West Antarctica and the Scotia Arc. '*Discovery*' *Rep.*, **23**, 37–102.

WAGER, L. R., BROWN, G. M. *and* W. J. WADSWORTH. 1960. Types of Igneous Cumulates. *J. Petrol.*, **1**, 73–85.

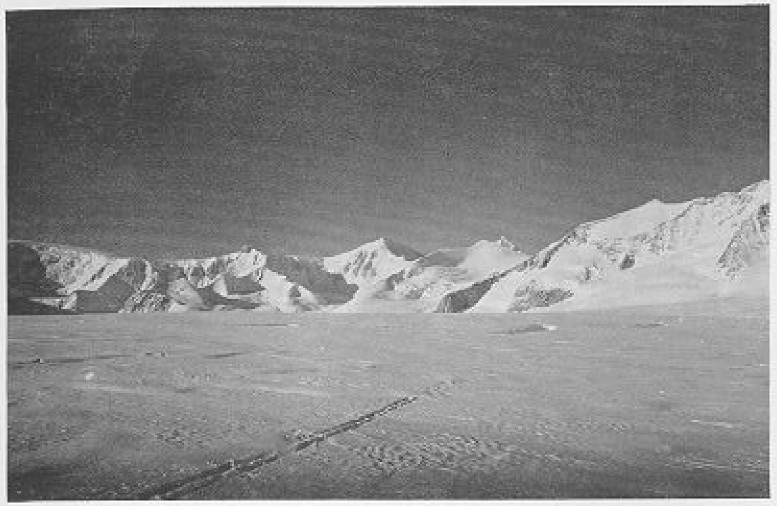
PLATE I

a. View of the mountains north of the Murphy Glacier. The entire area is composed of adamellite.

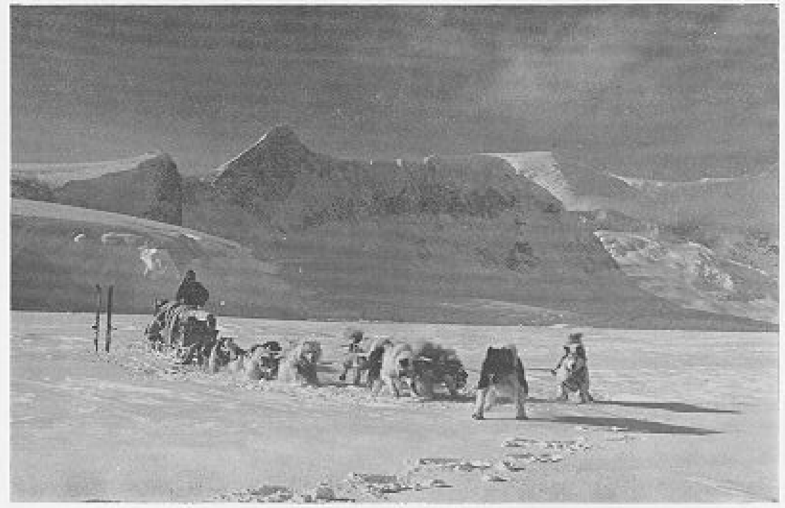
b. View of Panther Cliff from the south-west. The Upper Jurassic Volcanic Group is intruded by ? granodiorite and adamellite.

c. View of the Fowler Islands, the Bragg Islands and Protector Heights from the Bernal Islands.

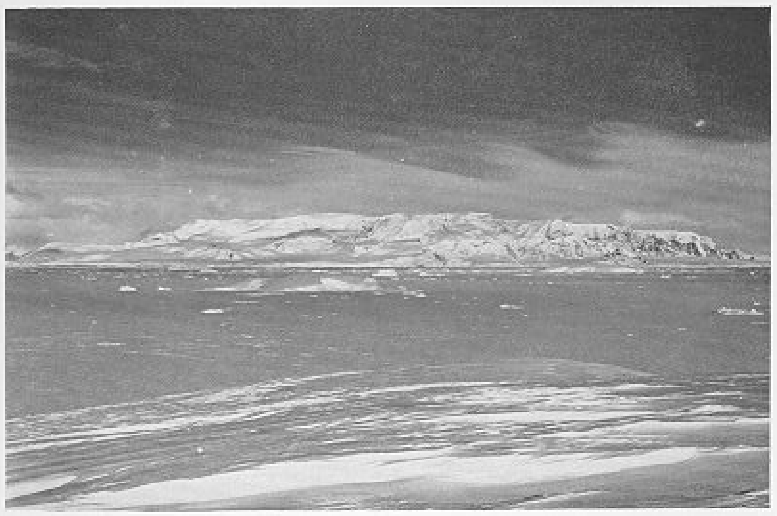
d. View of Gränicher Island, Pfaff Island and Mügge Island of the Bennett Islands. The mountains of central Adelaide Island are in the background.



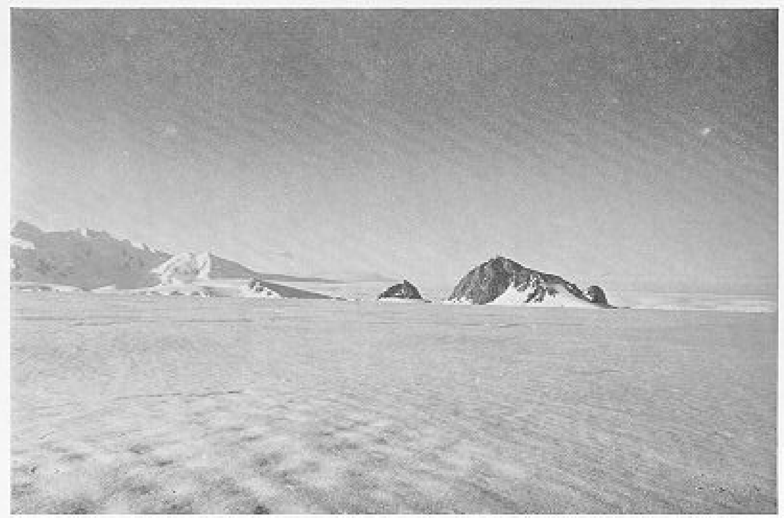
a



b



c



d

PLATE I

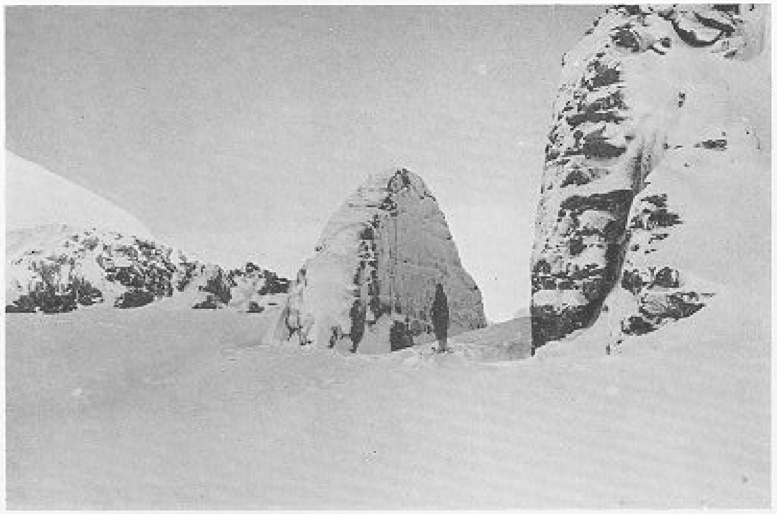
PLATE II

a. Stacks in well-jointed tonalite at the Bernal Islands (W.420).

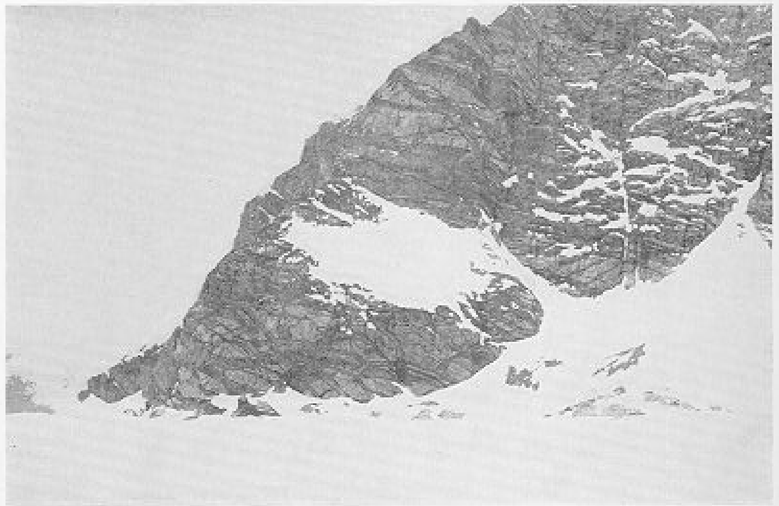
b. Dyke swarm cutting siliceous tuffs 3 miles (4·8 km.) north-east of Cape Bellue (W.525).

c. Adamellite dyke at granodiorite/tonalite contact; Orford Cliff (W.363).

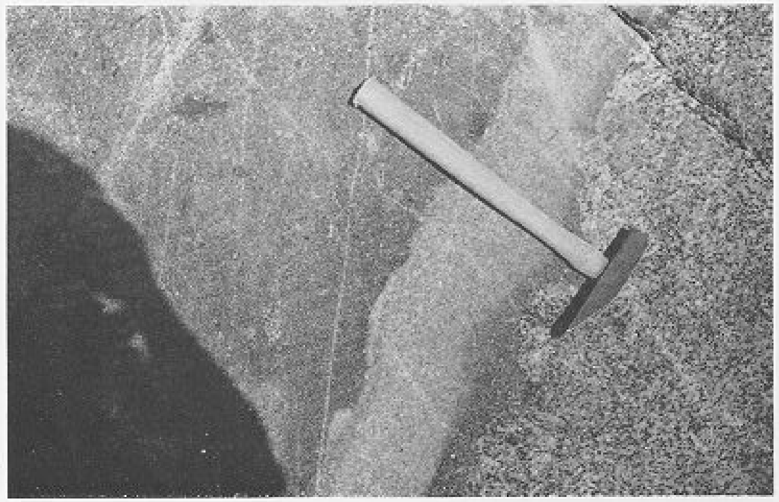
d. Faulted xenolith of hornblende-biotite-schist in granodiorite at Orford Cliff (W.363).



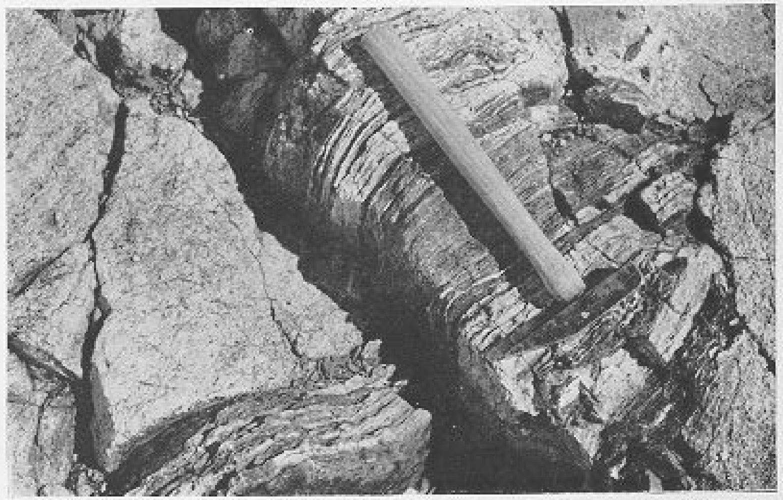
a



b



c



d

PLATE II

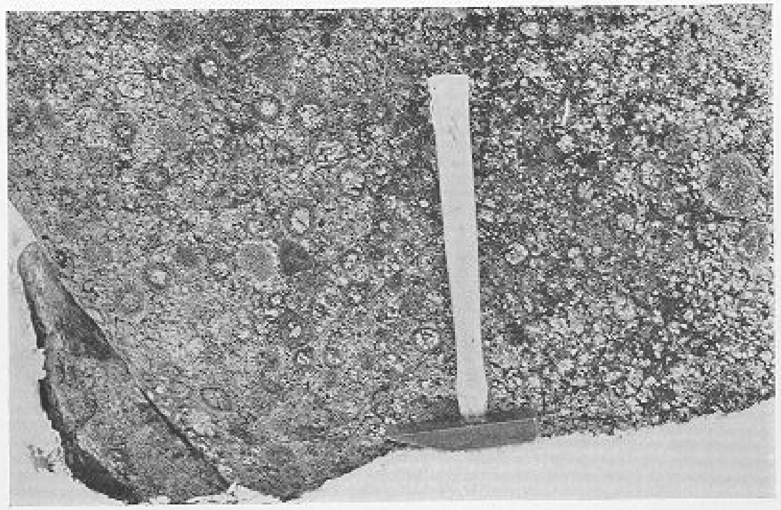
PLATE III

a. Orbicular structure in gabbros at Jona Island (W.541).

b. Dykes of gabbro at Megaw Island (W.536).

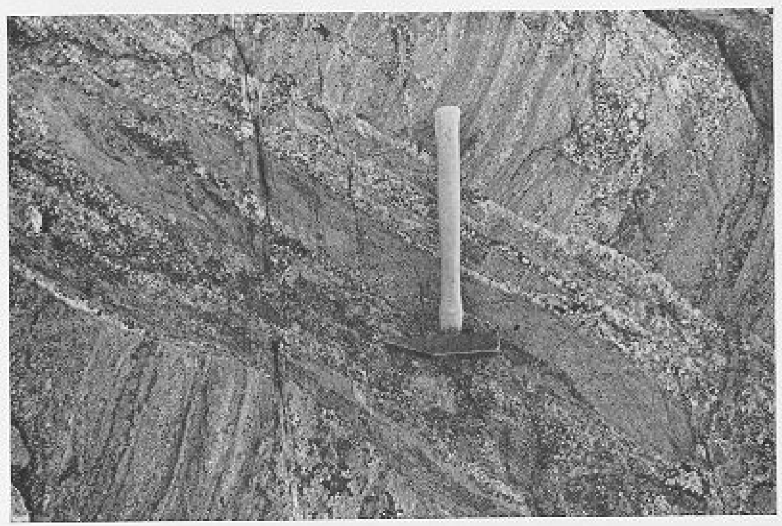
c. Rhythmical layering in gabbro dykes at Tutton Point (W.546).

d. Lenticular inclusions of hornfelsed gabbro and schlieren in quartz-diorites at the Foote Islands (W.506). The dark inclusion at the top is a hornfelsed volcanic rock.

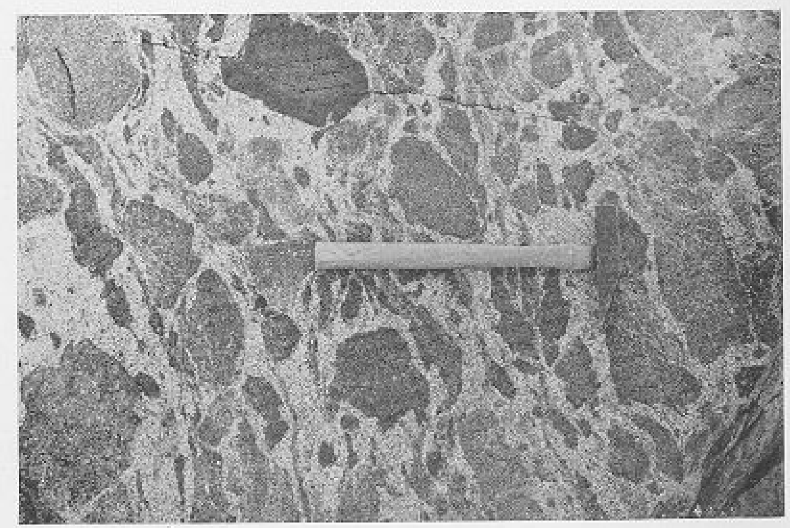


a

b



c



d

PLATE III

PLATE IV

a. Post-crystalline deformation of foliated granodiorite of the Orford Cliff Suite. The photograph shows strained biotite, quartz with undulose extinction and microcline; Orford Cliff (W.363.7; X-nicols; × 32).

b. Mylonitized granite-gneiss of the Orford Cliff Suite. Flaser texture is well developed; nunatak 2·8 miles (4·5 km.) east-north-east of Neb Bluff (W.307.2; X-nicols; × 32).

c. Flow texture in porphyritic dacite. Plagioclase phenocrysts have been replaced by albite and epidote; Detaille Island (W.82.1; X-nicols; × 32).

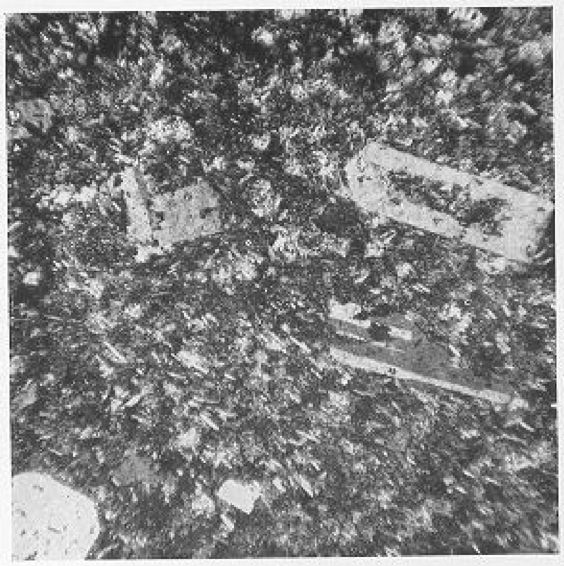
d. Siliceous crystal tuff. Quartz xenocrysts have euhedral or embayed margins. Spherulites of orthoclase and quartz are developed in the matrix. The veinlet is epidote; 3 miles (4·8 km.) north-east of Cape Bellue (W.525.1; X-nicols; × 32).

e. Troctolite. Anhedral remnants of olivine are enclosed by broad areas of hornblende and spinel (dark). The reaction products have replaced the surrounding plagioclase irregularly; Tutton Point (W.335.3; ordinary light; × 32).

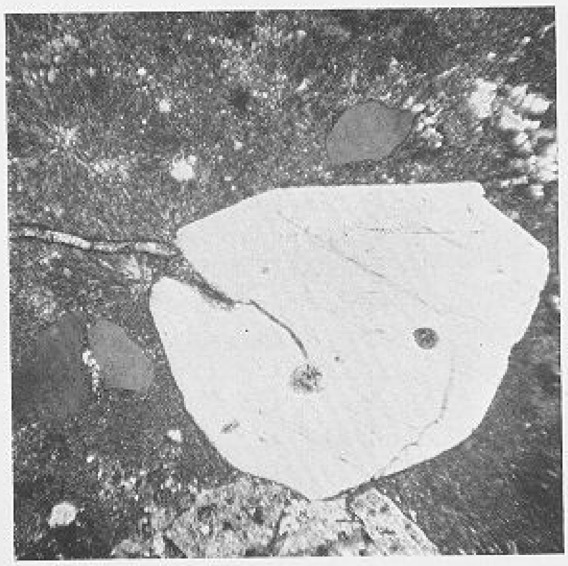
f. Amphibolized gabbro. Augite and bytownite have been extensively replaced by actinolite and spinel (dark). The central area of tremolite and fine magnetite represents former olivine; Jona Island (W.541.1; ordinary light; × 32).

a

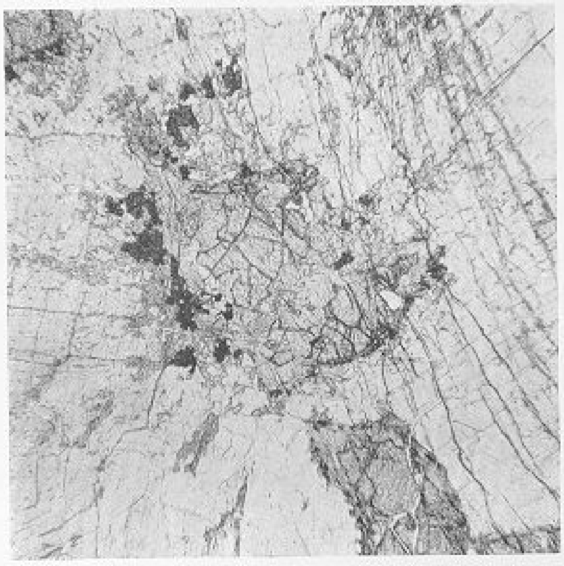
b



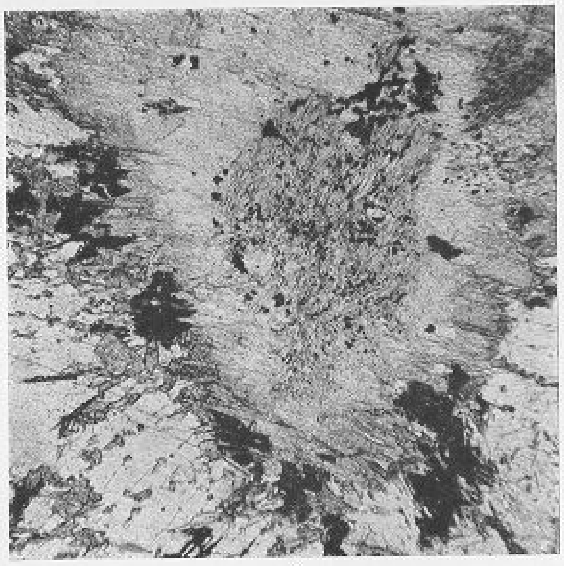
c



d



e



f

PLATE V

a. The selective replacement of bytownite by augite (dark patch) in a felsic schlieren in olivine-gabbro. There is a very fine-grained sieve texture; Megaw Island (W.535.1; X-nicols; × 32).

b. Reaction phenomena in olivine-hypersthene-gabbro. Rounded and embayed crystals of iron ore and olivine are enclosed by augite; Bragg Islands (W.386.1; X-nicols; × 32).

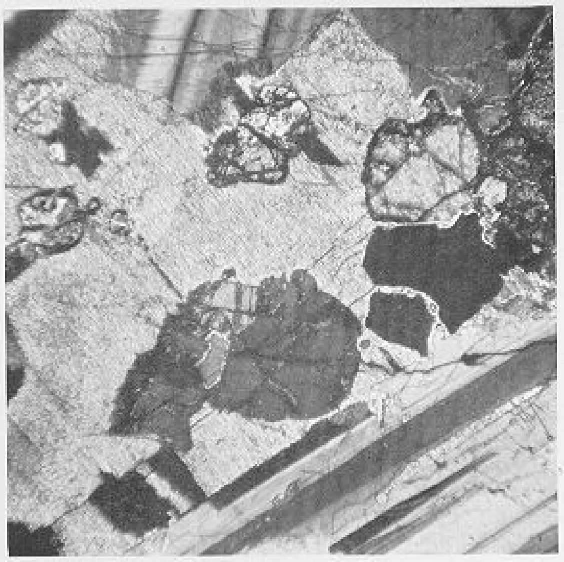
c. Amphibolized quartz-gabbro. Plagioclase and hornblende have been partly replaced by quartz. Porphyroblastic crystals of biotite are represented by chlorite and leucoxene; Hoodwink Island (W.461.3; X-nicols; × 32).

d. Tonalite showing typical replacement textures. Augite has been replaced by hornblende, biotite and quartz; Bernal Islands (W.524.1; ordinary light; × 32).

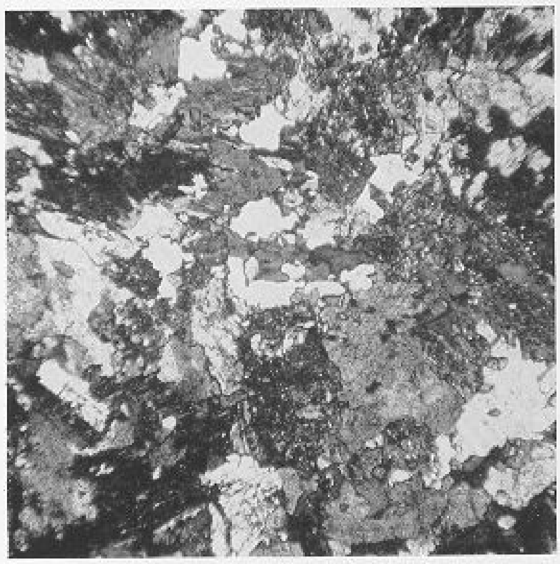
e. Adamellite showing granophyric texture and orientated lamellae of orthoclase in quartz; Shanty Point (W.449.1; X-nicols; × 32).

f. Alkali-granite showing the textural relationships between magnetite, aegirine-augite and riebeckite. Orthoclase-microperthite and quartz are also present; nunatak 2 miles (3·2 km.) north-west of Lampitt Nunatak (W.318.1; ordinary light; × 32).

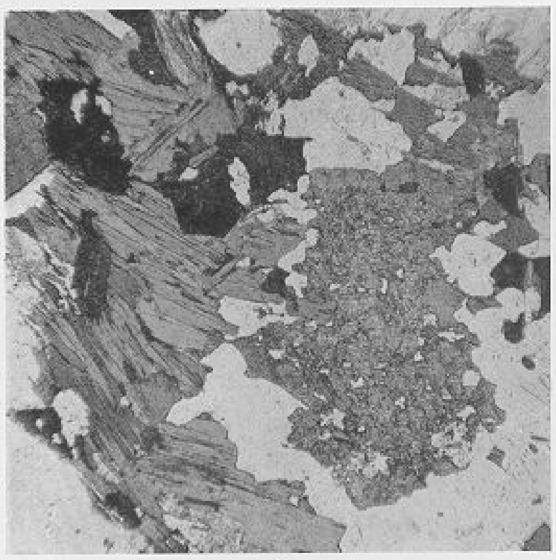
a



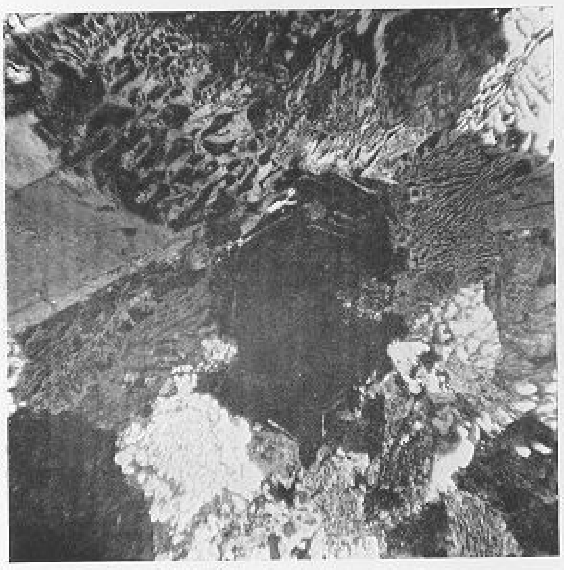
b



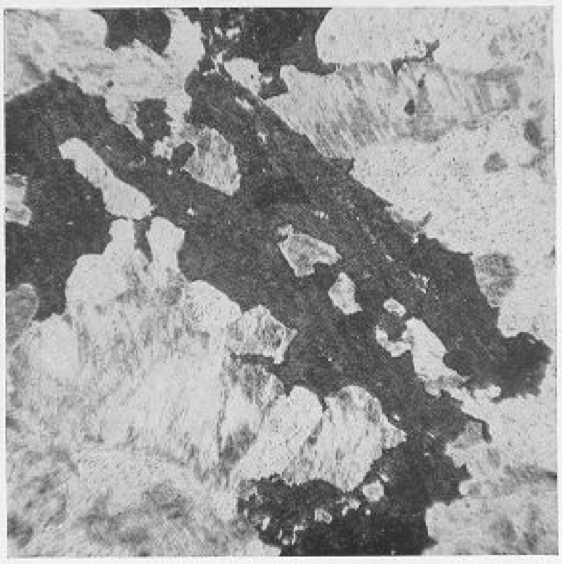
c



d



e



f