BRITISH ANTARCTIC SURVEY
(*formerly Falkland Islands Dependencies Survey*)
SCIENTIFIC REPORTS
No. 43

THE BASEMENT COMPLEX OF NENY FJORD, GRAHAM LAND

By
A. K. HOSKINS, B.Sc., Ph.D.
British Antarctic Survey
and
Department of Geology, University of Birmingham

LONDON: PUBLISHED BY THE BRITISH ANTARCTIC SURVEY: 1963

THE BASEMENT COMPLEX OF NENY FJORD, GRAHAM LAND

By

A. K. HOSKINS, B.Sc., Ph.D.

British Antarctic Survey
and
Department of Geology, University of Birmingham

(Manuscript received 15th January, 1963)

ABSTRACT

THE general stratigraphy of the Neny Fjord area of Marguerite Bay is described with specific reference to the Basement Complex metamorphic rocks. The scattered nature of the rock outcrops in this area precludes far-reaching petrological correlations and a form of metamorphic correlation has been used. The Basement Complex rocks have been subdivided into three major groups: banded biotite-gneisses, dioritic gneisses and granite-gneisses, of which the latter two groups are undoubtedly *ortho*-gneisses. The banded biotite-gneisses, which are the oldest and are believed to be of a sedimentary origin, formed a basement into which the dioritic gneisses and the granite-gneisses were successively intruded later. After the further intrusion of a series of basic dykes, metamorphism, potash metasomatism and local mobilization of the granite-gneisses took place. This metamorphism reached the lower stages of the almandine-amphibolite facies, and after the intrusion of a second group of basic rocks there followed another metamorphism of the albite-epidote-amphibolite facies. During the intrusion of the (?) early Palaeozoic plutonic rocks, the Basement Complex was locally mobilized, but when the Andean Intrusive Suite was emplaced the Basement Complex was rigid and block-faulting occurred in this area. At Randall Rocks the contact metamorphic aureole surrounding the Andean biotite-granite has been traced in the granite-gneiss. A major fault line which passes through Roman Four Promontory, Neny Island and Millerand Island subdivides this whole area into two distinct petrological parts.

CONTENTS

I. INTRODUCTION

MARGUERITE BAY, which is situated on the south-west coast of Graham Land, is backed by the Fallières Coast which extends approximately north–south between lat. 67°40′ and 69°24′S. Neny Fjord opens out on to the Fallières Coast at lat. 68°16′S. This report describes the coastal area which lies between Millerand Island and Neny Fjord, and extends inland to include Butson Ridge (Fig. 1).

The discovery of a Basement Complex of gneisses and schists by the British Graham Land Expedition, 1934–37, was the first reported occurrence of these rocks *in situ* on the mainland of Graham Land (Fleming and others, 1938, p. 509). The British Graham Land Expedition, which was based at the Debenham Islands, was followed by the United States Antarctic Service Expedition, 1939–41, which established its "East Base" at Stonington Island 4·25 miles (6·8 km.) south-south-east of the Debenham Islands. In the expedition's report on the geology of the south Palmer Peninsula [Graham Land], Knowles (1945, p. 142) subdivided the metamorphic rocks into:

i. Mica- and hornblende-gneiss.
ii. Metamorphic sediments, including slates and mica-schists.

He has described the metamorphic rocks as flanking a core of massive igneous rocks which form the Graham Land peninsula. From subsequent descriptions it appears that the gneisses and schists are limited to the west coast and the slates to the east coast of the peninsula. These slates do not belong to the Basement Complex and Adie (1957, p. 3) has correlated them with the Trinity Peninsula Series. Describing the gneisses on the coast adjacent to Stonington Island, Knowles (1945, p. 136) noted that they were mainly *ortho*-gneisses and that very few metamorphic minerals were present.

Adie (1954, p. 4) has subdivided the Basement Complex rocks of Marguerite Bay into eleven groups, of which only five (Adie, 1954, p. 13) are considered by him to be true, unhybridized members of the Basement Complex:

Pink granite-gneiss	*Younger* ↑
Biotite-gneiss	
Hornblende-schist	
Amphibolite	
Garnet- and quartz-mica-schist	*Older*

Of these rock types only the garnet- and quartz-mica-schists are not represented in the Neny Fjord area. Hornblende-schists have not yet been found *in situ* and xenoliths, not attributable to a metadoleritic origin, are rare in the area. Adie (1954) has recorded Basement Complex rocks from Bourgeois, Bigourdan and Neny Fjords, Millerand, north-east Alexander, the Debenham and Mica Islands, Black Thumb, the Batterbee Mountains and Square Bay. From this it can be seen that Basement Complex rocks are more widely distributed in north-east Marguerite Bay than was previously thought; this accounts for the frequent occurrence of these rocks on beaches and moraines in the north-east of Marguerite Bay (Fleming and others, 1938, p. 509).

In a short abstract Nichols (1947, p. 1213) mentioned only an inclusion-rich pinkish gneiss as the oldest rock. However, in the fuller report of his work (Nichols, 1955) he has subdivided the Basement Complex rocks into the "Neny Island Schist" and the "Roman Four Mountain Gneiss". He has added little to Adie's (1954) account of the petrology and has failed to recognize the metamorphic nature of some of the dioritic rocks of the area (Nichols, 1955, p. 41). Cordini (1957–59, 1959) has published a bibliography of Antarctic geological literature up to 1957, appended to which are some recent petrographic descriptions and chemical analyses of rocks from Graham Land. Two of the analyses are of Basement Complex rocks from the Neny Fjord area which he considers to be an ancient mass of schists that has been injected by granitic material. Without giving any evidence, he has assigned this injection to the Tertiary (Cordini, 1959, p. 150), a conclusion which ignores the relatively unaltered state of the Upper Jurassic Volcanic Group rocks in this area.

In a review of the geological work of the Falkland Islands Dependencies Survey, Adie (1958, p. 10) has suggested that the Basement Complex rocks have been deformed by "at least two phases of metamorphism" but he has not indicated the relative positions of these metamorphisms to his stratigraphical sequence in either this paper or the earlier one (Adie, 1954, p. 4).

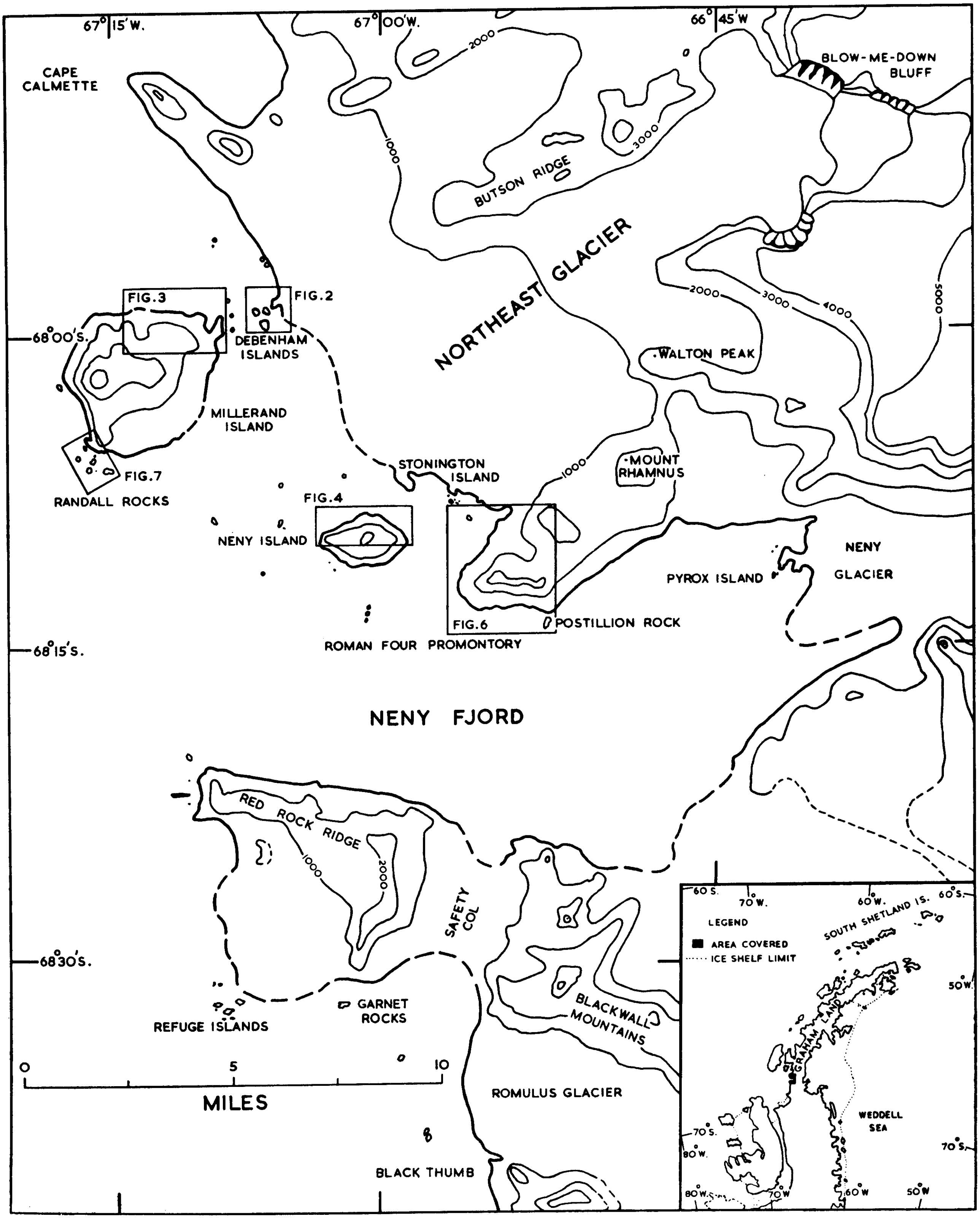


FIGURE 1

Sketch map of the Neny Fjord area, showing the respective positions and figure numbers of more detailed geological maps appearing elsewhere in this report. Contours in feet.

From the occurrence of glacial erratics in north-east Graham Land Adie (1954, p. 4) has suggested that Basement Complex rocks might be found *in situ* on the east coast of Graham Land. During the summer of 1959–60 Basement Complex rocks were collected by a Falkland Islands Dependencies Survey field party from Hub Nunatak in lat. 68°36′S., long. 66°14′W. and on the north side of Robillard Glacier which flows into Solberg Inlet. Both of these localities are on the east side of the Graham Land ice shed.

The Falkland Islands Dependencies Survey station at Stonington Island (lat. 68°11′S., long. 67°00′W.) was re-occupied in March 1958 and geological work was carried out during the latter part of that year. Geological stations visited between March 1958 and March 1959 are numbered E.1301–1559. In the following year the writer was stationed at Horseshoe Island (lat. 67°51′S., long. 67°12′W.) and travelled to the Neny Fjord area to work, when geological stations numbered Y.601–85 were visited.

Laboratory work was carried out between July 1960 and September 1962 in the Department of Geology, University of Birmingham, where all the specimens and thin sections referred to in this report are housed.

II. PHYSIOGRAPHY

THE Neny Fjord area is dominated to the east by the Graham Land plateau (Plate Ia). This undulating plateau, which varies greatly in width and extends for a distance of over 300 miles (483 km.) along the length of the peninsula, rises steadily from about 3,000 ft. (914 m.) a.s.l. in the north of Graham Land (lat. 63°40′S.) to about 6,000 ft. (1,829 m.) a.s.l. near Neny Fjord (lat. 68°10′S.). In the vicinity of the Neny Fjord area the plateau is cut by Neny Glacier, a narrow ice-filled valley trending north-west to south-east. At its western end Neny Glacier swings westward to enter Neny Fjord which is a large irregular inlet 5 miles (8 km.) wide and 11 miles (18 km.) long. It is not a true fjord like those of north-eastern Marguerite Bay in that it lacks truncated spurs and an angular coastline, the prominent features of fjord coasts. This is possibly due to the regional topography being more subdued than it is farther north.

At the head of Neny Fjord the sea approaches the plateau edge but to the north and south of the fjord there is a coastal area 10–15 miles (16–24 km.) wide, divided either by north-east–south-west or east–west ridges between which flow broad glaciers. These ridges have large ice falls and terminate in arêtes. Red Rock Ridge, on the south side of Neny Fjord, is a peninsula joined to the mainland by an ice-covered neck of land called Safety Col. The coastline of this area is bounded by ice cliffs where the glaciers terminate at the sea. These ice cliffs are only broken where the ridges form promontories, e.g. Roman Four Promontory, and where the ice foot rests on small islands, e.g. the Debenham Islands (Plate Ib). There are numerous offshore islands, the largest of which, Millerand Island, is geomorphologically analogous to the Red Rock Ridge peninsula. The smaller islets, some of which are up to 20 miles (32 km.) offshore, indicate the possible presence of an extensive offshore platform.

The northern and western faces of many of the mountains (Plate Ic) are relatively free from snow and ice, because they receive most radiation from the sun. Beaches, screes and block terraces (Nichols, 1953, p. 74; 1960, p. 1438) are developed at the foot of these rock faces. On the southern faces of the mountains it is usual to find ice aprons, ice falls and ice cliffs terminating at the sea.

The age of the existing landscape is unknown and there is no clear evidence of the geological history of the Neny Fjord area in the period between the intrusion of the late Cretaceous to early Tertiary Andean Intrusive Suite and the Recent raised beaches. Beaches are present on Millerand, Neny and Pyrox Islands and at Little Thumb at heights of approximately 20 and 40 ft. (6·1 and 12·2 m.) a.s.l.; so far, no evidence of their absolute ages has been found.

III. STRATIGRAPHY

DURING the present work the Basement Complex has been defined as the group of high grade metamorphic rocks which are older than the (?) early Palaeozoic intrusive rocks, the "Coarse Pink Granite" and the "White Granite", described by Adie (1954, p. 15–18). The (?) early Palaeozoic volcanic rocks are only represented in the Neny Fjord area by relatively unaltered xenoliths in the "Coarse Pink Granite" at Black Thumb. From this it is concluded that these volcanic rocks are post-Basement Complex

TABLE I

SUMMARY OF BASEMENT COMPLEX STRATIGRAPHY AND CORRELATION OF EXPOSURES

Butson Ridge	*Roman Four Promontory*		*Neny Island*		*Millerand Island*		*Debenham Islands*
	East	*West*	*East*	*North and West*	*South-west*	*North-east*	
	Metamorphism						
	Metadolerite						
	Appinitic gneiss	Appinitic gneiss					
Metamorphism	*Metamorphism*		*Metamorphism*		*Metamorphism*		*Metamorphism*
Plagioclase-amphibolite	Plagioclase-amphibolite and metadolerites		Plagioclase-amphibolite	Plagioclase-amphibolite and metadolerites			
Granite-gneiss	Granite-gneiss		Migmatitic granite-gneiss	*Lit-par-lit* granite-gneiss		Granite-gneiss	? Granite-gneiss
Biotite-granite-gneiss							
		Granite-gneiss			Granite-gneiss		
? Dioritic gneiss		Dioritic gneiss (several phases)		Dioritic gneiss (several phases)	Dioritic gneiss	Dioritic gneiss	? Dioritic gneiss
				Amphibolite			
	Metamorphism		*Metamorphism*		*Metamorphism*		*Metamorphism*
						Plagioclase-amphibolite	Plagioclase-amphibolite
	Banded biotite-gneiss		Banded biotite-gneiss			Banded biotite-gneiss	Banded biotite-gneiss
						? Hornblende-schist	

in age, that they have no metamorphosed equivalents in the Basement Complex and that they have been removed from this area by erosion.

The Basement Complex is composed of a series of plagioclase-amphibolites, dioritic and granitic gneisses, which contain only five essential minerals: amphibole, biotite, plagioclase, potash feldspar and quartz. Since the formation of the Basement Complex this area has had a turbulent history with frequently recurring igneous activity; at many of the exposures examined the Basement Complex forms only a small part of the total area exposed. In such circumstances it is impossible to trace variations in lithology and it is therefore necessary to attempt a metamorphic correlation, although this is not facilitated by the relatively few and insignificant mineral species present. The results of this attempted correlation, based on the field and laboratory work, are given in Table I.

The boundary between the Basement Complex and the (?) early Palaeozoic rocks is often difficult to define precisely. In the general absence of the (?) early Palaeozoic volcanic rocks the position in which the boundary is placed depends on the interpretation of the field relations and the textures in both the Basement Complex and the (?) early Palaeozoic intrusive rocks. This interpretation is difficult because many of these rocks are granitic in composition and the last metamorphism of the Basement Complex was only of medium grade. The post-Basement Complex stratigraphy is summarized in Table II.

TABLE II

SUMMARY OF THE POST-BASEMENT COMPLEX STRATIGRAPHY

Recent		Raised beaches
Late Tertiary		Basic dykes
Late Cretaceous to Early Tertiary	Andean Intrusive Suite	Granite, Diorite, Gabbro } Intrusions
Upper Jurassic	Upper Jurassic Volcanic Group	Pyroxene-andesite and rhyolite dykes. Lavas, tuffs and agglomerates
? Early Palaeozoic	Intrusive suite Volcanic rocks	Unfoliated "Coarse Pink Granite" and "White Granite" Foliated granites Propylitized porphyritic andesites and andesitic agglomerates
? Precambrian	Basement Complex	Plagioclase-amphibolites, dioritic and granitic gneisses

IV. BANDED BIOTITE-GNEISSES AND HORNBLENDE-SCHISTS

A. BANDED BIOTITE-GNEISSES

It is convenient to retain the field name "banded biotite-gneisses" for an important group of rocks which are best exposed at the Debenham Islands. These rocks are essentially fine-grained plagioclase-biotite-gneisses which contain varying proportions of hornblende, quartz and potash feldspar. In many cases the banding appears to be due to the formation of oligoclase and potash feldspar porphyroblasts in bands parallel to the foliation. At Roman Four Promontory, and Neny and Millerand Islands these gneisses are intimately associated with granite-gneisses which have invaded them in either a *lit-par-lit* or *tâche d'huile* fashion.

1. *Field relations*

The foliation of the banded biotite-gneisses exposed at the Debenham Islands (Fig. 2) has a general north-south strike and a regional dip eastwards, but this area has been severely disturbed by faults trending approximately north–south. These gneisses have been intruded by the (?) early Palaeozoic intrusive rocks, the Upper Jurassic Volcanic Group and the Andean Intrusive Suite; because of these later intrusions it is not possible to trace any distinct zones of metamorphism in the gneisses.

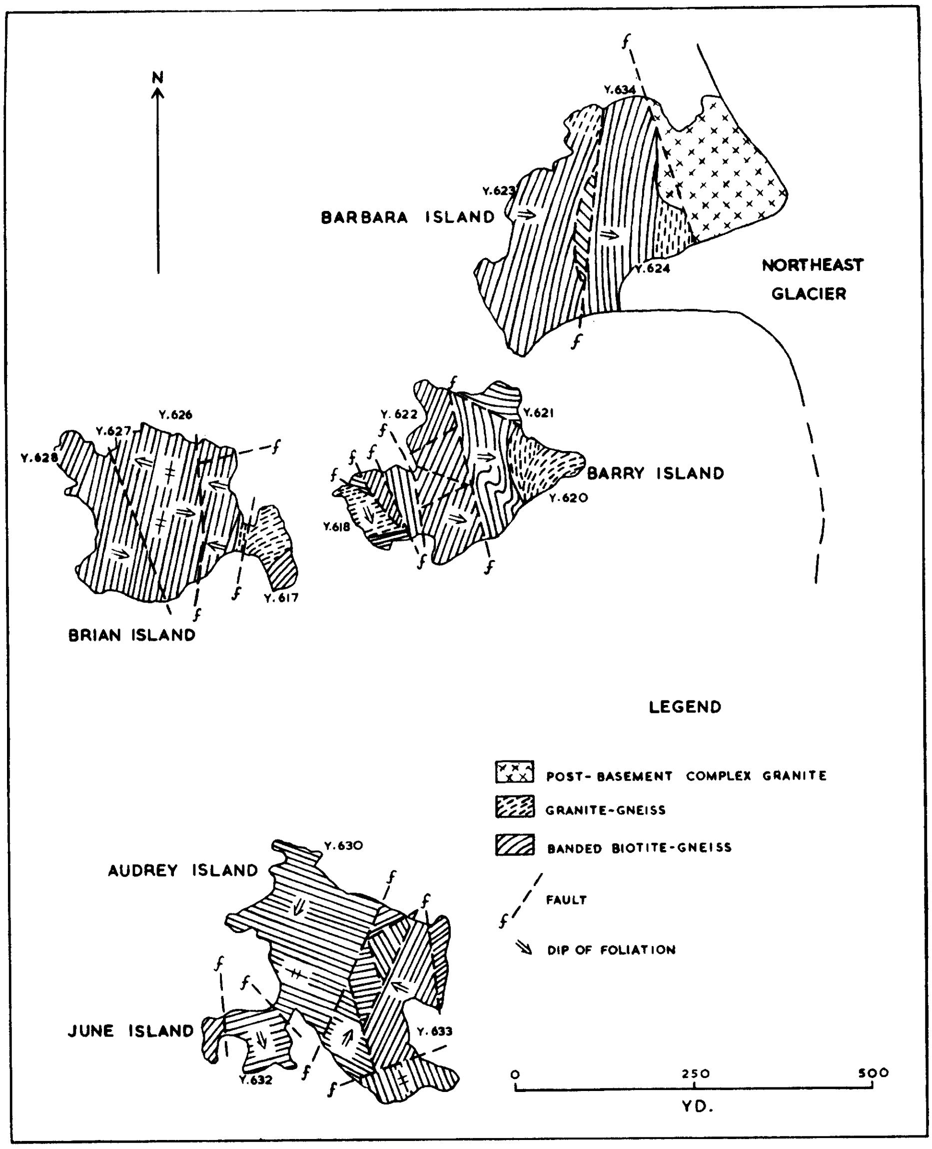


FIGURE 2

Geological sketch map of the Debenham Islands. The shading indicates the approximate strike of the foliation.

When they have not been disturbed the banded biotite-gneisses are, in the hand specimen, fine- to medium-grained, pale grey, almost schistose rocks with regular thin quartzo-feldspathic bands which are sometimes crenulated (Plate IIa). The banded biotite-gneisses contain quartz lenses which are usually exposed on vertical joint faces so that it is not always possible to determine their form. In many places the rock has been altered by small granite and granite-gneiss intrusions which have feldspathized and chloritized the country rock. Small folds on Brian Island suggest the upward movement of the granite-gneiss and at the eastern end of Barry Island the gneiss has folds plunging southward at 40°; this is the only evidence of gentle folds with axes orientated north–south (Fleming and others, 1938, p. 509).

The small exposures of biotite-gneiss on the northern sides of Neny Island and Roman Four Promontory have been intruded by granite-gneisses. At Neny Island the banded biotite-gneisses have been invaded in a *tâche d'huile* fashion by granite-gneisses and there is almost perfect gradation from banded biotite-gneiss into a fine-grained granite-gneiss. The latter also forms veins along the foliation but these deviate from the lithological banding when the gneisses are flexed into gentle folds. Similar gneisses with numerous acid veins extend eastward to just south-west of Store Point, where the granite-gneiss is intruded as distinct bands usually about 4 in. (10 cm.) thick, but the structural relationship of these two exposures is uncertain. A similar rock forms rafts in a migmatitic granite-gneiss on the east coast of Neny Island but this rock, like some of those from the Debenham Islands, contains more amphibole than the ones described above.

On the north-western end of Roman Four Promontory the country rock is a fine-grained banded biotite-gneiss (E.1558.1) which has been intruded *lit-par-lit* by a granite-gneiss (E.1558.2). These bands of granite-gneiss, which have been boudinaged, disappear rapidly westward and are absent 100 yd. (91 m.) away.

2. *Petrography*

One of the least altered specimens of the banded biotite-gneiss was obtained from the northern end of Audrey Island, Debenham Islands, where the rock is relatively uniform in appearance. Under the microscope this rock (Y.630.1; Plate IVa) has a saccharoidal, weakly schistose texture with an average grain-size of 0·3 mm. Biotite, which defines the foliation and is the chief mafic mineral (Table III), has the following properties: α = straw, $\beta \simeq \gamma$ = ochreous brown; β = 1·632 and 2Vα = small, which are comparable with those of a biotite quoted by Larsen and Berman (1934, p. 238). Chloritization of the biotite is more abundant in the epidotized parts of the rock, in minor shear zones perpendicular to the foliation and adjacent to quartzo-feldspathic veins. Near these, lenses of prehnite have distorted the cleavages of the biotite. The feldspar is predominantly plagioclase ($Ab_{64}An_{36}$), commonly twinned on the albite law but also occasionally on the Carlsbad law. Small blebs of quartz, ore and apatite are included in the plagioclase. Small quantities of potash feldspar are interstitial and, although some of the plagioclase develops albitic margins adjacent to the potash feldspar, myrmekite is conspicuously absent. The quartz is almost amoeboid in form and has an undulose extinction. The accessory minerals are titanomagnetite, which appears either as corroded relicts interstitial to the plagioclase or as small granules around the biotite, and apatite containing small zircons. A little xenoblastic sphene occurs in the feldspar. Quartzo-feldspathic veins are predominantly of quartz and the late veins contain epidote and calcite.

At the western end of Barbara Island the rock (Y.623.1) has a coarser grain-size (0·45 mm.) and hornblende is in excess of biotite (Table III). The optical properties of the hornblende are: α = straw, β = brownish green, γ = bluish green, $\gamma{:}c$ = 20° and $\gamma - \alpha \simeq 0{\cdot}010$. Potash feldspar, titanomagnetite and sphene have been introduced by late veins. A similar rock (Y.621.4) from Barry Island has a hemi-granoblastic texture and some of the plagioclase is distinctly porphyroblastic (up to 1·25 mm. long). The actinolitic amphibole has a higher birefringence ($\gamma - \alpha = 0{\cdot}014$) and no potash feldspar is present. Specimen Y.619.1, also from Barry Island, is a streaky rock and light bands can be distinguished under the microscope by a coarser grain-size and the presence of chloritized biotite. The amphibole is very pale and contains orientated inclusions and blebs of quartz which suggest a possible pyroxenic origin for the amphibole.

The *lit-par-lit* intruded banded biotite-gneiss from the eastern side of Neny Island (Y.642.1) has a gneissic texture with only rare cross-sections of amphibole and biotite showing an idioblastic form. The foliation is defined by phacoidal quartz crystals, biotite and amphibole, but the latter frequently has its crystallographic *c*-axis perpendicular to the plane of the foliation.

Plagioclase ($Ab_{64}An_{36}$), which is the dominant constituent of the rock and comprises over 50 per cent of the whole (Table III), is poorly twinned on the albite law. The twin lamellae are occasionally bent and much of the plagioclase has well-developed cleavages which are emphasized by slight saussuritization. Small quantities of interstitial microcline have myrmekite developed against them. The amphibole is pleochroic in very pale tints of greenish blue, the birefringence is low and $\gamma{:}c$=19°. Although the amphibole appears to have recrystallized, it is still essentially interstitial in its occurrence. Small subidioblastic sphene crystals are common throughout the rock and the broken, sheared crystals of iron ore enclosed by the plagioclase are surrounded by granular sphene.

The banded biotite-gneiss (E.1558.2) from Roman Four Promontory shows a finely gneissic texture with strongly porphyroblastic feldspars resulting from the local intrusion of the granite-gneiss. Biotite is intergranular but it is essentially idioblastic against the feldspar, and its cleavage is undistorted.

Poikiloblastically enclosed in the antiperthitic oligoclase porphyroblasts ($Ab_{71}An_{29}$) are anhedral crystals of a more calcic plagioclase, idioblasts of biotite and zircon, and blebs of iron ore and quartz. The small amount of hornblende is idioblastic against biotite but xenoblastic against quartz and plagioclase.

A modal analysis of specimen Y.630.1 is given in Table III together with those of similar rocks from this area. A chemical analysis of the same specimen is included in Table V with its mesonorm calculated according to the rules given by Barth (1959, p. 136).

TABLE III

MODAL ANALYSES OF BANDED BIOTITE-GNEISSES

	Y.630.1*	Y.623.1	Y.626.1	Y.642.1†
Quartz	16·4	19·1	21·4	28·0
Potash feldspar	2·4	3·8	6·8	tr
Plagioclase	54·6	46·9	40·9	52·0
Hornblende	—	14·9	—	9·0
Biotite	24·6	13·3	30·1	8·0
Iron ore	2·0	1·8	0·8	3·0
Accessory minerals	n.d.	0·2	n.d.	n.d.
Plagioclase composition	An_{36}	An_{45}	An_{39}	An_{36}

* Chemical analysis of this rock is given in Table V.
† Approximate analysis only.

Y.630.1 Banded biotite-gneiss, northern Audrey Island, Debenham Islands.
Y.623.1 Banded biotite-gneiss, western Barbara Island, Debenham Islands.
Y.626.1 Banded biotite-gneiss, northern Brian Island, Debenham Islands.
Y.642.1 Banded biotite-gneiss, eastern Neny Island.

3. *Contacts between granitic rocks and banded biotite-gneisses at the Debenham Islands*

The *lit-par-lit* intrusive contacts between the banded biotite-gneiss and the granite-gneiss at Neny Island and Roman Four Promontory are dominated by the granite-gneiss to such an extent that it is appropriate to describe them elsewhere (p. 33). At this point two interesting minor contacts will be described: the one between the banded biotite-gneiss and the granite-gneiss, and the other between the banded biotite-gneiss and a foliated granitic rock whose correlation with the other granite-gneisses is dubious.

The contact zone between the granite-gneiss and the banded biotite-gneiss on Brian Island (Fig. 2) is about 15 ft. (4·6 m.) wide and gradational. The typical unaltered rock is very similar to specimen Y.630.1 except that it has a hemigranoblastic texture. Near the granite-gneiss the banded biotite-gneiss of the contact zone has been intruded *lit-par-lit* on a very fine scale, and in the hand specimen it has a pink and grey streaky appearance. Under the microscope this rock (Y.617.7) is texturally unchanged but it contains alternating medium-grained acid and finer-grained basic bands. All of the biotite and plagioclase of the basic bands has been altered and the rock is traversed by folia of relatively unaltered microcline-microperthite, quartz and poikiloblastic amphibole representing the pink bands of the hand specimen. Towards the middle of the contact zone the rock (Y.617.8) loses its distinctive banding and the acid material occurs in irregular cracks and patches. The original biotite has been completely chloritized and is disrupted by wedges of prehnite. Titaniferous iron ore, which has been altered later to sphene, is common and is interstitial to the plagioclase. As before, amphibole is poikiloblastic but it is pleochroic in darker shades of green and the colouring is distinctly patchy with no trace of regular zoning. In the hand specimen the granite-gneiss is a pale pink, fine-grained rock with large quartz porphyroblasts, but in thin section the specimen (Y.617.6) has a saccharoidal hemigranoblastic texture consisting of plagioclase, microcline-microperthite and interlobate quartz. A little chlorite is present.

The contact between the banded biotite-gneiss and the foliated granite at the eastern end of Barry Island has been severely sheared, and the country rock (Y.621.4) about 20 ft. (6·1 m.) from the contact shows no signs of contact metamorphism. A rock (Y.621.3) collected 9 in. (23 cm.) from the contact is badly sheared and has been subsequently recrystallized. Sutured undulose quartz occurs in a fine-grained mosaic with small crystals of green biotite, most of which has been chloritized. There are distinct folia of iron ore, epidote, penninite and calcite. Within 6 in. (15 cm.) of the contact the shearing is concentrated in zones giving the rock (Y.621.2) an augen appearance with fragments of quartz and ghosts of saussuritized plagioclase. The sheared zones have completely recrystallized and quartz is the dominant constituent. Epidote is common and, although most of it is probably late stage, some may have formed during the destruction of the plagioclase. Iron ore is concentrated in distinct folia but it is not as abundant as in specimen Y.621.3. The contact rock itself (Y.621.1) has a cataclastic texture with pronounced augen of crushed rock and angular fragments of quartz. The quartz has an extremely undulose extinction and gives a biaxial figure. The completely recrystallized groundmass is liberally strewn with small greenish brown garnets, which are probably grossularite formed from the plagioclase (Harker, 1950, p. 174).

B. Hornblende-schists

Dark schistose xenoliths are abundant throughout the rocks of the Neny Fjord area and during the field work these were all grouped together as hornblende-schists, although the field evidence suggested that they were not all of the same origin. These hornblende-schists have never been found *in situ* and the only evidence for their existence as a group is their frequent occurrence in the later rocks. It is, therefore, not possible at present to enlarge on Adie's (1954, p. 6–9) original conception of these rocks. However, the occurrence of these inclusions in swarms and the comparative lack of evidence of assimilation suggest that many of them may have been derived from basic dykes which have been disrupted by subsequent metamorphism.

Most of these rocks are plagioclase-amphibolites (Harker, 1950, p. 281) but one example of a quartz-hornblende rock has been found. The action of the later granite-gneisses has been to convert much of the hornblende in the schists to biotite, and for this reason some of the hornblende-schists are difficult to distinguish from the hornblende-bearing banded biotite-gneisses.

1. *Field relations*

On the north-east coast of Millerand Island (station Y.670; Fig. 3) there is an exposure of fine-grained, hybrid hornblende-gneiss (Adie, 1954, p. 9). This rock contains many small xenoliths of hornblende-schist in all stages of assimilation and some of them have been reduced to mere basic clots. At the eastern end of the same exposure the hybrid hornblende-gneiss passes into a rheomorphic breccia (Plate IIb; Goodspeed, 1953) containing numerous fragments of schist in a dioritic matrix. On the east side of station Y.671, 400 yd. (366 m.) east of the previous station, strings of small, angular to subangular hornblende-schist inclusions occur as raft trains in a series of fine-grained granite-gneiss dykes. Only the raft trains and the dykes were seen because the country rock has weathered down and was hidden beneath the snow.

On Barry Island in the Debenham Islands numerous xenoliths of hornblende-schist which are present in the banded biotite-gneiss usually have sharp contacts with the enclosing gneiss. They show little or no sign of assimilation except where the banded biotite-gneiss has been altered by the intrusion of the granite-gneiss. The form of individual xenoliths varies considerably and they usually occur in groups especially when they have been cemented by the leucocratic amphibole-plagioclase rock. On the north coast of Barbara Island the banded biotite-gneisses are cut by a series of anastomosing granite veins in which the banded biotite-gneiss appears to have been basified and superficially resembles the hornblende-schists.

2. *Petrography*

The xenoliths in the rheomorphic breccia from the north-east coast of Millerand Island are a quartz-hornblende-plagioclase rock (Y.670.5) which has a texture that is intermediate between granoblastic saccharoidal and nematoblastic. The hornblende is pleochroic in pale shades of green with α = pale

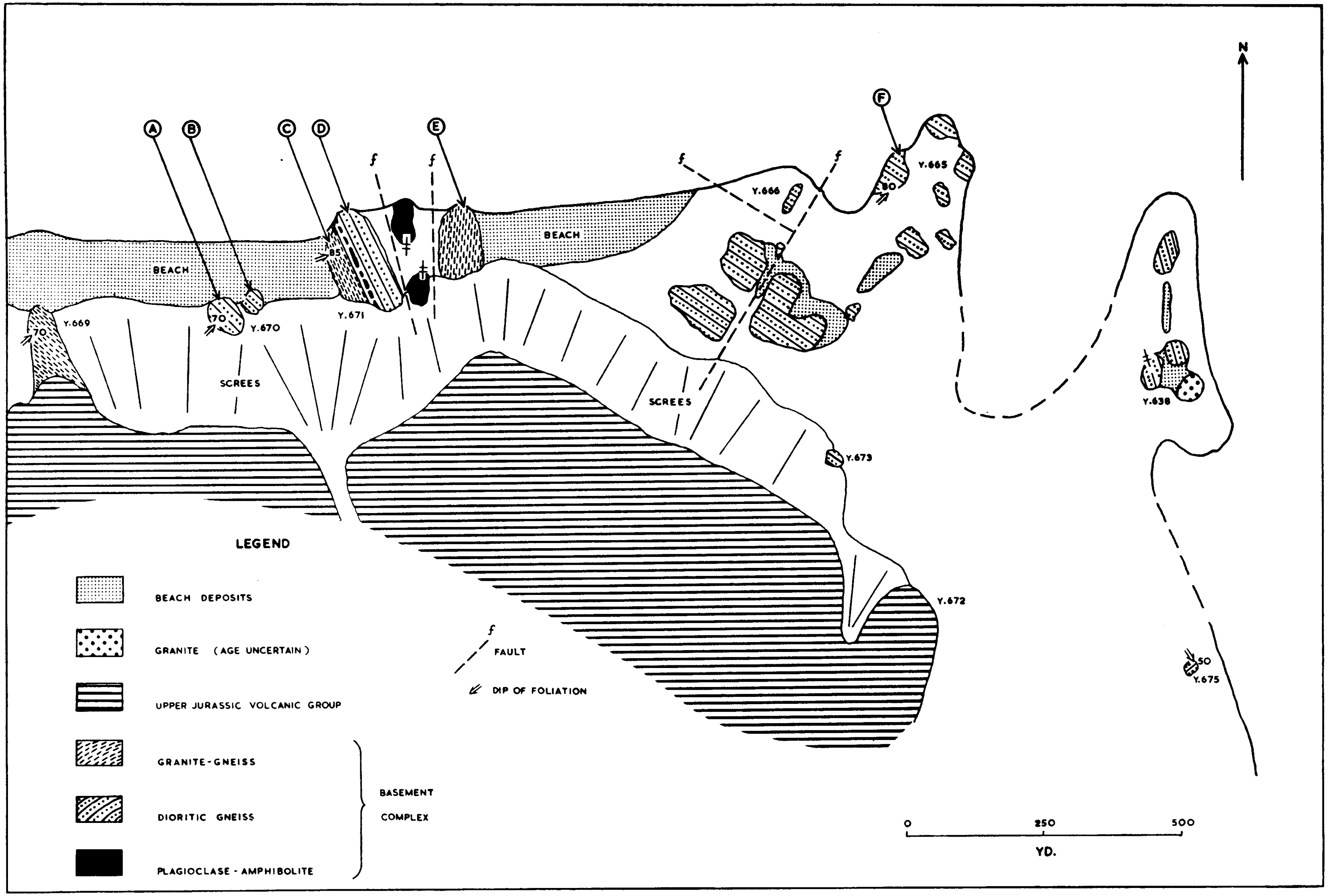


FIGURE 3

Geological sketch map of north-east Millerand Island. Dykes younger than the Basement Complex have been omitted.

A. Hybrid hornblende-gneiss.
B. Rheomorphic breccia with hornblende-schist xenoliths.
C. *Tâche d'huile* type granite-gneiss.
D. *Lit-par-lit* granite-gneiss invading dioritic gneiss.
E. Dykes of granite-gneiss with rafts of banded biotite-gneiss.
F. Metasomatized dioritic gneiss.

green, β = pale yellow-green, γ = pale blue-green, $2V\alpha = 72°$, $\gamma{:}c = 17°$ and $\gamma - \alpha = 0{\cdot}014$. Plagioclase ($Ab_{60}An_{40}$) has moderately well-developed albite twin lamellae and has been slightly saussuritized. Small flakes of chlorite, which are sometimes intergrown with the hornblende, have (in addition to the epidote) replaced the original biotite. The sharp contacts of the xenoliths are difficult to distinguish in the thin section, because there are no signs of recrystallization at the xenolith margins and there is no concentration of hornblende (Adie, 1954, p. 7). However, in the hybrid hornblende-gneiss (Y.670.1; Plate IVb) there are small fragments of a quartz-hornblende rock but at the margins of these xenoliths there is an almost monomineralic rock with a decussate texture. A large xenolith (Y.670.2) from the hybrid hornblende-gneiss is a massive plagioclase-amphibolite with a weak schistosity. This rock has been correlated with a series of later dykes similar to those found in the granite-gneiss.

The xenoliths of plagioclase-amphibolite which occur in the banded biotite-gneiss at the Debenham Islands show little or no sign of assimilation. In thin section one of these xenoliths (Y.621.6) has a nematoblastic texture with subidioblastic plagioclase ($Ab_{55}An_{45}$) and interstitial actinolitic hornblende. The grain-size is slightly finer than that of the enclosing gneiss and a little biotite, intergrown with the amphibole, has been altered to chlorite, ore and sphene. Quartz is absent except near the margin of the xenolith and no potash feldspar was seen in this rock. This xenolith is very similar to the type described by Adie (1954, p. 6) but in these rocks there is no trace of zoning in the plagioclase and there is no diopside or augite (Goldring, 1962, p. 6). The hornblende contains relict cores of a colourless amphibole which is possibly tremolite; since this occurs only just outside the xenolith, its formation could be attributed to the transfer of lime from within the xenolith (Turner and Verhoogen, 1960, p. 157). Another xenolith (Y.618.2) examined has been affected by the contact metamorphism of the granite-gneisses. This rock consists of a saccharoidal hemigranoblastic aggregate of feldspar and amphibole; quartz with an interlobate form is common. Porphyroblastic microperthitic orthoclase is fresh but the plagioclase has been saussuritized and there is no myrmekite, although some of the plagioclase has albitic borders. Chlorite, pseudomorphing biotite, is present only at the margin and does not occur inside the xenolith itself. Near the contact the banded biotite-gneiss lacks ferromagnesian minerals but amphibole and biotite become prominent again 2 mm. from the contact.

C. Discussion

In their petrology and field relations the hornblende-schists and the banded biotite-gneisses are closely related. It is proposed to discuss the banded biotite-gneisses first, because they are *in situ* and are more extensive in their occurrence. However, a full discussion of these rocks here is precluded by the important part played in the modification of these rocks by the granite-gneisses which are described elsewhere (p. 32).

The banded biotite-gneisses are equivalent to the fine- to medium-grained rocks of the biotite-gneiss group recognized by Adie (1954, p. 10), while his coarse-grained biotite-gneiss of Mount Nemesis appears to be equivalent to the biotite-granite-gneiss of the Butson Ridge area (p. 30). Adie (1954, p. 10) selected his type specimen of the fine-grained biotite-gneiss from Black Thumb and this appears to be comparable with the fresh material (Y.630.1) obtained from Audrey Island in the Debenham Islands. Both the hornblende-schists and the banded biotite-gneisses of Neny Island are included by Nichols (1955, p. 46) in his "Neny Island Schist" group. Cordini (1959, p. 150) has grouped all the gneisses and schists of the Basement Complex together and has expressed the opinion that the schists of Stonington, Neny and the Debenham Islands are all part of an ancient mass of schists. The gneisses, in which he includes rocks described by Knowles (1945, p. 144, table 2), are regarded by him as derivatives of the schists by later alteration.

Although the banded biotite-gneisses are widespread in the Neny Fjord area, occurring on Neny, Millerand, the Debenham Islands and Roman Four Promontory, most of the exposures are small and, apart from the Debenham Islands, they have been altered by subsequent intrusion and migmatization. The correlation of the banded biotite-gneisses depends to a large extent on either their field occurrence or their stratigraphical position, since it is not possible to trace lithological variations in the field. The mineralogical composition of these rocks varies both in species and amount, the most important variation being the respective amounts of amphibole and potash feldspar. According to Adie (1954, p. 10), hornblende is rare in these gneisses except where they appear to intrude the amphibolites, but the banded biotite-gneisses from Barbara and Neny Islands, and Roman Four Promontary all contain hornblende.

The difference between the mesonorm and the mode of specimen Y.630.1 (Table V) lies in the percentages of silica and alumina. Modal quartz, when recalculated on a weight per cent basis, is 15·7 per cent in comparison with 11·7 per cent excess quartz in the mesonorm, but the mesonorm shows 5·2 per cent excess alumina calculated as corundum. By recalculating the mineral composition of the mode (as weight per cent) it is possible to estimate the composition of the biotite after elimination of the minerals of simpler composition. It was found that this rock has a deficiency of silica and an excess of alumina to make up the required amount of modal biotite. It is possible to account for this in three ways:

i. Trivalent aluminium may substitute for tetravalent silicon (Groves, 1951, p. 308).
ii. Biotite calculated from orthoclase (as in the mesonorm) requires less silica than free orthoclase (Groves, 1951, p. 306).
iii. Some of the biotite has been altered to chlorite which is richer in alumina and poorer in silica than the micas.

Of these three explanations the third (the chloritization of the biotite) is probably the most important single factor in accounting for the deficiency of silica and excess of alumina.

While pointing out their resemblance to the psammitic types of the Moine Series of Inverness, Adie (1954, p. 11) has postulated that the biotite-gneisses are in fact derived from acid igneous rocks. However, there is very little evidence to indicate whether the banded biotite-gneisses are of sedimentary or igneous origin. In the field no relict bedding was found to suggest a sedimentary origin, but parts of the gneiss possess thin lime-rich bands containing skarn minerals such as diopsidic pyroxene and garnet. Similar pockets and bands also cut the granite-gneisses. Considered as a whole, the chemical analysis of the banded biotite-gneiss (Y.630.1; Table V) shows that an igneous origin is unlikely. Comparing it with the analyses given by Nockolds (1954), the only rocks with similar silica and alumina contents are anorthosites and nepheline-syenites but both the lime and total alkali contents in this rock are too low to be comparable.

In the event of metasomatism having taken place the most probable addition would have been alkalis. The effect of this would have shown that the original rock would have been even richer in alumina and therefore even less likely to have been of igneous origin. Bastin (1909, p. 472) gave the following conditions as probably indicative of a sedimentary origin for a metamorphic rock:

i. Dominance of MgO over CaO.
ii. Dominance of Na_2O over K_2O.
iii. Excess of Al_2O_3 over the 1 : 1 ratio necessary to satisfy the lime and alkalis.

As it stands the analysis satisfies only the last of these conditions. However, when it is plotted on the triangular diagram given by Pettijohn (1957, p. 106), it falls within the shale field, being slightly more aluminous than the marked average shale. No analysis of a sedimentary rock has been found to compare directly with that of specimen Y.630.1 without postulating at least the addition of soda and possibly lime; but this is considered to be the most probable explanation.

The hypothesis that the banded biotite-gneisses are of sedimentary origin precludes any theory that the hornblende-schists are xenoliths in the normally accepted sense. The majority of these xenoliths can be interpreted as fragments of plagioclase-amphibolite dykes which have been broken up during a later phase of metamorphism. It is only in the presence of the granite-gneisses that the hornblende-schist xenoliths appear to be more isolated, and this is attributed to a local increase in the intensity of metamorphism.

The metamorphic history of these rocks is complicated, and it is not easy to define exactly the operating temperature and pressure conditions. Biotite is not a good indicator of metamorphic conditions, because it is stable from the upper green-schist facies to the granulite facies (Ramberg, 1952, p. 45), nor is potash feldspar (Ramberg, 1952, p. 44), so that more precise information on the metamorphism must be obtained from the amphibole. This amphibole, which is pleochroic in shades of bluish green, has optical properties similar to those of a hornblende quoted by Larsen and Berman (1934, p. 175). Its relative uniformity throughout the basic rocks of this area suggests that it was the product of the last phase of regional metamorphism.

V. AMPHIBOLITES AND DIORITIC GNEISSES

In the area north of Neny Fjord amphibolite only occurs *in situ* at one small exposure on the north coast of Neny Island, but the occurrence of solitary amphibolite xenoliths in the dioritic gneisses is not uncommon.

The dioritic gneisses, comprising a number of small intrusions of variable lithology, occur at Roman Four Promontory, Neny and Millerand Islands. The composition of these rocks varies from gabbroic to granodioritic. At each exposure several varieties occur in close association but these are difficult to correlate from one exposure to the next. The stratigraphical position of these gneisses depends largely on the correlation of the various phases of the dioritic gneiss, and these in turn depend on the correlation of the varieties of the granite-gneiss. Because of the relative isolation of each exposure, it is convenient to describe these rocks on a regional basis and accordingly they have been subdivided into:

i. Northern Neny Island and Roman Four Promontory.
ii. Millerand Island and the Debenham Islands.
iii. Western Neny Island.

In the hand specimen the dioritic gneisses vary in colour, texture and grain-size but they are all coarsely foliated. Mineralogically, these rocks consist of hornblende, biotite and plagioclase with or without quartz and potash feldspar.

A. Amphibolites

1. *Field relations*

An amphibolite is exposed south of Store Point (Fig. 4) on the north coast of Neny Island. This rock is dark, coarse-grained and has a decussate texture, but sometimes in the field it is possible to detect a poor schistosity which appears to strike uniformly north-west–south-east and dips south-westwards. To the east and west the amphibolite is intruded by dioritic gneisses (Y.639.8, 647.1) whose foliation has the same direction of dip and strike. The contact was not seen in the field but the adjacent dioritic gneiss contains xenoliths of amphibolite.

2. *Petrography*

The amphibolite (Y.639.6) is essentially an amphibole-plagioclase rock with some biotite. An approximate modal analysis is given in Table V together with a chemical analysis and its mesonorm. In thin section the plagioclase appears to have been partially recrystallized into a granoblastic aggregate but locally there are suggestions of a relict gabbroic texture. Subsequent alteration of the feldspar is sporadic; a perfectly fresh crystal may remain adjacent to one which has been completely altered. The plagioclase ($Ab_{45}An_{55}$) is slightly zoned with the cores more calcic than the rims and some crystals show distortion of the albite twin lamellae. The feldspar encloses small hornblendes and fresh biotite.

There are two generations of amphibole; the more robust one is a green hornblende with the following properties: α = pale green, β = pale brownish green, γ = pale green tinged with blue; the absorption is $\alpha < \beta < \gamma$, $\gamma{:}c = 19°$, $\gamma - \alpha = 0{\cdot}027$ and $2V\alpha = 84°$. This hornblende is generally idioblastic to subidioblastic against the plagioclase. Twinning is common and the composition plane is parallel to (100). Orientated inclusions are present in some crystals and the cleavage planes are dark with dusty iron ore; other inclusions are plagioclase and iron ore. The second amphibole, which is also a hornblende, is not easy to distinguish from the first, because the two frequently appear to grade into each other with no distinct zoning. Both the colour and pleochroism are only very slightly paler but the birefringence is lower ($\gamma - \alpha = 0{\cdot}014$) and $2V\alpha = 76°$ (Table VIII, p. 44). Biotite occurs both as inclusions in the hornblende and as ragged sheaves. The small inclusions of biotite in the plagioclase are pleochroic from straw to brown, but elsewhere the biotite has been altered to chlorite and sphene; most of the former is a pale green penninite with anomalous birefringence but some appears to be an antigoritic variety of chlorite with very low birefringence colours. The cleavage traces of the original biotite have been severely distorted by the formation of prehnite and calcite lenses. Apatite is relatively common and occurs as large (0·05 mm.) xenoblastic crystals which are badly cracked. Rutile is present as small geniculate twinned crystals, pale orange in colour. The iron ore is titanomagnetite and pyrite, the former having thin rims of sphene.

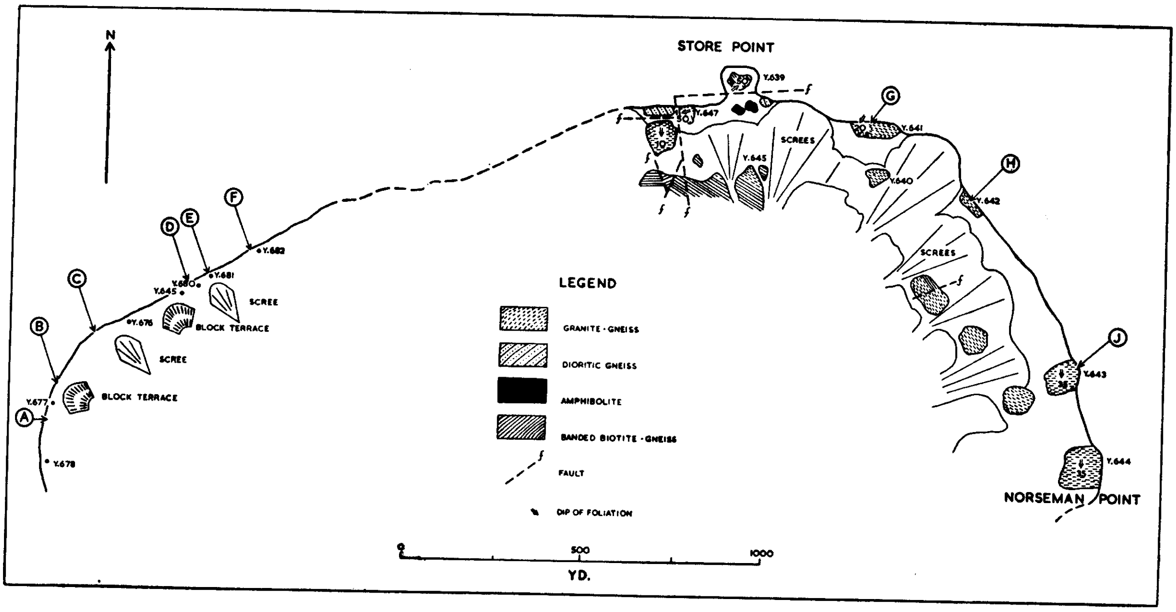


FIGURE 4

Geological sketch map of northern Neny Island. Dykes younger than the Basement Complex have been omitted.

A. Zone of xenoliths.
B. Sphene-rich dioritic gneiss.
C. Zone of xenoliths.
D. Metasomatic granite-gneiss dykes cutting dioritic gneiss.
E. Hybrid dioritic gneiss.
F. *Tâche d'huile* granite-gneiss.
G. Garnetiferous granite-gneiss dyke.
H. *Lit-par-lit* gneiss.
J. Sheets of hornblende-biotite-gneiss.

B. DIORITIC GNEISSES OF NORTHERN NENY ISLAND, ROMAN FOUR PROMONTORY AND MILLERAND ISLAND

The dioritic gneisses of northern Neny Island, Roman Four Promontory and Millerand Island are grouped together, since they have similar features of texture and composition. Locally, extensive hybridization has taken place with the adjacent country rocks and has consequently given rise to a series of small complex intrusions. The rocks from northern Neny Island and Roman Four Promontory will be described first, because their relationships are not complicated by the subsequent intrusion of the granite-gneisses.

1. *Northern Neny Island*

a. *Field relations.* South of Store Point on the north coast of Neny Island the dioritic gneiss (Y.647.1) intrudes the amphibolite, and its foliation has the same general direction of dip and strike. It is not a homogeneous rock but it contains dark streaks (Y.647.2) parallel to the foliation. Small patches of a coarser dioritic gneiss (Y.647.4) which intrude the dioritic gneiss (Y.647.1) are regarded as a hybrid phase. These lack sharp contacts and locally they become very coarse with amphibole crystals up to 7 mm. across (Y.647.7).

Westward, the field relations become obscure due to a break in the exposure (Fig. 4). The dioritic gneiss appears to form a southward-dipping layer which is underlain by the banded biotite-gneisses; a metadoleritic vein (Y.647.6) has been intruded along the contact. This dyke contains fragments of the dioritic gneiss but not of the banded biotite-gneiss. The upper contact, about 10 ft. (3 m.) above, was not seen but the upper part of the exposure consists of *lit-par-lit* injected banded biotite-gneisses. Here, the dioritic gneisses of this layer contain better though still poorly defined xenoliths of dioritic composition.

b. *Petrography.* A dark-coloured dioritic gneiss (Y.647.2) from south-west of Store Point embodies most of the features typical of the dioritic gneisses of northern Neny Island. In thin section the texture of this rock is crystalloblastic and the plagioclase shows a subidioblastic form against the completely xenoblastic hornblende. The plagioclase ($Ab_{50}An_{50}$) is generally well-twinned on the Carlsbad and albite laws, and some of the crystals have bent twin lamellae. Generally they are not zoned, although there is preferential alteration to fine-grained sericite and epidote in the cores of the crystals. A small amount of recrystallization has taken place and the new interstitial plagioclase is poorly twinned, whereas other crystals have a mottled extinction suggesting incipient recrystallization. The few inclusions in the plagioclase are small and consist of amphibole, biotite and iron ore.

Hornblende is almost completely xenoblastic against plagioclase and finger-like interstitial lobes suggest that some of the hornblende is replacing the plagioclase. The optical properties of the hornblendes are variable even within a single crystal, but it is not possible to distinguish distinct generations of hornblende. The majority of the amphibole has a pleochroism scheme α = dark straw, β = yellowish green, γ = slightly bluish green, an absorption $\alpha < \beta < \gamma$, $\gamma - \alpha = 0{\cdot}017$, $\gamma{:}c = 15°$ and $2V\alpha = 70°$. The pleochroism is in moderate tints and there is a weak zoning; the green colour is often bluer towards the margins.

Biotite, with a pleochroism scheme α = dark straw to γ = umber and forming irregular sheaves, is partly altered to chlorite and sphene, while prehnite and epidote have split and distorted the biotite crystals along the cleavage. Quartz, in irregular interstitial crystals with an undulose extinction, corrodes both the plagioclase and the amphibole. Large (0·25 mm.) crystals of apatite are a common accessory, and xenoblastic sphene is an alteration product of biotite and iron ore. The iron ore consists of both pyrites and titanomagnetite; the former, which occurs interstitially replacing plagioclase, is rimmed by a reddish alteration product.

A modal analysis of this rock (Y.647.2) is given in Table IV. In comparison, the lighter-coloured variety of the dioritic gneiss (Y.647.1; Plate IVc) has a lower colour index (Table IV), and the grain-size is more irregular and smaller (~ 1 mm.). This rock contains less biotite which is a darker brown and some of it has been replaced by plagioclase. Accessory apatite crystals are smaller, suggesting that the larger crystals in the darker rock result from contamination by the amphibolite.

TABLE IV

MODAL ANALYSES OF DIORITIC GNEISSES FROM NORTHERN NENY ISLAND AND ROMAN FOUR PROMONTORY

	Northern Neny Island			*Roman Four Promontory*		
	Y.647.1	Y.647.2	Y.647.4	E.1556.3	E.1555.1	Y.607.1
Quartz	3·8	3·7	4·4	8·6	10·0	16·5
Plagioclase	64·0	55·3	66·2	65·5	72·1	60·9
Hornblende	23·3	27·6	22·2	7·7	3·7	13·4
Biotite / Chlorite	6·2	9·8	5·1	16·2	12·7	7·9
Iron ore	1·2	1·0	0·1	2·0	1·4	1·2
Accessory minerals*	1·5	2·6	2·0	n.d.	0·1	0·1
Plagioclase composition	An_{49}	An_{50}	An_{50}	An_{44}	An_{38}	An_{46}

* Including sphene, epidote, prehnite and apatite.

Y.647.1 Light-coloured dioritic gneiss.
Y.647.2 Dark-coloured dioritic gneiss.
Y.647.4 Coarse hybrid dioritic gneiss.
E.1556.3 Dioritic gneiss, 75 yd. (68 m.) north of the navigation beacon.
E.1555.1 Dioritic gneiss, base of the navigation beacon.
Y.607.1 Dioritic gneiss, 300 yd. (274 m.) north-east of the navigation beacon.

The coarse hybrid rock (Y.647.4) which intrudes the dioritic gneiss (Y.647.1, 2) is similar to it in general textural features. The modal analysis of this rock is given in Table IV. When the modes of these gneisses are plotted on a variation diagram (Fig. 5), the major minerals, with the exception of quartz, vary according to a straight line relationship.

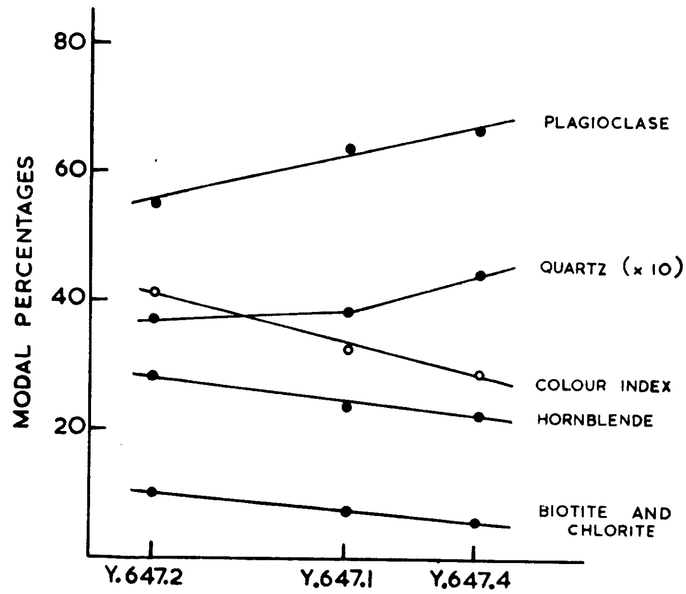


FIGURE 5

Variation diagram showing the linear relationship between the modal constituents of the dioritic gneisses from northern Neny Island.

Y.647.1 Light-coloured dioritic gneiss.
Y.647.2 Dark-coloured dioritic gneiss.
Y.647.4 Coarse hybrid dioritic gneiss.

2. *Roman Four Promontory*

Relatively fresh specimens of dioritic gneiss were obtained only from the western end of Roman Four Promontory. These gneisses which contain numerous xenoliths are separated from the banded biotite-gneiss by a complex series of dykes.

a. *Field relations.* At the western end of the promontory a small intrusion of dioritic gneiss is exposed. This is a medium-grained rock of heterogeneous composition containing many xenoliths in all stages of assimilation. The normal gneiss (E.1555.1) contains dark schlieren of biotite and amphibole which occur either alone or are associated with xenoliths. The isolated xenoliths comprise a variety of rock types and show all assimilation stages, varying from angular fragments with sharp contacts to feldspathized masses streaked along the foliation. Near swarms of these xenoliths the gneiss becomes darker as the number of xenoliths gradually increases, until between the xenoliths the gneiss loses its distinct foliation, the xenoliths become rounded and the texture of the gneiss becomes acicular.

Farther south the dioritic gneiss is cut by a series of dykes which can be traced into a metagabbroic rock. These dykes cut the foliation of the dioritic gneiss at right angles and the contact is semi-gradational with several marginal varieties. The extreme heterogeneity of this rock makes it difficult to correlate with any of the other rocks in the area, but it has been tentatively correlated with the appinitic gneiss (p. 41).

b. *Petrography.* Under the microscope the dioritic gneiss from the north-west face of the Roman Four Promontory appears to be similar to the dioritic gneiss from northern Neny Island, but it has been severely epidotized. The field relations suggest that the lighter-coloured dioritic gneiss from the western end of the promontory intrudes this rock (Plate IIc). In the lighter-coloured dioritic gneiss (E.1555.1) the plagioclase ($Ab_{62}An_{38}$) has a granoblastic texture with an average grain-size of 1 mm. but some crystals are porphyroblastic (up to 2 mm. in diameter). Biotite with a pleochroism scheme in dark straw to reddish brown is the dominant mafic mineral. When fresh it has twisted cleavages crushed between the plagioclases, while the altered biotite has its cleavages disrupted by the formation of epidote and prehnite lenses. The main alteration products of the biotite are an isotropic serpentine-like chlorite and small granules of sphene. Plagioclase replaces the biotite locally. Late epidote, which is usually pale-coloured but sometimes shows splashes of bright lime green, is present in both the biotite and the plagioclase. In contrast to the very altered state of the biotite are ragged crystals of fresh actinolitic amphibole which has remained unaltered even where the feldspar has been completely sericitized. This amphibole is zoned; the cores are pleochroic in very pale shades of green and are riddled with vermicular blebs of quartz, while the rims have deeper colours and contain very few inclusions. This zoning is no doubt due to the metamorphic break-down of original pyroxenes with uralitic rims and subsequent partial recrystallization of the uralite.

Dactyloid crystals of quartz and some iron ore appear to be replacing the plagioclase but the ore also occurs as large (1·5 mm.) xenoblastic crystals enclosing apatite and zircon. Most of the sphene is an alteration product of the biotite. In some rocks (E.1556.3) the biotite books are thicker and γ is a more golden brown colour. The actinolitic amphibole (E.1556.3, Y.607.1) is pleochroic in very pale colours and it has a bladed, almost fibrous, form. Most of it appears to have been derived from pyroxene, but strings of small sphene granules enclosed in the amphibole from adjacent biotite suggest that some of the amphibole is derived from the biotite.

The modes of these rocks (Table IV) again show the variety of their quantitative mineralogy. In one rock (Y.607.1) amphibole is the dominant mafic mineral, as in the Neny Island rocks, but texturally this rock has the same characteristics as specimen E.1556.3.

c. *Xenoliths.* The xenoliths which form swarms in the dioritic gneiss at Roman Four Promontory have a gabbroic composition and a granoblastic texture (E.1555.10). Two amphiboles are present in this rock; most abundant is a pale greenish blue hornblende which is riddled with blebs of quartz and appears to have been derived from pyroxene; the other amphibole is a brownish hornblende which encloses relatively fresh pyroxene and corroded plagioclase ($Ab_{45}An_{55}$).

The plagioclase-amphibole-schist which occurs as solitary xenoliths is a distinctive rock (E.1555.9) with dark spots of amphibole and biotite in parallel orientation; similar xenoliths have been found in a dioritic rock on an island south of Red Rock Ridge. Texturally, this rock (E.1555.9) is hemigranoblastic and, apart from a little chloritized biotite, it is composed of an actinolitic hornblende and plagioclase ($Ab_{48}An_{52}$). Adjacent to the xenoliths the dioritic gneiss contains diopsidic pyroxene which is being replaced by clusters of small bladed crystals of actinolitic amphibole. Distinctly separate from these clusters are small aggregates of chloritized biotite, sphene, iron ore and apatite.

3. *Millerand Island*

a. *Field relations.* The fine-grained hornblende-gneiss (Y.670.1; Fig. 3), which crops out on the north-east coast of Millerand Island, contains hornblende-schist xenoliths in all stages of assimilation. The foliation strikes 290° mag. and dips eastward, steepening in the lower part of the exposure. When traced westward across the strike, this gneiss passes into a rheomorphic breccia.

200 yd. (183 m.) to the east (station Y.671) there is a more homogeneous dioritic gneiss (Y.671.2) which has been intruded *lit-par-lit* by the granite-gneiss (Plate IId). This gneiss is cut by a boudinage dyke whose cracks have been filled with mobilized granitic material during metamorphism. This gneiss is terminated on its eastern side by a fault and it is not until the extreme north-eastern corner of the island that dioritic rocks recur. With the exception of one small exposure (Y.666), the dioritic gneiss of north-eastern Millerand Island has been metasomatized. Whether this is due to the granite-gneisses is uncertain, because the style of the alteration differs radically from that found elsewhere. This rock is cut by granitic veins which tend to follow the joints rather than the foliation and these veins peter out into the dioritic gneiss. This gneiss has a weak foliation which is not visible in thin section and is not always traceable in the field.

b. *Petrography.* The fine-grained, hybrid hornblende-gneiss from station Y.670 has been correlated with the hornblende-gneiss described by Adie (1954, p. 9), but the thin section (Y.671.1) contains microcline-microperthite as the potash feldspar. The dioritic gneiss (Y.671.2), which has been intruded *lit-par-lit* by the granite-gneiss, has a porphyroblastic saccharoidal texture. The feldspar, predominantly slightly antiperthitic plagioclase ($Ab_{58}An_{42}$) similar to that in the other dioritic gneisses, has distorted twin lamellae and contains biotite inclusions. As in the rocks from Roman Four Promontory, biotite has been almost completely chloritized but the pale actinolitic hornblende with pleochroism in pale bluish greens is remarkably fresh and forms large ragged crystals enclosing vermicular quartz and patches of pale spherulitic penninite. A closely similar rock (Y.666.1) occurs at the small exposure infaulted at station Y.666. In addition to the minerals described above it contains remnants of a diopsidic pyroxene. The freshest specimen from the metasomatized dioritic gneiss (Y.665.4) is similar to specimen Y.666.1, but it has antiperthitic plagioclase ($Ab_{56}An_{44}$). Small rectangular patches of potash feldspar form centres for the replacement of plagioclase by a small amount of microcline-microperthite. Large flakes of reddish brown biotite with bent cleavages have a corroded appearance adjacent to plagioclase and quartz, but they are idioblastic against and enclosed by unaltered hornblende. Quartz with an undulose extinction appears to be corroding most of the mineral constituents and is always interstitial. The alteration of this dioritic rock can be subdivided into two phases, although it is impossible to indicate clearly their separation in time:

i. The introduction of microcline-microperthite, sphene and orthite.
ii. The introduction of epidote, chlorite, prehnite and potash feldspar in the form of thin veins.

The dioritic gneiss is cut by granitic veins which tend to follow the joint faces and frequently grade into the gneiss, producing a rock (Y.665.5) with pink potash feldspars, pale green saussuritized plagioclases and dark green ferromagnesian minerals. Under the microscope the dominant feldspar is porphyroblastic microcline-perthite and the hornblende is more idioblastic and less poikiloblastic. Idioblastic orthite is a prominent accessory mineral and idioblastic sphene is relatively abundant but very little of this is associated with the iron ore. The late alteration of this rock (Y.665.5) can be subdivided into three phases which may have been almost simultaneous in time:

i. Irregular but distinct veins of prehnite and potash feldspar traverse the rock. Prehnite forms small flecks in the plagioclase and particularly replaces the plagioclase element of the myrmekite, while prehnite in the biotite tends to be more radiating at this stage. The potash feldspar is slightly kaolinized.
ii. Small cracks filled with chlorite cut the prehnite veins and attack the amphibole along its cleavages. Chloritization of the biotite cannot be wholly attributed to this stage, because disrupted biotite has been found enclosed in undisturbed amphibole.
iii. The last stage is the occurrence of parallel-sided veins containing epidote, quartz and potash feldspar. The epidote has disseminated through the rock into the biotite, encrusting the iron ore and replacing pyroxene relicts in the amphibole.

On Brian and Barry Islands in the Debenham Islands the banded biotite-gneisses are cut by small tongues of a granodioritic gneiss (Y.627.5) of uncertain age. This gneiss is at present correlated with the dioritic gneisses, because it shows the same textural features in the plagioclase.

C. Dioritic Gneisses of Western Neny Island

A series of banded gneisses, formed by the intrusion and metasomatism of the banded biotite-gneisses by the granite-gneisses, occurs on the north coast of Neny Island west of Store Point, while the north-western end of the island comprises a series of dioritic rocks. These rocks are recognized as a distinct group but they have been correlated with the other dioritic gneisses on the basis of the few granite-gneiss dykes that cut them. These gneisses are complicated by extensive hybridization, the irregularity of which in addition to their massive form gives them the appearance of igneous rocks. From the weight of stratigraphical and petrological evidence it has been concluded that they are in fact metamorphic rocks.

1. *Field relations*

At stations Y.680 and 681 (Fig. 4) a hybrid dioritic rock has been formed by the feldspathization of the banded biotite-gneiss, and this is cut by metasomatic granitic dykes which have been correlated with the granite-gneisses. To the west there is a series of massive, medium-grained dioritic rocks whose general foliation dips to the south-south-west at 60–90°. Because of the limited exposures, there are difficulties of correlation and, although they have similar textural features, their mineralogy is variable and each rock has certain distinctive characteristics, e.g. large (1·5 mm.) sphene idioblasts (Y.677.1; Plate IVd). The gneiss exposed between two of the block terraces at station Y.676 (Fig. 4) is a hornblende-biotite-plagioclase rock with occasional xenoliths, many of which have been reduced to basic clots. Just east of the westernmost block terrace this gneiss passes into a zone of xenoliths around each of which there is a slightly coarser-grained hybrid rock.

Just east of station Y.677 there is a light-coloured biotite-gneiss (Y.677.1) which contains long basic schlieren. Between this gneiss and a finer-grained biotite-gneiss (Y.677.4) at the western end of the same station there is a 60 ft. (18 m.) wide zone of amphibolite, hornblende-schist, banded biotite-gneiss and dioritic gneiss xenoliths.

2. *Petrography*

Near its contact with the banded biotite-gneiss the dioritic gneiss is a hybrid rock containing numerous schlieren of banded biotite-gneiss. The rock has been further altered by the addition of potash feldspar from the granite-gneiss dykes (p. 34). In many respects this hybrid gneiss (Y.680.1) is similar to the dioritic gneiss (Y.647.2) from the Store Point area, but it is distinguished from the latter by the presence of more quartz and more chloritized biotite. Although the texture is similar, the larger plagioclase crystals ($Ab_{58}An_{42}$) have more inclusions, and the hornblende, with a deeper green colour and lower birefringence, is being replaced by biotite. There is a little interstitial microcline-perthite around which myrmekite is developed.

In thin section the dioritic gneiss (Y.676.1) from between the two block terraces has a texture which is intermediate between granoblastic and porphyroblastic with larger plagioclase crystals up to 2·5 mm. in diameter. The slightly antiperthitic plagioclase ($Ab_{53}An_{47}$) is subidioblastic in form and most of the twinning is on the albite law, although a little Carlsbad twinning is also present. The twinned crystals are either extremely distorted or poorly developed and they have an irregular mottled extinction. Small inclusions in the plagioclase are common and consist of hornblende, biotite and iron ore. Alteration to prehnite is patchy and is sometimes limited to the cores, although the crystals are not zoned. Microcline-microperthite which forms large interstitial porphyroblasts has no well-developed twinning but it has an undulose extinction and myrmekite is developed in the adjacent plagioclase. The quartz, which tends to be interstitial, has an irregular, cataclastic sutured texture.

The hornblende is riddled with vermicules of quartz and some crystals contain relict fibrous pyroxene cores. The biotite with a pleochroism scheme of straw to dark golden brown is generally fresh but it has a little chlorite and some lenses of prehnite. However, sphene granules are associated with the biotite even when it is not chloritized. Among the accessory minerals there are subidioblastic apatites and large (0·2 mm.) zircons with prominent cleavages. Both titanomagnetite and pyrite are present; the former is rimmed with sphene but the latter is margined by a reddish limonitic decomposition product. Specimen Y.676.3 from the western end of the exposure shows similar textural and mineralogical features; it lacks microcline-perthite but it contains large crystals of accessory orthite enclosing hornblende. The modes and mesonorms of specimens Y.676.1 and Y.680.1 in Table V can be compared with the modes of other dioritic gneisses given in Table IV. The close similarities between the chemical analyses in Table V serve to show how little chemical variation there is between these gneisses and that most of the petrographic differences depend on texture, grain-size and mineralogy.

The light-coloured biotite-gneiss (Y.677.1) shows a similar texture, but in this rock biotite is the dominant ferromagnesian mineral and there is more microcline-microperthite replacing the plagioclase ($Ab_{57}An_{43}$). Large (1·5 mm.) idioblasts of sphene are characteristic of this rock and it is possible that it was this sphene that Nichols (1955, p. 41) mistook for garnet in his description of the hand specimen. A similar rock (Y.678.1) has interstitial sphene. A hemigranoblastic interlobate texture distinguishes some rocks (Y.677.3) from other dioritic gneisses and makes them comparable with some of the granite-gneisses. The plagioclase ($Ab_{63}An_{37}$) is extremely antiperthitic and the microcline-microperthite is an important constituent of this rock, while biotite remains the dominant ferromagnesian mineral; only small sphene crystals are present. The biotite-gneiss (Y.677.1) is traversed by shear zones (Plate IIIa) along which a granodioritic gneiss (Y.677.5) has been intruded. This rock is characterized by subrounded plagioclase ($Ab_{67}An_{33}$) and porphyroblastic microcline-microperthite with quartz and biotite filling the interstices.

D. Discussion

Undoubtedly the oldest rock of this group is the amphibolite, because it occurs as xenoliths in the later dioritic gneisses, but whether it belongs to the previous metamorphic cycle is unknown and the small exposure on Neny Island offers no conclusive evidence. There is no direct evidence of the age relationship between the amphibolite and the banded biotite-gneiss in this area. Since the amphibolite is a massive rock, it would resist metamorphic alteration, and therefore it is possible that it could pre-date the banded biotite-gneiss as Adie (1954, p. 4, 10) has suggested in his stratigraphical succession of the Basement Complex. No evidence of a previous metamorphism has been found in this amphibolite and it shows the same metamorphic features as the adjacent dioritic gneiss. The Neny Island amphibolite is not the same as the amphibolite from Black Thumb (Adie, 1954, p. 6), which is almost a monomineralic rock, possibly of pyroxenitic origin. The chemical analysis in Table V shows a high magnesia content, which together with the relatively high feldspar content suggests that the original rock was a gabbro with troctolitic affinities. While carrying out the modal analysis (Table V) of this rock it was impossible to distinguish between the two types of amphibole satisfactorily. The pale bluish green hornblende is attributed to a late metamorphism and its significance will be discussed elsewhere (p. 44). Comparative calculations between the mode and mesonorm are complicated by the presence of two complex minerals: a partially chloritized biotite and a heterogeneous amphibole. However, approximate calculations suffice to show that the amphibole is relatively poor in alumina and lime, whereas it is rich in magnesia, ferrous iron and silica.

When correlated with the rocks described by Adie (1954), it would appear that the dioritic gneisses include parts of his hornblende-gneiss, hornblende-biotite-gneiss and the biotite-granite-gneiss groups. However, Adie (1954, p. 9) states that in his hornblende-gneisses orthoclase is always in excess of plagioclase and that they are exposed on the north coast of Neny Island. Of the rocks examined only the biotite-gneisses from north-west Neny Island contain a few per cent of potash feldspar more than plagioclase and some of this is microcline-perthite. The typical cross-hatch twinning is frequently absent in the latter and the presence of microcline could only be confirmed by determining its 2V on the Universal Stage. The results obtained are variable but they show that two types of potash feldspar are present. Some of the antiperthitic plagioclase encloses distinct rectangular patches of potash feldspar. The rocks analysed by Knowles (1945, p. 144, table 2), which Cordini (1959, p. 150) has correlated with the banded biotite-gneisses of the Debenham Islands, contain more potash feldspar than these rocks and in this respect are more akin to the hornblende-gneisses described by Adie.

Nichols (1955, p. 41) has recognized only the granite-gneisses and the "Neny Island Schist" as Basement Complex rocks. He has considered the dioritic and gabbroic rocks of western Neny Island as being unmetamorphosed and he has correlated these rocks with the Red Rock Ridge and "Neny Glacier Island" [Pyrox Island] gabbros, both of which are typical unmetamorphosed rocks (Hoskins, 1960, p. 23, 28).

Among the characteristic features of the dioritic gneisses indicating that they have been metamorphosed are:

i. The corrosion of the plagioclase feldspar by potash feldspar.
ii. The twisted albite twin lamellae in the plagioclase.
iii. Irregular amoeboid crystals of quartz with an undulose extinction.
iv. The tendency of the ferromagnesian minerals to crystallize around the feldspars rather than forming clots.
v. The apparent absence of fibrous uralitic amphibole around the remnants of pyroxene, and the occurrence of numerous quartz blebs in the amphibole.

The latter feature is comparable with that in an example of a metamorphosed diorite from Scourie figured by Harker (1950, p. 288, fig. 148). Other features are the occurrence of distorted, prehnitized and chloritized biotite enclosed by undisturbed amphibole, and the lack of orientation in biotite as occurs when it replaces hornblende in igneous rocks. This suggests that the amphibole, which is usually a hornblende, recrystallized later than the biotite. Excluding the amphibolite, it is the more basic dioritic gneisses which have many features in common. In many cases these have been affected by later alteration but the fundamental ones which concern the plagioclase have been preserved. The plagioclase is andesine and it occurs as subidioblastic crystals with interstitial quartz which apparently replaces the feldspar along the intergranular boundaries. In most of the rocks plagioclase has bent albite twin lamellae and an uneven mottled extinction suggestive of incipient recrystallization. When present, potash feldspar is porphyroblastic and at the same time xenoblastic and surrounded by myrmekite.

These rocks are thought to have originated from igneous dioritic rocks which in many places were contaminated by the amphibolite, the banded biotite-gneisses and the hornblende-schists. Many of the textural features of the plagioclase are considered to be relict ones and that the main changes during subsequent metamorphism have been the destruction of the pyroxene and recrystallization of the amphibole and quartz.

The chemical analyses of the rocks from western Neny Island (Table V) are comparable with those of an igneous dioritic rock. When they are compared closely with the analyses of diorites of the Andean Intrusive Suite (Adie, 1955, p. 24, table VIIa), it can be seen that even these rocks of the Basement Complex share the provincial characteristic of a high alumina content.* A prolonged comparative discussion of the mesonorms and modes (Table V) of these rocks would be unprofitable. Both petrographic and optical evidence has indicated that much of the titania occurs in the biotite, while the amphibole is rich in magnesia and contains some soda; complexities such as these are not allowed for in the calculation of the mesonorms. However, the similarities are sufficiently close to indicate the general variations present in these rocks, e.g. biotite and hornblende.

It is possible to consider the dioritic gneisses as forming three petrological groups:

i. The more basic dioritic gneisses, which have been extensively contaminated by assimilation of the earlier basic country rocks.
ii. The relatively uncontaminated dioritic gneisses of granodioritic or tonalitic affinity.
iii. Hybrid dioritic gneisses formed by contamination of the granite-gneisses.

The first group of gneisses, which includes Knowles's (1945, p. 144) hornblende-gneiss, Adie's (1954, p. 9) hornblende-gneiss and Nichols's (1955, p. 41) "Neny Island Gabbro", forms the bulk of Roman Four Promontory and parts of Neny and Millerand Islands. The variation diagram (Fig. 5) illustrates that with the passage of time the gneisses of the Store Point area became steadily less contaminated and that the only change in the invading magma was an increase in silica. Extrapolation of the diagram to include the amphibolite fails to produce a linear relationship, from which it is concluded that amphibolite is not the only rock assimilated by the dioritic gneisses, and that the amphibolite is not a member of the dioritic gneiss series.

The granodioritic group of these gneisses is always found intruding the more basic gneisses. The occurrence of basic gneiss xenoliths in the granodioritic gniesses suggests that there was a distinct time lapse before their respective intrusions at Roman Four Promontory and Neny Island. These rocks, which are usually characterized by having biotite as the dominant ferromagnesian mineral, form small intrusions.

The hybrid gneisses include the metasomatized dioritic gneiss on north-eastern Millerand Island and a group of rocks on Neny Island (Y.681). At Millerand Island the original rock was a normal dioritic gneiss similar to that found farther west on the coast, but on Neny Island the original rock was the banded biotite-gneiss which was first intruded by the dioritic gneiss and then later feldspathized by the granite-gneisses. Because of their massive character, the dioritic gneisses tend to resist alteration by the granite-gneisses, which occur mainly as dykes or as *lit-par-lit* intrusions.

VI. PETROLOGY OF THE GRANITE-GNEISSES

ROCKS grouped as granite-gneisses are widespread in the Neny Fjord area, occurring at Neny and Millerand Islands, Roman Four Promontory and the north-west side of Butson Ridge (Fig. 1). In thin section each of these rocks shows similar mineralogical features but their appearance in the hand specimen and their mode of occurrence in the field is frequently significantly different from one locality to another. These rocks have been subdivided into two major groups based on their field occurrence:

i. Homogeneous granite-gneisses.
ii. Heterogeneous granite-gneisses.

In the first group the larger, more homogeneous intrusions of granite-gneiss are considered, while a variety of migmatitic granite-gneisses, which show local mobilization, metasomatism and *lit-par-lit* intrusion,

* Personal communication from Dr. R. J. Adie, 1962.

TABLE V

CHEMICAL ANALYSES, MESONORMS AND MODAL ANALYSES OF BASEMENT COMPLEX ROCKS

	1	2	3	4	5	6	7	8	9
SiO_2	55·08	51·93	58·33	58·95	68·23	72·01	75·21	70·19	51·55
TiO_2	0·81	0·81	0·53	0·74	0·26	0·12	0·36	0·26	0·72
Al_2O_3	21·91	12·97	18·16	17·42	16·09	14·76	12·64	10·40	15·39
Fe_2O_3	2·23	0·59	2·15	2·44	0·75	1·01	1·42	4·59	0·46
FeO	4·44	6·25	4·47	4·59	1·84	1·16	0·93	1·33	9·32
MnO	0·17	0·09	0·05	0·10	0·06	0·02	tr	0·04	0·15
MgO	2·28	11·95	3·38	3·13	1·40	0·38	0·07	1·73	7·08
CaO	5·33	9·32	7·02	6·92	3·00	1·66	0·84	2·86	9·80
Na_2O	3·92	2·06	3·71	3·83	3·75	3·67	3·67	7·15	2·30
K_2O	2·56	1·08	1·62	1·08	3·09	3·82	4·83	0·73	0·61
H_2O+	0·87	1·81	1·05	0·13	0·38	0·67	0·20	0·21 (H₂O+ and H₂O− together)	1·33
H_2O-	0·64	0·10	0·03	0·10	0·10	0·08	0·04		0·08
P_2O_5	0·22	0·19	0·21	0·41	0·38	0·20	0·06	0·29	0·39
CO_2	—	0·29	—	—	0·43	0·31	tr	0·20	—
S	n.d.	0·53	n.d.	n.d.	n.d.	n.d.	n.d.	0·09	0·13
F	n.d.	0·21	n.d.	n.d.	n.d.	n.d.	n.d.	—	0·22
	100·46	100·18	100·71	99·84	99·76	99·87	100·18	100·07	99·85
Less O	—	0·36	—	—	—	—	—	0·03	0·16
TOTAL	100·46	99·82	100·71	99·84	99·76	99·87	100·18	100·04	99·69
MESONORMS									
Q	11·7	7·4	13·6	15·7	28·1	30·9	31·8		11·9
Or	5·0	—	1·4	—	13·7	21·2	28·5		—
Ab	35·5	18·5	33·5	34·5	34·0	33·5	33·5		21·0
An	22·0	7·0	25·0	21·0	9·0	5·0	2·5		21·5
Bi	16·0	10·4	13·0	10·4	7·7	2·9	0·8		5·6
Ho	—	46·7	9·7	12·8	—	—	—		28·5
Mt	2·4	0·6	2·2	2·5	1·1	1·0	1·5		0·4
Ti	1·8	1·8	1·2	1·5	0·6	0·3	0·9		1·5
Ap	0·5	0·5	0·5	0·8	0·8	0·5	—		1·0
Cc	—	0·3	—	—	0·5	0·3	—		0·5
Py	—	0·4	—	—	—	—	—		0·1
Hm	—	4·1	—	—	—	—	—		0·7
Fr	—	0·3	—	—	—	—	—		0·3
C	5·2	—	—	0·9	3·7	3·1	0·5		—
MODAL ANALYSES									
Quartz	16·4	—	12·6	14·8	22·8	36·2	25·9		11·0*
Potash feldspar	2·4	—	—	1·3	21·4	29·1	33·7		—
Plagioclase	54·6	30·0*	56·0	54·7	44·8	30·0	35·8		27·0
Hornblende	—	60·0	15·5	16·7	—	—	1·0		56·0
Biotite / Chlorite	24·6	10·0	13·5	10·8	8·2	2·5	2·7		2·0
Iron ore	2·0	—	0·6	0·7	1·4	0·4	0·6		—
Accessory minerals	n.d.	—	0·8	1·0	1·4	1·8	0·3		4·0
Plagioclase composition	An_{36}	An_{55}	An_{47}	An_{42}	An_{30}	An_{25-40}	An_{25}		An_{32}

* Approximate analysis only.

1. Y.630.1 Banded biotite-gneiss, northern Audrey Island, Debenham Islands (anal. A. K. Hoskins).
2. Y.639.6 Amphibolite, Store Point, Neny Island (anal. A. K. Hoskins).
3. Y.676.1 Dioritic gneiss, north-western Neny Island (anal. A. K. Hoskins).
4. Y.680.1 Dioritic gneiss, north-western Neny Island (anal. A. K. Hoskins).
5. Y.680.3 Granite-gneiss dyke, north-western Neny Island (anal. A. K. Hoskins).
6. Y.609.1 Granite-gneiss, Randall Rocks (anal. A. K. Hoskins).
7. E.1559.1 Granite-gneiss, Roman Four Promontory (anal. A. K. Hoskins).
8. M.812 Granitic migmatite, eastern Neny Island (Cordini, 1959, p. 140).
9. Y.601.2 Plagioclase-amphibolite, western Mount Nemesis (anal. A. K. Hoskins).

TABLE VI

MODAL ANALYSES OF HOMOGENEOUS AND HETEROGENEOUS GRANITE-GNEISSES

	HOMOGENEOUS GRANITE-GNEISSES								HETEROGENEOUS GRANITE-GNEISSES					
	Roman Four Promontory and Mount Nemesis		*Butson Ridge*	*Randall Rocks and Millerand Island*			*Debenham Islands*		*Postillion Rock*			*Eastern Neny Island*		
	E.1553.1	Y.601.7	E.1309.2	Y.653.1	Y.654.2	Y.669.1	Y.617.6	Y.620.1	E.1552.3	E.1552.2	E.1552.5	Y.643.3	Y.641.3	Y.641.2
Quartz	33·2	33·8	33·7	42·4	28·9	35·5	45·7	35·8	24·1	31·1	26·5	23·7	25·2	37·6
Potash feldspar*	31·4	41·5	27·5	20·7	21·9	33·4	22·0	35·6	—	2·4	56·7	42·9	27·8	31·9
Plagioclase	32·1	22·0	29·2	32·2	41·9	27·3	27·1	24·6	53·6	60·1	15·4	25·6	38·4	22·7
Biotite } Chlorite }	2·0	2·4	9·2	3·4	6·9	3·4	4·3	0·7	16·3	5·8	1·3	7·6	7·0	6·8
Iron ore	1·1	0·3	0·1	1·3	0·1	0·3	0·6	1·6	3·9	—	—	0·2	0·1	0·4
Accessory minerals†	0·2	n.d.	0·3	—	0·3‡	0·1	0·3‡	1·7‡	2·1‖	0·6	0·1	n.d.	1·5‡	0·6§
Plagioclase composition	An_{15}	An_{16}	An_{28}	An_{27}	An_{15}	An_{28}	An_{32}	An_{25}	An_{32}	An_{31}	An_{23}	An_{32}	An_{24}	An_{28}

* Including microperthite.
† Including zircon, apatite, orthite, sphene and muscovite.
‡ Mostly epidote.
§ Mostly garnet.
‖ Mostly sphene.

E.1553.1 Pink granite-gneiss, eastern side of Roman Four Promontory.
Y.601.7 Pink granite-gneiss, western end of Mount Nemesis. (Specimen E.1559.1, Table V, also belongs to this group.)
E.1309.2 Biotite-granite-gneiss, Butson Ridge.
Y.653.1 Granite-gneiss, eastern Randall Rocks.
Y.654.2 Granite-gneiss, eastern Randall Rocks.
Y.669.1 Granite-gneiss, north-east Millerand Island. (Specimen Y.609.1, Table V, also belongs to this group.)
Y.617.6 Granite-gneiss, east end of Brian Island, Debenham Islands.
Y.620.1 Granite-gneiss, east end of Barry Island, Debenham Islands.
E.1552.3 Banded plagioclase-biotite-gneiss forming the country rock, Postillion Rock.
E.1552.2 Banded quartz-biotite-plagioclase-gneiss which forms a *lit-par-lit* gneiss with the country rock, Postillion Rock.
E.1552.5 Banded microcline granite-gneiss, Postillion Rock.
Y.643.3 Migmatitic granite-gneiss, eastern Neny Island.
Y.641.3 Migmatitic granite-gneiss, eastern Neny Island.
Y.641.2 Migmatitic garnetiferous granite-gneiss, eastern Neny Island.

are described in the second group. In the hand specimen the texture of these gneisses varies from coarsely augen to finely gneissic and their colour also varies from grey to brick red and almost to white. Thin sections show that these rocks are composed essentially of quartz, plagioclase and potash feldspar; the latter always appears to be replacing the plagioclase. The usual accessory minerals are sphene, zircon, apatite and magnetite, while small amounts of rutile, hornblende, garnet and muscovite may occur locally.

A. Homogeneous Granite-gneisses

At Roman Four Promontory, Millerand Island and Butson Ridge there are major intrusions of homogeneous granite-gneiss, each of which is individually distinguishable both in the hand specimen and in thin section.

1. *Roman Four Promontory and Mount Nemesis*

a. *Field relations.* Roman Four Promontory is the type area for Adie's (1954, p. 13) pink granite-gneiss and Nichols's (1955, p. 47) "Roman Four Mountain Gneiss". This gneiss, which also forms most of Mount Nemesis (Fig. 6) and the eastern part of Roman Four Promontory, is characterized by the

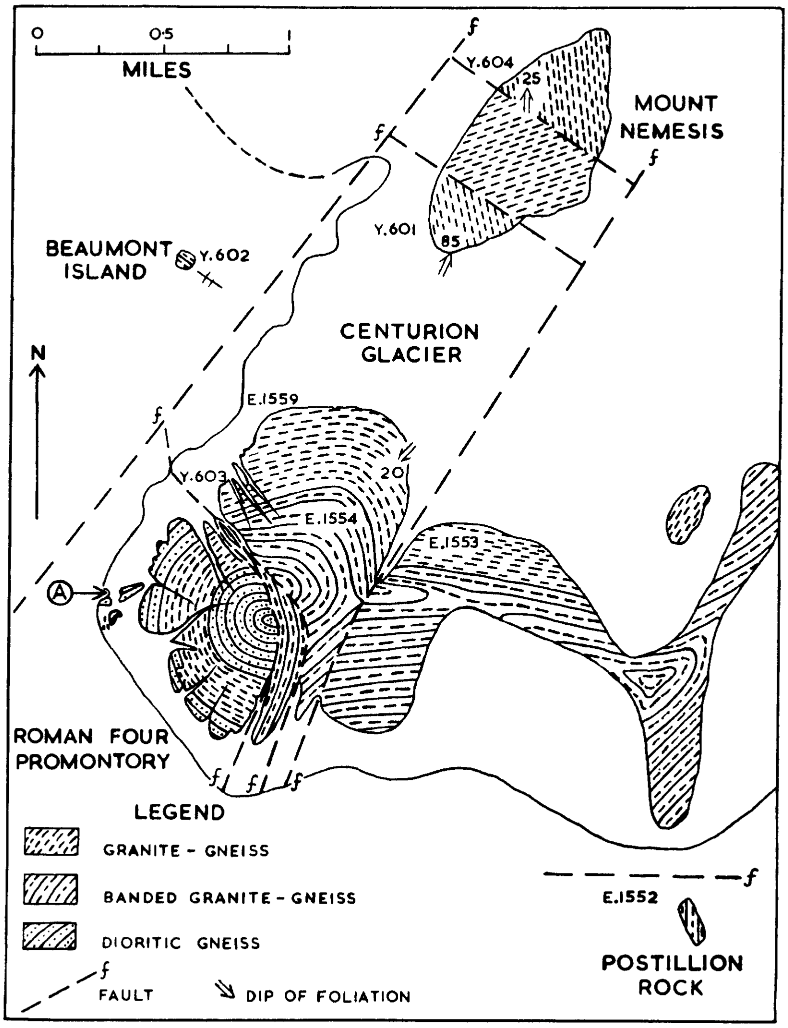


FIGURE 6

Geological sketch map of the Roman Four Promontory and Mount Nemesis area. The shading represents the approximate outcrop of the foliation planes. Dykes younger than the Basement Complex have been omitted.

A. Biotite-gneiss.

apparent sheet-like appearance of the intrusion (Plate Id). The dark bands seen in the north-west face of Roman Four Promontory are rafts, and in addition there are at least three types of dyke rocks which can be distinguished on their field relations. In the hand specimen the general characters of the gneiss vary considerably throughout the rock; in some places it is a delicate pink colour (E.1553) or pale buff (Y.601) with a fine-grained gneissic texture, but elsewhere (E.1559) it is a medium-grained gneiss with a brownish resinous appearance. Small biotites and phacoidal quartz crystals define the foliation. The general mineralogical variations are shown by the modal analyses in Tables V and VI. The mesonorm and chemical analysis of specimen E.1559.1 are given in Table V.

The strike of the foliation varies so unpredictably that it is difficult to decide whether this intrusion is wholly concordant or partly discordant. The contact between the pink granite-gneiss and the country rock has not been seen in this area. This intrusion is bounded on all sides by faults, but on Roman Four Promontory the gneiss is overlain by a sequence of banded granite-gneisses which also occur to the south-west at Postillion Rock and to the north-west at Beaumont Island. There is also an inaccessible mass of granite-gneiss high up on the western face of the promontory. A specimen of this gneiss (E.1557.8), collected from the scree at the base of the promontory, resembles the granite-gneiss from the extreme east end of Randall Rocks (Y.653.1).

b. *Petrography.* The granite-gneiss from the northern end of Roman Four Promontory has a brown resinous appearance, which in thin section (E.1559.1) is seen to be due to thin films of an unknown reddish mineral that has penetrated every crack in the fabric of the rock. It has a hemigranoblastic interlobate texture and an adamellitic composition with plagioclase and potash feldspar in approximately equal amounts (Table V). The antiperthitic plagioclase ($Ab_{75}An_{25}$) has poorly developed twinning on the albite law and is slightly altered in places to small prehnite flakes. The plagioclase has either myrmekite or albitic margins adjacent to the potash feldspar, which itself appears to be mostly microcline-microperthite with poorly developed cross-hatch twinning but the undulating extinction associated with microcline. Some of the string-like potash feldspar perthite might well be perthitic orthoclase. The ferromagnesian minerals are biotite and hornblende, both of which show extremes of pleochroism. They are scattered throughout the rock but, apart from a little localized mortar structure, there is no evidence for the cataclastic deformation of the rock. Quartz forms amoeboid masses elongated parallel to the foliation and orthite, zircon and ore are important accessories.

To illustrate local mineralogical variations in this gneiss the modal analyses of two other granite-gneisses from the same locality are included in Table VI. In these rocks biotite and amphibole are less strongly pleochroic (E.1553.1) and plagioclase sometimes replaces biotite (Y.601.7). Relatively large stumpy zircons with prominent cleavages are noticeable among the accessory minerals (Y.601.7).

2. *Millerand Island*

a. *Field relations.* The granite-gneisses form most of the western side of Millerand Island and, apart from a small exposure on the north coast, they are only accessible at the south-western corner of the island and at Randall Rocks (Fig. 7). There, the granite-gneiss is a medium-grained whitish rock tinged green by alteration products. At the south-west end of Millerand Island an elongated mass of quartz-biotite-plagioclase-gneiss cuts across the foliation which is only poorly developed and not always traceable in the field. This same quartz-biotite-plagioclase-gneiss, which resembles some of the dioritic gneisses, occurs as xenoliths, in varying degrees of assimilation, scattered throughout the granite-gneiss. There are also small sheared chlorite-plagioclase-schist xenoliths of an obscure origin. When traced to the westernmost of Randall Rocks, the granite-gneiss has been altered and sheared by the post-Basement Complex metamorphism which is discussed on p. 45. This rock is pink and green with well-defined folia of pink potash feldspar separated by chlorite bands. At the eastern end of Randall Rocks the granite-gneiss is a medium-grained, granitic rock with fresh biotite folia and pink potash feldspar porphyroblasts, but quantitatively this rock (Y.653.1; Table VI) contains less potash feldspar than the whitish gneiss (Y.609.1; Table V).

Numerous acid veins and dykes, some of which can be attributed to the Basement Complex, cut the granite-gneiss. At station Y.608 aplitic veins are ptygmatically folded and these are cut in turn by narrow, pegmatitic acid veins containing garnet. At Millerand Island the granite-gneiss is cut by numerous (?) early Palaeozoic and Upper Jurassic dykes.

b. *Petrography*. The granite-gneiss from south-west Millerand Island weathers to a pale cream colour and has a granular appearance caused by the weathering out of chlorite, leaving protrusions of quartz and feldspar. When freshly broken, this rock has a greenish tinge due to the chlorite and the saussuritization of the feldspar. The quartz has a purplish colour.

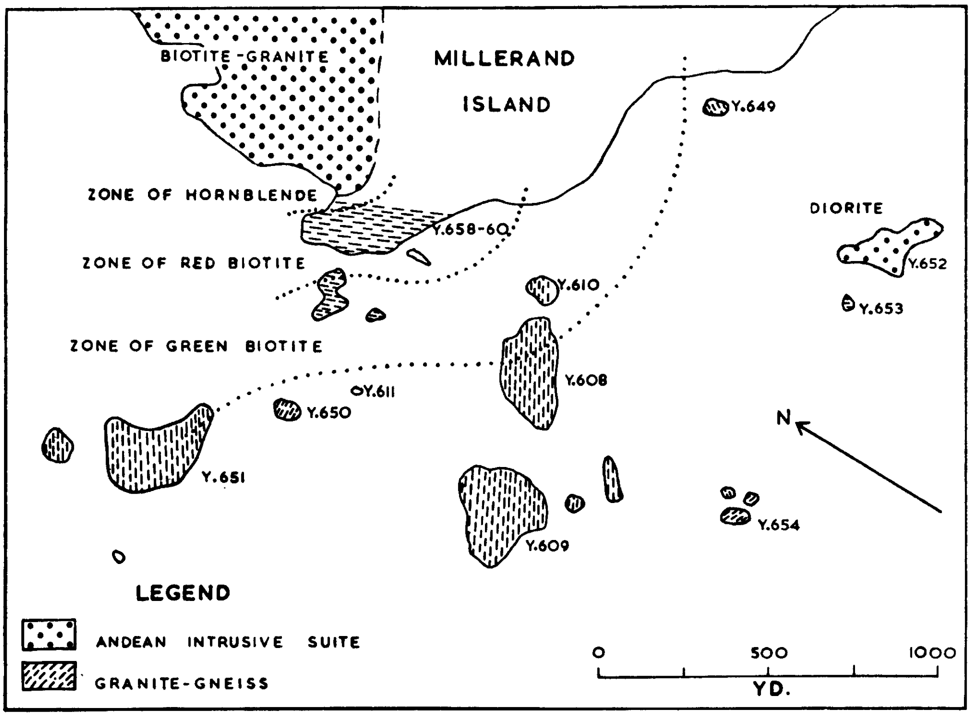


FIGURE 7

Geological sketch map of south-west Millerand Island and Randall Rocks. Dykes younger than the Basement Complex have been omitted.

The chemical analysis and mesonorm of specimen Y.609.1 are given in Table V. Under the microscope this gneiss has an interlobate, hemigranoblastic to porphyroblastic texture, in which the minerals are not regularly distributed but form agglomerations. Plagioclase, the dominant feldspar (Table V), is zoned with distinct cores of composition $Ab_{60}An_{40}$ and rims of $Ab_{75}An_{25}$. In some cases this zoning is so distinct that a Becke line forms between the core and the rim. The distribution of alteration is capricious and frequently limited to the cores or to a particular zone. Some of the plagioclase is porphyroblastic (up to 3 mm. in diameter) and encloses small subangular patches of potash feldspar. Porphyroblastic potash feldspar, which is microperthitic orthoclase, contains relicts of plagioclase with myrmekitic margins. Quartz forms irregular interlobate crystals with an undulose extinction. The principal ferromagnesian mineral is chlorite which occurs as crushed grains moulded around quartz and feldspar. This chlorite, together with epidote and magnetite, has been derived from biotite (α = straw, γ = medium brown) of which a few ragged crystals remain. These are not well orientated and they are only fresh when enclosed by the plagioclase or microperthite. The chloritized biotite contains lenses of prehnite and epidote. Muscovite has the same habit and occurrence as biotite but it is neither crushed nor distorted. Some of the plagioclase relicts in the microperthite have been replaced by sericite which has recrystallized to give muscovite. In some cases the muscovite is also intergrown with chlorite. Accessory zircon occurs either as long needle-like crystals or as short prisms with prominent cleavages. There are small pleochroic haloes in both the chlorite and biotite adjacent to zircon. Other accessory minerals include magnetite, pyrite, orthite and idioblastic cored apatites. When this rock is traced along the strike to the next islet, 700 yd. (640 m.) to the north-east, the outer aureole of the Andean biotite-granite is reached. The features of the contact metamorphism of the granite will be described more fully on p. 45. A specimen from this islet

(Y.608.4) shows considerable shearing and the only unaltered mineral is quartz. In both this rock and specimen Y.610.1 from the next islet, 250 yd. (229 m.) farther north-east, the only feature worthy of comment, apart from the contact metamorphism, is the absence of microperthite porphyroblasts, although specimen Y.610.1 contains antiperthitic plagioclase. In specimen Y.608.4 large (0·5 mm.) crystals of orthite are a prominent accessory. Transverse to the strike south-eastwards, the gneiss is exposed on a small islet (Y.654; Fig. 7) where it is in contact with a hornblende-biotite-gneiss (Y.654.1). In the hand specimen the granite-gneiss (Y.654.2) is finer-grained and more porphyroblastic than specimen Y.609.1, and it lacks the large purplish quartz crystals. The antiperthitic plagioclase ($Ab_{85}An_{15}$) is altered but the much fresher microperthitic orthoclase has been partially replaced by quartz and it also contains corroded relicts of plagioclase armoured with myrmekite.

Specimen Y.649.1 comes from a small islet just off the southern coast of Millerand Island (Fig. 7). Antiperthitic plagioclase ($Ab_{75}An_{25}$), showing both albite and Carlsbad twinning, is sometimes porphyroblastic and encloses lath-shaped crystals of a more calcic plagioclase (Plate IVe). Microperthitic orthoclase occurs in crystals up to 6 mm. across. Specimen Y.653.1 (Plate IVf) is very similar but the hand specimen displays pink potash feldspar. The thin section shows the same feldspathic features but there is less microperthite and the exsolution veins are coarser. Likewise, the albite margins of the plagioclase adjacent to the microperthite are more strongly developed. In spite of the presence of distinctly pink potash feldspar porphyroblasts in the hand specimen (Y.653.1), the modal analysis (Table VI) shows that this gneiss contains less potash feldspar than the whitish-coloured gneisses (Y.609.1; Table V). Biotite (α = straw, γ = light chestnut brown), which forms thicker books than usual, is deeply embayed where it has been replaced by potash feldspar and sodic plagioclase. Biotite is moulded onto the iron ore, which contains inclusions of apatite, zircon and orthite, the latter producing pleochroic haloes in the biotite.

The relationship between the granite-gneisses and the dioritic gneisses on the north-east coast of Millerand Island has already been described (p. 19). Farther westward (station Y.669; Fig. 3), along the north-eastern coast, the granite-gneiss is a massive homogeneous rock whose foliation dips uniformly north-east like that of the adjacent hybrid hornblende-gneiss. Although the general texture of this granite-gneiss (Y.669.1) is hemigranoblastic, some crystals are distinctly porphyroblastic and the crystal form ranges from saccharoidal to amoeboid. The original biotite has been completely replaced by chlorite and the whole is outlined by fine-grained ore dust concentrated mainly at the crystal margins and along the cleavages. Slightly sericitized antiperthitic plagioclase ($Ab_{72}An_{28}$) is subidioblastic and microcline-microperthite is interstitial with typical wavy extinction but no conspicuous cross-hatched twinning. There is also some porphyroblastic microcline-perthite which is apparently exactly similar to the interstitial form, but it has a well-developed rectangular form ($1 \cdot 25 \times 0 \cdot 75$ mm.) and encloses plagioclase, quartz and shapeless blebs of microcline-perthite. Among the accessory minerals are orthite with the usual rectangular form, zircon with prominent cleavages, interstitial fluorite and radiating chlorite, which are attributed to the nearby (?) early Palaeozoic granite which also carries fluorite (Hoskins, 1960, p. 20).

c. *Xenoliths.* At Randall Rocks and south-west Millerand Island the granite-gneiss contains xenoliths of quartz-biotite-plagioclase-gneiss and chlorite-plagioclase-schist. The degree of assimilation of these xenoliths by the granite-gneiss varies considerably, and superimposed are the effects of the various post-Basement Complex phases of metamorphism. A xenolith of quartz-biotite-plagioclase-gneiss (Y.608.2) from an islet 350 yd. (320 m.) south-west of Millerand Island has probably been least altered by assimilation. Its texture is gneissic with a regular grain-size of 0·5 mm., and zoned subidioblastic plagioclase (cores—$Ab_{58}An_{42}$, rims—$Ab_{68}An_{32}$) is the dominant constituent of the rock. All of the feldspar is clouded by alteration products. Next in order of abundance is quartz with an undulose extinction and forming irregular xenoblasts. The original mafic mineral was biotite and its interstitial form has been preserved, although the original biotite has been replaced by chlorite and a decussate aggregate of small green biotite crystals during post-Basement Complex metamorphism. Associated with this chlorite and recrystallized biotite is a little iron ore and some epidote. Apatite and orthite, the latter altered and surrounded by epidote, are accessories. A small xenolith in specimen Y.649.1 is much fresher but its assimilation by the granite-gneiss is much more complete. As in specimen Y.608.2, biotite is interstitial and it has been replaced along cleavages by a strongly pleochroic yellowish-green epidote. The contact between the granite-gneiss and the xenolith is sharp though disrupted by the porphyroblastic introduction of plagioclase.

In the hand specimen the chlorite-plagioclase-schist has the appearance of a very hard black shale.

This rock (Y.650.2) has a schistose slaty appearance and it has been altered to such an extent that very few crystals still have distinct boundaries. The feldspar is very poorly twinned and appears to be a plagioclase, possibly oligoclase, although some may be late albite. A little quartz and feldspar are set in a turbid groundmass of pale green chlorite, iron ore, epidote and amphibole. The xenolith has a 1–2 mm. wide selvage consisting of a cryptocrystalline mass of altered plagioclase, epidote and amphibole, which contains plagioclase relicts from the granite-gneiss. Fresh plagioclase has recrystallized on the older relict cores and the new plagioclase is more albitic.

3. *Butson Ridge*

a. *Field relations.* In the hand specimen the Basement Complex rocks exposed along the north-west side of Butson Ridge are a series of distinctive granite- and biotite-granite-gneisses. At three exposures (stations E.1308–10) the main rock type is a buff-coloured biotite-granite-gneiss which has dark micas wrapped around large rounded feldspars. This gneiss contains inclusions of massive plagioclase-amphibolite similar to those of Mount Nemesis (Y.601.2); at station E.1310 it has been intruded by sharp-sided dykes of a brick-red granite-gneiss. 0·5 miles (0·8 km.) eastwards at station E.1311 a granite-gneiss appears to have permeated the biotite-granite-gneiss and forms a broad band approximately 200 ft. (61 m.) high. At station E.1304 the granite-gneiss appears to intrude a biotite-gneiss which resembles the gneiss from the Debenham Islands. Specimens of a dioritic gneiss were obtained from the screes at station E.1309 but their relationship to the granite-gneisses is not known.

b. *Petrography.* In thin section the buff-coloured biotite-granite-gneiss (E.1309.2, 1310.3) has a hemigranoblastic texture with some mortar structure, phacoidal feldspar and amoeboid quartz. Biotite is the main ferromagnesian mineral, constituting 9·2 per cent of the rock (Table VI). The biotite has been slightly deformed and in local shear zones it has recrystallized to a greenish brown variety. Where the biotite has been completely chloritized sphene is most abundant, but this is uncommon. Slightly antiperthitic plagioclase ($Ab_{72}An_{28}$) is granoblastic and has bent twin lamellae. The potash feldspar, a microcline-microperthite, occurs in distinct folia. The number of inclusions is variable and some of the crystals are quite clear. Quartz with an undulose extinction is either amoeboid or phacoidal in form. Sheared but recrystallized orthite is associated with the biotite; apatite and subidioblastic zircons are accessories. Some of the shearing is late, having occurred after the formation of the myrmekite, but it is earlier than the late rutile (?), which has been deposited along minute cracks in the fabric of the rock. At station E.1309 the biotite-granite-gneiss contains a xenolith of a diopside-bearing dioritic rock which may be related to the dioritic rocks found on the scree.

The brick-red granite-gneiss (E.1310.1) has a hemigranoblastic interlobate to amoeboid texture. Large ($\sim$ 2·5 mm.) poikiloblastic microcline-perthite crystals have well-developed twinning and albite veinlets. Saussuritized plagioclase is antiperthitic (Plate Va) and quartz has irregular contacts, which, together with the unmixed perthite and antiperthite, are suggestive of cataclastic deformation. There is only about 2 per cent of biotite and this has been altered to chlorite. Orthite, apatite and a little iron ore are accessories.

4. *Debenham Islands*

a. *Field relations.* The contacts between the granitic rocks and banded biotite-gneisses at the Debenham Islands have been described on p. 10. The gneiss (Y.617.6) from the east end of Brian Island, which is characterized by compound porphyroblasts of quartz, also forms the western end of Barry Island (Y.618), where it contains numerous xenoliths of banded biotite-gneiss. The gneissic granite from eastern Barry Island and southern Barbara Island is a fine-grained pink rock with a pronounced foliation, showing more variation in trend than usually occurs in the granite-gneisses. Its contact with the banded biotite-gneiss is sharp and there are no signs of hybridization of the country rock. At several localities in these islands there are small patches of granite-gneiss, which occur sometimes as small veins but more often as pinkish patches of country rock containing more potash feldspar than usual.

b. *Petrography.* In thin section the granite-gneiss from the east end of Brian Island (Y.617.6) shows late epidotization and alteration of the feldspar. Its texture is granoblastic saccharoidal, differing from those of the other granite-gneisses in the occurrence of crystalloblastic plagioclase ($Ab_{68}An_{32}$) with an average grain-size of 0·3 mm. Microcline-perthite with very few inclusions is present in almost the same proportion as antiperthitic plagioclase (Table VI). Albitic and myrmekitic rims on the plagioclase adjacent to the potash feldspar are poorly developed. Original biotite has been replaced by chlorite and epidote, the latter having also replaced some of the plagioclase selectively along certain albite twin lamellae.

The gneissic granite (Y.620.1) from the east end of Barry Island is richer in potash feldspar than the granite-gneiss from Brian Island (Y.617.6; Table VI) and it has a coarser grain-size averaging 1 mm. The presence of equidimensional potash feldspar and plagioclase makes this rock atypical of the granite-gneisses. The plagioclase ($Ab_{75}An_{25}$) has clear twinned albitic rims around saussuritized cores and bent albite twin lamellae, but the potash feldspar is mostly orthoclase-perthite with altered albite strings. The quartz has recrystallized but lacks its usual amoeboid appearance in the granite-gneisses; instead it has intricately fretted contacts which are probably due to cataclastic deformation. Clusters of iron ore, chlorite and epidote replace the biotite. The high modal percentage of iron ore relative to the amount of chlorite derived from biotite and the penetration of the rock fabric by granular iron ore suggest that it has been introduced. Zircon and orthite are also accessories.

B. Heterogeneous Granite-gneisses

Apart from the large areas of granite-gneiss described already, there are numerous exposures where less homogeneous granite-gneisses occur. In the field it is possible to distinguish a number of broad groups on the basis of the reaction between the granite-gneiss and the country rock. At Millerand Island *lit-par-lit* gneisses grade into the *tâche d'huile* type, but elsewhere the correlation between these heterogeneous granite-gneisses is often obscure. Mineralogically and texturally they have many features in common.

1. *Banded granite-gneisses*

a. *Field relations.* At Roman Four Promontory the pink granite-gneiss is overlain by a group of banded granite-gneisses. Unfortunately, it was not possible to examine this contact with the pink granite-gneiss, but at station E.1554 on the upper part of the promontory the rock is streaky and resembles the contact rocks between the granite-gneiss and the banded biotite-gneiss on Brian Island in the Debenham Islands (p. 10). It has distinct pink and grey streaks with dark folia of biotite. At Postillion Rock the foliation dips steeply to the east-south-east, whereas on the main mass of the promontory it dips gently south-westward, so that it would appear there is a fault between Postillion Rock and Roman Four Promontory. The whole island is composed of a coarsely banded gneiss (Plate IIIb); bands of a hornblende-biotite-plagioclase-sphene-schist (E.1552.3) are enclosed in a series of granite intrusions which become progressively richer in potash feldspar. The earliest phase, which intimately penetrates the schist concordantly, is a granodioritic rock (E.1552.4) with biotite, but locally potash feldspar is less abundant and amphibole is the dominant ferromagnesian mineral (E.1552.13). The second phase is a biotite-granite-gneiss (E.1552.2) which is locally discordant (Plate IIIc) and grades into the final phase, a pale pink microcline-rich granite-gneiss (E.1552.5).

Beaumont Island, where the foliation is almost vertical, also appears to be faulted in relation to the main mass of Roman Four Promontory. The rocks forming this island show banding similar to that found at Postillion Rock but on Beaumont Island most of the rocks are granodioritic types with amphibole as the dominant ferromagnesian mineral. Small folds are also more common on Beaumont Island.

b. *Petrography.* The country rock of the banded biotite-gneisses at Postillion Rock is a hornblende- and/or biotite-plagioclase-gneiss (E.1552.3, 12), characterized by abundant small idioblasts of sphene (Plate Vb). This rock has been intruded *lit-par-lit* by a granodioritic rock, producing a quartz-biotite-plagioclase-gneiss (E.1552.4, 13) with a little perthitic microcline and amphibole. The latter mineral is variable in its properties and it appears to range in composition from a dark green hornblende to a pale green actinolitic amphibole; the amount of hornblende present is almost inversely proportional to the amount of potash feldspar. The banded gneisses (Y.602.1-3) of Beaumont Island are mainly of the amphibole-dominated type, and sometimes a diopsidic pyroxene (Y.602.4) may be present in addition. A quartz-plagioclase-biotite rock (E.1552.2) which intrudes the *lit-par-lit* hybrid gneiss has a hemigranoblastic interlobate texture with very weakly zoned plagioclase ($Ab_{69}An_{31}$) tending to be idioblastic. The plagioclase contains small antiperthitic patches of replacement potash feldspar and has been slightly saussuritized. Biotite with a pleochroism α = straw, $\beta = \gamma$ = umber is partially chloritized. Interstitial microcline forms approximately 2·4 per cent of the rock (Table VI) and adjacent to the plagioclase there is an abundant development of myrmekite.

In the field specimen E.1552.2 grades locally into a microcline-granite-gneiss (E.1552.5) which is the last phase of the banded gneisses at Postillion Rock. In thin section its texture is hemigranoblastic interlobate to amoeboid. Slightly perthitic microcline with well-developed twinning (Plate Vc) encloses small plagioclase crystals and quartz blebs poikiloblastically. The average size of the microcline crystals is 1·5 mm. and the contacts between individual crystals are irregular. Plagioclase ($Ab_{77}An_{23}$) has dusty cores and sometimes contains antiperthitic patches, but adjacent to the microcline it has well-developed rims of albite or myrmekite. Quartz with an undulose extinction forms irregular amoeboid crystals replacing microcline. The small amount of partially chloritized biotite is characterized by a distinctive burnt orange colour. Both albite and microcline have replaced the biotite.

Irregular tongues of microcline-granite-gneiss, comparable with this rock, also occur at Neny Island (Y.640.3) and at Randall Rocks (Y.608.7) where they cut the granite-gneiss.

2. *Migmatitic granite-gneisses*

On the east coast of Neny Island there is a granite-gneiss which is difficult to classify even on its field relations. Locally it embodies *lit-par-lit*, *tâche d'huile* and mobilization structures with no apparent regularity. Cordini (1959, p. 146) has referred to this rock as granitic migmatite but it is probably more apt to call this rock a migmatitic granite-gneiss, using the term "migmatite" in the same sense as Niggli's usage (Read, 1957, p. 66).

a. *Field relations.* The granite-gneiss on the east coast of Neny Island is medium-grained and pale grey in colour with discrete pink microcline-microperthite porphyroblasts. At station Y.642 (Fig. 4) this rock intrudes the banded biotite-gneiss *lit-par-lit*, separating 4–8 in. (10–20 cm.) wide bands of the latter by 12 in. (30·5 cm.) thick tongues of granite-gneiss. The continuity of the layers in the biotite-gneiss has been disrupted in such a way as to suggest that the upper part of the exposure has been thrust southwards over the lower part. The granite-gneiss (Y.642.2) is intimately penetrated by a lighter-coloured phase of granite-gneiss (Y.642.3). In the hand specimen this lighter colour can be attributed to:

i. The clearing of inclusions from the pink microcline porphyroblasts and the weak development of an augen structure.
ii. The segregation of quartz and feldspar into layers.
iii. The alteration of the biotite to chlorite.
iv. The alteration of the plagioclase.

Approximately 300 yd. (274 m.) north of Norseman Point (Y.643), this granite-gneiss contains sheets of a hornblende-biotite-gneiss (Y.643.2), which, although similar to the hornblende-bearing banded biotite-gneiss of Barbara Island, may conceivably be a dioritic gneiss. These sheets are up to 10 ft. (3 m.) thick and dip south-south-east at 35–40°. The general strike of the foliation in the granite-gneiss (Y.643.3) is about 065° mag. but when traced uphill to 150 ft. (46 m.) it swings round to 330° mag. and clearly defined sheets of banded biotite-gneiss are recognizable, similar to the occurrence at station Y.642. Schistose xenoliths occur in a zone parallel to the foliation and locally a feldspathic rock (Y.643.6) is developed around them. A pyroxene rim is present round the xenolith itself. The rock at the contact between the xenoliths and the granite-gneiss is not a hybrid, because it is frequently absent when the contact is sharp. The joints are well-developed at this locality and they control the form of the rock exposure. Norseman Point (Y.644) is almost an exact replica of the previously described locality (Y.643), but the granite-gneiss also contains long schistose inclusions which have been deformed into folds with axial planes dipping at 5° to the north.

At station Y.641 on the north-east coast of the island the grey migmatitic granite-gneiss forms the bulk of the exposure. While microcline is still important, the gneiss here lacks the pink microcline porphyroblasts so typical of it elsewhere. Westward across the exposure the gneiss becomes lighter in colour and passes into a dyke of garnetiferous granite-gneiss (Y.641.2). The lighter colour of the gneiss is due to the concentration of biotite into well-defined folia.

b. *Petrography.* In a rock as variable as the migmatitic granite-gneiss it is difficult to select type material, but specimen Y.643.3 is probably most representative of the area and is fully described below. In the hand specimen it is a medium-grained grey rock with pink microcline porphyroblasts. In thin section it has a granoblastic interlobate texture. A modal analysis is given in Table VI. Plagioclase ($Ab_{68}An_{32}$) occurs in subidioblastic crystals usually 0·5 to 1·5 mm. in diameter, but corroded relicts in the potash feldspar are smaller. Twinning on the albite law is dominant, although Carlsbad twinning is also present. The crystals are very slightly zoned (the cores being more calcic) and those adjacent to or included by the potash feldspar have an outer rim of either albite or myrmekite. The plagioclase is completely altered to epidote and calcite adjacent to late quartz-epidote-chlorite veins but away from these veins alteration of the plagioclase is only marginal. Perthitic microcline porphyroblasts up to 2 mm. in diameter are present and the albite lamellae have been sericitized. The typical cross-hatch twinning is not very well developed and the extinction tends to be shadowy. Included in the microcline are plagioclase, biotite, quartz and epidote. The porphyroblastic nature of the microcline suggests that it is of metamorphic origin. Biotite with a pleochroism α = straw and γ = brown to a greenish brown is the main coloured mineral and it occupies an interstitial position between the subidioblastic plagioclase, which locally corrodes it and is indicated by the pseudomorphing of the replaced biotite by albite. The biotite is partially altered to chlorite and small idioblastic sphene crystals. Small amounts of granular sphene, epidote, prehnite and iron ore are the main by-products of the alteration which appears to have occurred at the same time as the alteration of the plagioclase. Quartz with an undulose extinction usually occurs as small crystals interstitial to the plagioclase and resembles mortar structure, but there are larger amoeboid patches up to 2 mm. in diameter. The accessory minerals include fresh xenoblastic orthite, small idioblastic to xenoblastic apatites which are concentrated in or near the biotite, and small idioblastic zircons. The epidote shows no particular association with the orthite as it does in some rocks.

In comparison with specimen Y.643.3, specimen Y.642.2 has a more irregular grain-size and poorly developed mortar structure is more frequent. Microcline-microperthite is less abundant and biotite is more common. Plagioclase ($Ab_{71}An_{29}$) is also more abundant than in specimen Y.643.3 and some iron ore also occurs interstitially, apparently replacing the plagioclase. Sphene is present as xenoblastic crystals up to 0·5 mm. across.

The paler variety of granite-gneiss from station Y.642, described above, has a hemigranoblastic interlobate texture which is locally dominated by masses of amoeboid quartz with an undulose extinction. Large porphyroblasts of microcline-perthite have replaced the plagioclase ($Ab_{69}An_{31}$) and the contacts between individual microcline crystals are sutured. As in specimen Y.643.3, albitic plagioclase has replaced some of the biotite, which is less common than in specimen Y.642.2 and is particularly associated with apatite, sphene and iron ore. Large (0·5 mm.) crystals of orthite (Plate Vd) are prominent among the accessories.

In the granite-gneiss (Y.641.3; Table VI) the variations are mainly textural. There is the tendency towards the formation of elongated lenses of plagioclase and biotite, one of which is 2 mm. wide and 5 mm. long. The biotite is interstitial with very few accessory minerals, and the whole rock is reminiscent of the banded biotite gneisses. Large porphyroblastic microcline-perthite crystals are concentrated in layers with crystalloblastic aggregates of quartz, biotite and plagioclase interstitial to them. Quartz is often concentrated in veins parallel to the foliation; these are up to 2 mm. wide and contain a little biotite. Zircon occurs as small and large idioblastic crystals, the latter having very prominent cleavages. Intense pleochroic haloes are developed in the biotite around the smaller zircons. The garnetiferous granite-gneiss (Y.641.2; Table VI) from the same station is similar in general characteristics to specimen Y.642.3, but in addition it contains perfectly isotropic, pale pink garnets associated with quartz-feldspar aggregates and it appears to be corroded by the quartz. Biotite associated with the garnet has been completely chloritized but the garnet does not appear to be related to the chlorite and biotite as observed by Adie (1954, p. 12) in the garnetiferous granite-gneiss from Garnet Rocks. The microcline has well-developed typical cross-hatch twinning.

3. *Lit-par-lit granite-gneisses*

The *lit-par-lit* granite-gneisses include a variety of gneisses whose field relations show that they are intimately related to each other. Small exposures of these rocks are present at Millerand Island, Roman Four Promontory and Neny Island, where they form broad dykes, narrow veins and *tâche d'huile* type intrusions. They are distinguished from the migmatitic granite-gneiss by the general absence of evidence of mobilization.

a. *Field relations.* The mode of intrusion of the *lit-par-lit* granite-gneisses varies along the coast of northern Neny Island. South-west of Store Point (Y.647) the gneisses superficially resemble the banded gneisses described from Roman Four Promontory, but they are characterized by sharp-sided granite bands, 4–6 in. (10–15 cm.) wide. Farther west, at station Y.682, these banded gneisses grade into finer-grained granite-gneisses which have invaded the banded biotite-gneisses in a *tâche d'huile* fashion. The country rock at station Y.681 is a hybrid dioritic gneiss and the granite-gneiss takes the form of dykes. All of these granite-gneisses show the same textural features in thin section but the field relations vary from one dyke to another depending on the country rock. When they cut the dioritic gneisses the contacts of these dykes are gradational, but contacts between the granite-gneiss and the banded biotite-gneiss are sharp and the dykes contain sheets of banded biotite-gneiss parallel to the foliation.

The *lit-par-lit* granite-gneiss from north-east Millerand Island (Y.671) is similar to the granite-gneisses from northern Neny Island. Like specimen Y.680.3, specimen Y.671.3 shows relict patches of a dioritic texture similar to that of the dioritic gneisses; mineralogical changes similar to those in the Neny Island rocks can be traced in specimens Y.671.4 and 12. At the western end of Roman Four Promontory bands of granite-gneiss have been intruded *lit-par-lit* into the banded biotite-gneiss and here individual bands of granite-gneiss have been boudinaged.

b. *Petrography*. Where the *lit-par-lit* granite-gneiss grades into the *tâche d'huile* type at station Y.682 the granite-gneiss is a banded pink and grey rock. In thin section (Y.682.4) the grey bands are layers of hornblende-biotite-plagioclase-sphene-schist similar to the rock described from Postillion Rock, whereas the pink bands are a fine-grained granite-gneiss with a hemigranoblastic interlobate texture. Specimen Y.682.5 of the *tâche d'huile* type is a pale pink rock with grey schlieren; under the microscope the relict texture of the schist is preserved in spite of extensive replacement by the now dominant microcline.

The granite-gneiss dykes which cut the dioritic gneiss have contacts which are gradational over about 12 ft. (3·7 m.). The typical dioritic gneiss of the country rock has been described on p. 21 and its modal analysis is given in Table V next to one of a granite-gneiss (Y.680.3) from a dyke. The granite-gneiss (Y.680.3) has inherited the texture of a dioritic gneiss, although this has been partly destroyed by the amoeboid quartz and replacement by microcline-perthite. The potash feldspar is remarkably fresh compared with the plagioclase which has been partly altered to prehnite. The most unusual feature of this rock is the alteration of the hornblende to calcite and chlorite; elsewhere in this area it is more usual to find original hornblende replaced by a fresh actinolitic hornblende even when the alteration of the plagioclase has reached an advanced stage. This alteration appears to be due to intergranular solution, because fresh hornblende and biotite are preserved in the microcline-perthite. Calcite and chlorite are the main minerals pseudomorphing hornblende, but a little epidote and rutile are also present. In sections normal to the *c*-axis the position of the cleavage planes of the original hornblende are still clearly visible; chlorite has formed along the cleavage planes and calcite has infilled the resulting network. The rock is traversed by narrow veins of potash feldspar, epidote and calcite. The potash feldspar tends to crystallize with the same optical orientation as the marginal microcline-microperthite. Besides the chemical analyses Table V also contains the mesonorms and modes of the granite-gneiss dyke (Y.680.3) and the dioritic gneiss country rock (Y.680.1). A comparison shows that, within their limitations, the mesonorms reflect the same changes shown by the modes. From the chemical analyses it can be seen that the formation of the granite-gneiss involves the addition of silica (reflected in the mesonorm by an increase in free quartz), and a decrease of magnesia, lime and iron. It is particularly noticeable that the soda content has remained approximately constant but the potash content has risen sharply. The disappearance of hornblende, and the decrease in the percentages of biotite and the anorthite constituent of the plagioclase are shown up in the chemical analysis by a decrease in the percentages of magnesia, lime, iron and titania.

C. Discussion

On the basis of their field relations the granite-gneisses of the Neny Fjord area can be subdivided in the first instance into two major groups:

i. Homogeneous granite-gneisses.
ii. Heterogeneous granite-gneisses.

The larger exposures of relatively homogeneous granite-gneiss which occur at Roman Four Promontory, Butson Ridge and Randall Rocks are included in the first group, from which the gneissic granite of the Debenham Islands can be separated on its texture. Apart from a little cataclastic deformation and later alteration, this texture is essentially granitic and shows very few of the granoblastic features of the granitic gneisses. Goldring (1962, p. 8) has established a suite of early Palaeozoic gneissic intrusive rocks on the Loubet Coast. It is therefore possible that these rocks and the dykes which cut the granite-gneiss at Millerand Island belong to a similar suite.

The three types of homogeneous granite-gneiss described have very similar textural and mineralogical features, in which either perthitic potash feldspar or antiperthite are prominent. Nevertheless, each of these rocks is individually distinguishable both in the hand specimen and in thin section. The main distinguishing characteristics of each group are:

i. The Roman Four Promontory granite-gneiss has an overall pink colour, a low content of biotite which has been almost completely chloritized, and the development of the more extreme forms of an amoeboid granoblastic texture.
ii. The granite-gneiss from Randall Rocks is more variable due to local alteration. The relatively fresh rock from the eastern end of this island group is a coarse- to medium-grained, whitish-coloured granitic rock with weak foliation and prominent pink potash feldspars. The biotite is usually fresh and it is particularly associated with the accessory minerals.
iii. The Butson Ridge biotite-granite-gneiss is typically pale buff in colour, medium-grained and the most gneissic of the granite-gneisses with dark schlieren of biotite. It has a higher modal percentage of biotite (Table VI).

With the exception of the Butson Ridge biotite-granite-gneiss, these rocks are not only confined to the area from which they have been described. The rock from Roman Four Promontory resembles the brick-red granite-gneiss from Butson Ridge and the granite-gneiss from northern Millerand Island. If this correlation is accepted, then on the field evidence the Butson Ridge granite-gneiss is older than the Roman Four Promontory granite-gneiss. A rock very similar to the Randall Rocks granite-gneiss also occurs on the top of the western end of Roman Four Promontory. It is not possible to correlate this gneiss with the other granite-gneisses directly, because they occur on opposite sides of an important series of faults.

These faults are again important when the heterogeneous granite-gneisses are considered. Apart from the microcline granite-gneiss, the banded granite-gneisses of Postillion Rock occur only in the eastern part of the Neny Island area. These rocks are thought to have been formed by the intrusion of the granite-gneiss into the banded biotite-gneiss. The hornblende-bearing biotite-plagioclase-schist, which is the oldest unit of these rocks, resembles the hornblende-bearing banded biotite-gneiss of Barbara Island but, since there is no intermediate exposure of these rocks in the 6 miles (9·7 km.) between Roman Four Promontory and the Debenham Islands, it is not possible to be more precise. Nor is it possible to correlate the granitic bands with any particular intrusion.

The migmatitic granite-gneiss of eastern Neny Island is characterized by its grey colour and the augen appearance of the pink potash feldspars. Its structural position could suggest that it is the lateral extension of the Roman Four Promontory granite-gneiss. Both petrographic and field evidence suggest that metasomatism played a large part in the formation of this rock and that there was at least some mobilization during one of the phases of metamorphism. On the northern coast of Millerand Island there is evidence to suggest that the granite-gneiss (correlated with the Roman Four Promontory granite-gneiss) grades into the *lit-par-lit* and *tâche d'huile* types of gneiss. It is thought that many of these variations represent different levels of intrusion and alteration. Extensive faulting took place in this area at the time of the intrusion of the Andean Intrusive Suite, but the only reliable datum in this area is the unconformity at the base of the Upper Jurassic Volcanic Group. Because all of these granite-gneisses show similar metamorphic features, it must be assumed for the present that they are all part of the same metamorphic cycle.

Both the granite-gneiss from Randall Rocks and the biotite-granite-gneiss from Butson Ridge have the appearance of rocks intruded under stress, because they contain biotite and/or chlorite moulded round subrounded plagioclase crystals. A weak mortar structure in the biotite-granite-gneiss and diablastic antiperthitic feldspar (Berthelsen, 1960, p. 196) in the red granite-gneiss from Butson Ridge indicate that these rocks have been sheared, but so far no garnet has been found that can be attributed to this origin (Harker, 1950, fig. 151). The garnetiferous granite-gneiss from Neny Island appears to be a late metasomatic dyke. Petrographically, it resembles the garnetiferous granite-gneiss described by Adie (1954, p. 12) but the potash feldspar in the Neny Island rock is microcline. The origin of the garnet is obscure; although it appears to be almandine, it shows no relationship to the biotite and chlorite, and it is not uncommon to see a single garnet crystal isolated in the middle of either a feldspar or a quartz crystal.

The variability in composition of the granite-gneisses is reflected in their modal analyses (Tables V and VI), which show that even closely related rocks differ markedly in the respective amounts of their major constituents: quartz, potash feldspar and plagioclase. At first it was considered possible to distinguish rocks in which microcline predominates over orthoclase but this was later found to be difficult. Microcline, lacking in both characteristic cross-hatch twinning and shadowy extinction, was frequently found. This was revealed by a number of 2V determinations on the Universal Stage. Comparisons of the 2V determinations with Tröger's (1959) tables suggest that the potash feldspar contains a significant amount of soda even when perthitic structures are absent, but the results proved variable from one crystal to another within the same rock. The variation in these gneisses can also be seen from the chemical analyses and mesonorms given in Table V. Significant features are that soda remains at an approximately constant level while potash increases. The alumina content is approximately inversely proportional to that of silica. In the mesonorm biotite decreases as potash feldspar increases but not at the same rate, indicating that not all of the potash was derived from the destruction of the biotite.

The analysis given by Cordini (1959, p. 140) is also included in Table V; it shows significant differences from the other analyses. In particular, it has a very high ratio of soda to potash and a low alumina content. It was not possible to calculate the mesonorm of this rock according to the rules given by Barth (1959, p. 136) or in Larsen and Sørensen's (1960, p. 681) amendment, because of the excess of sodium over aluminium when the oxide percentages are converted to cation percentages. Calculation of the C.I.P.W. norm shows $\sim$ 10 per cent normative acmite, of which the equivalent amphibole would be riebeckite or arfvedsonite. These minerals and the low potash content seem to be incompatible with the petrographic description of the rock (Cordini, 1959, p. 146).

The granite-gneisses possess many of the textural features described by Cheng (1944, p. 139). Both types of sutured texture referred to by him are present:

i. The replacement of plagioclase by potash feldspar.
ii. The replacement of feldspar by quartz.

These textures have been described using the terms, interlobate and amoeboid, as defined by Berthelsen (1960, p. 24) in his classification of granoblastic textures. Although the potash feldspar is porphyroblastic and includes relicts of plagioclase, it always, even in the migmatitic gneisses of eastern Neny Island, occupies an interstitial position with re-entrant edges to the crystals. The quartz crystals with a sutured texture form either long lenses of crystal aggregates parallel to the foliation of the rock or dactyloid crystals with lobes penetrating between the feldspar crystals. In the latter case, as Cheng (1944, p. 139) has suggested, the quartz has a corrosive appearance. Sutured textures are most highly developed in the granite-gneisses containing a relatively high proportion of potash feldspar (as microcline), such as the microcline granite-gneiss from Postillion Rock or the red granite-gneiss from Butson Ridge. They are least developed in the granite-gneiss from the western end of Randall Rocks, where the potash feldspar is mostly orthoclase-microperthite. Myrmekite is formed at most of the boundaries between potash feldspar and plagioclase. This is usually best developed at the ends of plagioclase crystals perpendicular to [010] and extends as irregular lobes into the potash feldspar, indicating renewed activity by soda at a late stage in the history of these rocks. Sometimes small relicts of plagioclase in the potash feldspar are composed entirely of myrmekite. Elsewhere, the rôle of myrmekite, which appears to be that of a buffer between the plagioclase and the potash feldspar, is that of an albitic rim on the plagioclase. As in the case of the sutured texture, this phenomenon is best developed in those rocks relatively rich in microcline. In some rocks the albitic margins to the plagioclases are so extensive as to suggest that they are part of the recrystallization of the plagioclase (Cheng, 1944, p. 142). The relationship between the albitic rims and the myrmekite is not always clear but in some rocks the relation between the two suggests that the albitic rims are later than the myrmekite.

Most of the granite-gneisses contain antiperthitic plagioclase; potash feldspar forms small rectangular patches in the plagioclase but in the microcline-rich rocks the antiperthite develops a coarse replacement form. In most of the rocks the potash feldspar is remarkably fresh and unaltered but there appear to have been two phases of saussuritization of the plagioclase in many of the granite-gneisses:

i. During the introduction of potash feldspar and quartz, and associated with some of the chloritization of the biotite.

ii. During the late chloritization of the biotite by intergranular solutions which have only altered the rims of the plagioclase adjacent to the biotite.

The late renewal of the activity of potash-bearing solutions is indicated by the occurrence of thin veinlets of potash feldspar, quartz and sometimes epidote which traverse the rock.

The migmatitic rocks on the east coast of Neny Island are intimately associated with the potash metasomatism and it is possible to trace the gradually increasing potash feldspar content. Mineral replacements in general follow the latter part of the sequence recorded by Cheng (1944, p. 146) which indicates repeated action by soda- and potash-bearing solutions. Some of the potash can be attributed either to original potash feldspar in the granitic rocks which has been re-activated or to potash released from the biotite that has been replaced by plagioclase. Field relations suggest that the remainder of the potash was introduced where locally porphyroblastic potash feldspars of the *dent de cheval* type have formed in the hornblende country rock. In the field the migmatitic rocks appear to be confined to distinct zones similar to the occurrence described by Cheng (1944, p. 145):

> "The 'igneous' sheets, as we see them in the field, may be simply channels along which large amounts of magmatic fluids have repeatedly been introduced and have re-acted with the country rocks to form various kinds of granitic rocks."

The main reaction between the granitic rocks and the hornblende-bearing rocks is initially feldspathization and the replacement of hornblende by biotite. Continued reaction results in the increasing addition of quartz and feldspar with the gradual elimination of the biotite. The replacement of the original plagioclase by sodic plagioclase and potash feldspar has led to the release of lime, some of which has been taken up in the formation of epidote and sphene, while the rest has apparently been expelled. Epidote is ubiquitous and it is frequently difficult to decide whether the epidote is a metamorphic product or whether it was introduced during one of the later phases of intrusion. Sphene, which forms both interstitial crystals and veinlets, is also late in some of the rocks. In those rocks containing fresh biotite much of the titania is present in the biotite and it forms an important by-product during the chloritization of the biotite. Where the other mafic elements, e.g. iron and magnesium, have gone is uncertain. Some of the magnesium would be taken up initially by the biotite and would remain in the chlorite.

Some of the dark hornblende-schist and plagioclase-amphibolite inclusions are thought to be relicts of basic dykes intruded into the granites before metamorphism and migmatization. The alteration of these rocks is described on p. 32, but Crowder (1959, p. 871) has suggested that the formation of a hornblende-schist from an andesite would require the addition of iron, magnesium and calcium. This possibly offers a clue to both the original composition of the dykes and the destination of the mafic elements from the granite-gneiss.

The general history of the granite-gneisses can be summarized as follows: this area was originally intruded by rocks of granitic or adamellitic composition, of which the homogeneous granite-gneisses are the nearest present representative. These granites were partly responsible for the fine-grained *lit-par-lit* and *tâche d'huile* intrusions. The granites were then intruded by a series of basic dykes which are now represented by strings of hornblende-schist and plagioclase-amphibolite inclusions that have resisted alteration. During metamorphism, metasomatism by potash-rich solutions was concentrated in zones parallel to the foliation, resulting in local mobilization and the intrusion of the microcline-rich granite-gneisses.

VII. PETROGRAPHY OF THE PLAGIOCLASE-AMPHIBOLITES, SKARN ROCKS, APPINITIC ROCKS AND METADOLERITES

MANY of the minor Basement Complex rock types can be dated as younger than the granite-gneiss but it is not possible to be more precise. Furthermore, the relationship between some of these rocks and the later metamorphisms is uncertain.

A. PLAGIOCLASE-AMPHIBOLITE DYKES

The plagioclase-amphibolite and hornblende-schist dykes, which were intruded after the granite-gneisses, are important because they provide information on the last metamorphism of this area. These rocks vary considerably in their characteristics and they have been extensively modified by local mobilization that took place during metamorphism. Some of these rocks, preserving relict textures, are metadolerites, while others, depending on their degree of deformation, have been completely altered to schistose plagioclase-amphibolites. The deformation can be divided into three phases (Fig. 8):

i. Fracturing of the dyke and its penetration by veins of the mobilized country rock.
ii. Distortion of the dyke to form a series of pillow-shaped inclusions in the country rock.
iii. Formation of lens-shaped inclusions of schistose plagioclase-amphibolite distended over a considerable distance but with a general trend still definable.

Potash metasomatism has affected some rocks during metamorphism and this is reflected in the biotite and potash feldspar content.

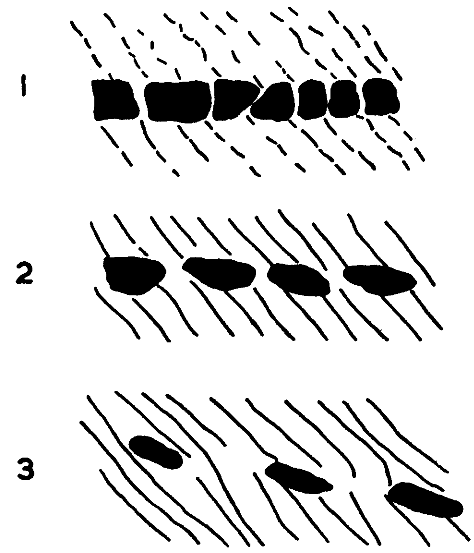


FIGURE 8

Diagrammatic representation of the progressive deformation of a basic dyke.

1. *Undeformed dykes*

On the north coast of Neny Island there is a small dyke, 10 in. (25·4 cm.) wide, of plagioclase-amphibolite cutting the foliation of the country rock, which is typical of the relatively undeformed dykes.

In thin section the texture of this rock (Y.681.5; Plate Vf) is essentially blastophyric and blastoporphyritic with an average grain-size of 0·05 mm. Biotite and iron ore are prominent and a modal analysis of this rock is given in Table VII. Both relict and recrystallized plagioclase are present, the latter forming crystalloblastic aggregates with hornblende and biotite in between the lath-shaped relict plagioclase, which is well-twinned predominantly on the albite law, but both Carlsbad and pericline twinning also occur. The recrystallized plagioclase is weakly albite-twinned and its lower refractive index indicates that it is more sodic. There are two distinct zones, the cores having a composition of $Ab_{50}An_{50}$ and rims $Ab_{62}An_{38}$. Hornblende, containing a few orientated inclusions, forms xenoblastic crystals that appear to be poorly orientated. This is the typical blue-green variety but it is pleochroic in deeper shades than usual. Partially chloritized biotite is intimately associated with the hornblende. Quartz with an undulose extinction generally forms single xenoblastic crystals which appear to be corroding all the other minerals in the rock. Sphene, which forms both large and small xenoblastic grains, shows corrosion and is xenoblastic against and includes the original lath-shaped plagioclase. Other accessory minerals include apatite, pyrite, titanomagnetite and occasional microcline porphyroblasts.

Another rock (Y.647.6) from near Store Point is better foliated, coarser-grained and has a higher modal percentage of ferromagnesian minerals (Table VII) of which patches of pale hornblende and granules of iron ore replace pyroxene. In specimen Y.647.3 (Plate Ve) with a schistose texture, the blue-green hornblende replacing pyroxene has been sheared out into lenses.

TABLE VII

MODAL ANALYSES OF PLAGIOCLASE-AMPHIBOLITES AND APPINITIC GNEISSES

	Plagioclase-amphibolites				*Appinitic Gneisses*		
	Y.647.6	Y.681.5	E.1559.3*	Y.641.5	E.1555.14	E.1557.1	Y.603.5
Quartz	tr	7·4	tr	9·4	22·6	—	5·6
Plagioclase	48·4	66·2	35·0	59·2	45·6	51·6	49·7
Hornblende	38·6	14·5	45·0	23·7	18·6	36·9	31·5
Biotite } Chlorite	9·2	10·7	15·0	3·9	10·9	4·0	10·5
Iron ore	3·4	0·7	—	3·3	—†	5·0	1·7
Accessory minerals	0·4	0·5‡	5·0§	0·5	2·3	2·5§	1·0
Plagioclase composition	An_{45}	An_{50-38}	An_{30}	An_{45}	An_{42}	An_{58}	An_{38}

* Approximate analysis only.
† Included with the accessory minerals.
‡ Mostly sphene.
§ Mostly epidote.

Y.647.6 Metadolerite, near Store Point, Neny Island.
Y.681.5 Metadolerite, north-eastern Neny Island.
E.1559.3 Plagioclase-amphibolite, northern Roman Four Promontory.
Y.641.5 Schistose plagioclase-amphibolite, eastern Neny Island. (Specimen Y.601.2, Table V, also belongs to this group of rocks.)
E.1555.14 Appinitic gneiss, western end of Roman Four Promontory.
E.1557.1 Homogeneous metagabbro, western end of Roman Four Promontory.
Y.603.5 Appinitic gneiss, north-western face of Roman Four Promontory.

2. *Deformed dykes*

Dyke rocks in an initial stage of deformation differ very little petrologically from undeformed ones, but by the second stage most of the relict textures have disappeared leaving only a crystalloblastic texture.

At the north-east end of Roman Four Promontory (E.1559) a dyke is separated into series of plagioclase-amphibolite xenoliths by veins of granite-gneiss (Plate IIId). These veins are composed of a medium-grained, leucocratic rock (E.1559.3) which grades into normal granite-gneiss; the contact between these two rocks is sharp and shows no signs of assimilation. At the western end of Mount Nemesis (Y.601) there is no equivalent leucocratic phase, but a crack across the dyke has been filled by a coarse-grained granitic segregation (Y.601.1) which appears to intrude both the plagioclase-amphibolite and the pink granite-gneiss.

In thin section the leucocratic rock (E.1559.3) shows slight schistosity, defined by amphibole and biotite, in a crystalloblastic texture. The plagioclase, an andesine with a composition of $Ab_{57}An_{43}$, forms a crystalloblastic aggregate which has been replaced locally by sericite and epidote. Although the feldspar adjacent to the contact with the granite-gneiss is relatively fresh, its alteration can be traced to thin veins of pink granite-gneiss penetrating the main mass of the plagioclase-amphibolite. The amphibole is a hornblende which forms xenoblastic aggregates against the plagioclase but is idioblastic against biotite. This hornblende is generally uniform in colour but it may show weak zoning and contain orientated inclusions. Besides biotite, hornblende encloses some small blebs of quartz; its vermicular form suggests that some hornblende has been derived from pyroxene. Biotite, generally pleochroic from α = pale straw to γ = dark ochre, is locally altered to a pale green chlorite and granules of sphene. The latter occurs either along the cleavages or around the margins of the chlorite crystals. Idioblastic epidote replaces some of the feldspar and chlorite. Idioblastic apatite and sphene are accessories, and the general absence of iron ore is conspicuous.

A less-altered dyke rock (Y.601.2) from the western end of Mount Nemesis has a more granoblastic texture and a coarser grain-size. This rock is fresher and has more quartz, but it contains less biotite (Table V) and iron ore is the dominant accessory mineral. The pleochroism schemes of both the hornblende and the biotite are similar to those of specimen E.1559.3 but the shades are deeper. The composition of this rock (Y.601.2; Table V) is similar to that of the average dolerite (Nockolds, 1954, p. 1021); it is lower in titania and ferric iron but it contains slightly more alumina. Both the mode and mesonorm do not compare as favourably as in previous cases but the plagioclase composition ($Ab_{68}An_{32}$) indicates that some lime, calculated in the mesonorm as anorthite, must be represented in the mode as an actinolitic amphibole.

A schistose xenolith (Y.641.3) from eastern Neny Island is typical of the more extreme type of deformation. These xenoliths which form an irregular line across the exposure slowly traverse the foliation of the granite-gneiss. Plagioclase ($Ab_{55}An_{45}$) is usually crystalloblastic but there are some larger (1·25 mm.) weakly zoned porphyroblasts. Hornblende, pleochroic in bluish green, is interstitial to the plagioclase and the lighter-coloured cores are riddled with quartz blebs. There is a little biotite. In addition to encrusting iron ore and biotite, sphene occurs in a late vein cutting the country rock.

3. *Xenolithic dykes*

At Roman Four Promontory (E.1556) there are a number of basic dykes, cutting across the foliation of the country rock, which have been intimately penetrated by acid granitic veins. The marginal granitic rock has a crenulated contact with the dyke rock, suggesting that the granite was intruded later, but the contact with the country rock is sharp but irregular. Elsewhere, at station Y.603, the contacts between these rock types are less sharp and the granitic rock is more basic than the country rock, but the dyke itself preserves a blastophitic texture similar to that of the undeformed metadolerites.

4. *Discussion*

There are two possible explanations to be considered for the formation of the deformed and undeformed dykes:

i. That each stage of deformation represents the cumulative effect of a series of metamorphisms and that the dykes are of different ages.
ii. That all of the dykes are of approximately the same age (though not necessarily of the same series) and that the different stages observed represent degrees of progressive migmatization.

Of these two explanations the second one is preferable, because it would correlate with the channel-like form of the mobilization in the granite-gneiss, although no exposure was large enough to show any lateral variation between the various stages of deformation. If each stage is treated as equivalent to a phase of metamorphism, there would have been three periods of post-granite-gneiss regional metamorphism, but there is no evidence for this.

The origin of the xenolithic dykes is uncertain but it is thought that the granitic margin developed around the rock at Roman Four Promontory might be equivalent to the first stage of the deformed dykes in an area of high temperature but relatively little mobilization. Wegmann (1938, p. 90) has described somewhat similar dykes from Greenland and he has attributed these to melting of the country rock by the dykes. This hypothesis could account for the dykes at station Y.603, but at station E.1556 the amount of granitic rock is often far in excess of the basic rock. The basic rock is considered to have been solid before the intrusion of the granitic rock, because of:

i. The homogeneity of the dyke.
ii. The uniform medium-grained texture of the rock.
iii. The straight-sided form of the dyke in the field.
iv. The occasional absence of the granitic margin.
v. The lack of hybridization.

By analogy with the disjunct deformed basic dyke at Mount Nemesis, segregation would be possible, but the granitic rock is much finer-grained than the usual segregation rocks. The absence of a fine-grained margin to the granitic rocks suggests that they were intruded during metamorphism when corrosion of the basic dyke, resulting in basification of its margin, took place.

B. Skarn Rocks

Rocks containing typical skarn mineral assemblages occur at several places in the Neny Fjord area, but it is probable that not all of them are of the same origin. The youngest of these rocks that have been found are the granite-gneisses adjacent to a plagioclase-amphibolite dyke near Norseman Point, Neny Island. Other occurrences are at Postillion Rock (E.1552), Brian Island (Y.626) and Roman Four Promontory (E.1556), where they usually consist mainly of epidote and garnet in a quartzo-feldspathic pocket. At Brian and Neny Islands thin epidote veins lead into these pockets but elsewhere they occur in apparent isolation. Near Norseman Point (Y.643) there is also a pyroxene skarn rock.

1. *Pyroxene skarn rock*

This rock occurs 300 yd. (274 m.) north of Norseman Point as an irregular vein partly marginal to a plagioclase-amphibolite dyke. It does not appear to be a hybrid rock, because when it is absent the contact between the plagioclase-amphibolite and the enclosing granite-gneiss is sharp. The main vein rock (Y.643.6) consists of a little quartz and altered plagioclase which has been partly replaced by prehnite. Fractures in the rock have been cemented with epidote. Adjacent to the dyke is an almost monomineralic rock consisting of a pale green, non-pleochroic pyroxene with the following optical properties: $\alpha = 1 \cdot 692$, $\beta = 1 \cdot 700$, $\gamma = 1 \cdot 719$, $2V\gamma = 57°$ and $\gamma{:}c = 44°$. These properties are similar to those of a salite quoted by Hess (1949, p. 663, analysis 37). Small irregular cavities in the rock are filled with calcite, prehnite and fluorite. The calcite forms acicular crystals across the cavities and radiating prehnite and fluorite crystals are interstitial.

A strongly pleochroic hornblende is prominent between the plagioclase rock and the pyroxene rock, occurring either as poikiloblastic crystals enclosing the pyroxene or as thin rims surrounding it. The pleochroism scheme of this hornblende is α = dark straw, β = yellowish green, γ = bluish green, in such strong tints that the body colour obscures the polarization colours; the absorption is $\alpha \ll \beta < \gamma$; the refractive indices are $\alpha = 1 \cdot 658$, $\beta = 1 \cdot 669$, $\gamma = 1 \cdot 675$ with $\gamma - \alpha = 0 \cdot 017$, $\gamma{:}c =$ (?) 28° and $2V\alpha = 74°$ (calculated).

2. *Garnet-epidote skarn rock*

The garnet-epidote skarn rock which occurs as pockets in the banded biotite-gneiss at Roman Four Promontory is typical of those from Brian Island and near Norseman Point. The dull orange-coloured garnet (E.1556.6; $n = 1 \cdot 790$) appears to be intermediate between grossularite and andradite. The margins of the pocket, consisting of a schistose aggregate of quartz and plagioclase ($Ab_{47}An_{53}$), are locally altered to white mica and epidote. Nearer the centre of the pocket epidote and garnet predominate, while a little quartz, pyroxene and plagioclase are also present. Thin veins of epidote extend out towards the margin. The centre of the pocket consists of large poikiloblastic plates of epidote enclosing idioblastic garnets and a colourless augite ($2V\gamma = 64°$, $\gamma{:}c = 46°$). The intergranular cavities are filled with quartz and calcite. In the rock from near Norseman Point (Y.643.8) the garnet is dark red and more variable in its refractive index ($n = 1 \cdot 841$–$1 \cdot 786$) but in thin section it shows no signs of colour zoning. Pyroxene is absent but large (2 mm.) apatites are prominent.

3. *Other skarn rocks*

At Postillion Rock the banded granite-gneisses contain a small (3 in. (7·6 cm.) diameter) nodule with a mixed assemblage of calcium- and iron-bearing minerals. Unlike the examples described above, this nodule has no sharp margins and the foliation in the enclosing gneiss is deflected around it. The core of the nodule consists of pyroxene, epidote and severely altered plagioclase. Small xenoblastic garnets, (?) sphalerite and pyrite are scattered throughout this groundmass. The pyroxene has been partially altered to a very pale green amphibole and, at the margin of the nodule, it is also rimmed with a dark green hornblende similar to the one in the rock from near Norseman Point (Y.643.6).

C. Appinitic Rocks

The relationship between the appinitic rocks of Roman Four Promontory and the plagioclase-amphibolite dykes is uncertain. A rock from the north-west face of the promontory cuts the foliation of the granite-gneiss but it pre-dates the regional joints. Furthermore, it does not show the same degree of metamorphism as the other rocks, although it contains the typical greenish blue hornblende.

1. *Field relations*

There are two small bodies of appinitic gneiss, one at the western end of Roman Four Promontory and the other on the north-west face of the promontory. At the first locality the main mass of the intrusion is a metagabbro from which a series of tongues extend south-westwards cutting the dioritic gneiss (p. 18). The irregular contact is approximately 8 cm. wide, cutting across the foliation of the dioritic gneiss. The composition of the tongues is granodioritic but locally this rock is most heterogeneous and contains prominent leucocratic segregations. As it passes into the main body of the intrusion this rock becomes coarser-grained, more homogeneous in texture and locally the composition approaches that of an amphibolite. This rock has been intensely altered by shearing and the intrusion of post-metamorphic dykes, resulting in the formation of a coarse, green-coloured rock (E.1557.6) composed mainly of chlorite and epidote.

On the north-west face of Roman Four Promontory the appinitic gneiss takes the form of a small dyke cutting the granite-gneiss. This dyke, which has sharp contacts, could only be traced for a short distance. The gneiss is essentially a hornblende-plagioclase rock and in the hand specimen patches of dark equigranular rock grade into and are penetrated by a light-coloured rock characterized by acicular hornblende.

2. *Petrography*

The rock from the western end of Roman Four Promontory has been altered by veins of epidote and sphene. In thin section (E.1557.1) the amphibole generally has a corroded, xenoblastic appearance against the feldspar. The cores of the cloudy plagioclase ($Ab_{42}An_{58}$–$Ab_{46}An_{54}$) are blastoporphyritic to blastogranular with ragged and untwinned recrystallized margins. Two types of amphibole are in association in the xenoblastic crystals. Usually, though not invariably, the cores of these crystals are a brownish amphibole with a pleochroism scheme α = dark straw and γ = pale ochre, while the rims have a pleochroism α = straw and γ = bluish green, but there is no difference in extinction or birefringence between these two types. Biotite is intimately associated with the amphibole and partly replaces it. Titanomagnetite has replaced the plagioclase interstitially and some of it is rimmed by sphene.

In the appinitic rock (E.1555.14) which cuts the diorite-gneiss the relict texture is not so apparent, because of recrystallization of the quartz which is absent in specimen E.1557.1 (Table VII). The plagioclase ($Ab_{58}An_{42}$) is more sodic and appears to have replaced some of the amphibole which is extremely variable. Orientated inclusions in the amphibole seem to have begun to concentrate into xenoblasts of iron ore. The biotite enclosed in the amphibole shows a preferred orientation with its cleavage parallel to [100] and [110]; adjacent to the amphibole it is bleached and has a higher birefringence. Extreme alteration, due to the intrusion of later unmetamorphosed dykes, has been responsible for the replacement of plagioclase in specimen E.1557.6 by fine-grained epidote, prehnite and spherulitic chlorite. The biotite has been chloritized and even the amphibole has been broken down to calcite and chlorite. Quartz and apatite alone remain unaltered.

The grain-size of the rock from the north-west side of the promontory is extremely variable, ranging from 0·2 to 2·0 mm. The texture, although generally crystalloblastic, shows a relict idiomorphism in the plagioclase which has been partially destroyed by recrystallization. Mineralogically, this rock (Y.603.5) is similar to the dyke rock (E.1555.14) and its modal analysis is given in Table VII. Some of the amphibole crystals have cores of quartz and plagioclase similar to those described by Wells and Bishop (1955, p. 146) in appinites from Jersey, Channel Islands. Sphene, the most important accessory mineral, occurs as:

i. An alteration product of the biotite.
ii. A primary mineral, occupying an interstitial position between plagioclase and amphibole.
iii. Granules around and bands in some of the iron ore.

The iron ore occurs as well-formed titanomagnetite octahedra, whereas the pyrite always appears to be xenoblastic and rimmed by a red limonitic product.

D. Late Basic Dykes

On the north-west face of Roman Four Promontory there is a schistose basic dyke (E.1559.2) of uncertain age but which might be younger than the Basement Complex. In spite of its schistosity, it differs from the deformed type of plagioclase-amphibolite dyke in that it follows the jointing in the granite-gneiss. In thin section it shows relicts of a colourless augite ($2V\gamma = 60°$, $\gamma{:}c = 42°$) that are sometimes surrounded by hornblende. The zoned hornblendes are idioblastic; their margins are pleochroic in pale shades of bluish green ($2V\alpha = 87°$, $\gamma{:}c = 25°$, $\gamma - \alpha = 0{\cdot}016$) but their cores are slightly paler-coloured with a lower extinction angle ($\gamma{:}c = 19°$) and higher birefringence ($\gamma - \alpha = 0{\cdot}022$). The pleochroism scheme (α = colourless, γ = light brown) indicates that the partially chloritized mica is a phlogopite, although its refractive index ($\beta = 1{\cdot}598$) is a little high compared with Tröger's (1959, p. 79) tables. Plagioclase ($Ab_{68}An_{32}$) occurs in small blastogranitic patches or as isolated crystals in the hornblende. Small patches of clinozoisite are also present.

VIII. METAMORPHISM

In Table I (p. 6) three phases of regional metamorphism are postulated within the rocks of the Basement Complex prior to the (?) early Palaeozoic volcanic rocks. Since these metamorphisms, there has been local mobilization of the Basement Complex rocks during the intrusion of the (?) early Palaeozoic plutonic rocks and various stages of contact metamorphism associated with the Andean Intrusive Suite. Innumerable phases of contact metamorphism could be postulated in the Basement Complex, as many of the rocks in this area are *ortho*-gneisses, but the effects of these have been modified by the regional metamorphism. The mineral assemblages of the Basement Complex rocks in the Neny Fjord area are particularly uncritical for determining the temperature and pressure conditions of metamorphism, and work on the amphiboles has not proved rewarding but it has only served to emphasize their variability (Berthelsen, 1960, p. 42). No direct connection between individual amphiboles and rock types was established. The petrographic evidence suggests that, of the three metamorphisms assigned to the Basement Complex, the second was the most important in the history of this area.

A. Basement Complex Metamorphism

1. *Metamorphism before the dioritic gneisses*

Very little is known about this metamorphism and in many places its existence can only be inferred. Proof of this early period of metamorphism is to be found in the occurrence of banded biotite-gneiss xenoliths in the dioritic gneisses. Different xenoliths have their schistosity and elongation at different angles relative to each other, from which it can be concluded that the xenoliths possessed schistosity before they were included in the dioritic gneiss. Elsewhere, the intimate *lit-par-lit* and dyke-like intrusions of the granite-gneisses, e.g. at Neny Island, demand a country rock with a degree of schistosity not found in unmetamorphosed rocks.

The banded biotite-gneisses show a general variation in their content of hornblende, biotite and plagioclase. Evidence from the limited exposures available suggests that these rocks have more biotite and plagioclase in the north-east of the area, which is approximately inverse to the distribution of the granite-gneisses. This could be attributed to soda metasomatism, either at a post-granite-gneiss stage or prior to the first metamorphism. The general weight of evidence appears to support the latter contention for the channel-like form of the potash metasomatism has no parallel in the distribution of the soda metasomatism. Apart from the banded biotite-gneisses, none of the other rocks show any evidence of enrichment in soda, although the plagioclase-amphibolites and the dioritic gneisses have had potash added to them at some time.

2. *First metamorphism of the granite-gneisses*

It is difficult to distinguish between the effects of the two post-granite-gneiss metamorphisms, and the only evidence of the second metamorphism is the existence of a late basic dyke cutting across the foliation of the granite-gneisses at Roman Four Promontory. It was during this period of metamorphism that intense but localized metasomatism, predominantly potash, took place, resulting in the potash-enriched migmatitic granite-gneisses of eastern and north-western Neny Island with their prominent potash feldspar porphyroblasts. The massive dioritic rocks have generally resisted this metamorphism, except for those on north-eastern Millerand Island, but even in those rocks relict textures are visible. Evidence of mobilization is the occurrence of distorted layers of banded biotite-gneiss at Neny Island and the boudinaged plagioclase-amphibolite dykes at Roman Four Promontory.

Away from the channels of mobilization and metasomatism, the undisturbed metadolerites, which have been correlated with the plagioclase-amphibolites, indicate that the response of these dykes to metamorphism was variable. Relict textures preserved in these rocks indicate that this metamorphism was not wholly capable of recrystallizing andesine, which suggests the lower part of the almandine-amphibolite facies. The optical data of the hornblendes (Table VIII) is no help in differentiating between the last two metamorphisms. Two of the factors controlling the stability field of these hornblendes, as listed by Ramberg (1952, p. 68), are the potash content, which would limit the field, and the titania content, which increases the field. In the Neny Fjord area the rocks containing this hornblende are sometimes rich in both potash feldspar and sphene, but those at Postillion Rock suggest that potash feldspar plays an important part in limiting the hornblende. The titania content of the analysed rocks is on the whole low; furthermore, the constant occurrence of sphene as a by-product of the chloritization of biotite and the relatively low refractive indices of the amphibole indicate that very little of the titania is present in the amphibole. Those amphiboles that showed distinct zoning were untwinned and because of this the possibility of obtaining accurate optical data was reduced. No consistent relationship was found between the optical properties and the intensity of colouring of the amphiboles.

TABLE VIII

OPTICAL DATA OF HORNBLENDES

Specimen Number	*Rock Type*	*Refractive Indices* α	β	γ	γ–α	$2V_{\alpha}$	γ:*c*
E.1559.2	Late basic dyke	1·639	1·650	1·655	0·016	87°	25°
Y.603.5	Appinitic rock	1·650	1·661	1·664	0·014	58°	19°
E.1557.1	Appinitic rock	1·654	1·664	1·669	0·015	74°	16°
Y.643.2	Dioritic gneiss	1·654	1·671	1·677	0·023	53°	15°
E.1555.10	Dioritic gneiss	1·632	1·641	1·645	0·013	75°	16°
Y.639.6	Amphibolite	1·640	1·651	1·654	0·014	76°	18°
Y.670.5	Hornblende-schist	1·640	1·651	1·654	0·014	72°	17°
A		1·634	1·647	1·652	0·018	62°	21°
B		1·659	1·673	1·681	0·022	66°	17°

All hornblendes have the following pleochroism scheme:
α = pale green, β = brownish green, γ = bluish green, $\alpha < \beta < \gamma$
A. Hornblende (Larsen and Berman, 1934, p. 175).
B. Green hornblende (Larsen and Berman, 1934, p. 182).

The occurrence of amphibole replacing chlorite and a comparison with data given by Larsen and Berman (1934, p. 175, 182) show that this hornblende is both rich in magnesia and has an appreciable soda content. The values for $2V\alpha$ and γ:*c* were also compared with figures given by Tröger (1959) and were plotted on a diagram similar to that given by Berthelsen (1960, p. 43). It was found that these hornblendes ($2V\alpha \simeq 70°$ and γ:*c* $\simeq 18°$) lie intermediate between common hornblende and barkevikite—Mg-hastingsite. Calculations from the analysis of the amphibolite (Y.639.6; Table V) show that the amphibole is poor in alumina. These blue-green hornblendes with a low alumina content are considered by Turner (1948, p. 90) to characterize the albite-epidote-amphibolite facies. The composition of the plagioclase is too calcic for this facies but, since the hornblende is often very late in formation, it could be considered as a retrograde product.

Epidotization has occurred so frequently with subsequent intrusions that this mineral is valueless as an indicator of metamorphic facies. The upper limit of the almandine-amphibolite facies, with the complete recrystallization of the metagabbroic rocks and the entry of pyroxene, was certainly not reached in this area.

3. *Second metamorphism of the granite-gneisses*

In the second metamorphism of the granite-gneisses two phases can be distinguished: that of the appinitic rocks pre-dating the joints and that of a late basic dyke (p. 42) post-dating the joints. The metamorphism of the appinitic rocks is similar to that of the earlier basic rocks and it can only be distinguished from them by the absence of fully developed amoeboid granoblastic textures and the cross-cutting relationship of the appinitic rocks to the granite-gneiss. Mineralogically, these rocks show the same features as earlier basic rocks.

The late basic dyke contains actinolitic amphibole which has a higher 2Vα than those found in the earlier rocks (Table VIII) but, since phlogopitic biotite is also present, this may be because the original rock was rich in lime. The foliation of this dyke is not the same as that of the surrounding granite-gneiss but dips at 15° to the vertical side of the dyke. Eskola (1914, p. 117), describing dykes with a schistosity parallel to their sides, concluded that only a single directional stress was necessary to account for either the schistosity of the dyke or the different direction of the foliation and that it was unnecessary to assume a full-scale metamorphism. However, the response of basic dykes to metamorphism is variable; a similar case was the alteration of the dykes at Scourie (Teall, 1885, p. 140) which were later found by Bailey (1951) to have passed through a higher degree of metamorphism.

The conclusion that the initial metamorphism of the granite-gneisses was of the almandine-amphibolite facies has not been invalidated by any other rock types in this area. Superimposed on this metamorphism is a retrograde metamorphism of albite-epidote-amphibolite facies. These phases of metamorphism are constant throughout this whole area, except where later post-Basement Complex metamorphism has taken place. This is in accord with similar regions in other parts of the world, where the grade of metamorphism has been found to be the same over large areas (Ramberg, 1949, p. 24).

B. Post-Basement Complex Metamorphism

Apart from the (?) granite-gneisses of the Debenham Islands, which might belong to the (?) early Palaeozoic plutonic rocks, there are no other occurrences of these plutonic rocks in this area around which it would be possible to trace any contact metamorphism. The dykes at south-western Millerand Island, which have been classified as foliated (?) early Palaeozoic plutonic rocks, are limited in extent but they suggest that the jointing of the gneisses in this area was later than the (?) early Palaeozoic plutonic rocks and pre-Jurassic, because the dykes associated with the Upper Jurassic volcanic rocks are joint-controlled whereas the (?) early Palaeozoic ones are not. The Upper Jurassic Volcanic Group may be responsible for some of the local alteration in the gneisses at Randall Rocks but it is only the aureole of the Andean Intrusive Suite that can be traced with any success. The hornblende-biotite-diorite of the Andean Intrusive Suite (Hoskins, 1960, p. 23) occurs in comparative isolation at the eastern end of Randall Rocks and very little can be said about its contact aureole. However, the gneiss (Y.653.1) forming a small islet 100 yd. (91 m.) to the west contains a partially chloritized biotite of a deep chestnut-red colour, which is associated with hornfelsing (Harker, 1950, p. 342).

The aureole of the Andean biotite-granite (Hoskins, 1960, p. 30) is easier to define (Fig. 7). The first apparent effect, which occurs 800 yd. (732 m.) from the contact, is the partial crystallization of a very pale green biotite (Y.608.2, 610.1). This biotite forms small mossy crystals whose optical orientation bears no relationship to the form of the original chloritized biotite and which are peppered with small grains of iron ore. In a zone starting approximately 130 yd. (119 m.) from the contact this biotite is replaced by a chestnut-red variety similar in colour to that mentioned above, and some of the iron ore has recrystallized (Y.658.1, 660.2). At the contact with the biotite-granite the gneiss (Y.665.5) is characterized by recrystallized iron ore and small idioblasts of hornblende, which suggest that lime was either introduced from the granite or released by the destruction of the plagioclase. The plagioclase forms either hornfelsic patches parallel to the foliation or corroded relicts mantled with perthite. Quartz, which has a less undulose extinction than usual, is idioblastic against, and graphically intergrown with, the perthite. Calcite and prehnite replace some of the plagioclase. Later alteration of a hydrothermal type, attributed to the granite, does not form any definable zones. Innumerable thin veinlets, cutting the Basement Complex rocks (Y.659.2, 660.2) and the (?) early Palaeozoic granite (Y.660.3, 661.1), contain quartz, epidote, actinolite and iron ore. A sheared Jurassic dyke (Y.651.3) appears to have had sphene and orthite introduced by these veins. In thin section (Y.658.3) the plagioclase has been replaced in distinct zones by small idioblasts of actinolite. Locally, the red-brown biotite idioblasts formed during the contact metamorphism have been chloritized.

IX. STRUCTURE OF THE NENY FJORD AREA

THE scattered occurrence of the outcrops and post-Basement Complex faulting make structural work on the Basement Complex rocks difficult. It is considered that much of the faulting within the Neny Fjord area is due to the emplacement of the Andean Intrusive Suite. The pre-Jurassic erosion surface, which is the only reliable datum in this area, occurs at 3,000 ft. (914 m.) in the Blackwall Mountains, at Black Thumb and on the western side of Millerand Island, and at 500 ft. (152 m.) on the north-east coast of Millerand Island. It is therefore postulated that all the rocks of the Upper Jurassic Volcanic Group below 3,000 ft. (914 m.) have been down-faulted. Pre-Jurassic faults are extremely difficult to prove conclusively, but a number of faults are suspected to have had repeated movement along them over a long period of time.

There is very little evidence of large-scale folding within the Basement Complex rocks. Schistosity is rare, and when it does occur it is almost always parallel to the foliation. Although at most exposures the Basement Complex rocks are shattered and faulted, the foliation generally remains constant within a single fault block. There are a few small folds and quartz rods but these are so wide-spaced that very little can be deduced from them. The small folds at Beaumont and Neny Islands and Postillion Rock are compatible with local migmatization but they show no uniformity in the trend of their axial planes. The general regional strike of the foliation is north-west to south-east with variations due to local faulting.

In the northern part of the Neny Fjord area the dips of the foliation are high (~ 60°). At Millerand Island the dip is to the west. Except for Postillion Rock and Beaumont Island, the dips in the southern part of this area are lower than those in the north but they are higher towards the west. The possible relationship between the strike of the foliation and the joints was briefly investigated but, owing to insufficient measurements, no significant result was obtained.

Roman Four Promontory is cut by a large fault which brings the dioritic gneisses into contact with the granite-gneisses (Plate Id). By considering the distribution of rock types within the Basement Complex it has been found that, in spite of the homogeneity of the metamorphism, this fault and similar ones on Neny and Millerand Islands divide the area into two: a western part dominated by dioritic gneisses and an eastern part dominated by banded biotite-gneisses. It is thought that these faults were initiated about the time of the first metamorphism of the granite-gneisses, because some of the metasomatic rocks occur in both parts of this area. Furthermore, by approximately matching the zones of the rock types across the strike it is possible to postulate large tear faults that trend from north-east to south-west.

The joints in the Basement Complex can only be dated in two areas. On the south-west coast of Millerand Island the joints can be shown to be post- (?) early Palaeozoic but pre-Jurassic in age; (?) early Palaeozoic granite dykes and the granite-gneisses are jointed as one rock, while the basic dykes of the Upper Jurassic Volcanic Group follow the present-day joint system. Joints in the granite-genisses at Roman Four Promontory are followed by the late basic dykes (p. 42) and so pre-date the second metamorphism of the granite-gneisses. The Basement Complex rocks of the Debenham Islands have been severely faulted (Fig. 2) possibly by the local intrusion of the (?) early Palaeozoic "Coarse Pink Granite". By plotting joints of known post-Basement Complex age in the area immediately south of Neny Fjord, evidence was found to suggest that the whole area had been rotated clockwise relative to the direction of the regional tensional forces.

The Andean Intrusive Suite and the (?) early Palaeozoic plutonic rocks form bosses, so that in such a small area it is not possible to demonstrate that the trend of the Basement Complex rocks has had any significant effect on the structure and positioning of the later plutonic rocks.

X. CONCLUSIONS

ROCKS attributed to the Basement Complex have a relatively wide distribution in British Antarctic Territory. Matthews (1959, table I, p. 428–29) has summarized the occurrence of Basement Complex rocks which have been found in the South Orkney Islands, Elephant and Clarence Islands, the South Shetland Islands and in Graham Land. Although glacial erratics and xenoliths of Basement Complex rocks are widespread over the Graham Land peninsula (Adie, 1954, p. 5, 6), they have only been found *in situ* south of lat. 67°S. Unlike those of the Marguerite Bay area, the Basement Complex rocks in the north of British Antarctic Territory are predominantly *para*-gneisses. The Basement Complex stratigraphy of the Neny Fjord area is summarized in Table I and the post-Basement Complex history in Table II.

The scattered nature of the rock exposures in the Neny Fjord area precludes any extensive correlations, but the Basement Complex can be subdivided into three main groups: banded biotite-gneisses, dioritic gneisses and granite-gneisses, of which the latter two groups are *ortho*-gneisses. The oldest rocks in this area are the banded biotite-gneisses and these were regionally metamorphosed before the intrusion of the dioritic gneisses and the granite-gneisses.

The banded biotite-gneisses are considered to be of sedimentary origin, whereas the hornblende-schists are, in most cases, interpreted as fragments of basic dykes disrupted during a phase of metamorphism. The dioritic gneisses contain xenoliths of the banded biotite-gneisses and are intruded by the granite-gneisses. The stratigraphy of the Basement Complex depends to a large extent on the correlation of the numerous phases of the dioritic gneisses and the granite-gneisses. The granite-gneisses were intruded by a series of basic dykes prior to their metamorphism and these are now represented by strings of schistose plagioclase-amphibolite xenoliths and metadolerites. During the first metamorphism of the granite-gneiss, which reached the almandine-amphibolite facies, potash metasomatism took place, resulting in the introduction of potash feldspar along narrow migmatitic zones. After this metamorphism the Basement Complex rocks were intruded by basic dykes following the joints in the granite-gneisses, and the metamorphism of these dykes indicates that the third and final metamorphism of the Basement Complex only reached the albite-epidote-amphibolite facies.

There is no stratigraphical evidence of the exact age of the Basement Complex rocks. Adie (1954, p. 5) has written:

> "The age of the metamorphics assigned to the Basement Complex cannot be stated with certainty. They may belong to the early Palaeozoic but more probably Archean like the Basement Complexes of South America and South Africa."

During the present investigation no evidence was found that would allow a more exact estimate of the age of the Basement Complex. If a foliated suite of (?) early Palaeozoic plutonic rocks could be established in this area, it would be possible to attribute the last regional metamorphism of the Basement Complex to their intrusion. However, the occurrence of relatively unaltered volcanic xenoliths in the (?) early Palaeozoic "Coarse Pink Granite" dates the last regional metamorphism of the Basement Complex as being older than the (?) early Palaeozoic volcanic rocks. No contact metamorphism in this area can be definitely attributed to the (?) early Palaeozoic plutonic rocks but the contact aureoles of the Andean Intrusive Suite can be readily traced in the field.

The foliation of the Basement Complex rocks strikes approximately north-west to south-east throughout the Neny Fjord area. It dips gently westward in the south of this area but it varies about vertical in the north. During the late Cretaceous and early Tertiary this area was extensively broken up by block-faulting associated with the Andean Intrusive Suite. Structural and petrographical evidence shows that this area can be subdivided into two: a western part dominated by dioritic gneisses and an eastern part dominated by banded biotite-gneisses. Subsequently, this area was cut by north-east to south-west trending faults which displace the Basement Complex zones of intrusion.

XI. ACKNOWLEDGEMENTS

THE field work was carried out from the Falkland Islands Dependencies Survey stations at Stonington and Horseshoe Islands between March 1958 and March 1960, when colleagues at those stations gave valuable assistance in the field. The laboratory work was done in the Department of Geology, University of Birmingham, by kind permission of Professor F. W. Shotton. I wish to record my gratitude to Dr. R. J.

Adie for supervising the laboratory study, for advising on many aspects of the work and help in the preparation of the manuscript. I wish to thank Mr. L. W. Vaughan, who prepared the plates, and Mr. D. J. Jones, who made the thin sections. Helpful discussion and criticism by members of the British Antarctic Survey research group in Birmingham has been much appreciated.

XII. REFERENCES

ADIE, R. J. 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.

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

BAILEY, E. 1951. Discussion. (*In* SUTTON, J. *and* J. WATSON. The Pre-Torridonian Metamorphic History of the Loch Torridon and Scourie Areas in the North-west Highlands, and its Bearing on the Chronological Classification of the Lewisian. *Quart. J. geol. Soc. Lond.*, **106** (for 1950), Pt. 3, No. 423, 303–04.)

BARTH, T. F. W. 1959. Principles of Classification and Norm Calculations of Metamorphic Rocks. *J. Geol.*, **67**, No. 2, 135–52.

BASTIN, E. S. 1909. Chemical Composition as a Criterion in Identifying Metamorphosed Sediments. *J. Geol.*, **17**, No. 5, 445–72.

BERTHELSEN, A. 1960. Structural Studies in the Pre-Cambrian of Western Greenland. II. Geology of Tovqussap Nunâ. *Medd. Grønland*, Bd. 123, Nr. 1, 223 pp.

CHENG, Y. C. 1944. The Migmatite Area around Bettyhill, Sutherland. *Quart. J. geol. Soc. Lond.*, **99** (for 1943), Pts. 3 and 4, Nos. 395–96, 107–48.

CORDINI, I. R. 1957–59. Estado del Conocimiento Geológico en Antártida. *An. Soc. cient. argent.*, Tomo 164, Nos. 5 and 6, 109–42; Tomo 165, Nos. 1 and 2, 3–45; Nos. 3 and 4, 65–98; Nos. 5 and 6, 123–42; Tomo 166, Nos. 1 and 2, 3–22; Nos. 3 and 4, 47–83; Tomo 167, Nos. 1 and 2, 7–38.

———. 1959. El Conocimiento Geológico de la Antártida. *Instituto Antártico Argentino, Publicación* No. 6, 160 pp.

CROWDER, D. F. 1959. Granitization, Migmatization, and Fusion in the Northern Entiat Mountains, Washington. *Bull. geol. Soc. Amer.*, **70**, No. 7, 827–77.

ESKOLA, P. 1914. On the Petrology of the Orijärvi Region in Southwestern Finland. *Bull. Comm. géol. Finl.*, **8**, No. 40, 277 pp.

FLEMING, W. L. S., STEPHENSON, A., ROBERTS, B. B. *and* G. C. L. BERTRAM. 1938. Notes on the Scientific Work of the British Graham Land Expedition, 1934–37. *Geogr. J.*, **91**, No. 6, 508–28.

GOLDRING, D. C. 1962. The Geology of the Loubet Coast, Graham Land. *British Antarctic Survey Scientific Reports*, No. 36, 50 pp.

GOODSPEED, G. E. 1953. Rheomorphic Breccias. *Amer. J. Sci.*, **251**, No. 6, 453–69.

GROVES, A. W. 1951. *Silicate Analysis: a Manual for Geologists and Chemists with Chapters on Check Calculations and Geochemical Data.* 2nd edition. London, George Allen and Unwin Ltd.

HARKER, A. 1950. *Metamorphism: a Study of the Transformations of Rock-masses.* 3rd edition. London, Methuen and Co. Ltd.

HESS, H. H. 1949. Chemical Composition and Optical Properties of Common Clinopyroxenes. Part I. *Amer. Min.*, **34**, Nos. 9 and 10, 621–66.

HOSKINS, A. K. 1960. The Geology of Parts of the Loubet and Fallières Coasts, Graham Land. *Falkland Islands Dependencies Survey Preliminary Geological Report*, No. 6, 38 pp. [Unpublished.]

KNOWLES, P. H. 1945. Geology of Southern Palmer Peninsula, Antarctica. *Proc. Amer. phil. Soc.*, **89**, No. 1, 132–45.

LARSEN, E. S. *and* H. BERMAN. 1934. *The Microscopic Determination of the Nonopaque Minerals.* 2nd edition. Washington, D.C., United States Government Printing Office. [U.S. Geological Survey Bulletin 848.]

LARSEN, O. *and* H. SØRENSEN. 1960. Principles of Classification and Norm Calculations of Metamorphic Rocks: a Discussion. *J. Geol.*, **68**, No. 6, 681–83.

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

NICHOLS, R. L. 1947. Geology of Stonington Island Area, Marguerite Bay, Antarctica. *Bull. geol. Soc. Amer.*, **58**, No. 12, 1213.

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

———. 1955. *Bedrock Geology of Marguerite Bay Area, Palmer Peninsula, Antarctica.* Washington, D.C., Department of the Navy, Office of Naval Research. [Ronne Antarctic Research Expedition, Technical Report No. 13.]

———. 1960. Geomorphology of Marguerite Bay Area, Palmer Peninsula, Antarctica. *Bull. geol. Soc. Amer.*, **71**, No. 10, 1421–50.

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

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

RAMBERG, H. 1949. The Facies Classification of Rocks: a Clue to the Origin of Quartzo-feldspathic Massifs and Veins. *J. Geol.*, **57**, No. 1, 18–54.

———. 1952. *The Origin of Metamorphic and Metasomatic Rocks: a Treatise on Recrystallization and Replacement in the Earth's Crust.* Chicago, The University of Chicago Press.

READ, H. H. 1957. *The Granite Controversy.* London, Thomas Murby and Co.

TEALL, J. J. H. 1885. The Metamorphosis of Dolerite into Hornblende-schist. *Quart. J. geol. Soc. Lond.*, **41**, No. 162, 133–44.

TRÖGER, W. E. 1959. *Optische Bestimmung der gesteinsbildenden Minerale. Teil 1. Bestimmungstabellen.* 3rd edition. Stuttgart, E. Schweizerbart'sche Verlagsbuchhandlung (Nägele u. Obermiller).

TURNER, F. J. 1948. Mineralogical and Structural Evolution of the Metamorphic Rocks. *Mem. geol. Soc. Amer.*, No. 30, 342 pp.

———. *and* J. VERHOOGEN. 1960. *Igneous and Metamorphic Petrology.* 2nd edition. New York, Toronto and London, McGraw-Hill Book Company, Inc.

WEGMANN, C. E. 1938. Geological Investigations in Southern Greenland. Part I. On the Structural Divisions of Southern Greenland. *Medd. Grønland*, Bd. 113, Nr. 2, 148 pp.

WELLS, A. K. *and* A. C. BISHOP. 1955. An Appinitic Facies Associated with Certain Granites in Jersey, Channel Islands. *Quart. J. geol. Soc. Lond.*, **111**, Pt. 2, No. 442, 143–63.

PLATES

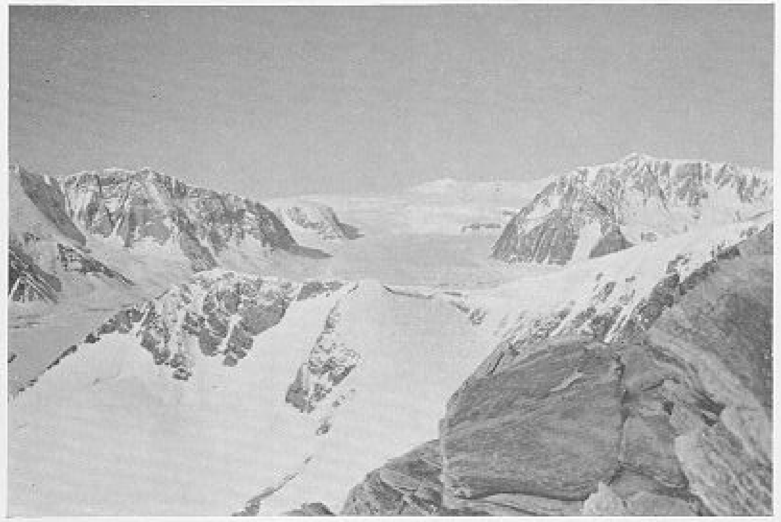
PLATE I

a. The Graham Land plateau north-east of Neny Fjord viewed from Roman Four Promontory at a height of 1,100 ft. (335 m.).

b. Barry Island viewed from Brian Island, Debenham Islands. Northeast Glacier and the Graham Land plateau can be seen in the background.

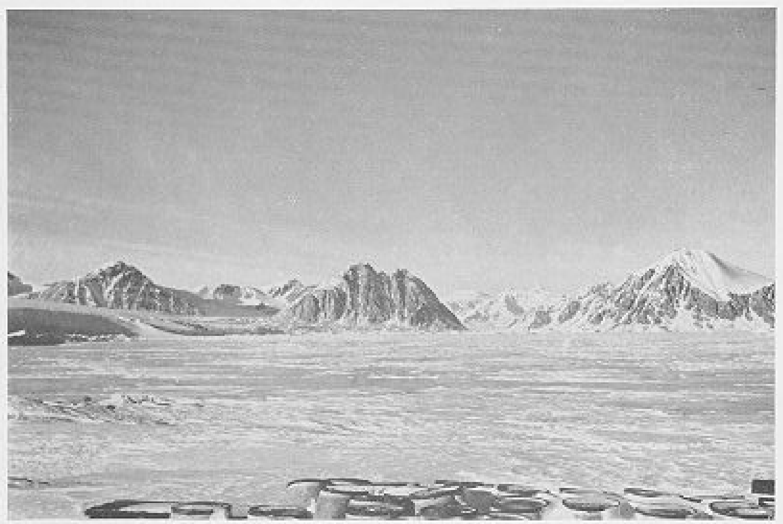
c. Looking south-east from the Debenham Islands towards Mount Nemesis, Roman Four Promontory and Neny Island.

d. The north-western face of Roman Four Promontory, showing on the left dark dykes, metadolerites and rafts. (Photograph by B. B. Roberts.)

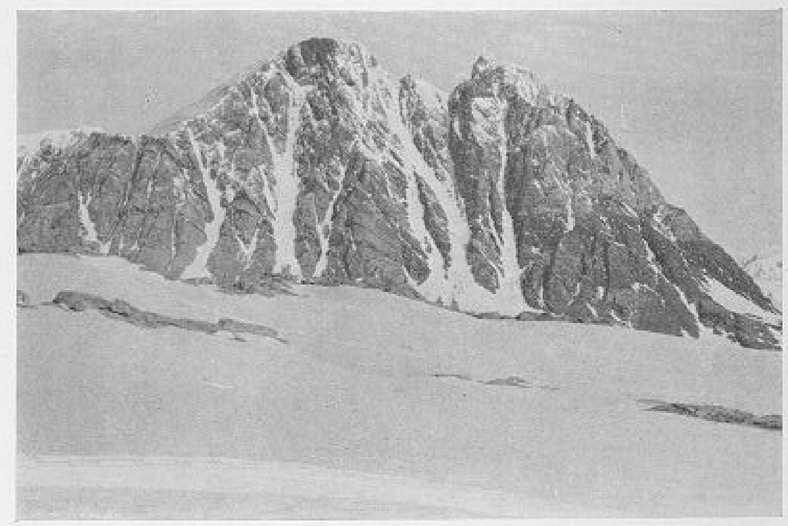


a

b



c



d

PLATE I

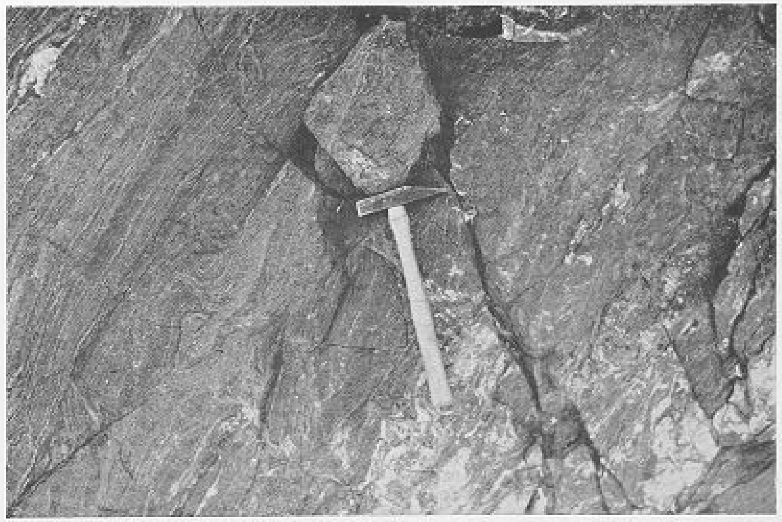
PLATE II

a. Banded biotite-gneiss; northern Audrey Island, Debenham Islands.

b. Rheomorphic breccia on the north-east coast of Millerand Island.

c. Tongue of dioritic gneiss in a darker dioritic gneiss; Roman Four Promontory.

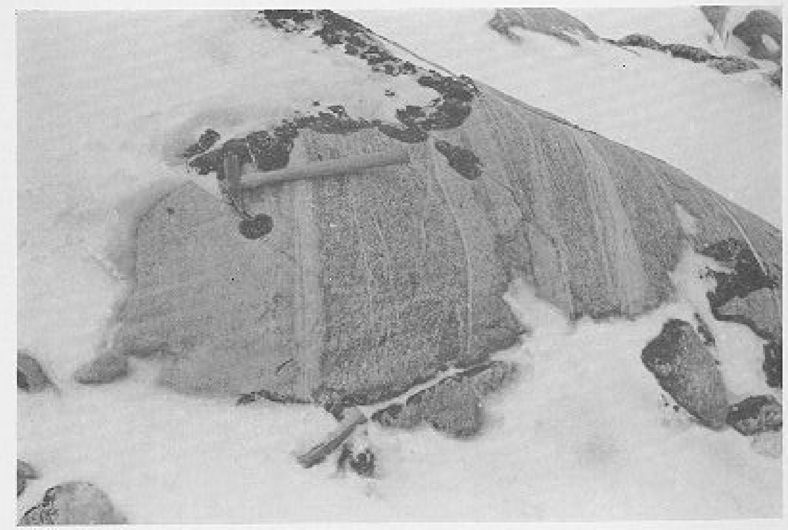
d. Granite-gneiss intruding dioritic gneiss *lit-par-lit*; north-east Millerand Island.



a

b

c



d

PLATE II

PLATE III

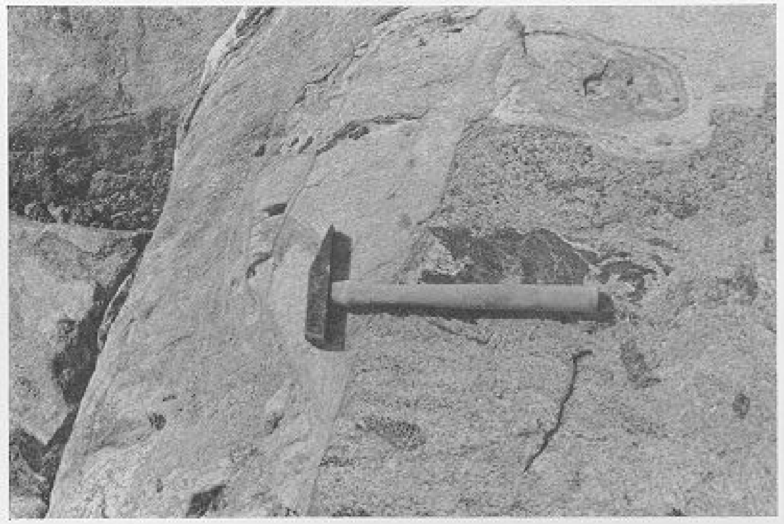
a. A granitic rock (Y.677.5) intruded along a shear zone in the biotite-bearing variety of the dioritic gneiss; north-west Neny Island.

b. Banded granite-gneisses at Postillion Rock with late segregation pegmatite. The dark patches are water on the rock.

c. Discordant biotite-granite-gneiss in the banded granite-gneisses at Postillion Rock.

d. A plagioclase-amphibolite dyke in the granite-gneiss at the northern end of Roman Four Promontory.

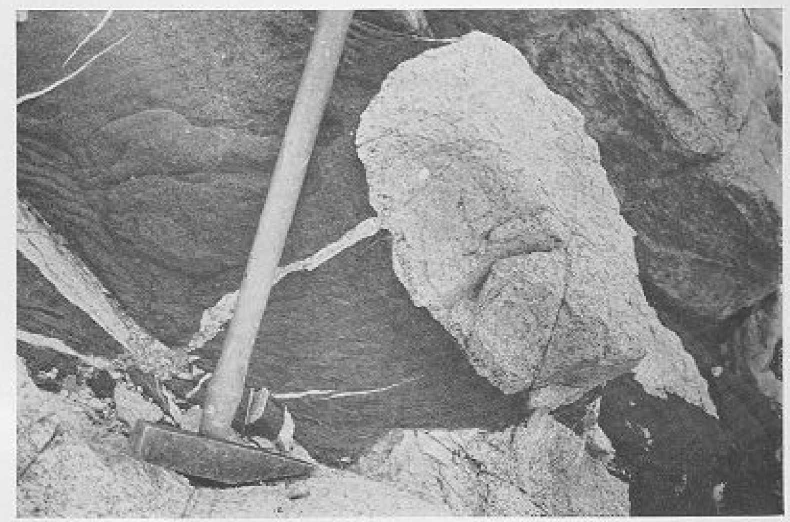
PLATE III



a

b

c



d

PLATE IV

a. Banded biotite-gneiss; Audrey Island, Debenham Islands (Y.630.1; ordinary light; × 30).

b. Hybrid hornblende-gneiss showing small fragments of hornblende-schist; north-east coast of Millerand Island (Y.670.1; ordinary light; × 8·25).

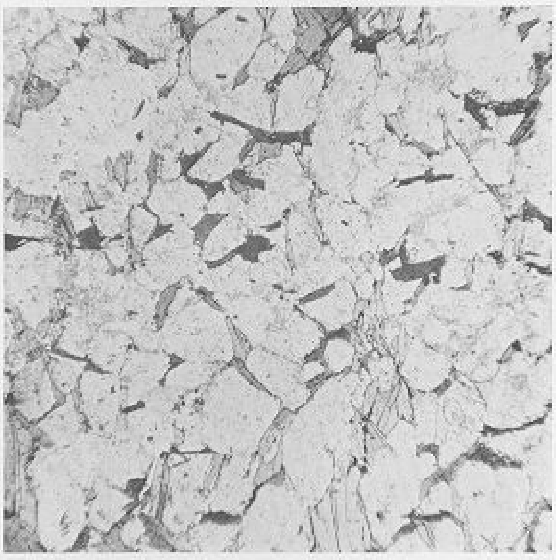
c. Dioritic gneiss; near Store Point, Neny Island (Y.647.1; X-nicols; × 35).

d. Sphene in a biotite-bearing dioritic gneiss; north-west Neny Island (Y.677.1; ordinary light; × 35).

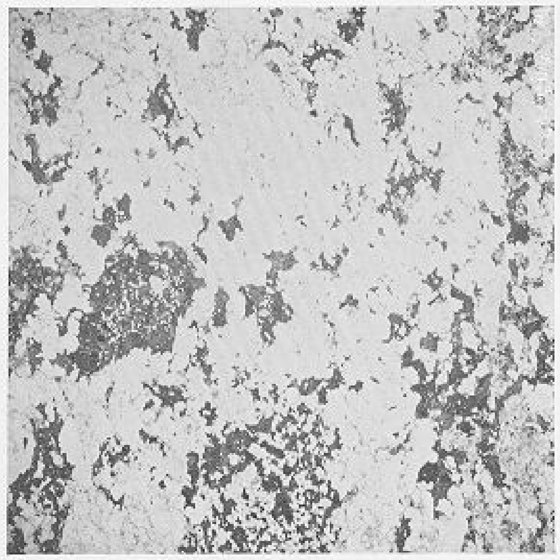
e. Small lath-shaped plagioclase crystals enclosed in a large antiperthitic plagioclase porphyroblast in the granite-gneiss; Randall Rocks (Y.649.1; X-nicols; × 30).

f. Granite-gneiss; Randall Rocks (Y.653.1; X-nicols: × 35).

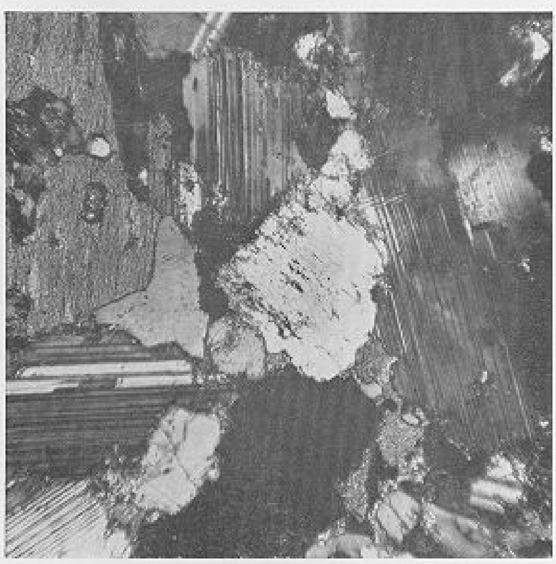
PLATE IV



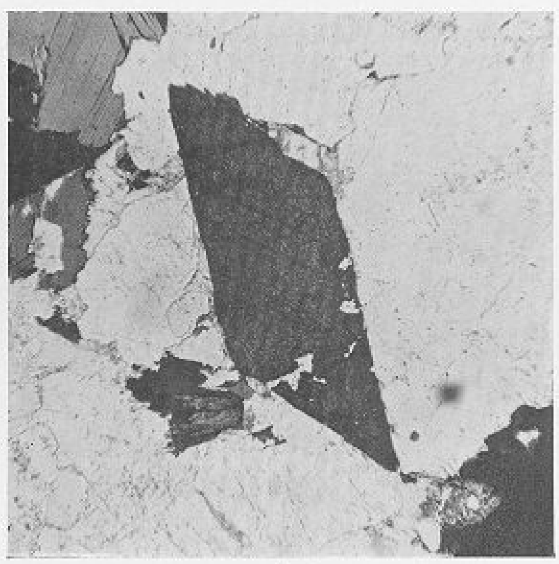
a



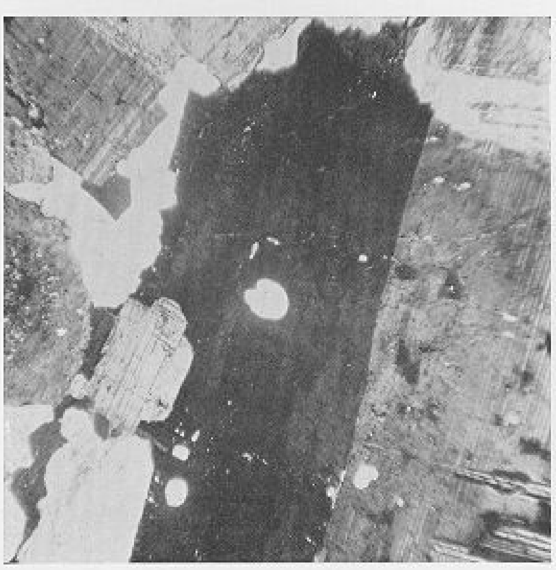
b



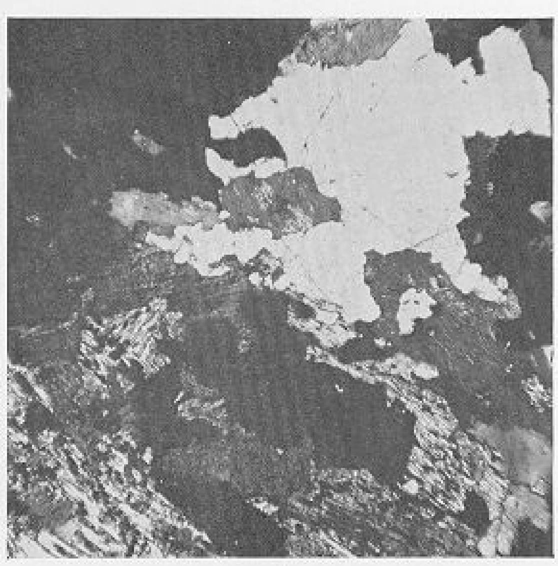
c



d



e



f

PLATE V

a. Antiperthitic plagioclase in granite-gneiss with potash feldspar in extinction; Butson Ridge (E.1310.1; X-nicols; × 30).

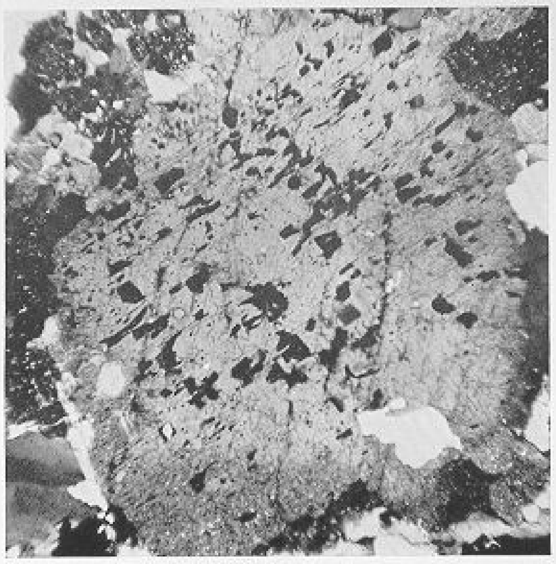
b. Contact between sphene-bearing plagioclase-biotite-gneiss and quartz-plagioclase-biotite-gneiss; Postillion Rock (E.1552.2; ordinary light; × 35).

c. Microcline-granite-gneiss; Postillion Rock (E.1552.5; X-nicols; × 35).

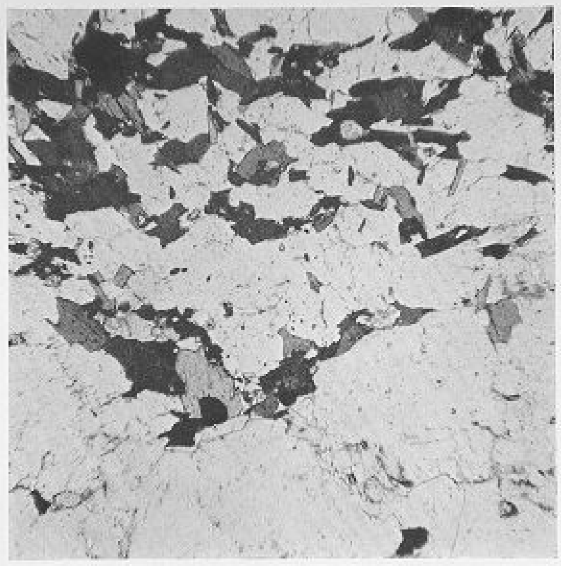
d. Large orthite crystal typical of those occurring in the granite-gneisses; eastern Neny Island (Y.642.3; ordinary light; × 55).

e. Schistose metadolerite; near Store Point, Neny Island (Y.647.3; X-nicols; × 35).

f. Metadolerite; northern Neny Island (Y.681.5; X-nicols; × 35).



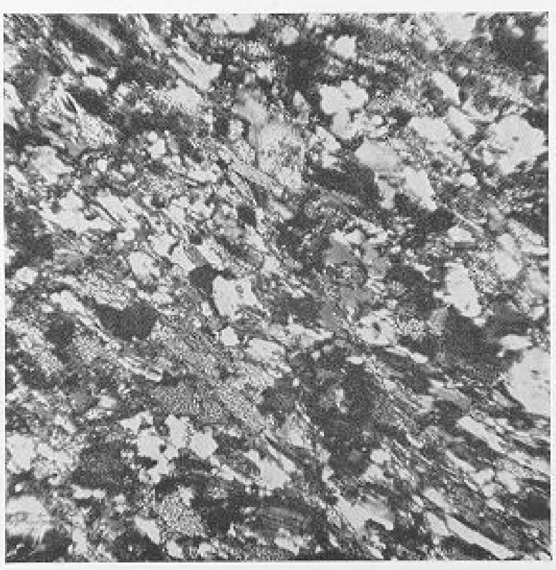
a



b

c

d



e

f