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A. G. FRASER, B.Sc., Ph.D.

British Antarctic Survey
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Department of Geology, University of Birmingham

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ABSTRACT

STONINGTON AND TREPASSEY ISLANDS are composed of a series of mainly intermediate *ortho*gneisses which are comparable in mineralogy and texture, and which probably belong to the same intrusive epoch. A tentative time sequence has been established from field evidence but no systematic mineralogical or chemical variation is apparent in the order of intrusion. The derivation of hornblende from pyroxene and the great compositional range in the plagioclases clearly show that most, if not all, of the *ortho*gneisses are of hybrid origin, resulting from the contamination of basic rocks by later material of acid or intermediate composition. The gneisses have been intruded by a complex network of dykes, sheets and veins. The metamorphic history can only be deduced indirectly since reliable indicators are absent. Exsolution, replacement phenomena and structural ordering in the feldspars are believed to signify very slow cooling from high temperatures. The general absence of pronounced metamorphic textures and the partial preservation of igneous textures suggest that the *ortho*gneisses were intruded either at or soon after the peak of metamorphism and that during the cooling period shearing stress was minimal. The varying modes of emplacement of minor intrusions and the textural differences between sheets and dykes of similar composition but of different age are attributed to repeated intrusion of magmatic material into country rock which was undergoing progressively decreasing metamorphism. The prolonged high-temperature conditions which prevailed during metamorphism resulted in unusual geological processes such as rheomorphism, the basification of acid dykes and the formation of xenolithic basic dykes. Basification occurred where a basic dyke intersected a partially or predominantly liquid acid dyke or vein; xenolithic basic dykes were formed when basic and acid magma were intruded simultaneously (or nearly so) along the same plane. In both these phenomena the basic and acid magma interacted to give hybrid rocks with variable texture.

CONTENTS

I. INTRODUCTION

STONINGTON ISLAND (lat. 68°11′S., long. 67°00′W.), a small island 0·5 miles (0·8 km.) long and 0·15 miles (0·24 km.) wide, is situated in Neny Bay, one of the several subsidiary bays of Marguerite Bay, on the south-west coast of the Antarctic Peninsula (Fig. 1). Trepassey Island, which is only 0·75 miles (1·2 km.) south-east of Stonington Island, is no more than 285 yd. (260 m.) long and 75 yd. (69 m.) wide.

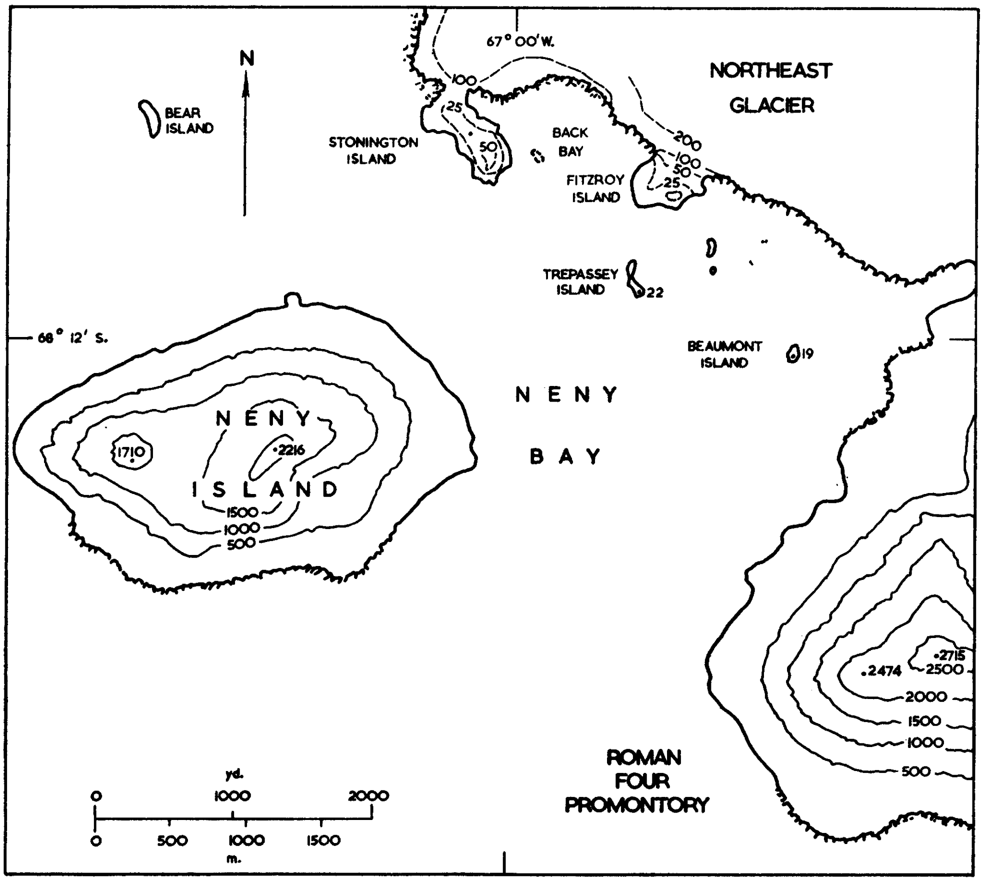

FIGURE 1
Sketch map of the Neny Bay area, showing the relative positions of Stonington and Trepassey Islands. Heights and contours are in feet.

During the past 25 years the geology of Stonington Island and adjacent areas has been studied in varying degrees of detail by several geologists. The results of these investigations have been summarized elsewhere (Adie, 1958; Hoskins, 1963, p. 3), and further elaboration is not necessary here. This report is based on a detailed geological survey in which Stonington and Trepassey Islands were mapped on scales of 1 : 300 and 1 : 500, respectively. The first part of the field work was carried out between May and July 1961 and geological stations established during this period are numbered E.2101–2107. Mapping was recommenced early in 1962 when stations E.2150–2165 were examined. Laboratory work on the material collected was undertaken between January 1963 and October 1964 in the Department of Geology, University of Birmingham, where all the rock specimens and thin sections described in this report are housed.

Stonington and Trepassey Islands are composed of rocks of igneous origin tentatively assigned to the Basement Complex, which forms extensive outcrops in Marguerite Bay and especially in the Neny Fjord area. Despite their small size, both islands are of considerable geological importance, since they provide valuable information relating to the geological history of the Basement Complex. The accumulation of data resulting from the investigations of previous workers has produced a fairly comprehensive account of the Basement Complex of the Antarctic Peninsula. The main purpose of the present work is to ascertain the more detailed aspects of the geological processes involved in the evolution of the complex so that more meaning can be given to existing knowledge.

Physiography

Stonington Island is a slightly arcuate island and most of the rock exposures lie on an axial ridge which trends between the south-west and south-east corners (Fig. 2; Plate Ia). In spite of its small size and low relief, Stonington Island supports limited areas of permanent and semi-permanent snow and ice (Fig. 2). Very strong south-east winds prevailing in the area cause large snowdrifts to build up on the lee side of the more prominent rock outcrops, and in some places these drifts extend to the shore to

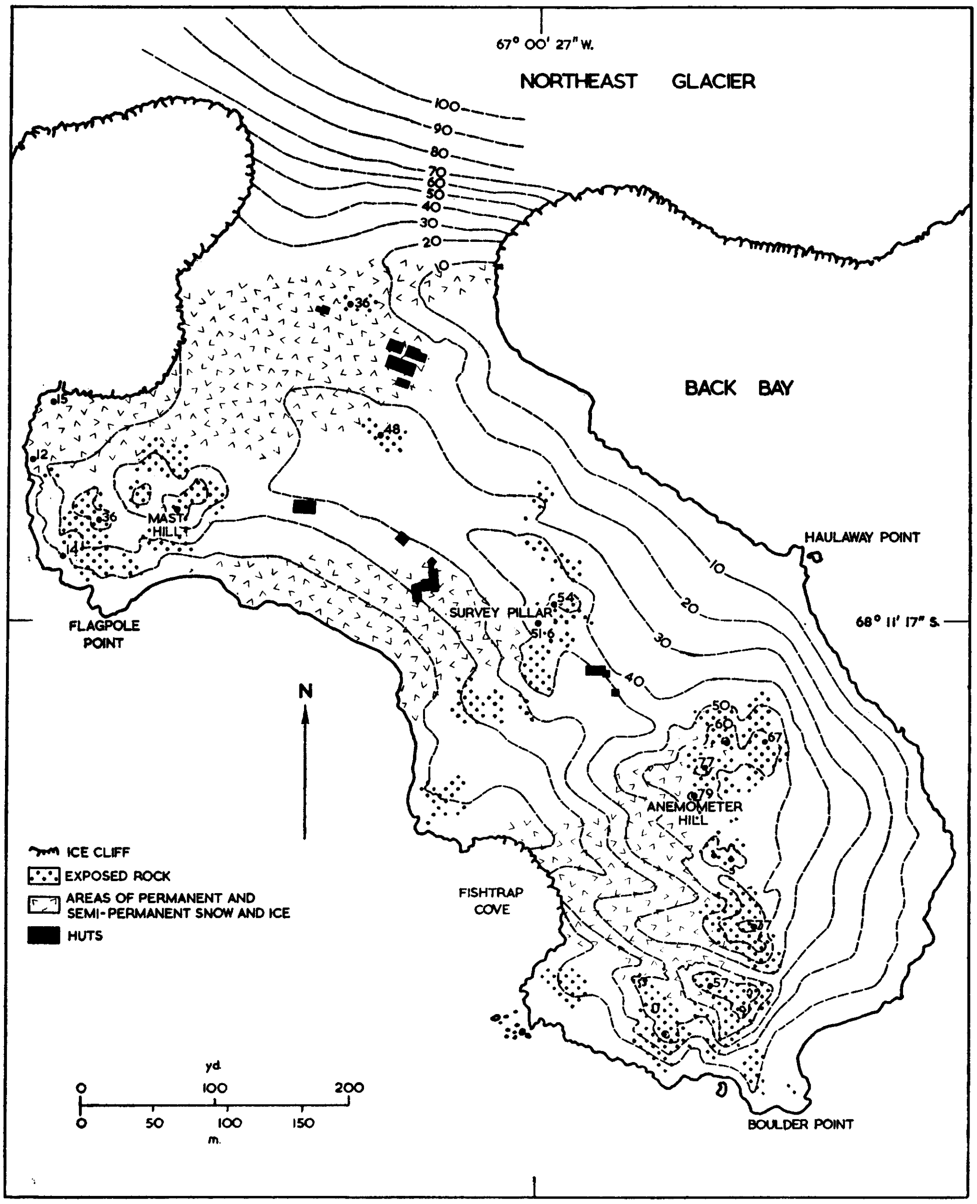

FIGURE 2

General physiographic map of Stonington Island. Heights and contours are in feet. The distribution of permanent and semi-permanent snow and ice shown in Figs. 2, 4 and 5 refers to the Summer of 1961–62.

give a low ice cliff such as the one at Fishtrap Cove. These semi-permanent masses of snow and ice are called "snowdrift ice slabs" by Nichols (1960, p. 1445).

The northern and southern parts of Trepassey Island are separated by a well-defined isthmus of low elevation (Fig. 3), and during the winter months when sea ice is well established, the island is represented by two smaller and apparently unconnected islands.

The narrow gently sloping ice ramp (Plate Ia) which connects Stonington Island to Northeast Glacier

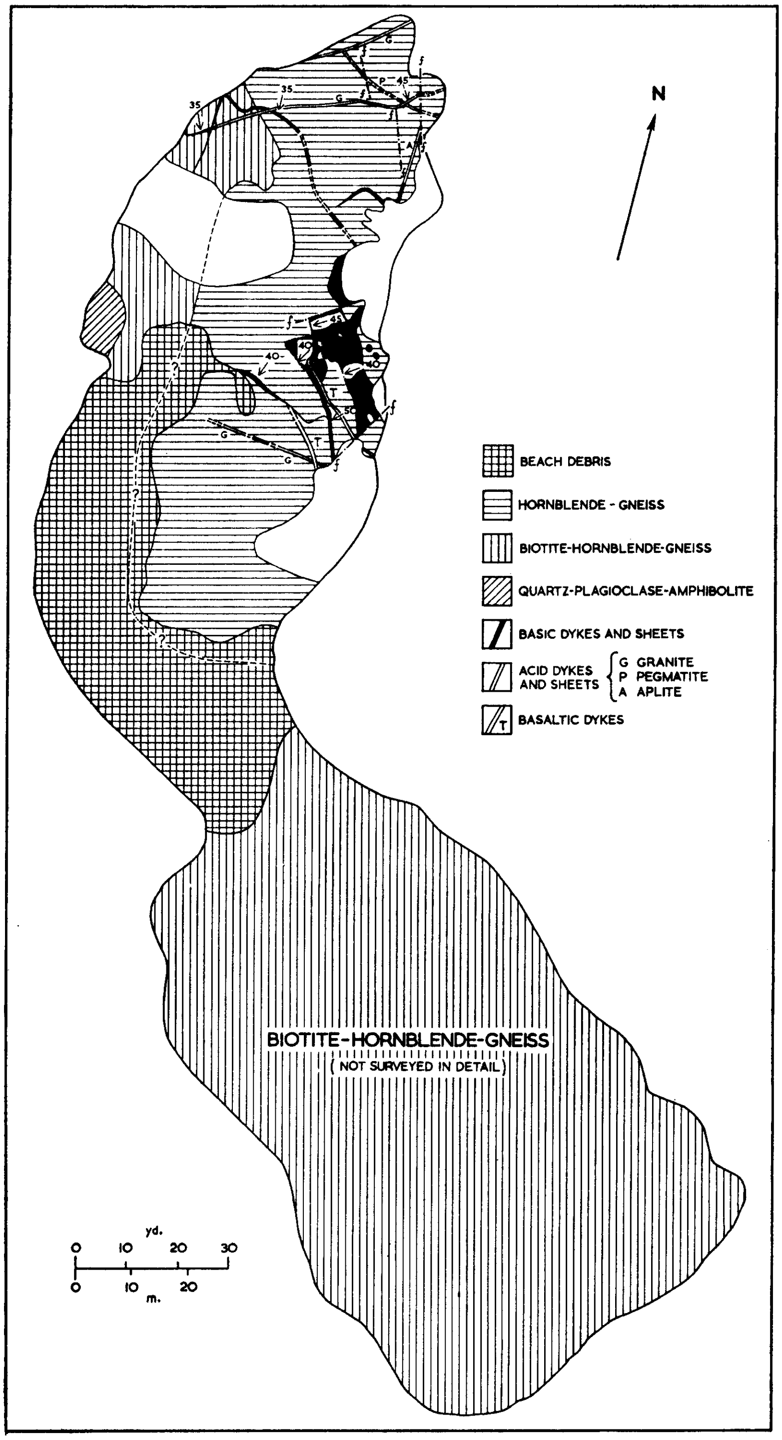

FIGURE 3

Geological map of Trepassey Island.

points to the recent emergence of the islands of Neny Bay from beneath the retreating glacier. However, while it is clear that the overall trend of Northeast Glacier has been one of retreat, it is known that the glacier is subject to relatively rapid fluctuations over short intervals of time. A comparison between figs. 1 and 2 in Nichols's (1960, opp. p. 1434) paper shows that between 1940 and 1947 the snout of the glacier just west of Stonington Island retreated at least 200 ft. (61 m.). When the writer left Stonington Island in early 1962, the glacier at this same locality had re-advanced to its 1940 position. This observation is consistent with that of Hoskins (1960, p. 10), who noted that, in the vicinity of the Debenham Islands, Northeast Glacier had advanced nearly 200 yd. (183 m.) since 1950.

On Stonington Island the existence of a 50 ft. (15 m.) raised beach reported by previous workers (Nichols, 1960, p. 1435; Hoskins, 1960, fig. 2) can be readily demonstrated in places by the transition from angular morainic debris above the beach level to sub-rounded pebbles and boulders below it. The uplift of land consequent on deglaciation was a gradual but steady process, since the beach deposits form a continuous gently inclined slope down to the present sea-level. An outstanding feature of the raised beach on Stonington Island is the presence of numerous terraces which, though they give rise to only very minor steps, are remarkably regular and of considerable lateral extent.

II. STRATIGRAPHY

STONINGTON AND TREPASSEY ISLANDS are composed of medium- to coarse-grained *ortho*gneisses whose distribution and general relationships are illustrated in Figs. 3 and 4. These gneisses are the

TABLE I

STRATIGRAPHY OF STONINGTON AND TREPASSEY ISLANDS

	Stonington Island	*Trepassey Island*
(?) TERTIARY	Altered basalt dykes	Basaltic dykes
PRECAMBRIAN	Pink pegmatite, aplite and granitic dykes many of which are garnet-bearing	
	Basic and xenolithic basic dykes	
	Melanocratic hornblende-biotite-gneiss	
	(?) Xenolithic basic, granite and pegmatite dykes and sheets	(?) Granite and pegmatite dykes
	Leucocratic hornblende-biotite-gneiss	
	(?) Basic, pink and grey granite and pegmatite dykes and sheets	Basic and acid dykes and sheets
	Xenolithic gneiss	
	Biotite-gneiss and injection gneiss	
	(?) Pegmatite, aplite, basic and xenolithic basic dykes and sheets	
	Grey acid gneiss	
	Biotite-hornblende-gneiss	Biotite-hornblende-gneiss
	Leucocratic gneiss	
		Hornblende-gneiss
		Quartz-plagioclase-amphibolite
	Amphibolite and hornblende-schist, occurring as inclusions in basic dykes. Origin uncertain	

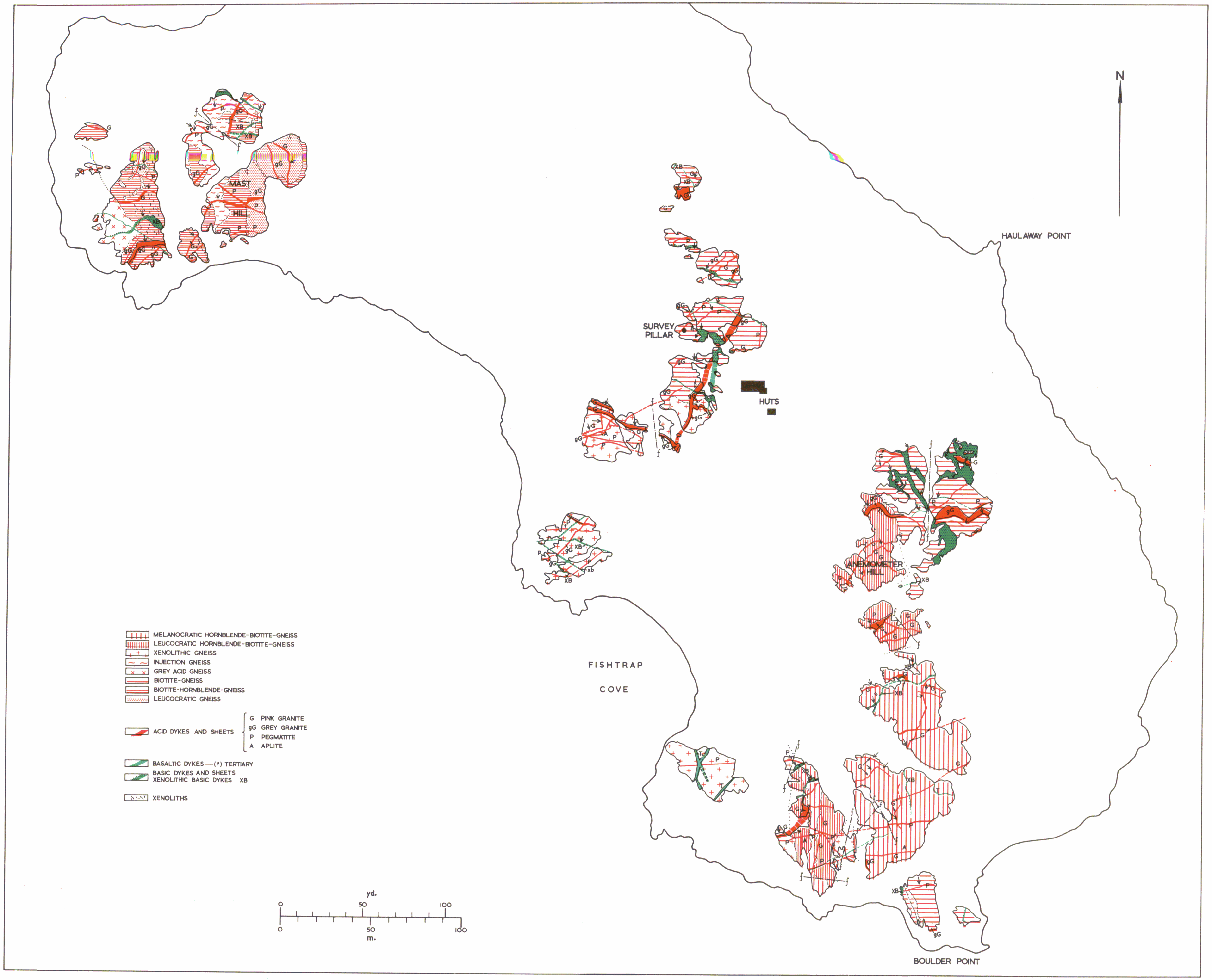

FIGURE 4
Geological map of Stonington Island.

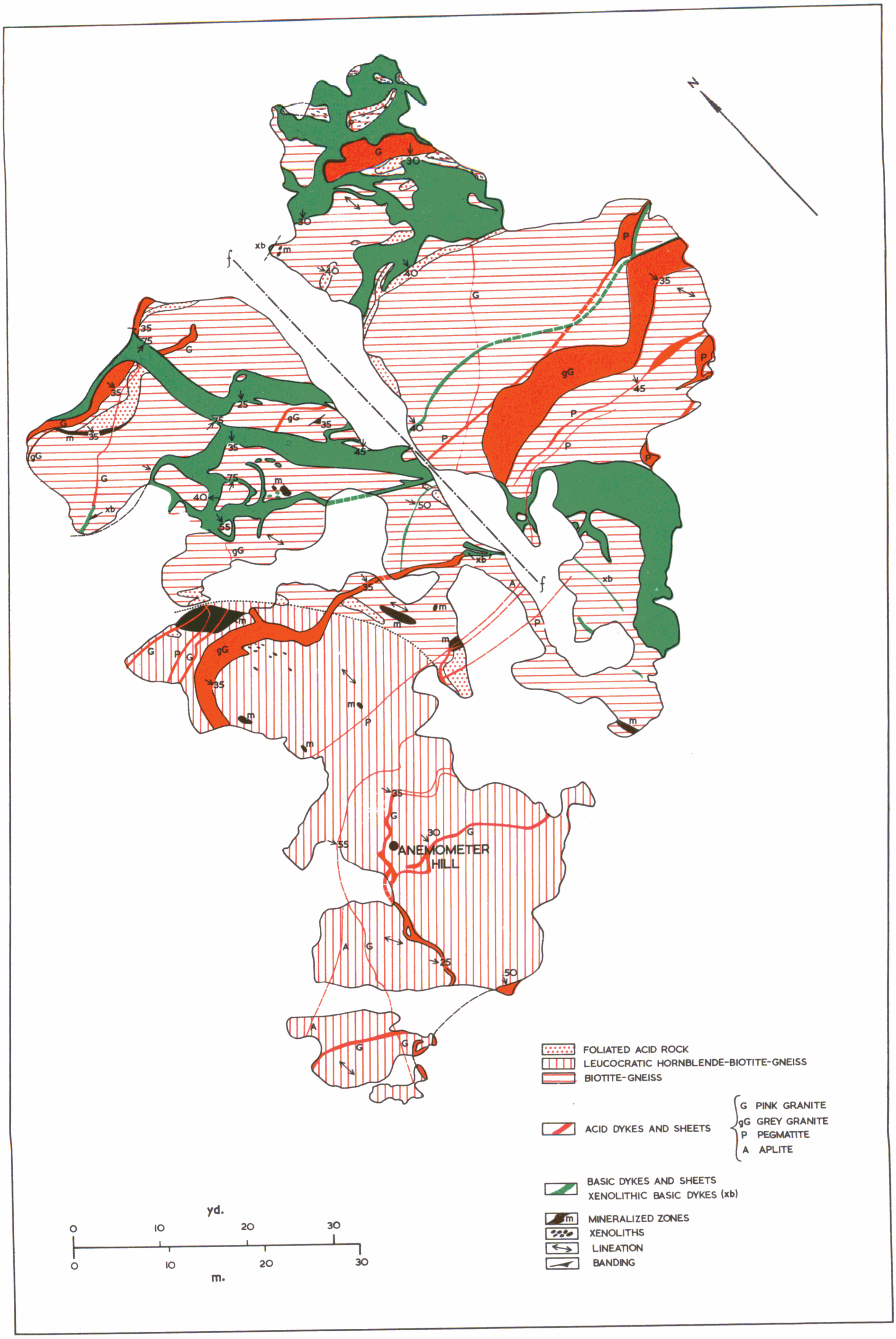

FIGURE 5
Geological map of the Anemometer Hill area, south-east Stonington Island.

metamorphosed equivalents of mainly intermediate plutonic igneous rocks, although rather more basic rocks are occasionally represented (as in the quartz-plagioclase-amphibolite of Trepassey Island). Mineralogical variation between the *ortho*gneisses is usually small so that, although a number of different types of gneiss have been distinguished on the basis of megascopic criteria, most of them approximate to diorite in composition with either biotite or hornblende or both present in all the rocks.

In the absence of any direct evidence, the age of the *ortho*gneisses can only be inferred by comparison with rocks of known age from the Neny Fjord area which have been described previously. Such a comparison shows that the gneisses of Stonington and Trepassey Islands correspond very closely to Hoskins's second major group of the Basement Complex, i.e. the dioritic gneisses (Hoskins, 1963, p. 6, table I), and also to Adie's (1954, p. 9 and 11) coarse-textured hornblende-gneisses and biotite-gneisses. Adie (1954, p. 10) has described a non-hybrid medium- to fine-grained hornblende-biotite-gneiss from two isolated localities in southern Marguerite Bay but this rock is not comparable with any of the gneisses on Stonington and Trepassey Islands, since the country rock of the latter is always medium- to coarse-grained.

The complex network of dykes, sheets and veins intruding the *ortho*gneisses is illustrated in Figs. 3, 4 and 5. The field evidence indicates that several phases of dyke activity are present and the considerable differences in dyke concentration in different gneisses suggest that the earlier dykes were emplaced prior to the intrusion of the later *ortho*gneiss phases.

The stratigraphy of the two islands is shown in Table I together with probable correlations. Apart from the basaltic dykes, all the minor intrusions are regarded as belonging to the Basement Complex. The exact age of the Basement Complex has never been ascertained, although it is generally thought to be Precambrian (Adie, 1954, p. 5). A brief discussion of the problems concerning the age of the gneisses of Stonington and Trepassey Islands is given in the section on metamorphism (p. 34).

III. FIELD RELATIONS AND PETROLOGY OF THE BASEMENT COMPLEX ROCKS

THE rock types listed in Table I are described by the field terms assigned to the Basement Complex rocks of Stonington and Trepassey Islands. The terms biotite-hornblende-gneiss, leucocratic gneiss and injection gneiss were originally proposed by Grimley (1961), and they have been retained without change of connotation in the present work. In general, microscopic examination has justified the sub-divisions given in Table I, but since several *ortho*gneisses have many features in common, particularly with regard to texture, it will not be necessary to describe the petrography of all the rock types in the same degree of detail here. The textural nomenclature of Berthelsen (1960, p. 24) has been used where applicable.

A. AMPHIBOLITE AND HORNBLENDE-SCHIST

1. *Field relations*

Both Adie (1954, p. 5–9) and Hoskins (1963, p. 11–15) have described coarse-grained amphibolite and medium- to fine-grained hornblende-schist from the Basement Complex of Marguerite Bay. On Stonington Island, non-schistose amphibolite, in which the amphibole content approaches or exceeds 50 per cent of the total rock, was found only as small isolated inclusions in basic dykes. Whether these xenoliths can be correlated with the amphibolites recorded by Adie and Hoskins is very uncertain, but one important difference is the much higher percentage of hornblende in the rocks described by them. Hoskins (1963, p. 25) noted that solitary amphibolite xenoliths commonly occur in the dioritic gneisses and, although there is no conclusive evidence, it is probable that fragments of amphibolite also occur in the *ortho*gneisses and that their identity has been lost as a result of modifications following their incorporation into the country rock. For example, several of the relatively coarse-grained hornblende-biotite-plagioclase xenoliths in the *ortho*gneisses, particularly the xenolithic gneiss, may represent altered amphibolite.

Hornblende-schist, the name assigned to medium-grained hornblende-rich rocks possessing a pronounced schistosity, is subject to the same restriction of occurrence as the amphibolite and the two rock types are found locally in close juxtaposition. As with the amphibolite, the origin of these hornblende-schist xenoliths is obscure, although their strongly banded nature suggests that some may have been derived from hornblende-bearing banded biotite-gneisses which Hoskins (1963, p. 14) believed to be of sedimentary origin.

Dark fine- to medium-grained xenoliths of hornblende-rich rocks commonly occur in the *ortho*-gneisses of Stonington Island but their general lack of any marked schistosity distinguishes them from the hornblende-schists already mentioned. However, inclusions of this type have been classed as hornblende-schists by Adie (1954) and Hoskins (1963), and they will therefore be regarded as such here. Since many of them have clearly originated from basic dykes, they are described more fully in the section on minor intrusions (p. 30).

2. *Petrography*

a. *Amphibolite*. Several amphibolite xenoliths are present in the broad north-west to south-east trending basic dyke to the north-east of Anemometer Hill, and one xenolith from this occurrence is typical (E.2102.16). In thin section the amphibolite displays a very variable texture but in general it consists of a decussate arrangement of xenoblastic hornblende and chloritized biotite set in a base of sharply zoned and heavily altered plagioclase. The amphibole has the pleochroism scheme: α = pale yellow, β = brownish green and γ = medium green with a slight bluish tinge; $\gamma{:}c = 17°$. Several crystals display prominent though rather irregular zoning, while a few have schiller-like inclusions of iron ore. A poikiloblastic texture is commonly developed in the amphibolite (Plate IVa). The chlorite derived from the biotite is a pale green, pleochroic penninite with epidote lenses disrupting the cleavages in places. Many small clusters of chloritized biotite are completely enclosed by hornblende. Much of the plagioclase is so extensively altered that composition determinations are impossible but one zoned crystal twinned on both Carlsbad and albite laws has a composition of $Ab_{25}An_{75}$ at the core and $Ab_{60}An_{40}$ at the margin. The main accessory is iron ore, most of which is titanomagnetite with a subsidiary amount of pyrite. Other accessories are apatite, sphene, zircon and deep reddish brown allanite, which produces pleochroic haloes in the hornblende.

b. *Hornblende-schist*. The best example of a hornblende-schist xenolith (E.2107.29) was found in the basic dyke which intrudes the grey acid gneiss on the western side of Mast Hill. In the hand specimen the schist is a medium-grained rock and the foliation, defined by alternate layers rich in hornblende and feldspar respectively, is very marked. The thin section shows that the relatively coarse hornblende-rich bands alternate with finer-grained granoblastic layers of plagioclase, hornblende and rare quartz. The generally fresh xenoblastic to poikiloblastic hornblende has the following optical properties: α = light brown with a faint greenish tinge, β = olive-green, γ = medium green; $\gamma{:}c = 19°$ and $\gamma-\alpha \simeq 0{\cdot}023$. Simple twinning on {100} is fairly common while narrow twin lamellae with the same composition plane are rarer. Biotite is uncommon and much of it is altered to chlorite, epidote, turbid prehnite and fine granular (?) leucoxene. Occasionally, the biotite is even more drastically altered giving aggregates of chlorite, potash feldspar, quartz, finely divided epidote and (?) leucoxene. The plagioclase has a composition of $Ab_{40}An_{60}$ and alteration to scaly mica is slight except in the vicinity of narrow late-stage veins of epidote, isotropic chlorite and turbid potash feldspar. Ilmenitic iron ore is encrusted with sphene, whereas iron pyrites has a narrow limonitic margin.

Although this hornblende-schist strongly resembles the hornblende-bearing banded biotite-gneiss in the hand specimen, the calcic nature of the plagioclase ($Ab_{40}An_{60}$ compared with an average of $Ab_{60}An_{40}$ in the banded biotite-gneisses described by Hoskins (1963)) and the predominance of hornblende over biotite show that it is of undoubted igneous origin.

B. QUARTZ-PLAGIOCLASE-AMPHIBOLITE AND HORNBLENDE-GNEISS

1. *Field relations*

These rock types are restricted to the northern half of Trepassey Island where both are intruded by biotite-hornblende-gneiss. Since they are nowhere in direct juxtaposition, their relative ages are unknown. Several small mesocratic patches or schlieren in the hornblende-gneiss are similar in appearance to the quartz-plagioclase-amphibolite, and this may indicate a close genetic relationship between the two rock types. Neither rock displays a marked gneissose structure and in this respect they are similar to the hornblende-gneisses described by Adie (1954, p. 9) and Hoskins (1960, p. 16).

2. *Petrography*

a. *Quartz-plagioclase-amphibolite.* This amphibolite (E.2165.1) has been derived from a gabbroic rock and contains remnants of both clino- and orthopyroxene. The former is a colourless diopsidic augite with $2V\gamma \simeq 65°$ and $\gamma{:}c = 40°$, and it shows advanced alteration to amphibole. The orthopyroxene is colourless with very weak polarizing colours and has $2V\gamma \simeq 80°$. Much of it has also been replaced by amphibole. The two amphiboles present in the rock are optically distinct and their relationships are clearly shown. The first has the following optical properties: α (= β) = colourless or very pale green, γ = very pale green, $\gamma{:}c = 21°$ and $\gamma - \alpha \simeq 0{\cdot}025$. The optic axial angle is large and negative so that this colourless amphibole is a member of the tremolite-actinolite series. The second amphibole is a common hornblende possibly containing a little soda. It has a pleochroism scheme: α = pale green, β = olive-green and γ = medium green with a slight bluish tinge. Its birefringence is distinctly less than that of the tremolite, having an approximate value of 0·020; the extinction angle, $\gamma{:}c$, is also slightly less. Of the two amphiboles the tremolite has clearly formed first, since it occurs either in aggregates possessing a broad peripheral zone of hornblende or as numerous small patches in the hornblende. In the latter case the tremolite and hornblende are epitaxially related with gradational contacts and in this setting the tremolite is characterized by inclusions of vermicular quartz which were probably liberated during the pyroxene→amphibole transformation (Harker, 1950, p. 312). Quartz inclusions in the hornblende are rare. Biotite is a prominent constituent and has rather variable optics, some of it having a distinctive khaki-green colour. Much of this khaki-coloured biotite is poikiloblastic, enclosing multitudes of vermicular quartz inclusions similar to those present in the tremolite. The biotite shows mild alteration to penninite accompanied by tiny (?) leucoxene granules and rarely by prehnite. Porphyroblastic plagioclase with a composition $Ab_{56}An_{44}$ is poorly twinned and locally antiperthitic. Saussuritization takes place in proximity to epidote clusters. Scarce potash feldspar has a uniform extinction and its irregular distribution and interstitial role is probably the result of potash metasomatism. It attacks plagioclase marginally but lobes of extremely delicate myrmekitic intergrowths extending into the potash feldspar from the plagioclase indicate renewed activity by the latter, a reaction possibly initiated by late introduction of soda. Quartz, which is clearly of secondary origin, is abundant and corrodes all the other mineral phases in varying degrees. Apatite is the main accessory; small idiomorphic crystals figure as inclusions in most of the essential minerals, while larger and less well-formed crystals occur at the margins of the ferromagnesian minerals. Other accessories include xenoblastic titanomagnetite, epidote, a few small zircons producing strongly pleochroic haloes in biotite and hornblende, and allanite.

b. *Hornblende-gneiss.* Typical specimens of hornblende-gneiss (E.2162.1, 2163.10) have a medium to coarse grain and possess little or no foliation. In the thin section the texture is hemigranoblastic and the main mineral phases are plagioclase and hornblende. Subidioblastic to xenoblastic hornblende with a pleochroism scheme α = pale straw, β = greenish brown, γ = bright green and $\gamma{:}c = 31°$ often shows faint irregular zoning with a large core having the above optical properties rimmed by a slightly bluish green hornblende. Simple twinning on {100} is common. In the large hornblendes, small bleached patches containing inclusions of honeycomb quartz may represent nuclei of pyroxene crystals which have been completely made over to amphibole. This view is strengthened by the occurrence of a few remnants of a colourless diopsidic augite enclosed in the hornblende and surrounded by a narrow bleached zone. A very pale or colourless tremolite, identical to that found in the quartz-plagioclase-amphibolite, is also present as rare inclusions in the hornblende. Virtually none of the original biotite remains, since it has been severely altered by late hydrothermal solutions rich in lime. The main alteration product is a green penninite, invariably accompanied by very finely divided turbid grains of a high-relief mineral which are usually arranged in trains parallel to the cleavage. This is a characteristic feature of chloritized biotite in all the *ortho*gneisses. In basal sections of chlorite a little of this material occurs in sufficiently large grains to be identified as rutile but it is impossible to determine whether all the minute grains, too small to be resolved under the microscope, are also rutile. However, since its relief is very high, it is probable that much of the material is leucoxene because, according to Schwartz (1958, p. 172), leucoxene is a very finely crystalline variety of rutile. Other common alteration products of biotite in the hornblende-gneiss include calcite, small lenses of rather scaly quartz, columnar crystals of epidote lying along the chlorite cleavages, and a little potash feldspar. Inclusions of the drastically altered biotite in completely fresh hornblende suggests that much of the amphibole has post-dated the chloritization of the biotite. Plagioclase ranges from large subidioblastic crystals (up to 5 mm. long) to small sub-rounded grains. Polysynthetic twinning on the albite law is common, especially in the smaller crystals, and severely bent twin lamellae occur in several of the larger crystals. The number of lamellae greatly increases in areas of maximum strain, illustrating that the twinning is secondary glide twinning (Vance, 1961). Dislocations commonly occur in the plagioclase, resulting in composite crystals built up of numerous discrete units possessing slightly different orientations. Some of the large hornblendes also show this phenomenon. In a few instances, quartz and potash feldspar corrode the composite plagioclase crystals preferentially. The average composition of the plagioclase is $Ab_{50}An_{50}$ and, although several crystals have a mottled extinction, zoning is rare and always weak. Sericitization of the plagioclase is generally slight and patchy but locally there is more intense alteration with epidote accompanying the scaly mica. Apart from these secondary products, there are occasional inclusions of apatite, small hornblendes and biotite. Many of the plagioclases are slightly antiperthitic, mainly as a result of internal replacement by potash feldspar. Much of the quartz forms large aggregates in which the individual grains have ragged margins and strong mosaic extinction. Plagioclase crystals adjacent to these concentrations of quartz are slightly corroded. Scarce potash feldspar possessing no crystal form occurs in small isolated pockets and, like the quartz, it marginally corrodes plagioclase. Accessories include ilmenitic iron ore, sphene, epidote, apatite and rare zircon. Of these minerals apatite is by far the most prominent. It usually occurs in close association with iron ore and the ferromagnesian minerals but it is also found as inclusions in plagioclase especially at inter-plagioclase boundaries.

C. LEUCOCRATIC GNEISS

1. *Field relations*

Leucocratic gneiss is confined to Mast Hill on the west side of Stonington Island where its main contact with the biotite-hornblende-gneiss trends north—south across the top of the hill. On the western side of the hill the leucocratic gneiss occurs as enclaves in the biotite-hornblende-gneiss. The inclusions vary considerably in size, the largest being almost 50 ft. (15 m.) in length and all are elongated in the direction of foliation of the biotite-hornblende-gneiss.

2. *Petrography*

In thin section, the leucocratic gneiss (E.2107.12) consists mainly of a coarse intergrowth of plagioclase with interlobate quartz. Many of the large tabular plagioclases possess good lamellar twinning on the albite law, while the smaller sub-rounded equidimensional crystals are usually poorly twinned. Much of the twinning is secondary. Combined Carlsbad-albite twins are generally of the synneusis type (Vance, 1961, p. 1107) and in these the composition planes of the Carlsbad twins are very irregular, consisting of minor steps and gentle curves (Plate IVb). The mutual boundaries of many plagioclase crystals interlock which suggests that some interfacial reaction has taken place. The plagioclase has an average composition of acid andesine, although complex zoning gives a compositional range of $Ab_{20}An_{80}$ to $Ab_{75}An_{25}$. Zoning and twinning are generally mutually exclusive (cf. Emmons and Mann, 1953, p. 41–43). Alteration to scaly mica and other indeterminate products tends to be concentrated in the relatively calcic zones and along cleavages and cracks. Marginal turbidity due to (?) kaolinite is characteristic. The quartz shows moderately undulose extinction and occupies numerous pockets from which wedge-shaped offshoots penetrate along inter-plagioclase boundaries. These irregularly shaped masses of quartz are normally optically homogeneous. Occasionally the quartz embays the plagioclase and forms small blebs within it. Potash feldspar is not abundant and it is present only interstitially. It replaces plagioclase both externally and internally; in the latter setting, it occurs as small blebs which generally extinguish in the same position. In some cases the separate patches coalesce to produce larger areas of potash feldspar within the plagioclase. Extremely fine vermicular intergrowths may form between the potash feldspar and the plagioclase.

Apart from a trace of amphibole, the only ferromagnesian mineral is biotite, which shows extensive alteration to green penninite, innumerable tiny granules of (?) sphene or (?) leucoxene, and rare prehnite. The chlorite has a pleochroism scheme α = colourless or very pale straw, β ($\simeq \gamma$) = medium green, with purple or brown anomalous interference colours. Some of the biotite forms long narrow sinuous trains round plagioclase and quartz in a manner very similar to that illustrated by Harker (1950, p. 299) and believed by him to be the result of intrusion under orogenic stress. A large amount of epidote is invariably associated with the altered biotite. Highly xenoblastic titanomagnetite is frequently rimmed by light brown and non-pleochroic sphene. Idiomorphic apatite is a conspicuous accessory; it is mostly marginal to biotite and iron ore but inclusions in plagioclase are also common. In some places it is enclosed in both iron ore and sphene, especially the former.

D. BIOTITE-HORNBLENDE-GNEISS

Biotite-hornblende-gneiss and hornblende-biotite-gneiss can be readily distinguished in the field, not so much by the differing relative proportions of the ferromagnesian minerals but mainly by the variable texture and hybrid nature of the former compared with the fresh appearance and uniformity in mineralogy and texture of the latter.

1. *Field relations*

Although it has not been mapped in detail, the whole of the southern half of Trepassey Island is composed of biotite-hornblende-gneiss, whereas in the northern part of the island it is much more limited in extent and intrudes both the hornblende-gneiss and quartz-plagioclase-amphibolite. The contact between the hornblende- and biotite-hornblende-gneiss is irregular in detail and, where it is transverse to the foliation, a narrow zone of hybrid rock is developed. On Stonington Island biotite-hornblende-gneiss was only recorded at Mast Hill where its relationship to the older leucocratic gneiss has already been described.

On both Stonington and Trepassey Islands, especially on the former, the biotite-hornblende-gneiss contains abundant xenoliths which are all basic in composition relative to the host rock and which vary in size from 1 in. (2·5 cm.) to more than 1 ft. (30 cm.) across. All the xenoliths are fine- to medium-grained hornblende-biotite-plagioclase rocks and most of them have a strong preferred orientation with their long axes parallel to the foliation of the gneiss. Many of the small xenoliths are in an advanced stage of assimilation and this accounts for the characteristic streaky and hybrid appearance of the biotite-hornblende-gneiss. The larger inclusions tend to occur in close concentration to form conspicuous dark zones up to 20 ft. (6 m.) across in which the host rock is virtually absent. In addition, narrow elongated zones containing small basic xenoliths in a much higher concentration than normal can be distinguished. These zones almost certainly represent older basic dykes disrupted by metamorphism. A strong reddish brown staining arising from the oxidation of finely divided iron pyrites characterizes the xenoliths in this second type of zone. In these zones, too, the gneiss is often considerably altered with both limonite- and malachite-staining in evidence.

2. *Petrography*

Many of the mineralogical and textural properties of this gneiss are very similar to those of the leucocratic gneiss and are therefore not repeated here. The only significant difference between the Stonington Island biotite-hornblende-gneiss (E.2107.4) and the same gneiss on Trepassey Island (E.2164.2) is the scarcity of potash feldspar in the former. Fresh xenoblastic to subidioblastic hornblende and partially chloritized biotite form independent clusters, a mode of occurrence which probably denotes an insufficient degree of metamorphism to promote effective diffusion and produce more uniform distribution of the mineral phases. One hornblende in the Trepassey Island rock has a core of diopsidic augite and the derivation of much of the remaining amphibole from pyroxene is indicated by patches of honeycomb quartz in the hornblende. Potash feldspar replaces plagioclase and in places this leads to small corroded remnants of plagioclase in relatively large interstitial areas of generally pellucid potash feldspar. Delicate vermicular intergrowths of quartz are common in these isolated plagioclases. The lime-bearing accessories and secondary minerals again indicate lime metasomatism.

E. GREY ACID GNEISS

1. *Field relations*

On the extreme western side of Stonington Island the biotite-hornblende-gneiss is intruded by a poorly foliated grey-weathering acid gneiss. One part of the contact between the two gneisses trends in a direction which is sub-parallel to the general foliation of the biotite-hornblende-gneiss and the other part is transverse to it. In the first case the contact dips very steeply to the south-west, whereas in the second it dips gently to the north-west. Because the grey acid gneiss has a very limited occurrence, its age relative to the main gneisses of Stonington Island cannot be determined but, despite the absence of a distinct foliation, it clearly belongs to the same rock series.

2. *Petrography*

The grey acid gneiss (E.2107.31) has the same ferromagnesian content as the leucocratic gneiss but apart from this there is little similarity. It has an intergranular texture with numerous well-formed plagioclase porphyroblasts separated by narrow sinuous channels which consist of an interlobate mosaic of quartz, potash feldspar and plagioclase. The plagioclase is of exceptional complexity and interest, and a typical crystal is described in greater detail on p. 20. The average composition of the plagioclase as determined from porphyroblasts possessing combined Carlsbad-albite twinning is $Ab_{55}An_{45}$ but zoning gives compositional extremes of $Ab_{14}An_{86}$ and $Ab_{68}An_{32}$. On occasion the plagioclase has a very narrow partial rim of potash feldspar. However, most of the potash feldspar in the rock occurs as equant and rather rounded crystals in the previously mentioned channels. Small blebs of quartz and plagioclase are commonly enclosed in the potash feldspar and vermicular quartz is intergrown with many of the larger plagioclase inclusions. The quartz has sutured margins and mosaic extinction. Isolated hornblende porphyroblasts with which biotite and sphene are intergrown constitute one mode of occurrence of amphibole in the grey acid gneiss. Small xenoblastic hornblendes are also present in the quartz-feldspar channels and these are invariably moulded on the quartz and plagioclase. Biotite, showing advanced alteration to chlorite and innumerable minute granules of sphene or leucoxene, is normally marginal to the amphibole. The accessories, which comprise xenoblastic ilmenitic iron ore, sphene, apatite, epidote and rare allanite and zircon, exhibit very similar characteristics to those in the previously described gneisses, although some of the sphene occurs as long thread-like veins.

F. BIOTITE-GNEISS

Biotite-gneiss is one of the commonest gneisses on Stonington Island but mineralogical variation makes its exact limits difficult to define. Hornblende locally appears as an essential mineral and it then resembles the least altered varieties of biotite-hornblende-gneiss; this suggests that the latter may represent hybridized biotite-gneiss. Adie (1954, p. 10–11) has described two types of biotite-gneiss and the Stonington Island one has close affinities with his Mount Nemesis type.

1. *Field relations*

There are two major occurrences of biotite-gneiss on Stonington Island. One of these forms the large outcrop to the east and north of Anemometer Hill and the other comprises the group of rocky knolls to the west and north-west of the new hut. Biotite-gneiss was also found on a low-lying exposure at Boulder Point at the southern tip of the island. In the biotite-gneiss there are several narrow elongated zones crowded with small limonite-stained basic xenoliths. These zones are very similar to those observed in the biotite-hornblende-gneiss but the relative scarcity of xenoliths in the biotite-gneiss outside these zones is in marked contrast to the biotite-hornblende-gneiss in which inclusions are widespread.

The precise position of biotite-gneiss in the stratigraphical sequence of Stonington Island is difficult to determine. Unfortunately, it is nowhere in contact with the biotite-hornblende-gneiss and it is virtually impossible to ascertain their age relationships even indirectly. Hoskins (1963, p. 23) has considered that the earlier dioritic gneisses were extensively contaminated by assimilation of the earlier basic country rocks, whereas the younger gneisses of the same group were relatively uncontaminated. Assuming this to be a reliable criterion, the biotite-gneiss is later than the biotite-hornblende-gneiss. However, by similar reasoning, this would make the xenolithic gneiss older than both of them and this is not supported by the field evidence (p. 14).

2. *Petrography*

Specimen E.2102.12 is a typical example of biotite-gneiss. In thin section its texture and the salient features of the constituent minerals are similar to those in the leucocratic and biotite-hornblende-gneisses except that the plagioclase is much more uniform in composition. Most of the potash feldspar present replaces the plagioclase. The biotite tends to be xenoblastic and normally occurs in aggregates usually with a composite nucleus of fragmentary iron ore. Lime-bearing accessories such as sphene, apatite and epidote are concentrated near chloritized biotite.

G. INJECTION GNEISS

Grimley (1961, p. 2) gave the name of injection gneiss to a grey- to buff-coloured migmatitic rock possessing a strong planar structure in which narrow discontinuous layers of dark minerals alternate with wider bands of pink quartzo-feldspathic material. The bands are often contorted and a flaser-like structure is prominent locally. In all probability the injection gneiss is equivalent to the granite-gneiss which Nichols (1955, p. 5) regarded as inclusions and possibly roof pendants in the country-rock "diorite".

1. *Field relations*

By far the most important outcrop of injection gneiss is on Mast Hill where it was mapped by Grimley. In this locality it forms a thick, irregular, gently dipping layer in the biotite-hornblende-gneiss. Only a very few small exposures of this rock type were recorded in the central and eastern parts of Stonington Island. Near Boulder Point it occurs as a 12 ft. (3·6 m.) wide steeply dipping band in the biotite-gneiss. A close affinity between the biotite-gneiss and biotite-hornblende-gneiss may be indicated by the fact that the injection gneiss only occurs in these two gneisses.

The assigning of a relative age to the injection gneiss depends on the interpretation put on its macroscopic characteristics and its mode of occurrence. It is not clear how it originated but its banded nature could be the result of *lit-par-lit* injection of an older fine-grained schistose rock by granitic material. If this is so, then it probably forms large inclusions in the country rock as postulated by Nichols and is therefore older than both the biotite- and biotite-hornblende-gneiss. However, its mode of occurrence indicates that it is a derivative of the gneiss in which it occurs. For example, the biotite-gneiss locally grades into a rock which is paler in colour and is more finely foliated. This variant of the biotite-gneiss is rather similar in appearance to the injection gneiss and probably represents an incipient stage in its development. In the following petrographic section it is shown that the rock contains a considerable amount of potash feldspar. It is believed that the injection gneiss is the result of restricted potash metasomatism of the biotite-gneiss along narrow channel-like zones (cf. Hoskins, 1963, p. 37), and that the influx of potassium ions imparted a limited mobility to the gneiss. Some shearing also seems to have occurred in these zones. Most of the general characteristics of the rock can be satisfactorily explained on this basis.

2. *Petrography*

Compared with the *ortho*gneisses described previously, the injection gneiss has several major differences; not least in the mineral content, as a glance at the modal analysis (Table III) shows. The distinctive features of this rock are best seen in specimen E.2153.2. Texturally, the main characteristic of the gneiss is the alternating relatively coarse- and fine-grained layers. The coarser bands consist of a granoblastic saccharoidal mosaic of acid andesine, some quartz and scarce potash feldspar, while the finer-grained layers are composed of abundant granulitic quartz, potash feldspar and only a little plagioclase. In the finer bands the quartz is markedly stretched and some quartzose augen occur, but undulose and mosaic extinction are not as widespread nor as severe as might be expected. Small biotite flakes, occasionally altered to chlorite, are arranged in remarkably straight lines which emphasize the planar structure of the rock. Trains of finely divided magnetite and pyrite are also present but they are normally independent of the biotite. Zircon and allanite are rare accessories. The very high quartz content of the injection gneiss clearly shows that there has been silica as well as potash metasomatism. Alternatively, the injection gneiss may represent mobilized and granitized quartzite but this is incompatible with the field evidence.

3. *Foliated acid rock*

This rock type is very distinctive in the field because of its finely banded appearance but its origin is obscure. It generally occurs as thin, gently dipping, discontinuous sheets in the biotite-gneiss and many of the individual outcrops are very small. At first it was thought that the foliated acid rock represents highly sheared and disrupted acid dykes; however, since it has several characteristics in common with the injection gneiss, notably the granulitic texture and the mineral content, it is more likely to have originated in a similar manner to the injection gneiss, i.e. by restricted potash metasomatism. Small epidote- and garnet-rich masses have been found in both rock types (cf. Grimley, 1961, p. 2) and this provides additional evidence that the injection gneiss and the foliated acid rock have a common origin.

The foliated appearance in the hand specimen (E.2102.2) is seen in thin section as a combination of alternating layers of different grain-size and extremely thin layers of magnetite. Relatively scarce oligoclase, which is distinguishable from potash feldspar by its greater turbidity and alteration, is extensively replaced by potash feldspar. The abundant potash feldspar ranges from orthoclase to microcline and contains numerous rounded quartz inclusions. Narrow albite rims on the potash feldspar are the result either of a little soda metasomatism or of exsolution. Quartz is intensely strained and the iron ore is finely divided. The accessories include zircon, chlorite, sericite and allanite, but they are all extremely rare.

H. XENOLITHIC GNEISS

1. *Field relations*

This rock, which comprises the low relief outcrops north and east of Fishtrap Cove on Stonington Island, is similar in some respects to the rheomorphic breccia described by Hoskins (1963, p. 11) from Millerand Island. Essentially, the rock consists of two parts: an acid host rock and dark relatively basic inclusions. The commonest type of inclusion is a fine- to medium-grained hornblende-biotite-feldspar rock with a colour index of approximately 50. Rare xenoliths of a grey acidic rock also occur. The host rock is generally more leucocratic and has a more granulitic texture than the biotite-gneiss.

In the main outcrops of xenolithic gneiss north of Fishtrap Cove the inclusions are large, averaging 1–2 ft. (0·3–0·6 m.) across, and constitute approximately 60 per cent of the rock. The gneiss is characterized by having a complex network of tiny acid veins (Plate Ib). In the outcrops east of Fishtrap Cove there is a definite trend involving a progressive decrease both in the size and number of inclusions, so that near the southern corner of the island the xenolithic gneiss contains only a few small inclusions. A preferred orientation can be detected in a large number of xenoliths and all of them have sub-rounded to rounded margins.

The xenolithic gneiss is of uncertain age, since its contact with the biotite-gneiss is never well-defined. However, at one locality south-west of the new hut, the contact appears to have a moderately steep dip to the south with the xenolithic gneiss overlying the biotite-gneiss. In the absence of any more specific evidence the latter is considered to be the older of the two gneisses. About 50 yd. (46 m.) south-east of Fishtrap Cove the sub-horizontal contact between the xenolithic gneiss and the younger hornblende-biotite-gneiss is exposed. Farther east the xenolithic gneiss re-appears as a narrow band with steeply dipping margins. In his preliminary report, Hoskins (1960, p. 19–20) referred to the "Stonington Island diorite" and described it as a granodiorite containing hornblende-schist and hornblende-gneiss xenoliths. From his description it is clear that the rock concerned is the xenolithic gneiss. Hoskins believed that the granodiorite was intruded into the Basement Complex rocks because of its inclusions, but there is no conclusive evidence to justify this post-Basement Complex age.

2. *Petrography*

Both the host rock and basic inclusions of the xenolithic gneiss are somewhat variable in composition and, although most of the large or moderately sized inclusions show little evidence of assimilation, the hybrid aspect of the host may be the result of almost complete digestion of small inclusions. Specimen E.2104.2 is a typical example of the white-weathering host rock with a dark inclusion. In thin section the host has a hemigranoblastic texture and contains relatively high percentages of quartz and potash feldspar. The potash feldspar, which is exceptionally clear in places, varies from small shapeless masses to larger subhedral crystals. A narrow zone impoverished in dark minerals surrounding the basic inclusion is due to a conspicuous increase in the amount of potash feldspar at the expense of biotite. Weakly zoned plagioclase of average composition $Ab_{58}An_{42}$ is frequently antiperthitic and only slightly sericitized. Rare crystals have small rectangular-shaped biotite inclusions. Where it is adjacent to potash feldspar the plagioclase may be rimmed by albite but myrmekitic intergrowths are more typical in this setting. Slightly chloritized biotite and scarce hornblende display a strong tendency to form aggregates and they are both xenoblastic, even towards sphene-rimmed titanomagnetite. Sphene, apatite and epidote almost invariably occur at the peripheries of the ferromagnesian minerals or grains of iron ore.

The basic inclusion is essentially a hornblende-biotite-plagioclase rock with skeletal iron ore, the usual lime-bearing accessories and rare allanite. Highly xenoblastic hornblende containing abundant quartz inclusions is typically fresh. The subidioblastic plagioclase is noteworthy in that it has a uniform grain-size and has exactly the same composition as the plagioclase of the host. In the few zoned crystals which are present inclusions of biotite together with very small amounts of amphibole are common. Scarce potash feldspar is confined to the proximity of the margin of the inclusion and replaces plagioclase by marginal encroachment. A little interstitial quartz is present.

Despite apparent differences in hand specimens, thin-section examination of other examples of the xenolithic gneiss (e.g. E.2104.4, 6) shows very little significant departure from the above description.

I. HORNBLENDE-BIOTITE-GNEISS

The main criterion distinguishing this gneiss from the biotite-hornblende-gneiss has already been given (p. 11). To this may be added the general scarcity of xenoliths in the hornblende-biotite-gneiss. Two kinds of hornblende-biotite-gneiss have been recognized on Stonington Island, a melanocratic and leucocratic type, although transitional types are common.

1. *Field relations*

Hornblende-biotite-gneiss is the most abundant of the *ortho*gneisses exposed on Stonington Island and a large proportion of the eastern part of the island is composed of the melanocratic type. It is also the most uniform rock, although locally it is slightly streaky due to incipient segregation of dark and light minerals. Occasional large enclaves of dark elongated masses of basic rock may represent xenoliths which have been mobilized by the invading magma. These inclusions are similar in type to some of the inclusions in the xenolithic gneiss. Small isolated groups of black biotite-hornblende-schist xenoliths, impregnated with pyrite and magnetite, also occur in the gneiss.

The hornblende-biotite-gneiss is believed to be the youngest gneiss on Stonington Island; the only uncertainty concerns its relationship with the biotite-gneiss. If, as seems probable, the xenolithic gneiss is younger than the biotite-gneiss, then the age of the hornblende-biotite-gneiss is established beyond doubt, since its age relative to the xenolithic gneiss is known (p. 14). Circumstantial evidence, based on the distribution of the minor intrusions, apparently confirms that the biotite-gneiss pre-dates the hornblende-biotite-gneiss. A study of Figs. 4 and 5 shows that a very complex system of dykes intrudes the biotite-gneiss, with basic dykes particularly abundant. In contrast, the hornblende-biotite-gneiss, especially the melanocratic type, has fewer dykes. The logical inference from this is that the biotite-gneiss was intruded by several dyke phases before the hornblende-biotite-gneiss was emplaced and that the biotite-gneiss is therefore the older of the two gneisses. However, in the knoll north of Anemometer Hill the leucocratic hornblende-biotite-gneiss is cut by a grey granitic dyke which in turn is cut by a broad basic dyke intruding the biotite-gneiss. This fact not only invalidates the method of determining the relative ages of the *ortho*gneisses which is based on the differences in dyke concentration, but also demonstrates that the distribution of dykes is largely random. In addition, it apparently indicates that most, if not all of the dykes were intruded after the emplacement of the final phases of the *ortho*gneisses. Against this, however, there is the possibility that the gneiss occurring on Anemometer Hill and on the knoll to the north is not a true leucocratic hornblende-biotite-gneiss but a hornblende-bearing variety of biotite-gneiss. Some support is given to this possibility by the presence of fairly typical biotite-gneiss at one point on Anemometer Hill. Alternatively, there may be a significant age difference between the leucocratic and melanocratic varieties of the hornblende-biotite-gneiss and that the former is comparable in age to the biotite-gneiss. There is evidence of this near the southern end of Stonington Island where the two types of hornblende-biotite-gneiss are in juxtaposition, the melanocratic variety forming an irregular band in the other. Of the two possible alternatives, the latter is considered the more likely, although neither explains the peculiar distribution of the basic dykes.

2. *Petrography*

No new textural or mineralogical feature appears in the hornblende-biotite-gneiss. The difference between the mineral content of the leucocratic (E.2152.3) and melanocratic (E.2151.11) types is evident from Table III, while a hemigranoblastic texture is common to both. In the leucocratic type most of the plagioclase occurs as large prismatic crystals in which the well-developed secondary twin lamellae are often severely bent, and in one instance the angular displacement is as much as 14° (Plate IVc). This value was measured on an unfractured crystal but, in general, the intense stress has resulted in dislocation of the plagioclase. The compositions of the plagioclase in the melanocratic and leucocratic hornblende-biotite-gneiss are acid labradorite and acid andesine, respectively. Only slight zoning was observed. Crudely zoned xenoblastic hornblende and ragged biotite form distinct clusters, some of which have formed round heavy concentrations of titanomagnetite. Amoebiform quartz appears to be entirely recrystallized and the very irregular form of the scarce potash feldspar may be due either to redistribution of the primary mineral or to potash metasomatism. Sphene is remarkably abundant in the leucocratic type and often forms large idioblastic crystals which are clearly discernible in the hand specimen. This is the only *ortho*-gneiss in which the sphene has its typical wedge-shaped outline.

J. GEOCHEMISTRY

Although most of the *ortho*gneisses of Stonington and Trepassey Islands approximate to diorite in their mineralogical composition (p. 7), the chemical analyses given in Table II show that significant variations exist in their geochemistry. These variations are particularly noticeable in such oxides as lime, magnesia and iron. Although only point samples were selected for analysis, the results of the chemical investigations support the validity of the sub-divisions given in Table I which were based on field evidence alone.

With the exception of the quartz-plagioclase-amphibolite and the injection gneiss, all the gneisses have a very high alumina content, a characteristic which is typical of rocks from orogenic belts and which is perpetuated in the very much younger diorites of the Andean Intrusive Suite of Graham Land (Adie, 1955, p. 24, table VIIa). The high alumina in the Basement Complex *ortho*gneisses is reflected in the high percentage of relatively calcic plagioclase present in the mode.

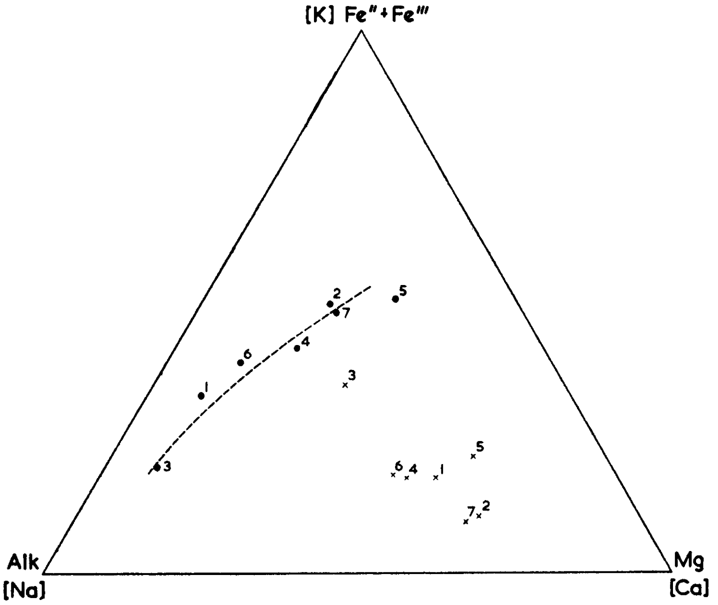

FIGURE 6

Triangular variation diagram with the co-ordinates $(\mathrm{Fe}''+\mathrm{Fe}''')$—Alk—Mg and K—Na—Ca, showing the analyses of the *ortho*gneisses from Stonington and Trepassey Islands (Table II).

● = $(\mathrm{Fe}''+\mathrm{Fe}''')$—Alk—Mg.

X = K—Na—Ca.

TABLE II

CHEMICAL ANALYSES OF *ORTHO*GNEISSES AND DYKES FROM STONINGTON AND TREPASSEY ISLANDS

	1	2	3	4	5	6	7	8	9	10	11	
SiO_2	60·08	52·75	74·96	59·84	59·53	58·07	55·19	49·98	55·90	71·20	75·90	SiO_2
TiO_2	0·55	1·00	0·12	0·68	0·53	0·95	0·82	1·03	0·98	0·26	0·08	TiO_2
Al_2O_3	21·37	18·96	13·07	17·39	9·53	20·57	18·28	16·93	18·31	14·57	12·29	Al_2O_3
Fe_2O_3	1·56	3·68	0·78	2·00	3·62	2·12	2·29	3·18	3·69	0·97	0·45	Fe_2O_3
FeO	1·75	4·28	0·87	3·66	6·85	3·12	4·76	7·32	4·30	1·25	0·56	FeO
MnO	0·05	0·11	0·02	0·09	0·33	0·08	0·12	0·14	0·06	0·04	0·03	MnO
MgO	1·10	4·12	0·90	3·38	8·08	2·00	4·14	5·83	3·07	0·95	0·42	MgO
CaO	7·17	8·99	2·81	5·50	5·85	6·10	7·76	7·24	6·95	2·42	0·74	CaO
Na_2O	3·75	3·49	3·13	3·65	2·04	4·52	3·37	2·83	4·23	3·77	3·73	Na_2O
K_2O	2·03	1·26	2·78	1·67	1·87	2·04	1·02	2·32	1·31	4·31	4·96	K_2O
H_2O+	0·43	1·05	0·46	1·21	1·77	0·64	1·68	1·95	0·79	0·14	0·35	H_2O+
H_2O-	0·04	0·04	0·04	0·08	0·04	0·04	0·12	0·04	0·08	0·07	0·06	H_2O-
P_2O_5	0·24	0·51	0·09	0·31	0·33	0·29	0·37	0·27	0·33	0·07	0·03	P_2O_5
CO_2	0·31	0·14	0·14	0·27	0·16	0·10	0·28	0·82	0·11	0·05	0·10	CO_2
TOTAL	100·43	100·38	100·17	99·73	100·53	100·64	100·20	99·88	100·11	100·07	99·70	TOTAL
	ANALYSES AS CATION PERCENTAGES											
Si	55·76	49·37	70·84	56·52	56·80	53·57	52·18	47·85	52·20	66·39	71·43	Si
Ti	0·38	0·70	0·08	0·48	0·38	0·66	0·58	0·74	0·69	0·19	0·06	Ti
Al	23·38	20·91	14·55	19·36	10·72	22·36	20·36	19·10	20·14	16·01	13·63	Al
Fe'''	1·09	2·59	0·56	1·42	2·60	1·47	1·63	2·29	2·88	0·68	0·32	Fe'''
Fe''	1·36	3·35	0·69	2·89	5·46	2·40	3·76	5·86	3·35	0·97	0·44	Fe''
Mn	0·04	0·08	0·02	0·07	0·27	0·06	0·10	0·12	0·04	0·03	0·02	Mn
Mg	1·52	5·74	1·27	4·75	11·49	2·75	5·83	8·31	4·27	1·32	0·59	Mg
Ca	7·13	9·01	2·84	5·57	5·98	6·03	7·86	7·42	6·95	2·42	0·74	Ca
Na	6·75	6·33	5·73	6·68	3·77	8·08	6·17	5·25	7·66	6·81	6·80	Na
K	2·40	1·51	3·35	2·01	2·27	2·40	1·23	2·84	1·56	5·12	5·95	K
P	0·19	0·41	0·07	0·25	0·26	0·22	0·30	0·22	0·26	0·06	0·02	P
H_2O+	(2·66)	(6·55)	(2·90)	(7·62)	(11·26)	(3·93)	(10·59)	(12·45)	(4·92)	(0·87)	(2·20)	H_2O+
CO_2	(0·39)	(0·18)	(0·18)	(0·35)	(0·21)	(0·13)	(0·36)	(1·07)	(0·14)	(0·06)	(0·13)	CO_2
TOTAL	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	TOTAL
	MESONORMS											
Q	15·9	7·9	38·6	20·6	21·9	11·8	12·7	8·9	11·3	26·1	31·8	Q
Or	8·0	—	13·9	—	0·5	4·5	—	—	—	22·6	28·9	Or
Ab	33·8	31·7	28·7	33·4	18·9	40·4	30·9	26·3	38·3	34·1	34·0	Ab
An	30·2	28·5	12·3	19·2	—	24·3	19·2	14·6	24·6	10·0	1·8	An
Bi	6·4	12·1	4·5	16·1	17·5	12·0	9·8	22·6	12·5	4·9	1·4	Bi
Ho	—	12·5	—	3·6	35·0	—	19·4	17·5	5·8	0·6	1·4	Ho
Mt	1·6	3·9	0·8	2·1	3·9	2·2	2·4	3·4	4·3	1·0	0·5	Mt
Ti	1·1	2·1	0·3	1·4	1·1	2·0	1·7	2·2	2·1	0·5	0·2	Ti
Ap	0·5	1·1	0·2	0·7	0·7	0·6	0·8	0·6	0·7	0·2	0·1	Ap
Cc	0·4	0·2	0·2	0·4	0·2	0·1	0·4	1·1	0·1	0·1	0·1	Cc
C	2·1	—	0·6	2·5	—	2·2	2·7	2·9	0·3	—	—	C

1.	E.2107.31	Grey acid gneiss, west Stonington Island (anal. A. G. Fraser).
2.	E.2151.11	Hornblende-biotite-gneiss, south-east Stonington Island (anal. A. G. Fraser).
3.	E.2103.3	Injection gneiss, central Stonington Island (anal. A. G. Fraser).
4.	E.2164.2	Biotite-hornblende-gneiss, Trepassey Island (anal. A. G. Fraser).
5.	E.2165.1	Quartz-plagioclase-amphibolite, Trepassey Island (anal. A. G. Fraser).
6.	E.2102.12	Biotite-gneiss, south-east Stonington Island (anal. A. G. Fraser).
7.	E.2163.10	Hornblende-gneiss, Trepassey Island (anal. A. G. Fraser).
8.	E.2107.6	Basic dyke, west Stonington Island (anal. A. G. Fraser).
9.	E.2152.20	Basic dyke, south-east Stonington Island (anal. A. G. Fraser).
10.	E.2104.3	Grey acid dyke, central Stonington Island (anal. A. G. Fraser).
11.	E.2160.1	Pink acid dyke, south-east Stonington Island (anal. A. G. Fraser).

It is impossible to establish linear relationships or any other systematic variations in the oxides of the gneisses but this fact does not necessarily imply that the original igneous rocks were not genetically related, because it is clear that the initial compositions of some gneisses have been masked by chemical re-arrangements taking place either during or after metamorphism. When the analyses are plotted on a triangular variation diagram with (Fe″+Fe‴)—Alk—Mg as co-ordinates, a poorly defined curve can be drawn through the points as shown in Fig. 6, but it is very doubtful if this curve has any significance except perhaps to indicate that the gneisses belong to the same rock series.

The mesonorms (Barth, 1959, p. 136) and modal analyses given in Table III show differing degrees of correspondence, the injection gneiss showing the greatest discrepancy probably because of its migmatitic origin. In some cases, while the sum of albite and anorthite in the mesonorm is usually approximately equal to the plagioclase of the mode, their relative proportions are inconsistent with the average plagioclase composition observed in the rocks. This discrepancy can be accounted for partly by the presence of much of the titania in the biotite rather than in sphene, and partly by the fact that the amphibole contains appreciable amounts of soda (Hoskins, 1963, p. 23, 44). Both these factors would result in an increase in the amount of available lime capable of entering into anorthite.

As given in Table II, the mesonorm of the quartz-plagioclase-amphibolite corresponds reasonably well with the mode, the outstanding exception being the absence of anorthite. The reasons for this are that the substitution of soda for lime in the hornblende is not allowed for in the mesonorm and that all the alumina has been taken up by the hornblende. In fact, in the calculation there was barely sufficient alumina to combine with the available lime to form hornblende. Consequently, there is a slight excess of lime which is not indicated in the mesonorm and the total for the rock is rather less than 100. Larsen and Sørensen (1960, p. 681) encountered a similar difficulty in several of their hornblende-rich rocks from Greenland and they attributed this to the high proportion of alumina in Barth's normative hornblende. However, if Larsen and Sørensen's modified procedure is used for the quartz-plagioclase-amphibolite, the mesonorm bears even less resemblance to the mode than that given in Table II.

There is little doubt that the *ortho*gneisses of Stonington and Trepassey Islands belong to a single rock series within the Basement Complex even although the chemical data do not provide any convincing support. That they are genetically related is shown by their close association in the field, the lack of clearly defined intrusive contacts and the general similarities in mineralogy and texture. In the absence of any definite systematic trend either in the constituent minerals or in the chemical compositions, it is not possible to give more than a generalized account of the derivation of this rock series.

One very important fact emerges from the petrographic studies, i.e. that many of the *ortho*gneisses were derived from relatively basic material. This is deduced from two principal lines of evidence. First, in some of the older rocks such as the hornblende-gneiss and biotite-hornblende-gneiss much of the hornblende has clearly originated from pyroxene. Secondly, the plagioclase shows a remarkable range in composition in several of the *ortho*gneisses and even in those rocks containing appreciable amounts of quartz and potash feldspar, the plagioclase has large zones as calcic as basic bytownite. The biotite-gneiss is the only one that gives no positive indication of having been derived from a basic rock.

In the light of the above evidence, it is believed that most, if not all, of the *ortho*gneisses were formed by the hybridization of an earlier basic rock by later and more acid intrusions. Whether these later intrusions originated from the basic material by a petrogenetic process such as crystallization-differentiation or whether they were formed independently cannot be proved, since the metasomatic activity invalidates any conclusions based on the lack of regular variation in either the chemistry or mineralogy. As was emphasized in the petrographic descriptions, late-stage introduction of lime occurs in almost all of the *ortho*gneisses. For example, sphene envelops ilmenitic iron ore and grows progressively at its expense, while epidote is abundant in narrow veins and in aggregates which are commonly associated with chloritized biotite. In addition, epidote (and more rarely prehnite) forms lenses along the chlorite cleavages, indicating that the biotite altered as a direct result of lime metasomatism. These reactions furnish additional evidence of hybridization, since a ready source of lime could well have come from basic material incorporated into the invading acid magma. The concentration of apatite at the peripheries of the ferromagnesian aggregates may also be explained in terms of hybridization, although apatite arising in this way occurs characteristically as minute needles (Nockolds, 1933, p. 563). The amphibole in the *ortho*gneisses is almost invariably fresh and some of it clearly post-dates the degradation of biotite and the

TABLE III

MODAL ANALYSES OF THE MAJOR ROCK TYPES ON STONINGTON AND TREPASSEY ISLANDS

	1	2	3*	4	5*	6	7*	8*	9*	10*	11	12	13	14	15*	16*	17*	18*	19*
Quartz	1·0	0·7	22·2	13·2	13·3	12·9	23·0	13·2	9·3	53·5	60·2	28·9	6·9	9·9	6·9	2·0	5·7	26·4	32·2
Potash feldspar	—	—	0·8	0·3	0·3	1·2	4·0	8·8	4·9	12·9	10·8	16·1	1·1	0·1	—	—	—	22·4	33·5
Plagioclase	27·4	42·0	22·2	58·5	50·7	79·4	57·6	70·9	68·1	31·4	26·0	43·6	71·1	61·0	62·5	42·7	67·2	44·8	32·3‡
Biotite Chlorite	17·4	2·1	13·9	9·0	7·9	4·5	9·0	4·2	14·7	1·5	2·6	8·6	12·4	17·4	12·3	18·4	11·2	3·6	0·9
Hornblende	49·2	52·6	37·0	17·2	22·1	†	5·4	1·0	—	—	—	1·2	4·1	8·4	15·4	35·9	11·5	—	—
Iron ore	2·6	1·6	1·4	0·8	1·3	0·6	†	0·8	2·2	0·6	0·2	1·2	1·2	2·0	0·9	0·5	2·0	1·8	0·3
Accessory minerals	2·4	1·0	2·5	1·0	4·4**	1·4	1·0	1·1	0·8	0·1	0·2	0·4	3·2§	1·2	2·0	0·5	2·4§	1·0**	0·8
Average plagioclase composition	An_{55}	An_{60}	An_{44}	An_{50}	An_{50}	An_{35}	An_{38}	An_{45}	An_{44}	An_{33}	An_{33}	An_{42}	An_{40}	An_{54}	An_{54}	An_{55}	An_{50}	An_{25}	An_{28}

* Chemical analyses of these rocks are given in Table II.
† Present in small quantity.
‡ Includes 3·3 per cent albite.
** Mostly epidote.
§ Mostly sphene.

1. E.2102.16 Amphibolite xenolith, south-east Stonington Island.
2. E.2107.23 Hornblende-schist xenolith, west Stonington Island.
3. E.2165.1 Quartz-plagioclase-amphibolite, northern Trepassey Island.
4. E.2162.1 Hornblende-gneiss, northern Trepassey Island.
5. E.2163.10 Hornblende-gneiss, northern Trepassey Island.
6. E.2107.12 Leucocratic gneiss, west Stonington Island.
7. E.2164.2 Biotite-hornblende-gneiss, northern Trepassey Island.
8. E.2107.31 Grey acid gneiss, west Stonington Island.
9. E.2102.12 Biotite-gneiss, south-east Stonington Island.
10. E.2103.3 Injection gneiss, central Stonington Island.
11. E.2153.2 Injection gneiss, south-east Stonington Island.
12. E.2104.2 Xenolithic gneiss (host), central Stonington Island.
13. E.2152.3 Leucocratic hornblende-biotite-gneiss, south-east Stonington Island.
14. E.2101.3 Melanocratic hornblende-biotite-gneiss, south-east Stonington Island.
15. E.2151.11 Melanocratic hornblende-biotite-gneiss, south-east Stonington Island.
16. E.2107.6 Basic dyke, west Stonington Island.
17. E.2152.20 Basic dyke, south-east Stonington Island.
18. E.2104.3 Grey acid dyke, central Stonington Island.
19. E.2160.1 Pink acid dyke, south-east Stonington Island.

growth of sphene around titanomagnetite. Again, this late development of amphibole may be attributable to the contamination of an acid magma by basic material.

IV. FELDSPARS OF THE *ORTHO*GNEISSES AND THEIR PETROGENETIC SIGNIFICANCE

THE feldspars present in the *ortho*gneisses of Stonington and Trepassey Islands possess certain features which are believed to be of considerable value in determining the geological history of these rocks, and this section is therefore devoted to a full description and interpretation of their properties.

1. *Plagioclase feldspar*

a. *Patchy zoning*. The most outstanding feature exhibited by the plagioclases is a complex patchwork or patchy zoning which is strikingly similar to that observed in the plagioclases of the gabbros and related rocks of the Anagram Islands (Fraser, 1964). The salient characteristics of this patchwork are best shown in one plagioclase porphyroblast from the grey acid gneiss (Fig. 7; Plate IVd). This particular plagioclase crystal displays synneusis twinning (Vance, 1961, p. 1107) and consists of three components, two of which are identical in orientation and related to the third by the Carlsbad twin law. Albite twinning is also present but it is not uniformly developed, being more constant and regular in one component of the Carlsbad twin than in the other two.

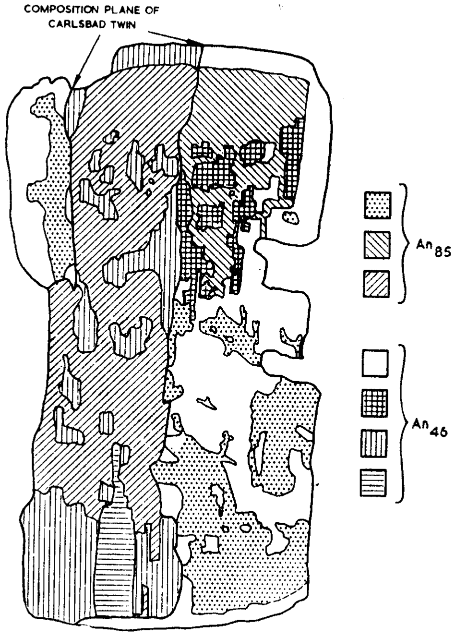

FIGURE 7

Diagrammatic representation of a plagioclase porphyroblast in the grey acid gneiss, part of which is illustrated in Plate IVd (E.2107.31; ×20).

The patches of different composition vary considerably both in size and shape, and several have complex margins consisting of rectangular-shaped embayments and prominences. Where polysynthetic albite twinning occurs it usually consists of alternating broad and narrow lamellae, so that individual patches become almost uniformly dark at the extinction position of the broad lamellae. The lamellae may show very slight changes in width in passing from a patch into the surrounding host. Although the patches appear to display a considerable range of composition, closer inspection shows that only two compositional values are represented (Fig. 7). The apparent diversity arises from the fact that the extinction position of the broad twin lamellae in one set of patches coincides with that of the narrow lamellae in another set of patches. This compositional pairing is best shown by the calcic patches; in the relatively sodic areas the correspondence is not quite so good. In some parts of the crystal, sodic patches possess narrow spindle-shaped lamellae which may be slightly bent. Twinning of this kind either occurs in restricted areas within the patches or else extends for a short distance into adjacent parts of the crystal. The sodic patches have slight continuous reversed zoning, whereas the calcic areas show faint normal zoning. In the plagioclase as a whole, the compositions of the calcic and sodic patches are $Ab_{15}An_{85}$ and $Ab_{54}An_{46}$, respectively. These values are based on the assumption that the calcic and sodic patches in the twin components are analogous. Where patches of different compositions are in direct juxtaposition, the Becke line is not readily discernible because there is normally a very narrow transitional zone.

One plagioclase from the xenolithic gneiss (E.2104.2) illustrates further aspects of patchy zoning. In this plagioclase several large areas with slightly distorted secondary albite twinning are separated by areas with little or no twinning. Small basic patches are abundant in the twinned areas but they are scarce in the untwinned parts of the crystal. Many of the patches have additional twin lamellae which may extend into the surrounding host for a short distance (Plate IVe). The main part of the crystal has a composition of $Ab_{56}An_{44}$, while the patches have a consistent value of $Ab_{27}An_{73}$.

A general study of patchy zoning in the plagioclases of the *ortho*gneisses shows that when individual crystals are compared there is considerable variation in the size, shape and number of patches. Large calcic patches such as those occurring in the plagioclase of the grey acid gneiss are comparatively rare; the vast majority of the crystals have a predominantly intermediate composition (about $Ab_{55}An_{45}$) and contain relatively small basic patches. It is noteworthy that in the basic gabbros of the Anagram Islands the reverse relationship holds with small relatively sodic patches in a predominantly calcic host. The compositions of both the patches and the host plagioclase were determined from (100) sections and Carlsbad-albite twins. Despite the relative inaccuracy of this method, certain compositions, especially $Ab_{27}An_{73}$, $Ab_{48}An_{52}$, $Ab_{57}An_{43}$ and $Ab_{62}An_{38}$, showed a strong tendency to recur. A few patches of $Ab_{20}An_{80}$ and $Ab_{15}An_{85}$ were found and one patch yielded a value of $Ab_{7}An_{93}$.

Albite twinning, possessing most of the criteria listed by Vance (1961, p. 1103) as evidence of a secondary origin, is commonly but by no means invariably present in plagioclases with patchy zoning. In some instances the development of this secondary twinning clearly originates in the immediate vicinity of the patches, indicating a causal relation between the two phenomena. A close association of well-developed glide twinning with a large number of small patches was noted in several plagioclases and this association occurs irrespective of whether the patches are calcic or sodic relative to the host.

In order to give a systematic descriptive account of patchy zoning in plagioclase, reference is now made to the intrusive rocks of the Anagram Islands in which the initial stages and subsequent development of the patchwork are clearly shown. The most basic members of this intrusive suite are olivine- and hypersthene-gabbros, and the calcic plagioclase in these rocks is generally uniform in composition apart from the presence of small relatively sodic, sub-rectangular patches which always have the same orientation with respect to the host. In the sequence from olivine-gabbro to tonalite there is a progressive increase in the number and size of sodic patches in the plagioclase, so that in the more acid members of the rock series the individual patches coalesce and leave only small remnant patches of basic plagioclase. That part of the progression in which the sodic and calcic zones are approximately equal in area is, however, not often observed. Several patches retain their sub-rectangular shape and clearly defined margins as they increase in size but the majority tend to assume less regular shapes and develop increasingly diffuse margins. Consequently, the relict basic patches have sub-rounded edges and they are usually rather poorly defined. Only the latter part of the above progression is present in the *ortho*gneisses of Stonington and Trepassey Islands, although a few plagioclases in the grey acid gneiss represent the middle part of the sequence.

At any stage in the sequence secondary glide twinning may be induced by the patchwork, although it does not invariably occur. This twinning generally commences either inside the patches (whether they are calcic or sodic) or at their margins and gradually spreads out to affect the remaining parts of the crystal. There is some evidence to suggest that, if the twinning develops still further, it begins to eliminate the patchy zoning, the ultimate product of this process being a well-twinned plagioclase in which all the patchwork has been removed. However, it is only in very rare instances that well-twinned plagioclases devoid of patchwork can be seen to have originated in this way, because in the *ortho*gneisses of Stonington and Trepassey Islands glide twinning has also arisen in response to shearing stress which accompanied metamorphism. Even in the non-metamorphic rocks of the Anagram Islands, secondary glide twinning has apparently resulted from local stresses during cooling. Since this twinning is indistinguishable from that which developed in the manner described above, it is generally impossible to determine the history of any single well-twinned plagioclase. Nevertheless, in several plagioclases with excellent glide twinning and with no patchwork, the adjacent twin lamellae display marked differences in extinction angles and therefore in composition, which suggests that the plagioclase may have possessed patchy zoning initially. In such cases the compositional differences were re-distributed rather than eliminated by the twinning.

The origin of the patchwork is problematical. In an important paper on normal and oscillatory zoning in igneous plagioclases, Vance (1962, p. 749, fig. 2) has illustrated two plagioclase crystals showing well-developed patchy zoning in which numerous patches of rim composition are present in the oscillatory zoned core. Vance interpreted this patchy zoning by postulating an initial phase of strong resorption of basic plagioclase followed by a phase of crystallization in which the corroded core was filled and surrounded by more albitic material. He attributed this sequence to the rise of a water-deficient magma in the crust followed by saturation of the melt in volatiles. Although Vance's interpretation of patchy zoning can account for many of the observed phenomena in the plagioclases described earlier, it cannot readily explain the progressive development of the patchwork in the sequence from basic to more acid rocks. In particular, it fails to explain the small relatively sodic patches in unzoned calcic plagioclase in the basic gabbros of the Anagram Islands. Nor can his hypothesis satisfactorily account for the small widely scattered but identically orientated remnant basic patches in a sodic host.

In view of the difficulties in interpreting the plagioclase patchwork on the basis of Vance's hypothesis, it is suggested that this phenomenon is the result of unmixing followed by replacement. In the intrusive rocks of the Anagram Islands the initial stages of patchy zoning are shown in the olivine- and hypersthene-gabbros in which the anorthitic plagioclases possess small patches of labradorite. These patches are believed to represent the unmixing of a relatively sodic phase, probably under conditions of very slow cooling, and its subsequent segregation into several small discrete units. The composition of the unmixed phase was probably structurally controlled and this would readily explain the consistency in composition of the patches. Whether such structural control is of the type postulated by DeVore (1956) or whether it can be explained in terms of the more recent theoretical models of the plagioclase structure (e.g. Megaw, 1959) is unknown. The small patches of exsolved material then acted as centres of replacement during subsequent stages in the history of the rocks. This replacement is believed to have occurred when the basic rock containing the calcic plagioclase came into contact with more acid material derived by fractionation from the original basic rock. The plagioclase patchwork is thus envisaged as developing under conditions of hybridization which are completely analogous to those described in detail by Nockolds (1934). Although the exsolution was probably structurally controlled, the composition values of the patches and host must also have depended to some extent on the nature of the original basic plagioclase and also on the composition of the intermediate or acid melt when hybridization occurred.

The patchwork represents an attempt by the plagioclase to attain equilibrium in a new physico-chemical environment. The extent to which the replacement occurred and the patchwork developed depended directly on the degree of hybridization, and this accounts for the progressive increase in the size and complexity of patches as the rocks become more acidic. The patchy plagioclases in the intrusive sequence of the Anagram Islands thus form a special type of discontinuous reaction series and there is an excellent correspondence between the evolution of the patchwork and the stage attained by the discontinuous reaction series of the ferromagnesian minerals.

If these arguments are extended to the *ortho*gneisses of Stonington and Trepassey Islands, it is evident that the conclusions reached earlier concerning the hybrid origin of the major rock types are amply confirmed. In this case, however, the hybridization may have occurred by interaction between a basic rock and an acid melt which were not genetically related. Judging from the advanced development of the patchwork in the *ortho*gneisses, hybridization has been considerable since the grey acid gneiss is virtually the only rock in which the plagioclase has large relict calcic zones.

A comparatively large number of plagioclases both in the more acid rocks of the Anagram Islands and in the *ortho*gneisses display no patchwork. These plagioclases have an intermediate composition and could have arisen in either of two ways. Several probably correspond to originally patchy crystals in which no secondary albite twinning was induced and in which the basic patches have been completely replaced. Others crystallized directly from the original melt which was contaminated by the earlier basic rocks.

One important consequence of the hybridization relative to its effects on the plagioclase is the considerable loss of lime implied by the progressive increase in sodic areas at the expense of the original calcic zones. There is little doubt that much of this lime became fixed in such minerals as sphene, apatite and epidote which are characteristically late in the *ortho*gneisses. Some of the lime may also have contributed to the late growth of amphibole.

The close connection between patchy zoning and the development of secondary glide twinning demonstrates that, when compositional differences were created by exsolution and replacement, structural strains were set up within the crystal. The few proven examples exhibiting the elimination of the patchwork by glide twinning show that the twinning represents an attempt by the plagioclase either to eliminate the compositional differences or to re-distribute them. Consequently, the twinning must be interpreted as a re-organization of the structure in order to reduce the potential energy of the system to a minimum. Since secondary twinning did not invariably occur, energy barriers which resisted the structural re-adjustments were clearly operative.

The removal of patchy zoning by twinning appears to contradict the view expressed by Goldsmith (1952, p. 288) that zoning in plagioclases, especially in those of old rocks, is good evidence that solid diffusion is not an important process in rock modification or formation. In general, such diffusion is very improbable on structural grounds, but Goldsmith believed that extensive re-organization of the plagioclase structure by diffusion could conceivably take place at high temperatures, i.e. near the melting point of the lowest-melting constituent. This conclusion is supported by Seifert (1964, p. 318), who has stated that glide twinning in plagioclase is easily possible only at high temperatures when the structure is in a disordered state. However, even at elevated temperatures structural re-organization must be sluggish and it is therefore concluded that elimination of the patchwork occurred under high-temperature conditions which persisted for a considerable time.

b. *Clouding*. The plagioclases in several *ortho*gneisses provide other evidence of their attempt to reach equilibrium during the thermal history. For example, in basic patches, especially those more calcic than $Ab_{30}An_{70}$, innumerable minute specks of (?) iron ore are usually present. These specks occur in well-defined layers, because raising or lowering the microscope objective brings successive layers into focus. This phenomenon is identical to the clouding of plagioclase in the basic dykes of Scourie described by MacGregor (1931) and attributed by him to exsolution of iron from the structure during thermal metamorphism. Poldervaart and Gilkey (1954) have also described clouded plagioclase and, although they broadly agree with the conclusions reached by MacGregor, they state that clouding may also result from diffusion of material into the crystal after its formation. Clouding arising in this second way is more intense than that caused by exsolution. Since the plagioclases in the *ortho*gneisses only exhibit light clouding, it is concluded that all the iron now present as specks was originally present in the crystal structure. The iron could only have been admitted into the structure at elevated temperatures and, furthermore, subsequent exsolution could only effectively take place under conditions of slow cooling. The presence of clouding thus gives a good indication of the thermal history of the *ortho*gneisses.

c. *Antiperthite*. Many plagioclases in the gneisses of Stonington and Trepassey Islands are antiperthitic. The potash feldspar inclusions may form tiny masses with square or rectangular cross-sections but larger and more complex shapes are commoner. In most instances the antiperthite is the result of replacement of the plagioclase by the potash feldspar. The regular spacing of the inclusions and their minute size in some crystals strongly suggests that the potash feldspar was initially exsolved from the plagioclase and that the exsolved material provided centres of replacement during subsequent potash metasomatism. This is exactly the same process as was envisaged for the plagioclase patchwork. The potash feldspar inclusions occur exclusively in plagioclase in the composition range of $Ab_{68}An_{32}$ to $Ab_{62}An_{38}$, which means that they are normally found only at or near the margins of zoned crystals. However, they are also present in patches which have the appropriate composition, and their occurrence is independent of the position of such patches within a particular crystal. The reason for this is not known but it is probably connected with the greater solubility of potash feldspar in plagioclase in this composition range.

If, as is believed, some of the antiperthites are of exsolution origin, then certain deductions can be made regarding the geological history of the rocks. Sen (1959) has given details of how potassium enters into the plagioclase structure in the first instance and of the conditions under which it subsequently exsolves to form antiperthite. High temperature gives the optimum state for the entrance of potassium into the plagioclase and exsolution antiperthites are thought to be the product of down-temperature adjustment in rocks. Sen (1959, p. 493–94) has stated that there are serious kinetic difficulties in exsolving potash feldspar from plagioclase. However, he has argued that, if large supplies of thermal energy are available, the possibility of exsolution occurring is greatly enhanced, since such energy would bring about structural re-organization more readily. Sen has also suggested that slow cooling, metamorphic re-heating or strain due to shearing stress could provide the necessary thermal energy.

2. *Potash feldspar*

This mineral is irregularly distributed throughout the gneisses of Stonington and Trepassey Islands. It is either very scarce or absent in the hornblende-biotite-gneiss and is relatively abundant in the xenolithic gneiss. Optically, it is variable, even in a single thin section, and there is usually a gradation from evenly extinguishing crystals to those possessing small patches with microcline-type twinning. Table IV

TABLE IV

VALUES OF 2V OF POTASH FELDSPAR IN THE *ORTHO*GNEISSES AND MINOR INTRUSIONS

Rock Type	2Vα	*Remarks*
Leucocratic hornblende-biotite-gneiss (E.2151.3)	54°	Uniform extinction
	59°	Slightly patchy extinction
	59°	Slightly patchy extinction
	60°	Faint shadowy extinction
Grey acid gneiss (E.2107.31)	57°	Uniform extinction
	61°	Very slight shadowy extinction
	60°	Uniform extinction
	61°	Uniform extinction
Xenolithic gneiss (E.2104.2)	61°	Microperthitic
	61°	Microperthitic
	63°	Microperthitic
	60°	Slightly microperthitic
	60°	Slight shadowy extinction
	57°	Slight shadowy extinction
Biotite-gneiss (E.2102.12)	54°	Uniform extinction
	56°	Very slight shadowy extinction
	59°	Slightly patchy extinction
	54°	Slightly patchy extinction
Acidified basic inclusion in xenolithic basic dyke (E.2105.8)	52°	Slightly patchy extinction. One patch has 2Vα = 65°
	60°	Uniform extinction
	57°	One small patch has 2Vα = 68°
	60°	
	54°	Slightly patchy extinction
	55°	Uniform extinction
Grey acid dyke (E.2102.15)	62°	Most of the potash feldspar has a slightly patchy extinction
	63°	
	63°	
	63°	
Greyish pink granitic dyke (E.2107.1)	65°	Streaky extinction. Microperthitic
	67°	Several patches have 2Vα = 79°
	67°	Many small patches with microcline twinning and 2Vα = 83°
	61°	Microperthitic. Patches with microcline twinning and 2Vα = 77° and 85°
	65°	Patches with 2Vα = 82° and with microcline twinning
Pink garnet-bearing aplite (E.2151.13)	73°	Patchy extinction
	88°	Microcline
	72°	Patchy extinction
	67°	Patches with microcline twinning and 2V = 82°

In all cases the 2V was determined by direct measurement so that the values quoted are accurate to within ±2°.

gives the values of 2V measured on several potash feldspar crystals in selected *ortho*gneisses, and in each case the optic axial angle is comparatively low. The low extinction angle in (010) sections suggests that the potash feldspars have a low soda content (Tröger, 1959, p. 96), and the value of the 2V indicates that they belong to the orthoclase—orthoclase-microperthite—low-albite series (Deer, Howie and Zussman, 1963, p. 6). According to Marfunin (1962), with constant composition, the 2V of potash feldspar depends on the degree of order-disorder alone. It follows that the 2V values quoted in Table IV are a consequence of a partially disordered structure, which in turn gives an indication of the thermal history of the rocks. Differences in the degree of ordering of the structure on cooling are indicated by the small areas of microcline twinning (especially in the xenolithic gneiss) and possibly also in the patchy extinction of much of the potash feldspar. There is a similar explanation for the occasional microperthitic intergrowths.

The potash feldspar does not, however, have the same value as the plagioclase in determining the history of the rock. If cooling was slow, it is unlikely that the original structural disorder would be preserved. Nevertheless, the fact that the potash feldspar has still a partially disordered structure (as shown by the 2V), and that the degree of ordering varies, indicates that it has attempted to reach equilibrium during cooling from at least moderately high temperatures. This is in accordance with the conclusions reached from a study of the properties of the plagioclases.

A study of the plagioclase and potash feldspars therefore indicates that the rocks in which they occur were subjected to high temperatures over a prolonged period, and that the rate of cooling was very slow.

V. MINOR INTRUSIONS

A STUDY of Figs. 3, 4 and 5, in conjunction with Table I, shows that Stonington and Trepassey Islands have had a very complex history with respect to minor intrusions. Although it is clear from the field evidence that there are several phases of dyke activity, it is very difficult to determine when the various phases occurred. Table I gives the possible time sequence of minor intrusions but, since the evidence on which it is based is indirect and not positive, no firm conclusions can be drawn from it.

With the exception of the late basaltic dykes, which are described on p. 45–46, all the minor intrusions are believed to belong to the Basement Complex and are therefore probably Precambrian in age. Certainly, they were all intruded into the country rock while it was still hot, because marginal chilling is absent. In contrast, the basalt dykes have prominent chilled margins and their trend is completely controlled by pre-existing jointing in the gneisses. The age of these dykes has not been definitely established, but their petrographic characteristics suggest that they are younger than the late Cretaceous to early Tertiary Andean Intrusive Suite.

A. GENERAL CHARACTERISTICS AND AGE RELATIONSHIPS

The majority of minor intrusions on Stonington Island strike in two main directions (Fig. 4). Those of one set trend approximately west—east and many intrusions which belong to this group have a moderately low dip (30–40°) to the south. Those in the other set have a general north—south trend and they occur mainly at the southern end of the island, i.e. where hornblende-biotite-gneiss is the country rock. There is no comparable pattern on Trepassey Island.

The minor intrusions are difficult to classify satisfactorily for at least two reasons. First, although several are sill-like, none are consistently concordant with the structure of the wall rock; secondly, their dips range from 25° to 90° and it is impossible to determine whether they have been tilted subsequent to their emplacement. An arbitrary dip value of 50° was chosen as the dividing line between sheets and dykes with the former having dips of less than 50°, but this simple two-fold division is complicated by the fact that several individual intrusions display considerable variation in both strike and dip. For example, one granitic sheet intruding hornblende-biotite-gneiss shows the following changes when traced along the strike. In the northern part of this sheet the trend is north-north-west to south-south-east and the contact with the gneiss dips at 35° to the east-north-east. At a certain point, there is a sharp change and the sheet then strikes in a north-north-east to south-south-west direction with a vertical contact against the gneiss. This trend is maintained in the southern part of the sheet but the dip reverts to 35°. This variable strike and dip is not clearly related to any fracture system. Many of the gently dipping sheets show apparent variation in trend as a result of changes in the topography, and thin sheets of this type have greatly increased outcrops when they veneer open joint planes. Because of the difficulties in classification, all minor intrusions are subsequently referred to as dykes except when specific examples are described.

The existence of several dyke phases has been determined by using several lines of evidence. One of these is the direct observation of cross-cutting relationships in a single outcrop. Another takes cognizance of the differing contact phenomena, since it is clear that the contacts reflect the physical state of the country rock at the time the dykes were intruded. Absence of marginal chilling, which is common to all the minor intrusions, indicates a hot wall rock but the actual conditions can usually be determined more precisely. The basic dykes are probably the most useful in this respect. On Stonington Island a definite sequence in the mode of emplacement of basic material can be observed. The earliest stage in this progression is seen in the formation of irregular streaks and patches, which represents the permeation of the basic material through the country rock rather than forceful intrusion. A more advanced stage is marked by dyke-like bodies, which are a little more regular and constant than the earlier streaks. Dykes of this kind may either peter out or else continue as a series of numerous pockets and xenoliths, which are generally connected by veins or stringers of the same material. Although the margins of these basic dykes are irregular in detail they are always well defined. Numerous tongues or apophyses penetrate the adjacent gneiss for short distances but more persistent offshoots also occur. The later basic dykes become increasingly regular and constant, and this progression is accompanied by a gradation from welded or physically continuous contacts to ones which are slightly more open.

In several respects the older basic dykes of Stonington Island are similar to the early transverse dykes in the main Donegal granite. Pitcher and Read (1960) have described these early dykes in detail and have attributed their peculiar characteristics to the fact that the dyke material was emplaced before the granite was entirely solid. It is believed that the earlier basic dykes of Stonington Island were emplaced under strictly analogous conditions.

The acid dykes display a similar, but not so marked, sequence. Thus, the earliest acid intrusions are characterized by slight pinching and swelling, variable trend and irregular margins. At the other extreme are dykes which intruded the country rock when the latter was at a sufficiently low temperature as to be virtually rigid. Such dykes are constant both in width and direction, they have steep or vertical contacts and their margins are locally sheared, although, as before, there is little or no chilling. Minor intrusions whose characteristics lie between these two extremes can be distinguished and hence the dyke intrusions are envisaged as having taken place over a long period during which the temperature of the country rock gradually decreased. The sharp changes in direction in many of the dykes on Stonington and Trepassey Islands (both acid and basic) and their displacement over joints are in accordance with this hypothesis, since the dykes would clearly be affected by the differential stresses involved in the final consolidation of the magma.

At this juncture it is necessary to point out that, as far as the acid dykes are concerned, many of the features described above may be taken as evidence of a replacement origin (King, 1948). Other criteria listed by King which indicate a replacement origin for the acid dykes, such as lack of offsetting in intersecting dykes, were observed in some places on Stonington Island but the dykes in question are generally so narrow that the evidence is not critical. The incipient development of a replacement dyke can be seen in Plate IIIa, and it is probable that there are other acid dykes of replacement origin but they are not considered to be of great importance.

Thin-section examination of several acid dykes and sheets shows that there are significant variations in the optical properties of the potash feldspar and these are believed to be partly a function of differing thermal histories. Three of the acid minor intrusions whose general ages could be ascertained from field evidence with reasonable certainty, illustrate these variations. The first is a moderately dipping grey granitic sheet (E.2102.15), which belongs to an early phase of the minor intrusions. In this sheet the potash feldspar consists almost entirely of orthoclase-microperthite with only a few crystals having patches of recognizable microcline twinning. Table IV shows that the orthoclase in this rock has a comparatively low 2V, indicating a partially disordered structure, and the small patches with microcline twinning and a higher 2V presumably represent certain areas in which structural ordering has proceeded to a more advanced stage. In the second sheet (E.2107.1), a greyish pink granite, the potash feldspar has a much more patchy extinction compared with that of the grey granite. The very irregular extinction is caused by numerous microcline patches with tartan twinning. The lower values of 2V in Table IV correspond to the untwinned areas and the higher values refer to the twinned patches. The third example is one of the youngest Basement Complex dykes on Stonington Island; it is a narrow garnet-bearing pink aplite which has a vertical contact with the hornblende-biotite-gneiss. In this dyke (E.2151.13) the potash feldspar comprises both orthoclase and microcline, the latter being considerably in excess of the former. The microcline often forms entire crystals as well as occurring as patches in orthoclase. These observations, together with the values of 2V given in Table IV, show that ordering of the structure has reached an even more advanced stage.

The above sequence, defined by the progressive increase in the degree of structural ordering in the potash feldspar, suggests that the respective dykes have been subjected to different thermal histories. Marfunin (1962, p. 305) stated that "a particular order-disorder state can exist, metastably, in the stability field of a more ordered (but not less ordered) phase", and it is therefore possible that the above variations in structural order may be accounted for by the initial temperatures of the dykes. This interpretation is consistent with the conclusion already stated (p. 26) that the dykes of Stonington and Trepassey Islands were intruded into country rock which was gradually cooling.

The association of orthoclase and microcline with features similar to those just described has been questioned by MacKenzie (1954), who contended that straight extinction in the zone [010] or absence of visible multiple twinning are not in themselves sufficient evidence of orthoclase. Indeed, he maintained that uneven extinction resulting from patches with cross-hatch twinning in untwinned areas is characteristic of microcline and is not an orthoclase—microcline association. However, the considerable variations in 2V shown in Table IV would appear to represent the inversion of a monoclinic to a triclinic phase. In a true orthoclase—microcline association, MacKenzie (1954) has related the inversion of orthoclase to microcline to chemical composition and not to structural ordering. He has stated that microcline is virtually pure $KAlSi_3O_8$ and that inversion to the fully triclinic form does not take place until the sodic phase has been exsolved. Despite this, he believed that this hypothesis is not entirely incompatible with the interpretation of the orthoclase—microcline inversion in terms of structural ordering, so that the conclusions reached concerning the differing thermal histories of the three minor intrusions are not necessarily invalidated. However, the more conspicuous development of microperthite in the dykes and sheets generally compared with the *ortho*gneisses shows that compositional factors are clearly involved and for this reason the conclusions based on the differences in degree of structural ordering in the potash feldspar should be treated with caution. Nevertheless, the three acid intrusions described above display significant differences in texture which tend to support the conclusions based on a study of the potash feldspars. Both the grey and the greyish pink granitic sheets have comparatively strong metamorphic textures with quartz showing intensely sutured margins and mosaic extinction (Plate IVf). In contrast, the pink aplite has a much weaker metamorphic texture and, although the quartz commonly has an undulatory extinction, the margins are free of suturing (Plate Va). Since the quartz lacks marked strain effects, the aplite is almost certainly younger than the two sheets in which the quartz is considerably deformed. This agrees closely with the conclusion based on the mode of intrusion and the nature of the potash feldspars.

B. PETROLOGY

1. *Pegmatites*

The pegmatites of Stonington and Trepassey Islands do not form a distinct group because pegmatite development is common in many pink medium- or fine-grained dykes. In addition, several composite pegmatite-aplite dykes occur on Stonington Island. Most of the pegmatites have a simple mineral composition, consisting essentially of quartz and microcline which are graphically intergrown in places (E.2163.7). Of the other constituents, chlorite (usually in very thin books) is the most widespread, while magnetite and epidote are sparsely distributed. Acid pegmatite occasionally occurs as small masses in basic dykes. In one such occurrence on Mast Hill the quartz and feldspar are graphically intergrown, local concentrations of iron pyrites are conspicuous and abundant large chlorite flakes impart a distinctive appearance to the rock (E.2107.15).

Several pegmatites are of a very early age and, since they contain abundant microcline, they do not fit into the previously described scheme for determining age relationships on the basis of the nature of the potash feldspar. It is possible that some of these pegmatites are of replacement origin.

2. *Aplites*

Aplites, characterized by their fine grain and saccharoidal texture, are relatively uncommon in this area and, like the pegmatites, they are always pink in colour. In several composite pegmatite-aplite dykes small garnets occur sporadically and they are almost invariably confined to the aplitic part of the dyke (E.2151.13, 2152.1). Judging by their occurrence, the garnets which are red-brown in the hand specimen probably approximate either to almandine or spessartine in composition. The origin of the garnet is obscure but its scattered distribution may denote contamination. It is noteworthy that garnet-bearing dykes always belong to the youngest set of Basement Complex dykes on Stonington Island and this fact, together with the extreme scarcity of biotite in these rocks, suggests that the environmental conditions at the time of intrusion favoured the growth of garnet rather than biotite.

In thin section (E.2151.13) the aplite consists essentially of a granular mosaic of quartz, potash feldspar and plagioclase. Acid oligoclase is locally corroded by both quartz and potash feldspar, especially by the latter in which it occasionally occurs as small remnants. Rare myrmekitic intergrowths indicate that replacement of potash feldspar by plagioclase also takes place. Chlorite and iron ore are extremely scarce. The anhedral garnet, which is restricted to a narrow discontinuous layer, is pale brownish pink in colour and is sieved by quartz. The most important textural feature in this dyke is the general absence of strain phenomena in the quartz. Although undulatory extinction is common, the margins are free of suturing. Tiny quartz inclusions are abundant in the potash feldspar and narrow quartz ribbons often occur between adjacent potash feldspar crystals.

3. *Granitic dykes*

This category also includes granodiorite and adamellite dykes. They are medium- to fine-grained and vary from grey to pink in colour. The widespread textural variations in the pink granitic dykes are in sharp contrast to the remarkably uniform grey-coloured dykes. A medium-grained greyish pink adamellite sheet from the west side of Mast Hill (E.2107.1) is typical of the minor granitic intrusions. Plagioclase, some of which is porphyroblastic, is approximately equal in amount to potash feldspar. The larger plagioclases display normal zoning from $Ab_{65}An_{35}$ to $Ab_{80}An_{20}$ and, although the cores are strongly sericitized, the margins generally escape alteration. The plagioclase has been partially replaced by potash feldspar in a few places but the converse reaction is more common and in this latter setting a narrow rim of albite occurs between the two feldspars. Vermicular intergrowths are rare. Orthoclase and microcline are both microperthitic but the unmixed phase has no preferred orientation. Amoebiform quartz, possessing intensely sutured margins and mosaic extinction, is abundant. The only ferromagnesian mineral is chlorite which has probably been derived from biotite since innumerable minute sphene or leucoxene granules accompany it. A little epidote and rare allanite are also associated with the secondary chlorite. Apatite frequently accompanies the irregular patches and aggregates of iron ore which are scattered throughout the rock.

In a grey acid sheet (E.2102.15) from the central part of Stonington Island porphyroblastic plagioclases have large euhedral cores of acid andesine surrounded by irregular rims of oligoclase which frequently enclose quartz blebs. The large porphyroblasts are heavily altered to sericite, epidote, calcite and (?) prehnite, but in the smaller crystals alteration is slight. Xenoblastic potash feldspar has numerous tiny quartz inclusions, while the quartz displays the usual frayed margins and mosaic extinction. Much of the biotite is altered to green penninite, in which skeletal networks of (?) iron ore often occur. Epidote is a common secondary mineral.

Two acid dykes (E.2104.3, 2160.1) were selected for chemical analysis and the relevant data are given in Table II. Analyses 10 and 11 represent the early and late phases of the acid dykes respectively, and the younger pink dyke is almost identical in composition to the granite-gneisses of the Basement Complex which were analysed by Hoskins (1963, p. 24, table V). There is a much better correspondence between the mesonorms and modal analyses of the acid dykes than in the *ortho*gneisses and basic dykes, which emphasizes the complexities introduced in the calculation of the mesonorm by minerals such as biotite and hornblende.

4. *Basic dykes*

Specimen E.2107.6 represents the earlier basic dykes. In the hand specimen it is a dark fine-grained hornfelsed rock studded with numerous small ovoid patches. In thin section hornblende aggregates impart a pseudo-porphyritic texture but the general texture is granoblastic (Plate Vb). The compact aggregates of randomly orientated hornblendes are dusted with iron ore and are probably pseudomorphs after pyroxene. Their distribution is uneven and they tend to occur in clusters. The hornblende has a pleochroism scheme α = light yellow or straw, β = green-brown, γ = rich blue-green and $\gamma{:}c = 25°$. The matrix consists of approximately equal amounts of fresh biotite and hornblende, abundant small plagioclase laths and rare interstitial quartz. The hornblende has the same optics as given above, but a later and slightly paler hornblende with characteristic acicular habit is also present. Relict plagioclase microphenocrysts with intensely altered cores and clear narrow margins are uncommon. The groundmass laths are generally poorly twinned and they are zoned from labradorite to acid andesine or basic oligoclase.

Specimen E.2152.20 is one of the later basic dykes. This is a dark grey fine-grained rock whose warty appearance is the outcome of differential weathering of the feldspar phenocrysts. Acicular hornblende is prominent on weathered surfaces. Abundant tabular plagioclase phenocrysts are poorly twinned and strongly zoned, the basic cores being clouded by iron ore and preferentially altered to scaly mica and epidote. One phenocryst with complex oscillatory zoning has a narrow layer of composition $Ab_{28}An_{72}$ near its margin. The groundmass has a texture between relict subophitic and granoblastic. Sharply zoned plagioclase laths with an average composition of basic andesine have extreme values of $Ab_{25}An_{75}$ and $Ab_{65}An_{35}$ at the core and margin, respectively. The other minerals in the groundmass include relatively plentiful quartz, tiny flakes of fresh biotite and small xenoblastic hornblendes. Very long slender hornblendes of late origin extend across earlier biotite and hornblende. This acicular hornblende is frequently twinned on $\{100\}$ and contains orientated inclusions of iron ore. Accessory titanomagnetite is often accompanied by granular sphene, scarce epidote and allanite.

The two basic dykes just described were chemically analysed (Table II, analyses 8 and 9). The basic dyke from west Stonington Island (analysis 8) is chemically similar to a normal dolerite except for the rather low lime and magnesia and the very high potash. There are considerable differences between the mesonorm and mode of this dyke and contributory factors probably include the sericitization of the plagioclase, the presence of soda and potash in the amphibole and the large amount of titania in the biotite. The comparatively acidic nature of the later basic dyke is well brought out in the chemistry, although the oxidation ratio is much higher and the potash content lower than in the earlier dyke. Mineralogically, the relative acidity of the later dyke is shown by the absence of hornblende aggregates and the higher percentage of quartz.

a. *Textural variations.* A few basic dykes on Stonington Island are extremely xenolithic locally. All the xenoliths have a basic composition but their origin is obscure, since they comprise rock types such as puckered hornblende-schist and amphibolite, which do not occur elsewhere on the island. In the xenolith-rich areas, the basic dyke is clearly hybrid, and a distinctive texture in which medium-sized hornblendes with acicular habit are set in large aggregates of feldspar (E.2107.24) is commonly developed. Another textural variation, apparently unconnected with the xenoliths, is the growth of ovoid quartzose patches which protrude from the surface of the rock as a result of differential weathering (E.2102.18). In thin section the hybrid nature of the basic rock adjacent to the patches is shown by the variable grain-size and texture. The general texture is granoblastic but the abundant plagioclase has retained its original lath-shaped form, producing a subophitic texture in places. Normal and oscillatory zoning in the plagioclase is sharply defined and composition extremes of $Ab_{25}An_{75}$ and $Ab_{67}An_{33}$ are common. Hornblende, which often has an acicular habit, and slightly chloritized biotite are subidioblastic to xenoblastic and occur in approximately equal amounts. The quartzose patches closely resemble the "ocellar structure" of the xenoliths in the Trégastel-Ploumanac'h granite described by Thomas and Smith (1932, p. 282). The first stage in their development (E.2102.18) is the local concentration of small quartz pockets which, although separate, are in optical continuity. These pockets increase in size until they eventually merge. At this stage they contain inclusions of plagioclase, biotite and hornblende, but as the ocelli become more fully developed the inclusions are gradually expelled, producing finally a rounded patch of pure quartz. This final stage, however, is rarely attained. The minerals associated with the ocelli become markedly coarser and several plagioclases enclosed by the quartzose ocelli are tabular, well-twinned and lack zoning, i.e. they are substantially different from the plagioclase present in the remainder of the rock. Thomas and Smith (1932, p. 287–88) regarded ocellar structure as the product of hybridization initiated by invading acid material enriched in silica. The quartzose patches described above clearly originated in a similar way. The incipient growth of very large rounded potash feldspar porphyroblasts ($\simeq$ 6 mm. in diameter) accompanying the quartzose patches provides further evidence of acidification. The porphyroblasts are crowded with biotite, hornblende and plagioclase, and are identical to those occurring in certain types of basification which are described in detail on p. 39–41. Of the accessories, which include apatite, sphene, allanite, epidote and iron ore, allanite is probably the most significant since it occurs in all acidified basic rocks.

b. *Hornblende-schist xenoliths.* In common with other Basement Complex rocks in the Neny Fjord area (Hoskins, 1963, p. 11), several *ortho*gneisses on Stonington and Trepassey Islands contain abundant dark xenoliths. In the hand specimen the xenoliths are variable both in texture and in grain-size, which suggests that they are of diverse origin. However, in thin section the xenoliths display a monotonous similarity in mineralogy, and most of them can be classified as biotite-bearing plagioclase-amphibolites (Harker, 1950, p. 281). The fine-grained inclusions are usually slightly schistose and many are virtually indistinguishable from the basic dykes. These fine-grained xenoliths are those which have been termed hornblende-schists by previous investigators and which are ubiquitous in the Basement Complex rocks. The close petrographic similarity between the hornblende-schist xenoliths and the basic dykes suggests that they have a common parent rock. While several xenoliths, especially those which are heavily concentrated in narrow linear zones, are clearly derived from the disruption of pre-existing basic dykes during metamorphism, it also seems certain that some basic xenoliths were derived from larger masses of basic rock which are not now represented *in situ.* Adie (1954, p. 4) and Hoskins (1963, p. 11, 14) reached the same conclusion.

In the field it is possible to trace a gradation from the fine-grained hornblende-schist xenoliths to medium-grained hornblende-biotite-plagioclase rocks. A similar gradation can be observed in the early basic dykes. The modification in texture and the concomitant increase in grain-size appear to be the result of acidification, notably the addition of silica and alkalis from the host to the xenolith. Impregnation of silica produces large interstitial areas of quartz and, in a few xenoliths, ocellar structure is conspicuous. The ingress of potash has generally been slight and its main effect has been the growth of biotite at the expense of hornblende, but in one xenolith (E.2104.4) some potash feldspar is present. The plagioclase feldspar becomes coarser in grain as acidification proceeds, a fact which was noted when ocellar structure in basic dykes was described (p. 29). The reason for this is obscure but a similar increase in plagioclase grain-size occurs in other settings on Stonington and Trepassey Islands; this topic is more fully discussed on p. 44.

It is highly improbable that all the medium-grained hornblende-biotite-plagioclase xenoliths were formed in the manner just described. For example, many xenoliths in the xenolithic gneiss probably represent earlier Basement Complex members such as amphibolite and banded biotite-gneiss, which were caught up in a later intrusive phase and subsequently acidified. The convergence of xenoliths of different origin towards one general rock type suggests that there was sufficient time for equilibrium to be attained.

5. *Xenolithic basic dykes*

a. *Field descriptions.* Xenolithic basic dykes are composite minor intrusions, in which rounded to sub-rounded metadolerite fragments are held in an acid or intermediate matrix. The ratio of basic to acid components varies considerably not only from one dyke to another but also within a single dyke, and several xenolithic dykes grade into homogeneous dykes of either basic or acid composition. Nearly all the basic inclusions have crenulated margins due to small tongue-like projections of the acid host, but much larger and deeper indentations also occur, leading to the detachment of small fragments from a larger inclusion. In addition, the inclusions may be penetrated by acid veins which are either highly sinuous and irregular with many offshoots (Plate Ic) or linear and comparatively constant in width (Plate IIa). In some cases a complex network of extremely thin acid veins ramifies through the inclusions. These veins have made the immediately adjacent basic rock relatively resistant to weathering, so that they are prominent in the hand specimen because of the fretted appearance which they produce (E.2101.1). Differential weathering of this kind but on a coarser scale is illustrated in Plate IIb. In a few xenolithic basic dykes the basic inclusions are restricted to a narrow zone at the core of the dyke, whereas in others there is a very broad and almost uniformly basic zone flanked by narrow acid margins.

b. *Petrography*. Although detailed petrographic studies were made on several xenolithic dykes, only a summary of the more important features, especially those which indicate the origin of the dykes, is given here. The main points are as follows:

i. The unmodified basic component in the xenolithic basic dykes is identical in mineralogy and texture to the typical basic dykes already described.

ii. Many inclusions have a narrow marginal zone which is distinctly fine-grained compared with the remainder of the inclusion (Plate Vc). Small fragments, some of which may have been detached from the larger ones, are uniformly fine-grained and reproduce the same changes in mineralogy and texture as occur in the fine-grained selvages of nearby large inclusions. The acid matrix never exhibits a similar decrease in grain-size against the basic inclusions.

iii. In addition to the frayed or crenulated edges which many of the basic inclusions possess, there are minor irregularities and embayments occupied by large tabular plagioclases. The biotite present at the margin is pushed aside by the plagioclase, which shows that the xenoliths possessed soft and ductile margins at some stage in their history. A similar conclusion is inferred from the small inclusions which have been drawn out into very irregular shapes by the enclosing acid rock (Plate Vd).

iv. A weak schistosity, defined mainly by the preferred orientation of biotite, can be detected in some inclusions, especially near their margins, and was probably caused by differential movements during crystallization. In one example the schistosity is sufficiently well developed to be observed in the hand specimen, and the acid component is also schistose.

v. Some xenolithic dykes possess an acidic matrix, which is similar to the contiguous country rock except that the grain is finer and the colour index is lower. Specimen E.2107.30 is the best example of this, because several plagioclases in the acid component have many features in common with those in the adjacent grey acid gneiss. These features include large compositional ranges (labradorite to oligoclase), oscillatory zoning, a little exsolved iron ore and potash feldspar, and the presence of small amphibole crystals in a few basic cores.

vi. Acidification of the basic inclusions always occurs but it varies considerably in intensity and takes several different forms depending on the composition of the acid matrix. Impregnation with quartz normally represents the initial stage in all forms of acidification and quartzose ocelli occur locally. In some instances the fine-grained margin largely escaped quartz impregnation but it was gradually detached from the inclusion by the growth of a coarse-grained quartz-plagioclase vein between it and the remainder of the inclusion. After it became completely detached the margin disintegrated and the remnants were strewn about in the acid matrix. In general, the main result of acidification was the conversion of hornblende to biotite and a progressive decrease in the former can often be traced as the margin of the inclusion is approached. This replacement was caused by the ingress of potash into the inclusion. Where there was an abundant supply of potash, all the hornblende was made over to biotite and any excess went into potash feldspar. One inclusion which has suffered extreme potash metasomatism is an anomalous rock containing approximately 50 per cent potash feldspar and 35 per cent biotite, plagioclase and quartz making up the remainder (E.2105.8). The potash feldspar is mostly orthoclase with a moderate 2V (Table IV) but microcline patches are prominent in some crystals. The potash metasomatism has resulted in a notable increase in grain-size compared with the adjacent inclusion which has undergone less acidification. Where vigorous interaction between the basic and acid components has occurred, the resulting hybrid rock is fairly similar to comparable rocks which were formed during the basification of acid dykes (p. 39–40). The plagioclase is clearly of mixed origin and this may explain the reaction which has commonly taken place at several inter-plagioclase boundaries. This is shown by lobes of one crystal penetrating into an adjacent crystal, resulting in a complex interlocking texture.

vii. One mineral invariably present in xenolithic basic dykes is allanite. Its mode of occurrence shows conclusively that it is closely connected with reactions between the acid and basic materials. For example, in specimen E.2102.19 there are numerous small crystals just at the interface between the basic and acid rocks and several others occur in the vicinity. Where extensive hybridization has taken place, the allanite may form large crystals (E.2155.2) or may be exceptionally well zoned (Plate Ve). Iron pyrites is sometimes found in a similar setting to allanite, which indicates the presence and movement of fluxes during hybridization.

c. *Discussion.* The main problem concerning the origin of the xenolithic basic dykes is to determine the relative ages of the basic and acid components. This, in turn, depends on the interpretation of the fine-grained margins. If they are recrystallized margins following reaction caused by a chemical gradient (Bishop, 1963, p. 294), the dykes are probably breccia dykes as suggested by Grimley (1961, p. 3). He believed that basic dykes were intruded along lines of maximum tension and that subsequent relaxation of the confining pressure caused fracturing of the dyke. A later acid dyke was then intruded along the same line thereby cementing the fragments. Nichols (1955, p. 6) favoured a similar origin. If, as is possible, some of the xenolithic basic dykes are breccia dykes, then the basic material must have been at a temperature which was comparable with the crystallization temperature of the acid magma, since the latter is never chilled against the inclusions. The tabular plagioclases which cause embayments in the inclusions confirm this since the margins of the inclusions were clearly soft and were therefore at a high temperature.

Composite dykes which are very similar to those found on Stonington Island have been recorded from parts of the Brito-Arctic Tertiary volcanic province (e.g. Cockburn, 1935, fig. 4, opp. p. 547). Wager and Bailey (1953, p. 68) believed that at least in some instances these dykes resulted from the injection of basic magma into acid magma. They postulated chilling of basic magma against cooler, but still liquid, acid magma, because the crystallization temperature of the latter is considerably lower than that of the former. This hypothesis is fully supported by observations on the composite rhyolite-basalt lavas of eastern Iceland (Gibson and Walker, 1963). The xenolithic basic dykes of Stonington and Trepassey Islands have several features in common with the composite intrusions from Iceland, which indicate that they originated in a similar way. Consequently, most, if not all, of the xenolithic dykes are interpreted as resulting either from the simultaneous injection of basic and acid magma, or from the injection of basic magma into a predominantly liquid acid dyke. In some instances, however, the basic magma was intruded into a pre-existing acid dyke which was largely crystalline. Plate IIc shows that in one dyke of this kind the acid margin has been extensively mobilized at the contact with subsequent injection of the mobilized material into the basic core. The detached xenoliths of the latter have identical features to those occurring in true xenolithic basic dykes.

This origin for the xenolithic dykes explains the commonly observed restriction of basic xenoliths to the centres of dykes and also accounts for the occasional absence of fine-grained margins, since fracturing of the solid basic inclusions and subsequent penetration of still liquid acid material along the cracks would not produce chilling (Wager and Bailey, 1953). The extensive hybridization, which occurs in several xenolithic basic dykes, is also more readily explained on the above hypothesis, because the petrographic features of the hybrid dykes are similar to those produced during the basification of acid dykes in which the basic material definitely post-dates the acid material.

At least one author (Chapman, 1962, p. 556) has rejected the "commingling theory" of Wager and Bailey. Chapman believed that composite dykes of this type resulted from the metasomatic replacement of dolerite by "granitic material". The field relationships of many Stonington Island xenolithic basic dykes definitely preclude replacement of this kind. A few dykes in which the ratio of basic to acid material is very high (Plate IId) may have originated by replacement, but it is very unlikely.

Petrographic evidence cited earlier shows that the acidic component in several xenolithic dykes is derived from the adjacent *ortho*gneiss. These dykes must have originated by the extensive fusion of the country rock as the basic material ascended from depth, with the subsequent simultaneous injection of the two magmas. Wegmann (1938, p. 91, 92) recorded similar dykes from Greenland, and he postulated the intrusion of basic magma into heated country rock. The fusion of pre-existing rock by hot dolerite to give a close association of granite and dolerite has been found in other areas (e.g. Krokström, 1937).

VI. METAMORPHISM

1. *Metamorphic history of the orthogneisses*

The *ortho*gneisses of Stonington and Trepassey Islands possess several textural features which show that they have been metamorphosed. The most convincing evidence includes the conspicuous bending of the plagioclase twin lamellae, the strongly deformed quartz crystals, potash metasomatism and the general though weak crystalloblastic fabric of the rocks. Unfortunately, the mineral content of the *ortho*gneisses is not reliable for determining the temperature and pressure conditions which characterized the metamorphism. Hoskins (1963, p. 43, 44) found that work on the amphiboles present in many Basement Complex rocks was inconclusive. Nevertheless, he established that there were three Basement Complex metamorphisms of which the second was the most important. From the meagre data, he deduced that the grade of this second metamorphism reached the lower part of the almandine-amphibolite facies.

On p. 25 it was concluded that the *ortho*gneisses had been subjected to high temperatures for a long period and that the subsequent cooling was very slow. The distorted plagioclase twin lamellae and strained quartz crystals clearly show that shearing stress was prominent during part of the metamorphism. Concerning the metamorphic history of the *ortho*gneisses, two major alternatives must be considered:

i. Fully crystalline plutonic rocks which were then regionally metamorphosed.
ii. Igneous rocks intruded during a period of regional metamorphism.

The first possibility is considered to be improbable, because the rock textures (particularly the tendency towards ferromagnesian clots), the lack of strong foliation and the relict igneous features such as plagioclase zoning, are incompatible with the rocks having been involved in a complete metamorphic cycle. The coarse grain of the *ortho*gneisses would undoubtedly render them effectively resistant to metamorphism for a time, but not to the extent implied by the relict textures. Consequently, it is assumed that the *ortho*gneisses were intruded during regional metamorphism and that their observed textures resulted from that part of the metamorphism which post-dated their intrusion. However, it is uncertain when the *ortho*gneisses were intruded relative to the maximum phase of metamorphism. Harker (1950, p. 300) has shown that, if shearing stress acts upon an igneous rock which has not fully crystallized, enforced flow will lead to parallelism of crystals of tabular or columnar habit. Such preferred orientation is not widely developed in the *ortho*gneisses which means that shearing stress did not become effective until the rock was almost solid. The quartz was at least partially mobile when shearing stress was operative, since it provides abundant evidence of crystallization under strain. But it is clear that the stress conditions did not persist long after complete crystallization, because crystal fracturing and granulation, although common, are never intense. On the whole, the facts indicate that the *ortho*gneisses were intruded at or soon after the peak of metamorphism, when high temperatures were dominant, and that as the temperature declined non-directional pressure was replaced by shearing stress. This stress was relatively weak and did not persist into the lowest grade.

As Harker (1950, p. 349) has pointed out, it is possible that the advent of shearing stress during decreasing temperature (as postulated above) will produce effects that are indistinguishable from those caused by a later dynamic metamorphism which is not related to a preceding regional metamorphism. In this case, it might have been dynamic metamorphism superimposed on normal igneous intrusion. However, in the absence of any positive evidence, it is unnecessary to invoke another period of dynamic or low-grade regional metamorphism.

During the initial stages of this slow cooling, localized potash metasomatism occurred. Although slight introduction of potash is evident in all the *ortho*gneisses, its main effect is seen in the injection gneiss and the foliated acid rock.

2. *Metamorphism of the basic dykes*

The basic dykes, like the *ortho*gneisses, normally possess relict igneous textures and their metamorphic trend corresponds to that described by Sutton and Watson (1951). In this trend the original texture is preserved during the initial stages of metamorphism and pyroxene is converted to a dark bluish green hornblende. As metamorphism progressively increases, more drastic changes take place until, in the lower part of the almandine-amphibolite facies, the original texture is destroyed and the plagioclase is completely recrystallized. In the basic dykes neither obliteration of the pre-existing texture nor the total recrystallization of the plagioclase has been fully achieved, so that the metamorphic grade has apparently not reached the almandine-amphibolite facies. However, this evidence is inconclusive since dolerites still possessing their original composition and texture have been found in some highly metamorphic terrains (Poldervaart, 1953, p. 262).

The above metamorphic trend, which by-passes the conversion of basic plagioclase to albite and epidote, is believed to have resulted in this particular case from the injection of basic dykes into country rock already undergoing metamorphism. The weakly developed granoblastic textures could be explained on a similar basis, because a hornfelsic texture indicates nothing but recrystallization (Grout, 1937, p. 1548). If the basic dykes only participated in a progressively decreasing metamorphism, total recrystallization would not occur. The later basic dykes have somewhat better preserved relict igneous textures than others (compare E.2107.6 with E.2151.20). This may be attributable to different metamorphisms, to the variable response of the dykes to the same metamorphism, or it could be explained in terms of the repeated intrusion of basic dykes into country rock which was suffering a gradual but progressive decline in metamorphism. This latter hypothesis is in closest accord with previous deductions concerning the differing modes of emplacement of both the basic and acid dykes (p. 26).

3. *Summary*

It is probable that only one major period of regional metamorphism is represented by the Stonington and Trepassey Islands rocks. There is no evidence for the advancing stages of this metamorphism and the maximum grade is not known with certainty. The main reason for this is the absence of any critical mineral assemblage which defines the temperature and pressure conditions. However, a detailed study of the feldspars and the minor intrusions implies that the metamorphism culminated in high temperatures but with a deficiency of shearing stress. These conditions indicate that the metamorphism reached the lower or middle part of the amphibolite facies in the andalusite-sillimanite type (Miyashiro, 1961, p. 280, fig. 2; p. 285, figs. 4, 5). A series of *ortho*gneisses was intruded during the metamorphism and was then subjected to the slow cooling conditions which characterized its decline. Throughout this period minor intrusions were injected into the *ortho*gneisses and their present metamorphic textures are a function of the length of time in which they were involved in the waning phase.

From the preceding account it is clear that the *ortho*gneisses have been subjected to a rather unusual type of metamorphism. This raises doubts as to their age, since other members of the Basement Complex usually have a well-defined foliation or schistosity which suggests a much more typical metamorphism. The general absence of such features in the *ortho*gneisses of Stonington and Trepassey Islands, together with the weakly developed metamorphic textures, suggests that these rocks may in fact belong to a later geological event. They may, for example, belong to the early Palaeozoic plutonic rocks whose known representatives in the Marguerite Bay area are the "White Granite" and the "Coarse Pink Granite" (Adie, 1954, p. 16). However, if the suggested correlation of these gneisses with the dioritic gneisses described by Hoskins (1963) is correct, these rocks must be regarded as belonging to the Basement Complex. The paucity of strong metamorphic structures can only be accounted for by assuming that the *ortho*gneisses were formed under conditions which were not typical of the Basement Complex metamorphism as a whole.

VII. RHEOMORPHISM AND BASIFICATION OF ACID DYKES

A. RHEOMORPHISM

Rheomorphism was originally defined as the partial or complete liquefaction of a pre-existing rock during migmatization-granitization (Backlund, 1937). Later definitions (Schieferdecker, 1959) also imply that rheomorphism is accomplished by ionic diffusion. Here, rheomorphism is defined as "the liquefaction of pre-existing rocks", so that they become capable of flow.

An excellent example of rheomorphism on a small scale is illustrated in specimen E.2105.10, which shows the contact of a basic dyke with xenolithic gneiss. The gneiss immediately adjacent to the dyke has been partially fused, and the rheomorphic material thus formed injects the basic dyke to give the latter a highly crenulated margin. A very thin but regular band of dark and relatively fine-grained rock coincides with the original contact between dyke and wall rock.

The sequence of changes across the rheomorphic zone is readily seen in thin section. The basic dyke is similar to the one described on p. 28–29, except that all the original biotite has been converted to chlorite and minute (?) sphene granules. Plagioclase laths with a composition of $Ab_{60}An_{40}$ are turbid, poorly twinned and occasionally zoned, while the iron ore includes both titanomagnetite and pyrite. The hornblende is completely fresh, except where it is traversed by epidote-rich veins. This particular thin section shows that the basic dyke is liberally sprinkled with epidote but it is obvious from the hand specimen that the epidote is restricted in its occurrence and occurs mainly in veins which have apparently been responsible for the chloritization of the biotite. As the contact between the basic dyke and the rheomorphic zone is approached, the hornblende tends to disappear and a definite though slight decrease in grain-size is apparent. This is possibly a pseudo-chilled margin caused by partial recrystallization of the basic dyke against the mobilized material. Conversely, it may be a true chilled margin originating in the same way as the fine-grained margins of basic inclusions in the xenolithic basic dykes. In places, the fine-grained margin is impregnated with quartz as a result of active corrosion by the latter, and the restricted occurrence of a little biotite in this setting is of interest because it shows that the biotite has escaped chloritization by inclusion into the quartz. Occasionally, the quartz-impregnated margin is separated from the remainder of the basic dyke by a narrow vein consisting of quartz and relatively large, heavily altered feldspars. The quartz in this vein is relatively free of inclusions and the plagioclase has clearly originated from the rheomorphic zone.

The rheomorphic zone is essentially a coarse intergrowth of quartz and plagioclase with relatively small amounts of chloritized biotite, epidote and iron ore. Where the plagioclase is unaffected by late veins, it has a composition of $Ab_{70}An_{30}$ and, although it is fresh and unaltered, it is moderately corroded by the quartz. It is evident that the quartz has been extensively mobilized since it forms large, irregularly shaped, optically continuous areas, many of which enclose small plagioclase remnants. Its extinction ranges from uniform to undulatory. Swarms of tiny apatite needles are concentrated near iron ore and the ferromagnesian minerals, and a little allanite is also present. Numerous anastomosing veins composed of epidote and turbid (?) potash feldspar are prominent in the rheomorphic zone and continue into the basic dyke. The plagioclase near these veins is intensely altered to scaly mica, epidote, prehnite and unidentifiable dust, and its low refractive indices indicate that it has also been albitized, but this is uncertain. The epidote and (?) potash feldspar have extensively replaced quartz both marginally and along a complex network of cracks.

The narrow dark band which defines the outer edge of the rheomorphic zone has an unusual composition characterized by a concentration of several lime-bearing minerals. Very turbid, limonite-stained plagioclase and quartz are the main mineral phases, although the distribution of the latter is erratic. Small crystals of brown allanite with fuzzy margins and indistinct pleochroism are abundant, especially as inclusions in the plagioclase. Dense swarms of extremely tiny apatite needles are common in the quartz and plagioclase, whereas larger apatites are occasionally intergrown with sphene. The presence of plentiful, finely divided magnetite suggests that iron has also been concentrated in this narrow zone. Pale green chlorite, sometimes intergrown with sphene, and epidote are prominent locally.

That part of the xenolithic gneiss present in the thin section consists of acid andesine, potash feldspar, quartz, chloritized biotite and accessories.

Several important facts emerge from this and similar examples of rheomorphism (e.g. E.2151.6). The complete absence of glass in the partially fused zone precludes rapid chilling after rheomorphism had occurred. This can only be explained satisfactorily by assuming that the country rock was already at an elevated temperature when the basic dyke was intruded. There is no evidence to suggest that the xenolithic gneiss suffered anything more than intergranular fusion. The original quartz has been extensively mobilized but the plagioclase has only been partially resorbed. It has, however, undergone a significant reduction in size compared with that in the unaltered gneiss.

In the example described above, a high content of water is demonstrated by the abundance of minerals such as hornblende, chlorite and epidote. This water, operating in conjunction with moderately high temperatures would greatly facilitate rheomorphism.

The late-stage veins indicate that the main chemical reaction during rheomorphism involved re-distribution of lime and potash. The thin dark band at the edge of the mobilized zone marks a line of chemical activity in which lime, iron and volatiles are concentrated. The preferential absorption of volatiles in the dark band is indicated by the occurrence of abundant apatite as very small needles (Nockolds, 1933, p. 563–65). The presence of allanite is especially interesting, because it occurs in all the examples of rheomorphism studied, and it demonstrates the fixing of rare ions in a particular mineral phase.

Rheomorphism is the exception rather than the rule where basic dykes intrude the *ortho*gneisses of Stonington Island. The reasons for this are uncertain but rheomorphism undoubtedly depended on several factors, including the composition and temperature of the wall rock at the time of intrusion, and the temperature and volatile content of the basic dyke. Of these factors, the latter is believed to be the most important, since a high volatile content would provide a medium of low viscosity through which diffusion would readily take place (Walker and Poldervaart, 1949, p. 678). Apparently, potash feldspar is not a vital factor in promoting rheomorphism and this is rather unexpected. Although the xenolithic gneiss contains a moderate amount of potash feldspar which was certainly involved in the subsequent mobilization, no potash feldspar is present in the hornblende-biotite-gneiss, and yet rheomorphism of this gneiss has also occurred in places (E.2151.6).

Rheomorphism was observed in other settings on Stonington Island, particularly where a basic dyke cuts an acid dyke. One instance of this is illustrated in Plate IIc. Another very good example occurs approximately 40 yd. (37 m.) north of the new hut where a narrow basic dyke cuts a 14 ft. (4·3 m.) wide greyish pink microgranite dyke. No rheomorphism or reaction of any kind is visible where the basic dyke intrudes the biotite-gneiss but where it crosses the acid dyke its margins have become very frayed. Small tongues of acid material extend into the basic dyke, while a zone of basic xenoliths occurs close to the margin (Fig. 8). The line of xenoliths does not follow the inferred continuation of the margins of the basic dyke, which means that the xenoliths detached from the dyke were carried into the acid dyke for a short distance. This slight migration of basic material along the acid dyke may provide an important link between simple rheomorphism and the more complex processes involved in the basification of acid dykes. The acid dyke has been conspicuously hybridized during the rheomorphism. Many of the basic xenoliths are embedded in a dense greyish green rock which has undoubtedly arisen from the interaction of basic and acid material, while several basic inclusions have been reduced to mere basic clots. In thin section (E.2106.4) these basic clots have been recrystallized into a fine-grained granoblastic fabric of quartz, plagioclase and tiny biotite flakes. The greenish grey hybrid has been derived from the original acid dyke by partial recrystallization of the quartz into small rounded grains and by addition of biotite flakes strewn from the relict basic clots. The biotite is extensively altered to chlorite. A little allanite and sphene are present.

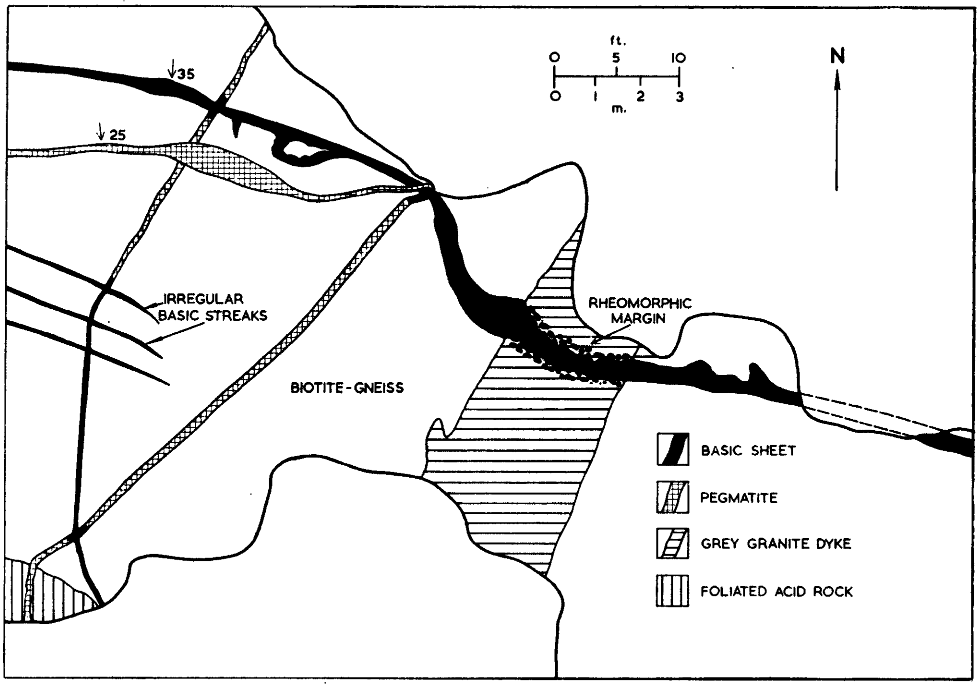

FIGURE 8

Field sketch of a small area in central Stonington Island, showing rheomorphism and the basification of acid dykes.

B. Basification of Acid Dykes

The basification of acid dykes is an interesting feature on Stonington and Trepassey Islands and it demonstrates how basic and acid material may interact under certain conditions. Basification occurs where a basic dyke intersects an earlier acid dyke or vein and, as the term implies, the altered acid dyke is made more basic in composition. An interesting fact concerning basification is that the length of the basified zone is usually inversely proportional to the width of the acid dyke, and is apparently independent of the width of the basic dyke. This is clearly illustrated in Figs. 8 and 9, the former showing a 2 in. (5 cm.) acid vein with a basified section at least 25 ft. (7·6 m.) long, and a 14 ft. (4·3 m.) wide dyke which has a very limited basified zone.

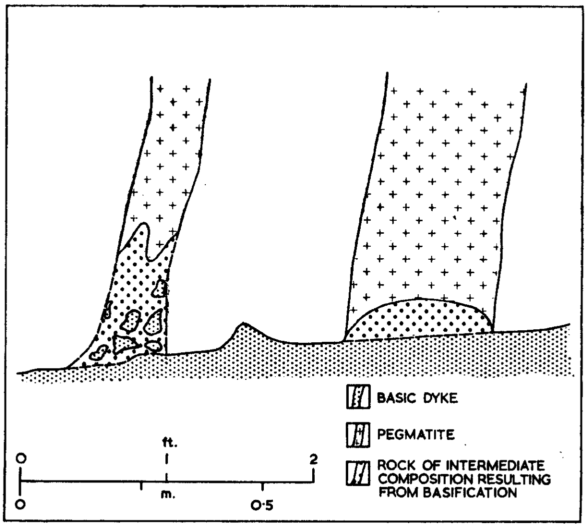

FIGURE 9

Field sketch showing the basification of pegmatites at the south-western corner of Stonington Island.

1. *Field descriptions*

A three-fold classification of basification was made on the basis of field observations, but transitions from one type to another are common. Only the third type is described in detail, because it was impossible to obtain good specimens from occurrences of the other two types of basification. The three types are:

i. The first kind of basification can be described as simple, because the basified zone superficially resembles the basic dyke which caused the alteration (Plate IIIa, b). The contact between the altered and unaltered parts of the acid dyke is normally sharp and distinct. Gradations between this and the second type of basification are common.

ii. In the second type of basification the acid dyke is altered so that its colour index and external appearance are very similar to that of the contiguous country rock, i.e. a uniform rock of intermediate composition is formed. As a result the acid dyke becomes less well defined and in some cases, particularly when it is coarse-grained, the dyke almost loses its identity. Two adjacent pegmatites are altered in this way when cut by a basic dyke (Fig. 9), although small basic inclusions occur in the basified zone in one of the dykes. This provides a link with the third kind of basification.

iii. In this case the basified section consists of altered basic xenoliths derived from the basic dyke which are set in a hybridized matrix of acid to intermediate composition. This type of basification is by far the commonest, and the best example occurs on the north-east corner of Trepassey Island, where a 9 in. (23 cm.) north–south trending aplite dyke is cut by an east–west basic dyke 2 ft. (0·6 m.) wide. In this particular example the intersection was obscured by snow but since basification in other parts of Stonington and Trepassey Islands is known to occur only where the basic dyke post-dates (or is approximately the same age as) the acid dyke, it is assumed that a similar relationship occurs here. The aplite is basified over a total length of 12 ft. (3·7 m.) and considerable interaction between the basic and acid components is apparent, being greatest near the basic dyke. Another example of this type of basification occurs on the north-western extremity of the large outcrop east and north of Anemometer Hill on Stonington Island where a north-east to south-west trending pink granitic dyke is basified by an intersecting basic dyke. The altered zone is 4 ft. (1·2 m.) long and is similar to the one on Trepassey Island just described, except that reactions between the basic and acid components have not been so violent. However, between the xenolithic zone and the basic dyke, there is a small basic zone similar to the one shown in Plate IIIa, extending into the granitic dyke from the basic dyke. This again illustrates the gradation of one type of basification into another. A similar kind of basification is inferred from Grimley's (1961, p. 3) description of the xenolithic basic dykes on Mast Hill. He has stated that "The margins of the [basic] fragments are often blurred and along one of the dykes there is a gradual transition along the strike from a leucocratic phase almost devoid of inclusions, hrough a xenolithic phase, to a mesocratic basic rock."

2. *Petrography*

Basification which is transitional between types (i) and (ii) is illustrated in specimen E.2102.14 and the relatively sharp contact between the unaltered acid dyke and the basified zone is clearly shown in the hand specimen. Under the microscope the acid dyke is essentially a quartz-oligoclase rock containing subordinate potash feldspar, a small amount of heavily chloritized biotite and lime-bearing accessories. In thin section the basified acid zone has all the characteristics of an acidified basic rock. Plagioclase is zoned from labradorite to oligoclase and therefore originated in the basic rock, although its grain-size is larger than in the unaltered basic dyke. Biotite is the only ferromagnesian mineral so that all the original hornblende in the basic rock has been replaced. The basified zone has a high content of quartz, much of it occupying large interstitial areas which are generally optically homogeneous apart from mosaic extinction. The quartz corrodes all the other minerals. The junction between the basified zone and the unaltered acid dyke is marked by increased alteration of biotite to chlorite and the presence of rare allanite crystals.

Numerous occurrences of the third type of basification were encountered and, although they have similar field characteristics, their petrographic features differ in several respects. In the Stonington Island example the basic dyke causing basification is fine- to medium-grained and is typical of the basic dykes which occur on the island. Compared with the basic dyke described on p. 28–29 it is a little coarser in grain and it is also slightly less basic, this being shown by the paucity of hornblende aggregates. The acid dyke is a medium-grained pink rock consisting of quartz, oligoclase, potash feldspar and minor amounts of biotite and chlorite. Plagioclase is more abundant than the potash feldspar.

In the basified section the basic inclusions tend to decrease in size away from the basic dyke. One inclusion which is relatively near to the basic dyke is a dark grey medium-grained rock containing conspicuous amounts of biotite in the hand specimen (E.2102.7b). The grain is decidedly coarser than in the original basic material. Plagioclase occurs as medium-sized laths or columnar crystals and as several comparatively large tabular crystals. Zoning consists of a moderately sericitized basic labradorite core enclosed by a narrow pellucid margin of acid andesine, although oscillatory zoning also occurs. This is produced by one or more narrow calcic layers just outside the basic core. Several basic cores possess a mottled extinction but the margin of the original core is partially preserved in most cases. Twinning, which is commonly of the combined Carlsbad-albite type, is widespread and tends to eliminate the zoning. Of the ferromagnesian minerals, biotite is considerably in excess of hornblende and appears to have formed at its expense. In addition, hornblende decreases markedly towards the margin of the basic inclusion, its place being taken by biotite. The inclusion has been partially impregnated with quartz which forms discrete patches throughout the rock.

A greater degree of acidification is apparent in a smaller basic inclusion (E.2102.8b) which is farther away from the basic dyke. At or near the margin of the inclusion, several small basic plagioclase laths from the parent basic rock are enclosed in a very clear and broad rim of oligoclase (Plate Vf). Plagioclases of this kind are generally surrounded by quartz. Away from the margin these oligoclase borders decrease a little in width and become less sharply defined. In the inclusion as a whole the plagioclase dimensions vary considerably, only a few being approximately equal in size to those in the original basic dyke. Large tabular crystals are rare, but they are noteworthy in that they contain tiny inclusions of biotite and amphibole. Amphibole is otherwise completely absent. The main effects of acidification are seen in the occurrence of large areas of quartz containing small corroded plagioclases, and the growth of relatively large plates of biotite (Plate VIa). Some of this biotite is poikiloblastic and it is only slightly altered to chlorite. Smaller biotite flakes are often squeezed between individual quartz grains in large composite quartz pockets.

The extent to which the acidic matrix is hybridized varies and in general it decreases away from the basic dyke. Where the acid component is severely hybridized, it becomes very similar to a highly acidified basic inclusion, and in specimen E.2102.7a there is an almost complete gradation from one to the other. In the thin section the hybridized acid matrix consists of plagioclase, biotite and quartz. The plagioclase ranges from porphyroblasts to small sub-rounded crystals but most of it occurs as columnar crystals of moderate dimensions. Several plagioclases are zoned from $Ab_{50}An_{50}$ to $Ab_{67}An_{33}$ and the unzoned crystals have the latter composition. Quartz and potash feldspar replace the large plagioclases internally. Biotite is prominent but it is variable both in distribution and size; small patches which have a high concentration of biotite represent ghost basic xenoliths. Quartz corrodes all the other minerals and generally occurs in large replacement pockets. Accessories are iron ore, zircon, apatite and scarce allanite.

Where hybridization has been less severe, biotite becomes scarcer and much of it is confined to small aggregates associated with sharply zoned plagioclase laths and iron ore (E.2102.8b). These are relict inclusions and their advanced stage of assimilation is shown by the complete merging of textures between them and the acid host. Allanite is probably the most conspicuous and significant of the accessories which occur in the hybrid rock. Occasionally it is slightly zoned and rimmed with epidote.

Specimen E.2102.8a, which was taken from near the limit of the basified zone, has a slightly less altered acid matrix. Plagioclase ranges from moderately large porphyroblasts with mottled extinction and complex oscillatory zoning to small grains and has a maximum composition of $Ab_{65}An_{35}$. Potash feldspar is irregularly distributed; it is mainly, although not entirely, a replacement mineral. Several plagioclase porphyroblasts have been extensively replaced by it so that only a few corroded remnants remain. Myrmekitic intergrowths between plagioclase and potash feldspar are common. Quartz also replaces plagioclase, occasionally to such an extent that the two minerals are graphically intergrown. Elsewhere the quartz has recrystallized under intense strain. Small fragments with extremely frayed margins are in identical optical orientation and are cemented by recrystallized quartz which also behaves optically as one unit. A large aggregate of xenoblastic iron ore, containing numerous plagioclase laths and often intergrown with biotite, is one of several concentrations which occur in the hybridized acid rock. The iron ore concentrations are either of magnetite or iron pyrites. Several tiny, almost completely assimilated, clots of basic rock are represented by fine-grained clusters of biotite, zoned plagioclase and iron ore. A few small biotites are irregularly strewn throughout the rock and larger, extensively chloritized biotites also occur.

In the Trepassey Island example of basification the basic dyke (E.2163.2) has a weak granoblastic to subophitic texture (Plate VIb) and the plagioclase microphenocrysts and laths have retained their original habit. Maximum zoning yields a composition range from acid labradorite to basic oligoclase. Subidioblastic to xenoblastic hornblende is fresh and unaltered, although the acicular hornblendes frequently enclose small chlorite flakes and turbid plagioclase laths. Biotite has been completely altered to chlorite.

The acid dyke is a medium-grained aplite with a saccharoidal texture (Plate VIc). More than half the rock is composed of microcline-microperthite which is less turbid than the oligoclase. Quartz contains corroded inclusions of plagioclase and potash feldspar, while the small amount of biotite has been almost completely converted to chlorite. Both the plagioclase and the microcline are rimmed with pure, though turbid, albite. The rims are not homogeneous and they sometimes consist of connected blebs. There are occasional concentrations in intergranular pockets but the albite never forms homogeneous crystals. Myrmekitic intergrowths occur where plagioclase and microcline are in juxtaposition with no intervening albite.

The highest degree of hybridization that has taken place in the basified zone is represented in specimen E.2163.3, which contains several large pale pink feldspar porphyroblasts in a dark varied groundmass. The rock slice reveals an extremely variable texture and the grain is often very much coarser than that of the two contributing rocks (Plate VId). Plagioclase displays a particularly wide range; on the one hand there are small laths mostly untwinned and heavily altered, and on the other there are large oligoclase porphyroblasts exceeding 5 mm. in length. These porphyroblasts are extensively but not severely sericitized, they are locally altered to epidote and prehnite and contain inclusions of amphibole, biotite, chlorite, iron ore, sphene and a little allanite, i.e. many of the constituent minerals of the basic dyke. In addition, they possess replacement patches of microcline and quartz, especially the former. Tabular, subidioblastic to idioblastic plagioclases with good albite twinning and having a composition of $Ab_{64}An_{36}$ are common and are approximately equal in amount to xenoblastic, poorly twinned plagioclases. Alteration to sericite, epidote and prehnite varies considerably, so that while some plagioclases are extremely turbid, others are almost clear. A few are extensively replaced by potash feldspar. Where quartz and potash feldspar both replace a single plagioclase, they have a strong tendency to occur in separate areas of the crystal. Potash feldspar actively replaces other minerals as well as plagioclase. The main centres of attack are small patches of basic rock which have generally preserved their original mineral composition, texture and grain-size. The potash feldspar occupies the full area of the basic patches (up to 6 mm. across), so that it occurs as spongy crystals similar to cordierite porphyroblasts in pelitic hornfelses (Plate VIe). Microcline twinning has often been induced at the margins of the inclusions and there are abundant tiny apatite needles. It is noteworthy that several basic patches escape this form of replacement and are almost devoid of potash feldspar. Some of the quartz also forms large patches full of corroded inclusions and apatite needles. Chlorite and hornblende are unevenly distributed and, unlike the plagioclase, they have not increased significantly in size. Incipient alteration of hornblende to chlorite is apparent along the cleavages but rather more drastic alteration has occurred locally. A late-stage vein of finely granulated quartz, plagioclase, sphene, calcite, iron ore and much epidote (sometimes rimmed by allanite) cuts the hybrid rock. In the hybrid rock the origin of the large oligoclase porphyroblasts is indicated by the partial replacement of small basic patches by potash feldspar. It is probable that, if more potash had been available, further reaction would have taken place and the inclusions would have been ultimately expelled to give a relatively pure potash feldspar porphyroblast. The oligoclase porphyroblasts probably developed by a similar process, and this is supported by the nature of the inclusions in them.

In the basified zone the original acid and basic components become more distinct with increased distance from the basic dyke. Near the limit of the altered section the basic xenoliths are usually fine-grained and the acidic matrix has relatively few dark minerals. Almost all the original hornblende in the basic xenoliths has been converted to chlorite which is now very plentiful (E.2163.4). However, clearly defined pseudomorphs after amphibole are rare. The xenoliths have been strongly corroded by quartz and potash feldspar, so that several have an almost continuous background of the two minerals, especially the former. Both the quartz and the potash feldspar contain many apatite needles. Near the margin of the inclusions acidification increases and there are small biotites which have apparently been preserved from chloritization by being enclosed in quartz.

Although the acid matrix is rather similar in appearance to the unaltered acid dyke in the hand specimen, the thin section reveals important differences. Potash feldspar is completely absent, while plagioclase may form tabular or columnar crystals, a few of which are zoned from $Ab_{38}An_{62}$ to $Ab_{68}An_{32}$. Quartz corrodes the plagioclase marginally. Chlorite contains lenses of epidote, prehnite and rare calcite. Epidote is much more abundant than in the unaltered acid dyke and, although it is mainly associated with chlorite and rims iron pyrites, it is also scattered throughout the entire thin section.

Another example of the third type of basification occurs on the west side of the fault gully north of Anemometer Hill where a grey acid dyke is cut by a broad basic dyke. A specimen taken from the basified zone (E.2102.20) shows an extremely heterogeneous rock with fine- to medium-grained basic inclusions set in a hybrid matrix of intermediate composition. The basic inclusions display considerable variation in size and shape, the smaller ones being distinctly elongated. Several have been reduced to mere clots which merge with and become almost indistinguishable from the hybrid matrix. A few of the smaller xenoliths are of amphibolite and hornblende-schist which are similar to those described on p. 8. Concentrations of iron ore, notably pyrite, are locally conspicuous and may be accompanied by much epidote, in which case the adjacent feldspar is strongly altered. One of the larger basic inclusions contains a very large sieved (?) potash feldspar porphyroblast in an incipient stage of development. The thin section shows great textural and mineralogical variation but only a summary of the main features is given here. Several small basic inclusions are present in the section; one is a slightly schistose medium-grained amphibolite consisting of approximately 80 per cent hornblende and 15 per cent andesine with subsidiary amounts of heavily chloritized and epidotized biotite, epidote, iron ore and a little interstitial quartz. The other basic inclusions are very altered and comprise hornblende, extremely turbid plagioclase, chlorite, epidote, iron ore and quartz in varying proportions. The chlorite is secondary after biotite and it is invariably accompanied by or intergrown with much epidote, granules of leucoxene or sphene, prehnite and possibly some calcite. Hornblende is also replaced by chlorite in places. Several rounded patches of relatively pellucid potash feldspar are present and these have developed by actively corroding and replacing the pre-existing minerals. There are local concentrations of iron ore. Apatite is a very prominent accessory. The essential minerals of the matrix are biotite, plagioclase, quartz and iron ore, but their relative proportions and grain-size vary enormously from one part of the thin section to another. In places the matrix consists of a fine-grained granoblastic mosaic of quartz and plagioclase accompanied by numerous small flakes of biotite; it is almost identical to an impure arenaceous hornfels. In the matrix generally, the plagioclase is clearly of mixed origin and exhibits considerable differences in the degree of alteration, twinning and zoning. The quartz is characterized by its mosaic extinction and cracked appearance. These cracks are infilled with a black opaque substance which is probably iron ore. Small clusters of biotite, chlorite, epidote and iron ore are irregularly distributed throughout the matrix. The iron ore is locally rimmed with sphene and the epidote may be intergrown with allanite. Very large rounded microcline porphyroblasts also occur. They are only in an incipient stage of development and are crowded with corroded inclusions.

3. *Discussion*

Two major processes occurred in basification and they were probably interdependent. The first is the migration of basic material into the acid dyke and the second is the physical and chemical interaction of the basic and acid components.

a. *Migration of material.* The most remarkable feature concerning basification of acid dykes is the considerable transportation of basic material along the acid dyke (cf. Plate IIIa). The most important conclusion that can be drawn from this is that the acid dyke was partially, if not predominantly, liquid when basification occurred. The migration may have been initiated by the inequilibrium present at the contact between the two materials. In his classification of igneous contacts, Dennen (1951, p. 556) has said that the direction in which the mobile components will move is determined by the difference in ionic concentration in the liquid medium, although temperature gradient may also exert some influence. It is very doubtful if a significant temperature gradient existed during basification, so that the controlling factor was the composition gradient. This may partly explain the general absence of reaction between the basic dykes and the country rock, although the physical state of the latter must also have been an important factor.

The actual mechanism of transportation is difficult to envisage. In their discussion of reaction phenomena between acid and basic rocks in the Slieve Gullion Complex, Ireland, Bailey and McCallien (1956, p. 490) stated that diffusion has carried basaltic magma for a short distance into a granophyre mush. Diffusion alone is very unlikely to have been responsible for the movement of material in basification, since the great distance the basic material migrated in the Trepassey Island example is in sharp contrast to the "few mm." recorded by Bailey and McCallien. In basification of types (i) and (ii) the basic material was uniformly acidified as it permeated the acid dyke, and some of the acid melt presumably migrated into the basic dyke, giving a two-way transfer of material. The third type of basification presents a more complex situation in that the basic material was fragmented and was subsequently subjected to widely differing degrees of acidification. Rheomorphism was probably involved in this case.

b. *Chemical reactions.* Only the third type of basification is considered here, because of the lack of adequate data from the other two types. In general, lime and iron were added to the acid material to give epidote, sphene and concentrations of iron ore, while alkalis and silica were transferred to the basic inclusions. Allanite, which occurs in all the examples of basification studied, marks the concentration of a few trace elements. The detailed petrographic descriptions given above reveal considerable variations in the products of reaction, which may be partly the result of differences in the initial compositions of the basic and acid components and partly the length of time over which effective interaction could take place. For example, in the Trepassey Island basification some of the basic xenoliths remained fine-grained when acidified and the addition of silica and potash produced an almost continuous background of quartz and potash feldspar. In contrast, the addition of silica and potash to the basic inclusions occurring in the Stonington Island example gave rise to large interstitial pockets of quartz and the growth of comparatively large biotites at the expense of hornblende. In this case a definite coarsening of grain in the pre-existing minerals is conspicuous. Another trend is seen in the conversion of small basic inclusions to amphibolite and puckered hornblende-schist but this is exceptional.

In the matrix, mechanical mixing of the modified basic and acid components has usually proceeded to a much greater extent than is apparent in the hand specimen. Even when the matrix appears to be virtually unaltered, thin-section examination shows that it often contains zoned plagioclase xenocrysts and small recrystallized fine-grained clots of basic material. In the Trepassey Island example intermixing of the two components was preceded by or accompanied by vigorous chemical reaction, producing the maximum degree of interaction observed in basification. This was the only instance in which it was possible to obtain suitable material for chemical analysis. Table V gives the chemical compositions of the basic and acid dykes and also of the hybrid rock resulting from their interaction during basification. The hybrid rock has a chemical composition which approximates fairly closely to a quartz-biotite-diorite (cf. Adie, 1954, p. 27, table VIIa) and this is confirmed by the mesonorm. The analyses are expressed graphically in Fig. 10. This shows that many oxides in the hybrid rock coincide with or are close to the arithmetic mean of the corresponding oxides in the acid and basic rocks. Thus, these particular oxides illustrate that chemically normal rocks can be produced by contamination as was suggested by Nockolds (1941, p. 506). The above coincidence has probably little other significance. However, the linear relationships are valuable, since they emphasize the marked variations in the remaining oxides. For example,

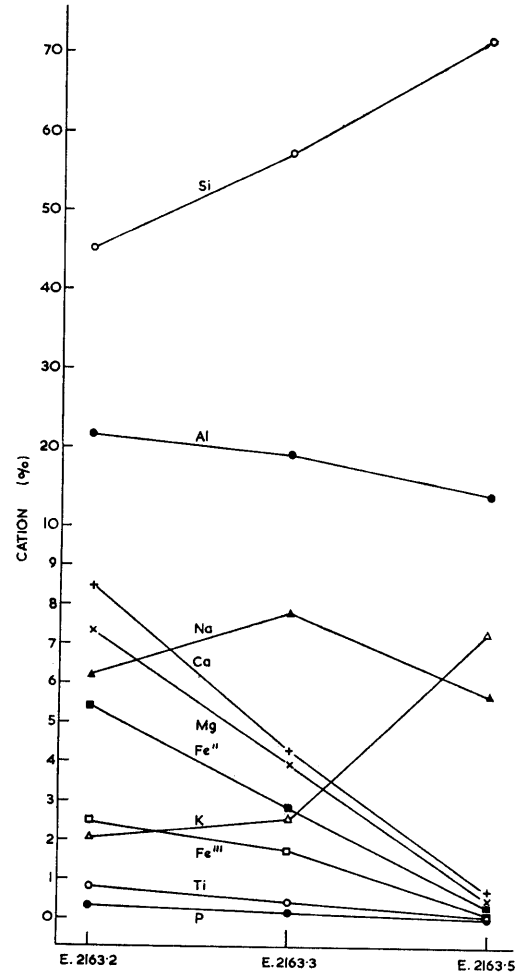

FIGURE 10

Variation diagram illustrating the relationships between the cations of the dyke rocks from Trepassey Island (see Table V).

TABLE V

CHEMICAL ANALSYES OF DYKE ROCKS FROM TREPASSEY ISLAND ILLUSTRATING BASIFICATION

	E.2163.2	E.2163.3	E.2163.5
SiO_2	47·62	60·45	76·48
TiO_2	1·15	0·62	0·08
Al_2O_3	19·36	17·07	12·61
Fe_2O_3	3·48	2·46	0·17
FeO	6·84	3·58	0·38
MnO	0·16	0·07	—
MgO	5·21	2·81	0·36
CaO	8·39	4·28	0·69
Na_2O	3·39	4·25	3·11
K_2O	1·72	2·15	6·13
H_2O+	2·27	1·55	0·18
H_2O-	0·12	0·13	0·07
P_2O_5	0·42	0·23	—
CO_2	0·36	0·17	0·10
TOTAL	100·49	99·82	100·36
	ANALYSES AS CATION PERCENTAGES		
Si	45·08	57·10	71·50
Ti	0·82	0·44	0·06
Al	21·59	19·00	13·89
Fe'''	2·48	1·75	0·12
Fe''	5·41	2·82	0·30
Mn	0·13	0·06	—
Mg	7·35	3·95	0·50
Ca	8·51	4·33	0·69
Na	6·22	7·78	5·63
K	2·07	2·59	7·31
P	0·34	0·18	—
H_2O+	(14·33)	(9·76)	(1·12)
CO_2	(0·47)	(0·22)	(0·13)
TOTAL	100·00	100·00	100·00
	MESONORMS		
Q	2·1	18·8	31·6
Or	—	3·0	35·5
Ab	31·1	38·9	28·2
An	19·8	16·9	2·3
Bi	16·6	16·0	1·7
Ho	20·2	—	0·4
Mt	3·7	2·6	0·2
Ti	2·5	1·3	0·2
Ap	0·9	0·5	—
Cc	0·5	0·2	0·1
C	2·7	1·9	—
	MODAL ANALYSES		
Quartz	—		30·9
Potash feldspar	—		38·0
Plagioclase	55·1		30·3*
Chlorite	16·3		0·7
Hornblende	23·8		—
Iron ore	2·2		0·1
Sphene	0·4		—
Apatite	0·8		—
Epidote	1·4†		—
Average plagioclase composition	An_{48}		An_{18}

* Includes 8·0 per cent albite.
† Includes prehnite and calcite.

E.2163.2	Basic dyke (anal. A. G. Fraser).
E.2163.3	Hybrid rock resulting from basification of an acid dyke by a basic dyke (anal. A. G. Fraser).
E.2163.5	Acid dyke (anal. A. G. Fraser).

the higher oxidation ratio of the hybrid rock compared with the acid and basic dykes is clearly illustrated. But by far the most important variations exist in the alkalis. Fig. 10 shows that, if the arithmetic mean is used as a datum, the excess of soda in the hybrid rock is almost equal to the deficiency of potash. This indicates that soda has diffused into the hybridized basic inclusion very much more rapidly than potash. A similar conclusion was reached by Walker and Poldervaart (1949, p. 679) in their study of transfusion phenomena in the Karroo dolerites. The rapid influx of soda is reflected in the well-developed oligoclase porphyroblasts.

c. *Growth of plagioclase.* A significant increase in plagioclase grain-size is apparent in all the examples of basification. A similar phenomenon was observed in acidified basic xenoliths in the *ortho*gneisses and in locally acidified areas in basic dykes, and they are therefore included in the present discussion. Three processes of plagioclase growth are believed to have taken place:

i. The direct crystallization of plagioclase from the modified magma. In some cases, as in many of the inclusions in the xenolithic gneiss, the plagioclase has the same composition as the host rock, but in other instances the composition is intermediate between that of the host and the inclusion. These plagioclases display greatly varying degrees of zoning and twinning. A few zoned crystals have a patchy or mottled basic core which suggests that a mechanism of internal replacement (rather similar to that present in patchy plagioclases in the *ortho*-gneisses) occurred during acidification. In such crystals the basic material was either completely replaced or glide twinning was induced at some stage. If the former occurred, the result was untwinned plagioclases of uniform composition.

ii. In a number of acidified basic inclusions the plagioclase consists of a labradorite core and a sharply defined oligoclase or andesine margin. The acid rims may be the result of simple recrystallization but, since the crystals are distinctly larger than those present in the unaltered basic dyke, it is possible that at least part of the oligoclase rim was deposited on the original plagioclase during acidification. Secondary glide twinning is present in a number of these strongly zoned crystals and where it is well developed it tends to obliterate the zoning. Unzoned, subidioblastic to idioblastic crystals with good secondary twinning may have grown by a similar process of accretion, the only difference being that the compositional differences were completely removed by the glide twinning. However, this is very uncertain because there is generally no way of distinguishing such plagioclases from those which formed by the first process and which later developed secondary twinning in response to deformation.

iii. Another process which produced large plagioclases during basification was the replacement of pre-existing minerals. The large oligoclase porphyroblasts described on p. 40 originated in this way but it does not seem to be an important process generally.

C. CONCLUSIONS

The most important conclusion which emerges from this study of rheomorphism and the basification of acid dykes is that both of these phenomena undoubtedly occurred in a high-temperature environment. This can be deduced in several ways. For example, in every instance of rheomorphism there is a complete absence of glass which demonstrates that the basic dykes were intruded into hot country rock. It is unnecessary to invoke an unusually high magmatic temperature for the basic material, because the dykes were rich in chemically active volatile constituents. In basification a high-temperature environment is inferred from the migration of basic material along the acid dykes and the complex reactions between the basic and acid components. Furthermore, a conspicuous coarsening in grain occurs in basification and, however this may be interpreted, it clearly required the existence of elevated temperatures over a long period.

The third type of basification has many features in common with the xenolithic basic dykes, which strongly suggests that they are closely related phenomena resulting from the simultaneous or nearly simultaneous injection of acid and basic magma. Basification occurred where a basic dyke intersected a predominantly liquid acid dyke or vein, whereas xenolithic basic dykes were formed when the contrasting materials were emplaced along coincident planes.

An examination of the hybrid rocks formed during basification leads to the conclusion that the textural variations commonly observed in the basic dykes of Stonington Island were caused by the incorporation of acid rock of unknown origin into the dykes with consequent interaction between them. The rare occurrence of small medium-grained amphibolite and hornblende-schist xenoliths in some types of basification may indicate a possible origin for the concentrations of these xenoliths which occur exclusively in basic dykes.

VIII. LATER DYKES

DYKES of basaltic composition which are considerably younger than those previously described but of uncertain age occur on both Stonington and Trepassey Islands. Their trend is strictly controlled by jointing in the *ortho*gneisses and, because they are considerably less resistant to weathering than the country rock, some of them are only represented by detached fragments. Marginal chilling is conspicuous even around the very small fragments of wall rock incorporated by the dykes. This is in marked contrast to the older basic dykes.

Nearly all the dykes belonging to this group occur on the north-east corner of Trepassey Island and on the low-lying outcrop east of Fishtrap Cove on Stonington Island. At the latter locality there is a very prominent basaltic dyke (Plate IIIc) which Knowles (1945, p. 138) described as a porphyritic enstatite-basalt. In the hand specimen this dyke (E.2154.11) has a weakly porphyritic texture with phenocrysts of plagioclase and pyroxene set in a dark aphanitic groundmass which contains visible plagioclase laths. There are several small concentrations of iron pyrites. Under the microscope the plagioclase phenocrysts have a maximum composition of $Ab_{35}An_{65}$ and they are generally fresh, although yellowish green scaly chrysotile commonly occurs along cracks and cleavages and also in small patches. Rare crystals display fine oscillatory zoning and some have slight normal zoning at their margins. The pyroxene is not enstatite but a purple-brown pleochroic titanaugite with $\gamma{:}c = 50°$. It is very abundant, much of it occurring as microphenocrysts which are ophitically intergrown with the plagioclase of the groundmass (Plate VIf). This strong ophitic texture tends to mask the porphyritic structure. The groundmass has a basaltic texture and consists of abundant plagioclase laths, intersertal scaly chrysotile and titanomagnetite together with some titanaugite and a little calcite. The plagioclase composition is similar to that of the phenocrysts but normal continuous zoning is much more conspicuous and gives marginal oligoclase in a few cases. Several clearly defined areas composed of finely granular quartz, calcite, yellow-green chrysotile and a little iron ore occur in the groundmass. The serpentine in these areas occurs characteristically as stringers but it also forms a narrow rim round many of them. It is not clear how these quartzose areas originated, since it is very unlikely that they represent modified xenocrystic or xenolithic material. They may be the result of secondary silicification.

At the same outcrop there is a broad porphyritic dyke with a green aphanitic groundmass (E.2154.6). Numerous unzoned plagioclase phenocrysts with a composition of $Ab_{32}An_{68}$ are severely altered to epidote, calcite, prehnite and scaly mica. Several are altered to pale green serpentine along cleavages and cracks, and a few have suffered local albitization. The large black ovoid patches conspicuous in the hand specimen may be altered amygdales and are composed of epidote, pale green fibrous serpentine and a little calcite. The groundmass has a typical basaltic texture and consists of pyroxene, plagioclase and iron ore, accompanied by abundant secondary products such as calcite, epidote and serpentine. The pyroxene is a pale brown slightly pleochroic augite, partially altered to calcite and epidote, and the plagioclase laths are slightly less calcic than the phenocrysts. Both augite and plagioclase also occur as microphenocrysts. Most of the iron ore has been converted to amorphous leucoxene.

In another dyke (E.2151.1) plagioclase phenocrysts (whose original composition has been completely masked by intense alteration to epidote, prehnite and serpentine), together with rare phenocrysts of slightly zoned unaltered pigeonite or sub-calcic augite, are set in a groundmass of plagioclase, pigeonite and iron ore. The groundmass possesses a trachytic texture and contains much secondary epidote, calcite, serpentine and leucoxene.

Chemical analyses of two of the later dykes are given in Table VI. Both are markedly basic but alteration has produced considerable discrepancies between the respective modes and norms. This is particularly true of the altered basalt (E.2151.1; Table VI, analysis 1) in which none of the potash occurs in modal potash feldspar. Table VI also gives the chemical analysis of a pre-Andean microdiorite dyke from the Argentine Islands (Elliot, 1964, p. 28, table II), and a comparison of this microdiorite with the later dykes of Stonington and Trepassey Islands shows that there are certain similarities in their chemistry. However, in petrography the later dykes have a much closer affinity to the post-Andean altered microgabbros of the Argentine Islands which have also been described by Elliot (1964, p. 19–20).

TABLE VI

CHEMICAL ANALYSES OF (?) TERTIARY DYKES, STONINGTON ISLAND

	E.2151.1	E.2154.11	F.110.1
SiO_2	47·86	45·65	49·89
TiO_2	0·99	1·78	1·21
Al_2O_3	19·66	15·59	19·36
Fe_2O_3	3·07	4·21	3·53
FeO	5·93	7·24	5·68
MnO	0·18	0·13	0·12
MgO	5·87	8·48	3·63
CaO	7·36	10·40	9·85
Na_2O	3·54	2·39	3·87
K_2O	1·77	0·36	0·90
H_2O+	3·22	2·66	1·27
H_2O-	0·36	0·47	0·09
P_2O_5	0·17	0·39	0·74
CO_2	0·40	0·83	0·10
TOTAL	100·38	100·58	100·24
	ANALYSES LESS TOTAL WATER (Recalculated to 100)		
SiO_2	49·44	46·85	50·46
TiO_2	1·02	1·83	1·22
Al_2O_3	20·31	16·00	19·58
Fe_2O_3	3·17	4·32	3·57
FeO	6·13	7·43	5·75
MnO	0·19	0·13	0·12
MgO	6·06	8·70	3·67
CaO	7·60	10·67	9·96
Na_2O	3·66	2·45	3·91
K_2O	1·83	0·37	0·91
P_2O_5	0·18	0·40	0·75
CO_2	0·41	0·85	0·10
	NORMS		
Q	—	—	—
or	10·6	2·2	5·56
ab	30·9	21·0	32·49
an	33·6	31·4	32·80
di	0·7	11·0	8·84
hy	1·1	17·2	8·27
ol	15·5	4·8	1·59
mt	4·6	6·3	5·10
il	2·0	3·5	2·28
ap	0·3	1·0	1·68
cc	0·9	1·9	0·20

E.2151.1	Altered basalt, Stonington Island (anal. A. G. Fraser).
E.2154.11	Basalt, Stonington Island (anal. A. G. Fraser).
F.110.1	Pre-Andean microdiorite, north-east island of Three Little Pigs, Argentine Islands (Elliot, 1964, p. 28, table II).

IX. STRUCTURES

OVER the whole of Stonington Island, the strike of the foliation in the *ortho*gneisses varies between 310° and 335° mag., and xenoliths and schlieren are elongated in a similar direction. The foliation is generally weak and poorly defined so that accurate determinations of dip were difficult or impossible to make. In many places the only structure observed was a lineation defined mainly by the preferred orientation of prismatic hornblendes. Where it could be measured, the dip of the foliation is moderate to steep to the east and it is usually steeper on the south-west side of the island than on the north-eastern side. On the higher parts of the island a sub-horizontal foliation was recorded locally. This may indicate that the general structure is a slightly overturned anticline whose axis coincides with the foliation direction. Grimley (1961) inferred a similar type of structure from observations at Mast Hill. In one locality the biotite-gneiss possesses a very regular banding resulting from mineral segregation (Plate IIId), but this is unrelated to the foliation. The banding has an approximate east–west (mag.) strike and dips at 35° to the south. On Trepassey Island no foliation is discernible except in the biotite-hornblende-gneiss where it strikes in a direction 335° mag.

Plots of the joint poles measured in the major rock types of Stonington Island are shown in Fig. 11a–d and a plot of all the joints is given in Fig. 11e. All the rock types have two well-defined maxima which correspond to steeply dipping joints with a strike of 330° and 210° mag., respectively, although in the xenolithic gneiss these two maxima occur at slightly different positions, suggesting a clockwise rotation of about 15° relative to those in the other rock types. Since Grimley's (1961, fig. 4) analysis of joints on Mast Hill gives the same maxima, it is clear that these are master joints. Fig. 11e shows that the best-developed joints are those which strike in a direction 330° mag., i.e. those which are parallel or sub-parallel to the foliation. With the exception of the leucocratic hornblende-biotite-gneiss, all the gneisses have joints which strike in a direction 285° mag. and whose poles form a prominent maximum in the north-east quadrant. These joints have the same orientation as the banding in the biotite-gneiss, and it is interesting to observe that many of the minor intrusions and almost all the outcrops of the foliated acid rock have a similar orientation; this suggests that there is an underlying structural fabric in the country rock.

As shown in Fig. 11, the *ortho*gneisses have additional joint systems to those just described. Joints trending in a direction 295° mag. and dipping at 65° to the south-west are prominent in the biotite-gneiss (Fig. 11a), and vertical joints of similar strike occur in the melanocratic hornblende-biotite-gneiss (Fig. 11d). In the leucocratic hornblende-biotite-gneiss the poles of steeply dipping joints trending north–south (mag.) give another well-defined maximum. Relatively weak maxima are quite common in the plots of the joint poles but it is doubtful whether these have any statistical significance.

Faults which can be proved conclusively are not common on Stonington and Trepassey Islands, and most of them are very minor in their effects. In most cases the only observed effects of faulting are the displacement of dykes and narrow shatter zones. The predominant fault direction on Stonington Island is approximately north–south and this observation concurs with that of Hoskins (1960, p. 34). On Trepassey Island there are two fault directions: one set trends north-east to south-west and the other trends north-north-west to south-south-east. The faults are of unknown age but their general north–south trend, and the fact that the rocks were almost certainly rigid when faulting occurred, suggests that they are associated with the emplacement of the Andean intrusive rocks.

X. CONCLUSIONS

THE *ortho*gneisses of Stonington and Trepassey Islands can with reasonable certainty be correlated with the dioritic gneisses described by Adie (1954) and Hoskins (1963), and therefore they belong to the Basement Complex as defined by Hoskins (1963, p. 5). The present study has made it possible to determine the relative ages of the various phases of the dioritic gneisses and it has also shown that most, if not all, of the gneisses are of hybrid origin, resulting from the contamination of basic rocks by later acid intrusions.

From his detailed work in the Neny Fjord area of Marguerite Bay, Hoskins (1963, p. 43) concluded that there are three phases of regional metamorphism within the Basement Complex rocks, of which the second is the most important. The first metamorphism is not represented at Stonington and Trepassey

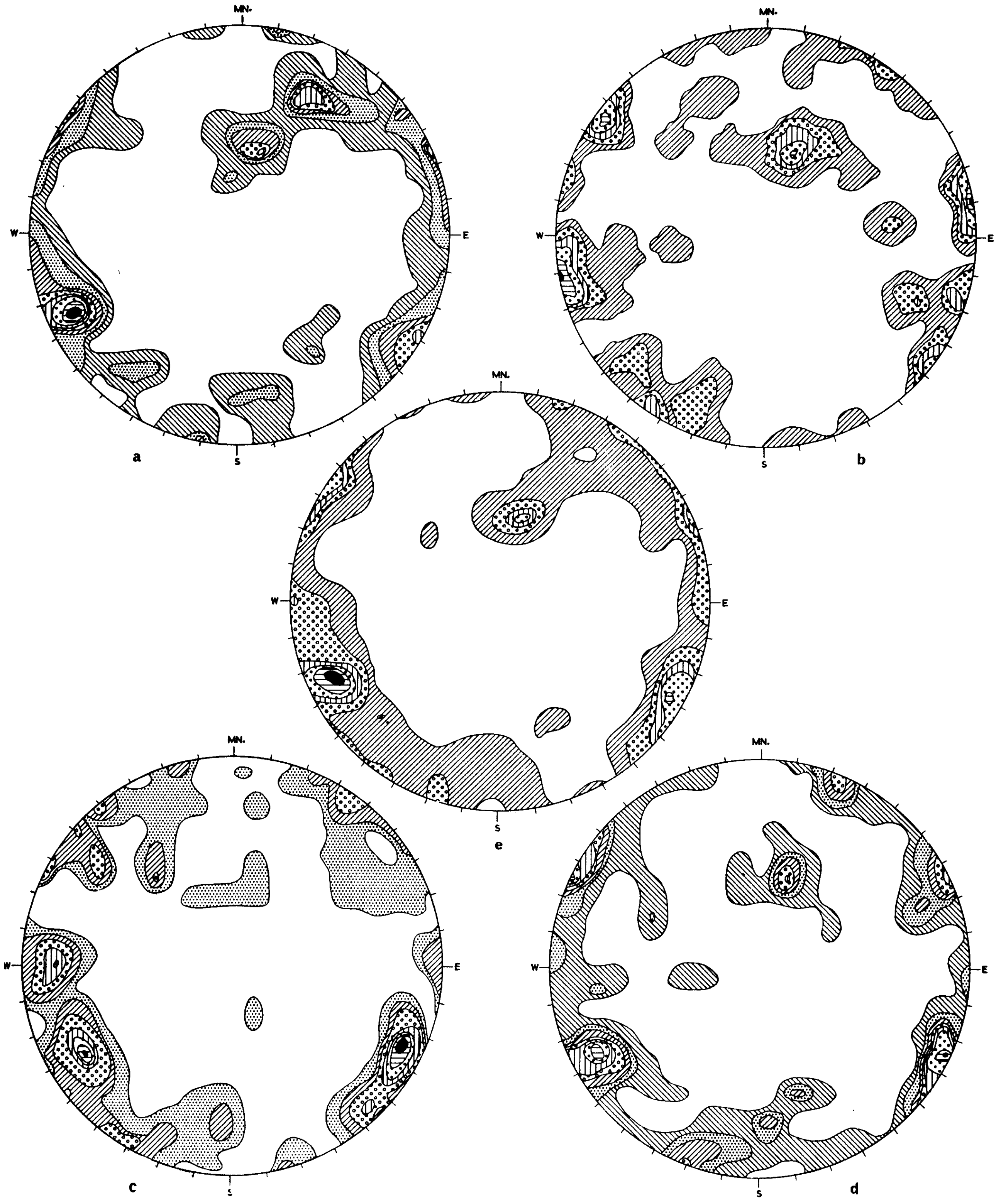

FIGURE 11

Poles of joints plotted on the lower hemisphere of an equal area net.

a. Joint directions in biotite-gneiss (222 observations; maximum of 9 per cent per 1 per cent area; contour interval of 1 per cent).

b. Joint directions in xenolithic gneiss (75 observations; maximum of 11 per cent per 1 per cent area; contour interval of 2 per cent).

c. Joint directions in leucocratic hornblende-biotite-gneiss (158 observations; maximum of 7 per cent per 1 per cent area; contour interval of 1 per cent).

d. Joint directions in melanocratic hornblende-biotite-gneiss (175 observations; maximum of 8 per cent per 1 per cent area; contour interval of 1 per cent).

e. Joint directions in all the major gneisses of Stonington Island (638 observations; maximum of 6 per cent per 1 per cent area; contour interval of 1 per cent).

Islands but it is evident that this metamorphism is quite distinct from the later one, because the relatively strong foliation of the banded biotite-gneisses described by Hoskins (1963, p. 7–10, 43) is in distinct contrast to the poorly defined foliation of the dioritic gneisses and presupposes a degree of shearing stress not generally attained in the second metamorphism. Investigation of the rocks of Stonington and Trepassey Islands has helped to elucidate the second metamorphism and has shown that it was characterized by:

i. High temperatures followed by very slow cooling.
ii. The absence of shearing stress except for a very limited period.

These temperature and pressure conditions were deduced from a detailed analysis of the various properties of the gneisses and their constituent minerals. Of the latter, the plagioclase is the most valuable in determining the thermal history of the *ortho*gneisses. It commonly exhibits a complex patchwork which is interpreted as an exsolution/replacement phenomenon taking place during very slow cooling. The patchwork developed in two stages: first, by the unmixing of a relatively sodic phase from calcic plagioclase with its subsequent segregation into several small discrete units, and secondly, by the progressive enlargement of these small sodic patches by a process of replacement which occurred when the basic rock containing the calcic plagioclase was hybridized by later acid intrusions. The antiperthitic plagioclase, which is widespread in the dioritic gneisses, is believed to have resulted from a strictly analogous process. Secondary glide twinning is very common in the plagioclase and it apparently developed during cooling, partly in response to externally imposed shearing stress and partly as a result of structural strains set up within the plagioclase by the patchwork. This secondary twinning ultimately resulted in the elimination of the patchwork and this clearly involved extensive structural re-organization in the plagioclase which could only have taken place when the structure was disordered. It is therefore concluded that the elimination of the patchwork occurred during slow cooling from high temperatures.

The thermal history deduced from a study of the plagioclase is supported by a detailed examination of the minor intrusions. The earlier dykes have very irregular margins and display considerable variations in thickness, because they were emplaced while the gneisses were still very hot and plastic, whereas the later dykes were intruded into comparatively rigid country rock, and consequently they are much more regular than the earlier dykes. The weaker metamorphic textures in the younger dykes reflect the shorter time in which these dykes were involved in a gradually declining metamorphism. This fact suggests that there were only two metamorphisms of the Basement Complex and that the apparent superposition of a lower grade of metamorphism on an earlier higher grade as postulated by Hoskins (1963, p. 45) could be attributed to successive events occurring during a waning metamorphism.

Further evidence that the second metamorphism of the Basement Complex was characterized by high temperatures, slow cooling and deficient shearing stress is furnished by the occurrence of xenolithic basic dykes and the basification of acid dykes. These are closely related phenomena which resulted from the simultaneous or nearly simultaneous injection of acid and basic magma, and the accompanying reactions involved considerable interaction between the basic and acid materials with the production of various types of hybrid rocks. Allanite is almost invariably a product of these reactions and one or two hybrid rocks contain more than 1 per cent of this mineral. Since this percentage is considerably in excess of that present in the unaltered basic and acid rocks, it is concluded that the allanite represents the concentration of certain rare-earth elements originally held in the structures of minerals such as biotite, hornblende and possibly potash feldspar. The grain-size in many of these hybrid products is considerably coarser than that of the rocks which represent the original unaltered magmas, and this marked increase in grain is unlikely to have taken place unless the interacting rocks had been maintained at high temperatures for a considerable period. Furthermore, these essentially magmatic reactions have not been substantially modified by metamorphic effects and this clearly implies the absence of strong shearing stress.

The basification of acid dykes and the development of xenolithic basic dykes on Stonington and Trepassey Islands occurred in a plutonic environment, although in other parts of the world, particularly in the Brito-Arctic Tertiary volcanic province, phenomena of this kind are generally found only in a volcanic environment.

XI. ACKNOWLEDGEMENTS

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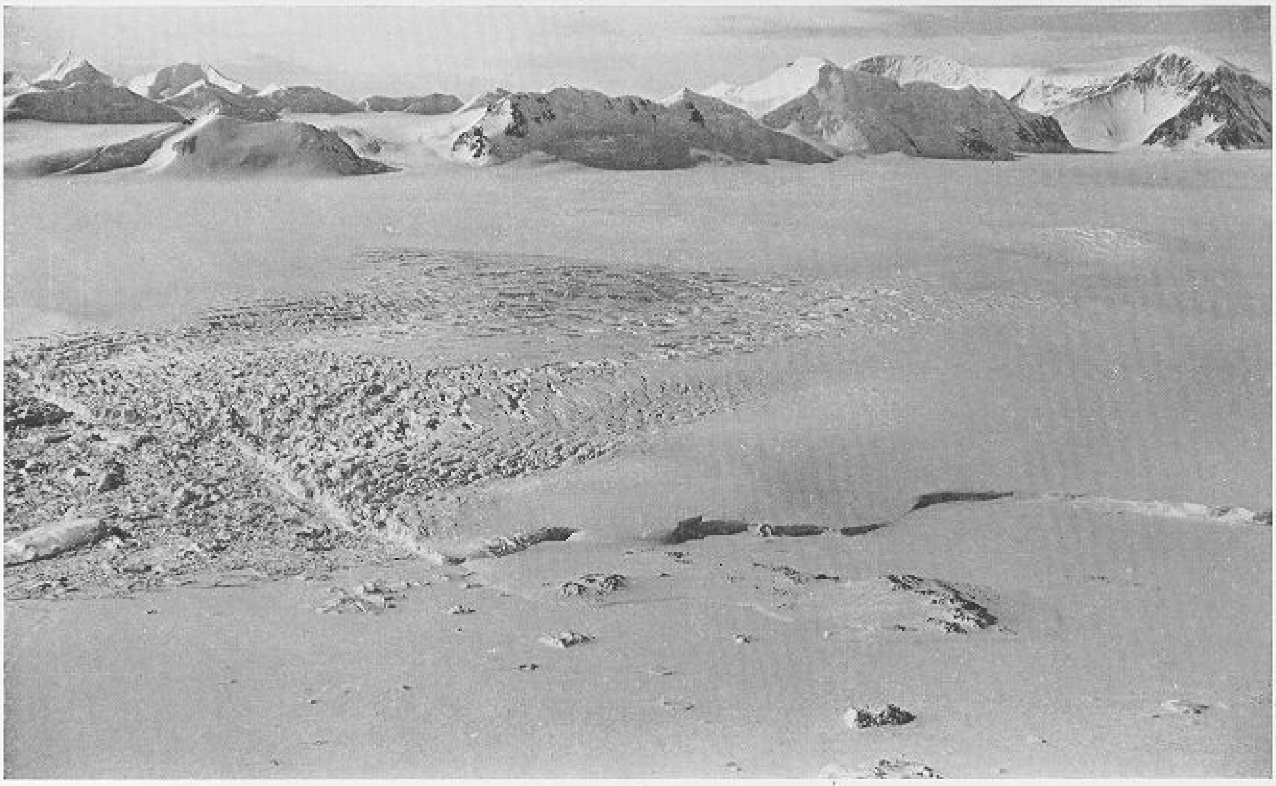
PLATE I

a. Stonington Island viewed from Neny Island at a height of 2,200 ft. (670 m.). Part of the Graham Land plateau is visible in the background.

b. Xenolithic gneiss; central Stonington Island.

c. Gently dipping xenolithic basic dyke in hornblende-biotite-gneiss; south-east Stonington Island.



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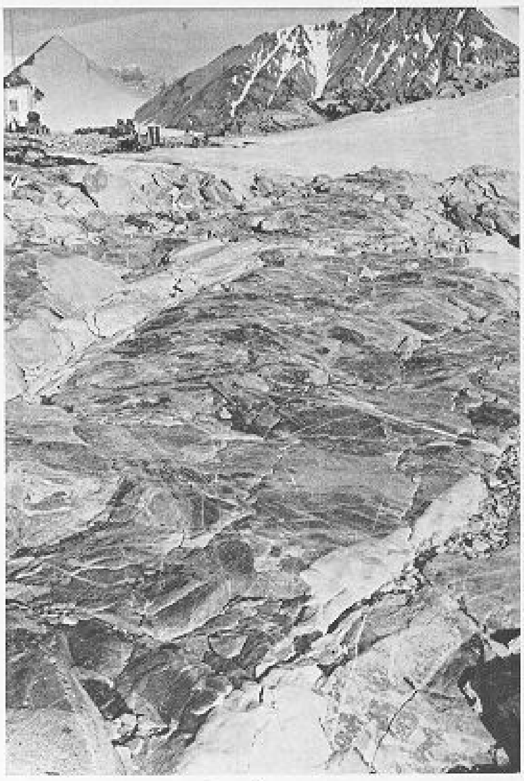

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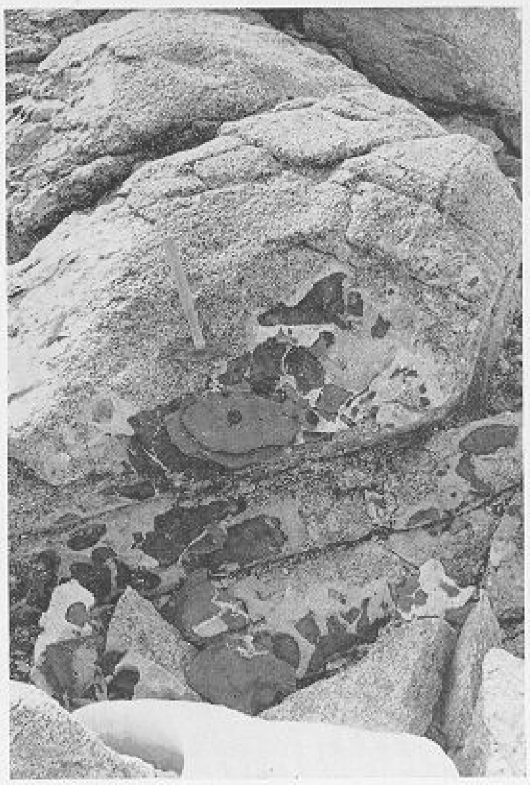

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PLATE II

a. Xenolithic basic dyke north-west of Fishtrap Cove; Stonington Island. The dyke is displaced by a minor fault and in the background it consists of a broad basic core flanked by very narrow acid margins.

b. Xenolithic basic dyke illustrating differential weathering of basic and acid components; south-east Stonington Island. The large basic inclusion behind the hammer has a slightly fretted appearance.

c. Basic dyke intruded along the core of an earlier acid dyke; south-east Stonington Island. The acid dyke has been mobilized in places with injection of the mobilized material into the basic dyke.

d. Xenolithic basic dyke north-west of Fishtrap Cove; Stonington Island.

PLATE II


a


b


c


d

PLATE III

a. Basification of a narrow acid vein by a basic dyke; north of the survey pillar, Stonington Island. A later acid vein cuts the basic dyke and a replacement dyke is visible in the middle distance.

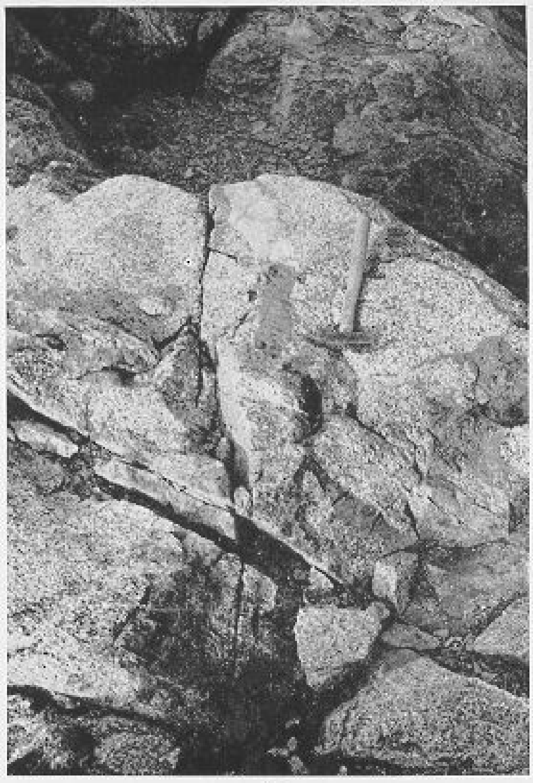
b. Basification of an acid vein; south-east Stonington Island. The basic material is considerably lighter in colour than that shown in Plate IIIa.

c. Basaltic dyke south-east of Fishtrap Cove; Stonington Island.

d. Banding in biotite-gneiss with concordant intrusion of a basic sheet; south-east Stonington Island.

PLATE III

a



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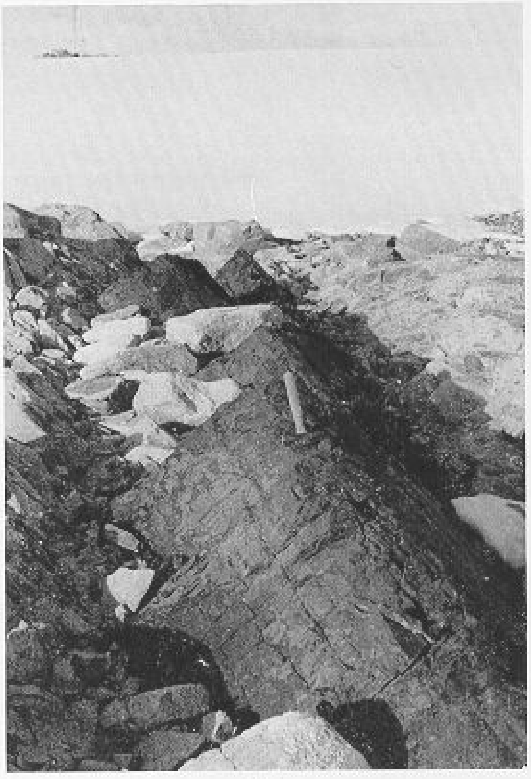

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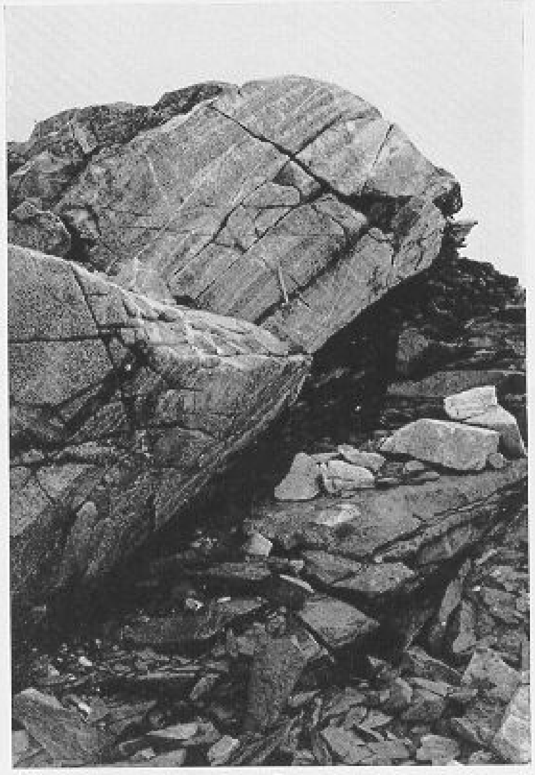

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PLATE IV

a. Poikiloblastic texture in an amphibolite xenolith; south-east Stonington Island (E.2102.16; ordinary light; ×40).

b. Plagioclase in biotite-hornblende-gneiss showing synneusis twinning; west Stonington Island. The crystal has combined Carlsbad-albite twinning with the albite lamellae in extinction (E.2107.4; X-nicols; ×40).

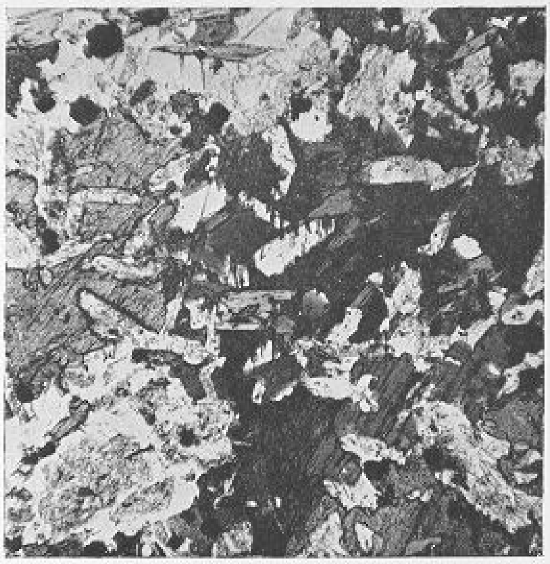
c. Bending of secondary albite twin lamellae in plagioclase in hornblende-biotite-gneiss; south-east Stonington Island. The lamellae increase in number in areas of greatest strain (E.2151.3; X-nicols; ×40).

d. Complex patchwork in plagioclase in grey acid gneiss; west Stonington Island (E.2107.31; X-nicols; ×82).

e. Plagioclase porphyroblast in xenolithic gneiss; central Stonington Island. The twinning is discontinuous and many of the small patches possess additional lamellae (E.2104.2; X-nicols; ×145).

f. Grey granitic dyke in which quartz exhibits intensely sutured margins and mosaic extinction; south-east Stonington Island (E.2107.1; X-nicols; ×50).

PLATE IV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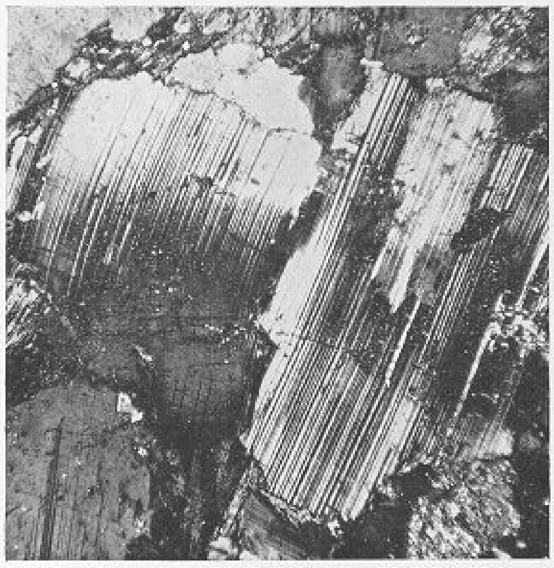
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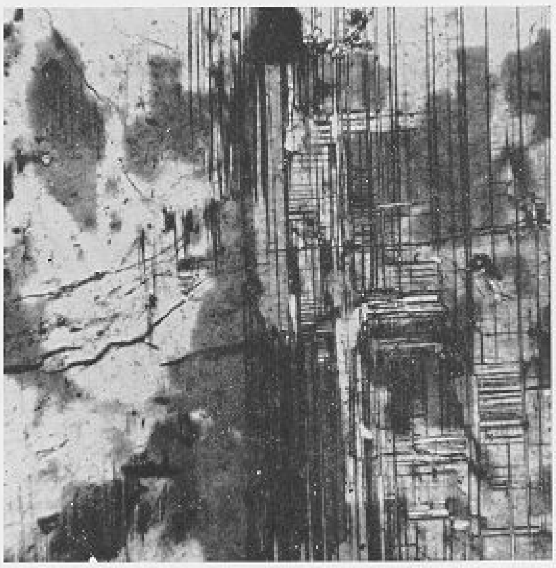
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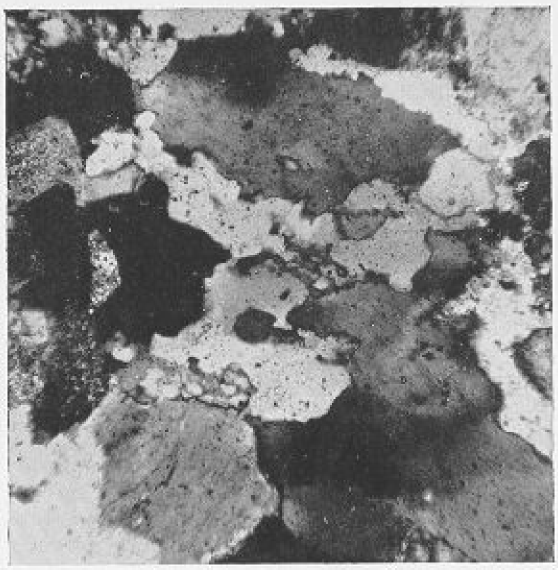
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PLATE V

a. Pink granitic dyke having a much weaker metamorphic texture than the dyke shown in Plate IVf; south-east Stonington Island (E.2151.13; X-nicols; ×50).

b. Typical basic dyke illustrating pseudo-porphyritic texture resulting from hornblende aggregates; west Stonington Island (E.2107.6; ordinary light; ×45).

c. Chilled margin of a basic inclusion in a xenolithic basic dyke; central Stonington Island (E.2155.2; ordinary light; ×33).

d. Sinuous margin of a small basic inclusion in a xenolithic basic dyke; central Stonington Island (E.2155.1; ordinary light; ×33).

e. Zoned allanite in the hybridized acid matrix of a xenolithic basic dyke; south-east Stonington Island (E.2102.11; X-nicols; ×186).

f. Sharply zoned plagioclases near the margin of an acidified basic inclusion; south-east Stonington Island (E.2102.8; X-nicols; ×60).

PLATE V

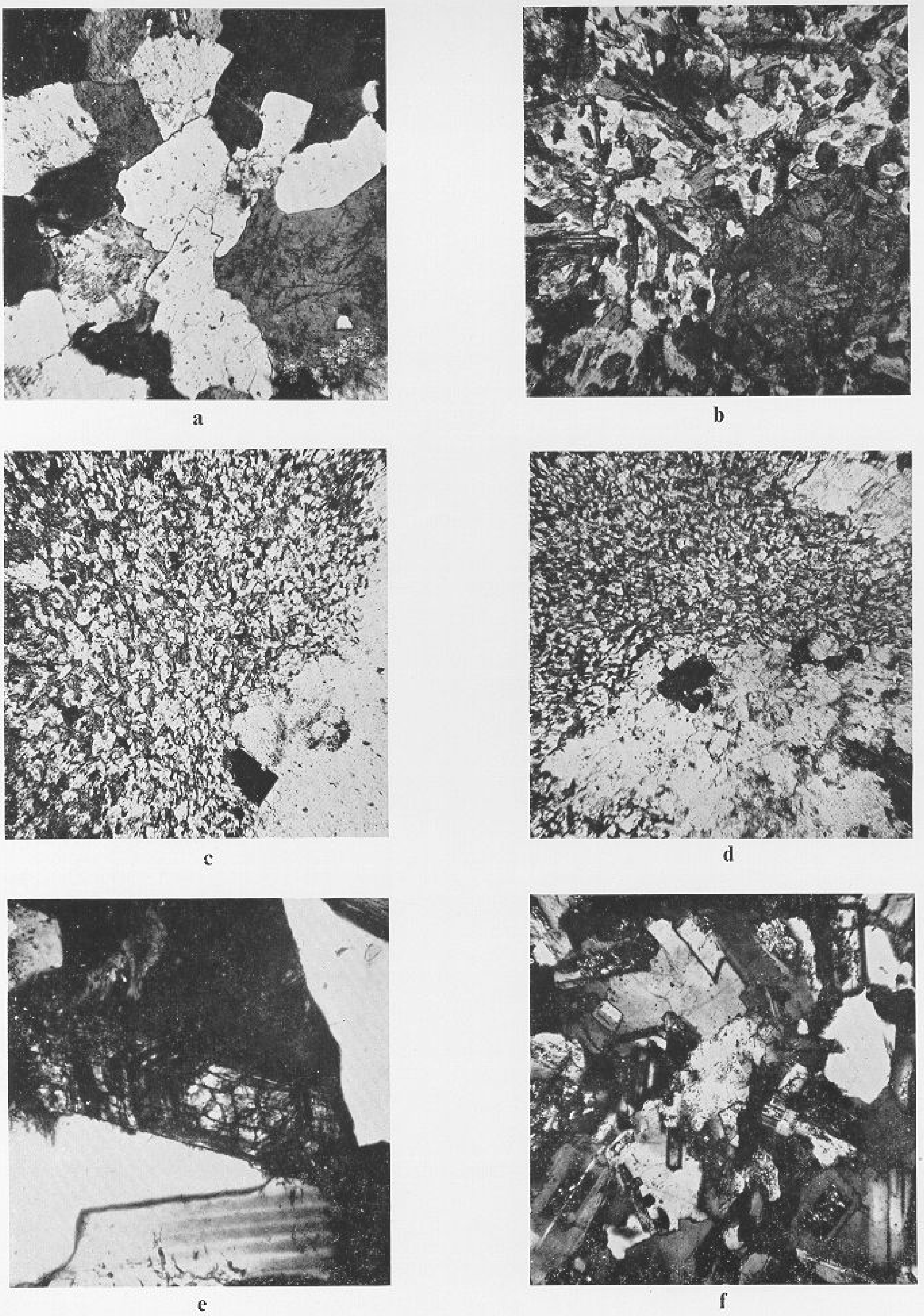


PLATE VI

a. Part of an acidified basic inclusion showing plagioclase laths corroded by quartz, and the growth of relatively large plates of biotite; south-east Stonington Island (E.2102.8; X-nicols; ×45).

b. Basic dyke consisting essentially of plagioclase, hornblende (occasionally twinned) and chlorite; Trepassey Island (E.2163.2; X-nicols; ×40).

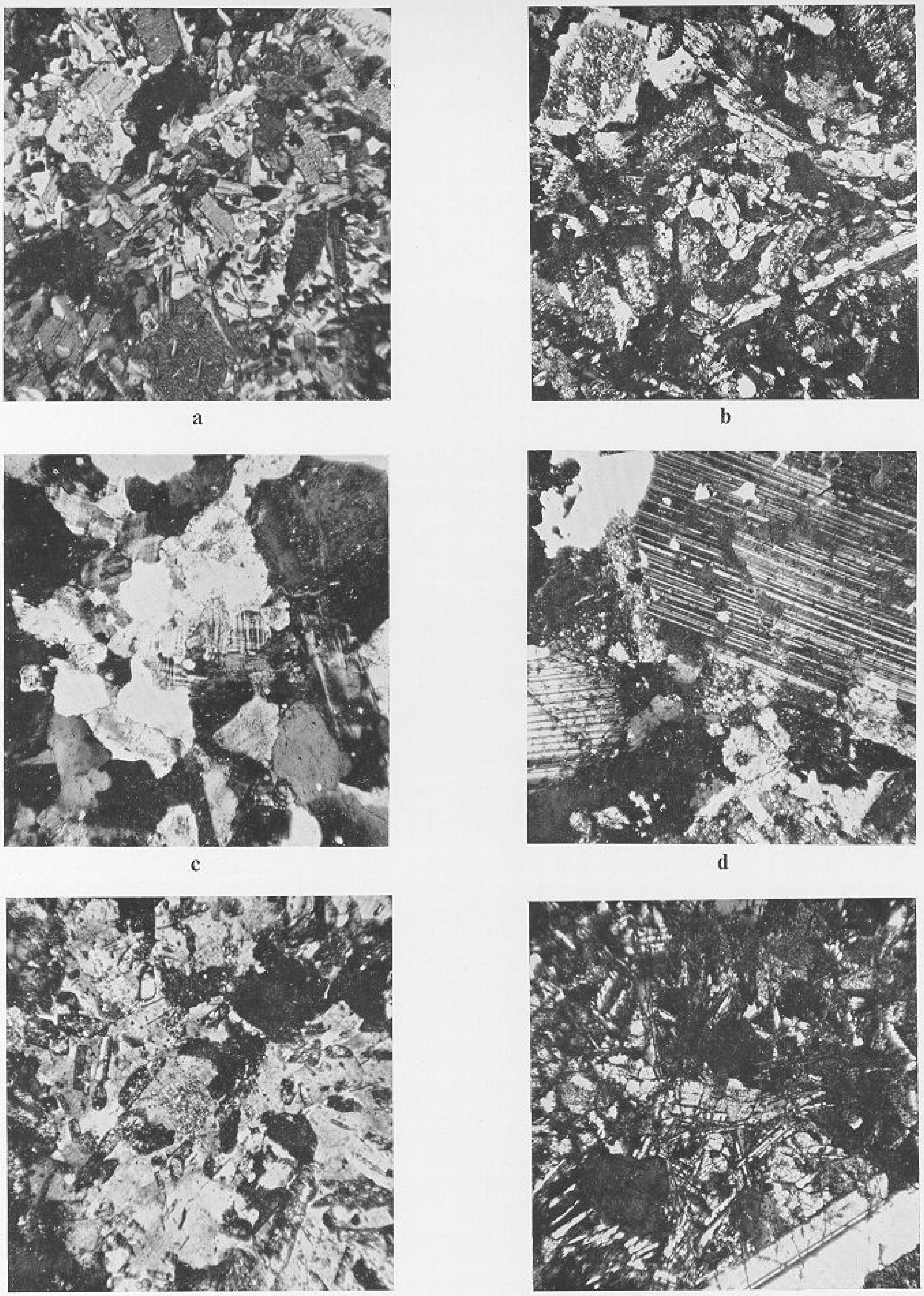
c. Aplite dyke; Trepassey Island (E.2163.5; X-nicols; ×40).

d. Hybrid rock resulting from the basification of an acid dyke (Plate VIc) by a basic dyke (Plate VIb). The grain is considerably coarser than in either of the unaltered dykes and the larger plagioclase is partially replaced by quartz (white) and potash feldspar (dark) (E.2163.3; X-nicols; ×40).

e. Large potash feldspar porphyroblast in the same hybrid rock (Plate VId) with inclusions of hornblende, chlorite and plagioclase (E.2163.3; X-nicols; ×40).

f. Basaltic dyke; south-east Stonington Island (E.2154.11; X-nicols; ×45).

PLATE VI



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