BRITISH ANTARCTIC SURVEY
(formerly Falkland Islands Dependencies Survey)

SCIENTIFIC REPORTS

No. 41

THE PETROLOGY OF THE ARGENTINE ISLANDS

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LONDON: PUBLISHED BY THE BRITISH ANTARCTIC SURVEY: 1964

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(Manuscript received 30th September, 1963)

ABSTRACT

THE petrology of the Argentine Islands is described in detail. The oldest rocks are lavas and pyroclastic members of the Upper Jurassic Volcanic Group which have been intruded by pre-Andean dykes and sills. The Andean Intrusive Suite has metamorphosed and metasomatized the volcanic and hypabyssal rocks. There is a later dyke phase which cuts both the volcanic and plutonic rocks; finally, there are a few late comparatively unaltered Tertiary dykes. Eight new analyses of hypabyssal rocks are included, but the composition range is too small to show conclusive trends.

CONTENTS

I. INTRODUCTION

THE Argentine Islands lie between lat. 65°13′ and 65°16′S., and long. 64°13′ and 64°20′W. off the west coast of Graham Land (Fig. 1). Most of the islands of the group have a permanent ice cover, but the north-facing slopes are generally snow- and ice-free during the summer months.

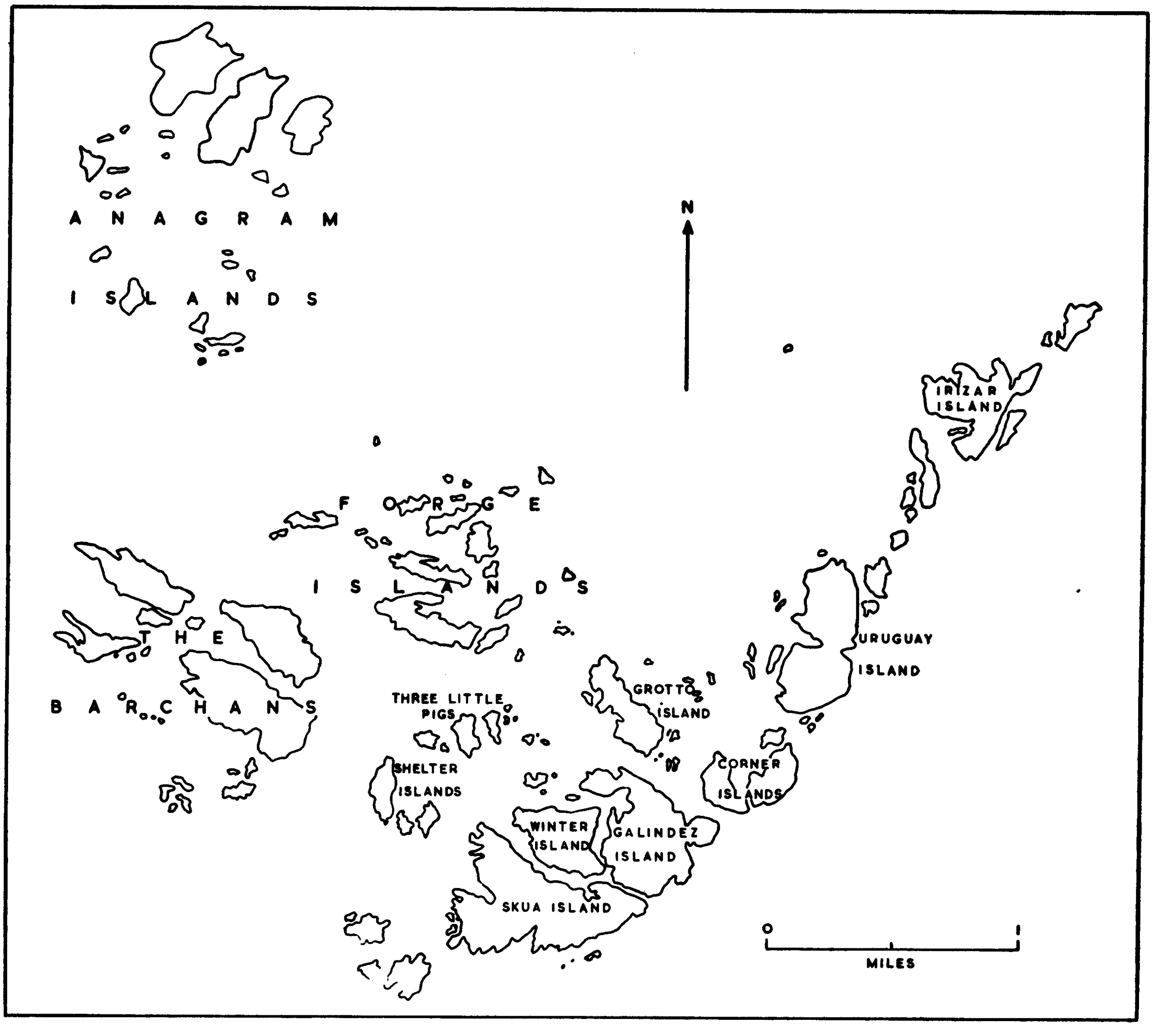
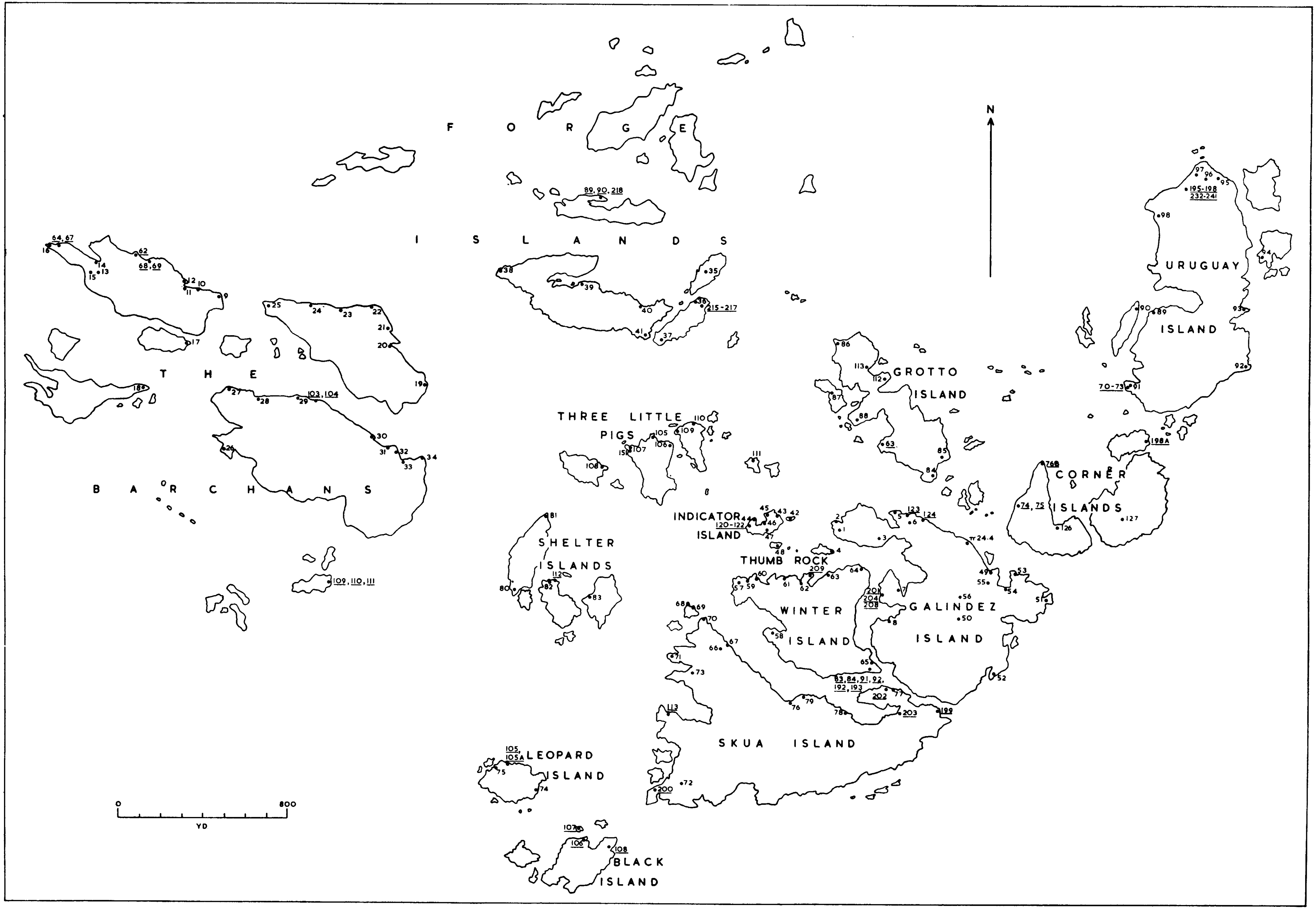


FIGURE 1
Sketch map of the Argentine Islands.

Although several expeditions had journeyed down the west coast of Graham Land in the early years of this century, it was not until the British Graham Land Expedition (1934–37) wintered on Winter Island that a geological reconnaissance of the islands was carried out. The Falkland Islands Dependencies Survey established a station on Galindez Island in 1954 and during 1958–59 G. J. Roe undertook the first detailed geological survey.

The Argentine Islands are composed entirely of igneous rocks (Figs. 2, 3, 4 and 5). Volcanic rocks of a Jurassic age occur in the eastern islands of the group and rocks of the Andean Intrusive Suite form


F O R G E
I S L A N D S
T H E
B A R C H A N S
THREE LITTLE PIGS
INDICATOR ISLAND
THUMB ROCK
SHELTER ISLANDS
GROTTO ISLAND
URUGUAY ISLAND
CORNER ISLANDS
WINTER ISLAND
GALINDEZ ISLAND
SKUA ISLAND
LEOPARD ISLAND
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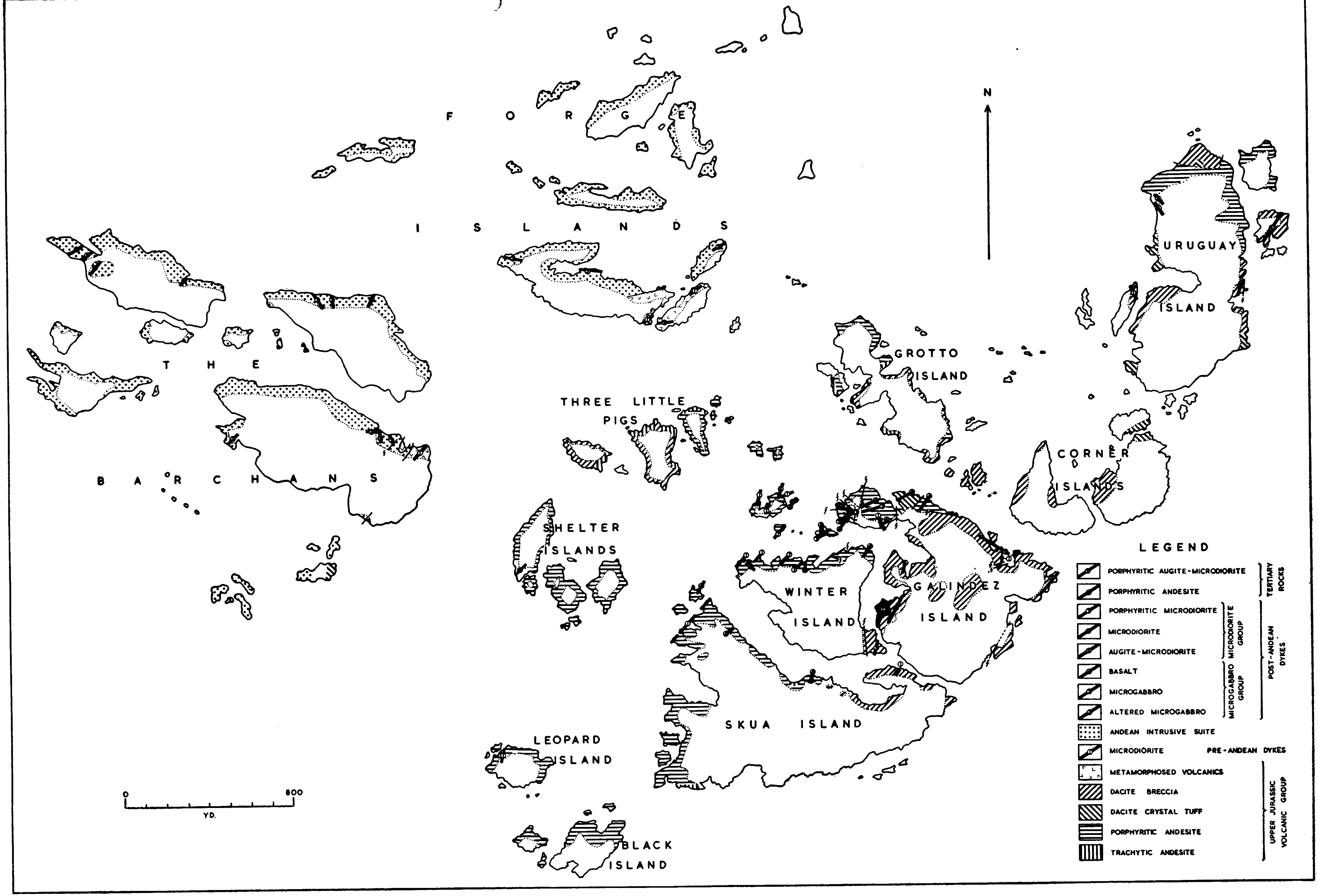


FIGURE 3
Geological sketch map of the Argentine Islands.

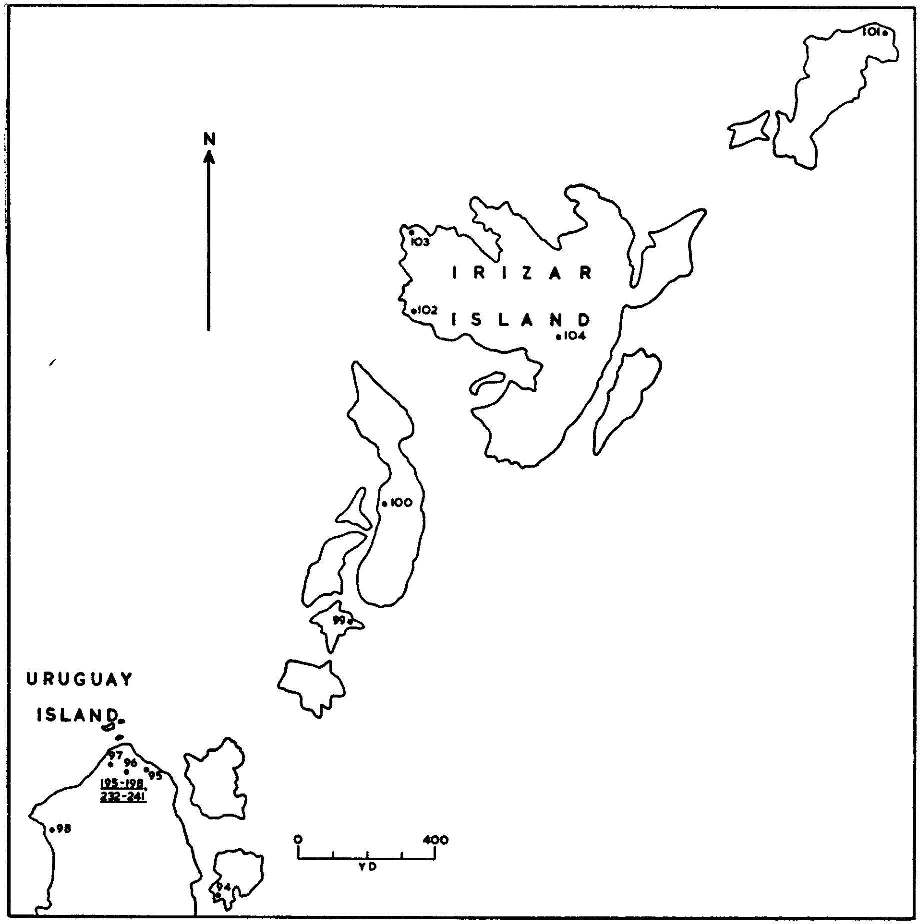


FIGURE 4
Sketch map of northern Uruguay Island (see Figs. 1 and 2) and the Irizar Island group showing the positions of geological stations. The British Graham Land Expedition, 1934–37, geological station numbers are underlined, whereas the 1958–59 geological station numbers are not.

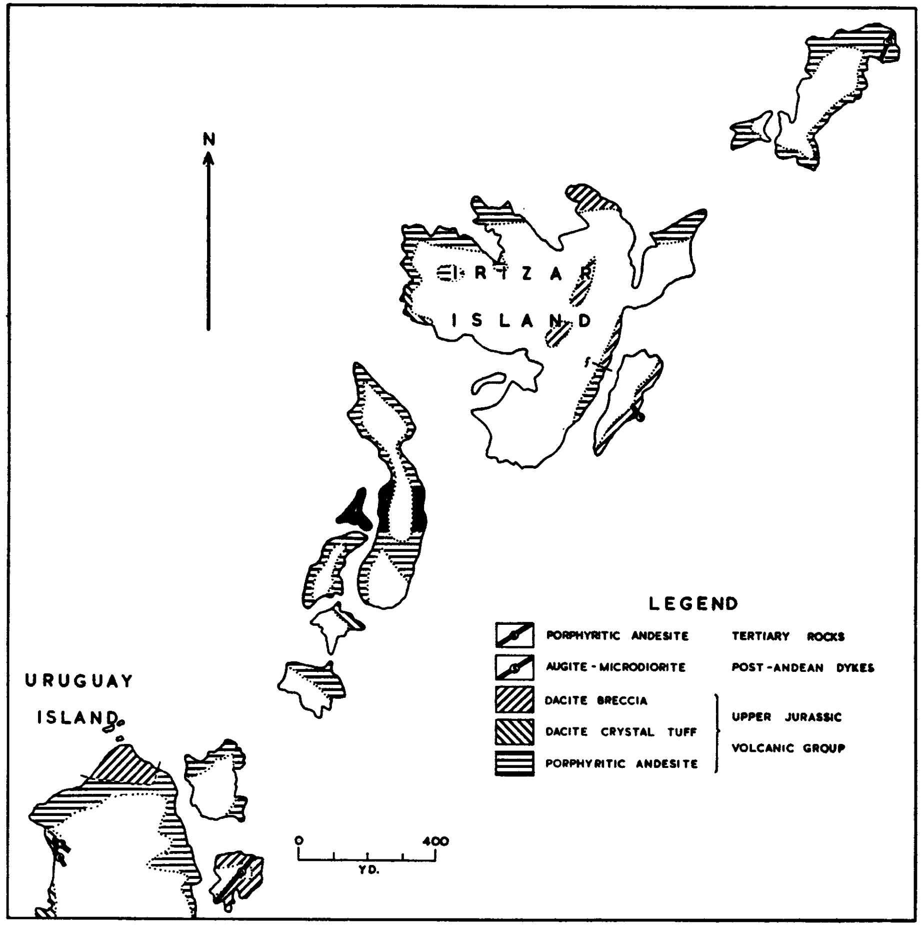


FIGURE 5
Geological sketch map of northern Uruguay Island (see Fig. 3) and the Irizar Island group.

the western islands. The volcanic rocks are mainly andesite lavas and associated pyroclastic rocks which have been metamorphosed and metasomatized by the Andean Intrusive Suite. They have been invaded by pre-Andean dykes and sills. In the Argentine Islands the Andean Intrusive Suite is represented only by granodiorites but in the descriptive part of the text reference is made to more basic members of this suite which occur in neighbouring islands. A late phase of dyke intrusion cuts both the volcanic and the plutonic rocks.

This petrological report is based on the field collections of W. L. S. Fleming (British Graham Land Expedition, 1934–37) and G. J. Roe (Falkland Islands Dependencies Survey, 1958–59). Since the earlier collection had not been described in detail previously, it was considered opportune to incorporate descriptions of this material in order to extend the scope of the present study. The British Graham Land Expedition specimens listed in the text are prefixed by "BGLE" (e.g. BGLE. 63), whereas the Falkland Islands Dependencies Survey specimens are prefixed by "F" (e.g. F.109.1). Both collections are housed in the Department of Geology, University of Birmingham.

II. UPPER JURASSIC VOLCANIC GROUP

THE apparent succession in the Upper Jurassic volcanic rocks of the Argentine Islands is:

Dacite breccias		Youngest
Dacite crystal tuffs		
Porphyritic andesites	} *interbedded*	
Trachytic andesites		Oldest

These four groups of volcanic rocks can readily be distinguished in the hand specimen. The trachytic andesites are grey to black aphanitic rocks with minor visible pyrite and epidote. The porphyritic andesites can be distinguished by two criteria: they are either porphyritic or the degree of alteration is much greater than in the trachytic andesites. The crystal tuffs can be separated from the breccias on the absence of visible rock fragments in the hand specimen. The tuffs contain crystal fragments in a microcrystalline matrix, whereas the breccias contain visible crystal and rock fragments in an aphanitic base.

Neither layering nor bedding is easily distinguishable in the field. The volcanic rocks are well jointed and it is possible that some of the joints are in fact bedding joints. In a few places bedding can be recognized but the angles and directions of dip are most variable. The individual lava flows and pyroclastic beds also have variable thicknesses. It is not possible to estimate the total thickness of the volcanic sequence from the available field evidence. The joints have developed subsequent to both the intrusion of the plutonic rocks and the later faulting and tilting.

The plutonic intrusion has metamorphosed the volcanic rocks both in The Barchans and the Forge Islands. There is evidence of low-grade metamorphism outside those islands in that minute flakes of biotite occur in the groundmass of most of the rocks. This is quite marked in a zone running through the Shelter Islands, Three Little Pigs, Indicator Island and Grotto Island. There is also some evidence of it at the northern point of Uruguay Island, in the Corner Islands and on the western tip of Winter Island. The slight development of biotite in the country rocks of Leopard Island is probably due to the intrusion of the microdiorite dyke (F.75.1), which does not itself possess any biotite. Metasomatic effects are widespread and are described later (p. 13).

1. TRACHYTIC ANDESITES

The trachytic andesites occur principally in the Three Little Pigs and on Grotto Island but there are a few outcrops elsewhere. They are grey to black aphanitic rocks which may carry secondary pyrite and epidote crystals. Specimen BGLE. 63 has very small felspar phenocrysts and specimen F.72.1 contains a moderate amount of epidote. Under the microscope the main feature of these rocks is their trachytic groundmass texture in which there are subordinate phenocrysts in most specimens. The subhedral plagioclase phenocrysts, which are about 1·0 mm. long, are albite twinned and have a composition range of $Ab_{62}An_{38}$

to $Ab_{68}An_{32}$, though in specimen F.109.1 it is $Ab_{52}An_{48}$. There is usually some secondary alteration to epidote and chlorite. The groundmass plagioclase forms elongated laths about 0·3 mm. long which have simple or multiple albite twinning and a composition range of $Ab_{64}An_{36}$ to $Ab_{72}An_{28}$, but in specimens F.109.1, 3 and F.76.2 the composition range is $Ab_{52}An_{48}$ to $Ab_{54}An_{46}$. There are minor amounts of quartz in the groundmass. The interstices are filled with various ferromagnesian minerals; there are ragged flakes of amphibole with a pleochroism scheme α = straw, β = pale green to yellow-green, γ = bluish green, $\gamma:c = 20°$ and $2V\alpha \simeq 70°$ (F.105.1). The small ragged chlorite flakes are the pale green variety with anomalous birefringence, which is penninite (F.106.1). Titaniferous magnetite grains which may be skeletal are scattered throughout. Very rarely they may be altered to leucoxene, except for specimens from Galindez Island and the north-west corner of Skua Island in which there is heavy alteration to leucoxene. Quite frequently there are clots of amphibole, chlorite and iron ore. Although one ferromagensian mineral may be dominant, all are usually present. There are no detectable pseudomorphs so the original nature of the mafic mineral cannot be inferred. Little flakes of biotite are quite common in the trachytic andesites of the Three Little Pigs and Grotto Island (F.105.3). The biotite forms separate flakes and clots though the latter in association with chlorite is more usual unless the biotite is strongly developed. The biotite is either a pale brown or slightly greenish variety and is indicative of low-grade thermal metamorphism.

There are veinlets and clots of secondary minerals in many specimens. Specimen F.106.1 possesses a vein and numerous clots of quartz, amphibole, chlorite and pyrite, which are coarser-grained in the clots and pass out to the country rock without a marked contact. The amphibole is an actinolite similar to that recorded in the groundmass of these rocks, but it is generally fresher-looking and is secondary. Specimen F.87.2 has an epidote-quartz-amphibole-chlorite vein which has altered the country rock, especially the titaniferous magnetite to leucoxene.

2. Porphyritic Andesites

The porphyritic andesites occur throughout the Argentine Islands. They can be distinguished either by their marked porphyritic texture or by heavy epidote alteration, or by a combination of these two features. The phenocrysts are very abundant in a few of the specimens (F.66.1, F.72.2, F.82.1) and are hypidiomorphic crystals up to 6·0 mm. long (F.72.2). The rocks have a grey to black aphanitic groundmass. Visible secondary alteration may be absent (F.72.2) but in a few cases it is intense (F.68.4).

Under the microscope all these rocks are porphyritic but the groundmass texture varies from fine-grained trachytic to very fine-grained non-trachytic. The groundmass of the typical porphyritic andesites has a very well-developed flow texture of minute plagioclase laths. The subhedral plagioclase phenocrysts, which are up to 3·0 mm. long, have albite and rare combined Carlsbad-albite twins with a composition range of $Ab_{63}An_{37}$ to $Ab_{70}An_{30}$. Often the composition of the phenocrysts cannot be determined because of albitization and the presence of epidote, chlorite, sericite, calcite or a combination of these minerals. Specimen F.109.2 has, in addition, little flakes of actinolite and grains of titaniferous magnetite. The actinolite has a pleochroism scheme α = pale yellow-green, β = pale green, γ = pale bluish green, $\gamma:c = 17°$ and $2V\alpha \simeq 75°$. The hydrothermal solutions which generated this mineral must also have been responsible for depositing the iron ore which is present (p. 14). The groundmass texture and grain-size varies from trachytic plagioclase laths 0·3 mm. long, through finer-grained semi-trachytic laths to a very fine-grained non-trachytic groundmass which carries numerous quartz crystals (F.85.2). The plagioclase laths may be altered in a similar manner to the phenocrysts and the composition of the finer-grained material cannot be determined accurately. The coarser-grained plagioclase has a composition range of $Ab_{66}An_{34}$ to $Ab_{76}An_{24}$ on albite twinning. Primary quartz is rather rare. Two generations of primary magnetite-ilmenite intergrowths have been altered to give lattices enclosing leucoxene which may have recrystallized to rutile (F.109.2). Specimens from Black and Leopard Islands, the south-west corner of Skua Island and Irizar Island contain unaltered titaniferous magnetite. Accessory apatite is quite common and in many specimens it has a dusting of an opaque mineral which gives a pleochroism from purplish black to reddish brown (F.66.1) or from deep red-brown to pale red-brown (F.61.1). Under high power the dusty material can be distinguished as minute reddish brown rods which are orientated parallel to the *c*-axis, and in specimen F.44.3 a basal section shows the rods to be orientated parallel to the three symmetry axes as well. This reddish brown mineral is probably hematite.

Alteration to secondary chlorites is common and gives penninite, a pale green variety with low order colours, and a pale brown chlorite with masked colours. Chlorite, epidote and sulphides often form coarser-grained aggregates and occasional veinlets; at the contacts with dykes pyrite and epidote are usually prominent. Both pyrite and pyrrhotite may occur and frequently there is a late comparatively unaltered magnetite which is associated with secondary minerals (F.44.3; Plate Ia). The more highly altered specimens (F.68.4) have been transformed into epidote-quartz-amphibole rocks which carry relict apatite crystals and leucoxene pseudomorphs after titaniferous magnetite. In many of the specimens there are little patches of secondary minerals round which the groundmass flows. This textural relation is the only real evidence of the pseudomorphing of former ferromagnesian minerals by secondary minerals, with the exception of specimen F.66.1. These pseudomorphs are in combinations of epidote, penninite, calcite and rare serpentine. The usual form of the aggregates is lenticular but the flow texture is often helpful in defining their exact shape (F.44.3). It is not possible to determine precisely the composition of the original mineral. Specimen F.82.1 has several vesicles which have been filled by aggregates of quartz, chlorite, epidote and titaniferous magnetite. Secondary quartz is a minor constituent in most specimens, but in some of those which lie in the low-grade metamorphic zone there is fairly extensive silicification of the groundmass (F.66.1). Some of the silicification is caused by internal redistribution of silica but usually it has been caused by the introduction of silica during metasomatic processes accompanying the intrusion of the plutonic rocks. Specimen F.72.2 is much more heavily silicified than those described above and has the appearance of some of the crystal tuffs. The lack of quartz phenocrysts and angular plagioclase fragments and the remnants of a trachytic texture in the groundmass indicate that this rock is undoubtedly a lava.

The porphyritic andesites which occur in the zone of low-grade metamorphism usually have some biotite in the matrix. It is sparsely developed (F.109.2) even when adjacent to trachytic andesites in which the development of this mineral is stronger (F.109.1, 3). The biotite has either a pale brown or a greenish colour and is similar to that recorded in the trachytic andesites.

Specimens F.66.1 and BGLE.200 possess a few large quartz xenocrysts which are slightly corroded by the groundmass and are cracked and veined by secondary minerals. In specimen F.66.1 there are also pseudomorphs of secondary minerals after ferromagnesian minerals. The secondary minerals are yellowish green chlorite, yellowish green serpentine and minor epidote. The chlorite is either penninite or a yellowish green variety with the birefringence masked by its colour. The serpentine is an antigorite with the characteristic anomalous birefringence. Dusty epidote is conspicuous and altered titaniferous magnetite is often associated with the pseudomorphs, which have a prismatic shape but there are no well-defined cross-sections. They are probably pseudomorphs after clinopyroxene.

In specimen BGLE.108, from Black Island, there is a strong development of epidote, penninite, minor apatite and strings of iron ore grains, which outline some patches of secondary minerals, but elsewhere they merely traverse the matrix in apparently random directions.

Several of the specimens (F.57.1, F.64.1) with a coarser matrix have a patchy appearance, because the plagioclase laths are poekilitically enclosed in a low birefringence and low relief mineral which could be either quartz or potash felspar or an intergrowth of both. The tight packing of the plagioclase laths precludes the determination of the interstitial mineral but on the evidence from specimen F.47.1 it is believed to be quartz. In specimen F.47.1 there are small areas of secondary quartz which are adjacent to the poekilitic patches, some of which are only partially filled. When the poekilitic mineral and quartz have a common boundary there is no detectable difference in relief. It is therefore inferred that the poekilitic mineral is quartz. This quartz is primary and hence these specimens really belong to a sub-group of porphyritic quartz-andesites. In other respects these specimens are similar to the normal porphyritic andesites.

At station F.85 there is a lava flow with characteristics unlike those of the majority of porphyritic andesites. This rock is grey and aphanitic with secondary veinlets. Under the microscope it is a porphyritic rock with small plagioclase phenocrysts in a very fine-grained matrix. The phenocrysts are highly altered and their composition cannot be determined. The matrix is composed of minute felspar laths and quartz crystals, some of which may be partly secondary. There is some altered titaniferous magnetite, accessory apatite and a speckling of chlorite. The veinlets traversing the rock are either of epidote-pyrite-penninite or quartz. The pyrite also forms porphyroblasts in the groundmass.

3. Dacite Crystal Tuffs

The crystal tuffs occur principally on Uruguay and Irizar Islands, but there are also limited outcrops elsewhere in the Argentine Islands. The crystal tuffs, which are clearly distinguishable from the breccias by the absence of visible rock fragments, vary from light-coloured flinty to grey porphyritic rocks carrying crystal fragments in a black aphanitic base. Specimen BGLE.123 carries prominent pyrite cubes, but no other specimen shows marked alteration. Specimens BGLE.71 and 72 are porphyritic and in the hand specimen they might well be confused with the porphyritic andesites. The British Graham Land Expedition specimens from the northern point of Uruguay Island all contain minute felspar phenocrysts in an aphanitic base.

Microscopically, the crystal tuffs exhibit a porphyritic texture with crystals and fragments of plagioclase and quartz in a very fine-grained quartzo-felspathic groundmass. The plagioclase fragments and crystals, which are up to 4·0 mm. long, have a composition of $Ab_{64}An_{36}$, but they are albitized and now enclose saussurite. There is albite and rarely combined Carlsbad-albite twinning in the plagioclase. Some phenocrysts are now completely pseudomorphed by secondary minerals. The quartz crystals and fragments may be corroded and have secondary quartz overgrowths. In the groundmass there is a fine-grained intergrowth of quartz crystals and plagioclase laths with straight extinction. The titaniferous magnetite of these rocks is unaltered except for the specimens from Galindez and Indicator Islands in which the iron ore is altered to leucoxene; they also have secondary pyrite. Chlorite specks and stringers occur throughout the matrix and epidote crystals are common. The groundmass is often silicified.

Specimens BGLE.71 and 72 contain a few small rock fragments of types similar to those described from the dacite breccias. The British Graham Land Expedition specimens from the northern point of Uruguay Island seem to have a high iron content.

In the groundmass of the two specimens, BGLE.109 and 198A, there is biotite, which is brownish green in the former and brown in the latter, where it is particularly well developed. This mineral is clearly a metamorphic product, but the isolation and strong development of biotite in the latter specimen suggests that it might have been caused by the thermal effects of a large dyke nearby rather than by the Andean intrusives. Specimen BGLE.109 was collected within a very short distance of the granodiorite contact and shows less biotite than BGLE.198A.

4. Dacite Breccias

The breccias occur on Uruguay and Irizar Islands and the Corner Islands, and in limited outcrops elsewhere. They are light-coloured to grey porphyritic rocks which carry crystal and rock fragments in an aphanitic base. The matrix may be epidotized but never heavily. The rock fragments may be up to 3·5 cm. long but they are generally rather smaller. The xenoliths are usually of a different colour to the matrix and can be seen quite easily. The rock fragments are microcrystalline and appear to be volcanic types.

Under the microscope these rocks have a microcrystalline base in which the rock fragments and plagioclase and quartz phenocrysts are set. The subhedral plagioclase phenocrysts and fragments, which are up to 2·5 mm. long, are twinned on the albite law and occasionally on the combined Carlsbad-albite law. They have a composition of approximately $Ab_{70}An_{30}$, but in most cases they have been altered very severely to chlorite, sericite, epidote or combinations of these minerals. The quartz fragments and crystals, which are up to 4·0 mm. across, are frequently corroded and embayed by the groundmass and may have developed secondary quartz overgrowths. The groundmass, which is a very fine-grained intergrowth of felspar laths and anhedral quartz crystals, has undergone considerable secondary silicification. Titaniferous magnetite, if present, is partially altered to leucoxene except in a few specimens from Uruguay Island and the Three Little Pigs, where it is fresh. There is a secondary generation of magnetite which is only very slightly altered and is a metasomatic introduction (p. 14). Yellowish green chlorite stringers and specks occur in the groundmass along with crystals of epidote and euhedral pyrite, which is particularly abundant in specimen F.49.3. In specimen F.108.3 brown chlorite and a bluish amphibole are developed near the contact with a dyke. This amphibole has a pleochroism scheme α = yellow-green, β = green, γ = blue, $\gamma{:}c = 18°$ and $2V\alpha \simeq 70°$. It occurs both as veinlets and aggregates and has also developed in the xenoliths (p. 14). Specimen F.89.2, which has a red tinge in the hand specimen, contains a fine dissemination of hematite derived from the breakdown of other iron minerals. This specimen also has a number of sericite pseudomorphs after plagioclase, which are traversed by strings of an unidentified opaque mineral and occasionally by subhedral titaniferous magnetite grains. The titaniferous magnetite must have been introduced, because the plagioclase could not normally hold that amount of iron, but the strings of the opaque mineral may be original to the felspar.

The breccias contain two main types of rock fragments: andesites and silicified tuffs. The andesites are either non-porphyritic trachytic andesites or porphyritic andesites with or without a trachytic groundmass. These rock types are all somewhat similar to those already described from the Argentine Islands, but they present a slightly different appearance; there is less alteration, the plagioclase laths are larger or there is more iron ore. There are also fragments which do not correspond to any rock type recorded from the Jurassic volcanics. These are mostly silicified fragments of which the original nature cannot be determined. The silicified tuff fragments are mostly fine-grained aggregates from the crystal tuffs described above.

The breccias, which occur in the low-grade metamorphic zone, sometimes contain biotite in the matrix (F.105.2). Specimen F.90.2, comparatively close to BGLE.198A, has a minor amount of biotite but very little compared with the latter.

On Uruguay Island there is a dyke (F.92.2, 3, 4), which under the microscope displays all the characteristics of the breccias and could therefore be the choked neck of a volcanic vent. Although the country rocks are also breccias, they must belong to an earlier phase of vulcanicity. The xenoliths in this dyke are similar to those already described but they are more numerous and include dacites as well as andesites.

5. Metamorphosed Andesites

The metamorphic aureole in the Jurassic volcanic rocks of the Argentine Islands extends up to 1,100 yd. (1,006 m.) from their mapped contact with the Andean intrusives, but the specimens from Uruguay Island, which show low-grade metamorphism, are an unknown distance from it. Rocks of moderate grade occur only in The Barchans and the Forge Islands. Low-grade effects are apparent in all groups of the volcanic rocks. They appear both as metasomatic alteration and the development of biotite from chlorite in the groundmass of the rocks. The low-grade metamorphic rocks cannot be classed in the albite-epidote-hornfels facies, because of the persistence of relics of the original lavas.

The hornfelses of The Barchans were originally non-porphyritic trachytic andesites but those of the Forge Islands were porphyritic andesites. These lavas are now plagioclase-amphibole-biotite-hornfelses. Although pyroxene occurs in some of the metamorphosed lavas, it is clearly an original constituent, because these rocks show no features of the pyroxene-hornfels metamorphic grade. The plagioclase shows only marginal recrystallization and at this stage pyroxene does not appear among the metamorphic products. Hence, all these rocks belong to the hornblende facies of contact metamorphism (Fyfe, Turner and Verhoogen, 1958, p. 205–11).

The amphibole-biotite-hornfelses of The Barchans are grey fine-grained rocks which are permeated by acid material from the intrusion and which have a schistosity resulting from the parallelism of biotite flakes and the streaky nature of the permeating material. In places the acid material forms lenticles and veinlets in which there are little flakes of biotite. Microscopically, these rocks have a granoblastic texture of quartz and felspars, in which there are orientated flakes of biotite; in specimen F.34.2 there are some blastophenocrysts of plagioclase. These phenocrysts are up to 2·5 mm. long but they are usually rather smaller. Their simple twinning appears to be according to the Carlsbad law. None of the usual albite twinning is present and it was probably destroyed during metamorphism. There are rare inclusions of amphibole, biotite and iron ore. Some of the plagioclase is heavily saussuritized. The granoblastic groundmass is made up of clear quartz crystals, rounded and slightly altered oligoclase and some metasomatic potash felspar. Biotite flakes which occur in the groundmass have a fairly good orientation, probably representing the original flow texture of the lava. Its pleochroism is usually from α = straw to γ = deep brown, but in specimen F.32.3 there is a green variety (α = straw, γ = green), which occurs only in certain bands and is usually associated with the pyroxene. Amphibole is more common in specimen F.34.2 where there is the usual green hornblende with a pleochroism scheme α = straw, β = brownish green, γ = green, $\gamma{:}c = 23°$ and $2V\alpha \simeq 70°$, and which forms small crystals in the groundmass. There is also a bluish variety with α = straw, β = green, γ = greenish blue to blue, $\gamma{:}c = 22°$ and $2V\alpha \simeq 80°$, which occurs in rather larger crystals and in areas of coarser grain-size, the latter as small lenticles in the hand specimen. Specimen F.34.5 has the latter type of amphibole in which there are cores of a colourless tremolite with $\gamma{:}c = 17°$ and $2V\alpha \simeq 85°$. Only specimen F.32.3 carries pyroxene which occurs as infrequent small individual crystals; it is an augite. It is associated with iron ore and green biotite which are the metamorphic degradation products of the mineral. This pyroxene is probably original to the rock and not a metamorphic mineral. The accessory minerals are magnetite, apatite, sphene and some orthite which has been introduced at a late stage from the granodiorites. Retrograde metamorphism has both altered the biotite to penninite and saussuritized the plagioclase.

There has been some potash metasomatism. In specimen F.34.2 orthoclase replaces the plagioclase phenocrysts as well as occurring in the groundmass as networks of crystals which are in optical continuity. The individual networks are about 1·0 to 2·0 mm. across. Orthoclase forms a high proportion of the rock in specimen F.32.3. Specimen F.34.2 also carries patches of coarser quartz intergrowths which were probably introduced at the same time as the potash felspar.

The hornfelses of the Forge Islands are grey fine-grained rocks which may carry felspar phenocrysts (F.37.1, BGLE.215). These rocks show no orientation except for BGLE.217, which is cut by one thin (0·3 mm. wide) hornblende and several acid veins, and also has undergone some metasomatic changes. The other specimens are cut by narrow acid veins with which a little pyrite and epidote are associated in specimen F.36.2. Microscopically, these rocks have blastophenocrysts of plagioclase in a granoblastic matrix. The plagioclase phenocrysts, which are most numerous in specimen F.37.1, are up to 5·0 mm. long and have a composition range of $Ab_{64}An_{36}$ to $Ab_{67}An_{33}$ on albite twinning. They are marginally recrystallized. The frequent inclusions of amphibole, biotite and iron ore represent the original breakdown products of the mineral. The granoblastic matrix is composed of small quartz crystals, rounded oligoclases, some introduced potash felspar and various ferromagnesian minerals. There are small brown biotite flakes, sometimes coarser and poekilitic to quartz and felspar and in aggregates (F.36.2). There are two varieties of amphibole: one is the common green hornblende with a pleochroism scheme α = straw, β = brownish green, γ = green, $\gamma{:}c = 26°$ and $2V\alpha \simeq 75°$, which occurs as small crystals, as poekiloblasts (F.36.4) and as aggregates, and is often associated with biotite and iron ore; the other variety has a pleochroism scheme α = straw, β = green to olive-green, γ = greenish blue to blue, $\gamma{:}c = 22°$ (F.36.2) and occurs mainly near an acid vein in the specimen. There are a few colourless augite crystals ($\gamma{:}c = 40°$) in specimen F.37.1 and these may form cores to the green hornblende crystals. The accessory minerals are magnetite, apatite, sphene and rare orthite which has been introduced by the granodiorites. There has been some degree of retrograde metamorphism, giving chlorite after biotite (F.36.4) and some alteration of the blastophenocrysts.

The metasomatic effects are more pronounced in some specimens than in others. Potash has been introduced into most specimens and forms small porphyroblasts (BGLE.215), poekilitic networks and small crystals of potash felspar. It is absent from the specimens which have been taken from contacts with dykes. Quartz has also been introduced and forms porphyroblasts and poekiloblasts (F.36.5). There has been some migration of soda, giving the bluish amphibole which is discussed under the metasomatism of the volcanic and hypabyssal rocks (p. 14). In specimen F.36.2 there are two veins, one of which carries clevelandite with enclosed quartz, oligoclase, amphibole and biotite and has associated pyrite crystals. It is heavily saussuritized. The other is a quartz-plagioclase-potash felspar vein, in which the potash felspar is clearly replacing the plagioclase and also passes outward into poekiloblastic crystals in the groundmass. Specimen BGLE.217 is the contact of a coarser acid vein and the metamorphosed lava. The vein contains small plagioclase crystals ($Ab_{56}An_{44}$) embedded in poekilitic quartz. There are minor amounts of comparatively coarse chloritized biotite and farther away from the contact there is some potash felspar. The quartz appears to replace the plagioclase. Quartz poekiloblasts can be traced from the vein into the country rocks, one part of the crystal being free of inclusions, whereas the other is crowded with plagioclase and iron ore.

From the veining and its relationship to the country rocks it is clear that both silica and alkalis have been introduced by the plutonic rocks. These effects are most marked in the heavily permeated rocks of The Barchans.

III. PRE-ANDEAN HYPABYSSAL ROCKS

1. Microdiorites

The pre-Andean hypabyssal rocks are mainly microdiorite dykes and sills of variable thickness. The dykes are up to 20 ft. wide and occur mainly on Winter and Skua Islands. They are generally near vertical and strike in a north-east to south-west direction. There are several dykes on Winter and Skua Islands which are characterized by xenoliths of basic and acid rocks. Although the strike of these dykes varies slightly, when their positions are plotted they are obviously all the same intrusion. The dykes on Winter Island are vertical, whereas those on Skua Island dip at between 50° and 55°. The evidence for bedding in the Jurassic volcanic rocks is rather meagre and when the bedding is restored to a horizontal position there is no better coincidence in dip and strike of the dykes. This may be due either to incorrect values for the dip and strike of the bedding or to the disturbed nature of the volcanic rocks at the time of their intrusion. The sills are probably thicker than the dykes, but exact measurements could not be taken because of the snow cover. They are almost horizontal or dip gently. One sill on Galindez Island can be traced across the island and possibly into the nearby ones where the microdiorite sills dip gently.

At station F.75 on Leopard Island a 12 ft. wide dyke is surrounded by a brecciated zone, which is about 3 to 4 ft. wide and composed of pale angular fragments in an epidotized base. It is probable that post-consolidation movement along the dyke plane caused brecciation of the country rock and formed channelways for the hydrothermal solutions that have been responsible for the epidotization. A small dark aphanitic dyke nearby has 6 in. xenoliths of an acid plutonic rock.

In The Barchans and the Forge Islands the Andean Intrusive Suite has metamorphosed the dykes to a moderate grade but elsewhere the only evidence of metamorphism is the slight development of biotite in the groundmass of some of the specimens in the low-grade metamorphic zone. Although the country rocks on Leopard Island (F.75) show slight metamorphism, the dyke does not, which suggests that the metamorphism was caused by the dykes.

In the hand specimen these dykes and sills are greenish grey to black aphanitic rocks, which often carry small felspar phenocrysts and secondary epidote and chlorite crystals. Petrographically, the microdiorite dykes and sills are rather variable, and are divisible into two groups on the type of alteration. The more common but more heavily altered types are centred round Galindez, Winter and Indicator Islands.

The more common types have plagioclase phenocrysts in a fine-grained groundmass with an intergranular texture, in which the ferromagnesian minerals are represented by epidote and chlorite. Specimens from the centres of the intrusions have a distinctive groundmass texture of intergranular stumpy plagioclase microlites with interstitial quartz (F.57.2; Plate Ib). The plagioclase phenocrysts which are up to 4·0 mm. long and have a composition ranging from $Ab_{53}An_{47}$ to $Ab_{60}An_{40}$ in the less altered crystals. The phenocrysts are highly altered and albitized, and now enclose combinations of sericite, penninite and pistacite. The groundmass plagioclase has similar properties. Clear quartz crystals occur interstitially. There are a few ragged amphibole flakes with a pleochroism scheme α = very pale straw, β = pale brownish green, γ = pale green, $\gamma{:}c = 16°$ and $2V\alpha \simeq 75°$. The abundant iron ore is a titaniferous magnetite which is normally altered to leucoxene (F.49.4), although a little sphene occasionally occurs as rims. Apatite needles are a common accessory. The secondary minerals are penninite, pistacite and pyrite. The two former minerals are the breakdown products of the ferromagnesian minerals. There are associated veinlets of the secondary minerals already mentioned and a few clots which carry, in addition, an unaltered actinolite with a pleochroism scheme α = straw, β = yellow-green, γ = green and $\gamma{:}c = 20°$.

One dyke (BGLE.201) has plagioclase phenocrysts with a composition of $Ab_{46}An_{54}$, while several others (F.70.2 (Plate Ic), F.71.2) carry phenocrysts of augite and rounded brown hornblende. The augite crystals ($\gamma{:}c = 44°$ and $2V\gamma = 58°$) are altered to a green amphibole, penninite and calcite. The hornblende crystals have a pleochroism scheme α = straw, β = red-brown, γ = brown, $\gamma{:}c = 17°$, $2V\alpha = 86°$ and twinning on (100). These crystals are also marginally altered to green amphibole and penninite. The penninite and the ragged green amphibole laths may pseudomorph both the pyroxene and the hornblende. The green amphibole has a pleochroism scheme α = straw, β = brownish green, γ = bluish green, $\gamma{:}c = 14°$, $2V\alpha = 70°$ and twinning on (100). The iron ore is only partially altered to leucoxene in these dykes, whereas in specimens BGLE.201 and π.24.4 rutile has crystallized from the alteration products of the iron-bearing minerals.

The margins of these dykes have a finer-grained intergranular to trachytic groundmass which lacks the characteristic quartz (F.8.1). A few dykes (F.43.2, F.55.2, F.90.2) are similar in that they have phenocrysts of plagioclase in a trachytic groundmass but they are rather coarser in texture. These dykes were cooled sufficiently rapidly for the characteristic texture not to develop. The plagioclase phenocrysts are smaller, have a composition range of $Ab_{50}An_{50}$ to $Ab_{56}An_{44}$ and are not so heavily altered. The groundmass composition is similar except for the absence of quartz and less alteration. The actual dyke contacts may be marked by a zone of glass not more than 0·5 mm. wide; this may have an accumulation of either plagioclase phenocrysts or epidote crystals. The contact is always irregular and stringers of the dyke often pass into the country rock. There are no contact metamorphic effects but there is some degree of brecciation at the contacts of most dykes.

The less common porphyritic types (F.95.2 (Plate Id), F.110.1) have medium-sized plagioclase and amphibole phenocrysts set in a fine-grained groundmass with an intergranular texture of plagioclase laths. The plagioclase phenocrysts and groundmass laths have a similar composition range to the more common dykes but they do not show marginal zoning. The amphibole has similar properties to the secondary green actinolite described above. There are only a few remnant cores of augite ($\gamma{:}c = 42°$) in the green amphibole (F.110.1) and only one completely pseudomorphed cross-section of a pyroxene crystal has been observed (F.75.1). The groundmass has less quartz, chlorite and epidote than the more common types but more secondary actinolite. Sphene rims or leucoxene may form round the numerous titaniferous magnetite grains.

The correlation of the two groups of microdiorites is rather tenuous. The second group shows magmatic hydrothermal alteration of the ferromagnesian minerals with only rare occurrences of remnants of the pre-existing minerals. The first group shows less magmatic alteration, since pyroxene and brown hornblende crystals are still preserved, but often with rims of actinolite similar to the pseudomorphs after those minerals. Later hydrothermal alteration has given rise to the secondary minerals. Both groups crystallized from wet magmas because they contain abundant iron ore and show magmatic alteration of the ferromagnesian minerals. These differences may be due to the reaction rims preserving the phenocrysts and the secondary hydrothermal alteration obliterating the interstitial amphibole originally present in the rocks. These rocks are discussed further on p. 27.

2. Metamorphosed Microdiorites

Metamorphosed dykes occur in the aureole in The Barchans and the Forge Islands but they do not show the low-grade effects observed in the volcanic rocks forming the zone parallel to the contact. These dykes are all hornblende-plagioclase-hornfelses which were originally microdiorites.

In the hand specimen these hornfelses are porphyritic with felspar phenocrysts in a grey to black aphanitic base. Under the microscope the texture is blastoporphyritic with a diablastic matrix of felspar and ferromagnesian minerals, of which an amphibole is dominant. The plagioclase phenocrysts, which are up to 4·0 mm. long, are twinned and in some specimens they are zoned at the edges (F.34.8; $Ab_{51}An_{49}$ to $Ab_{68}An_{32}$). The composition usually ranges from $Ab_{46}An_{54}$ to $Ab_{68}An_{32}$ and marginal recrystallization of the phenocrysts has taken place (F.41.2). They have inclusions of biotite, amphibole, iron ore and apatite. The first three minerals are metamorphosed degradation products of the original phenocrysts. There is also a fine dusting of an opaque mineral which under high power appears as minute (0·02 mm.) rods of a pale red mineral, which is probably hematite. These rods are orientated in three directions which appear to be parallel to the cleavage planes. This phenomenon is metamorphic clouding. The small subhedral groundmass plagioclase crystals are more acid and have a composition range of $Ab_{52}An_{48}$ to $Ab_{69}An_{31}$. There is a minor amount of quartz which tends to occur in mosaics together with the groundmass plagioclase. A green hornblende, the dominant amphibole, has a pleochroism scheme α = straw, β = brownish green, γ = green, $\gamma{:}c = 17\text{–}30°$ and $2V\alpha \simeq 75°$. It forms anhedral crystals which frequently occur in aggregates in association with other ferromagnesian minerals. Biotite flakes, which are pleochroic from α = straw to γ = deep brown, are prominent in specimens F.34.3 and 8, but they are only a minor constituent in specimens F.36.3 and F.41.2. Titaniferous magnetite is a prominent accessory, together with apatite and minor sphene. There is a little pyrite in specimen F.34.2. Saussuritization of some of the plagioclase (F.34.4) indicates there has been some retrograde metamorphism.

In specimen F.34.8, which is the contact facies of specimen F.34.3, the rock has a schistose texture which represents the original flow texture at the edge of the dyke. It is a biotite-hornfels in which the biotite flakes are set in a quartz-felspar granoblastic matrix. The plagioclase rarely shows twinning and has a composition of $Ab_{72}An_{28}$.

Specimen F.36.3 has a rather different mineralogical composition. The green hornblende has a sieve structure enclosing iron ore grains and small plagioclase crystals. It often has a core of very pale, faintly pleochroic actinolite (γ:c = 18°), which itself may have a pyroxene core. Both ortho- and clinopyroxene are present in this specimen. The orthopyroxene, a hypersthene which is pleochroic from α = pink to γ = pale green with a 2Vα $\simeq$ 70°, forms separate crystals and cores to amphibole crystals. Frequently it encloses very small flakes of a brown mineral, which occur at the margins of the crystals and also in the actinolite. They seem to be formed during the breakdown of hypersthene and the colour of the actinolite suggests that they may be an iron mineral. Thermal metamorphism has altered the hypersthene to actinolite and there is some post-metamorphic development of bastite from hypersthene. The clinopyroxene also forms separate crystals and cores to amphibole crystals. It is a colourless augite with γ:c = 39° and 2Vγ $\simeq$ 60° and may be altered to actinolite. The augite more usually forms separate crystals and skeletal grains up to 1·5 mm. across. The interstices are filled with groundmass plagioclase and iron ore. The contacts of this dyke (F.36.4, 5) have a diablastic texture composed of plagioclase and green hornblende with abundant iron ore grains. The actual contacts show increased iron ore and slightly more retrograde metamorphism.

The metamorphosed dykes all belong to the hornblende grade of contact metamorphism (Fyfe, Turner and Verhoogen, 1958, p. 205–11). Although specimen F.36.3 carries both orthopyroxene and clinopyroxene, it shows only the breakdown of these minerals. At the pyroxene-hornfels grade the plagioclase blastophenocrysts are recrystallized and new pyroxene forms small grains in the matrix. Neither condition applies to this rock in which the clinopyroxene is conspicuously skeletal and in the process of degradation.

The metamorphosed dykes do not show the metasomatic effects noted in the Jurassic volcanic rocks. The absence of metasomatism must be due to the impermeability of the dykes to the metasomatizing solutions.

The metamorphosed lavas of the Forge Islands (BGLE.215) enclose sheets or bands about 6 in. wide (BGLE.216), which are rather more basic and darker in colour and are cut by veins of pegmatite material. Microscopically, the rocks forming these sheets are a granoblastic intergrowth of plagioclase and hornblende. The felted plagioclase laths have a composition of $Ab_{62}An_{38}$. The hornblende is the typical green variety of the metamorphosed dykes. Brown biotite flakes and magnetite grains are embedded in the matrix. There has been a minor amount of retrograde metamorphism giving chlorite and epidote. The pegmatite veins crossing the rock comprise quartz, amphibole and biotite. They are much coarser-grained and in the centre of the veins they have coarse ferromagnesian minerals surrounded by quartz which passes out into the country rock as poekiloblastic crystals enclosing laths of the groundmass plagioclase. In these areas the groundmass ferromagnesian minerals are absent and it appears as though the amphibole and biotite have been dissolved and redeposited as large crystals in the centre of the vein. The amphibole in the vein is partly the normal green hornblende and partly a very faintly pleochroic actinolite (γ:c = 17°) which is rimmed by a pale bluish green actinolite. In the vein there are a few augite crystals, some of which are embedded in quartz and others form cores to amphibole crystals. An apparent cross-section of a vein shows a similar concentric arrangement of the minerals but with the addition of some plagioclase crystals ($Ab_{63}An_{37}$) coarser than the groundmass plagioclase.

IV. METASOMATISM

THE intrusion of the plutonic rocks of the Andean Intrusive Suite was accompanied by widespread metasomatic effects both in the Jurassic volcanic rocks and the pre-Andean microdiorites. The different minerals resulting from metasomatism are discussed in the description of each group of rocks.

Albitization is perhaps the most widespread effect and all the specimens examined microscopically show some degree of alteration in the plagioclase. Albitization could result from the reaction of CO_2-rich solutions with the anorthite molecule to give calcite and albite-enriched plagioclase. This is apparently of minor importance, because there is comparatively little calcite in any of the specimens; only in one case is there albite unaccompanied by secondary minerals in intimate association (F.92.6). Alternatively, lime and alumina could be replaced by soda and silica. This seems to be the more usual mechanism, because epidote normally accompanies the altered plagioclase. The other secondary minerals are pale green penninite, sericite and rare calcite.

Epidote, a colourless to pale yellow pistacite, occurs frequently. As well as being a common alteration product in these rocks, it forms veinlets with which quartz, chlorite, pyrite and amphibole are associated.

The vesicles in specimen F.82.1 have been filled by these minerals and magnetite grains. The yellow colour of the pistacite is possibly due to iron derived from the iron ore already present in the rocks.

Pyritization is fairly widespread and normally accompanies the epidotization. Normally pyrite is not so abundant in the pyroclastic rocks, but in specimen F.49.3 the pyritization is fairly severe. Pyrrhotite may accompany the pyrite, particularly in the porphyritic andesites (F.1.3, F. 61.1).

Silicification is of minor importance in the lavas but in the pyroclastic rocks it is very noticeable. Internal redistribution and secondary introduction of silica took place, though the lavas usually show only the latter feature. Quartz usually occurs in the veinlets of secondary minerals.

An actinolitic amphibole often occurs together with the secondary minerals; it has a pleochroism scheme α = straw to yellow-green, β = brownish green to green, γ = bluish green to blue (F.108.3). The bluish colour of an amphibole, normally related to soda content, is additional evidence for the mode of albitization discussed earlier. The actinolite is usually fairly fresh and lacks the ragged appearance of the actinolite which pseudomorphs pyroxene and amphibole crystals.

Magnetite has also been introduced during metasomatism. It occurs both in the vesicles of specimen F.82.1 and in the altered plagioclase phenocrysts of specimen F.109.2, both of which are porphyritic andesites. It is also present as slightly altered grains in the volcanic rocks, accompanying titaniferous magnetite which is almost completely altered to leucoxene.

Potash has been introduced into the metamorphosed andesites of The Barchans and the Forge Islands, where potash felspar forms small crystals, porphyroblasts and poekilitic networks. The chemical analyses (Table II) show that potash may also have been introduced into the more altered pre-Andean microdiorites (p. 11).

One side effect of metasomatism has been the formation of coarse epidote, quartz, pyrite, garnet and calcite in the lavas and breccias at one locality (F.151) in the Three Little Pigs. These minerals are often well crystallized and are concentrated at the contact of the two volcanic rock types.

The distribution of the secondary minerals indicates that there is a distinct zoning of the metasomatic effects. In a centre round Galindez, Winter and Indicator Islands and the north side of Skua Island the alteration is most intense, and passing out from that centre the degree of alteration decreases. This feature is most clearly seen in the intrusive microdiorites where there is a change in the type of alteration (p. 12), but the effect can be picked up in the lavas by the absence of alteration to the primary titaniferous magnetite and lack of secondary magnetite in the rocks farthest from the centre of alteration. The centre of alteration must have been an area particularly susceptible to the metasomatic process and, since there is no clear difference in the rocks of that area, it is probable that the control is structural and associated with the emplacement of the Andean plutonic rocks.

V. THE ANDEAN INTRUSIVE SUITE

THE Andean Intrusive Suite occurs only in The Barchans, the Forge Islands and the Anagram Islands. There is no direct evidence of its age but elsewhere there is evidence of a late Cretaceous to early Tertiary age (Adie, 1955). In the Argentine Islands it ranges in composition from gabbroic to granodioritic. Gabbros, norites and tonalites occur only in the Anagram Islands (Fig. 6) and granodiorites principally in The Barchans and the Forge Islands.

Contacts between the individual plutonic rocks of this suite occur only in the Anagram Islands. Although all these contacts are concealed beneath a snow cover, there is evidence of a gabbro-tonalite contact in that there are veins of acid material in the gabbro and xenoliths of gabbro in the tonalite. The contact of the granodiorite with the Jurassic volcanic rocks has been observed in the Forge Islands and The Barchans, but nowhere is it sharp. The volcanic rocks are often shattered and have been veined and permeated by acid material. The metamorphic aureole extends to a line running through Leopard Island, including the Three Little Pigs and Indicator Island, to Grotto Island. Medium-grade metamorphic rocks occur only in the Forge Islands and The Barchans. Metasomatism of the volcanic country rocks is widespread.

Apart from the gabbro-tonalite contact in the Anagram Islands, there is no evidence of the order of intrusion of the plutonic rocks. Adie (1955) has put forward evidence for a normal basic to acid calc-alkali trend for the Andean Intrusive Suite and it is most likely that there is a similar trend in the Argentine

TABLE I

MODAL ANALYSES OF ROCKS OF THE ANDEAN INTRUSIVE SUITE

Specimen Number	F.40.1	F.33.1	F.32.2	F.35.1	F.19.1	F.30.1	F.38.1	F.21.2	F.22.2	F.29.1	F.28.1	F.25.1	F.18.1	F.10.1	F.16.1	F.114.1	F.117.1	F.115.1	F.116.1
	Granodiorites and Tonalites																	*Gabbroic Rocks*	
Distance from Contact (yd.)	10	20	20	70	120	205	440	440	575	575	700	880	1,100	1,150	2,200	3,500	5,500	—	—
Quartz	25·1	18·8	18·7	18·7	18·7	19·6	17·1	19·2	21·6	18·4	19·2	18·5	17·2	18·7	17·6	23·0	22·6	0·5	—
Orthoclase	6·0	12·4	13·6	15·4	6·8	14·0	7·3	11·2	9·2	11·8	9·5	8·3	9·7	12·8	12·4	12·8	5·2	—	—
Plagioclase	53·9	48·7	42·0	53·9	52·5	41·6	56·0	48·0	51·1	48·5	51·1	49·7	50·8	47·0	55·5	53·0	54·9	70·5	59·7
Clinopyroxene	0·3	—	1·6	tr	*	0·9	0·1	0·2	tr	—	tr	1·2	—	0·1	*	1·1	0·3	10·2	3·2
Orthopyroxene	tr	—	—	—	—	*	—	—	—	—	—	—	—	—	—	1·3	—	5·6	0·3
Hornblende	4·6	4·1	12·8	6·0	11·0	11·8	8·4	9·7	7·7	9·1	10·0	12·5	11·1	11·1	7·7	3·5	8·6	—	—
Brown Hornblende	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	tr
Green Amphibole	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4·4	27·6
Biotite	7·3	0·7	8·4	3·7	3·7	9·8	4·7	4·1	5·1	9·1	6·3	7·4	1·4	7·0	1·6	2·6	6·8	5·6	0·4
Chlorite	0·9	12·8	0·6	0·7	4·9	0·7	4·4	4·9	3·2	0·9	2·3	0·2	7·4	1·0	2·6	*	0·2	—	1·5
Iron ore	1·7	1·4	1·7	1·4	1·7	1·5	1·2	1·6	0·6	1·8	1·1	2·0	0·8	1·7	1·2	2·6	1·4	—	—
Magnetite	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3·1	5·2
He[illegible]ite	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	*	0·1
Pyrite	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·1
Sphene	*	*	0·2	tr	0·3	tr	0·2	0·4	0·2	0·2	0·2	0·1	0·4	0·2	0·8	*	tr	—	—
Epidote	0·2	0·8	0·2	tr	0·1	tr	0·5	0·4	1·1	0·2	0·1	tr	1·1	tr	0·3	—	—	—	tr
Sericite	—	—	—	—	—	—	—	—	—	—	—	—	—	0·3	—	—	—	—	—
Serpentine	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	*	1·5
Apatite	tr	0·1	0·3	0·1	tr	0·1	tr	tr	0·1	tr	tr	tr	tr	tr	0·1	tr	tr	0·1	0·4
Zircon	*	*	*	*	tr	tr	tr	0·1	0·1	tr	0·1	tr	tr	0·1	tr	*	*	—	—
Plagioclase composition	An_{32}	An_{33}	An_{40}	An_{33}	An_{41}	An_{40}	An_{39}	An_{30}	An_{25}	An_{42}	An_{45}	An_{35}	An_{38}	An_{33}	An_{34}	An_{40}	An_{32}	—	—

tr Trace.
* Present but not recorded.

[*Facing page 14*

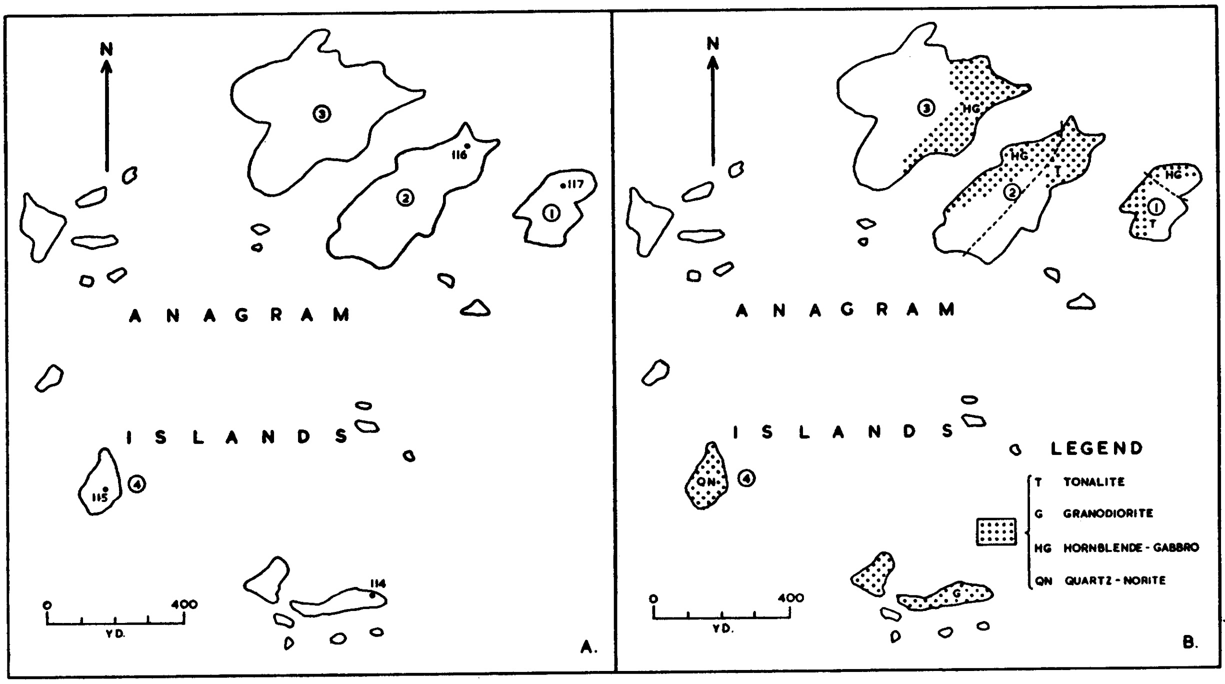


FIGURE 6

A. Sketch map of the Anagram Islands (see Fig. 1) showing the positions of the 1958–59 geological stations.

B. Geological sketch map of the Anagram Islands.

Islands. A number of modal analyses (Table I) have been carried out on these rocks but are considered to be of limited value, because of the heterogeneity of the rocks themselves.

Post-Andean dykes cut the plutonic rocks but apart from slight brecciation and rare hydrothermal alteration they have no effect. The plutonic rocks are well jointed and a contoured diagram of the poles to the joint faces shows two maxima (dip 78° to 350° mag. and 46° to 294° mag.). The poles to the dyke planes were also plotted and contoured but they show no significant maximum and it is not possible to relate the dykes to the joints. No dyke was found which cut the plutonics/volcanics contact.

There are a few late acid veins: specimen F.38.1 carries a 1·0 cm. wide veinlet of potash felspar and specimen F.41.3 shows an aplite vein cutting the country rocks. This aplite vein was reinjected by a 7·0 mm. veinlet of hornblende-bearing aplite. There is also a quartz vein (F.151.1) which shows comb structure and contains occasional vugs with fairly well terminated quartz crystals. Minor mineralization is associated with the Andean Intrusive Suite. Molybdenite occurs along some joint planes (F.38.4) and in a few specimens (F.20.4, F.25.2, F.29.2) there are veins of quartz which carry magnetite, a little pyrites and epidote. This magnetite is additional evidence of the mobility of iron which was mentioned on p. 14.

1. QUARTZ-NORITE

The only quartz-norite (F.115.1) occurs on Anagram Island (*4*) and is a grey medium-grained rock which carries visible felspar and amphibole crystals. Under the microscope this is a medium-grained rock with a hypidiomorphic texture of interlocking crystals in which there is a tendency for the ferromagnesian minerals to occur in clots. The anhedral plagioclase crystals, which are up to 1·5 mm. long, are twinned on the albite, combined Carlsbad-albite or pericline laws and are also zoned ($Ab_{40}An_{60}$ to $Ab_{56}An_{44}$). They have a fine dusting of iron ore* which is absent from the margins of the crystals. The crystals may enclose grains of pyroxene, amphibole, biotite and iron ore. Both ortho- and clinopyroxene are present.

* This opaque mineral occurs as minute rods less than 0·02 mm. long and they appear to be orientated parallel to the cleavage planes. This is probably hematite.

The orthopyroxene is a pleochroic hypersthene with α = pale pink, γ = pale green, and $2V\alpha \simeq 70°$. The hypersthene crystals are up to 2·0 mm. long but they are more usually 1·0 mm. The hypersthene is altered first to a green hornblende and then to biotite. The crystals may enclose iron ore, plagioclase blebs and quartz to give a sieve structure, and a few of the larger crystals develop a subophitic texture. The crystals and aggregates may have a symplectic iron ore intergrowth in their cores. One aggregate had the symplectic iron ore, a vermicular intergrowth of quartz and an unidentifiable mineral of much higher relief, and a serpentinous mineral (bastite). There is also incipient alteration to bastite in grains which have the usual rims of amphibole and biotite. The clinopyroxene is a colourless augite up to 1·0 mm. long with $2V\gamma \simeq 60°$ and $\gamma{:}c = 42°$. These crystals are smaller than those of hypersthene with which it is often associated, and they enclose numerous iron ore grains. Alteration to amphibole is much less marked, though that mineral does occur as an alteration product both at the rims and in the cores. The amphibole is a green hornblende with a pleochroism scheme α = brownish yellow, β = brownish green, γ = green, $2V\alpha \simeq 75°$ and $\gamma{:}c = 27°$. The amphibole occurs both as rims to the pyroxene and as crystals with pyroxene cores. Its alteration product is biotite, which is pleochroic from α = straw to γ = red-brown. Apart from the breakdown of pyroxene and hornblende it also mantles iron ore. The iron ore occurs as rounded grains and symplectic intergrowths. It shows neither leucoxene alteration nor sphene rims but as it occurs in a norite it is probably ilmenite. Accessory amounts of quartz occur interstitially and there are a few apatite crystals and a trace of secondary hematite. The rock is quite fresh and shows no secondary alteration so the breakdown of pyroxene to amphibole and then to biotite is clearly a magmatic alteration process. A modal analysis of this specimen is given in Table I.

2. Hornblende-gabbro

The only hornblende-gabbro (F.116.1) which occurs on Anagram Island (*2*) is a grey medium-grained rock which carries visible felspar and amphibole crystals. Under the microscope the hornblende-gabbro has a hypidiomorphic texture in which the ferromagnesian minerals tend to occur in clots. The anhedral plagioclase crystals, which are up to 1·5 mm. long, are twinned and zoned ($Ab_{36}An_{64}$ to $Ab_{57}An_{43}$). Albite, combined Carlsbad-albite and pericline twins occur. All the crystals are unaltered but they have a dusting of an opaque iron ore which is absent at the margins of the crystals. Both hornblende and actinolite are present. The former has a pleochroism scheme α = pale straw, β = brownish green, γ = green, $2V\alpha \simeq 60°$ and $\gamma{:}c = 28°$. It occurs as aggregates and occasionally as separate grains in the rims of actinolite aggregates. The actinolite occurs as aggregates of grains and laths and is an alteration product of orthopyroxene. The aggregates have a core of actinolite which has a pleochroism scheme α = colourless, β = very pale brownish green, γ = very pale bluish green, $2V\alpha \simeq 80°$ and $\gamma{:}c = 17°$. The core is mantled by an actinolite which has deeper colours and a pleochroism scheme α = pale straw, β = pale brownish green, γ = pale bluish green, but the two varieties of actinolite are often in optical continuity and the only difference is in the depth of colour. Both the paler- and deeper-coloured varieties of actinolite may occur as alteration products of single orthopyroxene crystals and the deeper-coloured actinolite often mantles the former variety. Both orthopyroxene and clinopyroxene are present though the former is less common than the latter. The orthopyroxene is a pleochroic hypersthene with α = very pale pink, γ = very pale green and with $2V\alpha \simeq 70°$. The hypersthene is altered either to bastite or the pale actinolite. Both alteration products occur together in a single aggregate and the bastite may be rimmed by the amphibole. The bastite is the alteration of hypersthene already rimmed by amphibole. The bastite forms fibrous aggregates which finger out into the surrounding minerals. The alteration to actinolite is accompanied by the release of minute iron ore granules which form a dusting round the hypersthene cores. The clinopyroxene is a colourless augite which is twinned on (100), has $2V\gamma \simeq 60°$ and $\gamma{:}c = 48°$. It is always marginally altered to an amphibole which is not the usual fibrous uralite but a pale actinolite. The alteration of the augite proceeds in stages from a thin rim to a large amphibole crystal, which is mottled with the remnants of the pyroxene crystal. The initial alteration of the augite gives rise to the very pale pleochroic actinolite or the deeper-coloured variety, though the former is often mantled by the latter. The ferromagnesian minerals occur in knots and aggregates of crystals enclosing iron ore grains and rare magmatic brown hornblende, as well as a few flakes of brown biotite. The biotite which is pleochroic from α = straw to γ = brown may be secondary after amphibole and also rims iron ore. The iron ore occurs as grains in amphibole and pyroxene crystals and as large anhedral grains moulded on to subhedral amphibole and pyroxene crystals in mafic aggregates like those in specimen F.115.1. It shows neither leucoxene alteration nor sphene rims, but as it occurs in a gabbro it is probably ilmenite. Penninite occurs as an alteration product of amphibole and biotite. The accessory minerals are apatite and pyrite in association with hematite and epidote. A modal analysis of this rock is given in Table I.

3. GRANODIORITES

The granodiorites occur in the Forge Islands and The Barchans. They are leucocratic medium-grained rocks which carry visible quartz, felspar, amphibole and biotite. Under the microscope all the granodiorites have a granitic texture. The quartz is clear and forms anhedral grains. It may be in graphic intergrowth with either orthoclase (F.10.1, F.38.1) or plagioclase (F.28.1) and may replace (F.15.2, F.38.1) or be poekilitic to the latter (F.10.1).* Frequently the quartz shows an undulose extinction which indicates slight straining. The potash felspar, which is usually sericitized, is an orthoclase perthite carrying small blebs of exsolved plagioclase. Very rarely it may have a myrmekitic intergrowth with plagioclase (F.35.1, F.38.1, BGLE.103) but more commonly it encloses the latter poekilitically (F.28.1). In nearly every specimen the orthoclase replaces plagioclase (F.10.1 (Plate Ie), F.18.1) and the textural relations show orthoclase cutting across the plagioclase twinning and a careous boundary between the two felspars. The plagioclase crystals are twinned and zoned with a composition range of $Ab_{54}An_{46}$ to $Ab_{77}An_{23}$, although it reaches a composition of $Ab_{84}An_{16}$ in specimen F.33.1. Both albite and combined Carlsbad-albite twins are present and the zoning may be oscillatory (F.18.1). Often the twinning almost completely disappears at the margins of the crystals. The textural relations with quartz and potash felspar have been mentioned already but in addition the plagioclase sometimes has very small, clear and untwinned crystals of albite at its contact with orthoclase (F.28.1, F.35.1, BGLE.103). These have been exsolved from the orthoclase in the late cooling stages of the rock. At the edge of one crystal in specimen F.10.1 the plagioclase has a zone which has a suggestion of twinning in it. This zone, which has a higher relief than the potash felspar with which it is in contact and a slightly lower relief than the twinned plagioclase, is albite and is a very late-stage replacement of the plagioclase. Saussuritization is common. Rarely, a few epidote grains may occur but in one specimen (F.16.1) there is some highly altered plagioclase together with the more normal andesine-oligoclase. These heavily altered crystals are almost certainly more basic xenocrystic material. There are also a few xenocrysts (F.19.1) which enclose small rounded crystals of pyroxene and amphibole and are zoned from $Ab_{36}An_{64}$ to $Ab_{70}An_{30}$.

Amphibole is the commonest ferromagnesian mineral. In every specimen there is evidence of its secondary origin, for there are cores of pyroxene and actinolite in crystals and aggregates of amphibole. The dominant amphibole, which forms anhedral crystals and laths, is a pale hornblende with a pleochroism scheme α = straw, β = brownish green, γ = green, $2V\alpha \simeq 80°$ and $\gamma{:}c = 27°$. The individual crystals of the aggregates may have a core of actinolite which is very faintly pleochroic with α = colourless to very pale straw, β = very pale brownish green, γ = very pale green, and which often passes to a deeper-coloured variety with α = pale straw, β = pale brownish green and γ = pale green but with similar optical properties in other respects ($2V\alpha = 74°$, $\gamma{:}c = 18°$ from Universal Stage measurements on specimen F.19.1) (F.19.1, F.21.2, F.28.1). The amphibole tends to occur in knots and aggregates (F.19.1; Plate If), in which there is a core of pyroxene or actinolite or both, surrounded by the green hornblende. Both the actinolite and the hornblende may be granular. In specimen F.28.1 the amphibole is glomeroporphyritic; elsewhere a sieve texture is fairly frequent (F.21.2, F.38.1A). Occasionally there is a symplectic iron ore intergrowth in the actinolite (F.19.1) though more usually it occurs as small grains enclosed in the latter. The amphibole breaks down to either biotite or chlorite and sphene. The comparatively rare orthopyroxene (F.40.1, F.114.1) is a faintly pleochroic hypersthene, which is altered to a slightly pleochroic actinolite which in turn passes to a deeper-coloured variety and finally to green hornblende; it may be cracked and veined by bastite, which is later than the amphibole minerals (F.30.3). The actinolite is formed when there is a rim of hornblende so that the alteration takes place without the external influences which give the green hornblende. The clinopyroxene is a colourless augite with $\gamma{:}c = 40°$. Occasionally it occurs as cores in the amphibole which may have a mottled appearance (F.19.1). In specimen F.32.2A there is much more augite which occurs as crystals up to 2·0 mm. long, with $2V\gamma \simeq 60°$, $\gamma{:}c = 40°$ and both the salite and the diallage structures. The augite alters to actinolite

* The evidence for replacement is that the plagioclase with a symmetrical extinction of 2° has lower relief than the quartz and the edges of the plagioclase crystals contain strings of inclusions of higher relief.

and hornblende as in the other specimens. In specimen F.30.1A hornblende and both types of actinolite surround augite crystals. The biotite flakes, which are pleochroic from α = straw to γ = deep brown, are partially altered to a pale penninite with a pleochroism scheme α = straw, γ = pale green and anomalous blue interference colours. The breakdown of biotite and amphibole is accompanied by the release of sphene and blebs of a fibrous mineral which is thought to be prehnite. Sphene forms irregular-shaped crystals rather than the more usual idiomorphic crystals of intermediate to acid plutonic rocks. In specimen F.16.1A the sphene occurs in two quite distinct settings: the one as irregular grains associated with chlorite, and the other as a grain moulded on to an amphibole lath. In the first case the sphene occurs as a single anhedral crystal enclosing epidote and iron ore and is associated with both iron ore and penninite. The penninite is derived from biotite which is itself derived from green hornblende. The lime released by the breakdown of amphibole has gone partly to form epidote and partly to form sphene. The titania has been derived from titanium-bearing iron minerals, for there are sphene rims to iron ore grains particularly where the iron ore is associated with altered ferromagnesian minerals. This iron mineral is a titaniferous magnetite and not ilmenite, since there is a grain of iron ore which is composed of grains and rods with a definite orientation with respect to each other. The orientation is that of an intergrowth on the octahedral face of a cubic mineral. The gaps in the grain are the sites of former intergrown ilmenite laths and are now filled with penninite or a greenish brown biotite. The other occurrence is of a single crystal moulded round one end of an amphibole lath and having a crystal form dictated by the surrounding minerals, indicating that it is a late-forming mineral. It is associated with iron ore grains with careous outlines, from which source the titania was derived. The lime must have come from a source external to that crystal and is not visible under the microscope, for the lath shows very little sign of alteration. An intermediate stage has been recorded where the sphene is interstitial and nearby there is an altered amphibole crystal to supply the lime. The accessory minerals are iron ore (titaniferous magnetite), which is often rimmed by sphene, separate grains of sphene, apatite, zircon and rare brown orthite. Pyrite with a little hematite alteration occurs in some specimens (F.18.1). Modal analyses have been carried out on sixteen granodiorite specimens and these are given in Table I.

The only tonalite (F.117.1) recorded occurs on Anagram Island (*1*). It is an acid tonalite and differs from the granodiorites only in the mineral proportions.

4. Xenoliths in the Granodiorites

Basic xenoliths up to 3·5 cm. in diameter occur quite frequently in the granodiorites. In specimen F.29.1 the xenolith is a grey fine-grained rock. Under the microscope it is a porphyritic rock with an intergranular groundmass texture in which the amphibole may have a slightly ophitic texture. There are areas in the xenolith which contain saussuritized plagioclase and ragged amphibole laths, whereas the remainder is clearer and the amphibole forms rounded and interstitial crystals. The more altered areas enclose plagioclase phenocrysts up to 2·5 mm. long and have a composition of $Ab_{48}An_{52}$. The groundmass plagioclase, which forms small saussuritized crystals up to 0·5 mm. long, has a more acid composition which is in the range $Ab_{60}An_{40}$ to $Ab_{65}An_{35}$. The ragged laths of amphibole are a hornblende with a pleochroism scheme α = straw, β = green, γ = bluish green, $\gamma{:}c = 30°$ and $2V\alpha \simeq 70°$. There is some alteration to biotite and chlorite. Titaniferous magnetite occurs as small grains which are enclosed either in ferromagnesian minerals or chlorite, when they are rimmed by sphene. In the less altered areas the plagioclase is only slightly saussuritized. The amphibole here is a green hornblende with a pleochroism scheme α = straw, β = brownish green, γ = green, $\gamma{:}c = 17°$ and $2V\alpha \simeq 70°$. It occurs as unaltered crystals which may have an actinolite core. The actinolite has a variable pleochroism scheme with α = colourless to very pale straw, β = very pale green to green, γ = very pale bluish green to pale blue, $\gamma{:}c = 17°$ and $2V\alpha \simeq 80°$. Iron ore may occur in the cores both as separate grains and as symplectic intergrowths. One of these less altered areas contains small augite crystals with $\gamma{:}c = 39°$, $2V\gamma \simeq 60°$ and an occasional alteration rim of hornblende. The amphibole is altered to biotite and chlorite. The occurrence of iron ore and sphene is similar to that previously described. At the contact with the granodiorite the clearer areas have a more frequent occurrence than the more altered areas, which in that position are transitional to the former. Potash felspar crystals have grown from the granodiorite into the xenolith and enclose biotite, amphibole and iron ore crystals. They have also grown within the xenolith and poekilitically enclose those minerals, plagioclase laths and rare quartz grains, which also occur sporadically throughout the xenolith. The xenolith is approaching mineralogical equilibrium but does not show signs of disruption. The clear areas in the xenolith represent areas of more advanced recrystallization.

The xenolith in specimen F.35.1 shows a more advanced stage of absorption. The plagioclase crystals are coarser-grained and are more acid in composition ($Ab_{67}An_{33}$). Potash felspar crystals occur more frequently, show a myrmekitic intergrowth with plagioclase and enclose small blebs of the latter as remnants of crystals which are partially replaced. A few quartz crystals occur near the potash felspar. The amphibole is usually a green hornblende though in the more altered areas a few ragged laths of the bluish green variety occur. Colourless augite crystals ($\gamma{:}c = 48°$ and $2V\gamma \simeq 60°$) with green hornblende rims occur in the clearer areas. Titaniferous magnetite grains which may be rimmed by sphene are a prominent accessory. There are a few large sphene grains which were probably derived in the same manner as in specimen F.16.1 (p. 18). Apatite needles occur infrequently. The plagioclase at the edges of the xenolith in specimen BGLE.68 are significant in that they are zoned from $Ab_{52}An_{48}$ to $Ab_{71}An_{29}$ at the rim and show very clearly the reaction relationship. These xenoliths are probably plutonic in origin.

Microscopically, there are two types of xenolith in specimen F.40.1. One is similar to those already described, but it carries orthopyroxene as well as clinopyroxene in the core of the amphibole aggregates. The orthopyroxene is a hypersthene pleochroic from α = pink to γ = colourless and with $2V\alpha \simeq 70°$. Its initial alteration is to green hornblende but later alteration gives rise to an actinolite within the hornblende. Bastite veins cut the hypersthene. The ferromagnesian minerals in this xenolith show the same characters exhibited by those of the granodiorites. The other xenolith in specimen F.40.1 is a biotite-plagioclase rock with minor amphibole and iron ore. It is a recrystallized rock in which there is a tendency to a poekiloblastic texture. The plagioclase with a composition of $Ab_{67}An_{33}$ is full of biotite and iron ore inclusions, and is recrystallized to granular aggregates with nearly the same orientation. One potash felspar actually crosses the margin of the xenolith; within the xenolith it is clear and poekilitic to both the plagioclase and quartz but outside it has the normal appearance of the potash felspar of the granodiorite. The red-brown biotite forms either irregular flakes, which have a sieve structure enclosing iron ore, quartz and plagioclase, or small interstitial flakes associated with green amphibole crystals. The amphibole is a green hornblende with a pleochroism scheme α = straw, β = pale brownish green, γ = pale green, $\gamma{:}c = 25°$ and $2V\alpha \simeq 70°$. Iron ore grains are scattered throughout. There are, in addition, small areas of biotite flakes and aggregates of small plagioclase and quartz crystals in the host rock. These are very similar to parts of the xenolith just described and are the remnants of similar xenoliths. These xenoliths are probably volcanic in origin.

These rocks show various stages in the disruption of the xenoliths, the production of features which are characteristic of the host granodiorites and, in particular, the relationships between the ferromagnesian minerals.

VI. POST-ANDEAN HYPABYSSAL ROCKS

THERE are two main groups of hypabyssal rocks which are post-Andean in age. The first group, which occurs as intrusions mainly in the plutonic rocks, is microgabbroic but the second, which occurs as intrusions mainly in the Jurassic volcanic rocks, is microdioritic. In each group there are several subdivisions based on petrographic characters. The post-Andean minor intrusions are generally not very much less altered than the pre-Andean microdiorites, but they may be considerably more altered as in the case of the altered microgabbros. No dyke has been observed cutting the contact between the Jurassic volcanic rocks and the Andean Intrusive Suite, and only one dyke (a microdiorite) has been recorded from the thermal aureole in the Forge Islands and The Barchans.

A. MICROGABBRO GROUP

1. *Altered microgabbros*

These rocks are confined to the plutonic rocks of the Andean Intrusive Suite. They generally strike in an east–west direction and have very steep dips. The widths of the dykes are from 1 to 4 ft. At station

F.38 there are several dykes parallel to each other and it is probable that the dyke at station F.39 is part of the same intrusive group. Some of the dykes taper out after a short distance.

In the hand specimen these dyke rocks are porphyritic with sparse small felspar phenocrysts in a greenish grey to grey aphanitic base. Under the microscope these rocks have plagioclase and infrequent pyroxene phenocrysts in a fine-grained intergranular groundmass. Although the rocks themselves are all highly altered, the pyroxene crystals are comparatively fresh (F.39.2; Plate IIa). The hypidiomorphic plagioclase phenocrysts are up to 2·0 mm. long but because of the heavy alteration to chlorite, sericite, epidote and calcite their composition cannot be determined. These secondary minerals may form complete pseudomorphs after the plagioclase. The augite phenocrysts are faintly pleochroic from pale yellow-brown to a greenish yellow-brown. The augite crystals are often rounded and cracked, and may show alteration to chlorite, calcite or epidote, which minerals may form complete pseudomorphs. The augite has $\gamma{:}c = 40°$, $2V\gamma = 56°$, twinning on (100) and very often a well-developed hour-glass structure and zoning (F.26.2). The intergranular matrix is composed of small highly altered plagioclase laths, augite grains similar in composition to the phenocrysts, iron ore and secondary minerals. The iron ore is normally an unaltered titaniferous magnetite but in specimen F.30.4 there are sphene rims. The interstices in the groundmass are filled by pale green penninite, minor epidote and rare calcite.

Many of the rocks carry mineral aggregates which are different from the matrix and may represent water-enriched pockets which crystallized slightly later. The aggregates comprise plagioclase and amphibole laths, augite crystals, iron ore and penninite. The plagioclase is highly altered. One comparatively unaltered aggregate in specimen F.26.2 has plagioclase with a composition of $Ab_{40}An_{60}$. The augite is similar to that in the matrix. The amphibole is a brown hornblende with a pleochroism scheme α = straw to γ = greenish brown or brown and $\gamma{:}c = 16°$. The laths of these minerals are ragged and small. The iron ore is mainly unaltered titaniferous magnetite grains but there is probably also a little ilmenite present in the form of skeletal crystals. In addition to penninite in the interstices, the aggregates may enclose vesicles of chlorite and sericite and a little pyrite, epidote or calcite (F.35.2). The chlorite grows in from the walls of the vesicles and the cores are filled either by calcite or a plexus of chlorite flakes. The magmatic alteration of augite to brown hornblende is clearly visible in specimen F.26.2. A certain amount of magmatic alteration took place in the aggregates, since in specimens from the edges of dykes they are altered, whereas the host rock is comparatively unaltered. Later hydrothermal activity has introduced the secondary minerals.

Specimen F.26.2 is different in that the iron ore is extensively altered to leucoxene. This alteration affects only the central parts of this dyke and the released iron has gone in part to form epidote, but most of it must have been taken up by the chlorite. The aggregate with unaltered plagioclase is characterized by sericite and augite and not the more usual penninite and brown hornblende. The plagioclase is quite heavily sericitized except for a few crystals that survived because of the cessation of conditions causing the sericitization. If the augite had been altered to amphibole, it is likely that penninite rather than sericite would have occurred, because of the iron and magnesium released.

The contact facies of these dykes are finer-grained but mineralogically similar. The plagioclase in specimens F.26.3 and F.38.3 is less altered, particularly in the latter, and the composition range is $Ab_{46}An_{54}$ to $Ab_{48}An_{52}$ based on small albite-twinned laths. Hour-glass structure is well developed in the pyroxene crystals in specimen F.26.3. Unaltered titaniferous magnetite occurs throughout the matrix and in specimen F.38.3 there is, in addition, a second generation of iron ore as a peppering in the groundmass. At the contact the groundmass becomes cryptocrystalline and in specimen F.39.3 the phenocrysts contribute to a trachytic texture. The actual contact may be rather diffuse owing to extensive alteration of the country rock and relatively slight alteration of the dyke (F.39.3). The minerals of the granodiorite are invariably broken down and secondary minerals, of which prehnite is conspicuous, are developed. The iron ore is unaffected, whereas in the dyke rock the iron ore within 1·0 mm. of the contact has been altered to leucoxene.

2. *Microgabbros*

In the hand specimen the dykes are slightly less porphyritic than the Tertiary porphyritic augite-microdiorites, but it is only on microscopic evidence that the two groups can be separated. The phenocrysts are slightly larger than those of the altered microgabbros. The dykes usually strike in a south-east to north-west direction, though there are exceptions, and the dips are variable. The widths of the dykes vary between 6 in. and 7 ft.

In the hand specimen these rocks are porphyritic with felspar phenocrysts in a greenish grey to black aphanitic base. Under the microscope the texture is porphyritic with a fine-grained intergranular groundmass. The phenocrysts in specimens from dykes cutting the Andean intrusive rocks are in fact xenocrysts of subhedral plagioclase and rounded quartz. The former are up to 2·5 mm. long and have an acid core surrounded by a basic rim. The composition range of such a zoned crystal (F.30.5) is $Ab_{78}An_{22}$ to $Ab_{54}An_{46}$, though the outer rim may be more basic as in F.24.1, where it is $Ab_{42}An_{58}$. The zoning is sometimes oscillatory. The plagioclase is extensively sericitized and contains a little penninite and brownish green biotite as well. Some of the xenocrysts enclose flakes of chloiite and laths of amphibole forming either a core to the crystal or a marked band near its margin (F.24.1). Incipient melting of the xenocrystic plagioclase in an environment in which a more calcic plagioclase would be stable has undoubtedly resulted in the growth of the inclusions (Kuno, 1950, p. 957). The quartz xenocrysts are up to 2·0 mm. across, are always rimmed by ragged amphibole flakes (F.23.1) and some of them are corroded by the groundmass of the dyke. The xenocrysts have clearly been derived from the granodiorite wall rocks.

Some of the dykes (F.80.2, F.98.5) which do not cut the Andean intrusive rocks contain phenocrysts of plagioclase and amphibole. The plagioclase has a composition range of $Ab_{40}An_{60}$ to $Ab_{48}An_{52}$ determined from albite twinning, and it is slightly altered to chlorite, epidote and sericite. The amphibole crystals frequently have cores of a colourless augite. The amphibole has a variable pleochroism scheme α = straw, β = brownish green to yellow-green, γ = bluish green to greenish blue, $\gamma{:}c = 17°$ and $2V\alpha \simeq 70°$. The amphibole in specimen F.80.2 is occasionally ophitic in relation to the groundmass plagioclase.

The groundmass is an intergranular intergrowth of plagioclase and amphibole with interstitial accessories. The plagioclase laths are up to 1·0 mm. long and have a composition range of $Ab_{36}An_{64}$ to $Ab_{45}An_{55}$, but Universal Stage determination gives a more basic composition of $Ab_{27}An_{73}$. There is a minor amount of zoning. Alteration to chlorite, epidote and sericite is common. The amphibole crystals are up to 1·0 mm. long and in specimen F.23.1 (Plate IIb) they reach the phenocrystic proportions of 2·0 mm. The amphibole is a green actinolite with a pleochroism scheme α = pale straw, β = pale brownish green, γ = pale green, $\gamma{:}c = 22°$ and $2V\alpha = 86°$. The high extinction angle is due to the fibrous nature of the amphibole, because the individual fibres are not parallel to each other. It forms ragged laths which occasionally have cores of pyroxene (F.30.5, F.98.3). The amphibole is a magmatic alteration product of the pyroxene, a colourless augite with $\gamma{:}c = 47°$, $2V\gamma \simeq 60°$ and typical hour-glass structure. The former uralite after pyroxene has recrystallized except for remnants now forming cores to the actinolite crystals. The amphibole is pseudomorphed by greenish brown biotite and penninite, and sphene develops in these pseudomorphs. There are minor amounts of unaltered titaniferous magnetite and irregular sphene grains (F.98.3). Sphene does not rim the titaniferous magnetite and is derived from a second generation of iron ore which could have been ilmenite. The iron has passed to the chlorite minerals. Greenish brown biotite or secondary penninite fills the interstices in the matrix. In specimen F.30.2 there is a little pyrite which is altered to hematite.

The contact facies of these dykes are much finer-grained and have small phenocrysts, which give rise to the trachytic texture, in a very fine-grained to cryptocrystalline matrix. The plagioclase phenocrysts are up to 1·0 mm. long and have a composition range of $Ab_{38}An_{62}$ to $Ab_{50}An_{50}$ on albite twinning. They are usually altered to sericite and rarely to epidote. In some of the specimens from The Barchans there are microphenocrysts of augite with $\gamma{:}c = 40°$, $2V\gamma = 56°$, hour-glass structure and twinning on (100) (F.23.2, F.31.2). The pyroxene forms small rounded crystals which may be altered to a brownish green uralitic or actinolitic amphibole. The fibrous ragged amphibole has a pleochroism scheme α = pale straw, β = pale brownish green, γ = bluish green, $\gamma{:}c = 19°$ and $2V\alpha \simeq 70°$. It is altered either to pale green penninite or combinations of chlorite, biotite and a little iron ore, and it may be pseudomorphed by the latter minerals or by a greenish biotite, which occurs widely in the groundmass of these specimens. The groundmass is very fine-grained to cryptocrystalline. It is composed of minute plagioclase laths with iron ore, greenish biotite and secondary chlorite. There may be two generations of iron ore: small 0·2 mm. crystals and a peppering of minute grains. The iron ore is a titaniferous magnetite which is only rarely altered to leucoxene (F.31.3). Secondary quartz is common. There are xenocrysts of plagioclase and quartz similar to those already mentioned. At the actual contact there is a slight development of glass in addition to increased iron ore and occasionally increased secondary alteration. The contacts with the plutonic rocks are sharp though irregular and stringers of dyke rocks invade the country rock. There is some brecciation of the country rock but there are no other marked effects apart from the few exceptions described below. In specimen F.14.2 the wall rock is granulated and there is slight contact metamorphism shown by the presence of green biotite in the interstices and green biotite fingering into the brown biotite. This is metamorphosed chlorite. In specimen F.31.3 there is granulation and extensive sericitization, particularly of the potash felspar. In specimen F.24.2 a pale green actinolite with a bluish tinge has developed.

The contact facies of specimen F.98.3 is rather different in that the rock has developed a trachytic texture and the felspar laths are smaller (about 0·5 mm. long) (F.98.2). There are aggregates of actinolite which pseudomorph pyroxene and brown hornblende. Interstitial brownish green biotite is common and there are the usual secondary minerals including a little epidote. Still closer to the contact (F.98.4) the rock becomes porphyritic with plagioclase phenocrysts in a trachytic groundmass. The phenocrysts have a composition of $Ab_{47}An_{53}$ and show very little alteration. The groundmass plagioclase microlites give the trachytic texture. Unaltered titaniferous magnetite grains, thin rods of a colourless amphibole and a chlorite speckling comprise the matrix. Quartz grains occur frequently in the groundmass but they are secondary. Specimen F.14.1 is very similar to F.98.4 but the contact of the former with the country rock (F.14.2) shows a greater similarity to the contact facies first described.

3. *Basaltic andesite dykes*

There are only three dykes of this type, specimens F.6.2, F. 49.2 and F.64.2. Two of these (F.6.2, F.64.2) are comparable, whereas the third probably belongs to another group of basaltic andesites of which it is the only representative. These dykes have been distinguished from the other dykes only on microscopic evidence. In the hand specimen they are grey aphanitic rocks which may carry secondary epidote crystals. Specimen F.49.2 cuts the pre-Andean microdiorite sill (F.49.1).

Microscopically, specimen F.64.2 (Plate IIc) carries pyroxene and amphibole crystals set in a groundmass of plagioclase laths with a trachytic texture. The colourless augite phenocrysts which have $\gamma{:}c = 45°$, $2V\gamma = 56°$, twinning on (100) and hour-glass structure, are up to 3·0 mm. long and tend to occur in aggregates. Chlorite may form a narrow alteration rim to some augite crystals while in others it occurs in the corroded cores. The rounded pale brown hornblende phenocrysts have $\gamma{:}c = 19°$, $2V\alpha = 84°$ and are occasionally marginally altered to chlorite. The groundmass plagioclase has a composition of $Ab_{42}An_{58}$. In the interstices there are augite grains similar to the phenocrysts, numerous titaniferous magnetite grains which have been altered to leucoxene, and a little quartz and chlorite. In the groundmass of the rock there are dark patches which have slightly coarser plagioclase laths, a few small augite and titaniferous magnetite grains and secondary minerals. The titaniferous magnetite is unaltered in the core, but it is altered to leucoxene at the margins of the patches. These clots were probably partially crystallized at the time of emplacement and consequently they were partly protected from the effects which caused the alteration of the iron ore in the main body of the rock. There are also numerous clots of secondary minerals, some of which are associated with the augite aggregates. The secondary minerals are pale green actinolite, penninite, epidote and a little quartz, leucoxene and sphene. There is no indication that these minerals were derived from either the pyroxene or hornblende phenocrysts, because the phenocrysts are conspicuously fresh. There are three possible explanations: they are clots of later hydrothermal minerals; they represent pre-existing phenocrysts; or they are magmatic hydrothermal minerals. They are probably not later hydrothermal minerals because of the lack of alteration to the rock as a whole. It is unlikely that they represent pre-existing phenocrysts because of the absence of remnants and the freshness of the other phenocrysts in the rock. However, it is most likely that they are magmatic hydrothermal minerals which crystallized at a late stage from pockets of water-enriched magma. In the rock there is also one xenocryst which is composed of antigorite and a little epidote with a few associated augite grains. This is probably a pseudomorph after a ferromagnesian mineral but it is not possible to infer its original composition.

Specimen F.6.2 is similar in that there are augite and brown hornblende phenocrysts in a groundmass of plagioclase laths with a trachytic texture. The groundmass interstices are filled by leucoxene, chlorite and quartz, some of which is secondary. The rock is more altered and carries hydrothermal veinlets of quartz-pyrite-epidote-actinolite, stringers of epidote-pyrite and clots of epidote. There are a number of actinolite pseudomorphs after amphibole some of which are well defined. The other phenocrysts are comparatively fresh but the rock as a whole is quite altered. The pseudomorphs are believed to be later hydrothermal alteration products, the phenocrysts surviving because of either the lack of channels for the hydrothermal solutions or a stable reaction rim.

The third dyke (F.49.2) is non-porphyritic and has a trachytic texture imparted by plagioclase laths which are rather coarser-grained (up to 1·0 mm.) than the groundmass of the other basaltic andesite dykes. The plagioclase has a composition of $Ab_{42}An_{58}$ deduced from multiple albite twinning. Numerous rounded colourless augite grains with $\gamma{:}c = 45°$, $2V\gamma = 60°$, rare hour-glass structure and zoning occur interstitially, and they are occasionally altered to pale green penninite. Minor amphibole flakes and titaniferous magnetite grains occur in the interstices as well and the latter have been quite heavily altered to leucoxene which has occasionally recrystallized to rutile. Quite often the fresh augite grains are surrounded by penninite which fills in the remainder of the groundmass. This penninite is believed to be primary because of the freshness of the augite and plagioclase crystals. There are occasional aggregates of secondary minerals throughout the rock and these comprise quartz and penninite, or epidote and chlorite with minor pyrite. The quartz-penninite aggregates are former vesicles, indicated by the poor flow structure round them.

The contact facies of this dyke is a porphyritic rock with a trachytic texture imparted by the phenocrysts. The plagioclase laths, up to 0·5 mm. long, have a composition of $Ab_{38}An_{62}$ from combined Carlsbad-albite twins. Near the contact they may be epidotized. The groundmass is very fine-grained to crypto-crystalline and it consists of a felted mass of plagioclase microlites with much interstitial leucoxene after titaniferous magnetite, rare amphibole laths with $\gamma{:}c = 16°$ but too fine-grained to determine any other properties, chlorite flakes, epidote grains and pyrite. The actual contact is sharp but irregular and there are no effects on the country rock.

B. Microdiorite Group

The rocks belonging to this group do not cut the plutonic rocks, though one specimen (F.37.2) comes from within the metamorphic aureole on the Forge Islands. These dykes are widely distributed throughout the Argentine Islands group. There are only two sills, both of which fall into the microdiorite sub-division of this group. The intrusions are up to 14 ft. thick though they are usually considerably less. There are a few contacts which enable the order of intrusion to be determined.

Both the dykes and sills are classified on the type of alteration suffered by the pyroxene and the field relations of the dykes to one another. The pyroxene is altered either to chlorite or to amphibole. Chloritic alteration indicates stability of the augite and deuteric alteration, and all dykes showing this feature have been classed as augite-microdiorites. Alteration to amphibole indicates instability of the augite and magmatic alteration, and the dykes showing this have been classed as microdiorites. On Galindez Island (F.1.1 and 4) the porphyritic microdiorites cut the microdiorites but the augite-microdiorites with the stable augite were probably intruded prior to the microdiorites.

1. *Augite-microdiorites*

In the hand specimen these are greenish grey to grey aphanitic rocks which may carry visible secondary epidote. Microscopically, they have an intergranular to trachytic groundmass texture, in which the albite-twinned plagioclase laths have a composition range of $Ab_{56}An_{44}$ to $Ab_{70}An_{30}$. They are usually slightly altered to epidote and penninite and in some cases they are albitized (F.51.2). Pyroxene crystals are rather rare but they are either unaltered or have a narrow chlorite rim. The pyroxene is a colourless augite with $\gamma{:}c = 42°$, $2V\gamma \simeq 60°$ and twinning on (100). It occurs as small rounded interstitial grains except in the contact specimens where it is microphenocrystic. Greenish brown hornblende laths occur in specimen F.65.2 and pale green actinolite laths with a pleochroism scheme α = straw, β = brownish green and γ = pale green may be scattered throughout the rock. Specimens F.37.2 and F.51.2 have comparatively fresh iron ore, whereas in the other specimens it is completely altered to leucoxene. The altered iron ore occurs in rocks with much epidote and it therefore seems that the hydrothermal alteration of these rocks has caused the breakdown of the iron ore. Small quartz crystals occur interstitially. The widespread secondary minerals, which include epidote, penninite, quartz and rare pyrite and calcite, may form aggregates with the pale green actinolite. Specimen F.51.3 has some vesicles which are filled by acicular actinolite, epidote, chlorite and pyrite. The contact facies of these rocks are much finer-grained but they have phenocrysts of plagioclase and pyroxene (F.101.3). Minute plagioclase laths and iron ore grains make up most of the groundmass. At the contact in specimen F.101.3 there is a thin zone of glass and a few stringers pass into the country rock but there are no other effects.

The only dyke (F.37.2) which cuts the metamorphic aureole belongs to this sub-division. These dykes are widely distributed but of rare occurrence. They have steep dips and strike in a north-east to south-west direction except for one (F.37.2) which strikes in an east–west direction.

2. *Microdiorites*

These dykes form the largest sub-division of the microdiorite group. The dykes occur outside the Forge Islands and The Barchans; two sills fall into this sub-division. Specimen F.4.3 is a small 1 ft. thick horizontal intrusion and specimen F.2.3 is a 14 ft. thick sill. The dips of these dykes are very variable, but generally they strike in a north-east to south-west direction.

In the hand specimen the dykes and sills are greenish grey to black aphanitic rocks which carry secondary epidote and pyrite. Specimen F.98.5 carries rare microphenocrysts of felspar. Microscopically, these rocks can be subdivided on their respective textures. There are a few porphyritic varieties but most of them are non-porphyritic with either an intergranular or a trachytic texture.

The two specimens with felspar phenocrysts have a trachytic groundmass. The plagioclase phenocrysts have a composition of $Ab_{65}An_{35}$ (F.62.4) but alteration has probably concealed the original composition of the felspars. The texture of the remainder of the specimens varies between intergranular and trachytic (F.8.2; Plate IId). The composition range of the plagioclase laths which make up most of the rocks is $Ab_{56}An_{44}$ to $Ab_{67}An_{33}$ but extensive alteration to epidote, sericite and chlorite masks the true composition which is probably basic andesine. The presence of epidote pseudomorphs after plagioclase (F.3.1) indicates albitization. There are numerous ragged amphibole crystals, which are a pale actinolite with a pleochroism scheme α = straw, β = brownish green, γ = bluish green, $\gamma{:}c = 24°$ and $2V\alpha \simeq 75°$, and they are altered to a pale green chlorite. Specimen F.8.2 also has pyroxene which is altered to a pale actinolite. It is likely that all the pale actinolitic amphiboles are derived in a similar manner. Clear quartz crystals occur in a few specimens (F.43.5) and titaniferous magnetite grains, which are in varying stages of alteration to leucoxene, are common. The secondary minerals are pistacite, chlorite, quartz, pyrite and a clean fibrous actinolite. The chlorite is penninite, either a brownish or very pale green variety with low first order birefringence colours. Veinlets composed of these secondary minerals cut specimen F.3.1. Specimen F.43.5 carries much brown biotite and clots of greenish brown biotite occur in specimen F.67.2. Several of the specimens are heavily altered to epidote and chlorite (F.79.2). The quartz occurs both in the groundmass and as secondary aggregates.

The specimens from the chilled margins of these dykes are fine-grained and have a trachytic texture. The plagioclase microphenocrysts are usually about 0·2 mm. long and have an acid andesine composition. Specimen F.69.3 contains albitized laths and it is likely that the other specimens have been similarly altered, although there is not a high proportion of secondary minerals. In most specimens the matrix containing the plagioclase laths passes from very fine-grained through cryptocrystalline to glassy at the actual contact. The matrix is felspathic with prominent chloritic alteration and encloses titaniferous magnetite grains which are altered to leucoxene, epidote crystals and chlorite flakes. In some specimens (F.43.5) the iron ore is of two generations: an earlier ilmenite altered to leucoxene and magnetite with little or no alteration. The contact zone is from 0·1 to 3·0 mm. in width and in the wider ones there is usually epidote development (F.43.6) and in every specimen there is increased iron ore. The contact itself is irregular and may be slightly brecciated. In specimens F.79.3 and F.94.2 the country rock is heavily epidotized but the comparative absence of epidote in the dykes suggests that the epidote was formed at a later stage. A few of the specimens are pierced by amphibole veinlets near the contact; the small fibrous ragged laths of amphibole are a very pale actinolite with a pleochroism scheme α = pale straw, β = pale brownish green, γ = pale green and $\gamma{:}c = 19°$ (F.59.2).

3. *Porphyritic microdiorites*

There are few representatives of this type and they differ from the pre-Andean microdiorite dykes and sills in that they generally possess fewer but coarser phenocrysts in a finer-grained matrix. Three of the specimens (F.1.1, F.4.4, F.61.2) are probably the same intrusion which passes from Winter Island through Thumb Rock to Galindez Island. They cut the microdiorites of this group. All the dykes strike in a north-east to south-west direction and have steep dips. In the hand specimen the three specimens from the same intrusion are porphyritic with large felspar phenocrysts in a greenish grey aphanitic base. Specimen F.48.2 is a grey aphanitic rock cut by veinlets of pyrite and epidote. Microscopically, these dykes are highly altered and have plagioclase and amphibole phenocrysts set in an intergranular groundmass. The plagioclase phenocrysts are up to 6·0 mm. long (F.1.2) though usually smaller. Their composition range is $Ab_{46}An_{54}$ to $Ab_{55}An_{45}$ but albitization and alteration to epidote, sericite and chlorite has masked their true composition in some specimens. The amphibole phenocrysts, which are absent in specimen F.48.2, are of fibrous actinolite with a pleochroism scheme α = straw, β = brownish green to pale green, γ = pale green to bluish green, $\gamma{:}c = 17°$, $2V\alpha \simeq 80°$ and have twinning on (100). In specimen F.1.1 it has a sieve texture enclosing quartz. This fibrous actinolite is uralite after pyroxene and is altered to epidote and chlorite. The groundmass is an intergranular intergrowth of plagioclase and dark minerals, and in most specimens the former is altered. The actinolitic amphibole is similar to the phenocrysts, but in specimen F.4.4 there are a few additional small laths of brown hornblende ($\gamma{:}c = 16°$) which are altered to green amphibole. Titaniferous magnetite grains occur frequently and are altered to leucoxene. There is a minor amount of interstitial quartz some of which is secondary. The secondary minerals include penninite, pistacite and pyrite (F.48.2). In specimen F.48.2 there are clots of secondary minerals in the groundmass.

A specimen from the contact (F.4.6) is a porphyritic rock with plagioclase and amphibole phenocrysts set in a fine-grained groundmass of plagioclase and amphibole laths, iron ore and secondary minerals. There is some pyrite in the plagioclase pseudomorphs. At the contact there is a very narrow zone of glass and increased epidote and chlorite but there are no effects on the country rock. The contact specimen (F.48.3) is a comparatively unaltered non-porphyritic rock with an intergranular texture of plagioclase laths, iron ore and secondary minerals. The contact itself is brecciated and highly altered. It appears that there was some post-consolidation movement, because the glass at the contact is broken and disorientated. It is this fractured rock that has provided channelways for the hydrothermal solutions which have altered the rock.

VII. TERTIARY ROCKS

THESE flow lavas and dyke rocks are described as Tertiary, although there is no direct evidence of their age. All these rocks are remarkable, since they show very little alteration and are quite distinctive types under the microscope if not in the hand specimen. The dykes can be compared with a dyke recorded from King George Island (Hawkes, 1961).

1. Porphyritic Andesite

Macroscopically, specimen F.100.1, from the Irizar Island group, is unlike any other rock type from the Argentine Islands; it is a fresh coarsely porphyritic rock with both large and small felspar and amphibole phenocrysts (up to 1·5 cm. long) in a black aphanitic groundmass. Microphenocrysts of plagioclase are more common than the large phenocrysts which are visible in the hand specimen (F.100.1; Plate IIe). The plagioclase crystals are zoned from $Ab_{47}An_{53}$ to $Ab_{67}An_{33}$. There is a little secondary chlorite alteration and development of pale fibrous amphibole in cracks in the phenocrysts. The amphibole phenocrysts, which may have an augite core, are of fibrous actinolite with a pleochroism scheme α = pale straw, β = pale brownish green, γ = pale green and $\gamma{:}c = 16°$. The original augite has been altered to uralite which has recrystallized to actinolite. The matrix has an intergranular texture of plagioclase laths of composition $Ab_{52}An_{48}$, with interstitial titaniferous magnetite, amphibole flakes and secondary chlorite. There are small patches of actinolite fibres and brownish green biotite flakes, which also occur in veinlets and have been hydrothermally introduced. The iron ore is in two generations, as microphenocrysts and very small grains in the matrix. The microphenocrysts are usually altered. The outlines of the individual crystals can be detected but most of them have been replaced by either nearly colourless isotropic chlorite or a brownish chlorite. The remaining iron ore is frequently skeletal. There is no obvious reason for the nature of this replacement, nor is there any evidence to show where the original constituents have gone. There are a few secondary quartz mosaics.

2. Porphyritic Augite-microdiorites

Four porphyritic augite-microdiorite dykes have been recorded from The Barchans. They strike in a north-east to south-west direction but dip at different angles. These dykes are between 4 and 6 ft. wide. All these rocks are unusual since they show very little secondary alteration.

In the hand specimen these dyke rocks are porphyritic with numerous small felspar phenocrysts set in a grey aphanitic base. Microscopically, there are phenocrysts of plagioclase and pyroxene in a fine-grained matrix. The phenocrysts, particularly the pyroxenes (F.15.1; Plate IIf), tend to occur in aggregates. The hypidiomorphic plagioclase phenocrysts are up to 5·0 mm. across, are twinned on the albite, combined Carlsbad-albite and pericline laws, and are slightly zoned. The zoning is marginal and may be oscillatory. The composition is in the range $Ab_{42}An_{58}$ to $Ab_{46}An_{54}$. The plagioclase is altered to sericite, chlorite and rare epidote and amphibole. The altered crystals have irregular patches of a clear, untwinned, low relief plagioclase which is albite. The subhedral to anhedral pyroxene phenocrysts are a colourless to yellowish augite with $\gamma{:}c = 43°$, $2V\gamma \simeq 60°$ and twinning on (100). In specimen BGLE.62 some crystals have a faint hour-glass structure and zoning. The rounded crystals are up to 1·0 mm. across. They sometimes show slight marginal alteration to a pale green uralitic amphibole with a pleochroism scheme α = straw, γ = pale green and $\gamma{:}c = 17°$. Occasionally the pyroxene is almost completely pseudomorphed by a pale green fibrous chlorite with low birefringence and thin laths of a uralitic amphibole (BGLE.62, F.22.1). One phenocryst in specimen F.15.1 has a small core of uralite.

In specimen F.15.1 there are also numerous pseudomorphs in pale green fibrous chlorite and thin laths of the uralitic amphibole with a pleochroism scheme α = pale straw, β = pale brownish green, γ = pale green and $\gamma{:}c = 16°$. The pseudomorphs have the form of pyroxene prisms and cross-sections. The prisms are frequently rimmed by thin laths of clinopyroxene with optical properties similar to those of the phenocrysts. The pseudomorphs also enclose sphene grains, and where iron ore is either in contact with or enclosed in them a sphene rim develops. The titania has been derived from the iron ore and the lime must have come from the original mineral. The absence of positive examples of augite either in the process of alteration to, or nearly pseudomorphed by chlorite and uralite, and the slightly lower birefringence of the chlorite in that case, indicate that the original mineral of the pseudomorph was not an augite like that still remaining. The form of the pseudomorphs and their lime content suggest that the mineral was either a pigeonite or an orthopyroxene. At a certain stage in the crystallization of the dyke the low-lime pyroxene ceased to crystallize and only augite was precipitated. Deuteric solutions altered the low-lime pyroxene but left the augite unaltered. The pseudomorphs are sometimes replaced by penninite, which retains the iron ore and sphene. Specimen F.22.1 has a symplectic iron ore intergrowth.

The groundmass has a fine-grained intergranular texture, in which there are small plagioclase laths up to 0·2 mm. long, and with a composition range of $Ab_{48}An_{52}$ to $Ab_{52}An_{48}$. Augite, similar to the phenocrysts, occurs in the interstices. Rounded titaniferous magnetite octahedra are either between 0·2 and 0·4 mm. across or occur as very fine-grained interstitial grains. A sphene rim is frequently developed, particularly when in association with chlorite. Vermicular iron ore in chlorite occurs in specimens F.15.2 and F.22.1. The chlorite is either isotropic or has a very dark blue anomalous birefringence. The vermicular iron ore must have formed as a result of the breakdown of the original pyroxenes or amphiboles. Some amphiboles tend to pass into an area with a chlorite-iron ore intergrowth similar to that described above. Apatite needles are a common accessory and there is a little interstitial quartz. Secondary chlorite and uralite after pyroxene, penninite which often pseudomorphs the uralite, thin laths of a brownish green chlorite and minor amounts of epidote comprise the matrix.

The contact facies of these dykes are finer-grained porphyritic rocks with a trachytic texture in the groundmass. The plagioclase phenocrysts are up to 1·5 mm. long and have a composition range of $Ab_{42}An_{58}$ to $Ab_{44}An_{56}$. They are often bent and cracked and have chlorite in the cracks. The pyroxene phenocrysts are similar but they are frequently altered first to uralite and then to penninite. Specimen F.15.2 has a few microphenocrysts of a greenish brown magmatic amphibole with $\gamma{:}c = 21°$. The groundmass is very fine-grained and the mineralogical composition is similar. The actual contact may either be sharp with slight brecciation of the country rock or irregular with stringers of the dyke passing into the country rock (F.22.2). Where the contact is irregular alteration of the felspars to calcite, epidote and sericite, and ferromagnesian minerals to epidote and chlorite is common. This may be a later effect because calcite is prominent in the dyke rock.

Specimens F.11.1 and 2 are somewhat different from the other contact specimens. The patchy appearance exhibited by the porphyritic andesites is well developed, there is a lower proportion of phenocrysts and the ferromagnesian minerals are more altered. The patchy appearance is due to a low relief and low birefringence mineral poekilitically enclosing the groundmass microlites. The plagioclase phenocrysts are occasionally corroded by the groundmass. All the pyroxene has been altered to a ragged fibrous green actinolite with a pleochroism scheme α = pale straw, β = brownish green, γ = pale green and $\gamma{:}c = 22°$. These crystals may form well-developed pseudomorphs after pyroxene as seen in cross-sections. Specimen F.11.2 has phenocrysts of magmatic brownish green hornblende ($\gamma{:}c = 23°$, $2V\alpha \simeq 80°$), which is altered to green actinolite and chlorite associated with exsolved iron ore. There are no chlorite-uralite pseudomorphs such as those in the other specimens. The glomeroporphyritic aggregates, which occur in the other specimens and are described later, differ only in that actinolite replaces augite. The trachytic matrix of minute plagioclase laths, iron ore and the poekilitic mineral carries a certain amount of green penninite or brown chlorite.

In the groundmass of some specimens there are glomeroporphyritic aggregates. These are composed of medium-grained augite crystals with uralite rims, plagioclase laths with a composition $Ab_{54}An_{46}$, titaniferous magnetite octahedra and secondary penninite (F.22.1). In this specimen the augite may also have a rim of magmatic brownish green hornblende which is preserved even after the chloritization of the pyroxene. There is a suggestion of an ophitic texture and penninite-uralite pseudomorphs after pyroxene in the matrix of specimen F.15.2.

The xenoliths were derived at depth from rocks which crystallized earlier from the same magma as the dykes. Xenocrysts of acid plagioclase, which are zoned to more basic plagioclase ($Ab_{62}An_{38}$ to $Ab_{49}An_{51}$ in specimen F.22.1), are quite common particularly in the contact specimens, in which xenocrystal quartz also occurs. The xenocrysts are undoubtedly derived from the granodiorite wall rocks (F.11.2).

These rocks can be compared with the Tertiary microdiorite described by Hawkes (1961) from King George Island but they have fewer phenocrysts, no potash felspar and no orthopyroxene, though there are pseudomorphs (F.15.1) after a mineral which might have been orthopyroxene.

VIII. GEOCHEMISTRY

A CONSIDERABLE number of specimens from the Andean Intrusive Suite of Graham Land have now been analysed, but there are few analyses of the hypabyssal rocks. Eight new analyses of hypabyssal rocks from the Argentine Islands have been completed and they are given in Table II. Two additional analyses of hypabyssal rocks from King George Island are also given in Table II for comparison. The rocks analysed have a variable composition in the intermediate range. All these rocks are characterized by relatively high alumina, a feature typical of the Andean intrusive rocks and in general of rocks from orogenic belts.

The analytical results have been plotted graphically on triangular variation diagrams with the co-ordinates Fe″+Fe‴—Alk—Mg and K—Na—Ca (Fig. 7). Because of the limited number of available analyses, the diagrams do not show any significant trends, but the plotted positions of the analyses with K—Na—Ca as co-ordinates show a marked deficiency in potassium. All the specimens analysed show affinities to calc-alkali rocks and not to basaltic rocks except in one case which will be discussed later. At least three phases of dyke intrusion have been described already. The pre-Andean microdiorites are probably associated with the Upper Jurassic Volcanic Group, the post-Andean micro-gabbros and microdiorites are probably associated with the Andean Intrusive Suite and the Tertiary porphyritic augite-microdiorites are possibly of Miocene age.

The chemical analyses of the pre-Andean microdiorites reveal several features which account for the unusual mineralogy of the less common types (F.95.2, F.110.1). The analyses show rather low silica, a high Fe‴ : Fe″ ratio and a high water content. A high water content has been postulated from the mineralogy (p. 12) and this accounts satisfactorily for the high Fe‴ : Fe″ ratio, the crystallization of iron ore rather than iron silicates and the presence of interstitial quartz. Quartz appears in the mode of both rocks but not in the norm of specimen F.110.1 which has a little normative olivine. The presence of modal quartz in a rock with under 50 per cent of silica is thus explained by the high water content. The high water content is also responsible for the magmatic hydrothermal alteration of the ferromagnesian

TABLE II

CHEMICAL ANALYSES OF DYKE ROCKS FROM THE ARGENTINE ISLANDS

	F.110.1	F.95.2	F.57.2	F.15.1	F.22.1	F.2.3	F.8.2	F.64.2	1	2	
SiO_2	49·89	51·82	54·91	57·88	57·41	56·13	56·81	53·19	55·38	53·45	SiO_2
TiO_2	1·21	1·34	0·93	0·84	0·79	0·67	1·14	0·84	0·76	0·66	TiO_2
Al_2O_3	19·36	18·16	16·87	17·22	17·66	17·56	16·54	19·01	16·51	19·37	Al_2O_3
Fe_2O_3	3·53	3·84	3·42	3·12	3·23	1·73	2·21	1·58	4·63	3·37	Fe_2O_3
FeO	5·68	6·43	4·37	4·68	4·41	6·63	7·14	6·19	2·99	4·09	FeO
MnO	0·12	0·22	0·15	0·17	0·16	0·19	0·20	0·15	0·10	0·04	MnO
MgO	3·63	4·25	4·18	3·62	3·20	2·65	3·03	5·35	3·89	4·42	MgO
CaO	9·85	7·60	7·40	6·65	6·58	4·84	5·00	8·18	7·34	8·18	CaO
Na_2O	3·87	3·99	3·41	3·66	3·52	5·41	4·25	3·06	2·94	3·55	Na_2O
K_2O	0·90	0·70	1·12	1·07	1·13	0·56	0·61	0·70	1·75	1·35	K_2O
H_2O+	1·27	1·39	2·42	1·36	1·49	2·36	2·67	1·79	1·75	} 1·69	H_2O+
H_2O-	0·09	0·08	0·11	0·08	0·07	0·09	0·08	0·08	1·17	}	H_2O-
P_2O_5	0·74	0·33	0·26	0·24	0·20	1·18	0·21	0·27	0·36	—	P_2O_5
CO_2	0·10	0·06	0·22	0·08	0·06	0·46	0·40	0·08	0·63	—	CO_2
TOTAL	100·24	100·21	99·77	100·67	99·91	100·46	100·29	100·47	100·20	100·17	TOTAL
	ANALYSES LESS TOTAL WATER (Recalculated to 100)										
SiO_2	50·46	52·48	56·47	58·33	58·37	57·28	58·24	53·95	56·93	54·27	SiO_2
TiO_2	1·22	1·36	0·95	0·85	0·80	0·68	1·17	0·85	0·78	0·67	TiO_2
Al_2O_3	19·58	18·39	17·35	17·35	17·96	17·92	16·96	19·28	16·97	19·67	Al_2O_3
Fe_2O_3	3·57	3·89	3·52	3·14	3·29	1·77	2·27	1·60	4·76	3·42	Fe_2O_3
FeO	5·75	6·51	4·49	4·72	4·48	6·76	7·32	6·28	3·07	4·15	FeO
MnO	0·12	0·22	0·15	0·17	0·16	0·19	0·20	0·15	0·10	0·04	MnO
MgO	3·67	4·31	4·30	3·65	3·25	2·70	3·11	5·43	4·00	4·49	MgO
CaO	9·96	7·70	7·61	6·70	6·69	4·94	5·13	8·30	7·55	8·31	CaO
Na_2O	3·91	4·04	3·51	3·69	3·58	5·52	4·36	3·10	3·02	3·61	Na_2O
K_2O	0·91	0·71	1·15	1·08	1·15	0·57	0·62	0·71	1·80	1·37	K_2O
P_2O_5	0·75	0·33	0·27	0·24	0·21	1·20	0·21	0·27	0·37	—	P_2O_5
CO_2	0·10	0·06	0·23	0·08	0·06	0·47	0·41	0·08	0·65	—	CO_2
	NORMS										
Q	—	2·46	9·48	12·06	12·96	8·22	11·58	4·92	13·44	3·66	Q
or	5·56	3·89	6·67	6·67	6·67	3·34	3·34	3·89	10·56	7·78	or
ab	32·49	34·06	28·82	30·92	29·34	45·59	36·15	25·68	24·63	29·87	ab
an	32·80	29·47	27·52	27·24	29·47	13·90	21·41	36·14	26·69	33·08	an
di	8·84	4·97	4·70	2·72	1·79	—	—	1·57	2·38	5·99	di
hy	8·27	14·91	12·33	12·92	11·49	16·50	17·37	21·61	9·00	11·94	hy
ol	1·59	—	—	—	—	—	—	—	—	—	ol
mt	5·10	5·57	4·87	4·41	4·64	2·55	3·25	2·32	6·73	4·87	mt
il	2·28	2·58	1·67	1·52	1·52	1·37	2·13	1·52	1·52	1·22	il
ap	1·68	0·67	0·67	0·67	0·34	2·69	0·34	0·67	1·01	—	ap
cc	0·20	0·10	0·50	0·20	0·10	1·00	0·90	0·20	1·40	—	cc
C	—	—	—	—	—	3·06	1·02	—	—	—	C

TABLE II—*continued*

	F.110.1	F.95.2	F.57.2	F.15.1	F.22.1	F.2.3	F.8.2	F.64.2	1	2	
Si^{+4}	23·56	24·51	26·37	27·24	27·26	26·76	27·20	25·19	26·59	25·34	Si^{+4}
Al^{+3}	10·36	9·73	9·18	9·18	9·50	9·48	8·97	10·20	8·98	10·41	Al^{+3}
Fe^{+3}	2·50	2·72	2·46	2·19	2·30	1·23	1·59	1·12	3·33	2·39	Fe^{+3}
Mg^{+2}	2·21	2·60	2·60	2·20	1·96	1·63	1·88	3·27	2·41	2·71	Mg^{+2}
Fe^{+2}	4·47	5·06	3·49	3·67	3·48	5·24	5·69	4·88	2·39	3·22	Fe^{+2}
Na^{+1}	2·90	3·00	2·60	2·74	2·66	4·10	3·24	2·30	2·24	2·68	Na^{+1}
Ca^{+2}	7·12	5·51	5·44	4·79	4·78	3·53	3·67	5·93	5·40	5·94	Ca^{+2}
K^{+1}	0·76	0·59	0·95	0·90	0·95	0·47	0·51	0·59	1·49	1·14	K^{+1}
Ti^{+4}	0·73	0·82	0·57	0·51	0·48	0·41	0·70	0·51	0·47	0·40	Ti^{+4}
Mn^{+2}	0·09	0·17	0·12	0·13	0·12	0·15	0·16	0·12	0·08	0·03	Mn^{+2}
P^{+5}	0·33	0·14	0·12	0·10	0·09	0·52	0·09	0·12	0·16	—	P^{+5}
O^{-2}	44·97	45·15	46·10	46·35	46·42	46·48	46·30	45·77	46·46	46·15	O^{-2}
Position $[(\frac{1}{3}Si+K)-(Ca+Mg)]$	−0·72	+0·65	+1·70	+2·99	+3·30	+4·23	+4·03	−0·21	+2·54	+0·94	Position $[(\frac{1}{3}Si+K)-(Ca+Mg)]$
{ Fe	75·9	74·9	69·6	72·7	74·7	79·9	79·5	64·7	70·4	67·4	Fe }
{ Mg	24·1	25·1	30·4	27·3	25·3	20·1	20·5	35·3	29·6	32·6	Mg }
{ Fe	54·3	55·7	49·2	50·1	50·9	51·1	56·4	49·3	48·2	46·2	Fe }
{ Mg	17·2	18·6	21·5	18·8	17·3	12·9	14·6	26·9	20·3	22·4	Mg }
{ Alk	28·5	25·7	29·3	31·1	31·8	36·0	29·0	23·8	31·5	31·4	Alk }
{ Ca	66·0	60·5	60·5	56·8	57·0	43·6	49·5	67·2	59·2	60·9	Ca }
{ Na	26·9	33·0	28·9	32·5	31·7	50·6	43·7	26·1	24·5	27·5	Na }
{ K	7·1	6·5	10·6	10·7	11·3	5·8	6·8	6·7	16·3	11·6	K }

F.110.1 Pre-Andean microdiorite, north-east island of Three Little Pigs, Argentine Islands (anal. D. H. Elliot).

F.95.2 Pre-Andean microdiorite, north Uruguay Island, Argentine Islands (anal. D. H. Elliot).

F.57.2 Pre-Andean microdiorite, north-west Winter Island, Argentine Islands (anal. D. H. Elliot).

F.15.1 Tertiary porphyritic augite-microdiorite, north-western island of The Barchans, Argentine Islands (anal. D. H. Elliot).

F.22.1 Tertiary porphyritic augite-microdiorite, north-eastern island of The Barchans, Argentine Islands (anal. D. H. Elliot).

F.2.3 Post-Andean microdiorite, north-west Galindez Island, Argentine Islands (anal. D. H. Elliot).

F.8.2 Post-Andean microdiorite, west Galindez Island, Argentine Islands (anal. D. H. Elliot).

F.64.2 Post-Andean basaltic andesite dyke rock, north-east Winter Island, Argentine Islands (anal. D. H. Elliot).

1 Porphyritic microdiorite (G.21.8), Keller Peninsula, King George Island (anal. K. Chaplin) (Hawkes, 1961).

2 Porphyritic pyroxene-andesite (9. "dolerite"), Admiralty Bay, King George Island (anal. B. Bruun) (Barth and Holmsen, 1939).

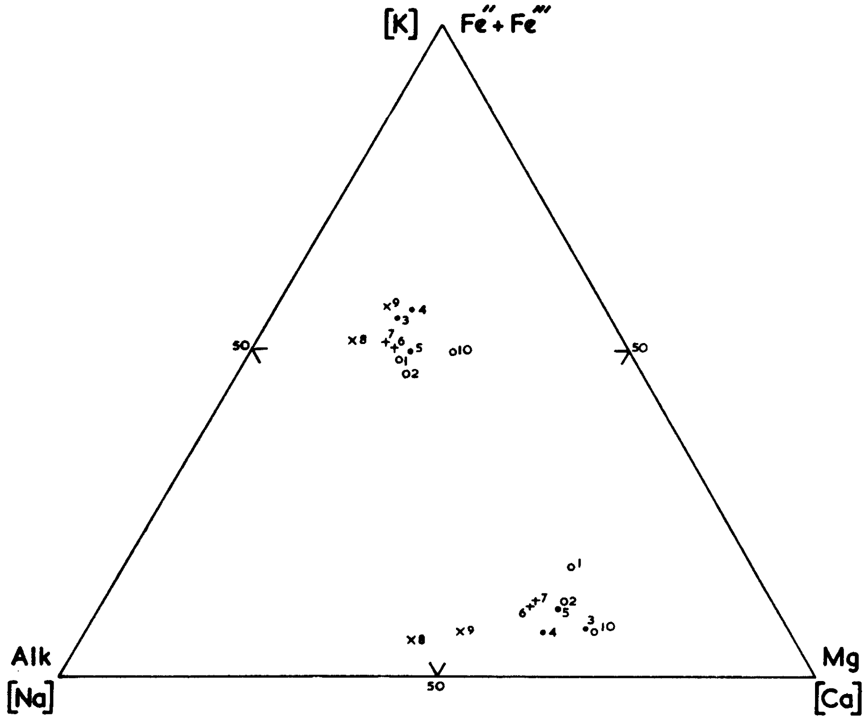


FIGURE 7

Triangular variation diagram (see chemical analyses in Table II) plotted on the co-ordinates Fe''+Fe'''—Alk—Mg and K—Na—Ca. The points plotted in the upper part of the diagram are on the co-ordinates Fe''+Fe'''—Alk—Mg, whereas those in the lower part of the diagram are on the co-ordinates K—Na—Ca.

No. 1. Porphyritic microdiorite (analysis 1; Table II).
No. 2. Porphyritic pyroxene-andesite (analysis 2; Table II).
Nos. 3, 4 and 5. Pre-Andean microdiorites (analyses F.110.1, F.95.2, F.57.2; Table II).
Nos. 6 and 7. Tertiary porphyritic augite-microdiorites (analyses F.15.1, F.22.1; Table II).
Nos. 8 and 9. Post-Andean microdiorites (analyses F.2.3, F.8.2; Table II).
No. 10. Post-Andean basaltic andesite dyke rock (analysis F.64.2; Table II).

minerals to actinolite and the alteration of the felspar. The chemical analysis of specimen F.57.2 casts some doubt on the direct correlation of the two groups of rocks in the pre-Andean microdiorites, though they may be later dykes in the differentiation of the same magma. This would account for the differences in chemical composition which are not immediately apparent from the mineralogy. The latter dyke (F.57.2) also has a high water content, which again accounts for the high Fe''' : Fe'' ratio, the abundant iron ore, the interstitial quartz and the partial magmatic hydrothermal alteration of the ferromagnesian minerals. From the mineralogy, it is possible that these rocks were more basic than the term microdiorite suggests, but the low magnesia content precludes anything apart from a calc-alkali trend.

The basaltic andesite (F.64.2) can be compared with the porphyritic pyroxene-andesite (analysis 2) from King George Island. The most striking difference is in the Fe''' : Fe'' ratio which is low for specimen F.64.2. This is the only analysed rock which has a magnesia content high enough to bring it into a basaltic range, but there is not enough evidence to be conclusive and the mineralogy points to a calc-alkali affinity.

The analyses of the post-Andean microdiorites show a remarkably high soda content and rather low potash. These rocks contain highly altered plagioclase, and the soda content may reflect alteration to a more acid composition.

The Tertiary porphyritic augite-microdiorites (F.15.1, F.22.1) can be compared with the porphyritic microdiorite (analysis 1) from King George Island. The unusual feature of these rocks is once again the high Fe''' : Fe'' ratio which is due to the high water content. This is reflected in the mineralogy in the usual way, the rocks having numerous iron ore crystals and grains, and chlorite and amphibole pseudomorphs after pre-existing ferromagnesian minerals.

IX. SUMMARY

THE Upper Jurassic volcanic rocks are mainly andesite lavas and dacite pyroclastic rocks which have been metamorphosed and metasomatized by the Andean Intrusive Suite. The pre-Andean microdiorites are quite numerous but very rarely have they been found within the contact aureole of the intrusive rocks. The metamorphic grade close to the contact rises to the hornblende facies of thermal metamorphism, but it falls off rapidly away from the contact. Low-grade metamorphic effects, and more particularly metasomatism, are much more widespread phenomena. The principal manifestation of metasomatism is the albitization of plagioclase in all the rocks. The introduction of soda and silica has also been responsible for some silicification of the groundmass and general epidotization. There has also been the introduction of a certain amount of iron ore (as pyrite and magnetite), and possibly a little potash as well. The zoning of the alteration products is believed to be controlled by structure.

In the Argentine Islands the Andean Intrusive Suite comprises mainly granodiorites but more basic members of the suite occur on nearby islands. Several modal analyses of these rocks are given in Table I.

The numerous post-Andean dykes and sills have been subdivided on both their mineralogy and the few direct age relationships observed in the field. Most of the dykes show some degree of secondary alteration and metasomatism, and it would appear that the Andean Intrusive Suite continued to affect the country rocks for a considerable time after its emplacement. Some of the comparatively fresh and unaltered dyke rocks are comparable with one of the dykes recorded on King George Island, and which is possibly of Miocene age.

The eight new chemical analyses of the Argentine Islands dyke rocks have been plotted on triangular variation diagrams, which show they have a limited composition range. All the analysed specimens have a relatively high alumina content which is typical of the Andean petrological province.

X. ACKNOWLEDGEMENTS

THIS work was carried out in the Department of Geology, University of Birmingham, during the tenure of a Falkland Islands Dependencies Survey Research Assistantship. Thanks are due to Professor F. W. Shotton for making available the facilities of the department, to Dr. R. J. Adie for supervising the work and to members of the department for helpful discussion and criticism. Mr. M. D. Rhodes kindly drew the text figures. Helpful discussion with Dr. G. D. Nicholls is gratefully acknowledged.

XI. REFERENCES

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

BARTH, T. F. W. *and* P. HOLMSEN. 1939. Rocks from the Antarctandes and the Southern Antilles. Being a description of rock samples collected by Olaf Holtedahl 1927–1928, and a discussion of their mode of origin. *Sci. Res. Norweg. antarct. Exped.*, No. 18, 64 pp.

FYFE, W. S., TURNER, F. J. *and* J. VERHOOGEN. 1958. Metamorphic Reactions and Metamorphic Facies. *Mem. geol. Soc. Amer.*, No. 73, 259 pp.

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

KUNO, H. 1950. Petrology of Hakone Volcano and the Adjacent Areas, Japan. *Bull. geol. Soc. Amer.*, **61,** No. 9, 957–1019.

PLATE I

a. Porphyritic andesite showing unaltered titaniferous magnetite, skeletal pyrite and epidote round a plagioclase phenocryst; Indicator Island (F.44.3; ordinary light; ×30).

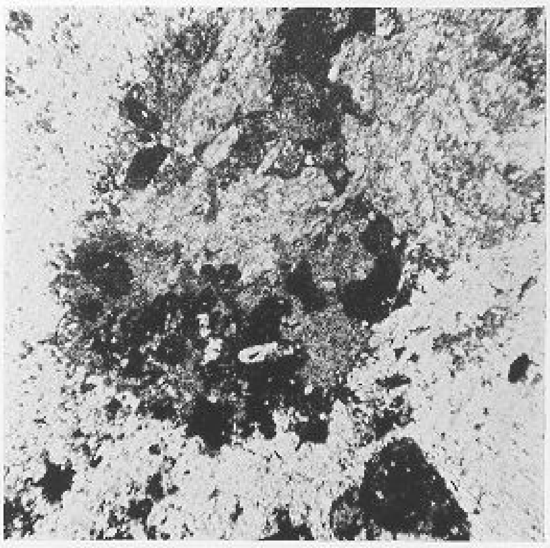
b. Pre-Andean microdiorite showing plagioclase phenocrysts and chlorite pseudomorphs set in an intergranular matrix of plagioclase crystals with a little quartz; north-western end of Winter Island (F.57.2; X-nicols; ×30).

c. Pre-Andean microdiorite with brown hornblende and plagioclase phenocrysts in a groundmass of plagioclase laths with interstitial iron ore, secondary minerals and rare augite; north-west corner of Skua Island (F.70.2; X-nicols; ×30).

d. Pre-Andean microdiorite with plagioclase phenocrysts set in a matrix of plagioclase laths with interstitial iron ore and amphibole; northern end of Uruguay Island (F.95.2; X-nicols; ×30).

e. Granodiorite showing untwinned orthoclase replacing plagioclase; north-west island of The Barchans (F.10.1; X-nicols; ×30).

f. Granodiorite showing a glomeroporphyritic aggregate of actinolite; north-east island of The Barchans (F.19.1; X-nicols; ×30).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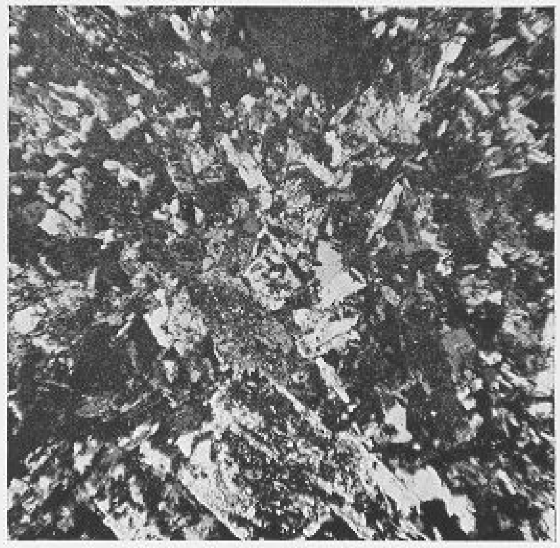
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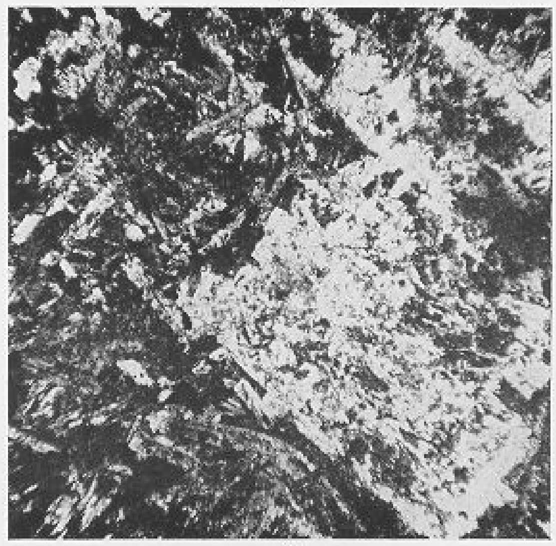
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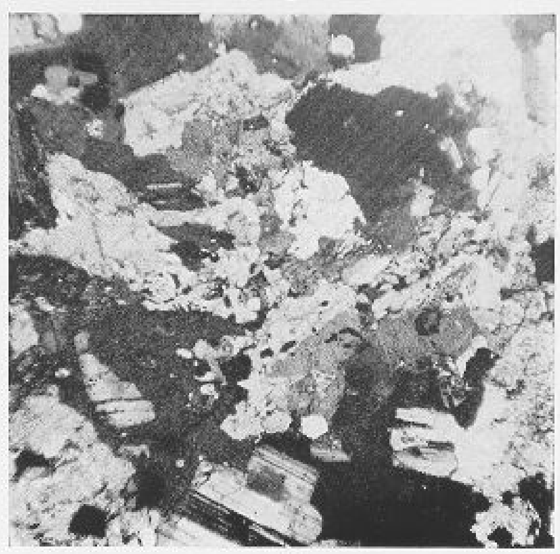
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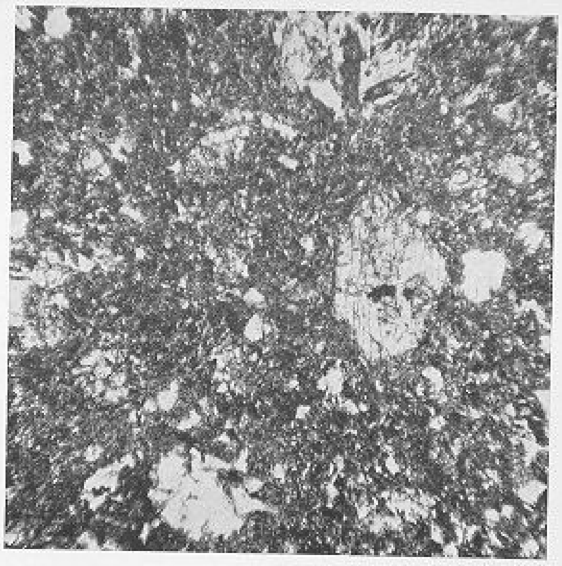
PLATE II



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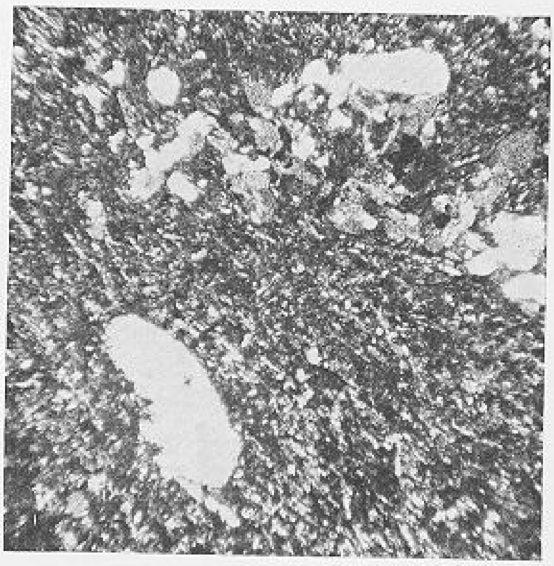

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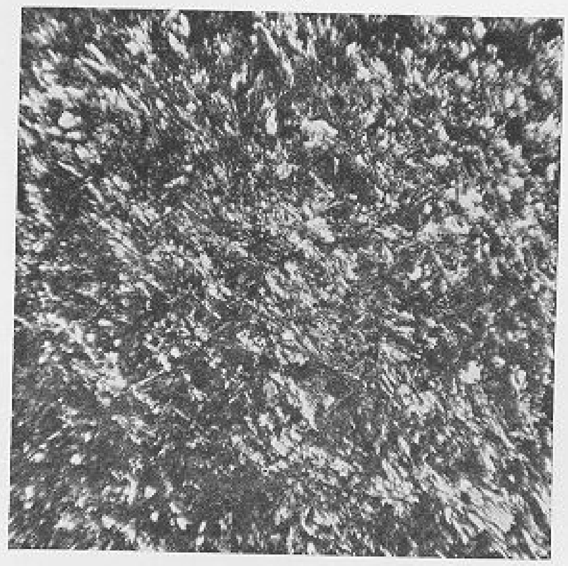

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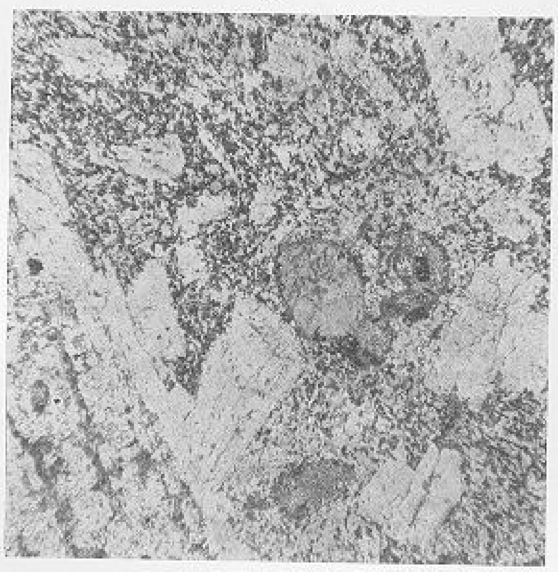

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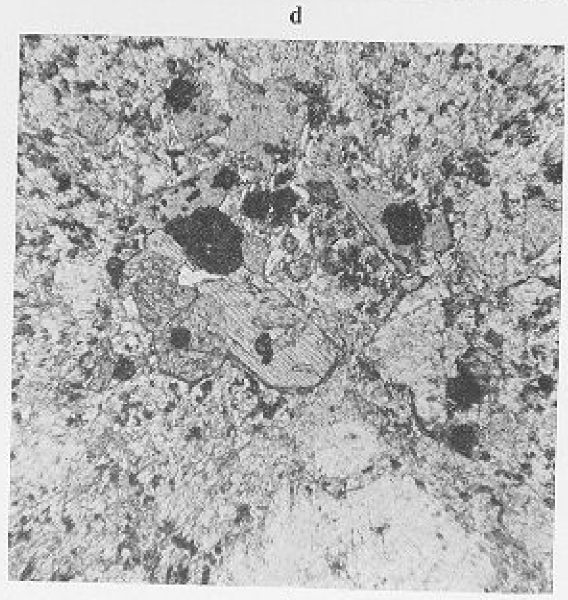

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PLATE II

a. Altered microgabbro with augite phenocrysts set in a matrix of plagioclase laths, iron ore and secondary minerals; southernmost of the Forge Islands (F.39.2; ordinary light; ×30).

b. Microgabbro showing a xenocryst of quartz in a matrix of plagioclase and amphibole laths and iron ore; north-east island of The Barchans (F.23.1; ordinary light; ×30).

c. Basaltic andesite dyke showing a brown hornblende phenocryst and an augite aggregate in a trachytic groundmass of plagioclase laths; north-east corner of Winter Island (F.64.2; X-nicols; ×30).

d. Microdiorite showing trachytic plagioclase laths; western part of Galindez Island (F.8.2; X-nicols; ×30).

e. Tertiary porphyritic andesite with plagioclase phenocrysts, and an augite crystal partly altered to actinolite in a matrix of plagioclase laths, iron ore and secondary minerals; island immediately south-west of Irizar Island (F.100.1; ordinary light; ×30).

f. Porphyritic augite-microdiorite showing an augite aggregate, plagioclase phenocrysts, chlorite pseudomorphs and iron ore with sphene set in a matrix of plagioclase laths, iron ore and secondary minerals; north-west island of The Barchans (F.15.1; ordinary light; ×30).