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THE GEOLOGY OF THE SOUTH SHETLAND ISLANDS

I. THE PETROLOGY OF KING GEORGE ISLAND

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I. THE PETROLOGY OF KING GEORGE ISLAND

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ABSTRACT

KING GEORGE ISLAND is almost entirely composed of igneous rocks; four volcanic episodes and one intrusive phase are represented. The oldest volcanics, which are believed to be Upper Jurassic in age, form a calc-alkaline suite with an andesite-rhyolite association. Recent field investigations indicate there is no evidence for the extensive areas of sedimentary rocks previously recorded. The presence of regionally metamorphosed xenoliths in the Jurassic Volcanics indicates that they rest upon a Basement Complex. The early Tertiary Andean Intrusive Suite, which is petrographically similar to that of Graham Land, forms an axial core to the island. The majority of the Jurassic Volcanics have been metasomatized by these intrusions and the significance of the resultant secondary minerals is discussed.

A linear pattern of Tertiary and Quaternary vulcanicity has been demonstrated and lavas of three distinct episodes are described. One of these volcanic groups is of unknown age, whilst the others are known to be Middle Miocene and Recent. The lavas include dominant pyroxene-andesites, basaltic andesites, olivine-basalts and rare trachyandesites. The petrogenesis of this volcanic suite is discussed and crystal separation is suggested as the most important factor in their evolution.

A geological map, compiled from all the available rock collections and field notes, shows the distribution of the volcanic and intrusive groups.

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* Now at the Geological Survey Department, Georgetown, British Guiana.

I. INTRODUCTION

THIS report is based on a laboratory study of the rock collections made by the following members of the Falkland Islands Dependencies Survey during the period 1947 to 1950:

A. Reece	January–March 1947
E. Platt	August–November 1948
G. Hattersley-Smith	December 1948–March 1949 (station numbers G.9–29 (H–S))
D. Jardine	July 1949–March 1950 (station numbers G.9–87).

These specimens together with the thin sections are housed in the Department of Geology, University of Birmingham. All station and serial numbers, except where otherwise stated, refer to the above collections. Through the courtesy of Professor T. Neville George, it has also been possible to re-examine Dr. G. W. Tyrrell's thin sections which are housed in the Hunterian Collection of the University of Glasgow. All the field observations in this report are quoted from the unpublished notes of D. Jardine.

King George Island, which lies between latitudes 61°50′ and 62°15′S., and longitudes 57°30′ and 59°00′W., is the largest member of the South Shetland Islands. An ice cap attaining some 2,000 ft. in height occupies the interior of the island, from which glaciers descend to the sea. There is a marked distinction between the smooth northern coastline and the deeply embayed southern coast. Most of the rock exposures occur in the south of the island, usually within two miles of the coastline.

Although it has been briefly mentioned in many published papers, no work deals exclusively with King George Island. The most important papers are those of Tyrrell (1921, 1945) and Ferguson (1921), and since they contain most of the published geological information for the island they are frequently cited in this report.

King George Island is composed almost entirely of igneous rocks and four important volcanic episodes and one intrusive suite are represented. Ferguson (1921) has described lavas and tuffs of two distinct groups of probable Upper Jurassic and mid-Tertiary age. He has shown that the Jurassic Volcanics are intruded by plutonic rocks, now known to belong to the Andean Intrusive Suite. Tyrrell (1945) has recognized a third volcanic group, represented by the Recent lavas and tuffs of Penguin Island, which are now considered as the closing phase of the Tertiary vulcanicity. A further volcanic episode described in this report is represented by the Fildes Peninsula Group, which is tentatively assigned an early Miocene age.

The only published geological sketch map of King George Island is the one in Ferguson's paper, but now that an accurate topographical map and air photographs are available it has been possible to compile the geological map shown in Fig. 1 from a petrographic study of the extensive rock collections. The suggested stratigraphical succession is given in Table I.

TABLE I

STRATIGRAPHICAL SUCCESSION AT KING GEORGE ISLAND

Penguin Island Group	Pliocene to Recent	**Olivine-basalts,** tuffs, hypersthene-augite-andesites, and augite-andesites.
Point Hennequin Group	Middle Miocene	**Hypersthene-augite-andesites,** tuffs, augite-andesites and basaltic andesites.
Fildes Peninsula Group	? Early Miocene	**Basaltic andesites,** hypersthene-augite-andesites and augite-andesites.
Andean Intrusive Suite	Late Cretaceous to early Tertiary	Quartz-gabbros, granodiorites and quartz-diorites.
Jurassic Volcanics	Upper Jurassic	**Pyroxene-andesites,** tuffs, basalts and rhyolites.
Basement Complex	? Archaean	Not exposed. Fragments in the Jurassic Volcanics and Penguin Island Group include quartzite and granite-gneiss.

Bold type indicates predominant lava types in each volcanic group.

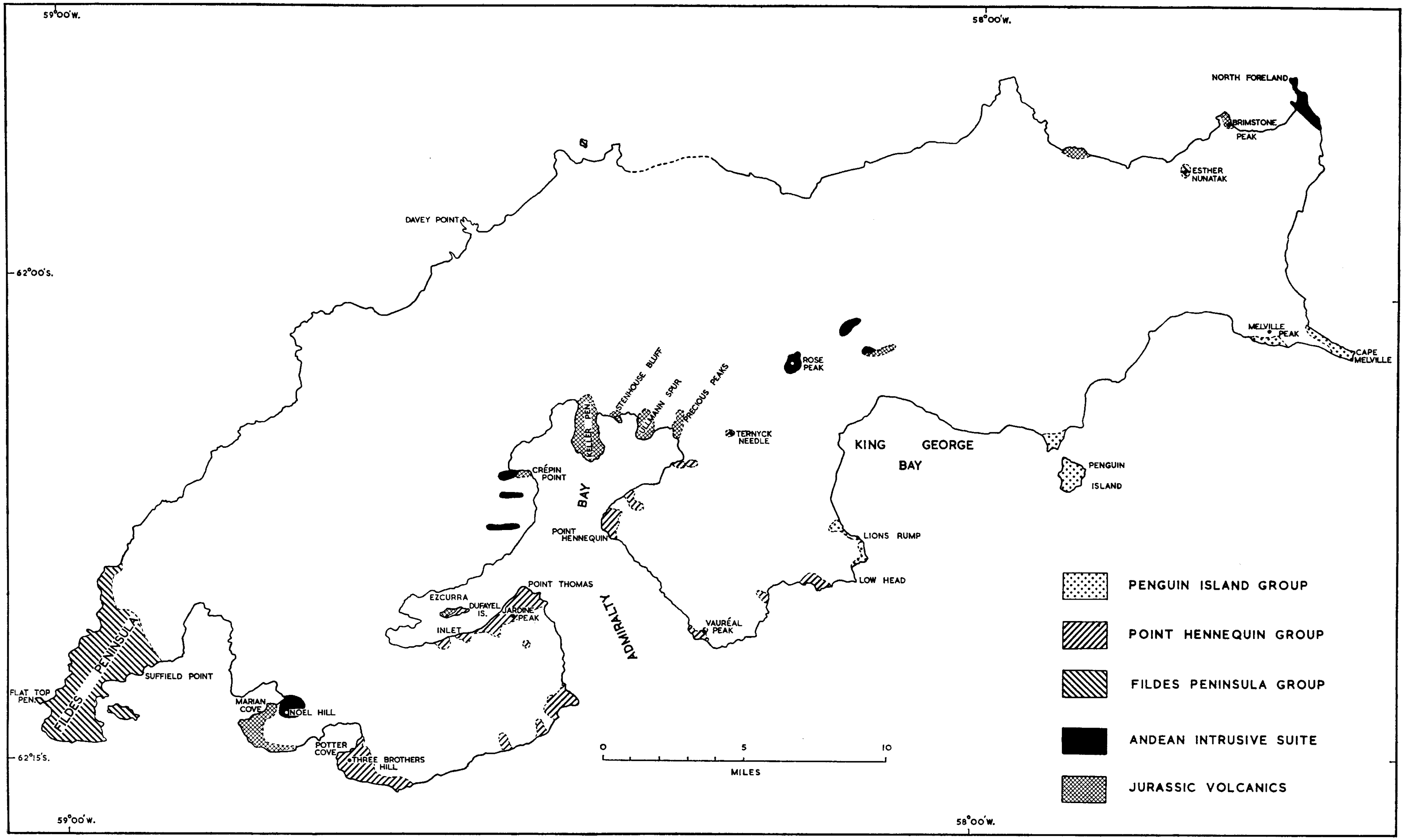


FIGURE 1
Geological sketch map of King George Island.

The Basement Complex. The Basement Complex is not exposed but fragments of green and black quartzite and hornblende-biotite-gneiss in the agglomerates north of Lions Rump, and erratics of garnetiferous granite-gneiss from the same locality, indicate its composition.

The Jurassic Volcanics. Ferguson (1921, p. 37) recorded a great thickness of mudstones and greywackes interbedded with the Jurassic lavas and tuffs, but it is now apparent that sediments constitute only a very minor part of the total succession in King George Island and that lavas and pyroclastics constitute the greater part of the Jurassic Volcanics. The carbonized, silicified and calcified woods in the agglomerates of the Keller Peninsula and Precious Peaks are similar to those from the Upper Jurassic rhyolites and rhyodacites of Cape Disappointment, Oscar II Coast (Adie, 1952) and the upper part of the Middle Jurassic sediments of Church Point and Mount Flora, Trinity Peninsula.

Ferguson regarded the entire western and central areas of the island as being composed of Jurassic Volcanics but, although Jurassic rocks are restricted to these parts, it is now considered probable that Tertiary volcanoes pierce the older lavas and tuffs. The lavas of Fildes Peninsula, derived from a vent at Flat Top Peninsula, and those associated with the Esther Nunatak neck are assumed to be a post-Jurassic, because they resemble those of the Tertiary petrographically. In thin section it is difficult to distinguish between the Jurassic and Tertiary lavas and the former can only be identified with certainty near the Andean plutonic intrusions, where they have been metasomatized and contain secondary minerals not present in the Tertiary rocks (p. 9).

The Andean Intrusive Suite. Reference to Fig. 1 shows that the Andean intrusions are more widespread than hitherto recorded, their outcrops forming an arcuate line across the island from Noel Hill to North Foreland. Petrographically they vary from quartz-gabbros to granodiorites and at Noel Hill two intrusive phases are probably present. The intrusive contact with the Jurassic lavas has only been observed at Crépin Point (Jardine, 1950). These plutonic rocks, which are now correlated with the Andean intrusions of Graham Land, are regarded as being late Cretaceous or early Tertiary (Adie, 1955). A minor intrusive phase which includes dykes and hydrothermal veins follows the main plutonic intrusions.

The Tertiary Volcanics. The discoveries of fossil plants on the scree-covered slopes one mile north of Point Hennequin, on Dufayel Island and on the south-west coast of Ezcurra Inlet indicate that most of the rocks south of the Andean intrusions are Middle Miocene in age. The lavas are fresh and were derived from a series of vents along the line of predominant hypersthene-augite-andesites (Fig. 2). They are well exposed near Point Hennequin and are referred to as the Point Hennequin Group.

Another succession of unaltered lavas and associated tuffs, which occurs north of the Andean intrusions in Fildes Peninsula and near Esther Nunatak, is referred to as the Fildes Peninsula Group. Their age is unknown but they are also tentatively assumed to be of mid-Tertiary age. Basaltic andesites are the commonest lavas.

The unconformity between the Tertiary and Jurassic Volcanics has been recorded on Dufayel Island (Diaz and Terrugi, 1956).

The Quaternary Volcanics. Penguin Island is a Recent volcano and its lavas together with those of Low Head and Cape Melville comprise the Penguin Island Group. The earliest lavas of this group are probably Pliocene in age and were erupted from a number of independent centres lying on or near the line of predominant olivine-basalts (Fig. 2).

II. THE BASEMENT COMPLEX

THE Basement Complex is not exposed on King George Island but fragments of quartzite and gneiss in the agglomerates of the Penguin Island Group at Lions Rump afford an indication of the nature of the underlying basement.

Quartzites. Specimen G.35.2 is a medium-grained green recrystallized rock composed mainly of a mosaic of quartz grains. Sericite flakes, leucoxene after ilmenite, sphene, calcite and a small amount of acid plagioclase comprise the rest of the rock.

Another variety of quartzite (G.35.3) is a very fine-grained black rock, composed of angular quartz grains, with a higher percentage of orthoclase, microcline and acid plagioclase fragments. Compared with the green quartzite it is poorly sorted and is of lower metamorphic grade. Brown fragments showing anomalous birefringence may represent shards of highly altered glass.

Granite-gneisses. One specimen (G.35.1) is a hornblende-biotite-gneiss which is a coarse-grained pink rock in the hand specimen. The texture is granoblastic and the bulk of the rock consists of a coarse intergrowth of quartz, microcline, orthoclase and some oligoclase. Both the plagioclase and the alkali-felspars are somewhat saussuritized. Biotite and hornblende clots form approximately 5 per cent of the total composition. The hornblende occurs as fresh crystals showing sieve structure and pleochroism in grass-green to light yellow-green, while the biotite occurs as ragged crystals, pleochroic in deep olive-green to straw and partially replaced along the (001) cleavage by chlorite. Granular sphene associated with both the hornblende and biotite is abundant.

A garnetiferous granite-gneiss (G.31.8) from the same locality was not found *in situ*. It is a white coarse-grained rock, composed of an intergrowth of quartz, orthoclase and acid plagioclase. Red subhedral almandine garnets are often surrounded by orientated flakes of biotite. In thin section the garnet is colourless to pale red and completely isotropic, but sometimes enclosing a single plate of biotite. Biotite occurs as ragged plates and is pleochroic in pale straw to pale brownish red. Nearly opaque yellow-brown sphene is a common accessory mineral.

III. THE JURASSIC VOLCANICS

THE Andean intrusive rocks have metasomatized the Jurassic lavas and the invariably altered state of these rocks, especially the acid differentiates, makes detailed petrographic study difficult. Nevertheless, it is apparent that the Jurassic lavas form a calc-alkaline suite with an andesite-rhyolite association. Among the lavas pyroxene-andesites are the most abundant, whereas rhyolites are rare and far subordinate to the great thickness of andesite. Basic rocks, which tend to be slightly oversaturated, are represented by occasional flows of basalt and basaltic andesite.

At this stage it would be premature to discuss the petrogenesis of the andesite-rhyolite association but it is sufficient to comment that the wide variety of rock types is unlikely to be correlated with any simple theory of linear differentiation. However, the following broad trend is probable:

Basalt → Basaltic andesite → Andesite → Dacite → Rhyolite
↘ Trachyandesite (Latite)

An apparent anomaly in the andesite-rhyolite association is the occurrence of albite-trachytes (p. 8). It is considered that most of these trachytes are not primary products derived from a soda-rich residual magma but were originally calcic rocks (probably porphyritic andesites) albitized by the Andean intrusions. Their consistent proximity to these intrusions and the ubiquitous presence of secondary minerals, such as calcite, epidote, pyrite, and chlorite, tends to support this view.

Jurassic rocks are well exposed on Keller Peninsula, Precious Peaks and Ullmann Spur. In these localities lava flows are interbedded with and succeeded by agglomerates and tuffs containing carbonized woods. The work of Jardine (1950) indicates that the Jurassic Volcanics may be sub-divided on a stratigraphical basis into

2. Tuff Beds (with fossil woods).
1. Lavas.

The lavas are intercalated with tuffs and agglomerates but consist mainly of great thicknesses of pyroxene-andesite with occasional basic and acid flows. The succession on Ullmann Spur is given in Table II and the petrography of the lavas is described below.

The Tuff Beds exceed 500 ft. in thickness on Ullmann Spur. Few specimens were collected by Jardine but from his report it may be concluded that the lower half of the succession consists of agglomerates containing andesite boulders up to 4 ft. in size. These agglomerates grade into well-bedded lithic tuffs both vertically and laterally toward the south.

1. Pyroxene-andesites

These andesites are invariably porphyritic, the dominant phenocrysts being composed of plagioclase accompanied by varying amounts of ferromagnesian minerals. The average composition of the plagioclase is that of labradorite but zoning of the phenocrysts is common and they often show secondary alteration to albite or saussurite. There is a gradation from the acid andesites, containing little or no mafic phenocrysts, to the basic types with noticeable amounts of these minerals. The ferromagnesian phenocrysts are either completely or partially altered but from the nature of the pseudomorphs it is probable that the original rocks included olivine-andesites, hypersthene-augite-andesites and augite-andesites. Hornblende is rarely present and then only in rocks better called dacites; biotite has not been recorded in the lavas. Tyrrell (1921, p. 70) has described a hornblende-bearing andesite from Noel Hill but this lava has been metasomatized and the amphibole is secondary after pyroxene. The groundmass of the andesites is commonly holocrystalline, but glassy varieties (now devitrified) occur especially in the more acid andesites. The groundmass is usually composed of microlitic andesine, intergranular augite and magnetite. In the acid andesites the microlites are orientated, giving a trachytic texture.

In the hand specimen the majority of the andesites have a greenish colour which is due to propylitization. The nature of the alteration products is discussed on p. 9.

With an increase in quartz the acid andesites grade into dacites, and with an increase in alkali-felspar into trachyandesites.

TABLE II.

GENERAL STRATIGRAPHICAL SUCCESSION ON ULLMANN SPUR

(after Jardine, 1950)

2. **Tuff Beds**	Coarse agglomerates and tuffs		500 ft.
	Fine-grained andesite	(G.15.6)	300 ft.
	Porphyritic basic andesite	(G.15.5)	
	Porphyritic basic andesite	(G.15.4)	
1. **Lavas**	Acid andesite	(G.15.3)	
	Porphyritic basic andesite	(G.15.2)	
	Andesite	(G.15.1)	

The Jurassic andesites are well exposed on *Ullmann Spur* and four specimens from this locality are described below in their stratigraphical order (Table II). Specimen G.15.2, taken from near the base of the succession, is a porphyritic basic augite-andesite and consists of numerous large (3 mm.) phenocrysts of basic labradorite ($Ab_{32}An_{68}$), accompanied by occasional 4 mm. phenocrysts of diopsidic augite and serpentinized microphenocrysts of olivine. The matrix, which has a microgranitic texture, apparently consists of an intergrowth of quartz and alkali-felspar pierced by numerous prismatic needles of apatite. Magnetite and much chloritic material, probably derived from pyroxene, are also present. The labradorite phenocrysts show partial albitization and the olivine crystals are completely pseudomorphed by serpentine, which is strongly pleochroic in dark green to pale yellow-green, and associated with minor amounts of calcite. Texturally this rock resembles some of the dyke rocks but no detailed record of its field relations is available.

A more acid rock (G.15.3) is composed of slightly zoned labradorite phenocrysts with an approximate composition of $Ab_{48}An_{52}$ set in a fine-grained matrix of andesine microlites showing a well-developed flow structure. No fresh ferromagnesian phenocrysts are present but they are undoubtedly represented by pseudomorphs of chloritic material, pleochroic in pale green and pale yellow-green. The calcite scattered throughout the groundmass probably replaces pyroxene granules. It also partially replaces labradorite phenocrysts which appear to have suffered incipient albitization and sericitization. Pleochroic brown apatite is a significant accessory mineral (p. 10). A small amount of interstitial glass, now turbid with alteration products, is also present.

A specimen (G.15.4) from the succeeding flow is a basic augite-andesite, but in comparison with G.15.2 the groundmass is very fine-grained and composed of orientated andesine microlites, pyroxene granules, minute octahedra of magnetite and a little interstitial glass. More than half the rock consists of large anhedral phenocrysts of bytownite ($Ab_{24}An_{76}$), pale yellow-green augite and serpentine pseudomorphs after olivine. The bytownite phenocrysts which contain augite and magnetite inclusions are fractured and some crystals are largely sericitized, whilst others are partially replaced by secondary calcite. The augite (2V approx. 55°) is quite fresh and the crystals are often deeply embayed, possibly due to magmatic corrosion. Magnetite occurs both as anhedral microphenocrysts in the groundmass and as a product of the serpentinization of the olivine. Calcite appears as numerous patches scattered in the groundmass.

The groundmass of specimen G.15.5, from a higher horizon, is largely cryptocrystalline with a mottled appearance between crossed nicols. Some microlites with straight extinction are oligoclase-andesine in composition. There are numerous labradorite phenocrysts showing normal and oscillatory zoning with a composition variation ranging from $Ab_{42}An_{58}$ to $Ab_{64}An_{36}$; some crystals are partly replaced by calcite and secondary albite (Plate IIa). Sparse phenocrysts of pale yellow augite (2V approx. 55°) accompany the plagioclase but they are now mostly replaced by pale green chlorite, calcite and a minor amount of epidote. A pale brown apatite and anhedral microphenocrysts of magnetite are the accessory minerals.

In *Keller Peninsula* (Plate Ia) a thickness of 1,500 ft. of Jurassic Volcanics is exposed (Jardine, 1950). This succession appears to be similar to that of Ullmann Spur with the same two-fold division (p. 6), but the stratigraphy is complicated by a fault of unknown magnitude. In the north-western part of the range an Andean quartz-gabbro intrusion crops out but no information is available on its relationship to the volcanics. Porphyritic pyroxene-andesites, many of which are similar to those of Ullmann Spur, are the predominant lavas in the volcanic suite, but in comparison with these the lavas of Keller Peninsula are more altered. Plagioclase phenocrysts are always the most numerous and are commonly labradorite but may be either bytownite or andesine. They are often albitized or replaced by calcite, while the pyroxene phenocrysts are usually completely pseudomorphed by chlorite or calcite. The shapes of the pyroxene pseudomorphs suggest that they replace hypersthene, and therefore many of the lavas were originally hypersthene-andesites. Silicification and pyritization are pronounced at some localities, whilst extensive replacement by carbonate is common especially at the southern end of the range (p. 10). Acid andesites, containing only a relatively small proportion of ferromagnesian phenocrysts, appear to be more abundant than the basic types. The groundmass is often trachytic, being composed of andesine or oligoclase-andesine microlites with intergranular augite and magnetite.

Dufayel Island is composed mainly of lavas, tuffs, and agglomerates. Pyroxene-andesites, similar to those described above, appear to be the most abundant lavas. Tyrrell (1921, p. 74) mentions two andesite specimens which have been completely replaced by epidote. A re-examination of these thin sections shows that in one specimen (3a) the porphyritic texture is still discernible; the plagioclase shows extensive sericitization, while the pyroxene is replaced by epidote. The second specimen (5a) is more altered and recrystallization has spread beyond the original crystal boundaries so that the rock is now composed of an aggregate of epidote, chlorite and leucoxene.

Near *Noel Hill* in the south-west and *Rose Peak* in the central part of the island, where pyroxene-andesites are adjacent to Andean intrusions, they show extensive metasomatism similar to that in the lavas of Dufayel Island.

The only exposures of Jurassic Volcanics north of the line of Andean intrusions visited by Jardine are west of *North Foreland.* The few specimens available for examination are clearly andesitic lavas similar to those already described from Ullmann Spur and Keller Peninsula. The proximity of the Andean intrusion at North Foreland has caused metasomatism and veining of the lavas (Jardine, 1950). A specimen from *Brimstone Peak* (G.29.3) is a typical pyroxene-andesite, composed of numerous labradorite phenocrysts accompanied by crystals of diopsidic augite, the latter largely replaced by chlorite and calcite. Cubes and irregular grains of pyrite and leucoxene are disseminated throughout the groundmass. *Esther Nunatak,* south-west of Brimstone Peak, is regarded as a Tertiary vent (possibly contemporaneous with the Fildes Peninsula Group), which pierces the surrounding Jurassic lavas, but the extent of the lavas derived from this vent is at present unknown.

2. BASALTS

Lavas with basaltic affinities appear to be a rarity in the Jurassic Volcanics. Two specimens from Keller Peninsula may be described as quartz-basalts. Texturally, these rocks are intergranular or intersertal, contrasting with the conspicuous porphyritic texture of the andesites already described on pages 6–7. Specimen G.21.10 is fine-grained and composed of zoned plagioclase laths ($Ab_{32}An_{68}$ to $Ab_{52}An_{48}$) with intergranular anhedral augite and magnetite. Areas of a yellow-brown amorphous substance are probably alteration products of original interstitial glass. The small amount of interstitial quartz appears to be primary. Two thin sections from specimen G.19.10 are similar to G.21.10, but they contain a slightly higher proportion of quartz. In these thin sections the plagioclase (with zoning from $Ab_{45}An_{55}$ to $Ab_{58}An_{42}$) and the augite ($2V\gamma'$ approx. 50°) occasionally form microphenocrysts, whilst the matrix possibly contains a small amount of alkali-felspar.

3. Acid Lavas

Compared with the great abundance of andesites, acid lavas are rare. They are interbedded with andesites and are often succeeded by a basalt or basic andesite flow. The fine grain and altered condition of the acid lavas renders them difficult to study under the microscope. There is a wide range in composition and Tyrrell (1921, pp. 71–2) has described albite-trachytes, latites (trachyandesites), dacites and rhyolites from King George Island.

The albite-trachytes described from Dufayel Island (Tyrrell, 1921, p. 72) consist of phenocrysts of cloudy albite set in a holocrystalline groundmass composed mainly of albite laths, which are enveloped by orthoclase. Interstitial quartz is present and an abundance of chlorite, epidote and calcite is disseminated through the groudmass. These secondary minerals strongly suggest that the original rock was much more calcic than an albite-trachyte.

Amongst the acid and sub-acid lavas, trachyandesites (latites) and dacites are the commonest rocks. Unfortunately, it is difficult to distinguish between these rock types, because the groundmass is frequently vitreous or cryptocrystalline and many of them cannot be named until chemical analyses are available.

A lava from the western side of Keller Peninsula has been identified as a latite of trachyandesite (Tyrrell, 1921, p. 71). This rock is porphyritic, being composed of sparse phenocrysts of albitized plagioclase (ranging from $Ab_{50}An_{50}$ to $Ab_{60}An_{40}$), pale green augite and magnetite. The groundmass is very dense and felsitic, probably composed of orthoclase microlites together with much unidentifiable felspathic material, altered ferromagnesian minerals and specks of iron ore.

Two other rocks from the same locality have been described by Tyrrell (1921, p. 71) as orthophyres. Sparse phenocrysts of soda-orthoclase are set in a fairly coarse groundmass of orthoclase, oligoclase, interstitial quartz and scattered patches of chlorite and titaniferrous magnetite. Although these rocks possess an orthophyric texture, it is preferable to call them dacites.

Another dacite from Keller Peninsula (G.21.11) is an altered, fine-grained lava composed essentially of andesine laths, augite, magnetite, interstitial quartz and probably alkali-felspar. The augite ($2V\gamma'$ approx. 50°) occurs as microphenocrysts and intergranular crystals partially replaced by chlorite and calcite. A few microphenocrysts of turbid orthoclase and hornblende (pleochroic in pale yellow-green and dark green) are also present. Pyrite is disseminated through the rock while chlorite and calcite occur as amygdales.

Tyrrell (1921, p. 72) has described from Noel Hill a felsite or devitrified rhyolite, which in thin section shows phenocrysts of turbid orthoclase in a dense, cryptocrystalline felsitic groundmass in which only quartz is identifiable. Secondary pyrite is disseminated throughout the lava.

4. Contact Metamorphism

The contact between the Andean intrusives and the Jurassic lavas has only been observed at Crépin Point. The lavas adjacent to the diorite are intensely veined with calcite and quartz and are intruded by basic and aplite dykes (Jardine, 1950). The diorite contains numerous xenoliths of the country rock and in the vicinity of the contact the andesites are hornfelsed. A thin section across the contact (G.23.3b) shows no decrease in grain size of the diorite and indeed plagioclase crystals are up to 3 mm. in size. The plagioclase is usually cracked and micropegmatite is conspicuous in the interstices. The main ferromagnesian mineral is a fibrous actinolitic amphibole and magnetite is a rare accessory. The country rock has been metamorphosed to a basic hornfels of the pyroxene-hornfels facies, which has a granoblastic texture and is composed of small granules of pleochroic hypersthene, recrystallized plagioclase and a significant amount of octahedral magnetite. There are minor amounts of apatite and biotite, the latter associated with magnetite. The biotite and amphibole replacing pyroxene are evidence of retrograde metamorphism. At some distance from the intrusion the lavas are epidotized (see below).

5. Metasomatism

All the Jurassic lavas examined show some degree of alteration and often the assemblage of the secondary minerals enables these rocks to be distinguished from those of Tertiary age. Many of the lavas appear to have been subjected to three distinct phases of replacement :

a. Local deuteric alteration in late Jurassic times.

b. Widespread metasomatism associated with the Andean intrusions.

c. Local metasomatism in the mid-Tertiary.

Prior to the onset of the Pleistocene glaciation exposed lava flows must have undergone subaerial weathering.

a. *Local deuteric alteration in late Jurassic times*

Because metasomatism associated with the Andean intrusions has severely affected them, it is impossible to identify the original alteration products. However, it is reasonable to assume that chloritization and serpentinization of the ferromagnesian minerals commenced at this time.

b. *Metasomatism associated with the Andean intrusions*

The Andean plutonic and hypabyssal intrusions have contact metamorphosed and metasomatized the Jurassic lavas and tuffs over a wide area. The high permeability of the tuffs has rendered them especially prone to alteration. The processes of epidotization and pyritization are of diagnostic importance since they affect only the Jurassic rocks. These processes, together with those of earlier chloritization and serpentinization, are described below.

Chloritization and serpentinization. The replacement of original ferromagnesian minerals by chlorite or serpentine, often resulting in the formation of magnetite, is invariably the first stage in the alteration of the Jurassic lavas. The composition of the secondary mineral depends on that of the original ferromagnesian mineral. Olivine and orthopyroxene are very susceptible to alteration, whereas the clino-pyroxene frequently persists in a fresh condition even when most of the rock has already been altered. In severely altered lavas, such as those near the Noel Hill intrusion, chlorite and serpentine occur in veins and amygdales associated with epidote and other secondary minerals.

Epidotization. Extensive replacement by epidote occurs only in Jurassic lavas and is confined to areas adjacent to Andean intrusions. The epidote, regarded here as a hydrothermal mineral, is patchily lemon yellow in colour and often occurs in veins and amygdales associated with secondary quartz and granular sphene. A pale yellow isotropic mineral, which may be grossularite, is associated with epidote in amygdales in a lava from station G.67.3. In the lavas showing only slight alteration, epidote is confined within the boundaries of plagioclase or clino-pyroxene phenocrysts, but at a more advanced stage the rock may be completely replaced by a granular intergrowth of chlorite and epidote. Epidotization of the Jurassic lavas is well developed at Rose Peak, Crépin Point, Dufayel Island and south of Noel Hill.

Pyritization. The introduction of secondary iron pyrites is restricted to the Jurassic lavas and is localized near the larger quartz-pyrite lodes, which occur in Keller Peninsula and west of North Foreland. These lodes appear to be associated with a late stage of the major Andean plutonic intrusions. In the hand specimen (G.19.1) the lode rock is dense, milky white and siliceous, containing pyrite cubes and veins. The adjacent lavas are silicified and contain disseminated microporphyroblasts of pyrite. The alteration of the pyrite to limonite or haematite is common. Leucoxene, probably derived from ilmenite, frequently accompanies the pyrite in both the lode rock and the pyritized and silicified lavas.

Albitization. Albitization of the plagioclase felspar is a common feature of all the Jurassic lavas. Soda enrichment has apparently been brought about by two different processes:

(i) Direct substitution of lime and alumina by soda and silica as a late stage process associated with the Andean intrusions. Epidotization and often pyritization accompanies albitization (p. 9). In this report the albite-trachytes are regarded as original calcic rocks which have undergone extensive albitization due to this process of substitution.

(ii) Reaction between CO_2-rich solutions and the anorthite molecule, resulting in the formation of calcite and the relative enrichment of the felspar in the albite molecule. This process is believed to have occurred mainly in mid-Tertiary times in the proximity of the volcanic vents along the hypersthene-augite-andesite line (p. 14).

c. *Local metasomatism in the mid-Tertiary*

Jurassic lavas are adjacent to the mid-Tertiary volcanic vents of the Point Hennequin Group, and fumarolic activity associated with these vents effected local carbon dioxide metasomatism of the Jurassic lavas.

Carbonatization. Although minor amounts of carbonate are present in many of the Jurassic lavas, abundant secondary calcite has only been recorded in the lavas of Keller Peninsula and Ullmann Spur, and Precious Peaks. In all cases carbonatization has been preceded by chloritization of the original ferromagnesian minerals. The lavas at the southern end of Keller Peninsula (G.20) illustrate this process well. In the early stages calcite appears as scattered patches in the groundmass but later it replaces the plagioclase phenocrysts along twin planes and cleavages, eventually completely pseudomorphing each crystal. In the replacement of the plagioclase clear patches of albite develop, but epidote is formed in only insignificant amounts. In some of the lavas south of Noel Hill zeolites associated with chlorite are present in amygdales. The introduction of these secondary minerals is probably related to the proximity of the mid-Tertiary vent of Three Brothers Hill.

An interesting feature is the widespread occurrence of brown apatite as a minor accessory mineral in these carbonatized lavas. In thin section it forms stumpy or long prismatic crystals, which are patchily brown in colour and show strong pleochroism in brown to colourless with an absorption $\varepsilon > \omega$. The colour is probably due to an abundance of minute unidentifiable inclusions arranged parallel to the vertical crystallographic axis. This distinctive mineral has been recorded from 14 localities in the presumed Jurassic and the mid-Tertiary lavas.

IV. THE ANDEAN INTRUSIVE SUITE

ANDEAN intrusive rocks, which are known from many localities in Graham Land, also occur in the South Shetland Islands and South Georgia. The age of the Andean intrusives is late Cretaceous or early Tertiary (Adie, 1955). They comprise a calc-alkaline suite ranging from ultrabasic to granitic types. In King George Island, where this suite is represented by quartz-gabbros, quartz-diorites and granodiorites, they form an axial core to the island trending approximately west-south-west to east-north-east. Vast areas of these rocks are probably concealed beneath the snowfields, but the only outcrops are at the following localities: Noel Hill, Crépin Point, Stenhouse Bluff, Rose Peak and North Foreland (Fig. 1). The only contact recorded on King George Island is the one at Crépin Point, where an Andean quartz-diorite intrudes a series of lavas and tuffs of probable Upper Jurassic age.

It seems probable that there are minor intrusions following the main plutonic phase and Jardine (1950) records "basic and aplite dykes" from North Foreland.

1. QUARTZ-GABBROS

These rocks are petrographically similar to the quartz-diorites but the plagioclase is basic labradorite or bytownite and usually both monoclinic and orthorhombic pyroxenes are present. So far, quartz-gabbros have only been recorded from one locality on King George Island.

Tyrrell (1921, p. 62) has described a quartz-gabbro (86b) from "*Le Poing*"† containing a pale green augite and fresh hypersthene (Table III). The plagioclase has an average composition of $Ab_{45}An_{55}$ and, although zoning is present, it is not as common a feature as in the quartz-diorites. The hypersthene,

TABLE III

MODAL ANALYSES OF THE ANDEAN INTRUSIVE SUITE

	86b	G.23.7	G.23.6	G.68.1	G.17.2 (H–S)	G.25.1	G.68.3	G.68.2
Quartz	—	4·3	5·9	7·6	9·5	13·2	13·4	19·6
Orthoclase	—	6·2	6·3	8·2	5·4	11·2	27·2	24·1
Micropegmatite	19·8	—	—	—	—	—	—	—
Plagioclase	48·2	66·7	57·9	63·0	62·1	61·0	44·5	46·1
Hypersthene	6·6	—	—	—	—	—	—	—
Augite	15·9	2·5	8·1	4·3	3·6	—	—	—
Hornblende[1]	—	16·7	14·0	13·0	—	12·0	11·2	4·8
Hornblende[2]	—	—	—	—	—	—	—	*
Biotite	—	—	—	*	—	0·2	0·1	3·1
Chlorite[3]	—	—	4·5	—	—	—	—	—
Chlorite[4]	—	—	—	*	13·9	—	—	—
Iron ore	7·9	2·9	2·7	3·0	3·8	2·0	3·5	2·1
Epidote	—	*	*	—	—	0·4	*	—
Calcite	—	—	—	—	1·4	*	—	—
Apatite	1·6	—	*	*	—	*	*	*
Zircon	—	—	—	—	—	—	—	*
Plagioclase composition	$Ab_{45}An_{55}$	$Ab_{42}An_{58}$	$Ab_{44}An_{56}$	$Ab_{48}An_{52}$	$Ab_{46}An_{54}$	$Ab_{53}An_{47}$	$Ab_{56}An_{44}$	$Ab_{58}An_{42}$
Colour index	31	22	29	20	22	14	15	10

[1] secondary after augite
[2] primary hornblende
[3] primary chlorite
[4] secondary chlorite
* present but not in sufficient quantity to be recorded

86b Quartz-gabbro, Le Poing (Tyrrell, 1921, p. 63).
G.23.7 Quartz-diorite, Crépin Point.
G.23.6 Quartz-diorite, Crépin Point.
G.68.1 Quartz-diorite, Noel Hill.
G.17.2 (H–S) Quartz-diorite, Stenhouse Bluff.
G.25.1 Granodiorite, Rose Peak.
G.68.3 Granodiorite, Noel Hill.
G.68.2 Granodiorite, Noel Hill.

† Referring to the ridge immediately west of Crépin Point.

pleochroic in salmon pink and pale green, is partly replaced by a green fibrous mineral showing straight extinction and low polarization colours; this is probably bastite. In another specimen (86a) from the same locality the hypersthene is completely pseudomorphed by bastite. There is an interstitial micrographic intergrowth of quartz and alkali-felspar. Magnetite and apatite are accessory minerals.

2. QUARTZ-DIORITES

With an increase in quartz and acidity of the plagioclase the quartz-gabbros pass into the quartz-diorites. Quartz always occurs as a minor constituent in these rocks and never exceeds 10 per cent. Hornblende is the dominant ferromagnesian mineral which is usually associated with and often replaces augite. The average plagioclase composition is either basic andesine or acid labradorite. Normal zoning is common and the maximum recorded compositional range is from labradorite ($Ab_{34}An_{66}$) in the core to oligoclase ($Ab_{71}An_{29}$) in the outer rim. Both oscillatory and reverse zoning have also been observed. The amount of orthoclase is always very subordinate to that of plagioclase but even the basic diorites contain at least 5 per cent of orthoclase. The quartz-diorites appear to be the commonest intrusive rocks on King George Island and they occur at all the localities mentioned previously.

Quartz-diorite forms part of the *Noel Hill* intrusion, and a specimen (G.68.1; Table III) from this locality is medium-grained with a hypidiomorphic texture. It contains a very pale green augite which has a large $2V \simeq 60–70°$, and an extinction angle, $\gamma:c = 48°$. It is partially replaced by pale green fibrous actinolite which is associated with granular magnetite (Plate IIc). Tyrrell (1921, p. 61) has recorded hypersthene in a similar rock (19) from this locality but a re-examination of his thin sections has revealed no definite orthorhombic pyroxene. The plagioclase is acid labradorite ($Ab_{48}An_{52}$) showing zoning and containing small augite, biotite and iron ore inclusions.

"Cape Crépin[1] is backed by a high rocky ridge trending east to west. South of the 'Crépin Glacier'[2] face, at the western end of the ridge, massive diorite forms grey cliffs two to three hundred feet in height" (Jardine, 1950). A petrographic examination of rocks from the *Crépin Point* intrusion indicates that quartz-diorite is the predominant rock type. Specimens G.23.6 and 7 (Table III) are medium-grained and are composed essentially of plagioclase, augite and its alteration products, iron ore and a small amount of quartz and alkali-felspar. The average plagioclase composition is acid labradorite ($Ab_{44}An_{56}$). Two generations, large laths up to 5 mm. in size showing only slight zoning and smaller crystals which are heavily zoned, have been recognized. The zoning is of the normal discontinuous type and three crystals from specimen G.23.7 showed the following variation:

Core	*Rim*
$Ab_{54}An_{46}$	$Ab_{71}An_{29}$
$Ab_{38}An_{62}$	$Ab_{56}An_{44}$
$Ab_{34}An_{66}$	$Ab_{71}An_{29}$

Combined Carlsbad-albite twinning is common and pericline twinning is also present. The plagioclases are fresh but often traversed by thin veins of pale green chlorite which shows very low birefringence. In the interstices between the felspar laths there are two varieties of chlorite, a very pale brown one which is completely isotropic and areas of fibrous pennine which is probably primary. The faintly brown augite forms euhedral crystals with good (110) cleavages and a parting parallel to (010) giving a schiller effect. Multiple twinning on (100) is common. The augite is biaxial positive with a $2V = 58°$ and an extinction angle, $\gamma:c = 45°$. It is partly altered and replaced by a faintly pleochroic, pale bluish-green actinolite with an extinction angle, $\gamma:c = 16°$.

The quartz-augite-diorite (G.17.2 (H–S); Table III) from *Stenhouse Bluff* is a grey medium-grained rock. In thin section it has a hypidiomorphic texture and the predominant constituents are plagioclase, augite and its alteration products, interstitial quartz and alkali-felspar. At least two generations of plagioclase are present; the large crystals are acid labradorite ($Ab_{46}An_{54}$), containing numerous small pyroxene inclusions, and the smaller ones are of andesine. Both generations are zoned but compositional differences of the individual zones are only slight. Combined Carlsbad-albite twinning is common and occasional

[1] Now called Crépin Point.
[2] Referring to the snowfield between Wegger and Admiralen Peaks.

crystals show pericline twinning. The augite, which occurs as subhedral crystals, is pale green when fresh and has a positive 2V = 50° and an extinction angle, γ:*c* = 46°. Simple and multiple twinning on (100) occur, but the former is more common. The augite is altered to chlorite, which shows moderate birefringence and a pleochroism scheme α = yellow-green, β = green, γ = green. It is biaxial negative with a very small 2V. Calcite and a minor amount of iron ore are always associated with the chlorite. Actinolite, which is a common secondary mineral in all the quartz-diorites described previously is not present in this rock. Quartz occurs both as large irregular patches and in interstitial areas together with intergranular allotriomorphic orthoclase and acid plagioclase.

The *North Foreland* peninsula is composed of another quartz-diorite intrusion but no specimens from this locality are available.

3. Granodiorites

The term granodiorite is used here for oversaturated rocks, in which acid plagioclase is dominant but up to one-third of the total felspar may be orthoclase. The ferromagnesian minerals are hornblende and biotite, and the accessory minerals include magnetite, apatite and zircon. The texture is typically hypidiomorphic. So far granodiorites have only been recorded from two localities, Noel Hill and Rose Peak, but it is likely that further field mapping will show that these rocks are more widespread.

Noel Hill, which rises to 1,200 ft. on the south side of Marian Cove, is reported by Ferguson (1921, p. 42) to be a large intrusion capped by dark mudstone, but observations by Jardine (1950) suggest that the mudstone, if present, is not at all extensive. Both granodiorites and quartz-diorites occur at Noel Hill and, although no contact between them has been recorded, it is likely that they represent two associated intrusive phases.

One specimen of granodiorite (G.68.2; Table III) is medium-grained, containing orthoclase as untwinned allotriomorphic crystals which are turbid with a very fine alteration product (probably kaolin). The average plagioclase composition is andesine ($Ab_{58}An_{42}$). Two generations are present, the earlier one showing marked zoning with cores of labradorite and rims of andesine and containing numerous inclusions of iron ore, biotite and minute pyroxene granules; the later generation is unzoned andesine. Both biotite and hornblende occur in this rock. The former is the common variety, which is strongly pleochroic with $\alpha = \beta$ = pale straw and γ = deep red brown. It is replaced along the (001) cleavages by a chlorite, showing pleochroism in pale straw to pale green, in optical continuity with the biotite but having anomalous brown and green polarization colours. The biotite, in clusters mantling the hornblende in normal reaction relationship, is associated with large crystals of magnetite (Plate IId). The hornblende has a pleochroism scheme α = colourless to pale yellow-green, β = pale olive-green, γ = olive-green and an extinction angle, γ:*c* = 23°. It is partially replaced by a fibrous actinolite with an extinction angle, γ:*c* = 16°, and which shows pleochroism in colourless to very pale green. Quartz occurs as large allotriomorphic crystals commonly containing minute bubbles and unidentifiable inclusions. Apatite and zircon are accessory minerals.

In two other specimens (G.68.3, 4; Table III) biotite is very subordinate to pale green actinolite which replaces the original pyroxene. Occasional remnant cores of clino-pyroxene occur in the fibrous actinolite which is peppered with small magnetite crystals. The pleochroism scheme of the actinolite is α = colourless, β = pale green, γ = pale green. It has an extinction angle, γ:*c* = 16° and is biaxial negative with a large 2V. Epidote is an important secondary mineral. The average composition of the heavily zoned plagioclase is $Ab_{56}An_{44}$. The interstitial areas are composed of a micrographic intergrowth of quartz and alkali-felspar. The modal analysis of G.68.3 (Table III) shows that the ratio of quartz to orthoclase is approximately 33 : 77, which is close to the eutectic ratio for these minerals.

Rose Peak is a frost-shattered nunatak rising from the snowfield north of King George Bay. Two specimens from this locality (G.25.1, 2) are medium-grained rocks petrographically similar to those from Noel Hill. In these rocks the amount of orthoclase is less than that in the granodiorites from Noel Hill, and it may be preferable to call these rocks quartz-hornblende-diorites (Table III). The average plagioclase composition is andesine, but zoning is common and the composition ranges from $Ab_{60}An_{40}$ in the cores to $Ab_{75}An_{25}$ in the rims. The plagioclase crystals are partially sericitized, and they are also traversed by a network of fine cracks (cf. G.23.3b (p. 8), in which cracking of the plagioclases occurs near an intrusive contact). The ferromagnesian minerals are hornblende and biotite, the latter occurring as large crystals which are strongly pleochroic with $\alpha = \beta$ = pale straw and γ = orange-brown, and are replaced by a pale green chlorite identical to that in one of the Noel Hill specimens (G.68.2). An intermediate mineral, which is pale green in colour and has a moderate birefringence, appears to have formed in the alteration of biotite to chlorite. The hornblende is again a fibrous actinolitic variety with an extinction angle, $\gamma{:}c = 16°$, pleochroism scheme α = colourless to pale yellow, β = greenish yellow, γ = pale green and an absorption $\alpha < \beta < \gamma$. The crystals are peppered with small grains of magnetite. This actinolite clearly replaces original pyroxene, because of the characteristic pyroxene-shaped pseudomorphs. Associated with the actinolite are abundant large crystals of lemon-yellow epidote, which also replace plagioclase. Quartz is present as large allotriomorphic grains and also as a micropegmatitic intergrowth with orthoclase, which is always partially altered to kaolin.

The Andean intrusions of King George Island are petrographically similar to those of Graham Land, but compared with the latter they show only a limited variation of rock type. As yet, only quartz-gabbros, quartz-diorites and granodiorites have been recorded. Quartz-diorites are the commonest, while granites, basic gabbros and ultrabasic accumulates do not appear to be represented. A characteristic feature of the King George Island intrusions is the presence of free quartz in both the diorites and gabbros. Chemically they form a calc-alkaline suite and the modal analyses (Table III) suggest a serial variation from basic to acid rocks.

The intrusions of King George Island form part of the Antarctandean orogenic belt, which extends from South America into Graham Land by way of the Scotia Arc. The South Shetland Islands form a subsidiary arc parallel to the main fold axis of Graham Land. No evidence is available from King George Island as to the precise age of the intrusions, but from their relationship to the Jurassic and Tertiary Volcanics it appears that they are post-Upper Jurassic and pre-Middle Miocene, and are therefore broadly contemporaneous with those of Graham Land.

V. THE TERTIARY VOLCANICS

IN the course of his field work on King George Island Jardine (1950) located the position of numerous volcanic necks. When they are plotted on a map it is evident that they form a definite linear pattern of vulcanicity. Furthermore, from a petrographic study of the lavas around each of these vents, it appears that on King George Island each line of vulcanicity is associated with a characteristic suite of lavas. There is conclusive evidence for two lines of vulcanicity in the area south of the Andean intrusives. A similar linear arrangement cannot be demonstrated north of the arc, because of limited exposures and collecting. However, it is of some significance that in Fildes Peninsula there is a preponderance of basaltic andesites. It is now postulated that there is possibly a third line joining the vents of Flat Top Peninsula and Davey Point. The following broad trends have been established (Fig. 2):

(i) A line of predominant basaltic andesites (Fildes Peninsula Group—? early Miocene).
(ii) A line of predominant hypersthene-augite-andesites (Point Hennequin Group—Middle Miocene).
(iii) A line of predominant olivine-basalts (Penguin Island Group—Pliocene to Recent).

In King George Island there was a progressive southward migration of volcanic centres during the Tertiary and Quaternary (Fig. 2).

Dykes of intermediate and basic composition (pp. 19–20), which have been recorded from Fildes Peninsula, Keller Peninsula, Stenhouse Bluff, Ullmann Spur, Precious Peaks and Point Hennequin, appear to be associated with the Tertiary Volcanics.

The Tertiary lavas are invariably fresh and are therefore ideal for petrographic study. Although each volcanic group is characterized by a predominance of one lava type, the subordinate lava types are often similar to those from other groups. For example, the occasional hypersthene-augite-andesites of the Penguin Island Group are petrographically similar to those of the Point Hennequin Group.

A. The Fildes Peninsula Group

The lavas associated with the basaltic andesite line belong to the Fildes Peninsula Group, which also includes subordinate hypersthene-augite-andesites and augite-andesites. The age of this group is unknown but its lavas are more similar to those of the Middle Miocene than to those of the Upper Jurassic. Therefore, this group is regarded as an integral part of the Tertiary Volcanics and is tentatively assigned an early Miocene age. The precise relationship of the lavas of Esther Nunatak to other groups is uncertain, and therefore for descriptive purposes they are included with the Fildes Peninsula Group.

Basaltic andesites

Basaltic andesites, which may be of different ages, have been described by Tyrrell (1921, p. 70) from Point Thomas, Vauréal Peak, Point Hennequin, Potter Cove and the northern shore of Ezcurra Inlet. An examination of the rocks in the present collections indicates that basaltic andesites are particularly abundant in Fildes Peninsula, which is now considered as the type locality of this group. Two distinct textural varieties of basaltic andesite have been distinguished:

(i) Porphyritic (Plate IIIb)

(ii) Intergranular (Plate IIIa)

The first type appears to be the commonest, and all the basaltic andesites described by Tyrrell are of this type. The phenocrysts, which are of basic labradorite or bytownite, often show marked zoning with a wide compositional range ($Ab_{20}An_{80}$ to $Ab_{70}An_{30}$). In the hand specimen these rocks resemble the andesites described on p. 16, but unlike the latter, pyroxene phenocrysts are rare. The two pyroxenes in the groundmass are subcalcic and pigeonitic augites. The texture of the groundmass is intergranular and the percentage of mafic minerals (> 30 per cent) is higher than that of a pyroxene-andesite.

The intergranular types often occur in the volcanic necks. They contain occasional phenocrysts and are composed almost entirely of a sub-ophitic intergrowth of labradorite, subcalcic and pigeonitic augite, with accessory iron ore and interstitial glass. A small amount of granular hypersthene is sometimes present. The presence of occasional serpentinized olivine crystals in both the porphyritic and intergranular types emphasizes the basaltic affinities of these rocks.

Jardine (1950) states that "... Fildes Peninsula consists of a series of lavas and agglomerates with a general easterly dip which lessens toward the east. Most of these rocks have been derived from the volcanic vent at Flat Top Island[1], although the succession has been complicated locally by small volcanoes now represented by Suffield Point and Mushroom Hill[2]". In thin section the lava from *Flat Top Peninsula* (G.77.1) is a basaltic andesite of the intergranular type (Plate IIIa). It is composed of roughly orientated plagioclase microphenocrysts (zoned $Ab_{30}An_{70}$ to $Ab_{50}An_{50}$) set in a sub-ophitic matrix of plagioclase laths ($Ab_{56}An_{44}$), colourless pigeonite ($2V \simeq 0$–$30°$) and subcalcic augite (2V approx. 45°). Small crystals of hypersthene are also present. Brown serpentinous areas probably replace original interstitial glass, whilst the small amount of original olivine may now be represented by carbonate and serpentine pseudomorphs. Anhedral magnetite grains are liberally scattered throughout the rock.

At *the hill one mile north-east of Horatio Stump* a fine-grained intergranular basaltic andesite (G.84.2) is interbedded with lavas of the porphyritic type. This very dense, dark grey rock is composed of labradorite laths ($Ab_{45}An_{55}$), very small granules of probable subcalcic and pigeonitic augite and magnetite. There are also a few phenocrysts of plagioclase and serpentinized olivine, the latter rimmed by magnetite grains and minute pyroxene granules.

Above this intergranular rock is a porphyritic basaltic andesite (G.84.3), which is composed of numerous 3.5 mm. labradorite phenocrysts (zoned $Ab_{33}An_{67}$ to $Ab_{56}An_{44}$) in monomineralic glomeroporphyritic clusters (Table VII), serpentinized olivine and a few glomeroporphyritic clusters of diopsidic augite. The groundmass consists of subcalcic and pigeonitic augite granules, plagioclase microlites ($Ab_{54}An_{44}$), magnetite and some interstitial dark brown glass which is largely altered to a yellow anisotropic substance.

Two specimens (G.81.1, 2) from a nearby locality are similar to the rock described above but they contain smaller and more numerous phenocrysts of zoned basic labradorite ($Ab_{30}An_{70}$ to $Ab_{70}An_{30}$), and anhedral magnetite crystals set in a matrix of subcalcic augite granules (2V approx. 40°), basic andesine

[1] Now called Flat Top Peninsula.
[2] Now called Horatio Stump.

laths and magnetite octahedra (Plate IIIb). Occasional carbonatized and serpentinized lozenge-shaped pseudomorphs after olivine are also present. The mode of G.81.1 is given in Table V.

The lava from the subsidiary vent at *Horatio Stump* (G.75.1) is porphyritic with anhedral plagioclase phenocrysts, serpentinized olivines and rare glomeroporphyritic clusters of ragged augites (2V approx. 50°). The plagioclase, often occurring as monomineralic clusters, shows both normal and oscillatory zoning from $Ab_{35}An_{65}$ to $Ab_{65}An_{35}$. Each olivine pseudomorph is rimmed by magnetite grains. The fine-grained, intergranular groundmass is composed of andesine microlites, abundant magnetite crystals and granules of subcalcic (2V approx. 45°) and pigeonitic ($2V < 30°$) augite.

B. The Point Hennequin Group

The lavas derived from the vents along the line joining Three Brothers Hill, Point Thomas and Ternyck Needle constitute the Point Hennequin Group. Although hypersthene-augite-andesites are the commonest lavas, this group includes basaltic andesites, augite-andesites and trachyandesites. Pyroclastic rocks are apparently subordinate to lava flows. The plant-bearing aqueous tuffs, which occur one mile north of Point Hennequin and along the south-west coast of Ezcurra Inlet, are included in the Point Hennequin Group, and indicate that these volcanics are Middle Miocene in age. The type locality for this group is shown in Plate Ib.

1. *Hypersthene-augite-andesites*

These are the commonest lavas in the Tertiary and are especially abundant in the Point Hennequin Group. They have been called bandaites by Tyrrell (1921, p. 67), because they have a modal composition very close to those originally defined by Iddings (1913). The majority of the hypersthene-augite-andesites have a porphyritic texture with conspicuous labradorite phenocrysts which usually show zoning ranging in composition from $Ab_{26}An_{74}$ to $Ab_{70}An_{30}$. In the more basic varieties, and particularly in the hyalo-andesites, olivine often occurs as rounded serpentinized crystals; in the latter rapid cooling has probably prevented the complete reaction of olivine with the magma. These basic andesites show petrographic affinities with the olivine-basalts of the Penguin Island Group. In the andesitic lavas the place of olivine is taken by phenocrysts of an orthorhombic pyroxene, usually hypersthene but occasionally enstatite. The orthorhombic pyroxene is accompanied in the basic varieties by a subordinate diopsidic augite and in the more acid andesites by common augite.

With the disappearance of hypersthene these rocks grade into the augite-andesites. Glassy types are very common and a glomeroporphyritic texture is typical in the hyalo-andesites. Mixed glomeroporphyritic clusters (p. 26; Table VII) are composed of anhedral labradorite, diopsidic augite and hypersthene with accessory magnetite and apatite. Tyrrell (1921, p. 68) notes the resemblance of the mixed clusters to inclusions of gabbro.

At many localities the hyalo-andesites are interbedded with tuffs and holocrystalline lavas. In hand specimen they are black or dark grey in colour and frequently have a vitreous appearance. To a large extent mineralogical variations in these rocks are masked by the glassy phase, but their "frozen state" enables the order of crystallization (p. 26) of the phenocrysts to be determined with certainty.

Ternyck Needle (Plate Id) is a volcanic neck forming a pinnacle which rises 370 ft. above the surrounding snowfield; it shows horizontal columnar jointing in its lower half and contorted jointing in its upper half (Jardine, 1950). The rock from this locality (G.13.1) is a basic andesite composed of numerous phenocrysts of labradorite and diopsidic augite with a few small crystals of fresh olivine set in a groundmass of dark brown glass which is charged with iron ore and andesine microlites. Both the labradorite and the pyroxene are strongly zoned, the former showing normal and oscillatory zoning with a compositional range from bytownite ($Ab_{24}An_{76}$) in the cores to andesine ($Ab_{58}An_{42}$) in the rims. The diopsidic augite (2V approx. 60°; $\gamma:c = 42°$) shows hour-glass structure and concentric zoning, but differences in composition of the individual zones appear to be slight.

A very fresh lava, occurring at *the small nunatak south-west of Ternyck Needle* (G.22.1A), consists of labradorite, hypersthene and subordinate diopsidic augite phenocrysts in a groundmass of pale brown glass ($n = 1.52$), which contains minute magnetite crystals and acid oligoclase microlites. The phenocrysts occur either as isolated subhedral crystals, or more commonly as mixed glomeroporphyritic clusters

(Plate IIIc). Each cluster is composed of an intergrowth of pale green diopsidic augite (2V approx. 50–55°; $\gamma : c = 44°$), slightly pleochroic hypersthene, and labradorite with minor amounts of anhedral magnetite and prismatic brown pleochroic apatite. The plagioclase phenocrysts are often fractured by flow and at least two generations are present. The earlier plagioclases are heavily zoned and have a composition of basic labradorite whereas the later ones are slightly zoned with an approximate composition of $Ab_{46}An_{54}$. The former show normal and oscillatory zoning and contain inclusions of diopsidic augite, magnetite, apatite and shards of glass. A few serpentinized areas probably replace original olivine which was a minor constituent.

TABLE IV

GENERAL STRATIGRAPHICAL SUCCESSION NEAR POINT HENNEQUIN
(after Jardine, 1950)

13.	Augite-andesite	(G.22.9)
12.	Augite-andesite	(G.22.8)
11.	Hypersthene-augite-andesite	(G.22.7)
10.	Andesite	(G.22.6)
9.	[Not exposed]	—
8.	Hypersthene-augite-hyalo-andesite	(G.22.5)
7.	Hypersthene-augite-hyalo-andesite	(G.22.4)
6.	[Flow inaccessible]	—
5.	Trachyandesite	(G.22.3)
4.	[Not exposed]	—
3.	Augite-andesite	(G.22.2)
2.	[Not exposed]	—
1.	Hypersthene-augite-hyalo-andesite	(G.22.1)

Total thickness about 900 ft.
Dip 5° to the north-east.

The excellent cliff section exposed near *Point Hennequin* (Table IV) includes three flows of hypersthene-augite-hyalo-andesite (G.22.1, 4 and 5). The lowest flow (G.22.1) is partly weathered and the glass of the matrix contains patches of cryptocrystalline silica, most of which appears to be secondary. Two generations of labradorite phenocrysts have been distinguished, the larger laths up to 7 mm. in length with saussuritized calcic cores and the smaller laths up to 3 mm. showing zoning $Ab_{26}An_{74}$ to $Ab_{46}An_{54}$. The mafic phenocrysts are pale green augite (2V approx. 55°; $\gamma : c = 47°$) and hypersthene, both commonly occurring in mixed glomeroporphyritic clusters associated with labradorite. Magnetite often occurs as large anhedral crystals near the margin of an augite crystal. Apatite is an accessory mineral.

Specimens G.22.4 and 5 are from two successive lava flows closely following a trachyandesite flow. Both these lavas are basic hypersthene-augite-hyalo-andesites containing a small amount of serpentinized olivine. Augite and hypersthene phenocrysts are abundant and occur both in mixed and occasional monomineralic clusters. The augite, which is pale green in colour, has a 2V approximately 50–60° and an extinction angle, $\gamma : c = 49°$. Both hour-glass structure and concentric zoning are marked and the extinction angles of individual zones differ by as much as 5°. The labradorite phenocrysts show normal and oscillatory zoning $Ab_{42}An_{58}$ to $Ab_{52}An_{48}$ and are riddled with inclusions of augite, hypersthene and shards of altered glass. Magnetite occurs as small anhedral crystals. The groundmass is composed of dark brown glass, pyroxene granules (probably augite), microlites of basic andesine and minute magnetite octahedra.

A similar rock (G.22.7) higher in the succession at Point Hennequin is composed of labradorite ($Ab_{39}An_{61}$), augite and hypersthene phenocrysts in a groundmass of felspar microlites ($Ab_{50}An_{50}$), augite and hypersthene granules, magnetite and green chloritic material partly replacing pyroxene and devitrified glass. The hypersthene occurs as subhedral prismatic crystals showing incipient alteration to serpentine. Frequently the hypersthene is surrounded by reaction rims of augite (Plate IIId). The augite occurs mainly as microphenocrysts (2V approx. 50°) showing concentric zoning. The presence of hypersthene both in the groundmass of this rock and the lava from Three Brothers Hill (p. 19) is of interest because Hess (1941) regards such occurrences as a rarity. The mode of specimen G.22.7 is given in Table V.

A rock from *the headland immediately south of Point Thomas* (G.52.3) contains only occasional phenocrysts of labradorite (approx. $Ab_{46}An_{54}$) showing slight zoning, diopsidic augite (2V approx. 50°; $\gamma : c =$

44°) and hypersthene in a groundmass of pale brown glass crowded with andesine microlites and octahedra of magnetite. The hypersthene is weakly pleochroic in pale buff and pale green, and occurs either as euhedral microphenocrysts or as mixed glomeroporphyritic clusters associated with diopsidic augite, magnetite and labradorite. The hypersthene is subordinate to augite and in some crystals possesses a reaction rim of augite. The pale brown glass of the groundmass shows a marked perlitic structure. Brown pleochroic apatite is present as an accessory mineral.

Tyrrell (1921, p. 69) has described a rock (84a) from *Point Thomas*, containing labradorite ($Ab_{40}An_{60}$), enstatite and subordinate augite set in a matrix of brown glass. A re-examination of this rock suggests that the orthopyroxene is hypersthene because it is biaxial negative and has weak pleochroism in pale buff and pale green. The rock is therefore a typical hypersthene-augite-hyalo-andesite and it can be matched closely with the hyalo-andesites east of Admiralty Bay.

The holocrystalline rock types occur at all the localities mentioned above and they are interbedded with glassy varieties, augite-andesites, rare trachyandesites and associated tuffs.

A specimen (30; Table V) from the major eruptive centre of *Three Brothers Hill* has been described in detail by Tyrrell (1921, p. 68). It is a hypersthene-augite-andesite consisting of phenocrysts of labradorite

TABLE V

MODAL ANALYSES OF THE TERTIARY AND QUATERNARY VOLCANICS

	G.33.2	G.81.1	G.46.2	30	30 (A)	30 (B)	G.22.7	G.22.7 (A)	G.22.7 (B)
Plagioclase	54·1	64·2	61·2	53·1	27·1	26·0	75·7	16·4	59·3
Olivine	12·5	*[1]	—	—	—	—	—	—	—
Hypersthene	—	—	—	4·2	4·2	—	1·7	1·7	—
Augite	28·1	29·3	28·6	23·6	3·6	20·0	18·5	2·2	16·3
Iron ore	5·2	5·8	2·8	8·1	1·1	7·0	3·2	—	3·2
Glass	—	—	5·1	11·0[4]	—	11·0[4]	—	—	—
Quartz	—	*[2]	2·0[3]	—	—	—	—	—	—
Plagioclase composition									
Phenocrysts	$Ab_{42-52}An_{58-48}$	$Ab_{30-70}An_{70-30}$	$Ab_{40}An_{60}$	$Ab_{34}An_{66}$			$Ab_{39}An_{61}$		
Matrix	$Ab_{46-52}An_{54-48}$			$Ab_{50}An_{50}$			$Ab_{50}An_{50}$		
Colour index	46	35	31	36			23		

[1] serpentinized
[2] secondary
[3] inclusions
[4] devitrified, with quartz
* present but not estimated

G.33.2 Olivine-basalt, Penguin Island.
G.81.1 Basaltic andesite, Fildes Peninsula.
G.46.2 Basaltic andesite, hill 1 mile SW. of Jardine Peak.
30 Bandaite, Three Brothers Hill (Tyrrell, 1921, p. 69).
30 (A) Bandaite (phenocrysts), Three Brothers Hill (Tyrrell, 1921, p. 69).
30 (B) Bandaite (matrix), Three Brothers Hill (Tyrrell, 1921, p. 69).
G.22.7 Hypersthene-augite-andesite, Point Hennequin.
G.22.7 (A) Hypersthene-augite-andesite (phenocrysts), Point Hennequin.
G.22.7 (B) Hypersthene-augite-andesite (matrix), Point Hennequin.

($Ab_{34}An_{66}$ to $Ab_{50}An_{50}$), hypersthene, subordinate augite and magnetite set in a groundmass of felspar microlites ($Ab_{50}An_{50}$), augite and hypersthene granules, magnetite and a small amount of interstitial glass. Tyrrell observed that the glassy matrix was partially devitrified and that some quartz was present.

A specimen (G.61.1) from the same locality is petrographically identical but no quartz could be detected in the groundmass.

2. *Augite-andesites*

With a decrease in the percentage of orthorhombic pyroxene the hypersthene-augite-andesites grade into the augite-andesites. In several thin sections (e.g., G.52.3 and G.22.7 (Plate IIId)) there is evidence of a reaction relationship between the hypersthene and common augite. Occasionally, a small amount of diopsidic augite also persists alongside the later generation of augite. These rocks possess a similar porphyritic texture to the hypersthene-augite-andesites. Phenocrysts of labradorite or basic andesine predominate and they are accompanied by augite phenocrysts set in a groundmass of felspar microlites, pyroxene granules and magnetite. The composition of the augite-andesites is more felsic than that of the hypersthene-augite-andesites and the microlites which are more sodic (usually oligoclase-andesine) frequently show a trachytic texture. Glassy varieties are subordinate to the holocrystalline types.

The Point Hennequin succession includes three flows of augite-andesite (Table IV). Specimen G.22.2 has a porphyritic texture with abundant labradorite phenocrysts (approx. $Ab_{36}An_{64}$) showing slight zoning together with fractured subhedral augite microphenocrysts (2V approx. 50°) in a groundmass composed of altered glass, magnetite and oligoclase-andesine microlites. Secondary calcite and quartz occur in small vesicles and the rock is veined with haematite.

The labradorite in specimens G.22.8 and 9, which shows slight zoning and has an approximate composition of $Ab_{36}An_{64}$, is traversed by thin veins of chloritic material. The augite is very pale green (2V approx. 50°) and commonly occurs as subhedral phenocrysts varying in size up to 1.5 mm., but occasionally it forms mixed glomeroporphyritic clusters with the felspar. Apatite, coloured grey by minute inclusions, is an accessory mineral in these clusters. The groundmass is carbonatized in patches and contains chloritic material which replaces pyroxene and probably glass. Microlites of oligoclase-andesine have a trachytic texture, and some alkali-felspar also appears to be present.

The augite-andesites are most abundant in the Point Hennequin Group, but they are also interbedded with the characteristic lavas of the Fildes Peninsula and Penguin Island Groups.

3. *Acid lavas*

Acid lavas seem to be a rarity in the Tertiary Volcanics and only one specimen (G.22.3), from a trachyandesite flow in the Point Hennequin succession (Table IV), was available for examination. The sparsely porphyritic lava is composed of andesine ($Ab_{60}An_{40}$) phenocrysts set in a very fine-grained felted groundmass of microlites with straight extinction which are possibly orthoclase. The andesine phenocrysts, which are partially replaced by albite, commonly show rhombic sections. Anhedral magnetite crystals and prisms of colourless apatite are the accessory minerals. The lava is veined with secondary quartz and haematite.

C. Dykes

Dyke rocks, which intrude the Jurassic Volcanics, have been recorded by Jardine (1950) from several localities in Keller Peninsula and Ullmann Spur, at the northern end of Admiralty Bay. Petrographic evidence suggests that the age of these dykes is likely to be mid-Tertiary; they are possibly associated with the volcanic centres of that period. In many areas the Jurassic Volcanics have been severely metasomatized by the Andean intrusives, but none of the dyke rocks described below show signs of albitization, epidotization or pyritization. This seems to indicate that the dykes are post-Andean in age.

Two specimens from the north-western part of *Keller Peninsula* (G.21.8, 9) are porphyritic microdiorites composed of labradorite, augite, iron ore and a minor amount of hypersthene with some interstitial quartz and alkali-felspar. The labradorite ($Ab_{40}An_{60}$) is fresh but it contains numerous inclusions of pyroxene and is traversed by narrow veinlets of chlorite. Zoning in the plagioclase has been observed but it is not typical. The pale green augite has a $2V\gamma = 70°$ and an extinction angle, $\gamma : c = 45°$. Idiomorphic hypersthene, pleochroic in pale buff and pale green, is present both as sparse microphenocrysts and as inclusions in the plagioclases. In the interstices between the large crystals of augite and labradorite are small laths of more acid plagioclase and an intergrowth of quartz and alkali-felspar associated with much chloritic material and flakes of biotite. A chemical analysis of G.21.8 is given below.

SiO_2	55.38
TiO_2	0.76
Al_2O_3	16.51
Fe_2O_3	4.63
FeO	2.99
MnO	0.10
MgO	3.89
CaO	7.34
Na_2O	2.94
K_2O	1.75
SrO	0.02
H_2O +	1.75
H_2O −	1.17
P_2O_5	0.36
CO_2	0.63
S″	0.12
Cl′	0.07
	100.41
less O″	0.08
	100.33

G.21.8. Porphyritic microdiorite, Keller Peninsula, King George Island (anal. K. Chaplin (Brit. Mus.)).

Two dykes of porphyritic microdiorite, which intrude the Jurassic Volcanics on *Ullmann Spur*, bear a close resemblance to those of Keller Peninsula. They are composed of labradorite ($Ab_{35}An_{65}$), augite, iron ore, interstitial quartz and probably some alkali-felspar. Two generations of labradorite phenocrysts are present. The earlier generation is heavily zoned, shows incipient sericitization and is traversed by narrow veins of chlorite. The later labradorite occurs as large fresh phenocrysts which contain numerous inclusions of augite and iron ore. Both normal and oscillatory zoning have been observed in these large phenocrysts but the variation in composition between individual zones is only slight. The augite phenocrysts ($2V \simeq 55°$) are subhedral and have multiple twinning on (100). Rounded and embayed faces are suggestive of resorption, while normal and oscillatory zoning of the augite is a common feature in these dyke rocks. In the interstices between the labradorite and augite phenocrysts the matrix is composed of more acid plagioclase laths intergrown with augite, iron ore, interstitial quartz and an abundance of chloritic material. Much of the chlorite replaces augite but some aggregates of chlorite and serpentine may replace original olivine or orthorhombic pyroxene.

The first of the Tertiary eruptions on King George Island probably commenced in the early Miocene and these initiated a cycle of vulcanicity that continued elsewhere in the South Shetland Islands almost to the present day. These volcanics are the basaltic andesites of the Fildes Peninsula Group, which were derived from a number of vents north of the Andean intrusions.

In the Middle Miocene the eruptive centres migrated southwards, giving rise to the great thicknesses of pyroxene-andesite which comprise the Point Hennequin Group. The occurrence of plant fossils in the associated aqueous tuffs has enabled the Point Hennequin Group to be dated accurately. On this basis it seems that the Point Hennequin Group is contemporaneous with the James Ross Island Volcanics of north-eastern Graham Land. The first eruptions of the Penguin Island Group probably occurred in the Pliocene.

Petrographically, the lavas of the Fildes Peninsula and Point Hennequin Groups form a calc-alkaline suite, but the occurrence of trachyandesites rather than rhyolites in the Point Hennequin Group indicates an alkaline trend. This is fully developed in the Recent lavas of Deception Island.

VI. THE QUATERNARY VOLCANICS

THE PENGUIN ISLAND GROUP

THE lavas derived from the vents lying along the line of predominant olivine-basalts are referred to the Penguin Island Group, and true olivine-basalts are restricted to this group. Penguin Island is a Recent volcano but it seems probable that the first lavas of this group were erupted in Pliocene times. These volcanic vents are located on or near the line connecting Low Head, Penguin Island and Cape Melville (Fig. 2). Although the present rock collections show that olivine-basalts are more widespread than hitherto recorded, they are of relatively restricted occurrence and are far subordinate in amount to the andesites of the Point Hennequin Group. The Penguin Island volcano is shown in Plate Ic.

Two basaltic dykes, which are clearly associated with these volcanics, occur on the south-west coast of Penguin Island.

Olivine-basalts

These rocks are either holocrystalline or hemicrystalline, and accordingly the texture of the groundmass is either intergranular or intersertal. In contrast with the andesites flow banding is rare in the olivine-basalts. They are usually porphyritic with subhedral phenocrysts of olivine and diopsidic augite. The frequency of magnesian olivine phenocrysts appears to be determined by the degree of crystallinity. Large fresh crystals are abundant in the hemicrystalline and very fine-grained rocks, whereas in the coarser-grained basalts olivine phenocrysts are sparse and usually serpentinized. The pale green diopsidic augite, which usually accompanies the olivine, has apparently crystallized alongside the olivine without any reaction relationship. The groundmass of the holocrystalline varieties is essentially composed of plagioclase microlites ($Ab_{32-52}An_{68-48}$), pyroxene granules and iron ore. Usually two pyroxenes, augite ($2V \simeq 45°$) and pigeonitic augite ($2V \leqq 30°$), occur in the groundmass. There are also vesicular and amygdaloidal lavas in which the principal secondary minerals are calcite, chlorite and zeolites.

The topographical features of the *Penguin Island* volcano have been described in detail by Tyrrell (1945, p. 45). Two specimens from the present collection (G.33.1, 2; Table V) have a porphyritic texture (Plate IIb) with numerous phenocrysts of a fresh magnesian olivine, pale green diopsidic augite and micro-phenocrysts of labradorite in an intergranular matrix of labradorite microlites, pyroxene granules and iron ore (magnetite and chromite). The olivine phenocrysts, varying in size up to 3 mm., contain inclusions of magnetite and chromite, and show evidence of resorption. Some examples of the skeletal shapes formed by the reaction of olivine with the magma are shown in Fig. 3. The diopsidic augite ($2V \simeq 50$–$55°$; $\gamma{:}c = 40°$) shows well-developed hour-glass structure and concentric zoning. Two pyroxenes, a subcalcic augite ($2V \simeq 45°$) and a pigeonitic augite ($2V \simeq 20$–$30°$), are present in the groundmass. The zoned plagioclase microphenocrysts range in composition from $Ab_{42}An_{58}$ to $Ab_{52}An_{48}$ and the microlites vary in composition from $Ab_{46}An_{54}$ to $Ab_{52}An_{48}$. Tyrrell (1945, p. 46) has described a similar rock containing a pale brown augite, and also other specimens, which have interstitial glass blackened with iron ore dust.

In a specimen (G.33.5) from a dyke or plug in the breached western crater of Penguin Island the amount of olivine is greatly reduced and is subordinate to that of augite. A little hypersthene takes the place of olivine. The latter is altered to brown serpentine and pale green chrysolite. The occasional plagioclase microphenocrysts have a composition of andesine-labradorite ($Ab_{50}An_{50}$). The subhedral clino-pyroxene shows concentric zoning and has a 2V of approximately 50° with an extinction angle, $\gamma:c = 40°$.

A vesicular lava (G.34.1) *from the mainland opposite Penguin Island* contains numerous phenocrysts of labradorite in addition to large olivines and augites. The olivines are slightly zoned and occur as crystals up to 3 mm. in size containing inclusions of magnetite. Both optically positive and negative olivines are present, and they are partially pseudomorphed by a red anisotropic substance. The pale green diopsidic augite occurs as glomeroporphyritic clusters of subhedral crystals, which have a 2V of approximately 50–55°, and an extinction angle, $\gamma:c = 45°$. Zoning of the plagioclase phenocrysts is marked and the composition of the zones varies from $Ab_{44}An_{56}$ to $Ab_{57}An_{43}$, whilst the groundmass microlites are of acid labradorite.

The olivine-basalt of *Low Head* (G.36.1) is holocrystalline with intergranular augite and labradorite ($Ab_{32}An_{68}$), and serpentinized microphenocrysts of olivine accompanied by diopsidic augite. The pyroxene has a 2V of approximately 45–50° and shows marked hour-glass structure (Plate IIIe). The labradorite is traversed by veins of serpentine.

At *Cape Melville* there is a hemicrystalline variety (G.31.1), which contains large (up to 3 mm.), fresh phenocrysts of subhedral magnesian olivine and glomeroporphyritic clusters of pale green diopsidic augite ($2V \simeq 60°$; $\gamma:c = 38°$). The groundmass is composed of plagioclase microlites ($Ab_{42}An_{58}$), subcalcic and pigeonitic augite, and much interstitial brown glass dusted with iron ore.

A specimen from *Melville Peak* (G.32.1) contains phenocrysts of fresh magnesian olivine and clots of diopsidic augite set in a trachytic groundmass of plagioclase microlites ($Ab_{42}An_{58}$), augite granules and iron ore with a little interstitial brown glass.

The olivine-basalts of the Penguin Island Group represent the closing phase of a cycle of vulcanicity which commenced on King George Island in the early Miocene. They were derived from a number of independent centres along the southernmost of the three lines of crustal weakness which determined the pattern of Tertiary and Quaternary vulcanicity (Fig. 2). Future investigation will probably show the existence of these same tectonic lines in the other parts of the South Shetland Islands. A microscopic examination of the lavas from Edinburgh Hill on Livingston Island shows that they are identical to those of Penguin Island, and lie close to the westward projection of the line joining Cape Melville, Penguin Island and Low Head.

A problem that requires elucidation is whether the Tertiary and Quaternary vulcanicity on King George Island is directly related either to the Andean orogenesis or to the supposed subsidence of the Bransfield Strait. Nordenskjöld (1913) has postulated that the Recent volcanoes of Deception Island, Edinburgh Hill and Bridgeman Island (and by analogy, Penguin Island) bear some tectonic relationship to the subsidence of the Bransfield Strait. Until such time as geophysical information is available on the structure of the Bransfield Strait it will be difficult to solve this problem.

VII. PETROGENESIS OF THE TERTIARY AND QUATERNARY VOLCANICS

In this report the Tertiary and Quaternary lavas of King George Island have been subdivided into three groups, each of which is characterized by the predominance of one lava type. Pyroxene-andesites are by far the commonest lavas but they are accompanied by subordinate basaltic andesites, olivine-basalts and rare trachyandesites. It is of some importance to note that the olivine-basalts, found only in the Penguin Island Group, were erupted not at the beginning but during the closing phases of vulcanicity. The age of the basaltic andesites of the Fildes Peninsula Group is uncertain but it is suggested here that they preceded the Middle Miocene lavas of the Point Hennequin Group. Therefore, the time sequence is:

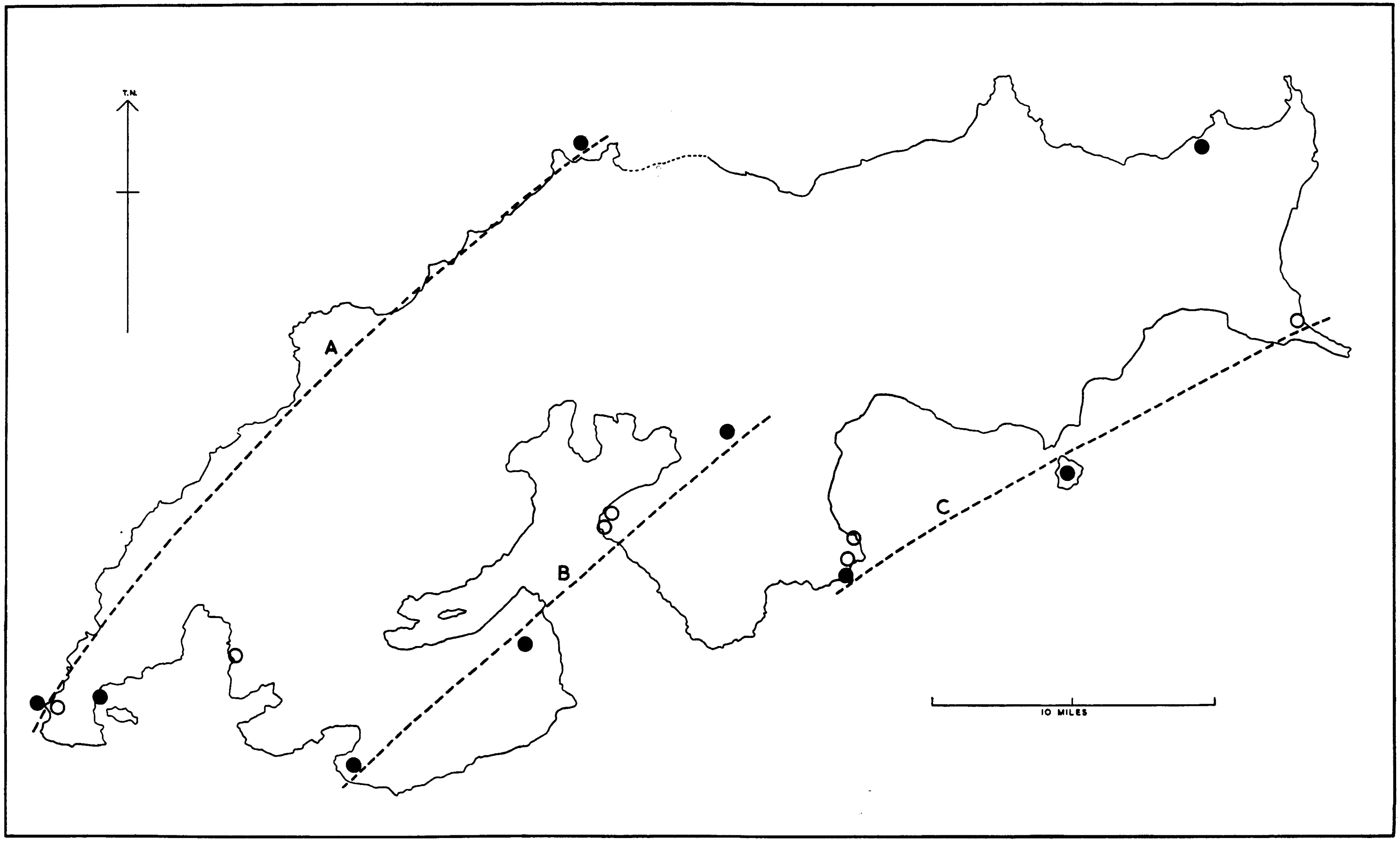


FIGURE 2

Map of King George Island showing the location of the eruptive centres and the linear pattern of Tertiary and Quaternary vulcanicity.

The solid circles represent known vents; the open circles represent probable vents.

A = Line of basaltic andesites.
B = Line of hypersthene-augite-andesites.
C = Line of olivine-basalts.

3.	**Olivine-basalts** Hypersthene-augite-andesites	(Penguin Island Group)
2.	**Hypersthene-augite-andesites** Augite-andesites Trachyandesites	(Point Hennequin Group)
1.	**Basaltic andesites** Hypersthene-augite-andesites Augite-andesites	(Fildes Peninsula Group)

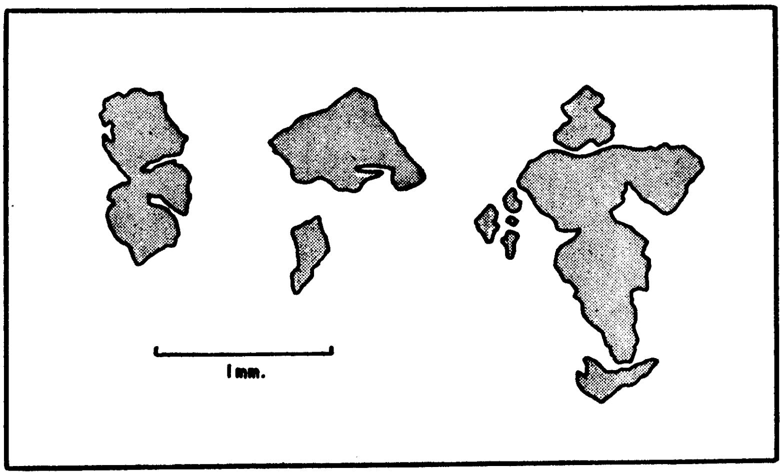


FIGURE 3

Resorption of magnesian olivine phenocrysts in the olivine-basalts of the Penguin Island Group.

The Point Hennequin Group includes an overwhelming abundance of hypersthene-augite-andesites, which with a decrease in mafic minerals grade into the augite-andesites and rare trachyandesites. Every gradation would appear possible. There is, however, a great difference in mineralogy between the andesites

TABLE VI

DISTRIBUTION OF PHENOCRYSTS IN THE TERTIARY AND QUATERNARY VOLCANICS

	Plagioclase	Olivine	Diopsidic augite	Hypersthene	Augite
Felsic lavas	X	—	—	—	—
Augite-andesites	X	—	—	—	X
Hypersthene-augite-andesites	X	—	X	X	—
Basaltic andesites	X	—	—	—	—
Olivine-basalts	—	X	X	—	—

X indicates presence in noticeable quantities.

TABLE VII

DISTRIBUTION OF GLOMEROPORPHYRITIC CLUSTERS IN THE TERTIARY AND QUATERNARY VOLCANICS

	Monomineralic Clusters			Mixed Clusters			
	Plagioclase	Diopsidic augite	Olivine	Olivine and Diopsidic augite	Plagioclase and Diopsidic augite	Plagioclase, Hypers-thene and Diopsidic augite	Plagioclase and augite
Felsic lavas	—	—	—	—	—	—	—
Augite-andesites	—	—	—	—	—	—	*
Hypersthene-augite-andesites	—	—	—	—	X	X	—
Basaltic andesites	X	—	—	—	—	—	—
Olivine-basalts	—	X	*	X	—	—	—

X indicates presence in notable quantities.
* indicates minor amount.

and the olivine-basalts. Both are porphyritic, but in the latter olivine and clino-pyroxene are the commonest phenocrysts, whereas in the andesites plagioclase felspar predominates (Table VI). The olivine-basalts can probably be regarded as differentiates of a pyroxene-andesite magma from which early olivine was precipitated.

The following hypothesis is tentatively put forward to explain the stages in the broad evolutionary trend of the Tertiary and Quaternary volcanic suite, but in the light of future research it may have to be modified or even discarded.

(i) At an early stage olivine, diopsidic augite and basic plagioclase started precipitating from the parent magma.

(ii) Gravitational separation proceeded, the olivine and diopsidic augite sinking to the bottom of the magma chamber, while the basic plagioclase tended to float. This subsequently gave rise to *three zones* in the magma chamber, the lowermost rich in olivine and diopsidic augite, the uppermost rich in basic plagioclase, and the intermediate zone a mush of diopsidic augite and basic plagioclase.

(iii) At the commencement of vulcanism the upper plagioclase-rich layer of magma was tapped from the chamber. This gave rise to the basaltic andesites and associated rocks of the Fildes Peninsula Group.

(iv) Vulcanism continued with the eruption of the intermediate layer, which consisted of a mush of diopsidic augite and basic plagioclase. This gave rise to the pyroxene-andesites of the Point Hennequin Group, which contain mixed glomeroporphyritic clusters.

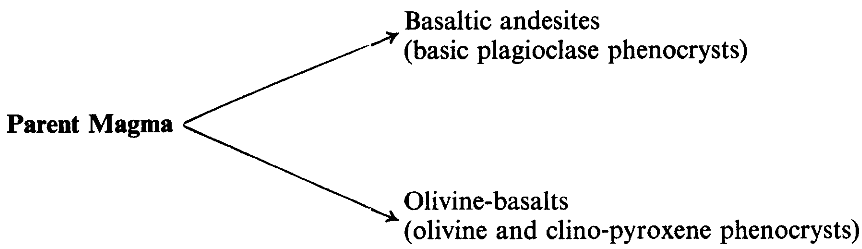
(v) The final phase was the eruption of the lowermost olivine-rich layer from the magma chamber and this is represented by the olivine-basalts of the Penguin Island Group.

Of particular significance is the widespread occurrence of glomeroporphyritic clusters of which two types have been distinguished:

(i) Monomineralic clusters.

(ii) Mixed clusters of two or more different minerals.

The monomineralic clusters contain euhedral or subhedral crystals grouped together but not intergrown, whereas the mixed clusters have two or more minerals which are often intimately intergrown. Table VII shows that the distribution of these two types is not haphazard, but that monomineralic clusters are common only in the basaltic andesites and the olivine-basalts. The clusters in the basaltic andesites are solely of plagioclase, whereas in the olivine-basalts they are of diopsidic augite or olivine. It is difficult to avoid the conclusion that crystal separation (illustrated in the diagram below) was responsible for the formation of the two contrasting basaltic lava types.



It is to be expected that complete separation of the felsic and mafic minerals would only occur near the top and bottom of the magma chamber and that there would be a large intermediate zone of incomplete separation. The mixed glomeroporphyritic clusters which commonly occur only in the pyroxene-andesites of the Point Hennequin Group could be formed in this way.

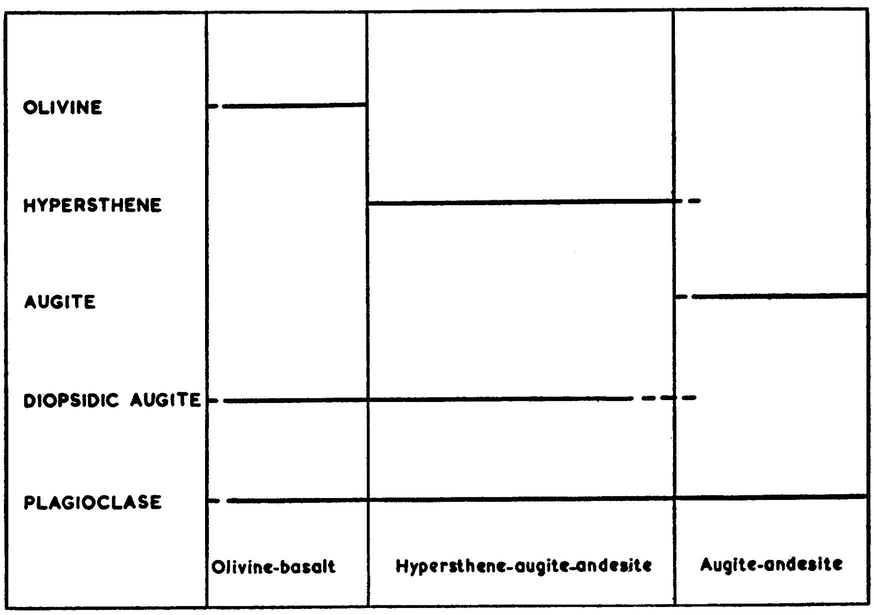


FIGURE 4

The sequence of crystallization in the Tertiary and Quaternary Volcanics.

Further detailed optical data and chemical analyses are necessary before it is possible to determine the precise crystallization history of this suite. However, from microscopic evidence it has been possible to establish the following trend for the sequence of crystallization of the mafic phenocrysts (Fig. 4):

(i) Crystallization of olivine and diopsidic augite. These two minerals are not a reaction pair and crystallize side by side in the olivine-basalts.

(ii) Removal and resorption of olivine; crystallization of hypersthene (olivine and hypersthene are antipathetic in these rocks); clino-pyroxene changing in composition toward common augite.

(iii) Reaction of hypersthene with the residual liquid to form augite.

These three stages are represented by the olivine-basalts, hypersthene-augite-andesites and augite-andesites respectively.

The modal analyses and few available chemical analyses (Tyrrell, 1945, p. 59) suggest that the Tertiary and Quaternary Volcanics of King George Island are calc-alkaline in character. The occurrence of trachyandesites, rather than rhyolites, in the Point Hennequin Group indicates a slight alkaline trend, which is more fully developed in the Recent lavas of Deception Island.

Of some interest is the occurrence of two contrasting basaltic lava types, the basaltic andesites of the Fildes Peninsula Group and the olivine-basalts of the Penguin Island Group. Tyrrell (1945, p. 44) has described some of the lavas from Fildes Peninsula and has stated that "a chemical analysis shows that these rocks must be regarded as of tholeiitic composition". More chemical data will be necessary before the petrology of the Fildes Peninsula Group can be worked out, but it appears probable that these basaltic andesites have crystallized from a tholeiitic magma, which was derived from a parent magma by the early precipitation and gravitational removal of olivine and diopsidic augite.

VIII. ACKNOWLEDGMENTS

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The photomicrographs were prepared by Mr. L. W. Vaughan of the technical staff. The new chemical analysis was done by Mr. K. Chaplin at the British Museum.

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APPENDIX

A LIST OF PLACE-NAMES AND THEIR CO-ORDINATES

Except where otherwise indicated, all features in the following list can be located on the 1/200,000 map of King George Island (Sheet W62 56, 1955), and F.I.D.S., Misc. 64 and 67 (unpublished). The approximate mid latitude and longitude of each feature is given. The 1/500,000 maps referred to are in the D.C.S. 701 series.

Admiralen Peak	62°06′S., 58°31′W.	
Admiralty Bay	62°07′S., 58°27′W.	
Bransfield Strait	—	1/500,000 Sheets A and B.
Bridgeman Island	62°04′S., 56°40′W.	1/500,000 Sheet B.
Brimstone Peak	61°54′S., 57°44′W.	
Church Point	63°41′S., 57°54′W.	1/100,000 Sheet 63 56 SW.
Crépin Point	62°06′S., 58°29′W.	
Davey Point	61°58′S., 58°34′W.	
Deception Island	62°57′S., 60°38′W.	1/500,000 Sheet A.
Disappointment, Cape	65°33′S., 61°45′W.	1/500,000 Sheet D.
Dufayel Island	62°09′S., 58°34′W.	
Edinburgh Hill	62°33′S., 60°01′W.	1/200,000 Sheet 62 60
Esther Nunatak	61°56′S., 57°47′W.	
Ezcurra Inlet	62°09′S., 58°33′W.	
Fildes Peninsula	62°12′S., 58°58′W.	
Flat Top Peninsula	62°13′S., 59°01′W.	
Flora, Mount	63°25′S., 57°01′W.	1/100,000 Sheet 63 56 NW.
Graham Land	—	1/500,000 Sheets A–D.
Hennequin, Point	62°07′S., 58°24′W.	
Horatio Stump	62°13′S., 59°01′W.	
James Ross Island	64°10′S., 57°45′W.	1/500,000 Sheet B.
Jardine Peak	62°10′S., 58°31′W.	
Keller Peninsula	62°05′S., 58°26′W.	
King George Bay	62°05′S., 58°05′W.	
King George Island	62°00′S., 58°15′W.	1/200,000 Sheets 62 56, 62 58
Lions Rump	62°07′S., 58°06′W.	
Livingston Island	62°36′S., 60°30′W.	1/500,000 Sheet A.
Low Head	62°09′S., 58°07′W.	
Marian Cove	62°12′S., 58°46′W.	
Melville, Cape	62°01′S., 57°33′W.	
Melville Peak	62°00′S., 57°39′W.	
Noel Hill	62°13′S., 58°46′W.	
North Foreland	61°52′S., 57°40′W.	
Penguin Island	62°05′S., 57°55′W.	
Potter Cove	62°13′S., 58°42′W.	
Precious Peaks	62°04′S., 58°19′W.	
Rose Peak	62°02′S., 58°12′W.	
South Georgia	54°20′S., 36°40′W.	1/200,000 D.O.S. 610
South Shetland Islands	—	1/500,000 Sheets A and B.
Stenhouse Bluff	62°02′S., 58°22′W.	
Suffield Point	62°11′S., 58°55′W.	
Ternyck Needle	62°03′S., 58°15′W.	
Thomas, Point	62°08′S., 58°29′W.	
Three Brothers Hill	62°14′S., 58°40′W.	
Trinity Peninsula	—	1/500,000 Sheet B.
Ullmann Spur	62°04′S., 58°22′W.	
Vauréal Peak	62°10′S., 58°18′W.	
Wegger Peak	62°06′S., 58°31′W.	

PLATE I

a. Keller Peninsula from the east showing the Upper Jurassic volcanic succession.

b. Point Hennequin, the type locality for the Point Hennequin Group (Table IV), from the north-west. The succession comprises 900 ft. of pyroxene-andesites dipping at 5° to the north-east.

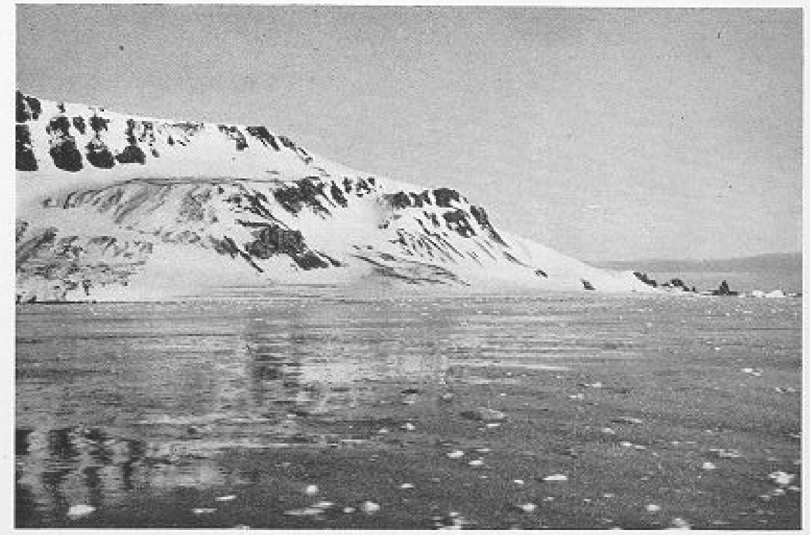
c. Penguin Island, a Recent volcano off the south-east coast of King George Island, viewed from the mainland.

d. Ternyck Needle (370 ft.), a prominent volcanic neck marking an eruptive centre of the Point Hennequin Group.

PLATE I

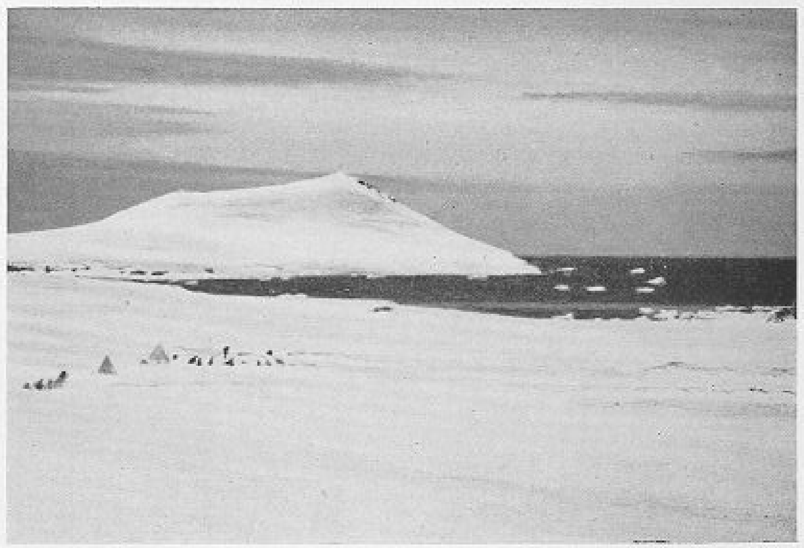
Photograph by D. D. HAWKES

a



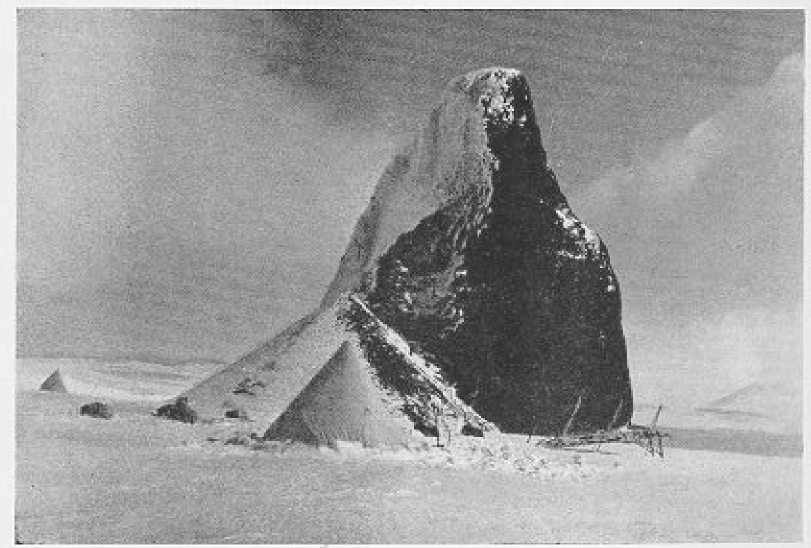
Photograph by R. J. ADIE

b



Photograph by K. PAWSON

c



Photograph by G. HATTERSLEY-SMITH

d

PLATE III

a. Basaltic andesite of the intergranular type, composed of occasional labradorite micro-phenocrysts in a matrix of labradorite microlites, pyroxene granules and iron ore; Fildes Peninsula Group, Flat Top Peninsula (G.77.1; ordinary light; × 56).

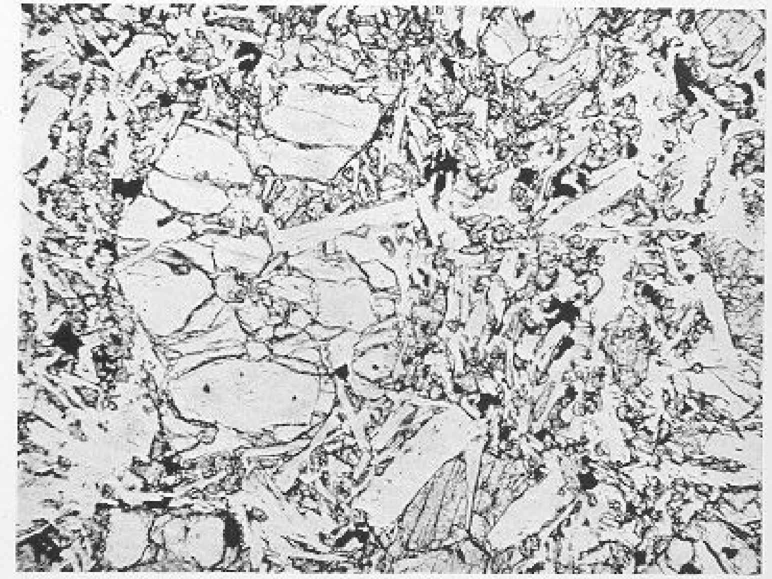
b. Basaltic andesite of the porphyritic type, composed of numerous large labradorite phenocrysts in an intergranular matrix of labradorite microlites, pyroxene granules and iron ore; Fildes Peninsula Group, Fildes Peninsula (G.81.1; ordinary light; × 56).

c. Hypersthene-augite-andesite showing a typical mixed glomeroporphyritic cluster composed of labradorite, diopsidic augite, hypersthene and iron ore; Point Hennequin Group, Point Hennequin (G.22.1A; ordinary light; × 32).

d. Hypersthene-augite-andesite showing hypersthene surrounded by a reaction rim of clinopyroxene; Point Hennequin Group, Point Hennequin (G.22.7; X-nicols; × 60).

e. Olivine-basalt showing pronounced hour-glass structure in diopsidic augite; Penguin Island Group, Low Head (G.36.1; X-nicols; × 100).

a



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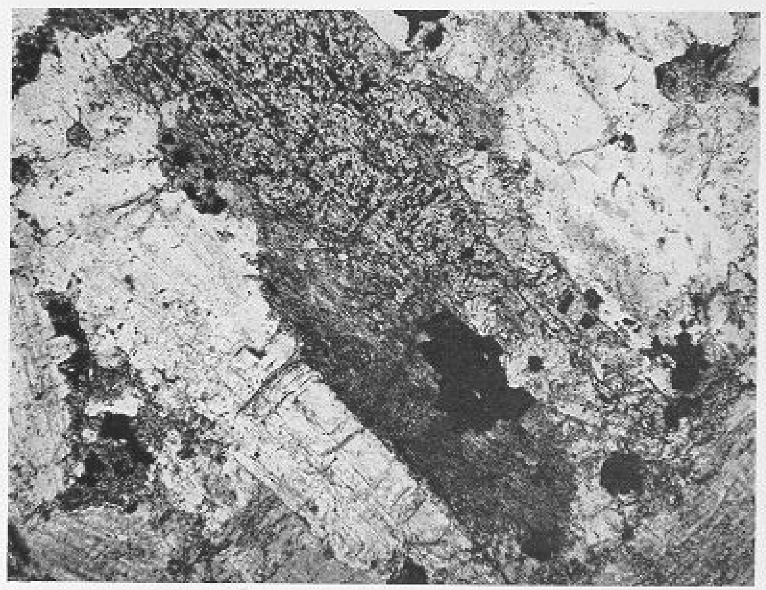

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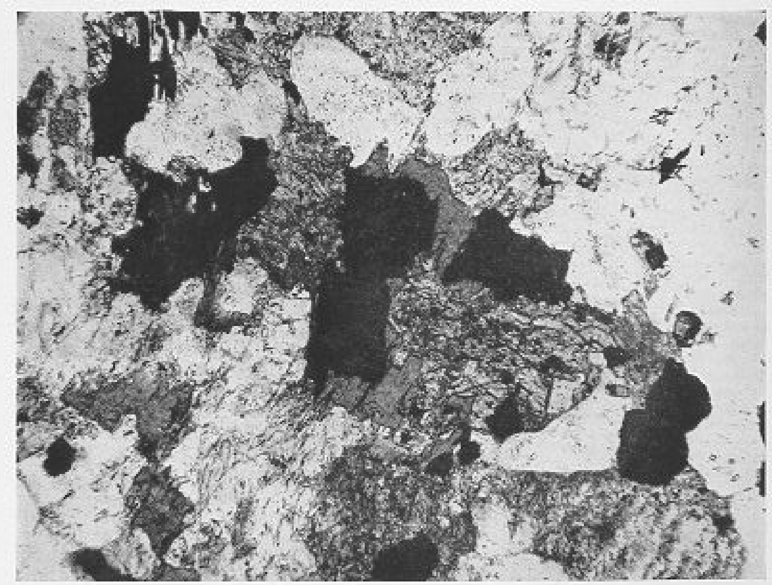

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PLATE II

PLATE II

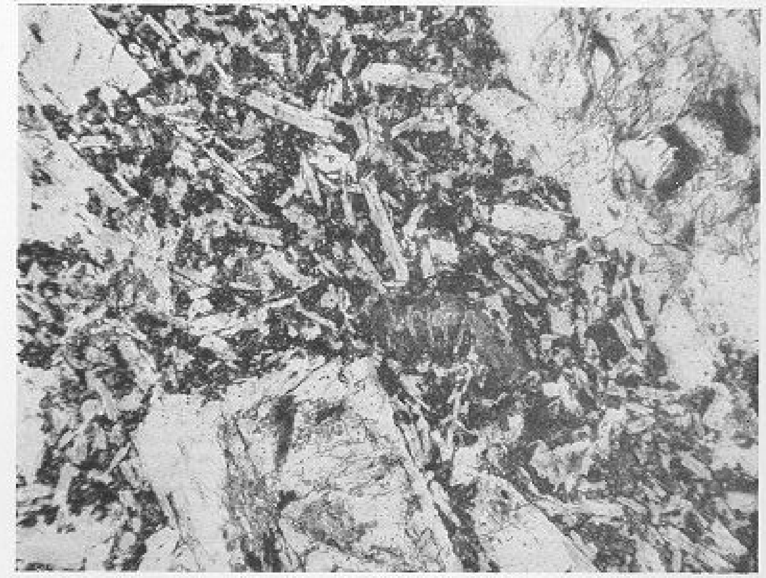
a. Pyroxene-andesite with a porphyritic texture and containing phenocrysts of albitized plagioclase (right) and augite partially replaced by chlorite (left); Jurassic Volcanics, Ullmann Spur (G.15.5; X-nicols; × 60).

b. Olivine-basalt containing large phenocrysts of magnesian olivine and diopsidic augite in a groundmass of labradorite microlites, augite granules and iron ore; Penguin Island Group, Penguin Island (G.33.2; ordinary light; × 60).

c. Quartz-diorite showing the replacement of augite by fibrous actinolite; Andean Intrusive Suite, Noel Hill (G.68.1; ordinary light; × 37).

d. Granodiorite showing biotite replacing hornblende in a normal reaction relationship; Andean Intrusive Suite, Noel Hill (G.68.2; ordinary light; × 56).

a



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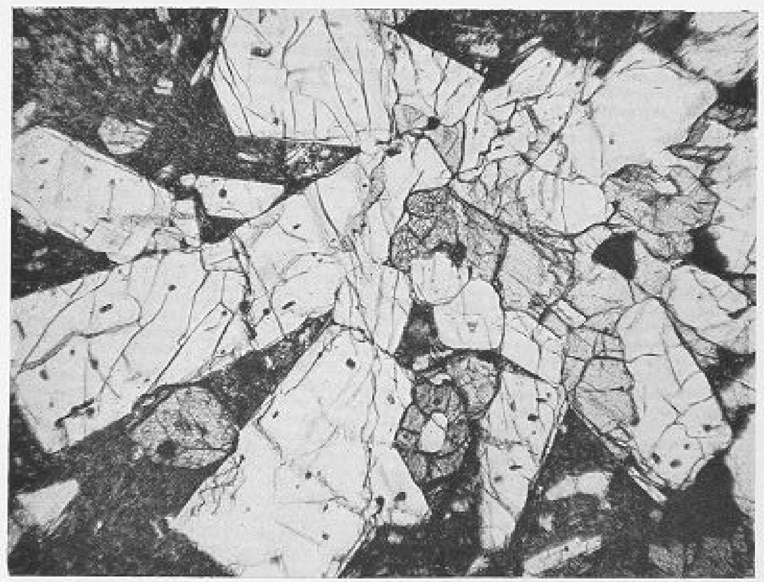

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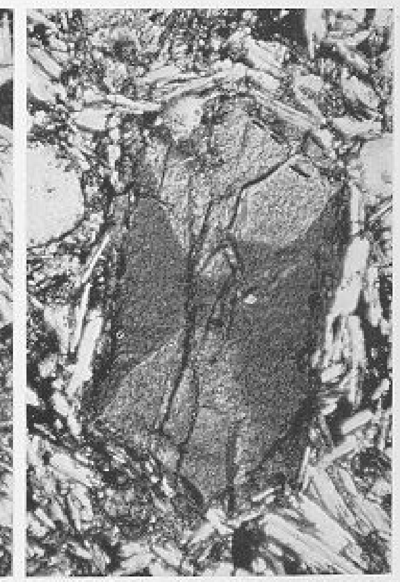

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PLATE III