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THE GEOLOGY OF THE DANCO COAST, GRAHAM LAND

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NATURAL ENVIRONMENT RESEARCH COUNCIL

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ABSTRACT

THE geology of the Danco Coast and offshore islands is described. The few exposures of cataclastically deformed, non-fossiliferous feldspathic sandstones and siltstones, which are thermally metamorphosed by younger plutonic rocks, are tentatively correlated with the Carboniferous Trinity Peninsula Series. It is considered that these sediments were deposited in a geosynclinal environment.

A hitherto unsuspected group of early granodiorites, adamellites and granites forms large outcrops on the Danco Coast and there are also associated hypabyssal intrusions. The extensive shearing at many of these exposures could be related to the large-scale faulting which is known to have occurred in the vicinity of Gerlache Strait. The chemical analyses of the granitic rocks provide the first evidence which might be of general use in distinguishing between granites of different ages in Graham Land.

Thick deposits of subaerially erupted tuffs and lavas, mostly of intermediate compositions, can probably be correlated with rocks of the Upper Jurassic Volcanic Group which occur elsewhere in the Antarctic Peninsula. Several of the basic lavas show chemical affinities with island arc tholeiites but otherwise the volcanic sequence is entirely calc-alkaline in composition. Many of these rocks have been modified by metasomatism and thermal metamorphism during a subsequent period of plutonism; the volcanic rocks also show signs of an earlier phase of alteration which could have been caused by burial metamorphism. Numerous altered basic and intermediate dykes were emplaced during this episode of volcanic activity.

At some time later than the eruption of the volcanic rocks, probably during the Cretaceous and Tertiary, a number of discordant gabbroic to granitic plutons were intruded into the country rocks of the Danco Coast. These rocks appear to have been emplaced in order from the most basic to the most acid, and they comprise the typical calc-alkaline assemblage of orogenic regions. Their chemistry is discussed with particular reference to the mode of formation of the various rock groups. Many of the intermediate rocks are interpreted as hybrids; in contrast to many other areas in the Antarctic Peninsula, such rocks are volumetrically unimportant on the Danco Coast. Representing the youngest intrusive phase of the area discussed here, the widespread microgabbro and microdiorite dykes are considered to be related to the volcanicity which existed at Anvers Island during Tertiary times.

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I. INTRODUCTION

THE Danco Coast (Fig. 1) is about 160 km. long, and it is situated on the north-west of the Antarctic Peninsula between Cape Renard (lat. 65°01′S., long. 63°43′W.) and Cape Herschel (lat. 64°04′S., long. 61°03′W.). The present study is concerned with the offshore islands and the mainland between Charlotte Bay and Cape Willems. In common with much of the western coast of the Antarctic Peninsula, the ice-cliffed fjord coastline is typified by a series of broad bays separated by high rocky promontories.

Following the discovery of Graham Land by Lt Edward Bransfield in 1820, many sealers explored the west coast. During the 1830–32 British expedition, John Biscoe landed in the Palmer Archipelago, probably at Anvers Island, and there were several expeditions with a geological bias in the late eighteenth and early nineteenth centuries. In 1921, T. W. Bagshawe and M. C. Lester wintered at Waterboat Point, Paradise

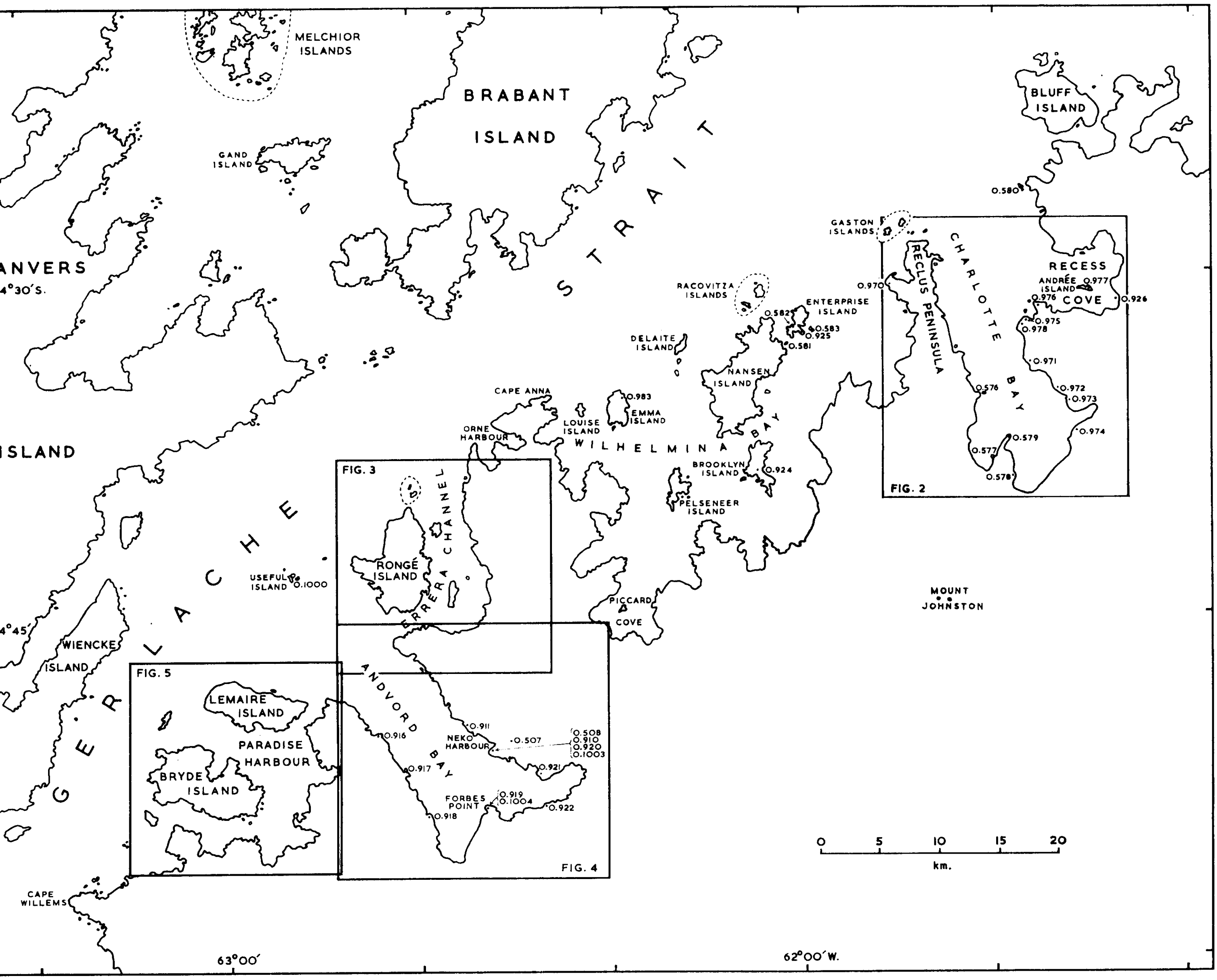

FIGURE 1

Geological sketch map of the Danco Coast showing the locations of Figs. 2–5.

Harbour, but they undertook no geological investigations. The Chilean expedition commanded by F. Toro and B. O'Neil made a reconnaissance survey as far south as Stonington Island in 1947; a permanent Chilean meteorological station was established at Waterboat Point from 1952. During their first visit to the Danco Coast in 1948, the Argentines built a refuge hut in Neko Harbour, Andvord Bay, although it was not until 1951 that a permanent Argentine meteorological station was occupied in Paradise Harbour. In 1956, the Falkland Islands Dependencies Survey established a station at the northern end of Danco Island (Plate Ia) and it was closed in 1959.

A. Geological Investigations

The first geologist to visit the Danco Coast area was H. Arçtowski during the 1897–99 Expédition Antarctique Belge, and his collection of rocks was described by Pelikan (1909). The geological work undertaken during the Expédition Antarctique Française in *Français*, 1903–05, and the Deuxième Expédition Antarctique Française in *Pourquoi Pas?*, 1908–10 (Gourdon, 1908, 1917), provided the first accurate accounts of the petrology of the volcanic rocks, granites, diorites and gabbros of north-western Graham Land. During 1913–14 Ferguson (1921) visited the Danco Coast, where he discovered sedimentary rocks, basic volcanic rocks and light green or grey igneous breccias. Igneous breccias were also collected from Brabant and Wiencke Islands, and Ferguson considered them as part of an extensive formation. Barth and Holmsen (1939) described similar breccias from the Joubin Islands, 8 km. south of Anvers Island, believing them to have originated by a down-folding and crushing of supercrustal rocks.

No further geological work was carried out on the Danco Coast for a number of years. Olsacher (1959) described andesites, schists and micaceous quartzites from Coughtrey Peninsula, and di Lena (1959) outlined the geology of Spring Point. In 1956, M. B. Bayly (1957) mapped the area between Andvord Bay and Orne Harbour, also making a reconnaissance of the coast between Cape Anna and Charlotte Bay. G. J. Hobbs worked southward from Danco Island (Plate Ib) to Cape Willems during 1957, and in 1958 he briefly visited localities in Charlotte Bay.

The present work is a petrographical and chemical study of the rocks collected by Bayly and Hobbs, supplemented by the interpretation of air photographs taken during the Falkland Islands and Dependencies Aerial Survey Expedition, 1955–57. Full use has been made of Bayly's preliminary report, together with the field maps, photographs and interim reports by Hobbs.

B. Physiography

The Danco Coast, which trends in a north-east to south-west direction, ranges from the dissected coastal region and offshore islands in the north-west to a high plateau in the south-east. Brabant, Anvers and Wiencke Islands form an outer belt of islands separated from the Danco Coast by the 8 km. wide Gerlache Strait.

Topographically similar to the coastal mainland, the offshore islands extend for 150 km. from Cape Herschel to Cape Willems. Their formation can be explained by changes in sea-level, although glacierization may have been important.

Much of the coastline is fringed by a 30–35 m. high ice cliff (Plate Ic), except where rock buttresses and peninsulas jut seaward. The broad bays often reach 30 or 40 km. in width but they rarely penetrate inland for distances greater than 20 km. Andvord Bay is the only exception to this general shape, possessing the long and narrow outline so typical of many Norwegian fjords. These larger bays are divided into a series of smaller, often rectangular, coves and at the end of each is a glacier or glacier system which cuts deeply into the mainland; several of these extend the full 4–8 km. to the plateau. There are all gradations between these long valley glaciers and the more localized cirque glaciers which have sometimes formed a short ice-covered foreland, particularly at rocky peninsulas. The local geology and structure have probably affected the courses of the glaciers to some degree, although no directional trend was detected.

The glaciers are divided by a skeleton of generally ice-covered cliffs and mountain ridges which are between 600 and 1,000 m. high, and rise inland to 1,700 m. They were formed by the glacial dissection of the plateau which fingers towards the coastal areas on both sides of the Antarctic Peninsula.

Varying from 0·8 to 24 km. across, this almost featureless plateau is 2,000–2,300 m. above sea-level. One or two ice-covered peaks project through the surface, including Mount Johnston to the south of

Lester Cove which reaches 2,600 m. The underlying rock is exposed in the high plateau scarp, although it is hidden by ice falls at several localities. At Flandres Bay, southern Arctowski Peninsula and southern Charlotte Bay, the plateau reaches westward to within 2 km. of the sea.

Along the coast, Holtedahl (1929) described the front of the low glacier ice as coincident with the boundary between the sea and bedrock. This is true for many localities along the Danco and Graham Coasts, although it appears to be absent farther south (Goldring, 1962). Comparing north-western Graham Land with coastal Norway, Holtedahl suggested the existence of a low rock foreland or strandflat under the ice, formed mainly by the plucking action of cirque glaciers. Before the last continental ice cover, strandflat glacierization was considered to have been particularly active on the seaward side of the Palmer Archipelago, but on the eastern side ice-filled sounds hampered its formation until comparatively recently. This could explain the fact that, although present, these forelands are never extensively developed along the Danco Coast. Moreover, the existence of a wave-cut platform and sea caves on Anvers Island led Hooper (1962) to believe that marine erosion had a considerable effect on the present landform.

Both Arçtowski (1908) and Holtedahl (1929) favoured a glacial origin for Gerlache Strait but, from observations of plateau slope on Brabant and Nansen Islands, Linton (1964) believed it to be the site of a major downwarp. There has been much emphasis on the importance of post-Andean block faulting in the structural evolution of the Antarctic Peninsula (Knowles, 1945; Goldring, 1962; Hooper, 1962; Curtis, 1966), and there is known to be severe faulting in Lemaire Channel, northern Graham Coast, and on Wiencke Island; many of the rocks from north-western Bryde Island and Lemaire Island are extremely sheared. Although subsequently deepened by glacial action, it therefore seems probable that faulting played a major role in the formation of Gerlache Strait.

C. Stratigraphy

The geology of the Danco Coast is illustrated in Figs. 2–5. Table I is based on a comparison of the Danco Coast rocks with similar rock types described by Adie (1953) from elsewhere in Graham Land.

The oldest rocks on the Danco Coast are a sequence of cataclastically deformed feldspathic sandstones and siltstones which have suffered contact metamorphism adjacent to later plutonic rocks. These sedimentary rocks are unimportant in areal extent. Younger granites and granodiorites, many of them sheared, form large rock outcrops at Mount Banck, Bryde Islands, Lemaire Island, Rongé Island, Neko Harbour and Charlotte Bay. Post-dating these acid plutonic rocks, the widespread deposits of volcanic rocks are tentatively correlated with the Upper Jurassic Volcanic Group (Adie, 1962; Goldring, 1962), and there are also associated hypabyssal rocks. Many of the tuffs and lavas have been metasomatized. Plutonic rocks, ranging in composition from olivine-bearing gabbros to granites, intrude the volcanic rocks. The acid plutonic rocks are typified by a granophyric texture and they are invariably younger than the more basic intrusions. There are many dykes which are contemporaneous with these plutonic rocks. Microdiorite and microgabbro hypabyssal intrusions represent the youngest rocks exposed on the Danco Coast.

II. SEDIMENTARY ROCKS

Isolated outcrops of sandstones and siltstones on the Danco Coast are closely comparable with the Trinity Peninsula Series sedimentary rocks (Adie, 1955; Aitkenhead, 1965; Elliot, 1965, 1966, 1967*b*) occurring elsewhere in the Antarctic Peninsula. This correlation is based on lithological, petrographical and field data, since macroscopic fossils are apparently absent from these rocks. Exposures of similar sedimentary rocks on the Graham Coast to the south of the Danco Coast have also been referred to the Trinity Peninsula Series by Curtis (1966).

Fissile schists and dark arkoses first recorded at Sophie Cliff, Piccard Cove (Arçtowski, 1908), were described by Pelikan (1909). Ferguson (1921) discovered greywackes, quartzites and mudstones at Coughtrey Peninsula, southern Leith Cove, on the mainland south of Orne Harbour, at eastern Rongé Island and western Danco Island. However, from Hobbs's field mapping and specimen collection, it seems probable that at the last two localities Ferguson misidentified bedded volcanic rocks as sedimentary rocks. Ferguson also described mudstones which had been fractured, uptilted and contact metamorphosed by a granodiorite intrusion at Forbes Point. At Spring Point, in the extreme north of the Danco Coast, sedimentary rocks form a small percentage of the total rock exposure (di Lena, 1959).

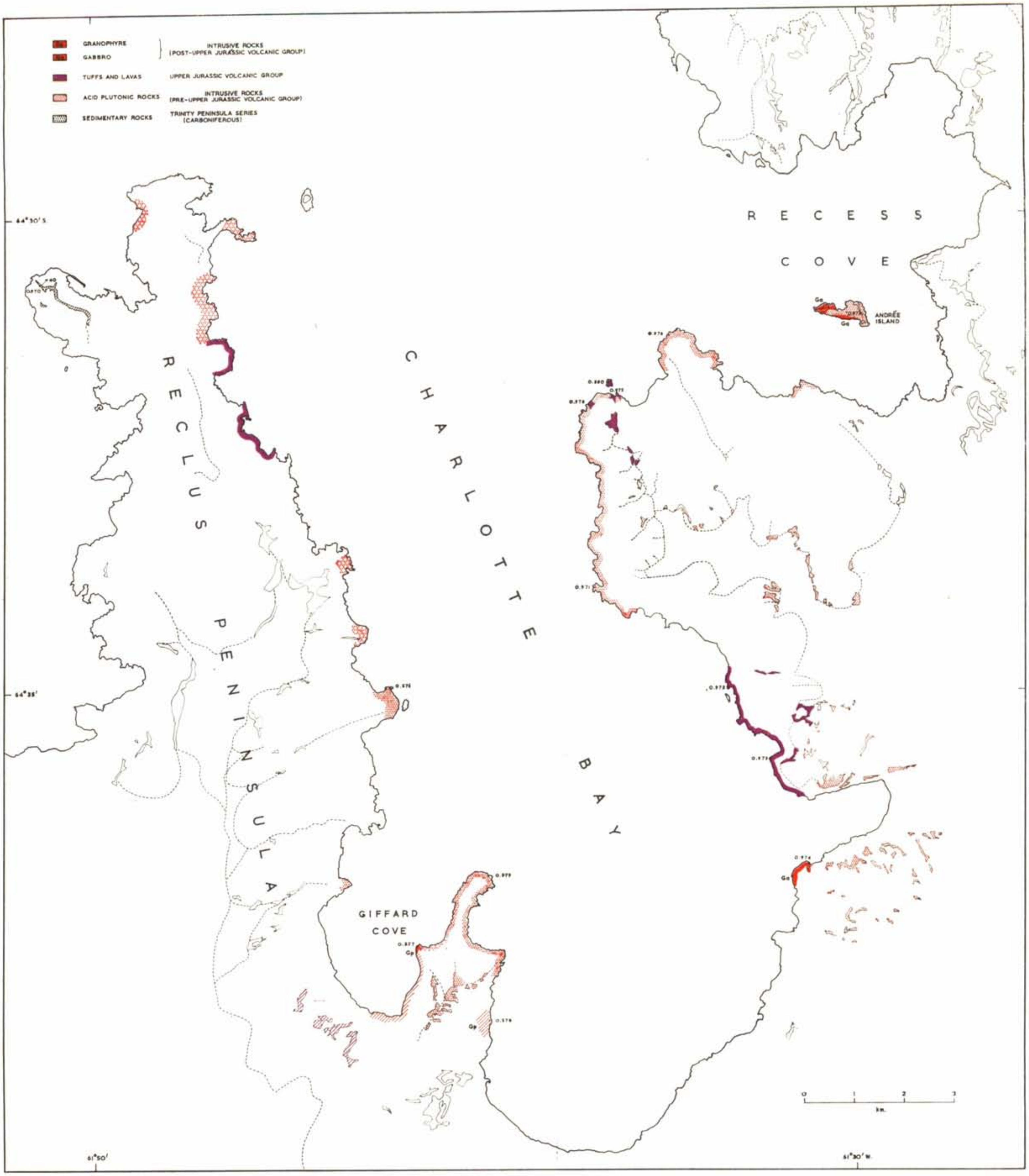

FIGURE 2

Geological sketch map of Charlotte Bay showing rock outcrops and the positions of the geological stations.

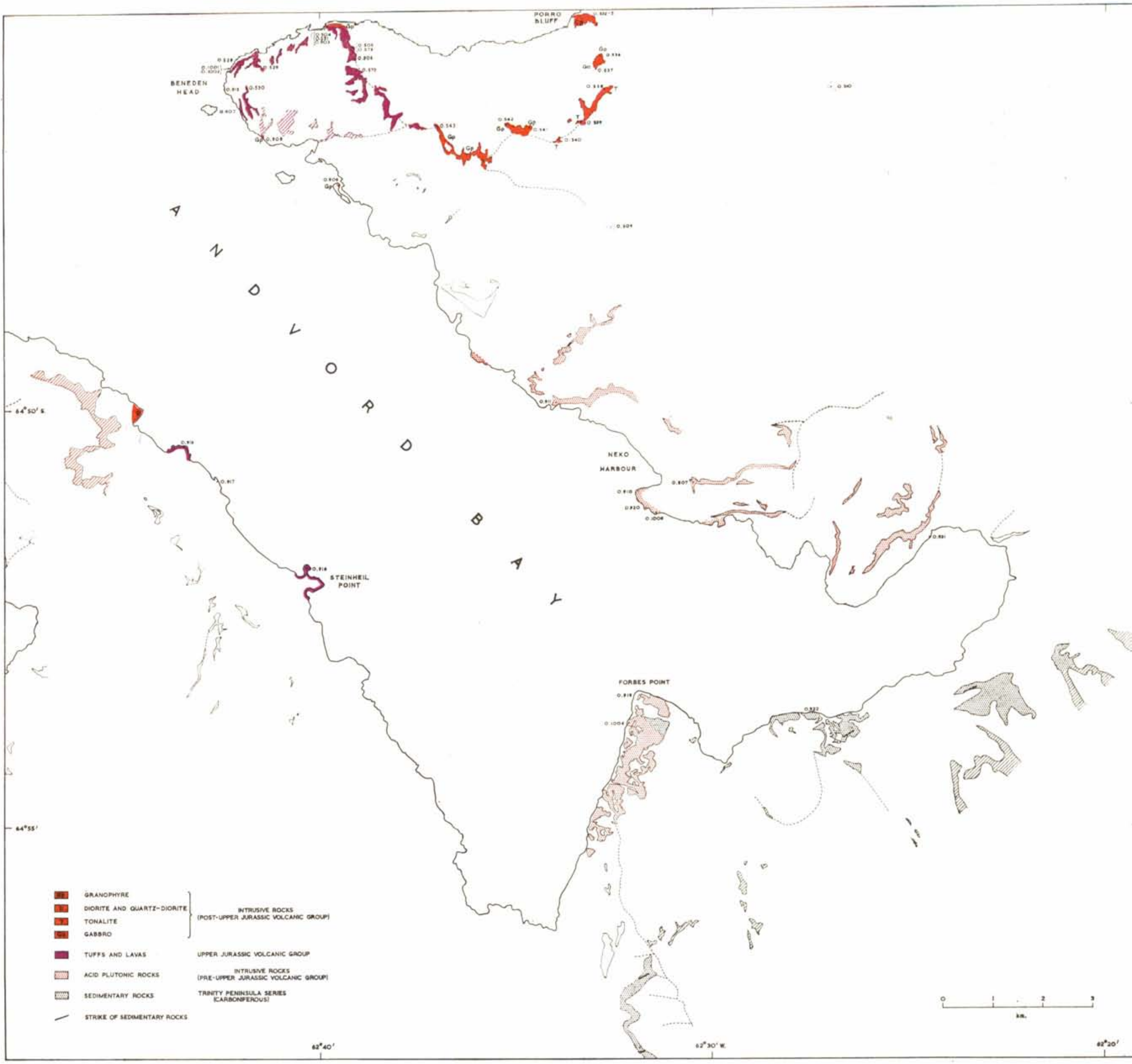

FIGURE 4

Geological sketch map of Andvord Bay showing rock outcrops and the positions of the geological stations.

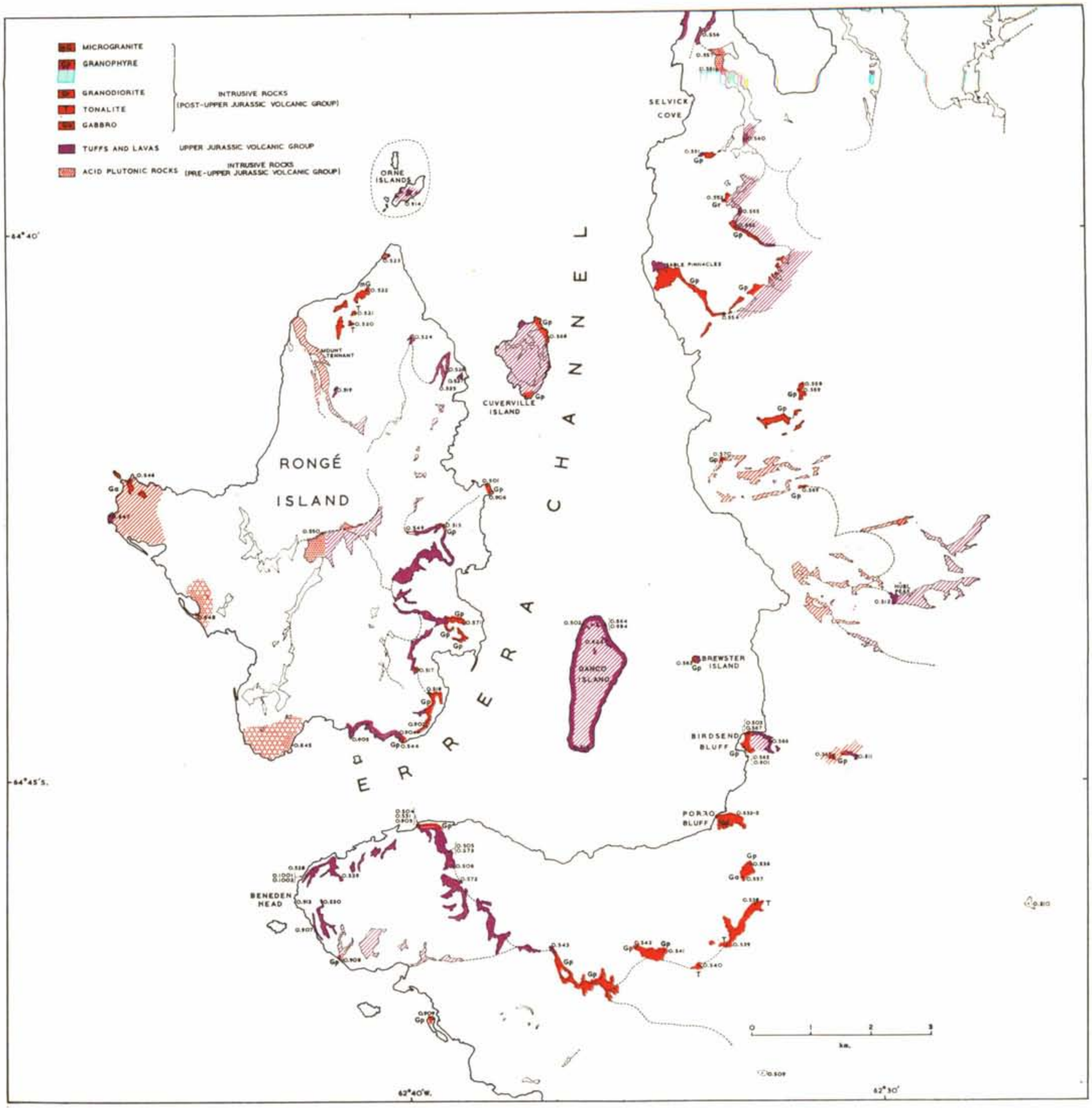

FIGURE 3

Geological sketch map of the Rongé Island area showing rock outcrops and the positions of the geological stations.

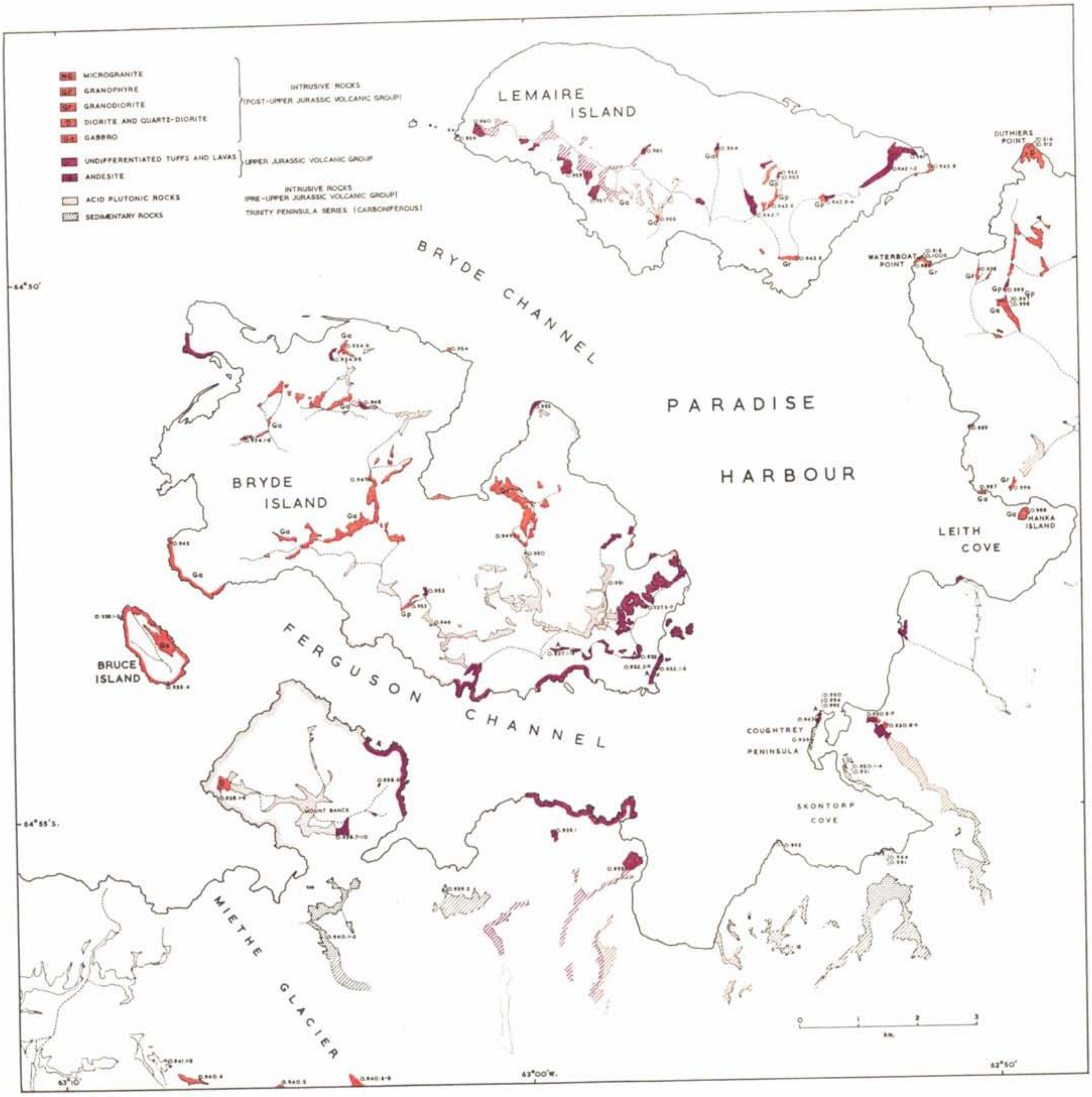

FIGURE 5

Geological sketch map of the Paradise Harbour area showing rock outcrops and the positions of the geological stations.

TABLE I
STRATIGRAPHY OF THE DANCO COAST

Tertiary	Microdiorite and microgabbro dykes
(?) Cretaceous to early Tertiary	Gabbros, diorites, tonalites, granodiorites and granophyres with associated hypabyssal rocks
(?) Upper Jurassic	Basaltic to rhyolitic tuffs and lavas Altered basic and intermediate dykes
(?)	Granites and granodiorites
(?) Carboniferous	Sedimentary rocks of the Trinity Peninsula Series

No specimens of sedimentary rocks were collected by Bayly but Hobbs visited several of the previously known sedimentary localities and he confirmed their presence. He discovered further exposures at Skontorp Cove and to the north of Miethe Glacier, and he also collected contact-metamorphosed sedimentary rocks from Paradise Harbour, Forbes Point and Reclus Peninsula.

A. FIELD RELATIONS

The most extensive exposures of sedimentary rocks occur on the mainland to the south of Paradise Harbour and Andvord Bay. Sediments are particularly well exposed for about 4 km. along the north-eastern flank of Miethe Glacier; the section shown in Fig. 6 represents at least 130 m. of interbedded

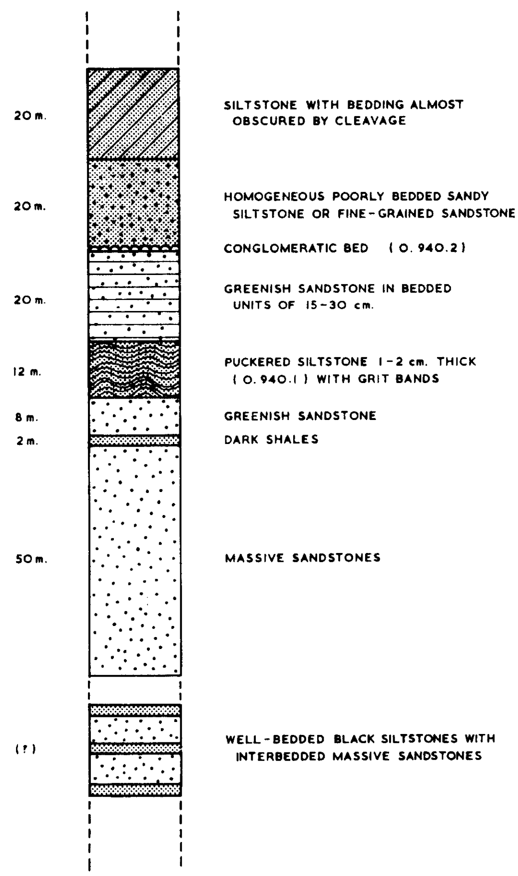

FIGURE 6
A stratigraphical section through the sedimentary rocks at locality O.940.1–2 near Miethe Glacier. (Drawn from G. J. Hobbs's unpublished field notes.)

shales, siltstones and sandstones at locality O.940.1 and 2 dipping at about 45° to the east. Several doleritic dykes (field term) are also present although they are not shown in the section. The sandstones occur either as thin beds in the siltstones or they form massive units up to 50 m. in thickness. A snow-covered gap, possibly a fault zone, separates these rocks from an outcrop of vertically dipping sediments to the west, and there is a further exposure of sandstone on the north-western side of a small glacier about 3 km. to the north-east.

Interbedded sandstones (1 m. in thickness) and siltstones (15–30 cm. in thickness) along the southern shore of Skontorp Cove show signs of slight contact metamorphism at stations O.944 and 991. Apart from the west-north-westerly dipping rocks at the southern entrance to the cove, the sedimentary rocks possess the same attitude as those near Miethe Glacier (O.940.1 and 2).

North of Skontorp Cove and at Coughtrey Peninsula the rocks are less arenaceous, comprising grey and black siltstones with sandy laminations. The proximity of an igneous intrusion is suggested by slight contact metamorphism in many of the rock specimens and by quartz–epidote veining. The bedding is more variable at this locality, dipping at angles between 18° and 90° to the south and east. At Coughtrey Peninsula a sharp contact (Plate IIIa) separates the sedimentary rocks from the younger overlying tuffs and agglomerates; slight puckering of the siltstones near the contact is possibly indicative of faulting.

The sedimentary rocks at Waterboat Point, Forbes Point and along the southern shore of Andvord Bay have been more intensely metamorphosed by later intrusive rocks. Bedding-plane slip and angular recumbent folds are indications of the severe deformation which has occurred at Forbes Point. Although hornfelses have been recorded at station O.922, it is not known whether the interbedded sandstones and siltstones seen on air photographs to extend at least 4 km. eastward have undergone similar contact metamorphism. These rocks have a uniform strike of about 100°.

Steeply dipping dark grey sandstone bands are interbedded with fine-grained black rocks on a small island south of Rongé Island (O.905). The well-developed current bedding in these sandstones youngs in a northerly direction. Unfortunately, there are no specimens of the country rocks but, if they were correctly identified in the field as "black basaltic lavas", it is possible that these sandstone bands are part of the Upper Jurassic Volcanic Group rather than the Trinity Peninsula Series.

B. Petrography

1. *Sandstones*

Most of these rocks are feldspathic greywackes. Averaging 0·3 mm. in grain-size, the crudely aligned clasts range from 0·07 to 0·5 mm. across in graded specimens. Quartz forms about half of the mineral content (Table II, O.994.1), although several of the grains are composite, consisting of both quartz and feldspar. Many of the plagioclase fragments (An_{10-30}) are water-clear but some are considerably sericitized (O.992.2). The usually perthitic potash feldspar is subordinate to plagioclase, containing rare apatite and quartz inclusions; some of the potash feldspar is turbid with good Carlsbad twinning. There are one or two fresh rounded fragments of microcline and myrmekite. Accessory minerals include zircon and apatite, although locally (O.992.2) there are also large and often well-formed crystals of sphene and epidote. In general, these sandstones contain little lithic material but there are a few acid lava and mudstone fragments in most of the rock specimens.

The sandstones (Table II, O.905.2) interbedded with (?) lavas to the south of Rongé Island have a particularly fresh appearance. The well-sorted unstrained clasts of quartz, potash feldspar, oligoclase and andesine are embedded in a matrix of calcite. Perthitic potash feldspar, myrmekite, microcline and lithic fragments are not observed. Aligned clastic biotite flakes (α = light brown and $\beta = \gamma$ = red-brown), subordinate muscovite and iron ore form thin sub-parallel bands, several of which contain concentrations of leucoxene, sphene, epidote, allanite, zircon, garnet and apatite.

2. *Siltstones*

Siltstones are the commonest sedimentary rocks on the Danco Coast, forming many of the rock exposures at Coughtrey Peninsula, the mainland to the south-east and the mountain ridge north-east of Miethe Glacier. In addition to the felsic minerals, some of the specimens contain much limonitic and sericitic material with minute spots of ilmenite (O.940.1 and 2).

TABLE II
MODAL ANALYSES OF SANDSTONES FROM THE DANCO COAST

	O.905.2	O.992.2	O.994.1
Quartz	23·9	32·9	37·6
Non-perthitic potash feldspar	16·0	11·3	12·5
Microcline	—	0·5	0·1
Perthite	—	4·9	5·6
Plagioclase	18·6	37·2	19·3
Myrmekite	—	tr	0·2
Muscovite	0·2	—	—
Biotite	6·6	—	0·1
Chlorite	tr	0·1	1·8
Iron ore	2·2	0·7	0·9
Prehnite	—	—	1·4
Apatite	0·1	—	1·4
Sphene	0·9	0·3	—
Epidote	0·1	0·6	—
Allanite	tr	—	—
Zircon	1·3	tr	tr
Garnet	tr	—	—
Quartz–feldspar fragments	—	1·1	—
Lithic fragments	—	1·9	5·3
Matrix	30·1*	8·5	13·8

tr Trace.
* Calcite.

O.905.2 Feldspathic sandstone; island to the south of Rongé Island.
O.992.2 Feldspathic sandstone; south-western Skontorp Cove.
O.994.1 Feldspathic sandstone; Coughtrey Peninsula.

Two erratic black siltstone specimens (O.909.3 and 4) from the eastern coast of Andvord Bay consist only of volcanic debris and they also contain unidentifiable plant remains. Bearing little resemblance to most of the fine-grained sedimentary rocks on the Danco Coast, they possibly form part of the younger Upper Jurassic Volcanic Group. They are tentatively correlated with the sandstones (O.905.2) at the small island south of Rongé Island.

C. METAMORPHISM

Many of the sedimentary rocks show the effects of a cataclastic or low-grade regional metamorphism. Clasts are often strained and broken with the result that the quartz has an undulose extinction and the plagioclase twin lamellae are often bent. Recrystallization of the quartz in small shear zones may be accompanied by associated quartz and calcite veining (O.940.1 and 2), and several of the sandstones are partially mylonitized. Detrital biotite is a fairly uncommon mineral but when present the crystals are often kink-banded and compressed around the more rigid clasts. At many localities a prominent slaty cleavage has developed in the siltstones, whereas at others there is slight puckering in the shales.

The intrusion of younger plutonic rocks into these sedimentary rocks has resulted in the localized contact metamorphism of the adjacent sandstones and siltstones; the initial stage of contact metamorphism, which is rarely of a higher grade than the hornblende-hornfels facies, can be detected in some of the sedimentary rocks from Paradise Harbour and north-western Reclus Peninsula. The sandstones and siltstones show little mineralogical reconstitution except perhaps for the slight development of biotite. However, dark mudstones contain up to 30 per cent of finely divided biotite (α = light brown and $\beta = \gamma$ = red-brown) associated with specks of iron ore. Several of the mudstones contain numerous lighter-coloured spheres or ellipsoids between 0·3 and 2 mm. in diameter in which there is a reduction or absence of biotite and iron ore. In specimen O.991.1 (Plate IVa) these ellipsoids contain biotite-rich cores with straw-coloured sericitic mantles. In some (O.970.2) small quartz-filled areas (possibly cordierite crystals) appear to have grown from muscovite poikiloblasts. Adie (1957) described similar features in Trinity Peninsula Series argillaceous sedimentary rocks which he also showed were incipient cordierite crystals.

Mauve and dark blue biotite-hornfelses from Forbes Point (Plates IIIb and IVb) comprise a recrystallized mosaic of quartz and feldspar with minute biotite flakes; mineralogically similar but dark grey biotite-hornfelses also occur at Waterboat Point (O.915.5). There are a few 0·5 m. long calcareous nodules in these rocks which reflect their high calcium content in the widespread growth of twinned diopside poikiloblasts.

D. Source Area, Depositional Environment and Post-consolidation History

To some extent, it is possible to deduce the provenance of the sedimentary material from a study of the clastic minerals.

Many of the sandstones on the Danco Coast contain composite quartz–feldspar clasts which have almost certainly been derived from (probably fairly acid) plutonic rocks, and large euhedral sphene crystals could have a similar origin. Microcline and perthite are commoner in plutonic igneous rocks than they are in metamorphic rocks. The presence of occasional lava fragments proves that the ancient landmass contained some volcanic material but it is thought to have been volumetrically unimportant. The rare mudstone and siltstone fragments could have been derived from an older sedimentary rock sequence, or they could have been penecontemporaneous with the formation of the host sandstone. Hence the detritus for these sedimentary rocks seems to have been derived from the erosion of mainly acid to intermediate plutonic rocks with subordinate tuffs and lavas.

The mineralogy and structures of many of the sedimentary rocks are indicative of re-deposition of the sand-sized particles in a geosynclinal environment, probably by turbidity currents. Both graded bedding and small-scale current bedding occur in the sandstones, and the siltstones often contain small pre-consolidation slump features.

The high proportion of fresh feldspar in the sandstones (Table II) is an important petrogenetic indicator. Mackie (1899) originally suggested that the presence of abundant feldspar in sedimentary rocks was due to the erosion of a landmass in conditions of extreme aridity or extreme cold. However, Krynine (1935) observed the accumulation of modern arkoses in tropical Mexico where temperatures of 27° C and an annual precipitation of 305 cm. are common. He suggested that detrital feldspar is the result of a balance between the rate of feldspar decomposition and the rate of erosion of the landmass providing the material. The high relief of the source area is believed to be more important than a rigorous climate. Thus the fresh feldspar in the sandstones of the Danco Coast could indicate the rapid deposition of the sedimentary detritus such that the weathering processes were reduced to a minimum. Besides the unaltered feldspar, the immaturity of these rocks is evident from the poorly sorted angular clasts and from the almost euhedral accessory minerals. In particular, the well-preserved shape of some epidote crystals (O.992.2) indicates that there was little prolonged transport of the detritus.

The sandstones south of Rongé Island differ from the other sandstones on the Danco Coast in a number of respects. The andesine fragments in the sandstones south of Rongé Island indicate that an intermediate to basic source area provided much of the accumulated debris. Typically "volcanic" quartz occurs both in this rock and in the siltstones (O.909.3 and 4) collected a few kilometres to the south; the unstrained and usually inclusion-free crystals contain bulbous to fingery resorption structures, and they are often bounded by well-defined crystal faces. The siltstones contain devitrified shards as well as pumice and lava fragments but these were not detected in the sandstone specimen. Nevertheless, volcanic rocks are considered as the main source of sedimentary material for both rock types.

E. Chemistry

Chemical analyses of five of the sedimentary rocks are given in Table III. Unfortunately, apart from the petrographically distinctive sandstone specimen from a small island to the south of Rongé Island, none of the more typical Danco Coast sandstones was available for chemical analysis.

The average of the four siltstone analyses and the analysis of an "average shale" (Table III, columns 1 and 2) show many similarities. Due to their high biotite content, two of the Danco Coast siltstones (O.930.4 and 936.1) are enriched in alumina, potash, magnesia and total iron, together with the associated trace elements (gallium, rubidium, nickel and chromium).

Many elements removed during weathering (for example, potash and magnesia) are restored during and after deposition by being absorbed in the clay mineral complex to form such minerals as authigenic sericite and chlorite. Since alumina and soda are the two constituents likely to remain constant during the sedimentation processes, Pettijohn (1957) has used their ratio as a maturity index, giving a value of 125 for lutites associated with orthoquartzites and 11 for similar rocks associated with greywackes. The immaturity of the sedimentary rocks on the Danco Coast is therefore emphasized by an average Al_2O_3/Na_2O ratio of 7·9 for the siltstones.

The chemistry of immature rocks will more closely resemble that of the source area than it would if the detritus had undergone considerable transport. Although finer-grained rocks would be expected to show rather more modification than their coarser-grained counterparts, the concentrations of many of the trace elements (rubidium, strontium, yttrium, zirconium, lanthanum, cerium and thorium) in the Danco Coast siltstones are often almost identical to those occurring in the granites and granophyres of this area. This agrees with the conclusion reached on petrographical evidence that the bulk of the sedimentary material was derived from a fairly acid plutonic source. Nevertheless, the chromium, nickel, copper and zinc values are high enough to assume that the landmass also contained some basic (? volcanic) rocks.

A soda/potash ratio greater than unity occurs in several of these sedimentary rocks, although it is an unusual feature in shales. A similar relationship is also found in three feldspathic sandstones from Trinity Peninsula and the Nordenskjöld Coast (Elliot, 1967*a*). These high soda/potash ratios could reflect the chemical composition of the source area providing the sedimentary detritus; it is perhaps significant that the soda contents of most of the acid plutonic rocks from the Danco Coast are greater than the corresponding potash values.

Specimen O.905.2, a sandstone, contains a high proportion of calcite cement which accounts for about 8 g. (weight per cent) of the lime value; no dolomite is present because the magnesia content of this rock is low. Although the Fe/Mg ratios are approximately constant for both this sandstone and the siltstone specimens, the Mg/Ni, Fe/Ni and Mg/Cr ratios are considerably lower in the sandstone, reflecting the greater relative values of nickel and chromium in this rock. Since chromium in particular tends to be concentrated in the clay minerals and with the carbon of the organic fraction, one would expect these trace elements to accumulate preferentially in the siltstones. It is possible that these low ratios indicate a more basic source area for the sandstone than for the siltstones.

III. PRE-VOLCANIC PLUTONIC ROCKS

Measurement of the ages of about 50 plutonic rocks has enabled Rex (1971) to identify the following five phases of igneous activity in the Antarctic Peninsula:

i. Lower to Middle Jurassic (180–160 m. yr.).
ii. Jurassic–Cretaceous boundary (140–130 m. yr.).
iii. Middle Cretaceous (120–80 m. yr.).
iv. Late Cretaceous basic rocks (75–70 m. yr.).
v. Early Tertiary acid rocks (60–45 m. yr.).

However, the altered state and small size of many of the plutonic rock specimens from the Danco Coast has made it impossible to date them by radiometric methods. Instead, the Danco Coast plutonic rocks

Table III

CHEMICAL ANALYSES OF FIVE SEDIMENTARY ROCKS FROM THE DANCO COAST AND AN ANALYSIS OF AN "AVERAGE SHALE"

	O.905.2	O.936.1	O.930.4	O.931.1	O.936.4	1	2
SiO_2	62·09	55·10	57·57	66·50	67·88	61·76	58·90
TiO_2	0·41	1·07	1·03	0·66	0·56	0·83	0·78
Al_2O_3	10·75	19·37	16·94	14·58	13·15	16·01	16·70
Fe_2O_3	0·86	2·14	2·50	2·15	2·22	2·50	2·80
FeO	1·45	4·99	4·83	3·23	3·28	4·08	3·70
MnO	0·05	0·08	0·03	0·02	0·05	0·05	0·09
MgO	1·07	4·24	3·51	2·74	2·86	3·33	2·60
CaO	10·94	1·84	2·25	2·01	1·86	1·99	2·20
Na_2O	2·78	1·69	1·72	2·88	2·44	2·18	1·60
K_2O	2·17	5·21	3·69	2·23	2·28	3·37	3·60
H_2O+	1·34	2·99	4·59	1·56	1·73	2·79	5·00
H_2O-	—	0·37	0·62	0·30	0·34	0·41	—
P_2O_5	0·18	0·19	0·18	0·16	0·15	0·17	0·16
CO_2	6·27	0·15	0·08	0·42	0·54	0·29	1·30
TOTAL	100·36	99·43	99·54	99·44	99·34	99·76	99·43
S	556	85	136	32	163	104	
Cr	60	81	85	50	46	66	
Ni	25	34	35	30	26	31	
Cu	177	70	112	129	211	131	
Zn	52	106	80	56	233	119	
Rb	98	327	214	147	126	204	
Sr	184	184	122	158	183	162	
Y	33	25	24	21	21	23	
Zr	452	172	162	249	215	200	
Nb	7	17	16	12	12	14	
Ba	391	1,016	665	450	852	743	
La	37	31	25	28	21	26	
Ce	81	80	56	44	45	56	
Pb	21	24	8	8	50	19	
Th	21	19	19	18	12	17	
Ga	10	25	22	15	15	19	
	RATIOS (CALCULATED WATER-FREE)						
Al_2O_3/Na_2O	3·9	11·5	9·9	4·8	5·4	7·9	
Na_2O/K_2O	1·3	0·3	0·5	1·3	1·1	0·8	
Fe/Mg	1·7	1·5	1·8	1·5	1·5	1·5	
Mg/Ni	260	782	641	565	682	668	
Fe/Ni	454	1,186	1,137	857	1,007	1,047	
Mg/Cr	109	328	264	339	385	329	

O.905.2 Feldspathic sandstone; island south of Rongé Island.
O.936.1 Siltstone, Coughtrey Peninsula.
O.930.4 Siltstone, northern Skontorp Cove.
O.931.1 Siltstone, northern Skontorp Cove.
O.936.4 Siltstone, Coughtrey Peninsula.

1. Average of four siltstones from the Danco Coast.
2. "Average shale" (mainly geosynclinal) from Clarke (1924) and Shaw (1956).

have been grouped according to their age relationships with the Upper Jurassic Volcanic Group. In this area, the pre-volcanic plutonic rocks are predominantly of granodioritic to granitic compositions. Pene-contemporaneous dioritic or gabbroic rocks are apparently absent on the Danco Coast apart from the isolated occurrence of basic plutonic pebbles in some of the tuff deposits.

A. Field Relations

A large granodiorite mass intruding the sedimentary rocks at Forbes Point is cut by several microgranite dykes, e.g. O.919.2. Because of their distinctive chemistry, these dykes are considered to be genetically related to the pre-volcanic granites and adamellites rather than to the later post-volcanic granophyres and microgranites. On this evidence, this granodioritic intrusion is also classified with the older plutonic rocks.

Rocks of adamellitic to granitic compositions are common along the Danco Coast (Figs. 2–5) and they range from white coarse-grained rocks (sometimes with a faint pink to purplish tinge) to medium-grained and often megacrystic pink rocks. A large adamellite-granite mass extends for 10 km. along the south-eastern shore of Andvord Bay between stations O.911 and 921, and there are compositionally similar rock outcrops at Mount Banck, Lemaire, Bryde, Rongé and Cuverville Islands, on the mainland to the east of Selvick Cove and at localities bordering Charlotte Bay. Many (but not all) of these rocks are sheared. This is in contrast to the younger post-volcanic plutonic rocks which are largely undeformed.

There are many features which indicate a pre-volcanic age for these acid plutonic rocks. At Mount Banck, southern Rongé Island (O.545), Cuverville Island and at rock outcrops bordering Charlotte Bay (O.970 and 975) both volcanic and plutonic rocks occur within short distances of each other. At these localities the pyroclastic rocks contain rounded granitic pebbles which are petrographically identical to the rocks forming the nearby granite outcrops; there is little doubt that these pebbles were derived from the country rocks. At Rongé Island, a granitic pebble was enveloped by lava before it was incorporated in the tuff deposit (Fig. 7). Large crystals of quartz, potash feldspar and albitic plagioclase usually form part of the tuffs at these granite/volcanic localities (O.545, 568, 918, 937, 938, 952 and 975) but they are conspicuously absent from pyroclastic rocks which are remote from granite exposures. It is probable that the quartz and feldspar are non-volcanic and are xenocrysts derived from the pre-existing granites. Many of the granite masses exposed near Charlotte Bay (O.576 and 977) are cut by tuff and lava dykes which are contemporaneous with the more extensive rocks of the Upper Jurassic Volcanic Group in these areas. As a result of their explosive emplacement, the tuff dykes contain considerable amounts of brecciated granite country rock (O.576.4).

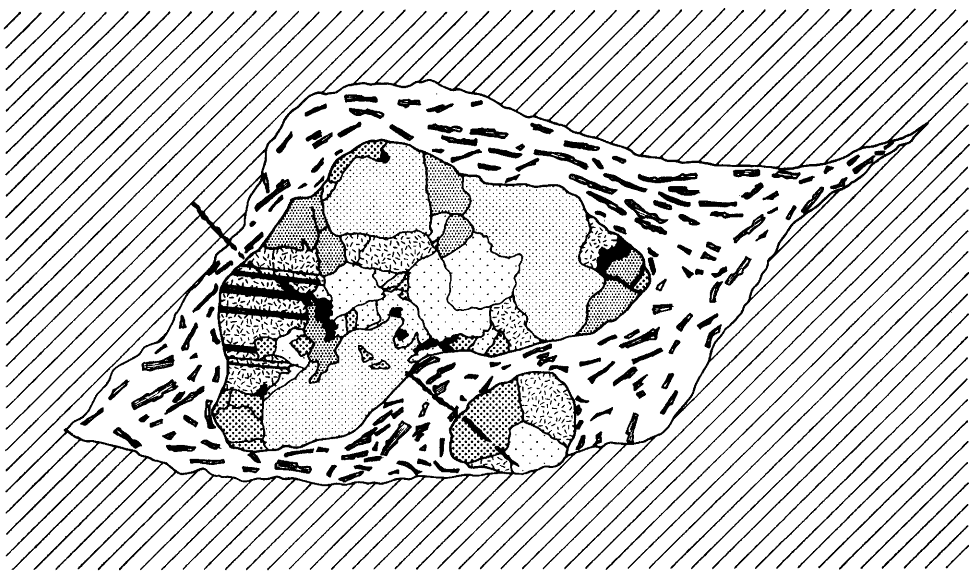

FIGURE 7

Rounded granite pebbles (feldspar, hatched; quartz, coarse to fine stippling; calcite, black) which are enveloped in a lensoid cocoon of lava and form part of the tuff-breccias at southern Rongé Island (O.545.12; X-nicols; ×48).

B. Northern Neko Harbour and Southern Neko Harbour Types

1. *Petrographical comparisons*

On the basis of their petrography it has been possible to group the pre-volcanic plutonic rocks of the Danco Coast as follows:

i. Northern Neko Harbour type (O.576, 911, 955 and 1004).
ii. Intermediate types (O.937, 938, 946 and 971).
iii. Southern Neko Harbour type (O.910, 941.3 and 1003).

The petrographical differences between groups (i) and (iii) are outlined in the following description. Modal analyses of some of these rocks are given in Table IV.

Table IV
MODAL ANALYSES OF PRE-VOLCANIC PLUTONIC ROCKS FROM THE DANCO COAST

	O.1004.1	O.911.1	O.937.2	O.941.3	O.946.1
Quartz	36·8	34·2	36·2	33·0	53·0
Potash feldspar	14·6	27·1	34·8	35·3	27·2
Plagioclase	38·6	35·4	25·6	29·6	16·4
Hornblende	—	—	0·3	—	tr
Biotite	8·7	1·5	—	0·3	—
Chlorite	0·3	1·5	2·0	1·0	3·0
Iron ore	1·0	tr	tr	0·5	0·4
Epidote	—	tr	—	0·2	—
Accessory minerals*	tr	0·3	1·1	0·1	tr
Plagioclase composition	An_{25}	An_{20}	An_{9-12}	An_{12}	An_{10}

tr Trace.
* Including apatite, allanite, prehnite, zircon, sphene and calcite.

O.1004.1 Granodiorite; Forbes Point.
O.911.1 Adamellite; northern Neko Harbour.
O.937.2 Adamellite; south-eastern Bryde Island.
O.941.3 Adamellite; west of Miethe Glacier.
O.946.1 Granite; southern Bryde Island.

a. *Texture.* At northern Neko Harbour the granites and adamellites are coarse-grained hypidiomorphic rocks with an average grain-size of about 5 mm. Subhedral plagioclase crystals are often larger than the other mineral constituents, reaching 8 mm. in length.

To the south, the plutonic rocks have an allotriomorphic-inequigranular texture. Spherical pools of quartz up to 2 cm. in diameter occur in these rocks but most of the minerals are small, averaging 2 mm. across. Crystal boundaries are noticeably indented and irregular.

b. *Plagioclase.* The plagioclase crystals (An_{20}) in the granitic rocks at northern Neko Harbour are lightly dusted with saussurite. However, the plagioclase in otherwise similar rocks at Forbes Point and Charlotte Bay (O.576) is mostly unaltered. Oscillatory zoning is common, particularly near the crystal boundaries. Apart from the weak development of intergranular albite, there is no other generation of plagioclase in these rocks.

Most of the plagioclase crystals (An_{11-12}) in the granites and adamellites at southern Neko Harbour are more albitic than the crystals observed in the more northerly granite type. Saussuritization is also more advanced and the crystal twinning is largely obliterated. Other alteration products of this plagioclase include calcite, sericite and potash feldspar. The abundant intergranular albite which characterizes these rocks has resulted from a subsequent period of plagioclase crystallization. There are also several water-clear patches of plagioclase up to 0·5 mm. across which are apparently associated with the intergranular albite since both have identical optical orientations.

c. *Potash feldspar*. Under the microscope, the potash feldspar in the northern Neko Harbour granitic rocks is either weakly or non-perthitic. The growth of the potash feldspar preceded that of much of the quartz but it post-dated the formation of the mafic minerals and some euhedral quartz inclusions.

At southern Neko Harbour, the potash feldspar is often intensely perthitic, the perthite being closely associated with the mantle of intergranular albite surrounding these crystals. Much of the potash feldspar contains corroded inclusions of iron ore, biotite, plagioclase, quartz and an earlier generation of potash feldspar. The potash feldspar has therefore undergone at least two growth periods, the latter incorporating and assimilating former crystals.

d. *Quartz*. In the northern Neko Harbour granites much of the quartz occupies the interstices between the other rock minerals, although there are a few dihexahedral quartz crystals which are included in the potash feldspar. Irregular and amoeboid quartz areas are indicative of a small amount of recrystallization, probably in response to stresses associated with the slight shearing of these rocks.

In contrast, the granitic specimens obtained farther south contain quartz of a more variable habit:

i. Quartz occurring interstitially between plagioclase.
ii. Euhedral quartz dihexahedra, 0·5 mm. across, which are included in, and therefore crystallized earlier than, some of the perthitic potash feldspar.
iii. Sub-rounded "groundmass" crystals; these often form a quartz mosaic with extremely crenulate intercrystal boundaries. Several have grown adjacent to euhedral potash feldspar crystals, possibly indicating that the quartz was the later of the two minerals to crystallize.
iv. Euhedral quartz occurring with epidote as poikilitic inclusions in pockets of calcite. The euhedral quartz which also surrounds these calcitic areas could have formed at a similar time.
v. Quartz megacrysts which could represent the last stage of quartz (re-)crystallization, since these ovoids contain undigested remnants of all of the other rock constituents.

e. *Mafic and accessory minerals*. In the granitic rocks at northern Neko Harbour, Forbes Point and Charlotte Bay, the mafic minerals, represented by iron ore and biotite, are either fresh (O.1004.1) or about half altered to chlorite (O.576.2 and 910.1). Tiny euhedral zircon and apatite crystals are common in and amongst these minerals but they are rarely encountered elsewhere in these rocks. The zircon commenced crystallizing before the apatite since it sometimes occupies the cores of the apatite needles.

At southern Neko Harbour, little unaltered biotite remains, the mafic minerals now consisting of iron ore and chlorite. These minerals are often associated with several euhedral crystals of zoned allanite which occur near, or are ringed by, epidote. Small apatite and zircon crystals are still visible within the chlorite pseudomorphs, although these accessory minerals are also randomly scattered throughout the rocks. Zircon sometimes occurs as undigested remnants within the quartz megacrysts.

f. *Epidote*. Rarely occurring at the more northerly granite outcrops in Neko Harbour, several of the granite specimens (O.910.1 and 1003.1) obtained farther south contain significant amounts of epidote. Besides forming as a result of the alteration of the plagioclase and biotite, epidote is also found as euhedral crystals along quartz/feldspar boundaries, as thin veins, as quartz inclusions, or, together with small idiomorphic quartz crystals, in the interstitial pockets of calcite between some of the larger euhedral quartz or potash feldspar crystals.

g. *Perthite*. Perthite is sometimes weakly developed in the coarser-grained white granites and adamellites (the northern Neko Harbour type) but it is far commoner in the pink megacrystic phase of these acid plutonic rocks (the southern Neko Harbour type). The perthite is mostly film microperthite with the albite lamellae averaging between 5 and 10 μm. in width. However, patch macroperthite is well developed in two of the granite specimens (O.938.1 and 946.1).

According to Tuttle (1952), the series sanidine–sub-X-ray perthite–X-ray perthite–cryptoperthite–microperthite–perthite represents crystallization on a decreasing temperature scale and on an increasing time scale. The finest grained perthites have often been considered as a result of exsolution or unmixing. Broad and irregular patch perthites, in which one component locally predominates over the other, indicate a relatively low temperature of formation and have been explained as a replacement phenomenon (Mehnert, 1968). However, Marmo (1971) believed that such coarse-grained perthites have formed by the simultaneous growth of albite and potash feldspar during conditions of protracted and low-temperature crystallization.

h. *Intergranular albite*. Although it is virtually absent from the northern Neko Harbour type, the southern Neko Harbour granitic rocks and similar rocks exposed elsewhere on the Danco Coast invariably contain intergranular albite between adjacent perthite crystals, and sometimes also at potash feldspar/plagioclase and potash feldspar/quartz boundaries. The albite, which is often twinned, forms a single or double row of crystals. It is possible that the intergranular albite in these Danco Coast granitic rocks has formed by exsolution from the potash feldspar but its precipitation from late-stage magmatic fluids (Stone, 1965) is another possible origin.

i. *Quartz–feldspar intergrowths*. Non-eutectic intergrowths of quartz and feldspar are contained in several of the granitic rocks (O.938.1, 8 and 9, and 971.1). The percentages of the two minerals in the intergrowths are variable, although the feldspar is usually in excess of the quartz (Plate IVc). In most cases the quartz has crystallized later than either the potash feldspar (Plate IVd) or the plagioclase (Plate IVe) and the optical orientation of the quartz is sometimes controlled by the host mineral (Plate IVd). In specimen O.938.11 (Fig. 8) quartz has partially assimilated three differently orientated potash feldspar crystals and it is graphically intergrown with two of them.

2. *Chemical comparisons*

The major-oxide and trace-element chemistry of nine of the granite specimens is given in Table V. It is immediately apparent that granitic specimens of the northern Neko Harbour type (O.576.2, 955.1 and 911.1) are more basic than granitic specimens of the southern Neko Harbour type (O.941.3, 910.1 and 1003.1); the higher silica, potash, rubidium, lead and thorium contents in the latter rocks are combined

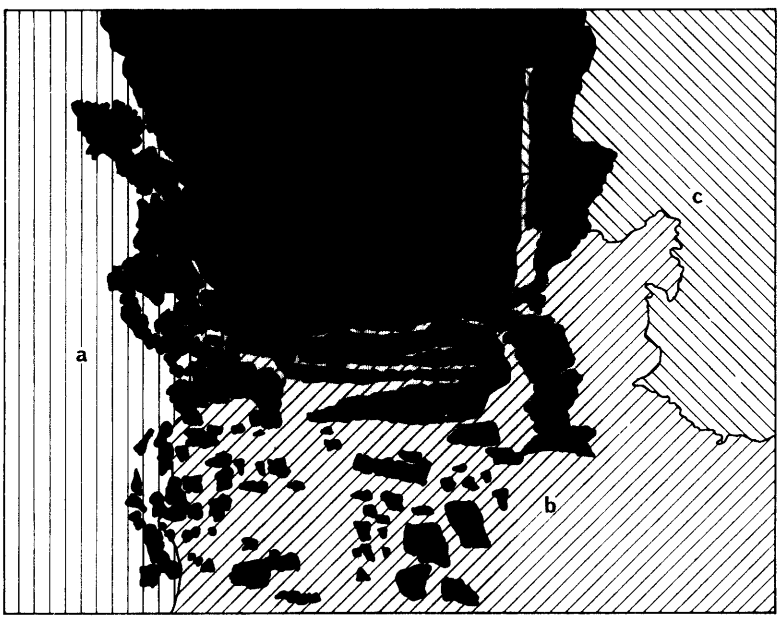

FIGURE 8

Optically continuous quartz (black) in a granite at Mount Banck. The quartz has partially assimilated three differently orientated potash feldspar crystals (a, b and c) and is graphically intergrown with two of them (a and b) (O.938.11; X-nicols; ×72).

with lower concentrations of titania, alumina, iron, magnesia, lime, zinc, strontium and zirconium in these rocks.

The chemical validity of the petrographically established granite types is even more obvious in a chemical study of the potash feldspars from several of the granites and adamellites. The potash feldspar analyses (Table VI) correlate closely with the granite types already outlined, in that they themselves form identical groups. These are largely defined on the basis of the alkali contents and on the abundance of certain trace elements. Thus soda, barium and strontium are concentrated in the potash feldspars from the granitic rocks of the northern Neko Harbour type, whilst the potash and rubidium contents are higher in the potash feldspars from the more acidic granites and adamellites exposed at southern Neko Harbour.

3. *X-ray data*

Potash feldspar samples from the Danco Coast granitic rocks have been subjected to X-ray diffraction studies using a Philips PW 1050 diffractometer. The instrument settings used were: ratemeter 2×10^2; time constant 2; slits 2°–0·2°–2°; scanning speed 1° 2θ/min.; chart speed 160 mm./hr.; Cu–Kα radiation. Some typical traces between $2\theta = 29°$ and 31° are reproduced in Fig. 9; most (type 1) show a single sharp 131 reflection at about 29·8° 2θ, indicating the presence of a dominantly monoclinic potash feldspar (orthoclase). Type 2 traces (O.938.1 and 941.3) probably reflect the co-existence of small amounts of high microcline with the orthoclase (compare traces given by Parsons and Boyd (1971) and by Vorma (1971)). Thus it seems that the two granite groups, although distinguishable on the basis of the petrographical and chemical data, cannot be differentiated according to the structural state of their constituent potash feldspars.

A granite specimen (O.946.1) from southern Bryde Island is unique amongst the analysed Danco Coast granitic rocks in containing potash feldspar of near-maximum triclinicity (type 3 trace). This was unsuspected from the thin-section study because of the complete absence of cross-hatch twinning. The development of microcline in this rock might be associated with the formation of the coarse-grained patch perthite which is restricted to this and one other (probably contact-metamorphosed) potash feldspar specimen (O.938.1).

4. *Discussion*

The inaccessibility of many of the rock exposures on the Danco Coast has frequently prevented the detailed examination of the field relationships. Therefore, it has been necessary to rely on the chemistry and petrography of these granites and adamellites in the interpretation of their crystallization histories.

Many of the granite specimens exhibit features which suggest the existence of a magma at some stage during their formation:

i. Much of the plagioclase shows a delicate oscillatory zoning reflecting the idiomorphism of the crystals throughout much of their growth.
ii. Some of the quartz crystals possess the dihexahedral shape characteristic of high-temperature crystallization.
iii. The analysed granites (Table V) show little variation both in their major-oxide and trace-element chemistry. The changes that do occur are those which often develop during magma fractionation.
iv. In the Q–or–ab diagram (Fig. 10) the analysed granites plot close to the region of ternary minima in Tuttle and Bowen's (1958) experimental "granite system".
v. In the Na–Ca–K diagram (Fig. 11) all of the rocks plot in the field occupied by magmatic granitic rocks (Raju and Rao, 1972).

a. *Northern Neko Harbour type*. These granitic rocks are interpreted as having evolved essentially in a magmatic environment, since they possess all of the characteristics listed above. In addition, they have undergone little secondary textural modification and a normal mineral crystallization sequence is recognizable. The formation of the accessory minerals was followed successively by the growth of the mafic minerals and of plagioclase, with potash feldspar and quartz crystallizing (sometimes simultaneously) at a later stage. The slight recrystallization of some of the quartz is the only evidence for crystal growth in the solid state. According to Barth's (1956) two-feldspar geothermometer, the granitic rocks of the Danco Coast crystallized between 520° and 600° C (Table VII); these temperatures closely correspond to values

TABLE VI

CHEMICAL ANALYSES OF POTASH FELDSPARS FROM SOME PRE-VOLCANIC GRANITIC ROCKS OF THE DANCO COAST

	O.576.2	O.911.1	O.955.1	O.937.2	O.938.1	O.938.8	O.1003.1	O.941.3	O.910.1
SiO_2	63·32	62·12	62·84	62·97	64·72	62·96	62·26	62·54	62·16
TiO_2	—	—	—	—	—	—	—	—	—
Al_2O_3	19·99	19·58	19·91	19·97	19·46	19·93	20·50	19·56	20·27
Fe_2O_3*	0·12	0·16	0·27	0·44	0·24	0·44	0·11	0·12	0·15
MnO	0·01	0·01	—	0·04	0·01	—	—	—	—
MgO	—	—	—	0·02	—	—	—	—	—
BaO	0·27	1·86	0·54	0·22	0·08	0·26	0·16	0·14	0·15
CaO	0·98	1·06	0·88	1·18	1·06	0·82	0·72	0·75	0·69
Na_2O	3·01	4·05	3·61	2·23	4·25	2·61	2·17	1·63	1·92
K_2O	12·27	11·24	12·19	12·30	9·56	12·89	14·02	15·05	14·66
H_2O	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
P_2O_5	—	—	—	—	0·01	0·01	—	0·01	—
CO_2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
TOTAL	99·97	100·08	100·24	99·37	99·39	99·92	99·94	99·80	100·00
Cr	13	13	11	9	11	15	15	12	11
Ni	—	1	—	67	2	—	—	—	—
Rb	413	421	400	408	381	450	681	609	620
Sr	243	285	234	100	57	77	114	97	111
Ba	2,376	16,666	4,876	1,948	732	2,317	1,326	1,287	1,428
La	—	—	—	—	3	—	—	—	—
Ce	—	—	—	—	6	2	—	—	—
Pb	46	23	27	32	25	33	32	36	20
Th	3	5	6	5	8	—	—	1	—
K/Rb	247	222	253	250	208	238	171	205	196
Ba/Rb	5·75	39·60	12·19	4·77	1·92	5·15	2·10	2·11	2·14

n.d. Not determined.
* Total iron as Fe_2O_3.

O.576.2 Adamellite; western Charlotte Bay.
O.911.1 Adamellite; northern Neko Harbour, Andvord Bay.
O.955.1 Adamellite; northern Bryde Island.
O.937.2 Adamellite; south-eastern Bryde Island.
O.938.1 Granite; west of Mount Banck.
O.938.8 Adamellite; south-east of Mount Banck.
O.1003.1 Adamellite; southern Neko Harbour, Andvord Bay.
O.941.3 Adamellite; west of Miethe Glacier.
O.910.1 Adamellite; southern Neko Harbour, Andvord Bay.

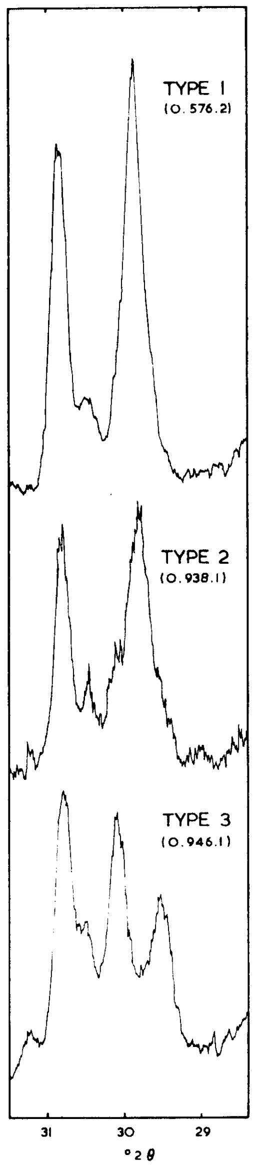

FIGURE 9

Examples of X-ray diffraction traces between 29° and 31° 2θ for potash feldspars from the pre-volcanic granitic rocks of the Danco Coast. The instrument settings used were: ratemeter 2×10^2; time constant 2; slits 2°–0·2°–2°; scanning speed 1° 2θ/min.; chart speed 160 mm./hr.; Cu-$K\alpha$ radiation.

quoted by Barth for "diapirite" granites. The occurrence of both orthoclase (as distinct from microcline) and oligoclase in granitic rocks is also characteristic of high-level (post-kinematic) intrusive rocks (Marmo, 1971).

b. *Southern Neko Harbour type*. The complex petrography of these rocks has already been described. The degeneration of plagioclase and biotite, the sutured anhedral crystal boundaries and the scattering of the accessory minerals imply that there has been considerable modification of an original granite fabric. Moreover, the presence of megacrystic quartz and the development of non-eutectic quartz–feldspar intergrowths are indicative of a period of subsolidus crystal growth. The earlier granite fabric, however, might well have been one which formed during magmatic crystallization; the occurrence of oscillatory zoning in the plagioclase crystals (this is most easily recognized in specimens which have been etched with hydrofluoric acid) and the dihexahedral shape of several of the older quartz crystals imply that the rocks have, at least in part, crystallized under magmatic conditions.

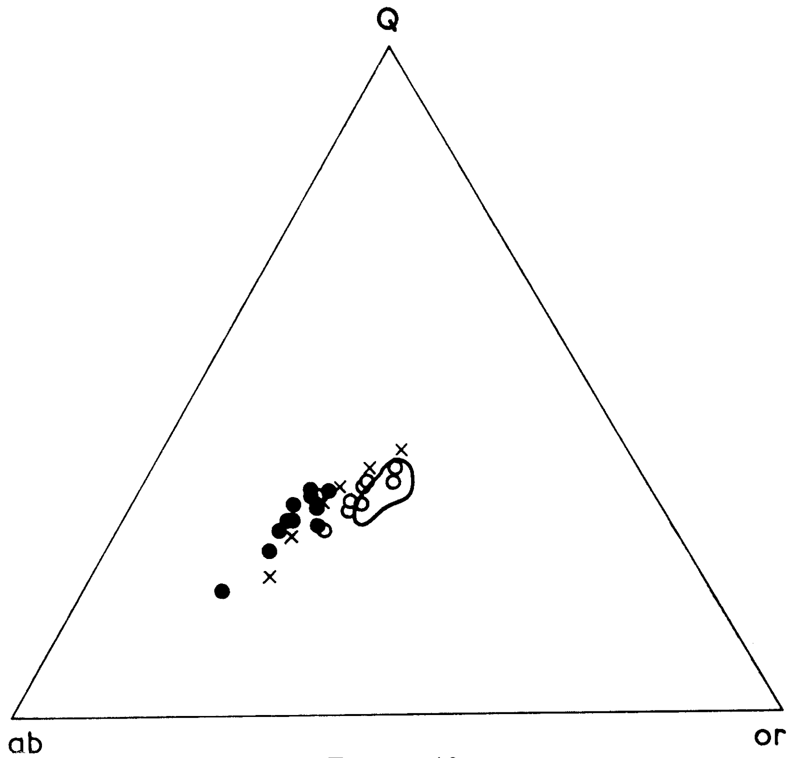

FIGURE 10

A plot of normative quartz, orthoclase and albite for the post-volcanic granophyres (solid circles) and the pre-volcanic granitic rocks (open circles) of the Danco Coast. The positions of the ternary minima at 0·5, 1 and 2 kbar water pressures (Tuttle and Bowen, 1958) and the ternary eutectics at 5 and 10 kbar water pressures (Luth and others, 1964) are denoted by the crosses (from top to bottom on the diagram × = 0·5, 1, 2, 5 and 10 kbar, respectively). The solid line encloses the area containing the highest concentration of analysed granitic rocks considered by Tuttle and Bowen.

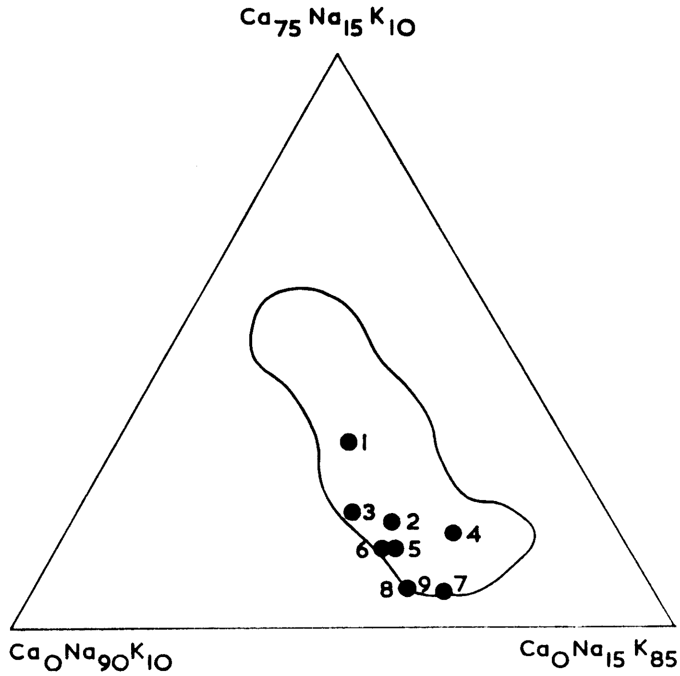

FIGURE 11

Part of the Na–Ca–K triangular diagram for the pre-volcanic granitic rocks of the Danco Coast. The solid line encloses the field occupied by magmatic granitic rocks (from Raju and Rao, 1972).

1. O.576.2.	4. O.937.2.	7. O.946.1.
2. O.955.1.	5. O.941.3.	8. O.1003.1.
3. O.911.1.	6. O.910.1.	9. O.938.1.

TABLE VII

THE TEMPERATURE OF FORMATION OF SOME OF THE GRANITIC ROCKS OF THE DANCO COAST CALCULATED ACCORDING TO THE METHOD OF BARTH (1956)

Specimen number	*Molecular percentage of albite in potash feldspar*	*Composition of co-existing plagioclase*	k_T	*Temperature* (°C)
O.576.2	20·74	An_{25}	0·28	555
O.911.1	26·85	An_{30}	0·34	600
O.955.1	19·36	An_{29}	0·24	520

The perthitic orthoclase crystals in these rocks, with lower K/Rb and Ba/Rb ratios than are found in the potash feldspars in the northern Neko Harbour type granites (Table VI), either crystallized at a later stage in the granite differentiation history (Taylor and Heier, 1960) or they crystallized in a non-magmatic environment from fluids relatively enriched in rubidium and depleted in barium. Since the alkali-feldspar crystals are microperthitic and are considered to have formed by exsolution, they must have crystallized from a system which has passed the maximum solvus (Michot, 1961). Thus, depending on the water pressure and anorthite content, Marmo (1971) would have envisaged crystallization temperatures of about 660–715° C. (Probably the physico-chemical conditions on the Danco Coast resulted in slightly lower temperatures—see Table VII.) Such temperatures would suggest a magmatic origin for the alkali feldspar, although its poikilitic habit indicates that its growth occurred whilst the already solidified parts of the granite body were in a state of inequilibrium.

It is suggested that the present fabric and composition of the granitic rocks assigned to the southern Neko Harbour type have arisen by autometasomatism associated with the gradual concentration of the residual magmatic fluids during crystallization (cf. Barth, 1969, p. 47). Highly differentiated magmatic fluids containing abundant potassium and rubidium but little calcium, sodium and barium (most of the barium would have been incorporated into the lattices of early potassic minerals) could have been responsible for the formation of potash feldspars with the observed low K/Rb and Ba/Rb ratios. The low albite content of these crystals could be explained either by crystallization in such a chemical environment or by subsequent exsolution. The chloritization of the biotite, the alteration of the plagioclase, the formation of non-eutectic quartz–feldspar intergrowths, the development of megacrystic quartz and the crystallization of interstitial pockets of calcite, quartz and epidote could all be explained by the action of late-stage magmatic fluids. The greater development of perthite in these granitic rocks might have been a result of the slower cooling rate which would be expected to occur in the interior of such a granite body.

C. CHEMISTRY

The Danco Coast granitic rocks (Table V) show all gradations from the high-calcium granites to the low-calcium granites as defined by Turekian and Wedepohl (1961). However, the soda contents in the Danco Coast granites are comparatively high and the potash and lime contents are also rather low. Amongst the trace elements, the granitic rocks on the Danco Coast contain greater amounts of copper, rubidium, thorium and lead, and less chromium, nickel, zinc, strontium, yttrium, niobium, lanthanum and cerium than the values recorded by Turekian and Wedepohl. Nevertheless, the concentrations of several of the trace elements in the Danco Coast rocks (e.g. zirconium, nickel, gallium, strontium and lead) compare favourably with the trace-element abundances in other calc-alkaline granites (Nockolds and Allen, 1953).

In the Antarctic Peninsula there have been few chemical investigations into granitic rocks which are associated with or pre-date the Upper Jurassic Volcanic Group. Indeed, there is a complete lack of trace-element analyses. Of the major-oxide analyses (Fleet, 1968, table IV, columns 8 and 9; Marsh, 1968, table IV, columns 17 and 18; Stubbs, 1968, table V, columns 7, 8 and 10), few contain the high soda values which characterize the Danco Coast granitic rocks. All seven of the Graham Land analyses have Fe^{3+}/Fe^{2+} ratios which are less than unity, in contrast to the rocks collected by Bayly and Hobbs.

The intense shearing of many of the pre-volcanic granitic rocks on the Danco Coast is apparently confined to the seaward side of the area studied here; exposures of crushed granitic rocks occur on Bryde, Lemaire and Rongé Islands and on the mainland near Orne Harbour. The deformation is possibly related to the severe faulting which is known to have occurred in the Lemaire Channel, northern Graham Coast, and on Wiencke Island. A comparison between the chemistry of the undeformed and sheared granitic rocks (Table V) reveals that the latter have lost significant amounts of their original potassium, rubidium and niobium. Other elements (such as sodium, barium, zirconium, lanthanum and zinc) show smaller but still detectable changes. In many respects, the composition of the sheared granitic rocks approaches that of the post-volcanic granophyres and this is particularly obvious in the plots in Fig. 12. The shearing of these granitic rocks might thus have some bearing on the formation of the younger granophyres (p. 49).

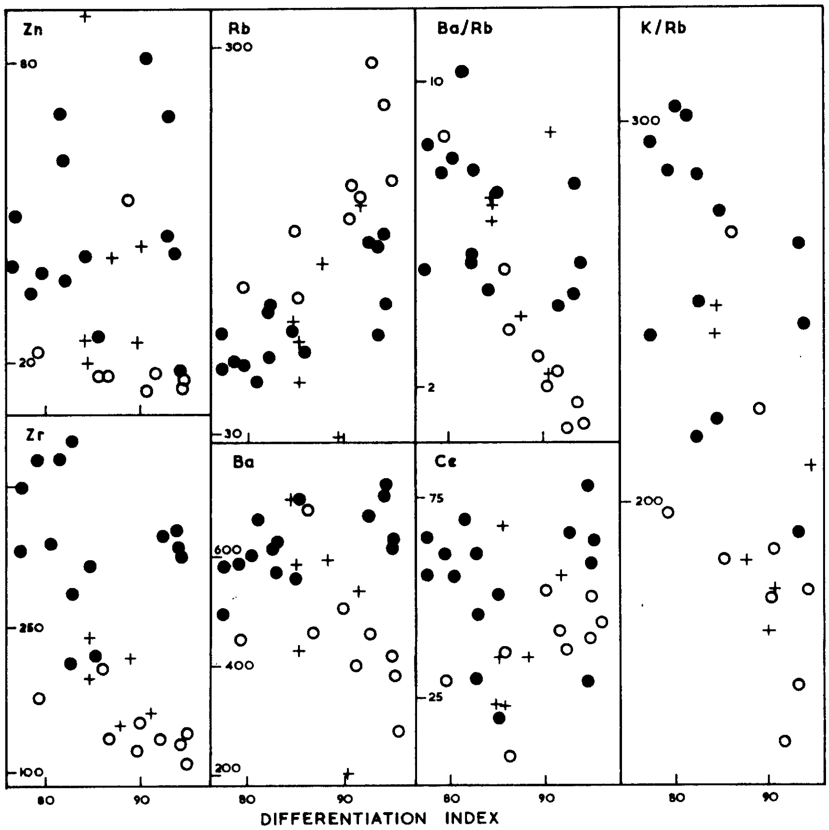

FIGURE 12

Plots of Zn, Rb, Zr, Ba, Ce, Ba/Rb and K/Rb against the Thornton and Tuttle (1960) differentiation index for the post-volcanic granophyres (solid circles), the pre-volcanic granites (open circles) and the pre-volcanic sheared granites (crosses) of the Danco Coast.

IV. VOLCANIC ROCKS

VOLCANIC rocks are exposed extensively along the Danco Coast, occurring both on the mainland and on the offshore islands; many of the smaller islands (Danco, Orne, Brooklyn, Emma and Enterprise Islands) are formed entirely of these rocks and there are thick successions at Beneden Head (Plate Id) and eastern Rongé Island. Massive grey-green pyroclastic rocks are commonest although lavas are also important. Andesites crop out at several localities but in contrast to the Graham Coast (Curtis, 1966) they are subordinate to more acid lava types. At most localities the volcanic rocks are massive and generally structureless.

Sedimentary fragments in many of the tuffs are identical to sandstones and siltstones of the Trinity Peninsula Series, possibly indicating a post-Carboniferous age for these volcanic rocks (Grikurov and others, 1967). The tuffs and lavas are also older than the (?) Cretaceous to early Tertiary plutonic rocks because they are extensively altered and metamorphosed by them. It is possible that they could be correlated with the Upper Jurassic Volcanic Group (Adie, 1962; Goldring, 1962) on the basis of petrographical and chemical similarities with the volcanic rocks of supposed Upper Jurassic age at Anvers Island (Hooper, 1962), the Graham Coast (Curtis, 1966), the Loubet Coast (Goldring, 1962) and Adelaide Island (Dewar, 1970). At Adelaide Island the volcanic rocks have been assigned to the Upper Jurassic because fossils of this age have been recovered from interbedded sedimentary rocks (Thomson, 1972). On the eastern side of Graham Land, an unaltered andesite specimen from Jason Peninsula has been dated as Middle Jurassic (165 ± 7 m. yr.) by Rb-Sr radiometric methods (Adie, 1971). Two other basic lava specimens from Jason Peninsula dated by K-Ar methods yielded Upper Triassic (186 ± 8 m. yr.) and Middle to Upper Jurassic (156 ± 6 m. yr.) ages (Rex, 1971). Whilst the climax of the volcanic activity probably occurred during the Upper Jurassic, it is evident that the volcanicity commenced at a much earlier time and possibly also extended into the Cretaceous.

Because of the scattered occurrence of the rock outcrops, no stratigraphical correlation is attempted here. In the following petrographical description, the lavas are classified according to Streckeisen's (1967) scheme; the volcaniclastic rocks are classified according to Fisher's (1966) scheme with the additional subdivision of the finer-grained rocks into lithic, crystal and vitric tuffs.

A. Field Relations

1. *Mainland*

Volcanic rocks form much of the eastern side of the peninsula near Mount Banck (Fig. 5) at the southern end of the Danco Coast. At localities O.938.7–10, vitric tuffs, porphyritic black rhyodacites and well-cleaved tuff-breccias are in contact with granites and adamellites. The relationship between these acid plutonic rocks and the volcanic rocks is not clear, although the apparent absence of contact metamorphism and the presence of small granitic pebbles in the tuffs could indicate that the volcanic rocks are younger than the granites.

The volcanic rocks at the northern end of Coughtrey Peninsula include volcanic conglomerates, tuffs and rare andesites. There is a sharp northerly dipping contact (Plate IIIa) between these rocks and the sedimentary rocks to the south but at one locality the tuffs pass almost imperceptibly into the siltstones. The tuffs are cut by a 15–30 cm. wide breccia dyke containing rounded fragments of sandstone and siltstone which have been brought up from the underlying sedimentary rocks.

At Waterboat Point, two small offshore islands are separated from the mainland by a 90 m. wide tidal channel. The northern island is formed by "stratified andesite sills or flows intruded by a quartz-diorite pluton" (Halpern, 1962). Both rock types are cut by small aplite dykes, particularly along the north-western coastline. Becoming porphyritic southward, andesites form much of the southern island, together with slumped and bedded tuffs. At station O.915, a black fine-grained andesitic lava has incorporated numerous sedimentary and volcanic pebbles up to 4 mm. in diameter. Apart from the microlitic texture of the lava, this rock resembles Halpern's description of a "metaconglomerate" which forms a 4 m. thick band in the lavas of this area.

The imposing cliffs at Beneden Head (Plates Id and IIa) are composed entirely of andesitic to rhyolitic lavas, together with crystal tuffs of corresponding compositions. The approximate strike of these rocks is east-north-east to west-south-west. Dykes and siliceous veins are common and there is good flow banding in the lavas at station O.903. Towards the top of the cliffs (O.529) there are coarser-grained lapilli-tuffs, and metamorphosed volcanic conglomerates occur to the south-west (O.907).

The extensive exposures of volcanic rocks between Beneden Head and Cape Anna possess the same textural and compositional variations as those to the south.

2. *Offshore islands*

A considerable part of south-eastern Bryde Island is formed of volcanic rocks. At locality O.937.5–7 an exposure of pale green and dark grey tuffs is overlain by a spherulitic rhyolite flow (Plate IVf). Granitic fragments in the tuffs could have been derived from the granite mass to the north-west; crystals of perthite and cracked quartz in the crystal tuffs are identical to those in the granite at stations O.946 and 951. Unfortunately, the contact between these acid plutonic rocks and the volcanic rocks is obscured by snow, making direct observation of the age relationships impossible. Farther to the south (O.932) a sequence of grey-green and sometimes red porphyritic andesites contains numerous scalloped amygdales (Plate Va). Similar lavas form a nearby group of small islands and there is a succession of andesites and interbedded crystal tuffs to the west at localities O.937.1–4.

ndesites and acid crystal tuffs are contact-metamorphosed by later granophyres at several localities Lemaire Island (O.942, 956, 958 and 959) and they are also traversed by numerous aplite veins. Near contact with the plutonic rocks at station O.958, the volcanic rocks have been almost completely ered to epidote.

The volcanic rocks at Rongé Island include basalts, andesites, acid lavas and tuffs which have been ruded and metamorphosed by the post-volcanic granophyres (Plates Ia, IIa and b). At the Orne Islands re are also dark blue basalts containing numerous siliceous amygdales.

Green-grey lapilli-tuffs and tuff-breccias, occurring almost to the exclusion of other rock types on the aller offshore islands, alternate with thin rhyolitic bands on Enterprise Island. Large andesite bombs incorporated in the slightly sheared lapilli-tuffs at Brooklyn Island, which together with parallel ale" fragments define a faint bedding (Plate IIIc) in the north-east of this island.

B. Petrography

Basalts

At Breakwater Island, a fine-grained lava (Table VIII, O.985.1) comprises trachytic plagioclase laths n_{50}; 0·12 mm. by 0·02 mm.), iron ore, interstitial green-brown "chlorite" and granular to interstitial roxene. There are a few larger pyroxene crystals which sometimes ophitically include the plagioclase ths. The sporadic plagioclase microphenocrysts are pseudomorphed by epidote, chlorite, calcite, prehnite d pumpellyite.

A basalt (O.527.2) at north-eastern Rongé Island is completely lacking in phenocrystic plagioclase. ugite phenocrysts ($2V\gamma = 58°$) are fresh apart from slight perpipheral alteration to tremolite–actinolite d chlorite. The former presence of olivine or orthopyroxene in this lava can only be surmised from the currence of scaly talc and chlorite pseudomorphs. Most of the mafic minerals of the groundmass are mpletely altered.

A basalt specimen (Table VIII, O.914.1; Plate Vb) from the Orne Islands contains little unaltered yroxene, the fairly coarse-grained groundmass comprising well-twinned and often zoned plagioclase n_{55}), chlorite, euhedral ilmenite and small patches of calcite. The normally and oscillatory zoned labra-orite phenocrysts have irregular twinning. Amygdales consist of concentric bands of quartz, chalcedony, lcite and chlorite.

. *Andesites*

Rocks recognizable as andesites were collected from Coughtrey Peninsula, south-eastern Bryde Island, anco Island and Rongé Island; contact-metamorphosed rocks of an apparent andesitic parentage also ccur on Lemaire Island (O.942.3 and 7, 960 and 964), Hanka Island and at station O.543 inland from eneden Head.

At eastern Bryde Island, dark grey augite-andesites (O.932.4) contain slightly turbid subhedral plagio-lase phenocrysts (An_{56}), which are partially pseudomorphed by pale green epidote, albite, prehnite and ggregates of clear quartz. Twinned and usually fresh phenocrysts of colourless augite ($2V\gamma = 58°$) are ometimes concentrically zoned. There are also glomeroporphyritic aggregates of plagioclase, ilmenite, ugite and apatite. The groundmass consists of sodic andesine microlites with spots or interstitial patches f ilmenite, sphene/leucoxene and minute acicular apatite. Specimen O.932.1 also contains haematite. Two pale green rocks (Table VIII, O.932.2; O.932.3) are identical to these andesites apart from the presence f considerable potash feldspar in the groundmass. Amygdales are widespread at this locality and they re formed of white analcite (Plate Va), chlorite (O.932.1 and 4), prehnite (O.932.4) and epidote in varying ssociations.

3. *Acid lavas*

Several of these lavas have been altered and have undergone alkali-metasomatism; although they now range in composition from dacite to rhyolite, it is thought that none of them was as acid as rhyolite on eruption.

In a green rhyolitic lava at Beneden Head, the fractured subhedral albite phenocrysts (An_7) are set in a groundmass of irregular albite laths, interstitial potash feldspar, quartz, chlorite and granular sphene. The phenocrysts are often fresh, although many of them are considerably altered to epidote. Ellipsoidal

TABLE VIII

MODAL ANALYSES OF LAVAS FROM THE DANCO COAST

	O.914.1	O.985.1	O.990.2	O.932.2	O.528.3	O.941.1	O.903.2	O.937.7
Phenocrysts								
Quartz	—	—	—	—	—	9·1	—	—
Potash feldspar	—	—	—	—	—	3·6	—	—
Plagioclase: fresh	31·4	—	1·6	—	11·4	33·8	1·5	3·3
altered*	—	1·8	0·6	34·7	1·7	—	6·4	—
Clinopyroxene	tr	1·8	0·1	4·0	—	—	—	—
Chlorite pseudomorphs	—	—	—	—	2·1	3·9	0·3	—
Iron ore	—	1·2	0·3	1·4	3·4	—	—	—
Total	31·4	4·8	2·6	40·1	18·6	50·4	8·2	3·3
Groundmass								
Quartz	—	—	—	—	26·0	12·8	15·8	19·4§
Potash feldspar	—	—	—	‡	30·3	35·0	59·9	45·4
Plagioclase	31·0	45·5	38·4	‡	23·4	tr	tr	28·0
Clinopyroxene	—	20·4	13·9	—	—	—	—	—
Chlorite	14·0	19·1	35·3	‡	—	—	—	1·6
Iron ore	15·8	10·2	9·8	--	—	0·4	1·6	—
Sphene/leucoxene	—	—	—	‡	0·1	—	—	0·6
Epidote	—	—	—	—	1·5	1·4	10·4	1·0
Calcite	tr	—	—	—	—	—	—	0·7
Apatite	—	—	—	0·1	0·1	—	—	—
Total	60·8	95·2	97·4	54·6	81·4	49·6	87·7	96·7
Amygdales and veins								
Quartz	3·0	tr	tr	tr	—	—	4·1	—
Chlorite	2·8	—	tr	4·7	—	—	—	—
Others†	2·0	tr	tr	0·6	—	—	—	—
Plagioclase composition								
Phenocrysts	An_{60}	—	An_{57}	An_{9}	An_{10}	An_{10}	An_{6}	An_{5}
Groundmass	An_{55}	An_{50}	(?)	(?)	An_{5}	(?)	(?)	(?)

tr Trace.
* Secondary minerals including albite, epidote, prehnite, chlorite, quartz, potash feldspar calcite and pumpellyite.
† Including iron ore, epidote, prehnite, chalcedony and calcite.
‡ Present but cryptocrystalline.
§ (?) Cristobalite.

O.914.1 Basalt; Orne Islands.
O.985.1 Basalt; Breakwater Island.
O.990.2 Andesite; Coughtrey Peninsula.
O.932.2 Altered andesite; south-eastern Bryde Island.
O.528.3 Rhyodacite; Beneden Head.
O.941.1 Quartz-latite; south-west of Miethe Glacier.
O.903.2 Rhyolite; north-eastern Beneden Head.
O.937.7 Spherulitic rhyolite; eastern Bryde Island.

amygdales up to 1 cm. across are formed of bladed epidote, quartz, potash feldspar and perfectly euhedral sphene crystals. A texturally similar quartz-latite (O.903.3) from 2 km. east of Beneden Head shows slight replacement of the plagioclase phenocrysts by potash feldspar. Prehnite and potash feldspar extensively replace phenocrystic plagioclase in a dacite (O.1001.4) from Beneden Head, also forming irregular segregations with associated epidote and quartz. This specimen contains xenoliths of sedimentary rocks and of an altered basic plutonic rock.

Apart from their cryptocrystalline groundmasses, three specimens from Beneden Head (Table VIII, O.528.3 and 903.2; O.913.1) and one from Waterboat Point (O.993.1) are similar to specimen O.528.2 described above. There is a marked flow structure in two of these rocks (O.528.3 and 913.1). Other acidic lavas contain corroded (O.939.1) or euhedral (O.937.1) quartz phenocrysts and pseudomorphs after mica and amphibole.

In a rhyolitic lava (Table VIII, O.937.7; Plate IVf) from south-eastern Bryde Island, numerous buff to green spherulites are incorporated in a pink cryptocrystalline felsic groundmass; perlitic cracks are commonly seen in the thin section. Most of the spherulites contain a colourless core of fibrous (?) cristobalite ($n <$ balsam) surrounded by a brownish zone of potash feldspar but sometimes the potash feldspar forms the entire spherulite. In many of them there is an intermediate straw-coloured zone consisting of an intimate intergrowth of these two minerals. The spherulites often eccentrically include subhedral albite phenocrysts. In a green epidotic lava (O.942.2) from the north-east of this island, the spherulites are less perfectly developed.

4. *Volcanic conglomerates*

At Coughtrey Peninsula, near the contact with the sedimentary rocks, there is a poorly bedded dark grey-green pebble conglomerate containing sub-rounded clasts up to 35 mm. across. Although rhyolitic pebbles predominate, there are also many of siltstone and sandstone derived from the sedimentary rocks to the south. The originally glassy volcanic pebbles include spherulitic rhyolites, porphyritic rhyolites and vitric tuffs.

South-west of Beneden Head (O.907), a contact-metamorphosed volcanic conglomerate contains no sedimentary material but andesitic pebbles are common. There are also a few pebbles of an originally basic plutonic rock which have also been metamorphosed and could have been derived from an older suite of plutonic rocks.

5. *Tuff-breccias, lithic tuffs and lapilli-tuffs*

These grey-green tuffs are the commonest pyroclastic rock type. Compositionally similar, their subdivision into tuff-breccias, lithic tuffs and lapilli-tuffs is based on the size of the constituent rock fragments.

Andesitic tuff-breccias occur at southern Danco Island, southern Rongé Island and on the north-eastern coast of Charlotte Bay. At Danco Island (O.513), the brown heterogeneous matrix of fine-grained quartz, penninite and epidote contains numerous small crystal fragments of plagioclase and pyroxene. The angular lithic fragments are almost entirely of augite–andesite. At southern Rongé Island (O.545), the tuff-breccias contain a greater variety of rock types, including rhyolitic crystal tuffs (sometimes well-bedded), andesites, granites and rare sandstones, together with crystals of quartz and feldspar. Two granitic pebbles are incorporated in a lensoid cocoon of lava (Fig. 7) in specimen O.545.12 and the rock as a whole is crushed and heavily veined by calcite.

Lithic and lapilli-tuffs are exposed at Beneden Head, on the mainland to the east of Danco Island (O.511 and 512), and on Bryde (O.937.6 and 952), Lemaire (O.956), Rongé (O.517, 524, 544 and 545), Danco, Cuverville (Plate IIc), Emma, Brooklyn and Enterprise Islands. Both andesitic and rhyolitic fragments are present in the tuffs, although many of them are too altered to chlorite, epidote and leucoxene for their original compositions to be determined. A few rounded sandstone and siltstone pebbles form part of the tuffs at Brooklyn and Enterprise Islands, and several of the tuffs are intruded by pink granite (O.942.1 and 983.1).

6. *Crystal tuffs*

In a brownish pink acid crystal tuff from eastern Bryde Island (O.937.5–7; Plate Vc) welded shards and pumice fragments are still visible in the potash feldspar-rich cryptocrystalline groundmass. The angular crystals of quartz, plagioclase and potash feldspar, together with penninite/sphene pseudomorphs, reach 1·5 mm. across. There are also a few strongly pleochroic brown allanite crystals, usually irregularly rimmed by epidote, and one or two sedimentary rock fragments.

Contact-metamorphosed crystal tuffs (O.975.1; Plate Vd) exposed on the eastern side of Charlotte Bay contain rounded granite xenoliths which are also contact-metamorphosed; many of the composite crystal fragments in these tuffs are derived from this granite source.

7. *Vitric tuffs*

In grey siliceous vitric tuffs at Mount Banck (O.938.10), the slightly bedded cryptocrystalline matrix contains devitrified shards, crystals of plagioclase, quartz and potash feldspar, and a few rounded granite fragments. Similar rocks are exposed to the south-east of Miethe Glacier (O.941.5) and on the western shore of Charlotte Bay (O.972.1).

C. Alteration

It is clear from their petrography that many of the volcanic rocks are to some extent altered. In some, the only change is the devitrification of the groundmass glass to chlorite but other rocks are completely spilitized (as defined by Cann (1969)).

1. *Phases of alteration*

From a study of the veins and amygdales, at least two phases of alteration have been recognized.

a. *Veins.* Four chronologically distinct vein types in the volcanic rocks have formed in the following order:

ia. Quartz (±chlorite).
b. Chlorite (±quartz).
iia. Epidote (±quartz±chlorite).
b. Prehnite (±quartz).
iii. Albite.
iv. Calcite.

Small quartz, quartz–chlorite or chlorite veins are the oldest group, since they are cut or replaced by all of the other vein types. Prehnite and epidote veins are contemporaneous, both of them showing identical relationships with other veins. The common and often large epidote veins cut and partially replace quartz–chlorite veins (O.528 and 990); epidote–chlorite–quartz veins therefore could be primary, or they could have resulted from the epidotization of former quartz–chlorite veins. Although albite veins are small and uncommon, they occur at many localities (O.511, 517, 556 and 913). The albite is often patchily altered to calcite, particularly at the junctions with the younger calcium-rich epidote (O.556) or prehnite (O.517) veins. Unlike these, the albite veins are rarely sheared. Abundant at rock exposures on Rongé Island (O.517 and 545), calcite veins cut across all of the other veins types but they are never cut themselves. They are therefore assumed to be the youngest.

b. *Amygdales.* The amygdaloidal minerals show a similar crystallization sequence to that of the vein minerals, quartz and chlorite having formed before epidote, prehnite and calcite.

There are several amygdaloidal mineral associations in the epidotized and prehnitized lavas at southern Bryde Island (O.932.1–4 and 937.4):

i. Chlorite (±quartz).
ii. Epidote+chlorite+quartz.
iii. Epidote (±quartz).
iv. Prehnite+chlorite (±quartz).
v. Prehnite.

However, a compositionally similar lava from the same locality contains little epidote or prehnite, either as mineral alteration or in the amygdales. The amygdales are formed of quartz and chlorite only, although they are cut by rare prehnite veinlets. It is evident that the prehnitization (and probably the epidotization) occurred after the vesicles had been filled by quartz and chlorite. A similar relationship is seen at Coughtrey Peninsula (O.990) where chlorite (+quartz) amygdales are partially replaced by vein epidote.

It is apparent that the volcanic rocks have been affected by at least two phases of alteration. The first, which has resulted particularly in the chloritization of some of the mafic minerals, is often obscured by the later crystallization of epidote, prehnite, albite and associated minerals. The later alteration is often severe, although it is usually restricted to localized patches in the lavas; the pyroclastic rocks have been more evenly and extensively altered. The isolated occurrences of pumpellyite (O.958 and 985) and hydrogarnet (O.925 and 958) formed at this stage.

The subsequent albite veining does not appear to have been accompanied by any major mineralogical changes within the rocks themselves. Calcite veins, however, are often associated with the significant calcification of the constituent minerals and have formed during an episode of shearing.

2. *Alteration environment*

Secondary minerals such as epidote, prehnite, chlorite, sphene, calcite and quartz can develop in many environments provided that the temperatures and water contents are high enough. The co-existence of prehnite and pumpellyite in the tuffs and lavas at Breakwater Island is indicative of prehnite–pumpellyite-facies metamorphism at temperatures between 250° and 380° C at 3 kbar pressure (Liou, 1971). At other localities, the occurrence of epidote and prehnite in the volcanic rocks, or of epidote-bearing lavas adjacent to prehnite-bearing lavas, suggests that these rocks may have been heated to temperatures up to 410° C (Strens, 1965; Liou, 1971).

Because of their greater porosity, pyroclastic rocks are less susceptible to autometasomatism than lavas; the volcanic fluids will be less abundant in them and will escape more easily. On the other hand, fluid phases from an external source (e.g. from underlying plutonic rocks) are more likely to affect the pyroclastic rocks than the less permeable lavas. On the Danco Coast, the tuffs are extensively altered but the lavas are only patchily altered. Since the greatest changes occur in volcanic rocks which are adjacent to the widespread intrusive granophyres, it is likely that these plutonic rocks were responsible for much of the secondary mineral formation in the volcanic sequence. Possibly, burial metamorphism has caused the earlier crystallization of chlorite and quartz.

D. Chemistry

1. *Classification*

18 lavas have been chemically analysed (Table IX) in the knowledge that only limited interpretations can be made from randomly collected and altered rock specimens. The analyses have been corrected for the iron oxidation which may have occurred during the alteration processes (Irvine and Baragar, 1971) and they have also been recalculated on a water-free basis.

A weight per cent diagram of alkalis against silica (Fig. 13) shows that the majority of the Danco Coast lavas fall well within the sub-alkaline field. Those occurring in the alkaline section of the diagram (O.932.2 and 937.7) and near the alkaline/sub-alkaline boundary (O.515.3, 932.1 and 4) are extensively altered, in contrast to the other rocks. Their high alkali contents are considered to be the result of some secondary influx of sodium and/or potassium. The sub-alkaline character of these lavas substantiates the view reached on petrographical grounds that the Danco Coast volcanic rocks form part of the Upper Jurassic Volcanic Group, which has been described as belonging to the continental branch of the calc-alkaline suite (Adie, 1964; Baker, 1971) and, together with the subsequent plutonic rocks, constitutes the characteristic assemblage of an orogenic belt.

One of the most prominent differences between calc-alkaline and tholeiitic rocks is the high alumina content (16–20 per cent) in the more basic members of the calc-alkaine suite. From the analyses in Table IX it can be seen that the majority of the alumina values in the Danco Coast lavas are not particularly high. Andesites analysed from other localities on the western side of the Antarctic Peninsula (Dewar, 1970) are similar in this respect. Since the alumina contents are similar in both the altered and unaltered lavas of the Danco Coast, it is considered unlikely that there has been any significant loss of alumina due to secondary alteration processes. When plotted on an A–F–M diagram (Fig. 14), most of the lavas lie close to the boundary line separating the tholeiitic and calc-alkaline fields, only some of the more altered

TABLE IX

CHEMICAL ANALYSES OF SOME LAVAS FROM THE DANCO COAST AND OF TWO BASALTS FROM JASON PENINSULA, OSCAR II COAST

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
SiO_2	48·57	45·52	49·37	50·27	53·20	54·75	53·65	53·26	55·33	60·27	65·88	65·62	66·55	67·99	67·37	68·33	71·10	65·89	48·69	50·77
TiO_2	0·72	1·01	1·35	1·19	1·59	1·11	1·17	1·23	0·70	1·07	0·58	0·62	0·42	0·55	0·37	0·30	0·36	0·03	0·88	0·87
Al_2O_3	14·90	17·30	14·69	14·81	14·79	15·90	14·86	14·01	15·97	14·76	15·51	14·46	15·28	14·22	14·68	14·81	14·02	17·77	16·72	18·10
Fe_2O_3	3·51	5·52	6·43	5·63	5·40	6·08	4·78	4·78	4·96	3·53	3·38	2·57	2·12	2·13	2·13	1·69	2·12	1·25	9·99†	8·73†
FeO	5·29	3·77	8·13	2·81	5·69	2·01	3·30	3·31	3·05	3·49	0·82	1·57	1·94	1·76	0·96	1·21	1·19	0·65	*	*
MnO	0·14	0·15	0·21	0·19	0·15	0·23	0·19	0·19	0·21	0·15	0·08	0·09	0·08	0·08	0·06	0·12	0·10	0·05	0·16	0·12
MgO	10·28	5·58	5·36	5·61	3·32	4·19	4·66	4·87	2·83	2·60	1·06	1·23	1·17	0·94	0·91	0·52	0·46	0·47	*	*
CaO	12·23	12·63	8·30	9·76	8·53	6·57	5·25	4·32	5·17	4·02	3·15	2·86	2·79	1·94	2·12	1·58	1·33	1·14	10·14	10·74
Na_2O	1·71	2·03	2·22	4·16	2·76	4·02	4·52	4·45	4·32	4·09	4·33	4·49	5·38	5·20	5·11	3·97	4·58	7·39	*	*
K_2O	0·33	0·11	0·47	0·28	1·13	0·25	2·32	1·73	1·70	1·77	3·03	2·91	2·33	2·14	3·52	4·09	3·63	2·77	0·96	0·79
H_2O+	1·05	2·82	1·79	3·90	2·14	3·76	3·93	3·93	3·00	2·07	0·28	1·97	1·51	1·98	1·54	1·46	0·14	1·88	*	*
H_2O-	0·21	0·29	—	0·59	0·29	0·20	0·60	0·38	0·50	—	—	0·29	—	0·19	0·17	0·40	—	0·05	*	*
P_2O_5	0·07	0·13	0·08	0·18	0·26	0·16	0·18	0·17	0·47	0·36	0·19	0·13	0·10	0·12	0·12	0·07	0·05	0·01	0·63	0·50
CO_2	0·08	2·58	1·13	0·96	0·10	0·96	0·64	2·95	1·49	1·12	0·83	0·96	0·07	0·35	0·14	0·96	0·14	0·19	*	*
TOTAL	99·09	99·44	99·53	100·34	99·35	100·19	100·05	99·58	99·70	99·30	99·12	99·77	99·74	99·59	99·20	99·51	99·22	99·54	*	*
ANALYSES WITH AMENDED FeO VALUES (IRVINE AND BARAGAR, 1971) AND LESS TOTAL WATER AND CARBON DIOXIDE, RECALCULATED TO 100																				
SiO_2	50·14	50·33	51·96	53·54	55·68	58·08	57·08	58·25	58·59	62·76	67·31	68·01	68·23	70·04	69·23	70·67	71·88	67·63	*	*
TiO_2	0·74	1·12	1·42	1·27	1·66	1·18	1·24	1·35	0·74	1·11	0·59	0·64	0·43	0·57	0·38	0·31	0·36	0·03	*	*
Al_2O_3	15·38	19·13	15·46	15·77	15·48	16·87	15·81	15·32	16·91	15·37	15·85	14·99	15·67	14·65	15·08	15·32	14·17	18·24	*	*
Fe_2O_3	2·29	2·78	3·00	2·87	3·23	2·77	2·84	2·99	2·33	2·78	2·13	2·20	1·97	2·11	1·92	1·75	1·88	1·28	*	*
FeO	5·87	7·16	10·64	5·06	7·04	4·74	4·81	4·89	5·87	4·45	2·03	2·03	1·56	1·90	1·22	1·25	1·44	0·67	*	*
MnO	0·14	0·17	0·22	0·20	0·16	0·24	0·20	0·21	0·22	0·16	0·08	0·09	0·08	0·08	0·06	0·12	0·10	0·05	*	*
MgO	10·61	6·17	5·64	5·98	3·47	4·45	4·96	5·33	3·00	2·71	1·08	1·27	1·20	0·97	0·94	0·54	0·47	0·48	*	*
CaO	12·63	10·65	8·74	10·40	8·93	6·97	5·59	4·72	5·47	4·19	3·22	2·96	2·86	2·00	2·18	1·63	1·34	1·17	*	*
Na_2O	1·77	2·24	2·34	4·43	2·89	4·26	4·81	4·87	4·57	4·26	4·42	4·65	5·52	5·36	5·25	4·11	4·63	7·59	*	*
K_2O	0·34	0·12	0·49	0·30	1·18	0·27	2·47	1·89	1·80	1·84	3·10	3·02	2·39	2·20	3·62	4·23	3·67	2·84	*	*
P_2O_5	0·07	0·14	0·08	0·19	0·27	0·17	0·19	0·19	0·50	0·37	0·19	0·13	0·10	0·12	0·12	0·07	0·05	0·01	*	*
ELEMENT PERCENTAGES LESS TOTAL WATER AND CARBON DIOXIDE																				
Si^{4+}	23·44	23·53	24·29	25·03	26·03	27·15	26·69	27·23	27·39	29·34	31·47	31·79	31·90	32·74	32·36	33·04	33·61	31·62	*	*
Ti^{4+}	0·45	0·67	0·85	0·76	1·00	0·71	0·75	0·81	0·44	0·67	0·36	0·39	0·26	0·34	0·23	0·19	0·22	0·02	*	*
Al^{3+}	8·14	10·12	8·18	8·35	8·19	8·93	8·37	8·11	8·95	8·13	8·39	7·93	8·29	7·75	7·98	8·11	7·50	9·65	*	*
Fe^{3+}	1·60	1·94	2·10	2·00	2·26	1·94	1·99	2·09	1·63	1·94	1·49	1·54	1·38	1·48	1·34	1·22	1·32	0·90	*	*
Fe^{2+}	4·57	5·57	8·27	3·93	5·47	3·69	3·74	3·80	4·56	3·46	1·58	1·58	1·21	1·47	0·95	0·97	1·12	0·52	*	*
Mn^{2+}	0·11	0·13	0·17	0·16	0·12	0·19	0·16	0·16	0·17	0·12	0·06	0·07	0·06	0·06	0·05	0·10	0·08	0·04	*	*
Mg^{2+}	6·40	3·72	3·40	3·60	2·10	2·68	2·99	3·21	1·81	1·63	0·65	0·77	0·72	0·58	0·56	0·32	0·28	0·29	*	*
Ca^{2+}	9·02	7·61	6·24	7·43	6·38	4·98	3·99	3·38	3·91	2·99	2·30	2·12	2·04	1·43	1·56	1·17	0·96	0·84	*	*
Na^{+}	1·31	1·67	1·73	3·29	2·14	3·16	3·57	3·61	3·39	3·16	3·28	3·45	4·09	3·97	3·90	3·05	3·44	5·63	*	*
K^{+}	0·28	0·10	0·41	0·25	0·98	0·22	2·05	1·57	1·49	1·53	2·57	2·50	1·98	1·83	3·00	3·51	3·05	2·36	*	*
P^{5+}	0·03	0·06	0·04	0·08	0·12	0·07	0·08	0·08	0·22	0·16	0·08	0·06	0·04	0·05	0·05	0·03	0·02	—	*	*
O^{2-}	44·64	44·88	44·31	45·12	45·20	46·28	45·64	45·95	46·03	46·86	47·77	47·80	48·02	48·28	48·01	48·30	48·42	48·13	*	*
NORMS																				
Q	—	6·80	9·91	3·38	12·65	13·88	4·09	13·20	13·99	20·96	23·85	23·99	19·31	25·63	19·96	28·67	27·80	9·86	*	*
C	—	—	—	—	—	—	—	4·41	2·29	2·33	1·78	1·29	—	0·95	—	3·45	0·59	1·03	*	*
or	1·99	0·67	2·84	1·73	6·89	1·53	14·35	10·73	10·44	10·75	18·11	17·63	14·02	12·98	21·33	24·75	21·65	16·77	*	*
ab	14·79	17·83	19·22	36·72	24·09	35·34	40·03	39·52	37·98	35·58	37·06	38·96	46·34	45·16	44·35	34·40	39·11	64·06	*	*
an	32·71	39·20	29·39	21·81	25·41	25·56	14·03	1·76	13·67	10·81	9·24	7·46	10·85	6·80	6·90	1·34	5·44	4·50	*	*
di	22·52	6·29	3·98	16·45	12·78	0·71	6·07	—	—	—	—	—	1·71	—	1·70	—	—	—	*	*
hy	19·90	12·49	19·68	6·94	6·12	10·51	9·87	13·20	8·09	8·72	2·67	3·14	3·43	3·13	1·54	1·89	1·18	1·41	*	*
ol	1·13	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	*	*
mt	5·20	8·31	9·54	6·50	8·08	4·17	7·25	7·27	7·47	5·26	1·24	3·65	3·13	3·17	2·27	2·51	3·10	1·86	*	*
il	1·40	1·99	2·62	2·36	3·12	2·19	2·33	2·45	1·38	2·09	1·11	1·21	0·81	1·07	0·72	0·58	0·69	0·06	*	*
ap	0·17	0·32	0·19	0·44	0·63	0·39	0·45	0·42	1·16	0·88	0·45	0·32	0·24	0·29	0·29	0·17	0·12	0·02	*	*
cc	0·19	6·09	2·63	2·28	0·23	2·27	1·52	7·04	3·52	2·62	1·91	2·24	0·16	0·82	0·33	2·24	0·32	0·44	*	*
COORDINATES OF TRIANGULAR DIAGRAMS																				
A	11·20	13·60	13·50	27·00	24·10	29·00	39·20	36·30	37·90	40·00	61·10	60·50	64·70	62·20	70·70	72·20	70·50	82·40	*	*
F	43·60	57·80	65·10	45·40	59·70	48·10	39·90	41·20	48·00	46·10	32·00	31·70	27·60	31·60	23·50	24·20	26·40	14·60	*	*
M	45·20	28·60	21·40	27·60	16·20	22·90	20·90	22·50	14·00	13·90	6·80	7·80	7·70	6·30	5·80	3·60	3·10	3·00	*	*
TRACE ELEMENTS																				
S	45	101	124	171	120	33	75	87	63	49	48	138	51	1253	57	260	293	15	171	286
Cr	231	85	28	34	18	38	39	37	5	15	10	14	12	8	5	7	8	7	87	115
Ni	68	22	7	16	5	10	12	11	—	3	—	—	2	1	1	—	—	—	39	40
Cu	174	127	92	*	107	90	94	101	67	208	41	63	60	86	28	45	7	49	*	*
Zn	70	84	100	*	92	94	80	82	82	121	53	73	74	59	63	70	82	50	*	*
Rb	7	—	8	8	34	9	92	62	60	74	127	135	94	92	149	168	147	139	21	17
Sr	492	670	338	285	460	270	375	352	673	373	328	295	327	233	397	183	170	164	566	584
Y	9	12	15	25	18	28	27	28	24	33	27	32	29	32	27	16	33	36	10	12
Zr	63	82	57	207	180	246	256	258	201	333	177	424	407	396	361	258	455	256	101	109
Nb	3	—	3	8	9	12	11	11	7	15	16	16	16	16	16	14	16	29	*	*
Ba	142	116	223	125	479	133	398	397	407	510	569	591	648	574	733	731	730	563	378	388
La	4	4	—	19	22	24	24	25	13	27	27	27	24	32	28	43	40	49	11	12
Ce	4	23	—	52	42	53	57	52	33	56	48	61	53	54	56	67	72	98	33	29
Pb	10	6	8	27	12	19	20	18	8	212	17	28	21	18	38	50	27	28	11	15
Th	3	3	4	11	5	11	10	11	3	6	15	15	25	12	21	14	15	37	—	3
Ga	13	17	15	*	15	19	19	18	14	15	15	15	16	14	14	13	17	19	*	*
D.I.	16·99	22·83	28·11	39·24	42·29	48·18	56·55	57·10	62·45	64·11	77·06	78·86	80·42	82·97	85·53	85·98	88·04	90·33	*	*

* Not determined.
† Total iron as Fe_2O_3.

1. O.527.2 Basalt; north-eastern Rongé Island.
2. O.914.1 Basalt; Orne Islands.
3. O.985.1 Basalt; Breakwater Island.
4. O.932.4 Andesite; south-eastern Bryde Island.
5. O.990.2 Andesite; Coughtrey Peninsula.
6. O.932.1 Andesite; south-eastern Bryde Island.
7. O.932.2 Andesite; south-eastern Bryde Island.
8. O.932.3 Andesite; south-eastern Bryde Island.
9. O.515.3 Altered (?) andesite; eastern Rongé Island.
10. O.1001.4 Dacite; Beneden Head.
11. O.939.1 Rhyodacite; south of Paradise Harbour.
12. O.528.3 Rhyodacite; Beneden Head.
13. O.942.2 Rhyodacite; north-eastern Lemaire Island.
14. O.903.3 Quartz-latite; Beneden Head.
15. O.952.2 Quartz-latite; southern Bryde Island.
16. O.937.1 Quartz-latite; north-eastern Bryde Island.
17. O.993.1 Quartz-latite; south of Paradise Harbour.
18. O.937.7 Spherulitic rhyolite; eastern Bryde Island.
19. D.2134.1 Basalt; northern Jason Peninsula, Oscar II Coast.
20. D.2136.1 Basalt; northern Jason Peninsula, Oscar II Coast.

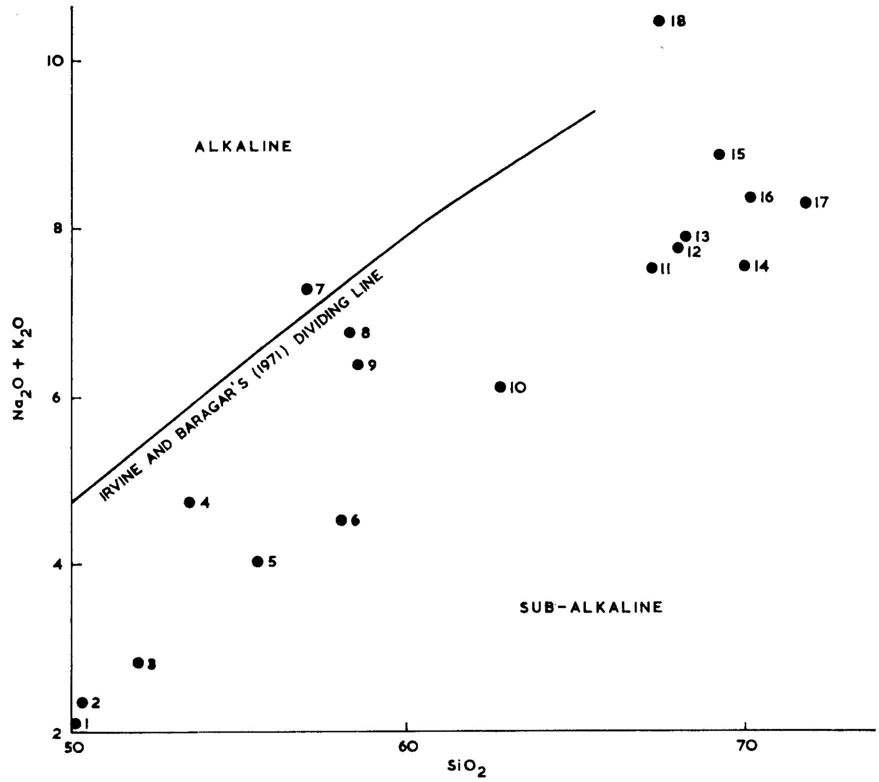

FIGURE 13

A plot of total alkalis against silica for the analysed lavas from the Danco Coast.

1. O.527.2.	7. O.932.2.	13. O.942.2.
2. O.914.1.	8. O.932.3.	14. O.903.3.
3. O.985.1.	9. O.515.3.	15. O.952.2.
4. O.932.4.	10. O.1001.4.	16. O.937.1.
5. O.990.2.	11. O.939.1.	17. O.993.1.
6. O.932.1.	12. O.528.3.	18. O.937.7.

volcanic rocks falling within the calc-alkaline zone. Similarly, most of the more basic lavas plot in the pigeonitic or tholeiitic part of Fig. 13 (Kuno, 1969). The trace-element abundances of the lavas are those typical of calc-alkaline rocks, although sometimes the rubidium, zirconium and barium concentrations of the more basic rocks are closer to the values commonly found in island arc tholeiites (Condie and others, 1969; Gill, 1970). The barium, lanthanum, cerium, lead and thorium contents in the Danco Coast andesites are particularly high in comparison with Taylor's (1969) average andesite. Since these elements are also abundant in two lavas (Table IX) from Jason Peninsula, eastern Graham Land, this may be a characteristic feature of the Upper Jurassic Volcanic Group rocks as a whole.

It therefore seems that, although the intermediate and acidic lavas of the Danco Coast are predominantly of a calc-alkaline type, many of the more basic eruptive rocks here resemble island arc tholeiites. However, the two analysed basalts from Jason Peninsula contain the high alumina and potash (and associated barium and strontium) typically found in calc-alkaline orogenic belts; rhyolitic rocks are also more extensive along this coastline. In a discussion on plate tectonics, Dickinson (1971) has shown that the potash content of extrusive rocks increases in a direction away from the trench and towards the continent (if present). Hence, it is possible that during Jurassic times the trench was situated off the western coast of the present-day Antarctic Peninsula, although further analyses of volcanic rocks from both sides of the Antarctic Peninsula are necessary to confirm this. Perhaps the Tertiary alkaline lavas of the James Ross Island group are a continuation of this easterly alkaline trend.

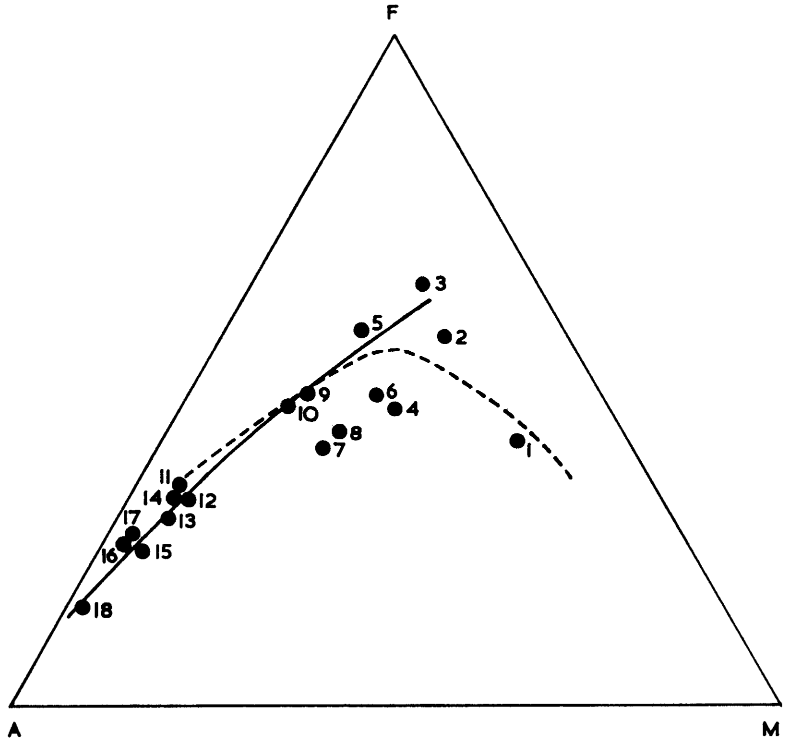

FIGURE 14

Triangular A–F–M diagram for the Danco Coast lavas. The dashed line divides the tholeiitic rocks (above) from the calc-alkaline rocks (below). The solid line is the trend determined by Adie (1955) for some of the Upper Jurassic Volcanic Group rocks from Graham Land. The lavas are numbered as in Fig. 13.

2. *Metasomatism*

Many of the more altered lavas (Table IX, O.515.3, 932.1–4 and 937.7) contain high percentages of total alkalis, largely due to elevated soda values. It is considered that these rocks have been soda-metasomatized. The spherulitic lava (O.937.7) from eastern Bryde Island contains about 7 per cent of soda but it differs from normal alkalic rocks in containing about 10 per cent of normative quartz and no normative nepheline. The unusually high amounts of lanthanum, cerium, thorium and niobium in this rock compared with the other lavas could have been derived from soda-bearing granitic emanations (e.g. from the younger granophyres which are exposed to the north), since these elements are commonly concentrated in late-stage magmatic fluids.

The variable potash contents of many of the volcanic rocks are apparently directly related to the rock texture, being noticeably higher in lavas with an originally vitric groundmass (Table IX, O.528.3, 932.2, 937.1, 939.1, 952.2 and 993.1). In discussing the petrology of some keratophyres, Battey (1955) also found that the glassy lavas were more susceptible to potash metasomatism than their coarser-grained equivalents. Besides the chemical evidence, a secondary origin for much of the potash is suggested by the high concentrations of potash feldspar in some of the lavas, together with its virtual absence in otherwise petrographically identical rocks; in several of the rock specimens the potash feldspar occurs only in veins and amygdales, although it has sometimes formed in the adjacent rock over a few millimetres.

V. POST-VOLCANIC PLUTONIC ROCKS

POST-VOLCANIC plutonic rocks form a considerable proportion of the rocks exposed on the Danco Coast. They include gabbros, diorites, tonalites, granodiorites and granophyres,* but it is the acidic rocks which are volumetrically the most important.

* The term "granophyre" is generally to be avoided in rock nomenclature since it implies a texture rather than a specific rock composition. However, on the Danco Coast it has proved useful in distinguishing between a group of late acid plutonic rocks (granophyres) and an earlier group of granodiorites, adamellites and granites. The former are characterized by a quartz–orthoclase intergrowth which often constitutes more than half the volume of these rocks; in the older rocks this intergrowth is often absent or is developed only on a small scale by post-magmatic processes.

The term Andean Intrusive Suite was originally introduced by Adie (1955) to describe the late Cretaceous to early Tertiary plutonic rocks in the Antarctic Peninsula. In the succeeding literature this name has been applied almost wholly to any plutonic rock group younger than the Upper Jurassic Volcanic Group, although more recently the term has been restricted to the two youngest phases (iv) and (v) (p. 14) (British Antarctic Survey Annual Report, 1969; Rex, 1971). Since the exact age of most of the plutonic rocks on the Danco Coast is unknown, the term Andean Intrusive Suite is not used in this report.

A. Field Relations and Petrography

1. *Gabbros*

The relative ages of the gabbros and rocks of the Upper Jurassic Volcanic Group are in some doubt because of the lack of observable contacts between the two groups. From the field evidence given in the following descriptions, the gabbros are all tentatively believed to post-date these volcanic rocks. There is, however, no doubt about the younger age of the gabbros relative to the early acid plutonic rocks, and the older age of the gabbros relative to the granophyres and microgranites.

The composition of the gabbros is only moderately basic; olivine is often present but it never forms more than about 2 per cent of the total mineral content.

a. *Bruce and Bryde Islands.* The largest gabbro outcrop discovered on the Danco Coast encompasses Bruce Island, the western half of Bryde Island and a small island lying to the north of Bryde Island. The southernmost extension of this gabbroic pluton is probably represented by the quartz-diorites exposed at south-western Mount Banck (O.938.1–5). These rocks intrude pre-volcanic granites and adamellites, and there is a similar relationship in central Bryde Island (O.950) where the gabbros clearly intrude sheared granitic rocks. The age relationships between the gabbros and volcanic rocks are not so apparent. Hobbs has described the occurrence of "basic plutonic segregations" in the tuffs and lavas at north-western Bryde Island; these volcanic rocks are cut by a microgabbro dyke 10 m. in thickness which could also be associated with the gabbro intrusion. Along the southern side of the island, Hobbs has mentioned that the gabbros contain numerous randomly orientated xenoliths of a volcanic appearance.

Petrography. In thin section, the gabbros (cf. Table X, O.546.2; Plate Ve) contain randomly orientated plagioclase crystals which are subhedral, unzoned and have a composition of about An_{58}. These are surrounded by interstitial or ophitic orthopyroxenes and clinopyroxenes up to 16 mm. across. Salite and diallage structures are well developed in the pale straw-coloured augite ($2V\gamma \sim 60°$; $\gamma : c = 45°$) and the liberation of minute specks of iron ore represents the initial stage of augite alteration; there is further alteration to a pale green micaceous mineral. Hypersthene is more severely altered to actinolitic hornblende, biotite and a fine-grained micaceous aggregate. The orthopyroxene often surrounds granular aggregates of bottle-green spinel and iron ore. Interstitial to euhedral ilmenite is surrounded by dark red-brown biotite. Small amounts of secondary quartz and potash feldspar, often sub-graphically intergrown, marginally replace the plagioclase, and some prehnite is also present in these areas.

The extensive uralitization of some of the gabbros (Table X, O.933.1; O.934.6) has converted much of the pyroxene, heavily dusted with iron ore, to flaky tremolite-actinolite, hornblende and chlorite (Plate Vf). No olivine remains although the plagioclase crystals are often unaltered.

b. *Northern Leith Cove to Waterboat Point.* The exposures of gabbroic rocks between the northern shore of Leith Cove and station O.998 to the north have been established as post-volcanic in age because the gabbros at Hanka Island contain numerous lava xenoliths and their hornfelsed equivalents.

Most of these gabbros are considerably altered. At station O.987, sericitization of the plagioclase, uralitization of the mafic minerals and the introduction of quartz and potash feldspar are common in the gabbros near several large aplite veins. A greater modification of the basic rocks is found near the contacts with some of the younger intrusive granophyres. Although clearly gabbroic in the field, in thin section it can be seen that there is an almost complete obliteration of the gabbroic texture and mineralogy in contact specimens. These rocks now consist of chlorite, leucoxene, albite, epidote, allanite, haematite, calcite and abundant apatite, and they are pervaded by coarsely intergrown quartz and potash feldspar. Aggregates of tourmaline crystals (dichroic between dark inky blue and pink) have also been introduced from the acid intrusion.

TABLE X

MODAL ANALYSES OF POST-VOLCANIC PLUTONIC ROCKS FROM THE DANCO COAST

	O.546.2	O.933.1	O.912.2	O.938.3	O.520.1	O.540.1	O.996.1	O.999.3	O.559.1	O.909.1	O.942.6
Quartz	0·5	—	0·9	5·6	24·2	14·6	30·6	23·0	23·3	30·3	33·9
Potash feldspar	—	—	—	—	1·4	2·0	22·5	23·2	26·9	39·3	36·7
Plagioclase	69·1	87·6	62·5	58·1	49·7	57·0	36·6	43·5	40·8	25·9	28·5
Olivine	1·6	tr	—	—	—	—	—	—	—	—	—
Hypersthene	3·9	tr	6·1	—	—	—	—	—	—	—	—
Augite	22·1	tr	4·1	tr	—	tr	—	—	1·9	—	—
Hornblende	—	—	19·6	17·8	12·7	14·5	8·5	7·7	0·2	—	tr
Tremolite-actinolite	—	11·0	—	—	8·0	tr	—	tr	0·8	—	—
Biotite	0·3	0·3	2·8	15·7	—	3·4	0·6	—	0·2	tr	—
Chlorite	—	tr	—	—	—	0·6	—	—	2·4	1·3	tr
Iron ore	2·3	0·3	4·0	2·8	3·7	6·7	1·2	2·5	2·6	1·8	0·9
Epidote	—	—	—	—	0·3	—	—	0·1	0·7	1·4	—
Apatite	0·2	—	tr	tr	—	1·2	—	tr	0·2	tr	—
Spinel	—	0·8	—	—	—	—	—	—	—	—	—
Accessory minerals*	—	tr	—	—	tr	tr	—	tr	tr	tr	tr
Plagioclase composition	An_{58}	An_{59}	An_{38-47}	An_{36-58}	An_{32-54}	An_{33-44}	An_{12-35}	An_{14-28}	An_{14-26}	An_{10}	An_{6}

tr Trace.
* Includes allanite, sphene, zircon, leucoxene and iron pyrites.

O.546.2 Gabbro; western Rongé Island.
O.933.1 Uralitized gabbro; northern Bruce Island.
O.912.2 Diorite; Duthiers Point.
O.938.3 Quartz-diorite; western Mount Banck.
O.520.1 Tonalite; northern Rongé Island.
O.540.1 Tonalite; about 2·5 km. south of Porro Bluff.
O.996.1 Granodiorite; northern Leith Cove.
O.999.3 Granophyric granodiorite; eastern Rongé Island.
O.559.1 Granophyric adamellite; mainland east of Cuverville Island.
O.909.1 Granophyric adamellite; north-eastern Andvord Bay.
O.942.6 Granophyric granite; eastern Lemaire Island.

c. *Western Rongé Island.* Gabbros, which are mineralogically identical to those exposed at Bruce Island, form a conspicuous promontory at western Rongé Island (O.546). There are no contacts with the volcanic rocks at this locality but at station O.547 to the south the mafic minerals in the lavas are replaced by a green, strongly pleochroic hornblende. It is conceivable that there is some connection between the formation of this secondary mineral and the emplacement of the gabbros. However, no hornfelsic texture or any mineral more typically ascribed to contact metamorphism has been discovered in the lavas. The gabbros invade pre-volcanic sheared granitic rocks at the centre of this island (O.550), intricately veining them along pre-existing joints.

d. *Charlotte Bay.* The gabbros at many localities bordering Charlotte Bay show the same intrusive relationship with the early sheared granites as are found elsewhere along the Danco Coast. This is apparent at Andrée Island in Recess Cove where the sheared granites are cut both by gabbros and by an acid sheet filled with gabbro inclusions. The granitic matrix of this sheet is petrographically distinct from the sheared granite country rock; it is finer-grained, none of the felsic minerals are strained and the biotite is rarely chloritized. Farther north, at station O.975, large quantities of gabbro have been incorporated in a similar granitic host rock. Here the gabbro masses are rounded and usually have chilled margins against the surrounding granite (Plate IIId). The extreme irregularity of some of the gabbro masses suggests that they were in a plastic or even liquid state at the time of their engulfment by the acid magma. It is possible that the gabbro intrusions have re-mobilized parts of the sheared granites with the subsequent mixing of the basic and newly formed acid magmas. The gabbro would have been chilled against the granite because of the temperature difference between the two melts. A characteristic feature of similar intrusions described in the literature (Walker and Skelhorn, 1966) is that the basic pillows are often cut by a network of straight-sided acid veins which connect with the surrounding granite. A few such veins are visible in Plate IIId.

2. *Diorites and quartz-diorites*

Bayly and Hobbs located exposures of dioritic rocks at Mount Banck and Duthiers Point. In thin section, two of these rocks show primary flow layering (O.912.1 and 938.3), although macroscopic layering was not observed in the field. Dated by K-Ar methods (Scott, 1965), the diorites at Duthiers Point yielded an age of 94 ± 8 m. yr., and they are therefore considerably younger than the rocks of the Upper Jurassic Volcanic Group.

There is field evidence at both of these localities that a gabbroic magma has intruded granites or acid lavas. In the quartz-diorites at Mount Banck partially digested xenocrysts of quartz and albite from the nearby granite mass indicate that a basic magma has assimilated significant quantities of the granitic country rocks. It is thus possible that the dioritic and quartz-dioritic compositions of these rocks have arisen primarily by the contamination of a basic magma with acidic material rather than by the fractional crystallization of a gabbro.

Petrography. Apart from their finer grain-size and the occurrence of minor interstitial quartz and a less basic plagioclase (mostly An_{36-41}), the dioritic rocks (Table X) closely resemble the gabbros at Bruce and Rongé Islands. In most of the rock specimens there are several mafic phases (hypersthene, augite, hornblende, biotite and iron ore) which are not in equilibrium with one another. Normal and patchy zoning are particularly noticeable in the plagioclase crystals, parts of which are as basic as An_{58} (i.e. the plagioclase composition usually encountered in the gabbros). At Mount Banck, hornblende and biotite are of equal importance and pyroxene is often absent. Since no potash feldspar xenocrysts from the included granite were observed in thin section, it seems that this mineral was quickly digested by the basic magma. This would have resulted in the addition of potassium to the system, which might have favoured the crystallization of biotite whilst suppressing that of pyroxene.

3. *Tonalites*

Rocks of tonalitic compositions are of minor importance on the Danco Coast but those discovered can be divided into two texturally and mineralogically contrasting groups.

a. *Northern Rongé Island.* Exposures of tonalites at northern Rongé Island (O.520 and 521) are flanked to the north by microgranites (O.522) and sheared pre-volcanic granites (O.523), to the south-east by volcanic rocks and to the south-west by gabbros. Although there are no visible contacts between the rock groups, the xenolithic content of the tonalites, which is considerable, suggests that these plutonic rocks are younger than both the gabbros and the lavas. At Bryde Island (O.945), a similar tonalite occurs as thin sheets in the gabbroic country rocks.

Petrography. In thin section (Table X), these rocks contain subhedral to anhedral plagioclase crystals, many of which are gabbro xenocrysts. The patchy zoning in the plagioclase reflects a variation in composition between An_{32} and An_{54}. Some of the smaller and more albitic idiomorphic crystals could have had a primary origin. The abundant and usually interstitial quartz sometimes shows an incipient intergrowth with small amounts of potash feldspar. Apart from iron ore, hornblende is the dominant mafic mineral in these rocks. Partially digested inclusions of plagioclase in the hornblende point towards the later formation of this mafic mineral.

b. *South of Porro Bluff.* The second group of tonalitic rocks differs from the first in a number of respects; these rocks, which are distinctly inequigranular (Plate VIa), contain a greater variety of often aggregated mafic minerals. Apatite (Plate VIb) is a particularly conspicuous accessory mineral, whilst it is almost absent from the other tonalite group.

The largest exposure of these tonalites (O.538–540) is situated about 1·5 km. south of Porro Bluff. At its northern end, that is, nearest to the gabbros at station O.537, the tonalites have a colour index greater than 90 (Shand, 1947), the small amounts of felsic material usually forming localized segregations. Farther to the south-east (O.540) the tonalites contain about equal quantities of light and dark minerals; fine-grained xenoliths are more abundant here and they were possibly derived from the large volcanic mass which extends eastward to Beneden Head. Similar tonalites were also collected from Useful Island, Cuverville Island, Birdsend Bluff (O.566) and from station O.552 to the north-east of Sable Pinnacles.

Petrography. These rocks (Table X) are predominantly composed of tabloid plagioclase crystals with crenulate margins, many of which show well-developed secondary twinning and patchy zoning. Zoned normally from An_{44} to An_{33}, the more calcic plagioclase crystals are usually absent from the rocks collected towards the south-eastern end of the outcrop. This plagioclase is surrounded and partially replaced by a later anhedral plagioclase of a more sodic composition. Varying amounts of rounded to lobate quartz occur interstitially and sometimes it is partially enveloped by turbid potash feldspar. In one case (O.552.1) the percentage of potash feldspar present is sufficient for the rock to be classified as a granodiorite. The mafic minerals, which form ragged interstitial clots, include hypersthene, augite, hornblende, tremolite-actinolite, biotite and iron ore. Spotted with ilmenite, the pyroxene is usually corroded and altered. Large stumpy apatite crystals are particularly common amongst these mafic minerals (Plate VIb) but they are largest in the interstitial quartz-plagioclase-potash feldspar areas where they reach a size of 1·2 mm. by 0·2 mm.

The origin of both of these tonalite groups will be considered elsewhere (p. 43-45) but from the field and thin-section evidence alone it seems that the gabbros have played an important part in their formation.

Many of the intermediate plutonic rocks, especially the tonalites, show the following textures which are interpreted as having resulted from hybridization:

i. Ragged aggregates of mafic minerals.
ii. The presence of many mafic minerals in the same rock specimen. Those minerals high in the crystallization sequence have partially altered to members lower in the sequence.
iii. The presence of numerous apatite crystals.
iv. The great range in grain-size.
v. Patchy zoning in the plagioclase.
vi. The plagioclase, although often zoned, does not show a continuous reaction series and there are often crystals with two distinct compositions in the same rock.
vii. Corrosion of the plagioclase by potash feldspar and sometimes by quartz.

These features are typical of many hybrid rocks described in the literature (e.g. Nockolds, 1941; Joplin, 1959), although several of them can be attributed to mechanisms other than hybridization. However, the presence of all the above features in the same rock (O.552.1) seems sufficient evidence that hybridization has occurred. The high xenolith content of these intermediate rocks, particularly the tonalites, may also be significant.

4. *Granodiorites*

The only sizeable exposure of post-volcanic granodiorites discovered on the Danco Coast occurs between Waterboat Point and northern Leith Cove. Waterboat Point has been mapped by Halpern (1962), who has described the area as consisting of volcanic and metasedimentary rocks which are intruded by quartz-diorites. Although the plutonic rocks at Waterboat Point vary slightly in composition, the term "quartz-diorite" as used by Halpern is applied to rocks containing between 15 and 30 per cent of potash feldspar; clearly, the difference is one of terminology rather than of actual compositional variation.

This granodioritic intrusion also apparently extends to eastern Lemaire Island. Scott (1965) has described intermediate plutonic rocks at station O.942.3–4 and his field sketch shows the intrusive contact between them and the volcanic country rocks. Hobbs's specimens from this locality are more acidic in composition but he did collect hybrid rocks with overall granodioritic compositions (O.942.5) from the south-eastern extremity of Lemaire Island.

Petrography. In thin section (Table X), two generations of plagioclase are recognized. First, there are large sericitized plagioclase crystals which often contain inclusions of pyroxene and iron ore; these inclusions could have formed by the crystallization of magma trapped in the cavities of partially resorbed plagioclase crystals. The presence of corrosional cavities implies that there was a period when these plagioclase crystals were out of equilibrium with the surrounding magma. Other plagioclase crystals (zoned from An_{36} to An_{10}) are subhedral with conspicuous normal and oscillatory zoning. The usually perthitic potash feldspar forms an allotriomorphic groundmass with quartz and sometimes the two minerals are granophyric. The mafic minerals are represented by hornblende (or tremolite-actinolite) and iron ore, and they are often aggregated. Allanite is a rare accessory constituent. Chlorite and skeletal sphene crystals are associated with the break-down of the mafic minerals; this seems to have occurred relatively early in the mineral crystallization history, since some of the sphene has good crystal shape and is included in the potash feldspar.

5. *Granophyres*

The granophyres, which volumetrically form the most important plutonic rock group on the Danco Coast, are younger than both the volcanic (O.511, 515, 517, 518, 533–535, 562, 942 and 999) and the basic to intermediate plutonic rocks (O.522, 537 and 998). The largest granophyre outcrop occupies much of the mainland between Selvick Cove and Andvord Bay where it is in contact with the tuffs and lavas of the Upper Jurassic Volcanic Group; similar acid plutonic rocks are exposed at southern and eastern Rongé (Plate IIa), Cuverville, Brewster, southern Lemaire and Bryde Islands (O.953), and at Charlotte Bay. Although they are predominantly adamellitic in composition, the granophyres range from granodiorites to granites.

There is little doubt that most of these adamellitic rocks have an intrusive origin. In thin section, a magmatic origin for the plagioclase is suggested by Carlsbad and Carlsbad-albite twinning (Gorai, 1951), synneusis twinning (Vance, 1969) and both normal and fine oscillatory zoning (Vance, 1962). Also, the acicular shape of the accessory apatite crystals is indicative of fairly high crystallization temperatures (Wyllie and others, 1962). The intrusive nature of the granophyres is even more obvious in the field; these acid plutonic rocks contact-metamorphose and show cross-cutting relationships with the volcanic country rocks (Plate IIa), and associated aplites occur at most of the granophyre localities.

Granophyric intergrowths are typical of high-level magmatic rocks of hypabyssal or sub-volcanic origin, although they are uncommon in relatively deep-seated granites. It is agreed by many authors that such a texture is the product of fairly rapid crystallization in a volatile-rich environment (Mehnert, 1968; Barker, 1970). On the Danco Coast it is evident that the volatile content of the granophyre melt was considerable. Lined with euhedral quartz and feldspar, tiny miarolitic cavities in several of the granophyre bodies (O.942.6) indicate that a gas phase was present in the magma, possibly due to the "boiling" of the volatiles at low hydrostatic pressures (Wager and others, 1965). The extensive alkali and silica metasomatism that occurs in the country rocks at all granophyre contacts was probably facilitated by this abundance of volatiles (O.543, 998 and 999); the country rocks have often acquired characteristics rendering them almost indistinguishable from the invading granophyres.

Several horizontally layered structures in the granophyres, which occur in cliff sections up to 100 m. in height, led Bayly (1957) to interpret these rocks as a sequence of bedded acid tuffs; since they usually underlie the Upper Jurassic Volcanic Group, he presumed that these "pink rocks" (granophyres) predated the "dark volcanics" (Upper Jurassic Volcanic Group). It is considered that both the thin-section and field evidence is inconsistent with such a view. The layering described by Bayly could, however, be attributed to the extensive metasomatic alteration of bedded volcanic rocks. Alternatively, this layering could have formed during the differentiation of the granophyre magma *in situ* (cf. Cobbing and Pitcher, 1972).

The granophyres contain "dark fragments with a volcanic appearance" (Bayly, 1957, p. 20) in varying stages of assimilation. They are up to 30 m. in length and at certain horizons they are elongated parallel to the layering in the plutonic host; thin-section work has confirmed their volcanic origin. It is possible that these almost undisturbed xenolithic horizons represent zones of volcanic rocks which have been in-completely assimilated *in situ* by the metasomatizing solutions associated with the granophyre intrusions.

In contrast to these raft-like bodies, there are several granophyre localities (O.553) at which the volcanic xenoliths are haphazardly distributed. There are chill zones at the granophyre/xenolith contacts and it seems that these often hornfelsed xenoliths (O.567.2) are detached blocks of the volcanic country rocks which have been incorporated by the granophyre magma.

Petrography. In thin section, the granophyres (Table X, O.559.1; Plate VIc) are composed of subhedral plagioclase crystals which are surrounded by an interstitial intergrowth of orthoclase and quartz. The plagioclase is zoned from about An_{26} at the crystal cores to about An_{14} at the crystal margins. The quartz of the intergrowth commonly occurs as irregular rods about 0·3 mm. by 0·02 mm., although exceptionally the quartz forms a regular geometric relationship with the surrounding orthoclase (Plate VId). Sometimes the granophyres are spherulitic (O.511.2 and 559.3), particularly near xenoliths or at intrusive contacts. Mafic minerals are never widespread. The few ragged clinopyroxene crystals encountered in thin section are mostly altered to tremolite–actinolite and iron ore. More commonly, the mafic minerals consist of chlorite, leucoxene, haematite and euhedral hornblende, and these minerals usually occur with epidote, allanite, prehnite and sphene. Rapid crystallization is thought to have influenced the virtual absence of primary mafic minerals. The formation of anhydrous quartz–orthoclase intergrowths could have led to the generation of water-rich, high-temperature residual liquids; if these were trapped, the alteration of the original mafic minerals might have been inevitable. It is likely that the epidote and some of the chlorite crystallized at a late stage in a fluid environment rather than during the secondary alteration of solid rock. Epidote occurs either interstitially between euhedral quartz (O.565.4) or potash feldspar (O.515.2), or, together with acicular amphibole, it forms idiomorphic crystals in the coarse-grained areas of quartz (O.565.4). In several of these rocks, chlorite is vermicularly intergrown with quartz or epidote. (This chlorite has brown interference colours and is distinct from the variety known as penninite which also occurs in the same rocks, usually pseudomorphing clinopyroxene.)

Several of the granophyres (O.537.4, 553.1 and 904.4) grade into allotriomorphic-equigranular microgranites and there is a close relationship between the two rock types.

6. *Contaminated granophyres and associated altered country rocks*

At the geologically complex localities of Birdsend Bluff (Plates Ic and IId) and Porro Bluff there is a suite of inhomogeneous plutonic rocks which has apparently formed by reciprocal reaction (Nockolds, 1933) between the volcanic country rocks and the granophyres which have intruded them. Rarely, gabbros (O.533) also form part of the contaminating material. The appinitic rocks (as defined by Haslam (1970)), occurring as rather diffuse xenoliths in the hybridized plutonic rocks, are considered to be highly altered basic lavas.

Reaction between the included volcanic material and the granophyre magma is variable, being dependent on the original composition of the volcanic xenoliths. The incorporation of acid and intermediate lavas in the magma has merely caused the crystallization of slightly greater quantities of iron ore, ragged tremolite-actinolite and apatite than is normal (O.533). Engulfed lavas of originally basic compositions have caused more obvious contamination of the granophyres. The resulting igneous rocks (O.562) are inhomogeneous, grading from leucocratic to more mafic varieties over distances of a few metres. The chemical alteration and the mechanical dispersal of the xenoliths are represented by all gradations from relatively coherent patches to what are no more than shadows of former volcanic inclusions.

Petrography. In thin section, the modified plutonic rocks contain albitized subhedral plagioclase, iron ore and megacrysts of brown hornblende. These euhedral hornblende crystals, which often contain peripheral inclusion-rich zones (Plate VIe), are particularly abundant adjacent to the lava xenoliths. Interstitial quartz and potash feldspar are present in smaller amounts than in the uncontaminated granophyres. There are also a few clinopyroxene crystals which have been altered to chlorite and leucoxene.

The appinitic xenoliths have irregular textures. Brown poikilitic hornblende crystals have also crystallized in these rocks, patchily grading into green varieties in some of the specimens. Sometimes (e.g. at stations O.518 and 553) tremolite-actinolite is also present and the amphibole content occasionally forms about 60 per cent of the total rock (O.552.3). Euhedral clinopyroxene crystals are common and, although some occupy the cores of the brown hornblende megacrysts, these two minerals usually co-exist in apparent equilibrium. Epidote and prehnite occur both in the xenoliths and, with a patchy albite (? pericline) in late-stage veins which cut them (Plate VIf). Many of the appinitic xenoliths also contain quartz, alkali-feldspar and large stumpy or skeletal apatite crystals. Similar rock suites described in the literature (Deer, 1935; Sadashivaiah, 1954; Joplin, 1959) have also been attributed to the alteration of basic country rocks by an invading granitic magma.

Besides the generation of this hybrid rock suite and the associated appinitic xenoliths, there is another more localized type of alteration of the volcanic rocks at the intrusive granophyre contacts along western Rongé Island and on the mainland east of Beneden Head (O.543) and Birdsend Bluff (O.511 and 565). The andesitic rocks at these localities also contain such secondary minerals as quartz, albite, potash feldspar and epidote; however, small flaky biotite crystals have formed instead of the megacrystic hornblende, and a hornfelsic texture has often developed. Contamination of the granophyre is negligible.

This inconsistency of mineralogy in the altered volcanic rocks can perhaps be ascribed to the amount of volatiles (particularly water) contained in different parts of the granophyre magma. It is possible that the hybrid plutonic rocks and the appinitic xenoliths developed at the roof of the magma chamber where a concentration of volatiles would be expected; a stoped roof contact is visible at the appinitic locality near station O.553. The intrusive contacts lower down in the granophyre mass would perhaps be relatively depleted in volatiles and it is possible that the more localized alteration processes took place in such an environment. The envisaged method of granophyre emplacement by stoping is shown in Fig. 15.

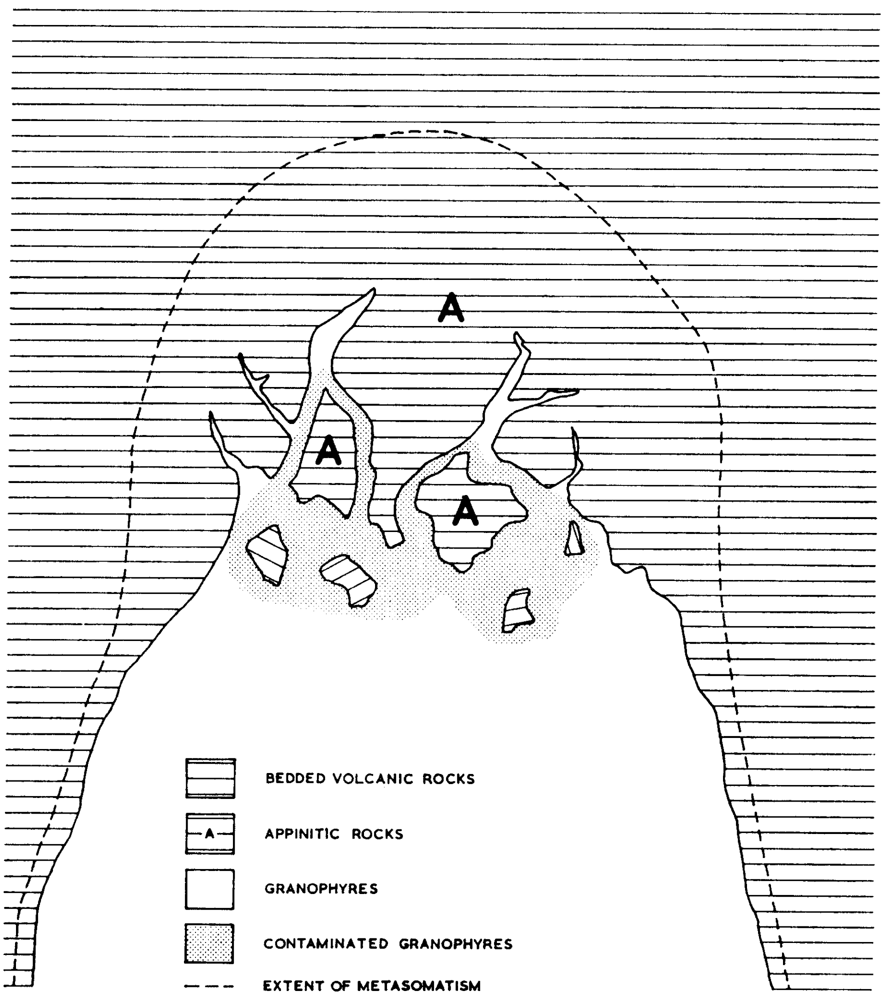

FIGURE 15

A sketch of the envisaged method of granophyre emplacement by stoping. Reaction between the magma and detached blocks of volcanic country rock has given rise to the contaminated granophyres and associated appinitic rocks.

Table XI
CHEMICAL ANALYSES OF POST-VOLCANIC PLUTONIC ROCKS FROM THE DANCO COAST

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	44·54	44·56	44·61	46·39	47·34	47·90	48·75	48·82	49·52	49·70	55·97
TiO_2	0·17	0·27	0·10	0·89	1·20	0·77	1·09	1·48	1·05	1·47	1·82
Al_2O_3	19·87	20·00	28·78	14·60	15·66	20·13	17·47	15·66	16·85	15·44	15·68
Fe_2O_3	3·81	3·00	1·61	3·94	5·82	3·83	3·34	6·03	4·88	4·39	2·93
FeO	4·21	3·49	1·93	5·60	6·02	4·05	6·83	4·54	5·16	6·10	4·81
MnO	0·11	0·10	0·06	0·15	0·16	0·12	0·16	0·22	0·05	0·17	0·20
MgO	10·76	13·17	5·55	10·44	7·62	6·82	7·25	7·98	6·35	5·80	2·84
CaO	12·08	12·95	16·20	11·67	11·32	12·97	10·12	10·09	10·07	9·48	7·07
Na_2O	1·12	0·88	1·11	1·96	1·85	2·01	2·82	3·21	3·15	3·06	3·95
K_2O	0·73	0·59	0·19	0·35	0·64	0·20	0·30	0·52	0·65	0·38	1·05
H_2O+	2·76	0·77	0·13	2·13	2·06	0·27	0·76	1·13	1·28	1·96	1·85
H_2O-	—	0·48	0·30	—	0·68	0·20	0·18	—	0·60	0·79	0·29
P_2O_5	0·01	0·04	0·01	0·07	0·05	0·04	0·08	0·31	0·19	0·48	0·72
CO_2	0·17	0·13	0·03	1·05	—	0·01	0·12	0·72	0·24	0·28	0·12
TOTAL	100·34	100·43	100·61	99·24	100·42	99·32	99·27	100·71	100·04	99·50	99·30
ANALYSES LESS TOTAL WATER (recalculated to 100)											
SiO_2	45·64	44·93	44·53	47·77	48·46	48·46	49·58	49·03	50·60	51·37	57·61
TiO_2	0·17	0·27	0·10	0·92	1·23	0·78	1·11	1·49	1·07	1·52	1·87
Al_2O_3	20·36	20·17	28·73	15·03	16·03	20·36	17·77	15·73	17·22	15·96	16·14
Fe_2O_3	3·90	3·02	1·61	4·06	5·96	3·87	3·40	6·06	4·99	4·54	3·02
FeO	4·31	3·52	1·93	5·77	6·16	4·10	6·95	4·56	5·27	6·30	4·95
MnO	0·11	0·10	0·06	0·15	0·16	0·12	0·16	0·22	0·15	0·18	0·21
MgO	11·03	13·28	5·54	10·75	7·80	6·90	7·37	8·01	6·49	5·99	2·92
CaO	12·38	13·06	16·17	12·02	11·59	13·12	10·29	10·13	10·29	9·80	7·28
Na_2O	1·15	0·89	1·11	2·02	1·89	2·03	2·87	3·22	3·22	3·16	4·07
K_2O	0·75	0·59	0·19	0·36	0·66	0·20	0·31	0·52	0·26	0·39	1·08
P_2O_5	0·01	0·04	0·01	0·07	0·05	0·04	0·08	0·31	0·19	0·50	0·74
CO_2	0·17	0·13	0·03	1·08	—	0·01	0·12	0·72	0·25	0·29	0·12
ELEMENT PERCENTAGES LESS TOTAL WATER AND CARBON DIOXIDE											
Si^{4+}	21·34	21·00	20·82	22·33	22·66	22·65	23·18	22·92	23·66	24·02	26·93
Ti^{4+}	0·10	0·16	0·06	0·55	0·74	0·47	0·66	0·89	0·64	0·91	1·12
Al^{3+}	10·78	10·67	15·20	7·96	8·48	10·78	9·40	8·32	9·11	8·45	8·54
Fe^{3+}	2·73	2·12	1·12	2·84	4·17	2·71	2·38	4·24	3·49	3·17	2·11
Fe^{2+}	3·35	2·74	1·50	4·48	4·79	3·18	5·40	3·54	4·10	4·90	3·85
Mn^{2+}	0·09	0·08	0·05	0·12	0·13	0·09	0·13	0·17	0·12	0·14	0·16
Mg^{2+}	6·65	8·01	3·34	6·48	4·71	4·16	4·45	4·83	3·91	3·62	1·76
Ca^{2+}	8·85	9·33	11·56	8·59	8·28	9·38	7·36	7·24	7·35	7·00	5·20
Na^{+}	0·85	0·66	0·82	1·50	1·41	1·51	2·13	2·39	2·39	2·35	3·02
K^{+}	0·62	0·49	0·16	0·30	0·54	0·17	0·25	0·43	0·21	0·33	0·90
P^{5+}	—	0·02	—	0·03	0·02	0·02	0·04	0·14	0·08	0·22	0·32
C^{4+}	0·05	0·04	0·01	0·30	—	—	0·03	0·20	0·07	0·08	0·03
O^{2-}	44·59	44·69	45·36	44·53	44·08	44·88	44·60	44·68	44·86	44·83	46·05
NORMS											
Q	—	—	—	—	1·84	0·17	—	0·45	2·07	4·42	12·17
C	—	—	—	—	—	—	—	—	—	—	—
Z	—	—	—	—	—	—	—	0·02	—	—	0·02
or	4·42	3·51	1·12	2·13	3·86	1·19	1·80	3·08	1·51	2·32	6·38
ab	9·71	7·50	6·97	17·08	15·99	17·19	24·24	27·25	27·22	26·74	34·36
an	48·17	49·24	72·80	30·90	33·23	45·81	34·67	26·87	31·76	28·17	22·57
di	9·68	11·47	5·80	17·02	19·04	15·13	12·33	13·31	13·25	12·53	6·58
hy	7·13	2·55	—	17·45	14·52	13·25	15·84	15·03	13·89	14·54	7·96
ol	14·45	20·40	9·36	5·17	—	—	3·56	—	—	—	—
mt	5·66	4·38	2·33	5·88	8·62	5·61	4·92	8·77	7·23	6·57	4·37
il	0·33	0·52	0·19	1·74	2·33	1·48	2·10	2·82	2·04	2·88	3·55
hm	—	—	—	—	—	—	—	—	—	—	—
ap	0·02	0·10	0·02	0·17	0·12	0·10	0·19	0·74	0·46	1·17	1·75
pr	0·02	—	—	—	0·45	—	—	—	0·03	—	—
cc	0·40	0·30	0·07	2·46	—	0·02	0·28	1·64	0·56	0·66	0·28
COORDINATES OF TRIANGULAR DIAGRAMS											
A	10·40	8·20	14·10	11·50	12·50	14·30	16·30	18·30	18·40	18·60	33·60
F	42·80	34·60	37·80	46·90	57·40	50·20	53·20	50·40	53·80	56·20	51·20
M	46·80	57·20	48·10	41·60	30·10	35·50	30·50	31·30	27·80	25·20	15·20
Ca	85·70	89·00	92·20	82·70	81·00	84·80	75·50	71·90	73·90	72·40	57·10
Na	8·30	6·30	6·60	14·40	13·70	13·60	21·90	23·80	24·00	24·30	33·10
K	6·00	4·70	1·30	2·90	5·30	1·50	2·60	4·30	2·10	3·40	9·80
Q	*	*	*	*	*	*	*	*	*	*	*
or	*	*	*	*	*	*	*	*	*	*	*
ab	*	*	*	*	*	*	*	*	*	*	*
TRACE ELEMENTS											
S	111	100	22	818	2345	63	90	89	136	88	54
Cr	73	177	162	259	62	130	259	83	35	29	7
Ni	56	170	27	100	29	31	60	53	9	11	3
Cu	73	119	95	158	237	83	113	94	152	121	69
Zn	61	58	57	80	718	56	86	88	77	117	93
Rb	25	18	8	12	20	6	3	18	23	9	45
Sr	535	489	738	354	421	497	623	574	473	641	528
Y	7	5	—	11	9	5	9	14	17	17	30
Zr	42	63	29	81	42	28	56	101	43	60	100
Nb	—	—	—	3	4	—	—	3	6	5	8
Ba	127	106	68	115	157	108	166	222	191	199	296
La	—	—	—	—	—	—	3	7	8	8	18
Ce	—	5	7	9	7	—	10	6	18	20	42
Pb	7	7	17	5	15	6	4	10	7	9	7
Th	—	3	—	—	—	—	—	3	2	—	6
Ga	14	11	13	11	14	13	13	18	16	16	15
K/Rb	242	272	197	251	266	277	830	240	222	351	194
K/Th	∞	1633	∞	∞	∞	∞	∞	1439	1038	∞	1453
Ba/Rb	5·08	5·89	8·50	9·58	7·85	18·00	55·33	12·33	63·67	22·11	6·58
D.I.	14·10	11·00	9·40	19·20	21·70	18·60	26·00	30·80	30·80	33·50	52·90

	12	13	14	15	16	17	18	19	20	21	22	23
SiO_2	56·26	54·94	56·82	57·21	57·88	58·91	53·78	59·02	62·31	65·12	66·58	66·99
TiO_2	0·77	1·94	1·13	1·02	0·85	1·49	1·04	0·86	0·58	0·33	0·48	0·45
Al_2O_3	14·57	15·65	16·53	16·46	15·66	15·65	16·57	14·25	15·20	16·22	14·94	15·05
Fe_2O_3	6·95	4·04	3·84	2·82	2·51	3·12	4·12	3·59	2·47	2·06	2·22	2·17
FeO	4·05	3·94	2·91	3·06	3·51	3·32	3·32	3·44	2·40	1·56	1·41	1·57
MnO	0·17	0·22	0·15	0·11	0·10	0·16	0·12	0·13	0·09	0·07	0·06	0·06
MgO	5·87	3·85	3·73	3·90	4·60	3·18	4·70	4·12	2·25	0·94	1·36	1·51
CaO	7·84	7·43	7·72	6·33	6·84	5·90	8·50	5·49	4·66	3·85	3·16	3·43
Na_2O	2·50	4·16	3·87	4·17	3·77	4·23	4·04	3·42	3·53	4·57	4·29	3·53
K_2O	0·64	0·83	1·12	1·87	1·17	1·16	0·93	2·03	2·43	1·26	2·69	2·93
H_2O+	0·31	1·40	0·74	1·58	2·07	1·35	1·45	1·75	2·81	2·97	2·29	1·46
H_2O-	0·20	0·22	—	0·23	0·38	—	0·18	0·93	0·23	0·59	0·18	0·11
P_2O_5	0·18	0·80	0·51	0·29	0·20	0·57	0·21	0·22	0·15	0·11	0·09	0·09
CO_2	0·02	0·12	0·16	0·15	0·22	0·12	0·55	0·09	0·42	0·08	—	0·21
TOTAL	100·33	99·54	99·23	99·20	99·76	99·16	99·51	99·34	99·53	99·73	99·75	99·56
ANALYSES LESS TOTAL WATER (recalculated to 100)												
SiO_2	56·36	56·11	57·69	58·74	59·48	60·23	54·94	61·06	64·58	67·71	68·44	68·36
TiO_2	0·77	1·98	1·15	1·05	0·87	1·52	1·06	0·89	0·60	0·34	0·49	0·46
Al_2O_3	14·60	15·98	16·78	16·90	16·09	16·00	16·93	14·74	15·75	16·87	15·36	15·36
Fe_2O_3	6·96	4·13	3·90	2·90	2·58	3·19	4·21	3·71	2·56	2·14	2·28	2·21
FeO	4·06	4·02	2·95	3·14	3·61	3·39	3·39	3·56	2·49	1·62	1·45	1·60
MnO	0·17	0·22	0·15	0·11	0·10	0·16	0·12	0·13	0·09	0·07	0·06	0·06
MgO	5·88	3·93	3·79	4·00	4·73	3·25	4·80	4·26	2·33	2·98	1·40	1·54
CaO	7·85	7·59	7·84	6·50	7·03	6·03	8·68	5·68	4·83	4·00	3·25	3·50
Na_2O	2·50	4·25	3·93	4·28	3·87	4·32	4·13	3·54	3·66	4·75	4·41	3·60
K_2O	0·64	0·85	1·14	1·92	1·20	1·19	0·95	2·10	2·52	1·31	2·77	2·99
P_2O_5	0·18	0·82	0·52	0·30	0·21	0·58	0·21	0·23	0·16	0·11	0·09	0·09
CO_2	0·02	0·12	0·16	0·15	0·23	0·12	0·56	0·09	0·44	0·08	—	0·21
ELEMENT PERCENTAGES LESS TOTAL WATER AND CARBON DIOXIDE												
Si^{4+}	26·35	26·23	26·97	27·46	27·81	28·16	25·69	28·55	30·19	31·66	32·00	31·96
Ti^{4+}	0·46	1·19	0·69	0·63	0·52	0·91	0·64	0·53	0·36	0·21	0·30	0·28
Al^{3+}	7·72	8·46	8·88	8·94	8·52	8·47	8·96	7·80	8·34	8·93	8·13	8·13
Fe^{3+}	4·87	2·89	2·73	2·03	1·80	2·23	2·94	2·60	1·79	1·50	1·60	1·55
Fe^{2+}	3·15	3·13	2·30	2·44	2·80	2·64	2·64	2·77	1·93	1·26	1·13	1·25
Mn^{2+}	0·13	0·17	0·12	0·09	0·08	0·13	0·09	0·10	0·07	0·06	0·05	0·05
Mg^{2+}	3·55	2·37	2·28	2·42	2·85	1·96	2·90	2·57	1·41	0·59	0·84	0·93
Ca^{2+}	5·61	5·42	5·60	4·65	5·02	4·31	6·21	4·06	3·45	2·86	2·32	2·50
Na^{+}	1·86	3·15	2·92	3·18	2·87	3·21	3·06	2·62	2·71	3·53	3·27	2·67
K^{+}	0·53	0·70	0·94	1·59	1·00	0·98	0·79	1·74	2·09	1·09	2·30	2·48
P^{5+}	0·08	0·36	0·23	0·13	0·09	0·25	0·09	0·10	0·07	0·05	0·04	0·04
C^{4+}	0·01	0·03	0·04	0·04	0·06	0·03	0·15	0·03	0·12	0·02	—	0·06
O^{2-}	45·67	45·90	46·30	46·41	46·57	46·71	45·84	46·53	47·47	48·26	48·04	48·11
NORMS												
Q	16·29	10·14	11·69	8·68	11·86	15·02	5·94	15·43	20·86	25·11	23·63	26·67
C	—	—	—	—	—	—	—	—	—	0·75	—	0·47
Z	0·04	0·03	0·05	0·05	0·04	0·05	0·02	0·06	0·05	0·04	0·06	0·05
or	3·79	5·00	6·71	11·33	7·10	7·00	5·61	12·40	14·91	7·74	16·36	17·69
ab	21·18	35·90	33·21	36·19	32·75	36·55	34·90	29·90	30·93	40·18	37·28	30·45
an	26·67	22·01	24·77	21·20	22·95	20·72	24·84	18·12	19·09	18·76	13·92	15·59
di	8·70	7·66	7·77	6·62	7·47	3·84	10·58	6·49	1·02	—	1·39	—
hy	11·32	7·30	6·38	8·69	11·44	7·66	8·21	9·76	6·95	3·21	2·91	4·28
ol	—	—	—	—	—	—	—	—	—	—	—	—
mt	10·09	5·98	5·65	4·19	3·74	4·62	6·10	5·38	3·71	3·10	3·31	3·21
il	1·46	3·76	2·18	1·99	1·66	2·89	2·02	1·69	1·14	0·65	0·94	0·87
hm	—	—	—	—	—	—	—	—	—	—	—	—
ap	0·43	1·93	1·22	0·70	0·49	1·38	0·51	0·54	0·37	0·27	0·22	0·22
pr	—	—	—	—	—	—	—	—	—	—	—	0·02
cc	0·05	0·28	0·37	0·35	0·51	0·28	1·28	0·21	0·99	0·19	—	0·49
COORDINATES OF TRIANGULAR DIAGRAMS												
A	17·10	31·50	34·60	40·90	34·20	38·00	31·20	35·50	48·40	57·90	61·00	58·10
F	57·50	49·10	45·00	38·30	40·70	44·20	45·30	43·60	37·50	34·70	29·80	31·50
M	25·40	19·40	20·50	20·70	25·20	17·80	23·50	20·90	14·20	7·40	9·20	10·50
Ca	70·10	58·40	59·20	49·30	56·50	50·70	61·70	48·20	41·80	38·30	29·40	32·70
Na	23·20	34·00	30·80	33·70	32·30	37·70	30·40	31·10	32·90	47·20	41·50	34·90
K	6·60	7·60	10·00	16·90	11·20	11·60	7·80	20·70	25·30	14·60	29·10	32·40
Q	*	*	*	*	*	*	*	*	*	*	*	*
or	*	*	*	*	*	*	*	*	*	*	*	*
ab	*	*	*	*	*	*	*	*	*	*	*	*
TRACE ELEMENTS												
S	60	86	20	91	57	75	100	67	68	93	71	107
Cr	53	13	31	42	61	11	20	72	32	12	15	19
Ni	29	3	11	24	33	3	7	28	12	1	6	8
Cu	237	84	96	156	165	66	61	98	64	47	63	82
Zn	633	87	79	77	84	115	53	109	37	51	34	35
Rb	20	23	34	65	38	43	47	72	120	57	96	122
Sr	380	554	515	507	504	526	431	368	333	346	271	283
Y	22	33	25	22	19	32	16	27	20	27	27	19
Zr	190	165	242	253	180	260	111	296	217	183	297	232
Nb	3	12	6	9	9	15	6	14	8	13	8	2
Ba	173	326	402	465	358	448	262	482	412	331	509	478
La	—	20	20	18	12	24	11	23	21	19	18	20
Ce	8	51	41	46	29	49	30	49	25	27	32	32
Pb	7	11	9	16	17	13	10	45	11	23	14	23
Th	5	4	6	6	6	6	3	8	13	14	11	24
Ga	12	15	16	14	13	16	15	14	14	16	12	13
K/Rb	266	300	273	239	256	224	164	234	168	184	233	199
K/Th	1063	1722	1550	2587	1619	1605	2573	2106	1552	747	2030	1013
Ba/Rb	8·65	14·17	11·82	7·15	9·42	10·42	5·57	6·69	3·43	5·81	5·30	3·92
D.I.	41·30	51·10	51·60	56·20	51·70	58·60	46·50	57·70	66·70	73·00	77·30	74·80

	24	25	26	27	28	29	30	31	32	33	34
SiO_2	57·78	63·21	65·97	66·06	66·63	67·06	68·25	68·94	69·02	70·39	70·81
TiO_2	1·32	0·71	0·60	0·75	0·56	0·52	0·52	0·60	0·40	0·36	0·25
Al_2O_3	15·72	15·56	15·54	15·47	15·71	14·93	15·61	14·62	15·16	14·67	14·33
Fe_2O_3	3·98	2·97	2·51	2·48	2·44	2·65	2·03	2·40	1·76	1·59	1·25
FeO	2·70	2·30	1·40	1·25	1·30	1·75	1·10	1·40	1·52	0·91	0·80
MnO	0·23	0·09	0·07	0·09	0·06	0·07	0·03	0·09	0·09	0·05	0·09
MgO	2·43	1·75	1·21	1·26	1·10	1·23	0·93	0·89	0·87	0·93	0·36
CaO	5·71	4·69	3·08	2·87	2·78	2·89	2·73	2·43	2·10	2·37	1·00
Na_2O	5·04	3·99	4·88	6·05	4·96	4·23	4·64	4·93	4·46	4·32	5·10
K_2O	1·30	2·34	2·52	2·38	2·70	2·86	2·79	2·85	3·50	2·87	3·31
H_2O+	1·69	1·49	1·29	1·02	0·42	0·48	0·13	0·26	0·29	0·30	0·97
H_2O-	0·18	0·20	0·12	0·26	0·38	—	0·43	—	—	0·21	0·45
P_2O_5	0·63	0·19	0·15	0·18	0·14	0·13	0·11	0·14	0·10	0·08	0·44
CO_2	0·68	0·27	0·32	0·13	0·17	0·29	0·02	0·17	0·08	0·05	0·42
TOTAL	99·39	99·76	99·66	100·25	99·35	99·09	99·32	99·72	99·35	99·10	99·58
ANALYSES LESS TOTAL WATER (recalculated to 100)											
SiO_2	59·25	64·45	67·15	66·75	67·61	68·01	69·11	69·31	69·67	71·40	72·14
TiO_2	1·35	0·72	0·61	0·76	0·57	0·53	0·53	0·60	0·40	0·37	0·25
Al_2O_3	16·12	15·87	15·82	15·63	15·94	15·14	15·81	14·70	15·30	14·88	14·60
Fe_2O_3	4·08	3·03	2·55	2·51	2·48	2·69	2·06	2·41	1·78	1·61	1·27
FeO	2·77	2·35	1·42	1·26	1·32	1·77	1·11	1·41	1·53	0·92	0·81
MnO	0·24	0·09	0·07	0·09	0·06	0·07	0·03	0·09	0·09	0·05	0·09
MgO	2·49	1·78	1·23	1·27	1·12	1·25	0·94	0·89	0·88	0·94	0·37
CaO	5·86	4·78	3·13	2·90	2·82	2·93	2·76	2·44	2·12	2·40	1·02
Na_2O	5·17	4·07	4·97	6·11	5·03	4·29	4·70	4·96	4·50	4·38	5·20
K_2O	1·33	2·39	2·56	2·40	2·74	2·90	2·83	2·87	3·53	2·91	3·37
P_2O_5	0·65	0·19	0·15	0·18	0·14	0·13	0·11	0·14	0·10	0·08	0·45
CO_2	0·70	0·28	0·33	0·13	0·17	0·29	0·02	0·17	0·08	0·05	0·43
ELEMENT PERCENTAGES LESS TOTAL WATER AND CARBON DIOXIDE											
Si^{4+}	27·70	30·13	31·39	31·20	31·61	31·79	32·31	32·40	32·57	33·38	33·72
Ti^{4+}	0·81	0·43	0·37	0·45	0·34	0·32	0·32	0·36	0·24	0·22	0·15
Al^{3+}	8·53	8·40	8·37	8·27	8·44	8·01	8·36	7·78	8·10	7·87	7·73
Fe^{3+}	2·85	2·12	1·79	1·75	1·73	1·88	1·44	1·69	1·24	1·13	0·89
Fe^{2+}	2·15	1·82	1·11	0·98	1·03	1·38	0·87	1·09	1·19	0·72	0·63
Mn^{2+}	0·18	0·07	0·06	0·07	0·05	0·05	0·02	0·07	0·07	0·04	0·07
Mg^{2+}	1·50	1·08	0·74	0·77	0·67	0·75	0·57	0·54	0·53	0·57	0·22
Ca^{2+}	4·18	3·42	2·24	2·07	2·02	2·09	1·98	1·75	1·52	1·72	0·73
Na^{+}	3·83	3·02	3·68	4·54	3·73	3·18	3·49	3·68	3·34	3·25	3·85
K^{+}	1·11	1·98	2·13	2·00	2·27	2·41	2·35	2·38	2·93	2·42	2·80
P^{5+}	0·28	0·08	0·07	0·08	0·06	0·06	0·05	0·06	0·04	0·04	0·20
C^{4+}	0·19	0·08	0·09	0·04	0·05	0·08	0·01	0·05	0·02	0·01	0·12
O^{2-}	46·67	47·37	47·97	47·78	48·00	47·99	48·26	48·15	48·20	48·64	48·89
NORMS											
Q	12·25	20·20	21·07	15·57	20·87	24·72	23·87	23·87	24·08	28·43	28·45
C	—	—	0·21	—	0·23	0·54	0·22	—	0·56	0·38	2·53
Z	0·04	0·05	0·08	0·09	0·09	0·07	0·07	0·09	0·06	0·04	0·07
or	7·87	14·12	15·14	14·19	16·17	17·15	16·68	16·91	20·90	17·22	19·96
ab	43·67	34·39	41·98	51·66	42·54	36·26	39·71	41·89	38·06	37·04	43·91
an	16·83	17·95	12·70	8·10	12·18	12·00	13·08	9·39	9·55	11·28	0·38
di	2·95	2·34	—	3·52	—	—	—	0·73	—	—	—
hy	4·83	4·11	3·06	1·54	2·78	3·38	2·34	1·89	3·04	2·35	1·11
ol	—	—	—	—	—	—	—	—	—	—	—
mt	5·68	4·39	3·05	2·17	2·80	3·89	2·11	3·08	2·57	2·08	1·84
il	2·57	1·37	1·16	1·44	1·08	1·00	1·00	1·14	0·77	0·69	0·48
hm	0·16	—	0·45	1·01	0·54	—	0·60	0·29	—	0·18	—
ap	1·53	0·46	0·36	0·43	0·34	0·31	0·26	0·33	0·24	0·19	1·06
pr	0·04	—	—	—	—	0·02	0·03	—	—	—	—
cc	1·58	0·63	0·74	0·30	0·39	0·67	0·05	0·39	0·18	0·12	0·97
COORDINATES OF TRIANGULAR DIAGRAMS											
A	43·20	49·90	61·50	65·10	63·70	58·20	67·00	64·60	67·90	70·10	79·20
F	43·70	39·30	30·60	27·30	29·20	33·90	26·50	29·70	26·40	22·80	18·10
M	13·10	10·70	7·90	7·70	7·10	7·80	6·50	5·80	5·70	7·00	2·60
Ca	45·90	40·60	27·80	24·10	25·10	27·30	25·30	22·40	19·50	23·30	9·90
Na	42·00	35·90	45·80	52·70	46·50	41·40	44·70	47·10	42·90	44·00	52·20
K	12·10	23·50	26·40	23·20	28·30	31·30	30·00	30·50	37·70	32·70	37·90
Q	18·04	29·02	26·43	19·12	25·92	31·02	29·67	28·64	28·75	34·31	29·92
or	12·50	20·64	19·49	17·43	20·38	22·17	20·82	20·51	25·25	20·85	21·91
ab	69·46	50·34	54·09	63·45	53·70	46·81	49·51	50·85	45·99	44·84	48·18
TRACE ELEMENTS											
S	212	18	59	23	85	118	139	83	30	71	52
Cr	7	13	11	9	10	8	6	10	16	10	6
Ni	3	4	3	—	6	4	—	2	4	—	—
Cu	83	84	68	71	89	66	84	75	43	74	41
Zn	193	37	49	78	33	39	37	69	60	35	80
Rb	23	93	72	66	79	99	77	83	116	111	165
Sr	415	322	293	385	284	270	331	252	237	288	162
Y	32	21	29	40	31	26	29	40	15	13	24
Zr	205	231	394	423	425	331	340	445	289	217	348
Nb	7	7	13	19	15	11	13	15	11	11	18
Ba	466	480	605	692	610	510	623	640	646	588	694
La	34	20	33	29	29	26	31	30	27	21	36
Ce	62	38	55	68	59	64	54	59	46	30	65
Pb	25	15	18	12	19	16	24	37	21	20	36
Th	4	12	6	8	10	11	10	9	16	15	15
Ga	18	13	18	18	15	13	13	15	12	15	*
K/Rb	469	209	291	299	284	240	301	285	251	215	167
K/Th	2698	1619	3486	2470	2241	2158	2316	2629	1816	1588	1832
Ba/Rb	20·26	5·16	8·40	10·48	7·72	5·15	8·09	7·71	5·57	5·30	4·21
D.I.	63·80	68·70	78·20	81·40	79·60	78·10	80·30	82·70	83·00	82·70	92·30

	35	36	37	38	39	40	41	42	43	44
SiO_2	71·50	71·83	73·46	74·04	74·14	70·60	71·50	72·96	69·42	72·02
TiO_2	0·40	0·32	0·22	0·16	0·16	0·50	0·31	0·29	0·44	0·34
Al_2O_3	14·89	14·66	13·88	13·86	14·23	14·13	14·35	14·42	14·88	14·44
Fe_2O_3	1·62	1·69	1·19	1·20	1·49	2·22	1·43	1·01	1·95	1·76
FeO	0·96	0·72	0·68	0·44	0·42	1·34	0·72	0·89	1·13	0·92
MnO	0·06	0·03	0·05	0·05	0·08	0·05	0·03	0·01	0·07	0·05
MgO	0·76	0·83	0·10	0·05	0·09	0·39	0·78	0·52	0·82	0·60
CaO	2·03	1·89	0·73	0·57	0·64	1·09	1·56	2·00	2·19	1·67
Na_2O	4·45	4·16	5·20	4·85	4·88	5·35	4·14	5·57	4·74	4·84
K_2O	3·30	3·40	3·17	3·54	3·77	3·31	3·79	1·50	3·02	2·25
H_2O+	0·25	0·83	0·81	0·51	0·51	0·40	0·19	0·17	0·64	0·33
H_2O-	—	—	0·35	0·22	—	0·20	—	—	0·18	—
P_2O_5	0·08	0·07	0·02	0·01	0·02	0·06	0·08	0·05	0·12	0·16
CO_2	0·42	0·16	0·21	0·10	0·09	0·33	0·34	0·01	0·19	0·13
TOTAL	100·72	100·59	100·07	99·60	100·52	99·97	99·22	99·40	99·79	99·51
ANALYSES LESS TOTAL WATER (recalculated to 100)										
SiO_2	71·17	72·00	74·27	74·89	74·13	71·05	72·20	73·53	69·49	72·62
TiO_2	0·40	0·32	0·22	0·16	0·16	0·50	0·31	0·29	0·46	0·34
Al_2O_3	14·82	14·70	14·03	14·02	14·23	14·22	14·49	14·53	14·86	14·56
Fe_2O_3	1·61	1·69	1·20	1·21	1·49	2·23	1·44	1·02	2·08	1·77
FeO	0·96	0·72	0·69	0·45	0·42	1·35	0·73	0·90	1·20	0·93
MnO	0·06	0·03	0·05	0·05	0·08	0·05	0·03	0·01	0·07	0·05
MgO	0·76	0·83	0·10	0·05	0·09	0·39	0·79	0·52	0·88	0·60
CaO	2·02	1·89	0·74	0·58	0·64	1·10	1·58	2·02	2·33	1·68
Na_2O	4·43	4·17	5·26	4·91	4·88	5·38	4·18	5·61	5·06	4·88
K_2O	3·28	3·41	3·20	3·58	3·77	3·33	3·83	1·51	3·22	2·27
P_2O_5	0·08	0·07	0·02	0·01	0·02	0·06	0·08	0·05	0·14	0·16
CO_2	0·42	0·16	0·21	0·10	0·09	0·33	0·34	0·01	0·21	0·13
ELEMENT PERCENTAGES LESS TOTAL WATER AND CARBON DIOXIDE										
Si^{4+}	33·27	33·66	34·72	35·01	34·66	33·21	33·75	34·37	32·79	33·95
Ti^{4+}	0·24	0·19	0·13	0·10	0·10	0·30	0·18	0·18	0·26	0·21
Al^{3+}	7·84	7·78	7·43	7·42	7·53	7·53	7·67	7·69	7·96	7·70
Fe^{3+}	1·13	1·18	0·84	0·85	1·04	1·56	1·01	0·71	1·38	1·24
Fe^{2+}	0·74	0·56	0·53	0·35	0·33	1·05	0·57	0·70	0·89	0·72
Mn^{2+}	0·05	0·02	0·04	0·04	0·06	0·04	0·02	0·01	0·05	0·04
Mg^{2+}	0·46	0·50	0·06	0·03	0·05	0·24	0·48	0·32	0·50	0·36
Ca^{2+}	1·44	1·35	0·53	0·41	0·46	0·78	1·13	1·44	1·58	1·20
Na^{+}	3·29	3·09	3·90	3·64	3·62	3·99	3·10	4·16	3·55	3·62
K^{+}	2·73	2·83	2·66	2·97	3·13	2·77	3·18	1·25	2·53	1·88
P^{5+}	0·03	0·03	0·01	—	0·01	0·03	0·04	0·02	0·06	0·07
C^{4+}	0·11	0·04	0·06	0·03	0·02	0·09	0·09	—	0·05	0·04
O^{2-}	48·67	48·75	49·09	49·16	48·99	48·41	48·78	49·14	48·40	48·96
NORMS										
Q	28·59	29·87	30·20	31·52	29·98	24·97	29·69	29·90	*	31·74
C	1·39	1·14	1·05	1·23	1·15	0·59	1·50	0·08	*	1·64
Z	0·06	0·05	0·07	0·07	0·07	0·09	0·05	0·04	*	0·05
or	19·43	20·15	18·95	21·18	22·31	19·66	22·63	8·93	*	13·40
ab	37·44	35·25	44·44	41·47	41·25	45·50	35·34	47·46	*	41·26
an	7·03	8·16	2·34	2·28	2·62	3·18	5·34	9·77	*	6·64
di	—	—	—	—	—	—	—	—	*	—
hy	1·88	2·07	0·25	0·13	0·22	0·98	1·96	1·65	*	1·51
ol	—	—	—	—	—	—	—	—	*	—
mt	2·07	1·45	1·73	1·13	1·15	3·05	1·53	1·47	*	2·16
il	0·76	0·61	0·42	0·31	0·30	0·95	0·59	0·55	*	0·65
hm	0·18	0·69	0·01	0·43	0·70	0·13	0·39	—	*	0·28
ap	0·19	0·17	0·05	0·02	0·05	0·14	0·19	0·12	*	0·38
pr	0·02	0·02	—	—	—	—	—	—	*	—
cc	0·95	0·36	0·48	0·23	0·20	0·75	0·78	0·02	*	0·30
COORDINATES OF TRIANGULAR DIAGRAMS										
A	72·10	72·50	82·00	84·40	82·60	70·40	75·40	75·90	*	70·30
F	22·40	21·40	17·20	15·20	16·70	27·20	18·90	19·70	*	25·10
M	5·50	6·10	0·80	0·40	0·70	2·50	5·70	4·40	*	4·70
Ca	19·40	18·60	7·40	5·90	6·30	10·40	15·20	21·00	*	17·90
Na	44·10	42·50	55·00	51·80	50·20	53·00	41·90	60·70	*	54·00
K	36·60	38·90	37·50	42·30	43·40	36·70	42·90	18·30	*	28·10
Q	32·53	34·70	31·85	33·29	31·92	27·08	33·20	34·66	*	*
or	23·05	23·73	20·36	22·54	23·89	22·00	26·10	10·32	*	*
ab	44·42	41·58	47·79	44·17	44·19	50·93	40·70	55·00	*	*
TRACE ELEMENTS										
S	125	125	31	12	23	36	70	319	66	31
Cr	13	—	11	6	6	8	15		9	8
Ni	—	2	—	—	—	—	—	—	2	—
Cu	57	73	87	43	53	65	59	57	67	50
Zn	41	24	44	41	68	22	28	10	49	20
Rb	123	102	99	120	163	81	114	53	105	85
Sr	192	305	77	55	78	174	234	291	235	211
Y	21	5	36	44	32	36	14	17	27	29
Zr	319	226	351	328	334	468	229	220	333	240
Nb	10	10	14	12	20	19	13	11	13	12
Ba	575	734	734	639	750	877	754	389	635	546
La	29	16	26	34	39	29	26	19	28	20
Ce	50	20	29	58	77	61	43	29	52	35
Pb	27	19	30	27	35	14	18	12	24	11
Th	15	14	13	13	17	8	15	22	12	13
Ga	13	15	14	16	18	15	13	12	15	13
K/Rb	223	277	266	245	192	339	276	235	*	220
K/Th	1826	2016	2024	2260	1841	3435	2097	566	*	1437
Ba/Rb	4·67	7·20	7·41	5·32	4·60	10·83	6·61	7·34	*	6·42
D.I.	85·50	85·30	93·60	94·20	93·50	90·10	87·70	86·30	*	86·40

* Not determined.

1. O.945.1 Gabbro; south-western Bryde Island.
2. O.934.6 Gabbro; north-western Bryde Island.
3. O.933.1 Uralitized gabbro; Bruce Island.
4. O.974.2 Gabbro; south-eastern Charlotte Bay.
5. O.934.1 Gabbro; western Bryde Island.
6. O.522.3 Gabbro xenolith; northern Rongé Island.
7. O.546.2 Olivine-gabbro; western Rongé Island.
8. O.537.1 Gabbro; 1 km. to the south of Porro Bluff.
9. O.520.3 Gabbro xenolith; northern Rongé Island.
10. O.912.1 Diorite; Duthiers Point.
11. O.938.8 Quartz-diorite; east of Mount Banck.
12. O.520.1 Tonalite; northern Rongé Island.
13. O.540.1 Tonalite; 2·5 km. to the south of Porro Bluff.
14. O.568.18 Tonalite; Cuverville Island.
15. O.552.1 Granodiorite; south-east of Selvick Cove.
16. O.1000.1 Tonalite; Useful Island.
17. O.539.1 Tonalite; 2 km. to the south of Porro Bluff.
18. O.556.1 Granodiorite; north-east of Selvick Cove.
19. O.915.2 Granodiorite; Waterboat Point.
20. O.935.2 Granodiorite; east of Waterboat Point.
21. O.974.1 Granodiorite; southern Charlotte Bay.
22. O.561.1 Granodiorite; east of Selvick Cove.
23. O.996.1 Granodiorite; northern Leith Cove.
24. O.533.3 Contaminated granophyre; Porro Bluff.
25. O.999.3 Granophyre; east of Waterboat Point.
26. O.559.1 Granophyre; south-east of Sable Pinnacles.
27. O.531.3 Granophyre; north-east of Beneden Head.
28. O.515.2 Granophyre; eastern Rongé Island.
29. O.904.4 Granophyre; southern Rongé Island.
30. O.559.2 Granophyre; south-east of Sable Pinnacles.
31. O.554.1 Granophyre; south-east of Sable Pinnacles.
32. O.577.2 Granophyre; south-western Charlotte Bay.
33. O.532.3 Granophyre; Porro Bluff.
34. O.909.2 Granophyre; south-east of Beneden Head.
35. O.942.8 Granophyre; eastern Lemaire Island.
36. O.904.1 Granophyre; southern Rongé Island.
37. O.942.4 Granophyre; eastern Lemaire Island.
38. O.942.6 Granophyre; eastern Lemaire Island.
39. O.909.1 Granophyre; south-east of Beneden Head.
40. O.537.7 Microgranite; 1 km. to the south of Porro Bluff.
41. O.541.1 Microgranite; 6 km. inland from Beneden Head.
42. O.522.1 Microgranite; northern Rongé Island.
43. Average Danco Coast granophyre (analyses 25 to 39).
44. N.145.1 Cape Monaco granite; Cape Monaco, Anvers Island (new analysis).

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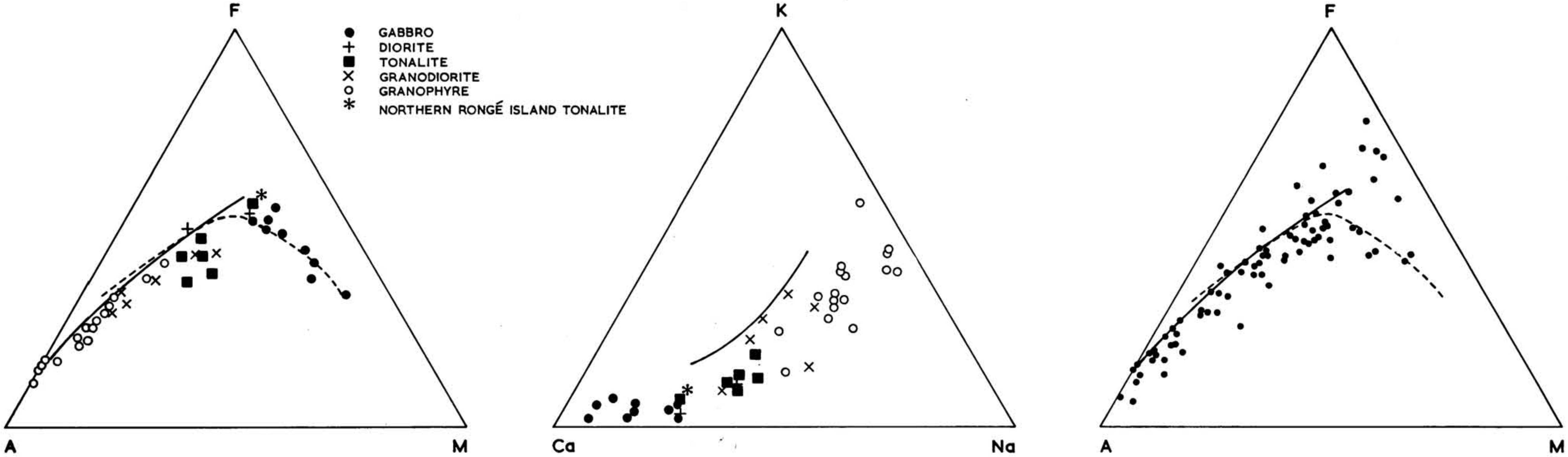

FIGURE 17

Triangular A–F–M and Ca–Na–K diagrams for the Danco Coast post-volcanic plutonic rocks. The A–F–M diagram on the right represents all the known analyses of apparently contemporaneous Graham Land plutonic rocks (Gourdon, 1908; Pelikan, 1909; Bodman, 1916; Adie, 1955; Hooper, 1962; Marsh, 1968; Stubbs, 1968; Dewar, 1970). The solid lines are the trends determined by Adie (1955) for the Andean Intrusive Suite, and the dashed lines separate the tholeiitic fields (above) from the calc-alkaline fields (below).

B. Chemistry

Of the 42 post-volcanic plutonic rocks which have been analysed for 12 major oxides and 16 trace elements (Table XI), it can be seen that high alumina contents are characteristic of the more basic rocks, and that there is little iron enrichment in the intermediate members. In addition, all of the analysed rocks contain only moderate amounts of alkalis (Fig. 16). These properties are diagnostic of calc-alkaline rocks, which is in agreement with the findings of previous workers in Graham Land (Adie, 1955; Dewar, 1970). In Fig. 17 all of the known chemical analyses of apparently contemporaneous plutonic rocks from Graham

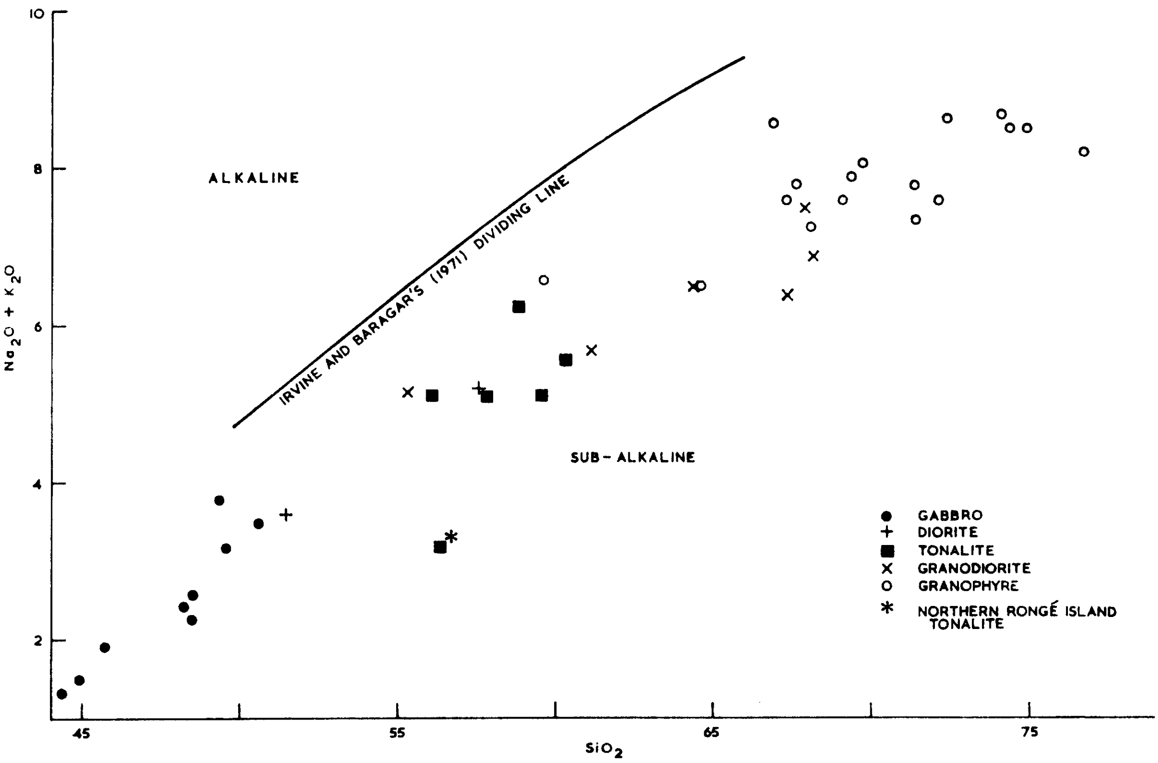

FIGURE 16

A plot of total alkalis against silica for the analysed post-volcanic plutonic rocks from the Danco Coast.

Land are plotted on the A–F–M diagram. Many follow a similar trend to the Danco Coast rocks, although several of the gabbros and diorites show a considerable iron enrichment which is absent from the area studied here. (Some of these rocks have been interpreted as cumulates by the analysts concerned.) The A–F–M and Na–Ca–K trends determined by Adie (1955) for some Graham Land plutonic rocks differ slightly from the chemical variations observed on the Danco Coast, being displaced a little towards the A–F and Ca–K lines, respectively. Since Adie's chemical analyses were carried out by classical gravimetric methods and not by X-ray fluorescence as in the present work, the observed differences in trends may be due to the different analytical techniques used.

The only published trace-element analyses of penecontemporaneous plutonic rocks from Graham Land are those of Adie (1955). When compared with the Danco Coast rocks, these Graham Land rocks contain similar concentrations of yttrium, zirconium and lead, but they are comparatively impoverished in chromium and lanthanum, and enriched in rubidium, strontium and barium. Again, these chemical differences could be ascribed to analytical technique; Adie's trace-element abundances were determined spectrographically, whilst the rocks from the Danco Coast were analysed by an X-ray fluorescence method. The similar zirconium abundances found in the Graham Land gabbros and in the gabbros of the Danco Coast are only about half those normally encountered in basaltic rocks (Prinz, 1967). Additional analyses of Graham Land gabbros would be most valuable in establishing whether these low zirconium concentrations are fortuitous or whether they are a regional characteristic.

It is considered that the Danco Coast gabbros are primary rocks which could have been derived from the mantle or lower crust by processes such as those outlined by Green and Ringwood (1969). However, chemical, petrographical and field considerations indicate that the intermediate plutonic rocks are products of magma contamination rather than the result of gabbro fractionation. Similarly, the relative volume of the granophyres compared with that of the more basic rock types is at variance with their derivation from the gabbros by differentiation, and magma origin through crustal anatexis is considered more likely. In the major element–differentiation index plots (Fig. 18), phosphorus, titanium, manganese and calcium give non-curvilinear trends, particularly in the intermediate compositional range; this would not be so in an unmodified differentiation series (Nockolds and Allen, 1953). Various element ratios support this view. The K/Rb ratio would be expected to decrease slightly with fractionation, since rubidium is concentrated relative to potassium in the felsic fractions. However, the plot of K/Rb against the Thornton and Tuttle (1960) differentiation index (Fig. 19) is irregular; the individual rocks of the various rock groups tend to cluster together but there is no systematic fall in the ratio from the basic to the acidic plutonic rocks. In particular, the granodiorites have lower K/Rb ratios in comparison with the other post-volcanic plutonic rock groups. The Ba/Rb ratio, which is also predicted to decrease with magmatic differentiation (Gill, 1970), shows a similar distribution (Fig. 19). For these reasons, an origin by the fractional crystallization of a basic magma is not favoured for most of the Danco Coast plutonic rocks. However, fractionation may have occurred to some extent within the different rock groups.

1. *Gabbros*

With increasing differentiation index, the nine analysed gabbros (Fig. 18) show a progressive increase in silica, phosphorus, manganese, iron oxide and soda, together with a general decrease in lime and magnesia. Amongst the trace elements, zinc, yttrium, zirconium, niobium, barium, lanthanum and cerium increase slightly with increasing differentiation index, whilst chromium and nickel tend to decrease. All of these chemical changes could have been caused by the differentiation of a basic magma. However, the higher K/Rb and Ba/Rb ratios in the gabbros of western Rongé Island (Table XI, O.546.2) compared with the chemically more basic gabbros of Bruce and Bryde Islands argues against a relationship by differentiation processes; it is more probable that these two areas of basic plutonic rocks represent chemically distinct intrusions. The relatively high chromium content (259 p.p.m.) in the western Rongé Island gabbro outcrop could be due to the abundant pyroxene contained in these rocks (Table X). One of the gabbro specimens from Bruce Island (Table XI, O.933.1) is interpreted as a plagioclase cumulate. This rock is enriched in alumina (about 29 per cent), lime (16 per cent) and strontium, but it is impoverished in magnesia and nickel.

The average of eight of the analysed gabbros (Table XI) from the Danco Coast (i.e. excluding the cumulate gabbro specimen O.933.1) has a similar major-oxide chemistry to Nockolds's "average gabbro" (Nockolds, 1954, table 7, column 1), although the average gabbro from the Danco Coast contains less titanium and has a higher Fe^{3+}/Fe^{2+} ratio. Since the Fe^{3+}/Fe^{2+} ratios of most of the analysed Graham Land gabbros (Gourdon, 1908; Pelikan, 1909; Bodman, 1916; Adie, 1955; Marsh, 1968; Stubbs, 1968; Dewar, 1970) compare more favourably with the values given by Nockolds than with the values determined in this area, it is possible that the latter might be attributed to weathering processes.

2. *Diorites and quartz-diorites*

Although most of the major oxides and trace elements in the Mount Banck and Duthiers Point diorites are in accord with the trends of the other rock types on the Danco Coast (Fig. 18), both of these plutons contain unusually high amounts of phosphorus and titanium. In this respect, they are similar to tonalites (O.539.1 and 540.1) and granophyres (O.553.3) from rock exposures near Porro Bluff, which are believed to be contaminated. Both the assimilation of acidic material by a basic magma and the differentiation of a gabbro could have resulted in dioritic compositions such as those shown in the variation diagrams. It is apparent from the field relationships that some contamination of these diorites has occurred. However, the relative importance of contamination and crystal fractionation in the generation of the bulk of the diorites is unknown at the present time.

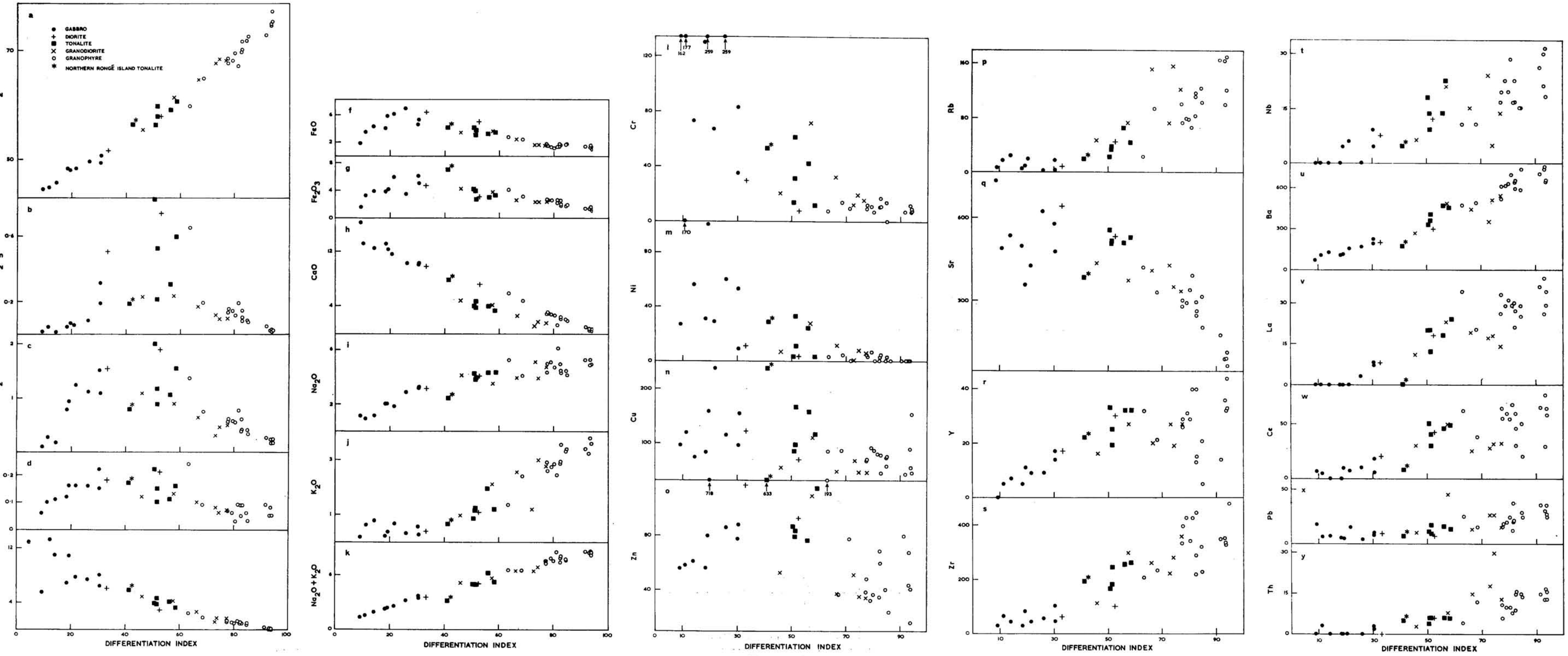

FIGURE 18

Plots of the major oxides and trace elements against the Thornton and Tuttle (1960) differentiation index for some Danco Coast plutonic rocks.

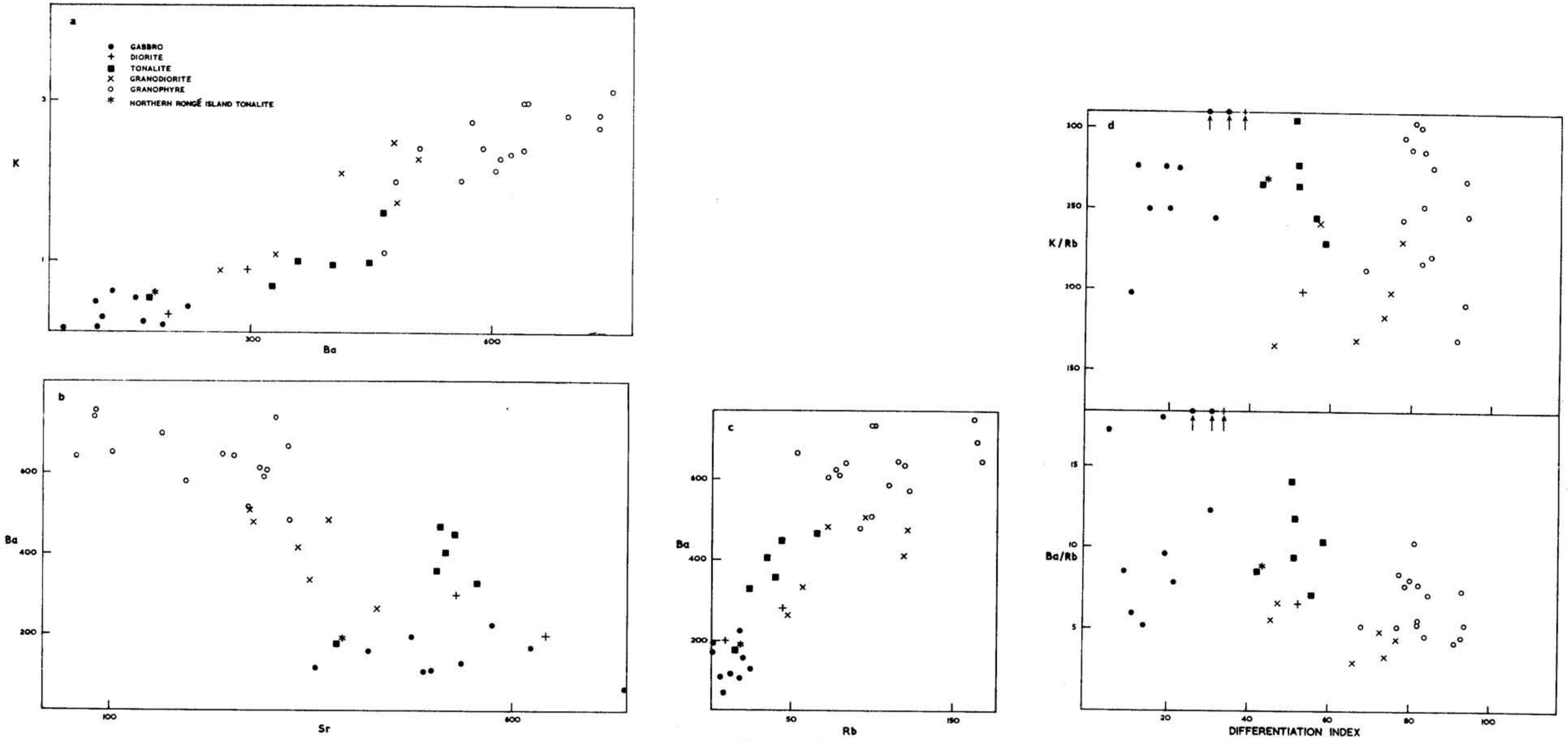

FIGURE 19

Plots of some Danco Coast post-volcanic plutonic rocks.

a. K against Ba.
b. Ba against Sr.
c. Ba against Rb.
d. K/Rb against differentiation index.
e. Ba/Rb against differentiation index.

3. *Tonalites*

The two texturally and mineralogically contrasting tonalite groups can also be distinguished from each other according to their chemistry.

a. *Northern Rongé Island.* In the differentiation index plots this tonalite lies on many of the major-oxide trends for the other Danco Coast plutonic rocks, although it has a rather high ferric iron content and a low alkali content (particularly soda). The trace-element concentrations of copper and zinc are high but the strontium, niobium, barium, lanthanum and cerium concentrations tend to be low, especially in comparison with the group (b) tonalites. The northern Rongé Island tonalite plots in the gabbroic fields of the A–F–M, Ca–Na–K, Ba–Rb, K–Ba and Ba–Sr diagrams; its low rare earth content also implies an affinity with these gabbroic rocks. From petrographical considerations and from its unusual chemistry, it is probable that this tonalite is a hybrid.

It is relevant here to reconsider the general geology of northern Rongé Island. The tonalites exposed at stations O.520 and 521 contain numerous gabbro xenoliths and, although some lava xenoliths are present, these are volumetrically far less important. Farther north, at station O.522, gabbro xenoliths are included in microgranites. Finally, there is an exposure of sheared pre-volcanic granitic rocks at the northern extremity of this island (O.523). Rock specimens from this last locality indicate that many of its constituent minerals, particularly quartz, have recrystallized.

It is chemically feasible to produce a compositionally similar tonalitic melt by the acidification of the gabbro magma with sheared granites; a mixture of two-thirds basic and one-third acid material is required (Table XII, columns 6 and 7). However, the resulting rock would be comparatively deficient in iron, zinc and zirconium, but enriched in chromium and barium. Another operative hybridizing mechanism would be one which favoured the selective movement of the major oxides and trace elements. It is conceivable that the sheared granites were re-mobilized to form a granitic magma which then re-intruded the gabbros. The heat necessary for this melting process could have been provided by the emplacement of the gabbros themselves. This newly formed granitic melt might have subsequently reacted with incorporated basic material, giving rise to intermediate rocks such as the tonalites.

A chemical comparison (Table XII) between the gabbros, microgranites, sheared granites, and the gabbro xenoliths in the microgranites and in the tonalites, lends support to this hypothesis. That the sheared granites and microgranites are related to each other is suggested by their similar but rather unusual chemistry (e.g. their high soda and low potash contents) (Table XII, columns 2 and 4). The composition of the gabbroic xenoliths occurring in the microgranites (Table XII, column 3) is similar to the computed average of the Danco Coast gabbros (Table XII, column 1). In this instance, it seems that there has been little chemical exchange between the host granite and the basic inclusions (Table XII, columns 3 and 4). In contrast, a significant ion exchange has occurred between the gabbro xenoliths and the tonalite (Table XII, columns 5 and 6). The movement of silica, soda, potash, rubidium, niobium, barium, lanthanum, cerium, lead and thorium from the magma to the gabbro xenoliths is complemented by the transfer of ferric and ferrous iron, magnesia, manganese, lime, chromium, nickel, zinc and strontium from the xenoliths to the (now) tonalitic magma. Alumina, zirconium and gallium appear to have remained chemically stable during this process.

If either mechanism is invoked to explain the unusual chemistry of these tonalites, it is necessary to accept that the shearing of the pre-volcanic granitic rocks (and the associated chemical changes) occurred prior to the emplacement of the gabbros.

b. *South of Porro Bluff.* Although specimens of this tonalite group were collected from widely separated localities, they form a particularly coherent chemical group. The largest tonalite exposure, which is situated about 1 km. south of Porro Bluff, shows some enrichment in phosphorus, titanium and manganese (Table XI, O.540.1), the former being attributable to the abundant apatite in these rocks. In many of the variation diagrams (Fig. 18) the tonalites occupy a position intermediate between that of the gabbros and the granophyres. However, the lime/differentiation index plot shows that the tonalites are depleted in lime in comparison with both of the other rock groups. Thus, it is considered unlikely that the gabbros, tonalites and granophyres are related to each other by differentiation processes. The displacement of the tonalites from an intermediate gabbro–granophyre position in the Ba–Sr diagram substantiates this view.

TABLE XII

POSSIBLE CHEMICAL RELATIONSHIPS BETWEEN THE GABBRO XENOLITHS, GABBROS, TONALITES, MICROGRANITES AND SHEARED GRANITES AT RONGÉ ISLAND

	1	2	3	4	5	6	7
SiO_2	47·23	72·42	47·90	72·96	49·52	56·26	55·62
TiO_2	0·87	0·25	0·77	0·29	1·05	0·77	0·66
Al_2O_3	17·53	13·60	20·13	14·42	16·85	14·57	16·22
Fe_2O_3	4·33	1·55	3·83	1·01	4·88	6·95	3·40
FeO	4·99	0·64	4·05	0·89	5·16	4·05	3·54
MnO	0·15	0·05	0·12	0·01	0·05	0·17	0·12
MgO	8·80	0·65	6·82	0·52	6·35	5·87	6·08
CaO	11·41	1·80	12·97	2·00	10·07	7·84	8·20
Na_2O	2·12	5·11	2·01	5·57	3·15	2·50	3·11
K_2O	0·45	1·84	0·20	1·50	0·65	0·64	0·91
Cr	135	11	130	9	35	53	94
Ni	64	—	31	—	9	29	43
Zn	129	43	56	10	77	633	100
Rb	13	77	6	53	23	20	34
Sr	496	256	497	291	380	473	418
Y	10	13	5	17	22	17	11
Zr	57	192	28	220	43	190	102
Nb	—	10	—	11	3	6	3
Ba	149	417	108	389	173	191	238
La	—	29	—	19	—	8	10
Ce	7	44	—	29	8	18	19
Pb	8	35	6	12	17	7	17
Th	—	16	—	22	5	—	5
Ga	14	12	13	12	16	12	13

1. Average of eight gabbros from the Danco Coast (Table XI, O.945.1, 934.6, 974.2, 934.1, 522.3, 546.2, 537.1 and 502.3).
2. Average of three sheared granitic rocks from Rongé Island (Table V, O.548.1, 550.2 and 549.2).
3. Gabbro xenolith in the northern Rongé Island microgranites (Table XI, O.522.3).
4. Microgranite from northern Rongé Island (Table XI, O.522.1).
5. Gabbro xenolith in the northern Rongé Island tonalites (Table XI, O.520.3).
6. Tonalite from northern Rongé Island (Table XI, O.520.1).
7. Hypothetical tonalite composition computed from a mixture of two parts of (1) and one part of (2).

The field and petrographical evidence implies that these tonalites are hybrid rocks, and that they are intimately related to the gabbros 0·25 km. to the north at station O.537; it is possible that the tonalites owe their origin to gabbro contamination. The high strontium contents of the tonalites relative to barium (Fig. 19), calcium and potassium restrict the contaminant to rocks of non-acid compositions, since acid rocks would contain insufficient amounts of this element. About 6 km.^{2} of volcanic rocks are exposed in the vicinity of Beneden Head, and specimens collected there by Bayly are mainly of rhyodacitic or quartz-latitic compositions. In Table XIII the chemistry of the average Danco Coast gabbro and that of three lava specimens from Beneden Head are compared. A mixture of equal proportions of each of these results in a hypothetical rock composition which is similar to the average of the five tonalite analyses. Clearly, such an origin is chemically possible and it agrees with the field evidence already outlined.

4. *Granodiorites*

Since the granodiorites are restricted to a few outcrops on the Danco Coast, it is believed that these rocks also originated by the local modification of a pre-existing magma. Chemically, the granodiorites have differentiation indices which are intermediate between those of the granophyres and the hybrid tonalites. Because of the great distances separating the tonalite and granodiorite exposures, these two rock groups are thought to have formed independently. The phosphorus and titanium enrichment of the tonalites has no parallel in the granodiorites, although both rock groups are noticeably depleted in calcium.

The granophyres and granodiorites are often closely associated in the field and, since both show petrographical similarities, it is more plausible to suspect a genetic relationship between these two rock groups. Generally, the granodiorites contain more chromium, nickel and strontium, and less barium, lanthanum, cerium and zirconium than the more acid rocks. Because the granophyres have K/Rb and Ba/Rb ratios which are higher than those found in the granodiorites, the relationship between these two rock groups by differentiation processes is unlikely. The relative volumes of the granodiorites and granophyres are also inconsistent with such a mechanism.

The field relationships, thin-section work and chemistry are most satisfactorily explained by the contamination of a granophyre magma by pre-existing basic or intermediate rocks. Basalts, andesites, gabbros, diorites and sedimentary rocks are known to have existed in this area prior to the intrusion of the granophyres. Hence each of these rock types must be considered as a possible source of contaminating material.

The analyses given in Table III can hardly be representative of the entire sedimentary succession on the Danco Coast but no additional analyses are available at the present time. It is clear that a rock resulting from the assimilation of such material by a granophyre melt would contain trace-element abundances which would depart significantly from those of the granodiorites; the rubidium, barium, lanthanum, cerium and possibly lead contents would be too high and the strontium content would be too low. However, the contamination of the granophyres by such rocks as the Bruce and Bryde Islands gabbros or by the Duthiers Point diorites, could produce rocks of comparable granodioritic compositions (Table XIV). Since there appears to be little difference between the chemical compositions of the deep-seated and the extrusive igneous rocks on the Danco Coast (Tables IX and XI), it is equally possible that the lavas and the pyroclastic rocks also contributed towards the formation of the granodiorites; about six parts of acid and four parts of basic material would be required.

5. *Granophyres*

a. *Chemical comparisons*. The average granophyre (Table XI, column 43) of the Danco Coast is enriched in soda in comparison with both the high-calcium and low-calcium granites as defined by Turekian and Wedepohl (1961). Apart from soda, the major-oxide chemistry of the granophyres is intermediate between these two granite types; the trace elements chromium, manganese, strontium, zinc, barium and thorium in the granophyres follow a similar pattern. The rubidium and yttrium contents of the Danco Coast rocks are closer to those of the high-calcium granites than to the low-calcium granites. Their higher zirconium concentrations (205–445 p.p.m.) and lower rare earth concentrations (20–39 p.p.m. of lanthanum and 20–77 p.p.m. of cerium), however, deviate considerably from Turekian and Wedepohl's (1961) values. Although the Danco Coast granophyres contain unusually high amounts of soda, this soda enrichment is rarely encountered in other analysed Andean granites from the Antarctic Peninsula (Adie, 1955; Fleet, 1968; Marsh, 1968; Stubbs, 1968). An interesting exception is the Cape Monaco granite (Hooper, 1962) which occurs on Anvers Island. A specimen (N.145.1) from this granite has been re-analysed in the present work because only major-oxide determinations had been carried out by Hooper. The chemistry of the Cape Monaco granite (Table XI, column 44) and several of the Danco Coast granophyres are very similar. Hooper has suggested a metasomatic origin for these Anvers Island rocks, although from the evidence

TABLE XIII

CHEMICAL COMPARISON BETWEEN THE GROUP (b) TONALITES AND A HYPOTHETICAL ROCK COMPUTED FROM A MIXTURE OF THE DANCO COAST GABBROS AND LAVAS

	1	2	3	4
SiO_2	64·63	47·23	56·93	57·17
TiO_2	0·75	0·87	0·81	1·29
Al_2O_3	14·48	17·53	16·01	15·99
Fe_2O_3	2·74	4·33	3·54	3·27
FeO	2·27	4·99	3·63	3·35
MnO	0·11	0·15	0·13	0·15
MgO	1·59	8·80	5·20	3·85
CaO	2·94	11·41	7·18	6·84
Na_2O	4·59	2·12	4·36	4·04
K_2O	2·27	0·45	1·36	1·23
H_2O+	2·01	1·35	1·68	1·43
H_2O-	0·16	0·27	0·22	0·17
P_2O_5	0·20	0·10	0·15	0·47
CO_2	0·81	0·30	0·56	0·15
Cr	12	135	74	32
Ni	1	64	33	15
Zn	84	129	107	88
Rb	100	13	57	41
Sr	300	496	408	521
Y	32	10	21	26
Zr	384	57	220	220
Nb	16	—	8	10
Ba	558	149	354	400
La	29	—	15	19
Ce	57	7	32	43
Pb	23*	8	15	13
Th	11	—	6	6
Ga	15	14	15	15

* Average of two.

1. Average of three lavas from Beneden Head. (Table IX, O.1001.4, 528.3 and 903.3).
2. Average of eight Danco Coast gabbros (Table XI, O.945.1, 934.6, 974.2, 934.1, 522.3, 546.2, 537.1 and 520.3).
3. Mixture of equal parts of (1) and (2).
4. Average of five group (b) tonalites (Table XI, O.540.1, 568.18, 552.1, 1000.1 and 539.1).

TABLE XIV

CHEMICAL COMPARISON BETWEEN THE GRANODIORITES AND HYPOTHETICAL GRANODIORITIC COMPOSITIONS COMPUTED FROM MIXTURES OF THE GRANOPHYRES, GABBROS AND DIORITES OF THE DANCO COAST

	1	2	3	4	5	6
SiO_2	45·48	49·70	70·55	62·20	62·27	62·28
TiO_2	0·55	1·47	0·37	0·81	0·55	0·61
Al_2O_3	18·51	15·44	14·55	14·91	15·61	15·37
Fe_2O_3	4·21	4·39	1·75	2·81	2·67	2·73
FeO	4·57	6·10	1·10	3·10	2·48	2·34
MnO	0·12	0·17	0·06	0·10	0·09	0·09
MgO	10·52	5·80	0·67	2·72	3·56	2·39
CaO	12·12	9·48	2·01	5·00	5·35	4·81
Na_2O	1·28	3·06	4·62	3·99	3·73	3·80
K_2O	0·65	0·38	3·09	2·01	2·15	2·13
H_2O+	1·86	1·96	0·77	1·25	0·99	2·24
H_2O-	0·39	0·79	0·19	0·43	0·22	0·37
P_2O_5	0·03	0·48	0·08	0·24	0·09	0·14
CO_2	0·10	0·28	0·25	0·26	0·27	0·28
Cr	104	29	11	18	55	26
Ni	85	11	1	5	23	9
Cu	143	121	68	89	90	68
Zn	60	117	41	71	52	53
Rb	21	9	109	69	75	88
Sr	482	641	162	354	281	330
Y	7	17	31	25	24	22
Zr	49	60	307	208	218	214
Nb	—	5	11	9	7	9
Ba	130	199	607	444	444	421
La	—	8	27	19	17	19
Ce	4	20	44	24	31	33
Pb	10	9	25	19	19	20
Th	—	—	13	8	8	12
Ga	13	16	14	15	14	14
K/Rb	260	351	235	242	238	200
Ba/Rb	6·27	22·1	5·57	6·43	5·92	5·06

1. Average of three gabbros from Bryde and Bruce Islands (Table XI, O.945.1, 934.6 and 933.1).
2. Diorite from Duthiers Point (Table XI, O.912.1).
3. Average of four granophyres from near Waterboat Point (Table XI, O.999.3, 942.8, 942.4 and 942.6).
4. A mixture of six parts of (3) and four parts of (2).
5. A mixture of about six parts of (3) and four parts of (1).
6. Average of six granodiorites from the Danco Coast (Table XI, O.556.1, 915.2, 935.2. 974.1, 561.1 and 996.1).

already outlined, it seems most unlikely that such processes have influenced the formation of the Danco Coast granophyres.

To date, the only published trace-element analyses of Graham Land granites are those of Adie (1955, table VII, analyses 11 and 12). No marked trace-element similarity was expected between these rocks and the Danco Coast granophyres because of the lack of soda enrichment in the former; these granites from Mount Reece and Cape Roquemaurel in Trinity Peninsula also contain lower amounts of iron oxide and higher amounts of lime and potash. Among the trace elements, the Trinity Peninsula granites contain far less zirconium, yttrium and lanthanum, and generally more strontium, barium and rubidium.

The pre-volcanic granitic rocks and the post-volcanic granophyres of the Danco Coast also show many chemical dissimilarities (cf. Table V, column 1; Table XI, column 43). Generally, the earlier granitic rocks are more acidic and possibly more highly differentiated than the granophyres. This is illustrated both by the major-oxide contents and by the values for the K/Rb and Ba/Rb ratios (Fig. 12). These ratios are a direct result of the lower amounts of barium and the higher amounts of rubidium contained in the pre-volcanic granitic rocks. In addition, the pre-volcanic granites are comparatively impoverished in zinc, zirconium, cerium (Fig. 12), copper, yttrium, lanthanum and lead. Since these differences occur in all of the analysed rocks (i.e. they are apparent in granites and granophyres of identical differentiation indices), it is proposed that the pre-volcanic granites and the post-volcanic granophyres originated either under different conditions or from chemically distinct parents. This is further substantiated by the fact that, although it is more basic, the average post-volcanic granophyre has a strontium content lower than that found in the average pre-volcanic granite. The chemical dissimilarity of these two rock types is not altogether unexpected because of the considerable time interval separating their formation. Their importance is in providing the first chemical evidence which might be of general use in distinguishing between granitic rocks of different ages in Graham Land.

b. *Origin and mode of intrusion.* A magmatic origin has already been suggested for the Danco Coast granophyres on the basis of their mineralogy and field relationships. The limited chemical variation of these acid rocks (Table XI) argues against their formation by metasomatic means. When plotted against the Thornton and Tuttle (1960) differentiation index (Fig. 18), the granophyres form well-defined and often curvilinear trends which could be ascribed to differentiation processes. Specimens from Porro Bluff (O.531.3 and 533.3) consistently plot away from the main granophyre fields. Known to be contaminated with basic volcanic and plutonic material, this pluton is relatively enriched in phosphorus, titanium, manganese, sodium, zinc, lanthanum and cerium, but it is relatively impoverished in calcium (O.531.3 only), silicon, potassium, rubidium and thorium.

Normative data from the Danco Coast granophyres are plotted in relation to the experimental "granite system" (Tuttle and Bowen, 1958) in Fig. 10. Only those rocks with Q+ or +ab$\geqslant$80 per cent are considered. Most of the granophyres plot between the ternary minimum at 3 kbar water pressure (Tuttle and Bowen, 1958) and the ternary eutectic at 5 kbar water pressure (Luth and others, 1964). This is further evidence that a magma was involved at some stage in the evolution of the granophyres.

Thus it appears that fairly substantial water pressures accompanied the formation of the granophyres. According to Middlemost (1971), such "wet" granites are typically found at great depths in the crust because these granite magmas cannot survive the ascent to high crustal levels in the liquid state. However, the presence of granophyric intergrowths and miarolitic cavities in these Danco Coast rocks implies high-level crystallization. A possible mechanism for the production of such water-rich high-level magmas might be one which has been adopted to explain the formation of ignimbrites (Middlemost, 1971). This requires the magma to be oversaturated in volatiles so that it would exert a lithostatic pressure on the surrounding country rocks. The magma could become a gas/fluidized system, forcing its way to the surface. Such a mechanism of intrusion is consistent with the envisaged emplacement of the granophyres by stoping (p. 40) and could also explain the existence of several apparently penecontemporaneous breccia dykes which occur at Coughtrey Peninsula and southern Bryde Island (O.952).

Granitic magmas are commonly believed to have formed by crustal melting or anatexis. The heat necessary for the melting processes can be generated in several ways:

i. By frictional heat such as is produced during shearing in orogenesis.
ii. By the lowering of crustal material into a high-temperature environment.
iii. By the upwelling and emplacement of high-temperature magma into the crust.

Any of these three mechanisms could have been operative during the generation of the granophyre magma.

It is unlikely that the pronounced albite enrichment which is evident in certain of the granophyre specimens from the Danco Coast can be attributed entirely to their crystallization at high water pressures, since the rather extreme values of 7 kbar and, in one instance, greater than 10 kbar, are indicated (Fig. 10). A high albite content, or rather a high Ab/An ratio (Winkler, 1967), in the source material could also produce such albite-rich melts. Albitic rocks are commonly found amongst geosynclinal sediments and it is possible that the geosynclinal sedimentary rocks of the Danco Coast have contributed to the formation of the granophyres. Unfortunately, it has not been possible to determine the chemical compositions of more than a few of these rocks. Nevertheless, the excess soda over both potash and lime in several of the siltstones, and the similarity of the yttrium, niobium, barium, lanthanum, cerium, lead and thorium contents in both the siltstones and in the granophyres suggests a possible relationship between the two rock types (Table III, column 1; Table XI, column 43). Another possibility is that the granophyre magma was derived by the frictional melting of the pre-volcanic granites during a period of extensive faulting (p. 25).

VI. HYPABYSSAL ROCKS

DYKES are common on the Danco Coast; most of them are microgabbros, microdiorites or their altered equivalents, although several are more acidic in composition.

A. GROUPING OF THE HYPABYSSAL ROCKS

The dykes of the Danco Coast have been divided into six groups on the basis of the petrographical, chemical and field evidence. They are described in what is believed to be their order of emplacement. Modal analyses of some of the dyke specimens are given in Table XV.

1. *Early microgranite dykes*

These pale green and often well-banded dykes were observed at three localities bordering Andvord Bay. The dykes are intruded into granodiorites (O.919), adamellites and granites (O.921 and 1003) which are thought to have been emplaced prior to the extrusion of rocks of the Upper Jurassic Volcanic Group. At Neko Harbour, these hypabyssal rocks represent the oldest of several dyke phases; the particular dyke examined by Hobbs showed an indistinct contact against the host granite, possibly implying that the microgranites were intruded before the country rocks had completely crystallized.

In thin section, the dykes are formed of a cryptocrystalline groundmass of quartz, potash feldspar and albite, although sometimes the quartz and the potash feldspar have crystallized as imperfectly developed spherulites. There are also a few coarser-grained patches of quartz, calcite, chlorite or iron ore, together with sparse subhedral plagioclase phenocrysts.

The one early microgranite dyke which was analysed for both major oxides and trace elements shows closer chemical affinities with the pre-volcanic granitic rocks than it does with the other acid plutonic rocks (i.e. the granophyres) exposed on the Danco Coast (cf. Table XVI, O.919.2 with Table V, column 1 and Table XI, column 43). Thus both the field and chemical evidence suggest that these early microgranite dykes represent a final intrusive episode of the pre-volcanic acid plutonism.

2. *Early altered basic to intermediate dykes*

These numerous dykes petrographically resemble the rocks of the Upper Jurassic Volcanic Group which they often intrude (O.544, 551, 553, 555, 560, 568, 573, 925 and 934.3–5). At several localities they are demonstrably older than the post-volcanic plutons: at station O.551 the dykes have been metamorphosed by the nearby extrusive granophyres, and the extensive and mineralogically similar alteration often found both in the dykes and in the associated volcanic country rocks can usually be attributed to these plutonic rocks. Cutting the tuffs and lavas near Sable Pinnacles (O.553 and 555), the easterly dipping leucocratic hypabyssal rocks are truncated by similar granophyre bodies.

A few dykes assigned to this group also cut other rock types occurring, for example, in the large pre-volcanic granite mass which extends along the south-eastern coast of Andvord Bay. In one of these dykes, numerous basic lava-like xenoliths which are petrographically distinct from the dyke host could also indicate a common origin for this dyke group and the volcanic rocks.

TABLE XV

MODAL ANALYSES OF HYPABYSSAL ROCKS FROM THE DANCO COAST

	O.551.4	O.920.1	O.545.5	O.563.4	O.904.2	O.941.2	O.554.3
Phenocrysts							
Plagioclase: fresh	1·0	5·1	—	35·2	—	33·4	4·9
altered*	—	1·3	—	—	—	0·4	—
Augite	—	—	—	—	—	5·5	0·7
Hornblende	—	—	—	—	—	—	1·1
Iron ore	—	—	—	—	—	—	0·5
Total	1·0	6·4	—	35·2	—	39·3	7·2
Groundmass							
Quartz	4·1	17·3	5·9	22·4	17·0	—	§
Potash feldspar	tr	33·0	tr	36·4	2·1†	—	§
Plagioclase	58·7	31·6	50·4	—	65·5	17·4	§
Augite	—	—	17·5	—	—	19·4	—
Tremolite-actinolite	16·0	—	—	1·5	—	—	—
Chlorite	tr	2·9	0·9	tr	3·4	16·7	§
(?) Serpentine	—	—	21·5	—	—	—	—
Iron ore	20·2	—	3·8	4·2	0·8	7·2	§
Leucoxene	—	0·2	—	0·1	1·0	—	—
Epidote	—	8·6	—	0·2	10·2‡	—	—
Accessory minerals‖	tr	tr	tr	tr	—	tr	—
Total	99·0	93·6	100·0	64·8	90·4	60·7	92·8
Plagioclase composition							
Phenocrysts	(?)	An_{12}	—	Albite	—	An_{56}	An_{56}
Groundmass	Albite	An_{8}	(?)	—	Albite	An_{50}	(?)

tr Trace.
* Calcite and epidote.
† In amygdales and veins.
‡ Including 7·5 amygdaloidal epidote.
§ Fine-grained and included in total groundmass.
‖ Including sphene, calcite and apatite.

O.551.4 Early altered intermediate dyke (metamorphosed); south-east of Selvick Cove.
O.920.1 Early altered intermediate dyke; Neko Harbour.
O.545.5 Microgabbro dyke; southern Rongé Island.
O.563.4 Microgranite dyke; Brewster Island.
O.904.2 Altered intermediate dyke; south-eastern Rongé Island.
O.941.2 Late augite-microgabbro dyke; south-east of Miethe Glacier.
O.554.3 Late hornblende- and augite-bearing microdiorite dyke; mainland east of Cuverville Island.

Only a few of the dykes were probably as basic as microgabbro when they were emplaced. One of these, a particularly altered greenish dyke (Table XVI, O.925.2), intrudes the tuffs on a small island north-east of Nansen Island. Now consisting of albite, epidote, calcite, chlorite, quartz, sphene, iron pyrites, haematite and leucoxene, the basic composition of this dyke is evident both from the major-oxide and trace-element chemistry. The original rock texture is still preserved in a compositionally similar basic dyke (Table XVI, O.568.4) at Cuverville Island. Uralitic amphibole has replaced the original pyroxene, whilst the less common alteration products, such as sericite, leucoxene, chlorite, epidote and calcite, represent the partial break-down of the other primary minerals.

The more numerous intermediate dykes are petrographically equivalent to some of the quartz-latite or rhyodacite lavas (see p. 27). Other slightly contact-metamorphosed dykes (O.551.3 and 4) are composed of irregular felted albite laths with granular iron ore and variable amounts of ragged acicular tremolite-actinolite. The few turbid plagioclase phenocrysts in these rocks have crenulate margins and they are sometimes traversed by a dendritic web of iron ore.

On the Danco Coast, the chemical similarity between the rocks of the Upper Jurassic Volcanic Group and the post-volcanic plutonic rocks (Tables IX and XI) makes it difficult to ascertain whether these dykes are comagmatic with the plutonic or the volcanic rocks. However, their close field association with the volcanic rocks and the apparent absence of pre-Upper Jurassic Volcanic Group gabbros and diorites suggest that a genetic relationship between the dykes and the extrusive rocks is more likely. The evidence, nevertheless, is incomplete and must be assumed tentative.

3. *Microgabbro dykes*

Dykes of this type have been identified at one locality (O.545) at southern Rongé Island but they are so petrographically distinct from the other dykes on the Danco Coast that they are considered separately. The field evidence provides no clue as to their age, since the country rocks, comprising pre-volcanic sheared granites, have been succeeded by several phases of igneous activity.

These dykes have a coarse-grained "plutonic" texture which is so similar to that of the gabbros in the west of this island (O.546) that a common origin for the two must be considered. In thin section (Table XV), this dyke is composed of subophitic plagioclase and augite, each about 0·5 mm. across, together with iron ore, quartz and secondary chlorite/serpentine. Much of the plagioclase has been acidified. Although present in the gabbros, neither olivine nor orthopyroxene were identified in the microgabbro dyke, but these minerals could easily be obscured by the ubiquitous alteration products.

Unfortunately, the only dyke specimen collected is too small for chemical analysis.

4. *Microgranite dykes*

These microgranite dykes (Table XV, O.563.4; Table XVI, O.563.4, 568.14, 568.8, 917.2, 905.1 and 920.2) are the hypabyssal equivalents of the post-volcanic granophyres. At Brewster Island (O.563.4) this is easily recognizable, since the dyke is both petrographically and chemically similar to the granophyre country rocks which it intrudes. The relationship is not so obvious at Cuverville Island (O.568.8 and 14), where the microgranite dykes possess a texture reminiscent of some spherulitic lava flows (O.937.7 and 942.2; p. 29) and they are intruded into volcanic rocks. Elsewhere, the dykes are intruded into granites (O.920) and into granodiorites (O.917 and 919) which are thought to have formed prior to the extrusion of the Upper Jurassic Volcanic Group.

In the following discussion these microgranite dykes are compared chemically with the plutonic and volcanic rocks occurring on the Danco Coast. It has already been mentioned that most of the elements in the extrusive rocks show similar trends to those in the deep-seated intrusive rocks. However, the alkalis show certain differences and Fig. 20 shows a plot of total alkalis against the Thornton and Tuttle (1960) differentiation index. In order to preserve the clarity of the diagram, only the outlines of the volcanic and plutonic fields have been drawn. The slightly differing trends followed by the volcanic and the plutonic rocks are obvious at the two extreme ends of the differentiation-index scale, the fields occupied by the two rock groups with intermediate differentiation indices being essentially the same. The acid dykes have been plotted on this diagram and they can be seen to show closer affinities with the plutonic rocks than with the acid lavas.

The postulated derivation of these microgranite dykes from the granophyres is not unreasonable, since such rocks are known to occur in the vicinity of all of the dyke outcrops.

5. *Altered basic to intermediate dykes*

These invariably altered hypabyssal rocks (Table XV, O.904.2; Table XVI, O.920.3, 562.8 and 904.2) are younger than the post-volcanic microgranites, granophyres and tonalites which they intrude almost

TABLE XVI

CHEMICAL ANALYSES OF HYPABYSSAL ROCKS FROM THE DANCO COAST

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
SiO_2	72·76	48·60	50·91	55·34	59·97	60·11	61·38	61·86	63·62	68·05	73·12	74·47	71·43	76·70	72·55	49·86	56·09	60·54	47·51	44·93	53·01	49·90	53·81	51·20	55·82	60·19
TiO_2	0·15	1·29	1·07	1·42	1·27	1·59	0·93	1·22	0·61	0·72	0·32	0·32	0·11	0·11	0·13	1·47	0·89	1·14	0·83	1·25	0·75	0·99	0·87	0·97	0·88	0·83
Al_2O_3	14·45	11·83	14·93	13·48	15·90	13·57	14·30	14·58	14·81	14·50	13·84	13·24	15·76	13·22	13·97	14·62	15·63	14·61	18·32	16·00	15·65	16·37	16·58	17·35	16·04	15·62
Fe_2O_3	1·06	4·18	5·23	4·05	4·06	3·93	3·20	2·92	1·36	2·03	1·48	1·55	0·96	0·74	1·38	5·03	4·01	3·47	3·72	4·47	3·31	5·46	3·85	5·66	3·07	3·98
FeO	0·61	5·33	4·90	3·96	2·26	2·82	2·88	3·17	3·10	1·36	0·62	0·68	0·72	0·56	0·80	5·62	3·45	2·44	5·04	4·57	3·78	4·22	4·95	4·66	4·24	2·69
MnO	0·03	0·15	0·16	0·15	0·07	0·14	0·17	0·11	0·11	0·11	0·04	0·05	0·04	0·04	0·06	0·24	0·14	0·15	0·11	0·15	0·08	0·14	0·13	0·09	0·13	0·15
MgO	0·13	5·17	6·91	3·28	2·92	3·28	2·13	1·83	1·83	1·02	0·67	0·64	0·13	0·04	0·03	3·95	3·27	2·97	7·80	6·95	6·96	5·51	4·12	3·57	3·34	2·38
CaO	1·00	9·12	5·47	9·16	5·72	4·71	3·87	4·24	3·13	2·46	1·29	1·21	0·89	0·92	0·57	5·40	5·69	3·74	10·22	11·29	8·39	8·68	7·51	6·77	7·58	4·90
Na_2O	3·78	2·57	3·80	4·19	5·83	3·81	3·63	5·45	4·58	5·82	3·81	3·60	4·82	3·90	4·93	2·62	3·96	5·99	1·99	2·09	2·45	2·68	3·16	4·18	3·10	4·09
K_2O	4·82	0·60	1·77	0·06	0·22	2·19	3·17	1·53	2·50	2·27	3·89	4·08	4·26	3·01	3·39	4·02	1·42	0·75	0·78	1·58	0·94	1·36	1·60	1·89	1·77	1·72
H_2O+	0·44	6·95	3·69	2·90	0·57	1·98	2·20	1·94	1·92	0·92	0·10	0·12	0·37	0·63	0·45	4·03	0·69	1·53	2·72	3·08	3·57	3·74	2·02	2·53	2·32	2·06
H_2O-	—	—	0·08	0·31	—	0·30	0·20	—	0·59	—	—	—	—	—	—	0·61	0·11	0·69	—	0·40	—	—	0·20	0·21	0·58	0·30
P_2O_5	0·03	0·20	0·14	0·44	0·46	0·18	0·32	0·37	0·18	0·15	0·06	0·06	0·05	0·02	0·02	0·35	0·12	0·35	0·14	0·24	0·14	0·14	0·15	0·15	0·19	0·18
CO_2	0·23	4·30	0·20	0·73	0·08	0·78	1·03	0·66	0·85	0·13	0·85	0·07	0·32	0·19	0·82	2·01	3·89	0·98	0·22	2·46	0·22	0·02	0·39	0·35	0·44	0·43
TOTAL	99·49	100·29	99·53	99·47	99·33	99·39	99·41	99·88	99·19	99·54	100·09	100·09	99·86	100·08	99·10	99·83	99·36	99·35	99·40	99·46	99·25	99·21	99·34	99·58	99·50	99·52
ANALYSES LESS TOTAL WATER (recalculated to 100)																										
SiO_2	73·46	52·07	53·31	57·49	60·72	61·90	63·27	63·16	65·80	69·00	73·13	74·49	71·80	77·12	73·54	52·38	56·91	62·33	49·14	46·81	55·40	52·27	55·41	52·87	57·78	61·95
TiO_2	0·15	1·38	1·12	1·48	1·29	1·64	0·96	1·25	0·63	0·73	0·32	0·32	0·11	0·11	0·13	1·54	0·90	1·17	0·86	1·30	0·78	1·04	0·90	1·00	0·91	0·85
Al_2O_3	14·59	12·67	15·64	14·00	16·10	13·97	14·74	14·89	15·32	14·70	13·84	13·24	15·84	13·29	14·16	15·36	15·86	15·04	18·95	16·67	16·36	17·15	17·07	17·92	16·60	16·08
Fe_2O_3	1·07	4·48	5·48	4·21	4·11	4·05	3·30	2·98	1·41	2·06	1·48	1·55	0·96	0·74	1·40	5·28	4·07	3·57	3·85	4·66	3·46	5·72	3·96	5·84	3·18	4·10
FeO	0·62	5·71	5·13	4·11	2·29	2·90	2·97	3·24	3·21	1·38	0·62	0·68	0·72	0·56	0·81	5·90	3·50	2·51	5·21	4·76	3·95	4·42	5·10	4·81	4·39	2·77
MnO	0·03	0·16	0·17	0·16	0·07	0·14	0·18	0·11	0·11	0·11	0·04	0·05	0·04	0·04	0·06	0·25	0·14	0·15	0·11	0·16	0·08	0·15	0·13	0·09	0·13	0·15
MgO	0·13	5·54	7·24	3·41	2·96	3·38	2·20	1·87	1·89	1·03	0·67	0·64	0·13	0·04	0·03	4·15	3·32	3·06	8·07	7·24	7·27	5·77	4·24	3·69	3·46	2·45
CaO	1·01	9·77	5·73	9·52	5·79	4·85	3·99	4·33	3·24	2·49	1·29	1·21	0·89	0·93	0·58	5·67	5·77	3·85	10·57	11·76	8·77	9·09	7·73	6·99	7·85	5·04
Na_2O	3·82	2·75	3·98	4·35	5·90	3·92	3·74	5·56	4·74	5·90	3·81	3·60	4·84	3·92	5·00	2·75	4·02	6·17	2·06	2·18	2·56	2·81	3·25	4·32	3·21	4·21
K_2O	4·87	0·64	1·85	0·06	0·22	2·26	3·27	1·56	2·59	2·30	3·89	4·08	4·28	3·03	3·44	4·22	1·44	0·77	0·81	1·65	0·98	1·42	1·65	1·95	1·83	1·77
P_2O_5	0·03	0·21	0·15	0·46	0·47	0·19	0·33	0·38	0·19	0·15	0·06	0·06	0·05	0·02	0·02	0·37	0·12	0·36	0·14	0·25	0·15	0·15	0·15	0·15	0·20	0·19
CO_2	0·23	4·61	0·21	0·76	0·08	0·80	1·06	0·67	0·88	0·13	0·85	0·07	0·32	0·19	0·83	2·11	3·95	1·01	0·23	2·56	0·23	0·02	0·40	0·36	0·46	0·44
ELEMENT PERCENTAGES LESS WATER AND CARBON DIOXIDE																										
Si^{4+}	34·34	24·34	24·92	26·88	28·39	28·94	29·58	29·53	30·76	32·26	34·19	34·83	33·56	36·06	34·38	24·49	26·61	29·14	22·97	21·88	25·90	24·44	25·90	24·72	27·01	28·96
Ti^{4+}	0·09	0·83	0·67	0·88	0·77	0·98	0·57	0·75	0·38	0·44	0·19	0·19	0·07	0·07	0·08	0·93	0·54	0·70	0·51	0·78	0·47	0·62	0·54	0·60	0·55	0·51
Al^{3+}	7·72	6·71	8·27	7·41	8·52	7·39	7·80	7·88	8·11	7·78	7·32	7·01	8·38	7·03	7·49	8·13	8·39	7·96	10·03	8·82	8·66	9·07	9·03	9·48	8·79	8·51
Fe^{3+}	0·75	3·13	3·83	2·94	2·88	2·83	2·31	2·09	0·98	1·44	1·04	1·08	0·67	0·52	0·98	3·70	2·85	2·50	2·69	3·26	2·42	4·00	2·77	4·09	2·22	2·86
Fe^{2+}	0·48	4·44	3·99	3·20	1·78	2·26	2·31	2·52	2·49	1·07	0·48	0·53	0·56	0·44	0·63	4·59	2·72	1·95	4·05	3·70	3·07	3·44	3·96	3·74	3·41	2·15
Mn^{2+}	0·02	0·12	0·13	0·12	0·05	0·11	0·14	0·09	0·09	0·09	0·03	0·04	0·03	0·03	0·05	0·20	0·11	0·12	0·09	0·12	0·06	0·11	0·10	0·07	0·10	0·12
Mg^{2+}	0·08	3·34	4·36	2·06	1·78	2·04	1·32	1·13	1·14	0·62	0·40	0·39	0·08	0·02	0·02	2·50	2·00	1·84	4·87	4·37	4·39	3·48	2·56	2·22	2·09	1·48
Ca^{2+}	0·72	6·98	4·09	6·80	4·14	3·47	2·85	3·09	2·31	1·78	0·92	0·87	0·64	0·66	0·41	4·05	4·13	2·75	7·56	8·41	6·27	6·50	5·53	5·00	5·61	3·60
Na^{+}	2·83	2·04	2·95	3·23	4·38	2·91	2·78	4·13	3·51	4·38	2·83	2·67	3·59	2·91	3·71	2·04	2·98	4·58	1·53	1·62	1·90	2·08	2·41	3·20	2·38	3·12
K^{+}	4·04	0·53	1·54	0·05	0·18	1·87	2·71	1·30	2·15	1·91	3·23	3·39	3·55	2·51	2·85	3·51	1·20	0·64	0·67	1·37	0·82	1·18	1·37	1·62	1·52	1·47
P^{5+}	0·01	0·09	0·06	0·20	0·20	0·08	0·14	0·16	0·08	0·07	0·03	0·03	0·02	0·01	0·01	0·16	0·05	0·16	0·06	0·11	0·06	0·06	0·07	0·07	0·09	0·08
C^{4+}	0·06	1·26	0·06	0·21	0·02	0·22	0·29	0·18	0·24	0·04	0·23	0·02	0·09	0·05	0·23	0·58	1·08	0·28	0·06	0·70	0·06	0·01	0·11	0·10	0·12	0·12
O^{2-}	48·85	46·18	45·11	46·02	46·90	46·90	47·20	47·16	47·75	48·13	49·11	48·97	48·74	49·69	49·16	45·14	47·35	47·38	44·91	44·87	45·92	45·01	45·64	45·09	46·11	47·01
NORMS																										
Q	30·41	9·01	0·66	12·53	11·97	17·63	18·47	14·90	17·93	20·42	32·76	34·58	25·15	40·68	30·25	2·84	12·18	13·07	—	—	8·73	4·99	7·76	1·26	11·47	17·45
C	1·28	—	—	—	—	—	—	—	—	—	1·17	0·85	1·74	1·94	1·23	—	—	—	—	—	—	—	—	—	—	—
or	28·82	3·98	10·98	0·37	1·32	13·43	19·51	9·29	15·41	13·62	23·19	24·13	25·38	17·92	20·48	25·49	8·86	4·61	4·78	9·98	5·82	8·42	9·77	11·57	10·88	10·51
ab	32·36	24·42	33·74	37·10	49·97	33·46	31·99	47·39	40·43	49·99	32·51	30·49	41·12	33·24	42·64	23·78	35·39	52·70	17·45	18·91	21·71	23·75	27·64	36·65	27·27	35·77
an	4·82	21·30	19·36	18·62	16·78	13·97	13·92	11·10	13·01	6·84	6·06	5·62	4·12	4·47	2·76	17·45	21·84	11·19	40·17	31·66	30·30	29·98	27·22	23·83	25·60	19·83
di	—	22·49	6·46	20·61	6·94	7·06	3·11	6·44	1·61	3·55	—	—	—	—	—	7·13	5·68	4·46	9·12	21·01	9·77	11·18	8·30	7·95	9·87	3·21
hy	0·38	8·71	18·36	0·70	4·15	5·21	5·53	3·24	7·89	0·93	1·68	1·60	0·75	0·41	0·31	11·60	7·82	5·63	20·72	0·20	16·80	11·06	11·47	7·96	8·07	5·20
ol	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·20	8·17	—	—	—	—	—	—
mt	1·56	6·81	7·96	6·15	3·88	5·12	4·83	4·35	2·06	2·70	1·21	1·43	1·40	1·08	2·05	7·83	6·14	5·23	5·59	6·93	5·03	8·29	5·77	8·50	4·63	5·97
il	0·29	2·75	2·13	2·82	2·44	3·13	1·84	2·38	1·21	1·39	0·61	0·61	0·21	0·21	0·25	3·00	1·79	2·25	1·63	2·54	1·49	1·97	1·71	1·91	1·74	1·63
hm	—	—	—	—	1·44	0·54	—	—	—	0·20	0·66	0·57	—	—	—	—	—	—	—	—	—	—	—	—	—	—
ap	0·07	0·53	0·35	1·09	1·10	0·44	0·79	0·90	0·44	0·36	0·14	0·14	0·12	0·05	0·05	0·89	0·30	0·86	0·34	0·61	0·35	0·35	0·37	0·37	0·47	0·44
TRACE ELEMENTS																										
S	36	4372	217	1393	20	94	17	153	64	32	116	328	133	62	47	37	138	63	121	279	62	205	90	131	92	70
Cr	8	40	33	11	10	13	10	9	16	10	12	9	8	10	9	19	17	10	111	87	109	50	20	36	45	11
Ni	—	14	9	3	2	3	1	1	4	—	—	—	—	—	—	5	2	2	42	37	82	14	11	12	17	2
Rb	246	24	75	—	10	90	171	57	118	72	139	147	142	148	143	178	45	33	22	88	24	39	61	53	51	61
Sr	120	424	624	136	529	445	300	320	451	351	175	176	82	117	83	251	524	298	589	641	526	954	488	899	345	584
Y	10	15	11	27	31	30	29	39	29	45	21	21	33	26	34	16	18	35	13	12	10	13	12	22	22	22
Zr	141	100	116	212	231	289	333	364	464	501	249	257	316	173	316	144	140	248	87	69	110	112	101	152	233	183
Nb	15	5	5	11	8	11	14	15	17	18	12	13	16	13	15	8	5	10	5	5	3	4	4	2	7	5
Ba	458	1286	317	116	276	440	605	533	658	689	592	677	760	608	717	826	365	216	216	282	235	407	364	458	403	463
La	24	9	10	20	20	28	27	33	29	35	22	23	36	30	52	8	9	16	7	—	8	12	8	11	14	14
Ce	41	7	17	41	41	51	54	69	64	77	32	29	68	58	90	16	15	36	13	27	22	30	14	22	30	30
Pb	30	12	36	14	23	16	16	19	23	31	70	134	37	28	40	30	10	17	—	5	12	9	26	19	12	15
Th	26	4	4	8	5	10	10	10	14	10	16	15	18	17	20	6	5	8	—	—	2	4	6	6	5	5
Ga	14	13	15	20	17	20	*	17	18	17	14	12	17	13	*	*	14	16	15	15	13	15	15	14	14	16
D.I.	91·90	37·60	45·30	50·00	63·20	64·40	69·90	71·50	73·60	83·80	88·30	89·00	91·50	91·80	93·20	52·00	56·40	70·30	22·20	28·80	36·20	37·10	45·10	49·40	49·50	63·60

* Not determined.

1. O.919.2 Early microgranite; Forbes Point.
2. O.925.2 Early altered basic dyke; small island to the north-east of Nansen Island.
3. O.568.4 Early altered basic dyke; Cuverville Island.
4. O.528.4 Early altered intermediate dyke; Beneden Head.
5. O.551.4 Early altered intermediate dyke (metamorphosed); south-east of Selvick Cove.
6. O.940.7 Early altered intermediate dyke; at the head of Miethe Glacier.
7. O.920.1 Early altered intermediate dyke; Neko Harbour.
8. O.573.3 Early altered intermediate dyke; 3 km. to the east of Beneden Head.
9. O.910.2 Early altered intermediate dyke; Neko Harbour.
10. O.563.4 Microgranite dyke; Brewster Island.
11. O.568.14 Microgranite dyke; Cuverville Island.
12. O.568.8 Microgranite dyke; Cuverville Island.
13. O.917.2 Microgranite dyke; western coast of Andvord Bay.
14. O.905.1 Microgranite dyke; station O.905 to the south of Rongé Island.
15. O.920.2 Microgranite dyke; Neko Harbour.
16. O.920.3 Altered basic dyke; Neko Harbour.
17. O.562.8 Altered intermediate dyke; Birdsend Bluff.
18. O.904.2 Altered intermediate dyke; south-eastern Rongé Island.
19. O.930.2 Late augite-microgabbro dyke; east of Coughtrey Peninsula.
20. O.941.2 Late augite-microgabbro dyke; east of Miethe Glacier.
21. O.568.3 Late augite-microdiorite dyke; Cuverville Island.
22. O.537.8 Late augite-microdiorite dyke; south-east of Porro Bluff.
23. O.915.3 Late augite-microdiorite dyke; Waterboat Point.
24. O.951.1 Late augite-microdiorite dyke; eastern Bryde Island.
25. O.934.4 Late augite-microdiorite dyke; north-western Bryde Island.
26. O.554.3 Late hornblende-augite-microdiorite dyke; mainland east of Cuverville Island.

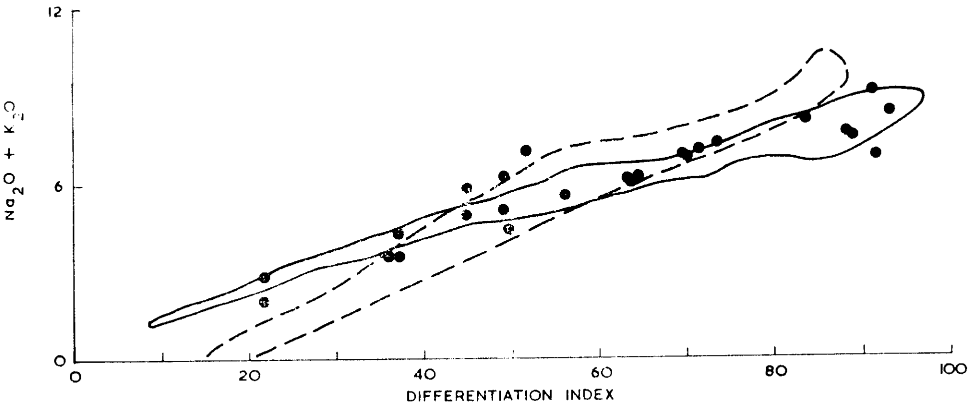

FIGURE 20

A plot of total alkalis against the Thornton and Tuttle (1960) differentiation index for the analysed hypabyssal rocks from the Danco Coast. The outlines of the fields occupied by the Danco Coast volcanic (dashed line) and plutonic (solid line) rocks are also shown.

without exception. It is possible that the dyke emplacement occurred whilst the plutonic rocks were still hot; associated fluids would then be plentiful and could account for the present altered state of the dyke rocks. The rather diffuse dyke/granophyre contacts at south-eastern Rongé Island (O.902) lend support to this hypothesis.

At Useful Island, a fine-grained dyke (O.1000.2) which is intruded into tonalites has a groundmass of weakly flow-aligned plagioclase microlites, granular iron ore, sphene and interstitial chlorite. Pyroxene phenocrysts are almost completely replaced by calcite, and plagioclase phenocrysts are pseudomorphed by calcite and muscovite. Irregular quartz segregations also occur in the groundmass. There are petrographically identical dykes in the tuffs at Mount Banck (O.938.10) and in the granites and adamellites at Neko Harbour. One of the latter dykes (O.920.3) is representative of the youngest of three dyke phases recorded by Hobbs at Neko Harbour.

The coarser-grained dykes are often petrographically similar to some of the early altered basic to intermediate dykes. The only difference is the presence of rare pyroxene remnants amongst the chlorite/epidote pseudomorphs in the younger rocks. The chemical analyses of these altered basic to intermediate dykes are also generally similar to those of the early altered basic to intermediate dykes.

6. *Late microgabbro and microdiorite dykes*

Microgabbro and microdiorite dykes occurring on the mainland east of Cuverville Island (O.554), at stations O.536 and 537 south of Porro Bluff and at Waterboat Point intrude the post-volcanic plutonic rocks, and they are probably Tertiary in age. Several similar dykes cut the earlier volcanic rocks (O.568.3 and 934.4), sedimentary rocks (O.930.2) or the pre-volcanic sheared granites (O.951.1). Since these dykes are usually even fresher in appearance than many of those in the post-volcanic plutonic rocks, they are considered with them in this section.

The modal and chemical analyses of some of these rocks are given in Tables XV and XVI. The groundmass is typically composed of randomly orientated plagioclase laths (about An_{58} in specimen O.930.2), granular augite, iron ore, devitrified glass and alteration products. When present, cryptocrystalline interstitial potash feldspar is often an important constituent (O.934.4 and 951.1). The dykes always contain subhedral phenocrystic labradorite which sometimes shows both normal and oscillatory zoning. The ubiquitous straw-coloured augite phenocrysts ($2V\gamma = 50°$) are commonly twinned. Many of them show a well-developed hour-glass structure and there is sometimes slight marginal zoning. Most of the augite is fresh despite the altered state of the surrounding rock. There are a few colourless hypersthene crystals in some of these dykes (O.934.4), and ilmenite forms irregular and skeletal patches.

Similar but finer-grained and hornblende-bearing microdiorite dykes intrude the granophyres south-east of Sable Pinnacles (O.554). Twinned on (100), the hornblende phenocrysts are often euhedral although the crystals are sometimes rounded and embayed. Accessory apatite is also present.

Chemically, the late microgabbro and microdiorite dykes have the high alumina values characteristic of calc-alkaline rocks. The two most basic dyke specimens analysed (O.930.2 and 941.2) contain total alkalis in concentrations similar to that of the gabbros exposed on the Danco Coast (Fig. 20) but otherwise the chemistry of these dykes cannot be differentiated from either the plutonic or volcanic rocks.

B. Chemical Changes during Alteration

Because there is a general chemical similarity between the intrusive and extrusive rocks on the Danco Coast, it should be possible to determine the chemical changes caused by the alteration processes by comparing the analyses of the considerably altered basic and intermediate dykes (p. 49 and 51-52) with those of the relatively fresh (?) Tertiary microgabbro and microdiorite dykes (p. 52).

From Table XVI it is apparent that the oxides of iron, manganese and magnesium are similar in both the altered and unaltered dyke rocks. However, in most of the altered rocks there is a noticeable alumina loss, together with an increase in titania, phosphorus and water; the soda, potash and carbon dioxide contents are variable. Lime usually shows little change but in some of the altered dykes (e.g. in the analysis of specimen O.568.4) it is slightly depleted.

Many of the trace elements (chromium, nickel, yttrium, zirconium, niobium, cerium, lanthanum and thorium) are apparently unaffected by the alteration processes. In other altered dykes the rubidium and barium contents vary in sympathy with potassium, particularly in the analyses of specimens O.528.4, 551.4, 920.3 and 904.2. The low potash content of a dyke at southern Rongé Island (O.904.2) is reflected in the unusually small amounts of potash feldspar contained in this rock; its high soda value is possibly indicative of albitization. Abnormally high concentrations of barium (1,286 p.p.m.) in the analysis of specimen O.925.2 suggests that most of the barium has not substituted for potassium but is contained in its own mineral such as barytes. However, this mineral was not observed in the thin section examined. Two of the dyke rocks which have been tentatively correlated with the Upper Jurassic Volcanic Group (O.528.4 and 925.2) are particularly enriched in sulphur.

VII. CONCLUSIONS AND COMPARISONS WITH OTHER AREAS

A. Sedimentary Rocks

The oldest rocks exposed on the Danco Coast are cataclastically deformed, non-fossiliferous and often well-bedded siltstones and feldspathic sandstones which are tentatively correlated with the Trinity Peninsula Series. Accounting for only a small proportion of the rocks exposed on the Danco Coast, the most important outcrops of sedimentary rocks form a belt stretching from Miethe Glacier in the west to the head of Andvord Bay in the east. Smaller exposures of hornfelsed sediments have been discovered at Waterboat Point and Reclus Peninsula. Re-deposition of the sediment by turbidity currents in a geosynclinal environment could explain the lithology, sedimentary structures and microscopic textures of the sandstones and siltstones.

In the type area of Trinity Peninsula, the sedimentary rocks have been folded into at least two asymmetrical anticlinoria, arranged *en échelon*, with steeper north-dipping limbs and east-north-easterly trending axes (Elliot, 1965, 1966, 1967*b*). In parts of eastern Trinity Peninsula some of the sedimentary rocks are probably overturned (Aitkenhead, 1965). No folding has been detected in these sedimentary rocks on the Danco Coast; in the area between Miethe Glacier and Andvord Bay, the strata often dip at about 45° to the south or south-east and local variations in attitude can usually be explained by faulting or by the intrusion of later plutonic rocks.

The apparent absence of Permian–Triassic sedimentary rocks on the Danco Coast suggests that the conditions became unfavourable for the further accumulation of marine sediments. Such a situation might have arisen as a result of uplift during late Palaeozoic earth movements.

B. Pre-volcanic Plutonic Rocks

Large outcrops of grandioritic to granitic rocks and associated hypabyssal intrusions crystallized later than the deposition of the sedimentary rocks but prior to the extrusion of the rocks of the Upper Jurassic Volcanic Group. Chemically distinct from the younger granophyres of this area, the analyses of the granitic rocks (particularly the trace-element analyses) provide the first chemical evidence which might be of general use in distinguishing between granitic rocks of different ages in Graham Land. The mineral content of the Danco Coast granites implies that they are the products of high-level crystallization. Two granite types are recognized at Neko Harbour and these are believed to represent the marginal and central parts of a pluton crystallizing from its margin inwards. The extensive shearing of these rocks could have been associated with the large-scale faulting known to have occurred in the vicinity of Gerlache Strait.

No comparable rocks have been described from either the Graham Coast or Anvers Island. Although petrographically similar granitic rocks are common in the Antarctic Peninsula (e.g. the extensively sheared pre-volcanic acid plutonic rocks of the Loubet Coast (Goldring, 1962) and the "white granites" and the "coarse pink granites" (Adie, 1954) of the Fallières Coast), no characteristics have emerged from a study of these rocks by which any Antarctic Peninsula granite could be assigned to a particular age. Clearly, petrographical descriptions alone are inadequate for correlation purposes. It is considered that in the absence of radiometric dating, little progress can be made in the regional correlation of the Antarctic Peninsula granitic rocks without extensive trace-element analyses and field observations.

C. Volcanic Rocks

The widespread sequences of volcanic rocks and associated dykes on the Danco Coast have been correlated with the Upper Jurassic Volcanic Group which is exposed elsewhere in the Antarctic Peninsula. Although the volcanic rocks of the Danco Coast range from basalt to rhyolite, the two extreme rock compositions are rare, and rhyodacitic and quartz-latitic rocks probably predominate over the andesitic tuffs and lavas. This is in contrast to most of the other areas investigated in western Graham Land where andesitic rocks are usually more abundant than the more acidic types (Goldring, 1962; Hooper, 1962; Curtis, 1966).

The predominance of pyroclastic deposits and the apparent absence of extensive water-laid strata and pillow lavas suggests that much of the volcanic activity on the Danco Coast was of an explosive nature and occurred under subaerial conditions. Since water-deposited volcanic rocks are exposed only 50 km. to the south-east (Curtis, 1966), it is probable that a shoreline was not far distant at this time. On the Danco Coast the thickness of the volcanic sequence is unknown but it has been established that there are between 1,300 and 1,800 m. of tuffs and lavas at Anvers Island (Hooper, 1962) and on the Graham (Curtis, 1966) and Loubet (Goldring, 1962) Coasts.

Some of the more basic lavas on the Danco Coast have chemical affinities with island-arc tholeiites and, in this respect, they can be compared with the rocks of the Upper Jurassic Volcanic Group at Adelaide Island for which Dewar (1970) has suggested a tholeiitic basalt parent. The more acidic lavas on the Danco Coast are entirely calc-alkaline in composition. The initial state of many of the tuffs and lavas has been masked by subsequent alteration and alkali-metasomatism. Whilst the crystallization of much of the secondary albite, epidote and prehnite is thought to be related to later plutonism, it is possible that an earlier phase of alteration in these rocks was caused by burial metamorphism.

In the Anvers Island area, the volcanic rocks unaffected by Andean intrusions usually dip at angles of less than 10° (Hooper, 1962). However, Curtis (1966) discovered that the volcanic rocks in Penola Strait, Graham Coast, have been folded into an asymmetrical syncline with a north-easterly trending axis. At most localities on the Danco Coast the volcanic rocks are massive with little evidence of structure.

D. Post-volcanic Plutonic Rocks

At some time subsequent to the extrusion of the volcanic rocks, a number of discordant gabbroic to granitic plutons were emplaced in their present positions on the Danco Coast. Although the diorites at Duthiers Point were intruded during the Middle Cretaceous, the absolute age of most of the Danco Coast plutonic rocks is unknown. They appear to have been intruded in order from the most basic to the most acid and thus most of the granophyres would be expected to yield even younger ages than the Duthiers Point diorites. This basic-to-acid order of emplacement is characteristic of the Andean Intrusive Suite in Graham Land (Adie, 1955; Curtis, 1966; Dewar, 1970).

The exposures of gabbros are usually situated on the coastal extremities of the Danco Coast and few gabbroic rocks have been discovered inland. The chemistry of these rocks suggests that the gabbro outcrops represent several separate basic plutons which do not interconnect at depth. Although many layered gabbroic intrusions have been described from Graham Land, no macroscopic layering was observed either by Bayly or Hobbs on the Danco Coast. Several of the rock specimens examined exhibit a microscopic layering which can probably be ascribed to magmatic flowage rather than to crystal settling.

Several authors have remarked on the widespread occurrence of intermediate plutonic rocks in various parts of the Antarctic Peninsula (Adie, 1955; Curtis, 1966). However, on the Danco Coast, as on the Loubet Coast (Goldring, 1962), these rocks appear to be relatively uncommon. Although Adie (1955) originally believed that there was a continuous crystal differentiation series from the gabbroic to the granitic rocks of the Andean Intrusive Suite, many penecontemporaneous plutonic rocks on both the eastern and western sides of the Antarctic Peninsula have since been interpreted as hybrids. Because of the diversity of primary magmas which are supposed to have existed at this time (e.g. gabbroic and tonalitic magmas at Anvers Island, and gabbroic and granodioritic magmas on the Graham and Loubet Coasts), and the variable composition of the country rocks which these have intruded, it is not surprising that several mechanisms have been advanced to explain the genesis of the diorites, tonalites and granodiorites (Goldring, 1962; Hooper, 1962; Curtis, 1966; Dewar, 1970). All of the Danco Coast intermediate plutonic rocks are considered to have formed by hybridization processes and several new mechanisms are advanced to explain them.

Rocks comparable with the Danco Coast granophyres are widely distributed in the Antarctic Peninsula. Adie (1955) has described similar rocks from Marguerite Bay (the Red Rock Ridge granite), and petrographically identical granophyres occur on the Graham (Curtis, 1966) and Loubet (Goldring, 1962) Coasts. Both Curtis and Goldring considered that the acid plutonic rocks of the respective areas studied by them were the differentiation products of a granodioritic magma. The chemical data are inconsistent with such an origin for the Danco Coast granophyres, and instead it is postulated that these rocks have formed by the melting of granitic or sedimentary rocks at depth. It is considered that the granophyre magma, oversaturated with volatiles, forced its way to the surface as a gas/fluidized system and was emplaced into the predominantly volcanic country rocks by stoping.

The plutonic rocks of the Danco Coast comprise the typical calc-alkaline assemblage of orogenic belts. The rocks have been found to be chemically indistinguishable from the lavas of the Upper Jurassic Volcanic Group in this area, apart from slight differences in the alkali contents of the more basic and acidic rocks. Well-defined trends emerge when these rocks are plotted on A–F–M and Na–Ca–K diagrams, and these are in agreement with the trends and analyses recently determined by Hooper (1962), Fleet (1968) and Dewar (1970) for similar Graham Land rocks. However, the plots given by Adie (1955) as being representative of the Andean Intrusive Suite of Graham Land are slightly displaced towards the M and the Na apices of the A–F–M and the Na–Ca–K diagrams, respectively; these plots could probably be modified in the light of additional chemical analyses which are now available. Since it is well known that there is a close relationship between the orogenic belt of the Antarctandes and the mountains of the South American Andes, it is interesting that the A–F–M and the Na–Ca–K trends of the Danco Coast plutonic rocks are almost identical to those computed by Adie (1955, fig. 16) for some Andean intrusive rocks from Patagonia. The Cretaceous–Tertiary batholith of Peru (Cobbing and Pitcher, 1972) also exhibits many features which are characteristic of penecontemporaneous plutonic areas in Graham Land. This South American batholith has stoped its way into Mesozoic volcanic rocks, it contains a predominance of intermediate plutonic rocks over gabbros and granites, and it shows a basic-to-acid order of emplacement. Often basified with xenoliths which are "probably disrupted, spalled-off flakes of the roof volcanics", the Peruvian granophyres of the Puscao unit contain large-scale layered structures which may be compared with a similar layering observed in the Danco Coast granophyres (p. 38).

Classically, such gabbro-to-granite assemblages have been regarded as the result of the crystallization of a dioritic magma, the gabbros forming by crystal accumulation and the granites representing the residual fraction of the magma (cf. Adie, 1955). Cobbing and Pitcher (1972) have suggested that the main bodies of magma of the Peruvian batholith formed as a result of re-melting processes, the products being further diversified by crystal differentiation and assimilation. Such a mechanism has already been advanced to explain the origin of the acidic rocks of the Danco Coast and this hypothesis might have an even wider application in other areas of the Antarctic Peninsula.

E. Hypabyssal Rocks

The numerous hypabyssal rocks on the Danco Coast have been divided into six groups, five of which are probably related to the volcanic and plutonic episodes already described. However, the relatively fresh (?)

Tertiary microgabbro and microdiorite dykes are considered to be associated with the Tertiary volcanicity, which existed at Anvers Island (Hooper, 1962), rather than with the preceding cycle of plutonism.

Earlier geological reports describing the north-western and western coasts of Graham Land have emphasized the abundance of dykes found over this area. Several of the dykes have been chemically analysed but, apart from the present work, the trace-element contents of the dyke rocks are unknown. No diagnostic features have emerged from these chemical analyses by which different phases of dyke activity might be distinguished. A possible exception are some Tertiary hypabyssal rocks on the Nordenskjöld Coast amongst which Elliot (1967*a*) recognized dykes with calc-alkaline, alkaline and tholeiitic affinities. However, all of the unaltered Danco Coast dykes are calc-alkaline and no representatives of those with tholeiitic and alkaline affinities have been discovered.

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PLATE I

a. The Falkland Islands Dependencies Survey station at Danco Island. At south-eastern Rongé Island (background) the granophyres (grey) have intruded volcanic rocks (black; far right). (Photograph by R. J. Adie.)

b. Danco Island (centre) and part of the coastal mainland bordering Errera Channel. (Photograph by R. J. Adie.)

c. View of Hübl Peak (centre) and Birdsend Bluff (far right). The low ice cliff which fringes this part of the coastline is typical of many other localities on the Danco Coast. (Photograph by R. J. Adie.)

d. Beneden Head (left) and southern Rongé Island (right) viewed from Danco Island. Lemaire Island is visible in the distance. (Photograph by G. J. Hobbs.)

a

b

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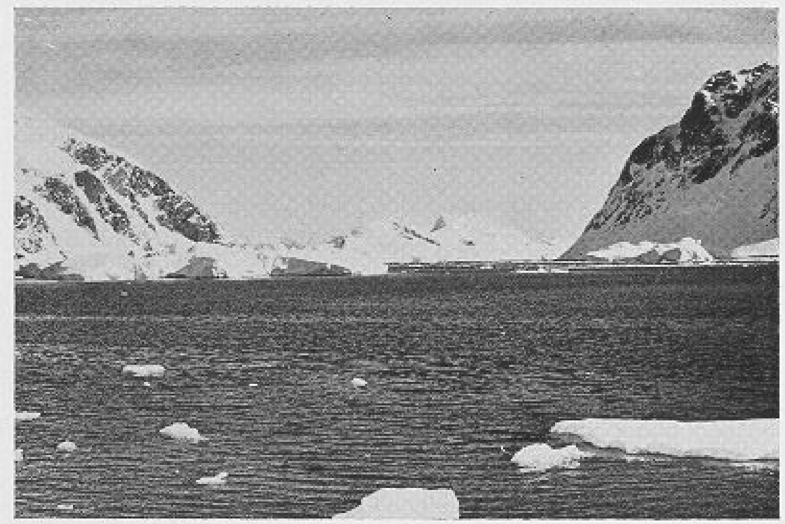

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PLATE I

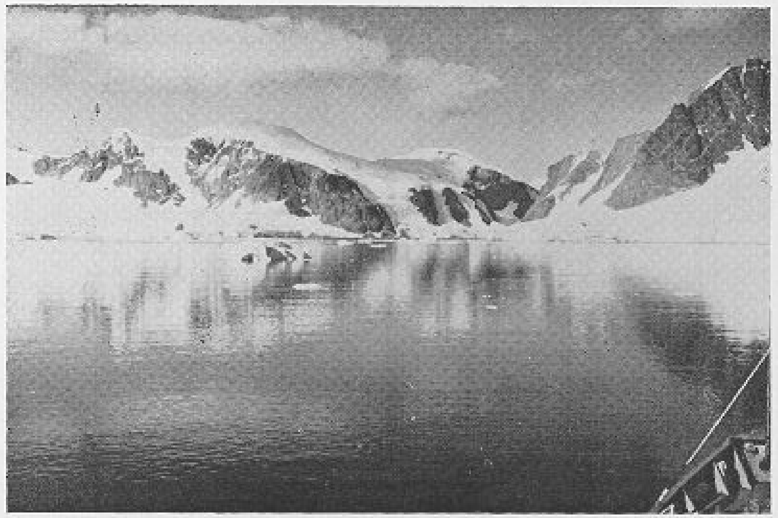
PLATE II

a. The mainland leading to Beneden Head at the southern end of Errera Channel (left and centre). At south-eastern Rongé Island (right) the intrusive granophyre/volcanics contact is particularly well exposed. (Photograph by R. J. Adie.)

b. The volcanic rocks at north-eastern Rongé Island (O.525–527) with R.R.S. *Bransfield* anchored offshore. (Photograph by R. J. Adie.)

c. Part of Cuverville Island (left) and the adjacent mainland viewed from the east. (Photograph by R. J. Adie.)

d. Birdsend Bluff viewed from the south-east. (Photograph by G. J. Hobbs.)



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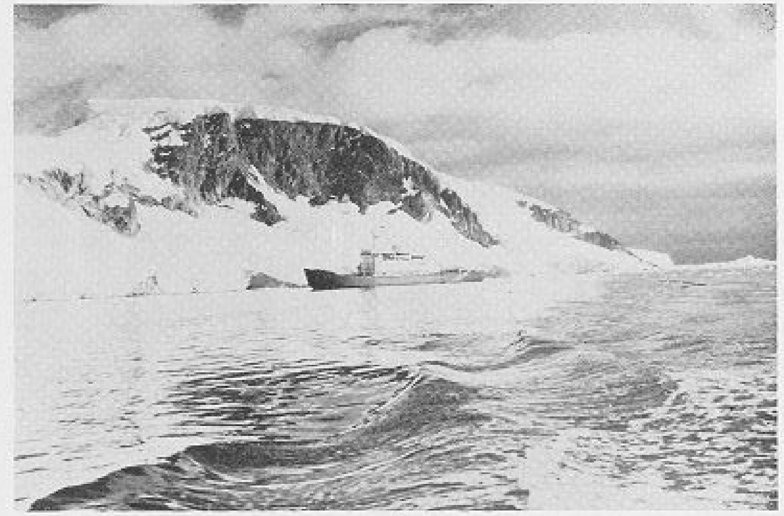

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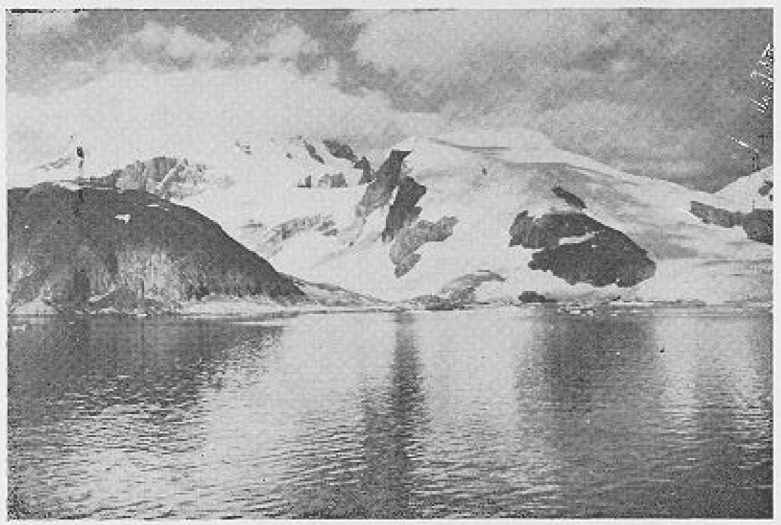

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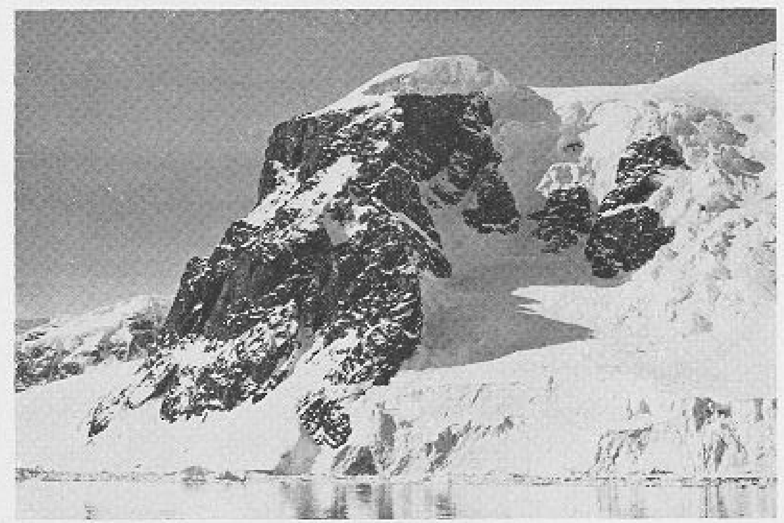

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PLATE II

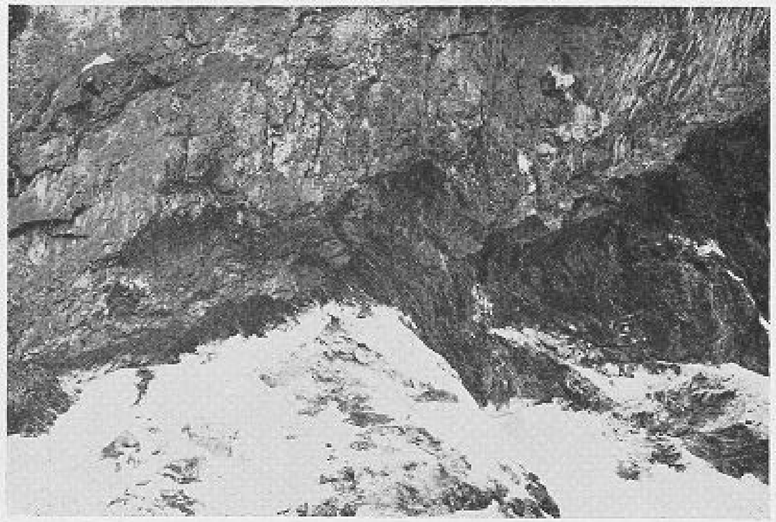
PLATE III

a. The contact between volcanic (grey) and sedimentary (black) rocks at Coughtrey Peninsula. (Photograph by G. J. Hobbs.)

b. Biotite-hornfels (dark grey) included in granodiorite at Forbes Point. (Photograph by G. J. Hobbs.)

c. Bedding in the tuffs at Brooklyn Island. (Photograph by G. J. Hobbs.)

d. Rounded gabbro xenoliths in a granitic host on the eastern coast of Charlotte Bay (O.975). (Photograph by G. J. Hobbs.)



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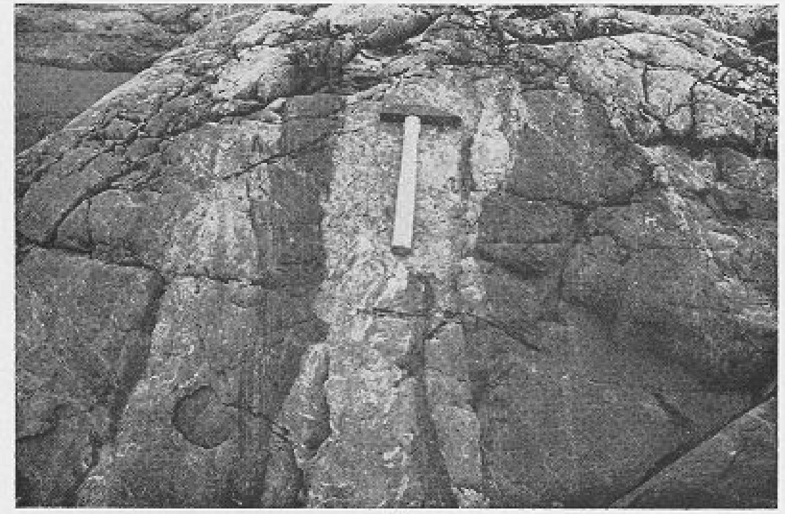

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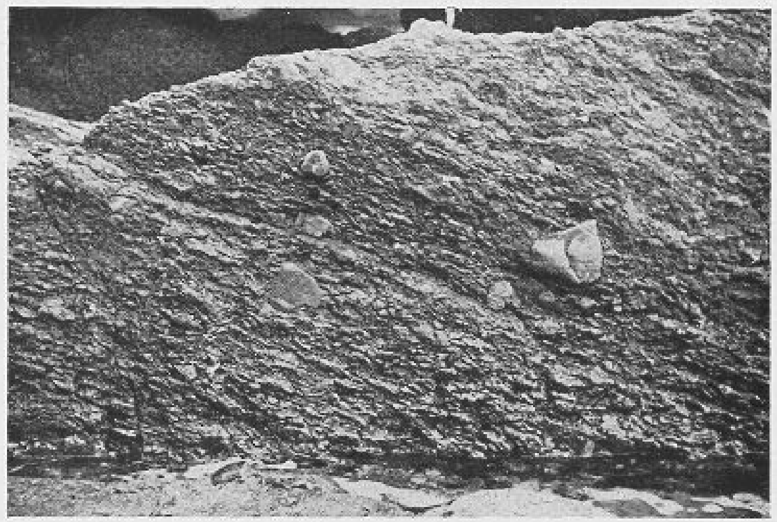

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PLATE III

PLATE IV

a. A slightly contact-metamorphosed mudstone at Skontorp Cove containing elliptical spots of (?) incipient cordierite. The spots in this specimen are unusual in that they contain biotite-rich cores with narrow sericitic mantles. (O.991.1; X-nicols; ×40)

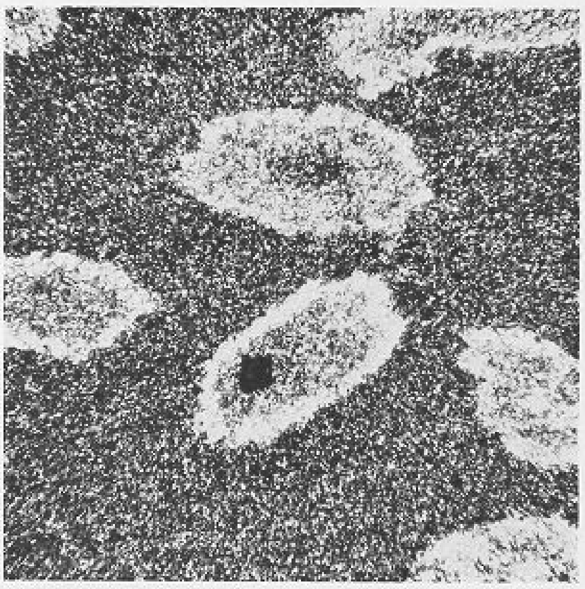
b. The texture of the biotite-hornfels at Forbes Point, showing a recrystallized mosaic of quartz and feldspar with flakes of biotite. (O.1004.1; X-nicols; ×150)

c. A granophyric intergrowth of quartz and perthitic potash feldspar in a granite at Mount Banck. The potash feldspar is in excess of the quartz. (O.938.8; X-nicols; ×325)

d. A granophyric intergrowth of quartz and potash feldspar in a granite at Mount Banck. Quartz has penetrated the potash feldspar crystal along pre-existing cleavage planes and was clearly the last mineral to crystallize. (O.938.8; X-nicols; ×315)

e. Quartz which has partially replaced the subhedral plagioclase in a granite at Mount Banck. (O.938.8; X-nicols; ×400)

f. The texture of a spherulitic rhyolite at south-eastern Bryde Island. (O.937.7; X-nicols; ×7)



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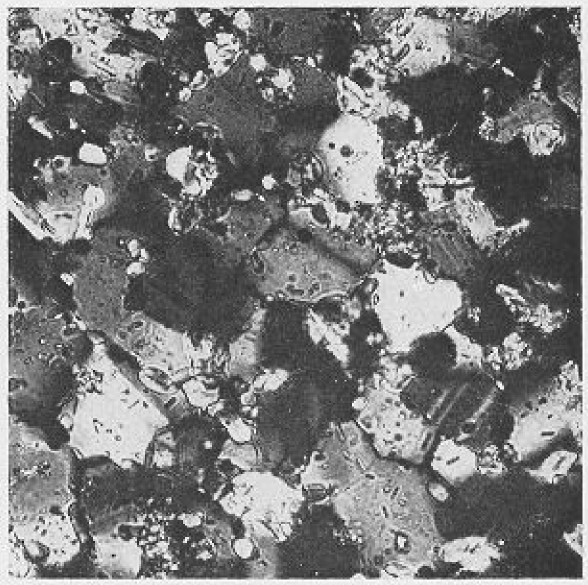

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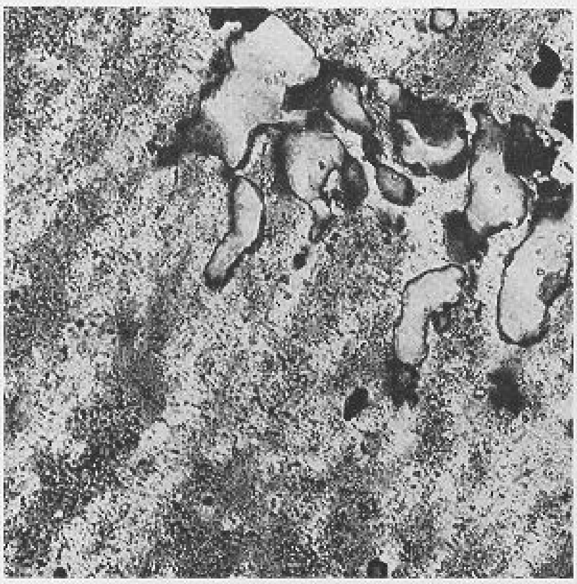

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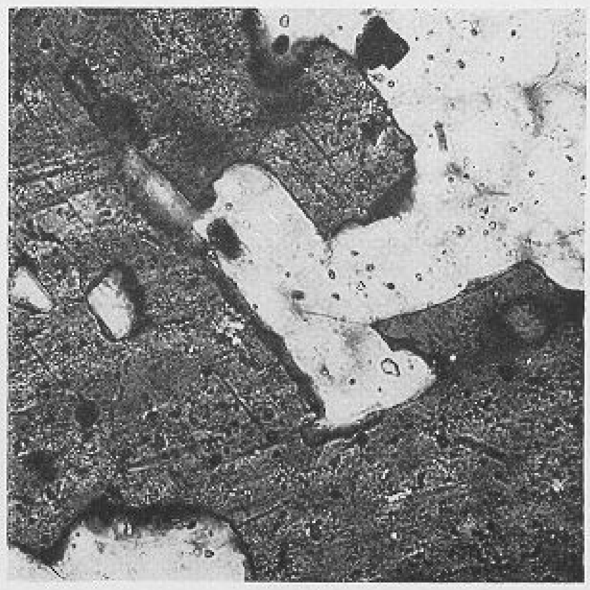

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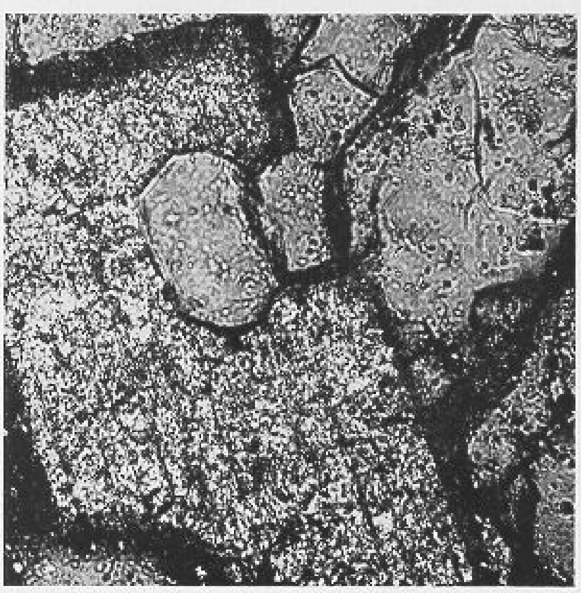

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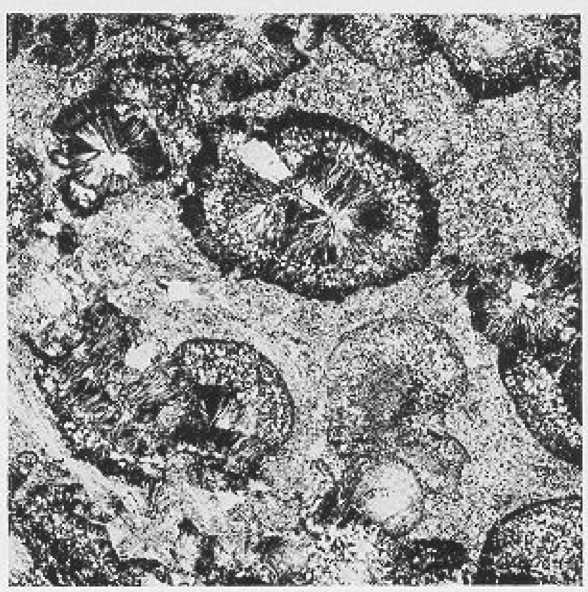

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PLATE V

a. Scalloped amygdales in an andesite at south-eastern Bryde Island. (O.932.1; ordinary light; ×1·5)

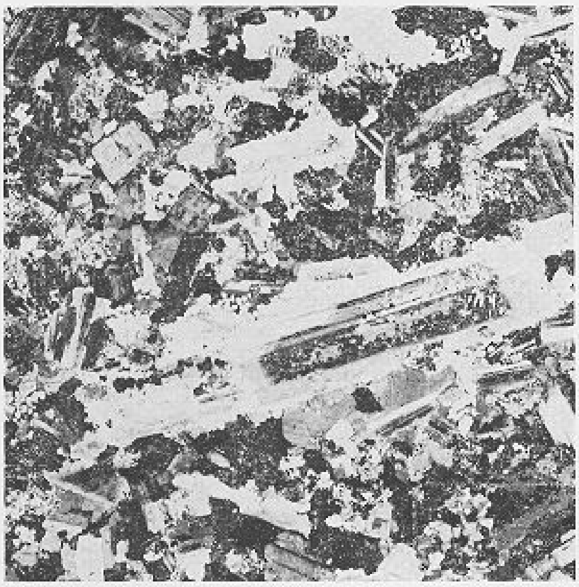
b. Texture of an amygdaloidal basalt at the Orne Islands showing phenocrystic plagioclase set in a groundmass of plagioclase, chlorite, ilmenite and calcite. (O.914.1; X-nicols; ×8)

c. Texture of an acid crystal tuff at eastern Bryde Island. One or two siltstone fragments (right and bottom left) are also present. (O.937.5; X-nicols; ×6·5)

d. A rounded granite pebble in contact-metamorphosed acid crystal tuffs at the eastern side of Charlotte Bay. (O.975.1; X-nicols; ×6·5)

e. The texture of the gabbro at western Rongé Island. (O.546.3; X-nicols; ×4·5)

f. The alteration from schillerized augite (left) to a zone of augite and patchy amphibole (centre) and finally to marginal hornblende (right) in a uralitized gabbro at Bruce Island. (O.933.1; X-nicols; ×40)



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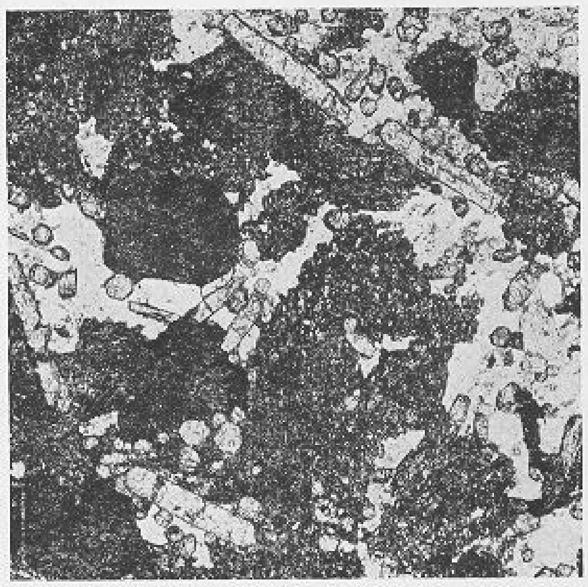

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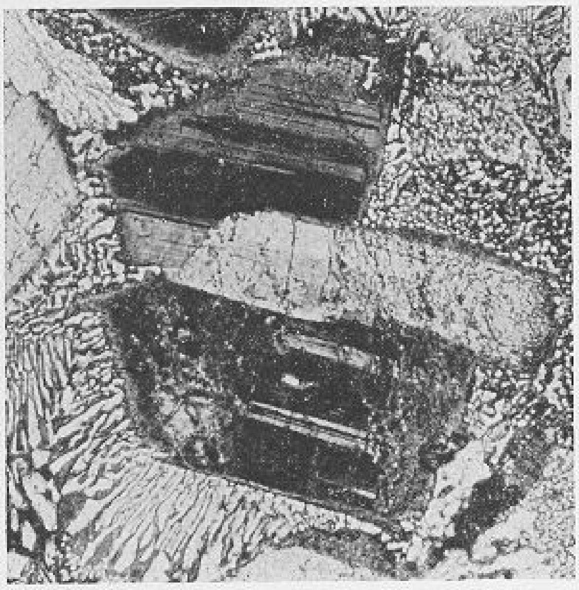

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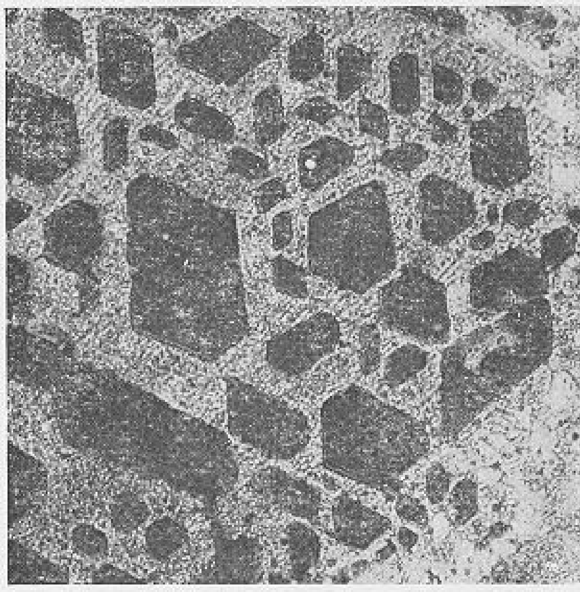

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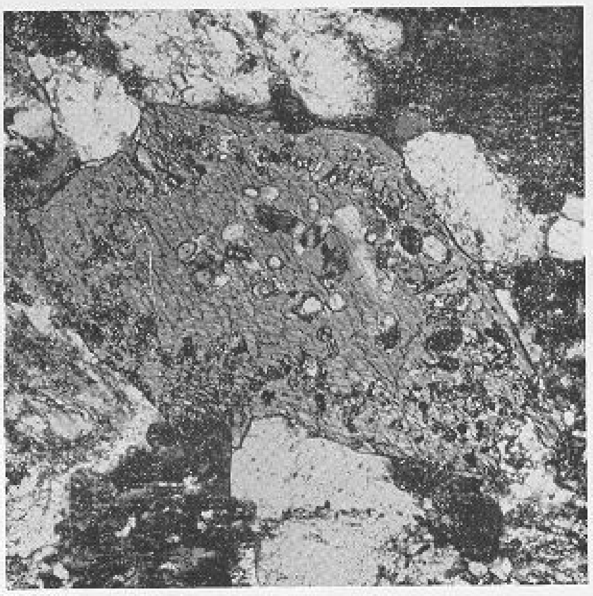

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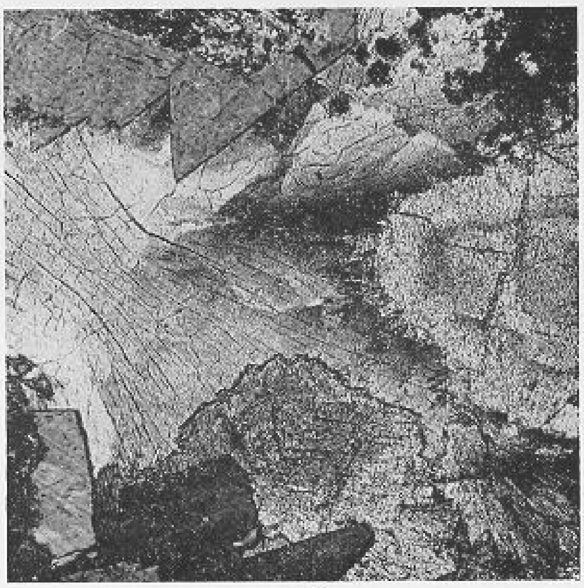

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